ENERGY CONSERVATION AND EXERGY ANALYSIS OF CAPTIVE POWER PLANT BASED ON CFBC BOILER

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ENERGY CONSERVATION AND EXERGY ANALYSIS OF CAPTIVE POWER PLANT BASED ON CFBC BOILER

Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

(Thermal Engineering)

By

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Declaration

This is to certify that

1. 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 or diploma.

2. Due acknowledgement has been made in the text to all other material used.

Darshan A Gandhi.

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Undertaking for Originality of the Work

I, **Darshan Anilkumar Gandhi**, Roll. No. **16MMET04**, give undertaking that the Major Project entitled "**Energy Conservation and Exergy Analysis of Captive Power Plant based on CFBC Boiler**" 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.

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This is to certify that the Major Project Report entitled "**Energy Conservation and Exergy Analysis of Captive Power Plant based on CFBC Boiler**" submitted by **Mr. Darshan Anilkumar Gandhi (16MMET04)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Thermal Engineering)** of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the 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

The ratio of energy available to requirement decreasing day by day around the world due to the increase in population and use of energy consuming equipments. This can be fulfilled by installing new power plants but it needs many years and huge investment. There is another plan which can be worked out with development of new plant and that is to improve existing plant performance. This dissertation study deals with the exergy analysis and energy conservation of thermal power plant stimulated by coal as fuel. The exergy analysis includes exergy input, exergy utilization, destruction of exergy, irreversiblity of components and exergy efficiency. The Sankey diagram and Grassmann diagram for the plant is prepared to carry out exergy analysis of various components. In present study based on performance analysis, the energy saving opportunity identified in power plant auxiliary systems like Conveying Compressor, Instrument Compressor, Plant cleaning air Compressor and Coal Handling Plant. The utilization of compressors to supply air for various functions are optimized. This lead to saving in energy and cost as 48.26 MWh per year and 2.37 lacs per year respectively. Similarly installation of new coal handling plant also lead to reduction in consumption of energy and cost as 260.11 MWh per year and 12.75 lacs per year respectively. Energy and exergy analysis of boiler furnace, economizer, air preheater, primary and final super heaters, turbine, condenser, cooling tower, pressure reducing desuperheating systems, attamparators are carried out. Based on study it was found that steam coming out from the boiler is at higher pressure than the need of condensate turbine. This issue is solved by use of Pressure reducing desuperheating systems. To improve performance of economizer using hp heater 1, it is suggested to extract steam from the turbine however it is not used in the plant. Also the steam coming out from the turbine is condensed in condenser which leads to loss in energy. To over come this issues a new back pressure turbine having capacity similar to boiler is installed. Also steam is extracted from this turbine and utilized in hp heater 1. Use of new turbine eliminated to use of Pressure reducing desuperheating system, condenser and cooling tower. This lead to reduction in energy consumption and exergy destruction in the plant. The steam coming out from the turbine is used in deaerator. This modifications lead to improve utilization efficiency of steam from 57 % to 97.1 % and exergy efficiency from 31.36 % to 45.53 %.

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Nomenclature

m_{dfg}	Mass of dry flue gas
Ψ_{in}	Exergy at Inlet for Open System
Ψ_{out}	Exergy at Outlet for Open System
M_L	Mass of Limestone
m_{in}	Mass entering in Control Volume
m_{out}	Mass leaving the Control Volume
W	Net work done
G'	Gibbs free energy
m_s	Mass of Steam
X	Mole fraction in atmosphere
Q	Heat loss in atmosphere
$\triangle G$	Net change of Gibbs free energy
m_w	Mass of Water
T_0	Ambient Temperature
T_s	Surface Temperature
I_{irrev}	Irreversibility
B	Keenan Function
E	Exergy Function
C_{dfg}	Specific heat of Dry Flue Gas
C_a	Specific heat of Air
S_{gen}	Entropy Generation of System
Ψ_{ch}	Chemical Exergy of Fuel
E_d	Exergy Destruction

Greek Symbols

μ	Chemical potential
ϕ	Power factor
Ψ	Exergy
η	Efficiency
ε	Effectiveness
Σ	Summation
Δ	Difference
σ	Stiffen boltzmann constant

Abbreviations

CFBC	Circulating Fluidization Combution Boiler
APH	Air Preheater
PRDS	Pressure Reducing Desuperheating System
FSH	Final Super Heater
PSH	Primary Super Heater
LMTD	Log Mean Temaperature Difference
HMBD	Heat and Mass Balance Diagram
CV	Control Volume
AAS	Actual Air Supply
TPH	Tonnes per Hour
mmwc	milimeter of water column
EAS	Excess Air Supply
SSC	Specific Steam Consumption
HR	Heat Rate
CHP	Coal Handling Plant

Chapter 1

Introduction

For developing country economy, the need of the energy is playing very important and crucial role. The overall growth of the country dependent on availability of energy for completing various tasks. Energy is working as driving force for development of growth. Energy consumption is one of the most important factor that showing the development stages of country and living standards of communities. As per Energy Information Administration, India is the third largest energy consumer and offers immense potential for investors. Energy industry is considered as the primary driver of Indian economy as it is the major fuel for various industries like power sector, steel, chemical, fertilizers, paper, cement, transport and thousands of burgeoning small and medium enterprises in India.

Energy sector in India is one of the most challenging sectors for various players given the presence of large profit making Public Sector Units with strong regulatory back up and market presence. In upcoming decades, consumption of electricity and energy resources are further going to increase due to liberalization of economy, population increment, urbanization, industrialization and technological development. So, it is necessary to manage the use of energy resources in effective manner. The use of energy resources is required to be reduced by effective utilization of electricity which is termed as energy conservation and management. Energy management includes planning and operation of energy production and energy consumption units.

1.1 Energy demand and supply in India

India accounts for almost 17% of the increase in global electricity demand from 2013 to 2040. Per capita electricity consumption grows from over 710 kWh to more than 2 000 kWh per year, an average annual growth rate of 4.0%. The anticipated increase in the reliability of power supply, including during times of peak demand, has widespread implications for the level of power consumption. It also releases some pent-up demand, as households expand their range of appliances, in the knowledge that they can be reliably used. In figure 1.1 [13] the Energy demand from year 2013 to 2040 shown by new policy scenario, the unmet demand shows that estimated amount linked to the incidence of load shedding in today's electricity supply steadily over the coming years and disappears entirely by the mid of 2020s.

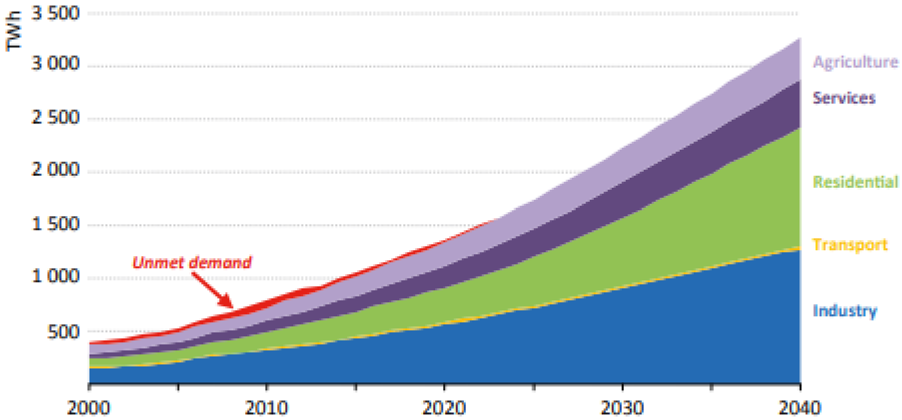

Figure 1.1: Energy demand in TWh by sector in India[13]

The pace at which energy consumption is expected to expand means that India mobilizes supply on all available fronts in the New Policies Scenario. Deployment of wind and solar power increases at the fastest pace, but the production of all domestic sources of energy is higher in 2040 than in 2013, with the sole exception of oil, where India's resource limitations come into play. Yet domestic energy production is not sufficient in aggregate to keep up with demand, leaving a growing gap that needs to be filled by imported fuels which shows in Figure 1.2 [20]. Increases in domestic coal production keep the need for coal imports at least partly in check. But net oil imports rise dramatically, to reach 9.3 Mb/d by 2040, an import dependence of greater than 90%.

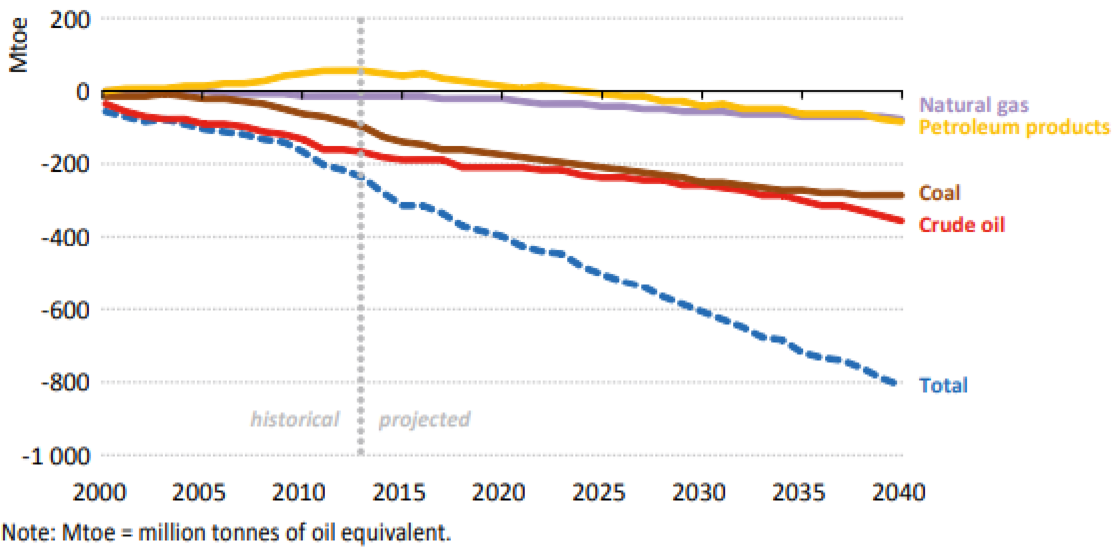

Figure 1.2: Fossil fuel trend balance in India[20]

Consumption across India's end-use sectors – buildings, industry, transport and agriculture – increases by around 3.3% per year on average to 2040, more than doubling to reach 1275 M toe, by which time it overtakes the level of final consumption in the European Union today. The main fuels contributing to this end-use demand growth are coal (in industry), oil (in transport), and electricity (in buildings, industry and agriculture) shown in figure 1.3[13].

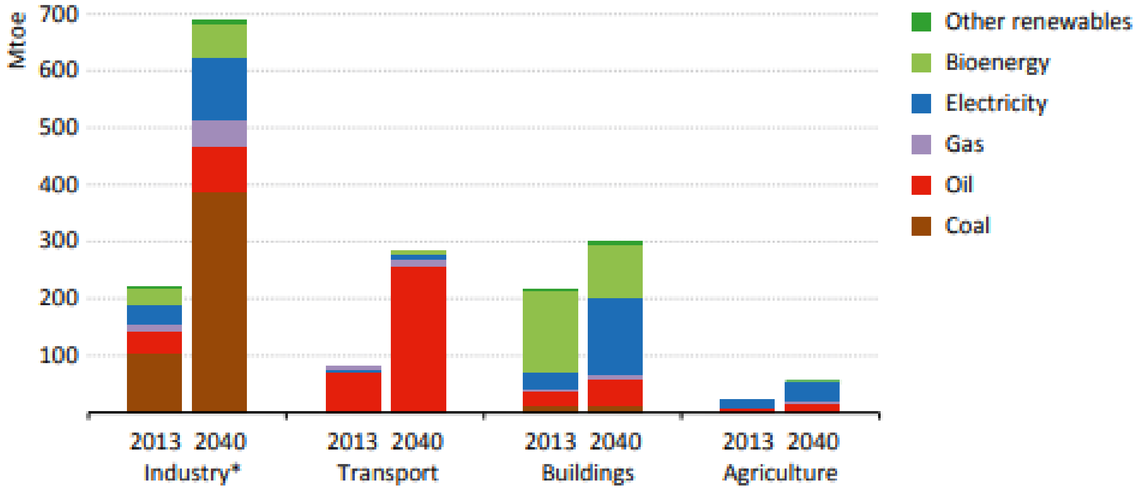

Figure 1.3: Energy demand by Fuel in India[13]

The electricity sector in India has one National Grid with an installed capacity of 331.11 GWh as on 31 October 2017. Renewable power plants constituted 31.7% of total installed capacity. During the fiscal year 2016-17, the gross electricity generated by utilities in India was 1,236.39 TWh and the total electricity generation (utilities and non-utilities) in the country was 1,433.4 TWh. The gross electricity consumption was 1,122 kWh per capita in the year 2016-17. India is the world's third largest producer and third largest consumer of electricity. Electricity generation in different sector according to type of fuel used shown in table 1.1[18]. Electric energy consumption in agriculture was recorded highest (17.89%) in 2016-17 among all countries.

Table 1.1: Energy generation in MWh for different sector[18]

Sector	Coal	Gas	Diesel	Nuclear	Hydro	Other	%
Private	74012	10580	473	-	3240	55283	43
State	65145	7257	363	-	29703	1963	32
Central	55245	7490	-	6780	11651	-	25
Overall	194402	25329	837	6780	44594	57260	100

1.2 Energy strategy for fulfillment of future Energy demand

Energy system planning and development involves the effective utilization of energy resources and technologies for meeting energy demand in a sustainable manner. To meet the challenges for global energy demand various support schemes, policies and planning are required to promote. Low impact renewable energy technologies offer important benefits compared to conventional energy sources, such as fossil fuels or nuclear power. However due to their uncertainty different kinds of renewable energy resources need to be operated in an integrated way, which complement each other.

There are various tools which gives opportunity to save energy more effectively. Details of such tools are as follows [20].

1. Energy and Power Evaluation Program : ENPEP is a tool that lets researchers and planners compare alternatives quickly to determine the most cost-effective and environmentally safe solutions for a country's energy needs. The balance module of ENPEP uses a non linear equilibrium approach to determine the energy supply and demand balance. For its simulation, the model uses an energy network that is design to trace the flow of energy from primary source to energy demand. Demand is the sensitive to the price of alternatives. Supply price is sensitive to the quality demanded. In its operation, balance simultaneously tried to find the intersection for all energy supply form and all energy uses that are included in the energy network. The equilibrium is reached when the model finds a set of prices and quantities that satisfied all relevant equation and inequalities. The model is typically used to analyze a 20-30 year forecast period.

2. Market Allocation Program : MARKEL is a linear programming (LP) model of a generalized energy system. It is demand drive for which feasible solutions are obtained only if specified end-use demands for energy are satisfied for every time period. The end-use energy demand for each demand sector and for each time period is exogenous forecast. The objective is to determine the optimum activity levels of processes that satisfy the constraints at minimum cost

3. Long-Range Energy Alternative Planning System : LEAP is an energy accounting framework. It contains a full energy system which enables consideration of both demand-side and supply-side technologies and accounts for total system impacts.

4. Model for Analysis of Energy Demand : MAED model evaluates future energy demand based on medium- to long-term scenarios of socioeconomic, technological and demographic developments. The model relates systematically the specific energy

demand for producing various goods and services identified in the model, to the corresponding social, economic and technological factors that affect this demand.

5. Comparison of Energy Modeling Tools : ENPEP, MARKAL and LEAP are economy level models. They are used to facilitate the decision to provide the economy with energy supply to satisfy the future energy demand by least cost by taking into consideration issues such as energy security, new technologies and environmental problems. There are no set rules as such for selecting a model to be the ideal model for an economy's energy planning. However, MARKAL is a good choice if technical and statistical data are relatively plentiful and assumptions of optimizing models are reasonable in the study context. ENPEP-BALANCE is a good choice in similar situations to MARKAL, particularly if there is need to take a market- simulation approach, and optimization assumptions are not appropriate.

1.3 Energy conservation

Energy conservation is achieved by decreasing the quantity of energy using certain steps including energy efficiency. It plays very important role in Energy security. Energy conservation make impact on major area's like heating ventilation and air conditioning, lighting and household application, building construction and design, industrial process and product, electricity distribution and transmission, mining operations, mass transportation. Energy conservation may result in maximize environmental value, personal security, national security, financial capital and human comfort. Energy conservation provides the eco-friendly life by giving energy, which saved your cost and saved the earth automatically by reduce the global warming effects. One of the way to achieving Energy conservation is Energy efficiency. It reduces the need of energy generation resources as well as reduction in pollution.

1.3.1 Silent features of Energy conservation

Characteristics of energy conservation are as follows.

- Establish and prescribe energy consumption norms and standard for designated consumer.
- Notify commercial building as designated consumers, other establishments and intensive industries.
- Appoint or designate certified energy manager in other activities for efficient use of energy conservation.
- Establishment of Bureau of Energy Efficiency.

- Implement international programs and prepare educational curriculum on Energy conservation.
- Do Energy Audit of plant regularly as per government rules in specified interval and systematically manners.
- Notify standards for equipment and appliances with energy conservation norms and the regulation.
- Furnishing the information with regards to power consumed and take action on the recommendation of the accredited energy auditor to the designed agency.
- Develop strategies and policy with trust on market principles and self-regulation within the framework of the Energy Conservation Act, 2001.
- To leverage multi-lateral, bi-lateral and private sector support in implementation of the Energy Conservation Act and programmers for efficient use of energy and its conservation.

1.3.2 Benefits of Energy Conservation

Benefits can be achieved due to proper energy conservation and management are mentioned below.

- It will reduce the energy imports of country.
- Overall electricity bill of industry is reduced.
- Enhances energy security.
- Increase productivity, competitiveness, overall quality of company.
- Reduce costs which can be sued for poverty reduction.
- Reduce GHG and other emissions.
- Maintains a sustainable environment and reduce Global warming effect.

1.4 Design parameters and details of Captive power plant

A Captive power plant is a facility that is dedicated to providing a localized source of power to an energy user. The plants may operate in grid parallel mode with the ability to export surplus power to the local electricity distribution network. In these plant, the power is generated centrally and distribute among the all small unit inside the plant. whenever the quantity of power generation more than the requirement it is export to the Grid. In chemical plant generally the requirement of steam is also very important such as generation of power.

Main advantage of captive power plant is as the requirement of steam quantity in the plant increasing, the power generation rate reduces. At that time additional power required from Grid. Likewise in case of less requirement of steam, the power generation by plant is more than the requirement. At that time plant decided to export these additional power.

- Coal based plant with Circulating fluidization combustion Boiler.
- Boiler design code as per IBR : single drum, water tube, with compact separator.
- All the accessories of Boiler designed as shell and tube type Heat exchanger.
- Surface heating area of Boiler is equal to 7803 m^2.
- Steam generation capacity of plant is equal to 150 Tonnes per Hour.
- Steam pressure and temperature are 109 $kg/cm^2$and 520 $\pm$ 5 ^{0}C respectively.
- Drum level maintain between 40% to 60% with the pressure of 136 kg/cm^2.
- Turbine design : multistage, pressure-velocity compounding, condensate Turbine.
- Steam turbine generator has capacity of 21.5 M.
- DM plant has a capacity of 60 m^3/hr respectively.
- Coal handling plant has a capacity of 50 tonnes per hour.
- Shell and Tube type Surface condenser used with steam ejector and hoggers.
- The capacity of Primary air flow and secondary air flow are 142 TPH and 80 TPH respectively.
- Deaerator temperature and pressure is 200^{0}C and 5 Bar respectively.
- Furnace average temperature and bed temperature are 1050 ^{0}C and 1000 ^{0}C respectively.
- Furnace average pressure and bed pressure are 250 mmwc and 550 mmwc respectively.

The process flow diagram of captive power plant is shown in figure 1.4 provided by plant head.

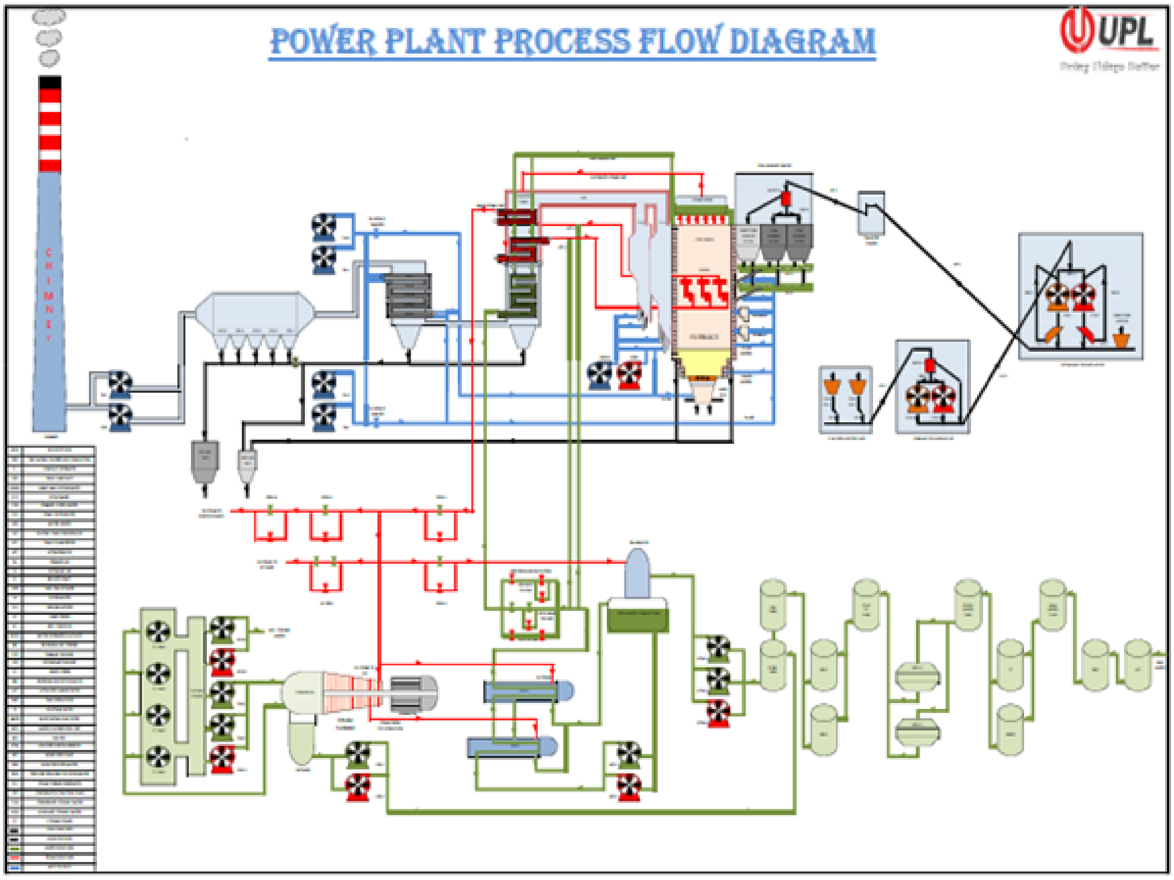

Figure 1.4: Process flow diagram of Captive power plant

1.5 Objective of Project

- To carry out performance evaluation and exergy analysis of various equipment of power plants such as Boiler, Turbine, Condenser, Cooling tower, Economizer, Pumps, Air preheater, Super heaters, Fans, PRDS, Attamparators and HP Heaters.
- Suggest the solutions for improvements in major exergy losses components.
- To study economic analysis of suggestions and cost saving opportunity in a plant.
- To study possibilities of implementation of suggestions to increase plant energy and exergy efficiency.
- If implementation of suggestion is carried out then to verify the effect of suggestions.

Chapter 2

Literature Review

2.1 Concept of Exergy

The First Law of thermodynamics defines energy as property which is having certain quantity at a particular state. First law analysis provides information relating exchange of energy in form of quantity when it is transferred from one form to other form. Quantification of effectiveness of such energy transfer is defined as 1st law efficiency. The limitation of first law is can not differentiate between natural or man made direction of energy exchange. This limitation is overcome by Second Law of thermodynamics. It states that over and above quantity different energy forms have different quality and due to that conversion of high grade of energy in to low grade is found higher than reverse one. Thus forms of energy don't have same quality and it will be always degrades due to irreversiblity associated with processes occurring in various equipment. The study of such degradation of quality of energy is possible using exergy analysis. Exergy of any system is defined as maximum useful work obtained by any process or cycle, till it comes to the state of thermodynamically and chemically equilibrium with a surrounding (popularly known as dead state). It is also known as Available Energy. The minimum energy that has to be rejected to sink as per second law is known as unavailable energy or Anergy. Thus, the exergy is a combine property which depends on state of system and surrounding.The Exergy analysis includes quantification of Exergy available, Exergy utilization, Exergy destruction due to irreversiblity, and Exergetic efficiency (also known as second law efficiency). Performance of any equipment/process based on first law includes determination of energy losses (first law efficiency) and based on 2nd Law includes determination of exergy losses (second law efficiency).

2.1.1 First Law Analysis

The first law of thermodynamic said that, " When a system undergoes a cyclic process, the net work done on the surroundings is equal to the net heat transfer to the system."

Most of the engineering processes are associated with the flow of matter from one plant component to another. Thus it is not convenient to study the processes using closed system analysis, since a system boundary does not permit the flow of matter across it and it is necessary therefore to reformulate relations to make them directly applicable to analysis of a control region.

Mass balance for control region under steady flow,

$$\mathring{m}_{in} = \mathring{m}_{out} \tag{2.1}$$

In applying the energy equation to a system undergoing an infinitesimal process as it moves through the control region. In general, the control region may interact thermally with several stream of matter entering and leaving the control region.

Energy balance equation for control region where one stream of fluid is entering and leaving under steady flow,

$$(h + \frac{V^2}{2} + gz)_{in} + \frac{Q}{m} = (h + \frac{V^2}{2} + gz)_{out} + \frac{W}{m} \tag{2.2}$$

Equation (1) and (2) are used to carry out 1st law analysis of various components using control volume approach.

2.1.2 Second law Analysis

The second law of thermodynamics is known as directional law and leads to definition of Entropy that increases with addition of heat. It provides the criterion to evaluate perforamnace of various processes. This is possible similar to energy balance in 1st law analysis. The only difference is that in case of second law instead of energy, exergy balance is carried out as mentioned below.

Heat Input = Available Energy(Exergy) + Unavailable Energy

The total exergy of system can be divided in two categories (i) physical exergy and (ii) chemical exergy. Discussion about these two forms of exergy is as follows.

2.1.2.1 Physical Exergy

Physical exergy is due to physical process (non flow as well as flow) including only thermal interaction with the environment, is equal to the maximum amount of work obtained when the stream of substance is brought from its initial state to the dead state define by Po and To.[2]

Exergy of Non-flow process,

$$E_W = A_1 - A_2 + \sum E_Q – T_0 S_{gen} \tag{2.3}$$

here, A is Exergy function, E is .

$$A = E - T_0S + P_0V \tag{2.4}$$

Exergy of Steady-flow process,

$$E_W = \sum E_Q + \sum(mb)_{in} - \sum(mb)_{out} - T_0S_{gen} \tag{2.5}$$

here, b is known as Keenan function.

$$b = h - T_0S \tag{2.6}$$

2.1.2.2 Chemical Exergy

Chemical exergy is equal to the maximum amount of work obtain when the substance under consideration is brought from the initial state to the dead state by processes involving heat transfer and exchange of substances only with the environment state. To find out chemical exergy first step is analyses the exergy of reactant and product of a particular reaction. For example, the Exergy of any hydrocarbon fuel is calculated by following equations.[2]

$$C_aH_b + (a + \frac{b}{2})O_2 \rightarrow aCO_2 + \frac{b}{2}H_2O(vapour) \tag{2.7}$$

Chemical potential of Oxygen, Carbon dioxide and Water is calculated as equation (8), (9) and (10).

$$\mu O_2 = G'O_2(P_0, T_0) + RT_0 ln X_{O2} \tag{2.8}$$

$$\mu CO_2 = G'CO_2(P_0, T_0) + RT_0 ln X_{CO2} \tag{2.9}$$

$$\mu H_2O = G'H_2O(P_0, T_0) + RT_0 ln X_{H2O} \tag{2.10}$$

The reversible(maximum) work per mole of fuel is given by equation (11),

$$Wmax = \mu C_aH_b + (a + \frac{b}{2})\mu O_2 - a\mu CO_2 - \frac{b}{2}\mu H_2O \tag{2.11}$$

Since the fuel enters the combustion chamber as a single component at P_0 and T_0. So their chemical potential is equal as G'CaHb (P_0, T_0).

Net change of Gibbs free energy,

$$\triangle G(P_0,T_0) = aG'CO_2(P_0,T_0) + \frac{b}{2}G'H_2O(P_0,T_0) - [G'C_aH_b(P_0,T_0) + (a+\frac{b}{4})G'O_2(P_0,T_0)] \quad (2.12)$$

Chemical Exergy of fuel,

$$\Psi_{ch} = -\triangle G(P_0,T_0) + RT_0 ln(\frac{X_{O2}^{a+0.25b}}{X_{CO2}^{a}.X_{H2O}^{b}}) \quad (2.13)$$

Where, μ= Chemical potential, G' = Gibbs free energy, X is mole fraction in atmosphere

For certain hydrocarbon the value of – ΔG directly given in Moran table which is given in Appendix. When coal is used as fuel than chemical exergy of coal is calculated by following Equation [1],

$$\Psi_{ch,Coal} = 34183.16(C) + 21.95(N) + 11659.9(H) + 18242.9(S) + 13269.9(O) \quad (2.14)$$

Where C, N, H, S, O are the % mass of carbon, nitrogen, hydrogen, sulphur, oxygen which is obtained by ultimate analysis of coal. Generally, for any fuel the ratio of chemical exergy to calorific value is between the 1.15 to 1.30. So, the chemical exergy of fuel can be verified.[1]

2.1.2.3 Exergy Analysis

Exergy balance equation for control region under steady flow,

Exergy Input = Exergy Output + Exergy Losses + Exergy Destroyed

$$\sum b_{in} - \sum b_{out} \pm Q(1-\frac{T_0}{Ts}) \pm W - i_{irrev} = 0 \quad (2.15)$$

By using above equation the irreversiblity of system calculated.

The exergy efficiency is the measure of performance in terms of optimum performance by applying both 1st Law and 2nd Law of thermodynamics and it avoid limitations of 1st Law Efficiency. Exergy Efficiency improve performance of system by eliminate Internal Irreversibility and External Irreversibility.[2]

Second law Efficiency or Exergy Efficiency can be calculated by,

$$ExergyEfficiency = \frac{ExergyOutput}{ExergyInput} = 1 - \frac{(ExergyDestroyed + ExergyLoss)}{ExergyInpu} \quad (2.16)$$

2.2 Irreversibility of System

As per concept of Carnot Engine, assume that during respective heat interaction heat engine is thermally equilibrium with every temperature reservoir. That would be required infinitely large heat engine reservoir contact surface for equilibrium. But in actual practice it is not possible due to size constrain and cost of components. The extracted power from particular hot stream by received stream of cold fluid across finite size heat transfer area. For example, when cold stream is evaporated as it gains a part of hot stream that is divided heat exchange in to three section: liquid preheat, liquid boiling, vapor super heating. The performance of heat engine affected due to Irreversibility when heat transfer occurs between finite temperature gap that reside the outside of power cycle. This Irreversibility is classified in two categories.[2]

2.2.1 External Irreversibility

Consider Ideal Rankine cycle with assumed that the internal Irreversibility is absent as shown in figure.

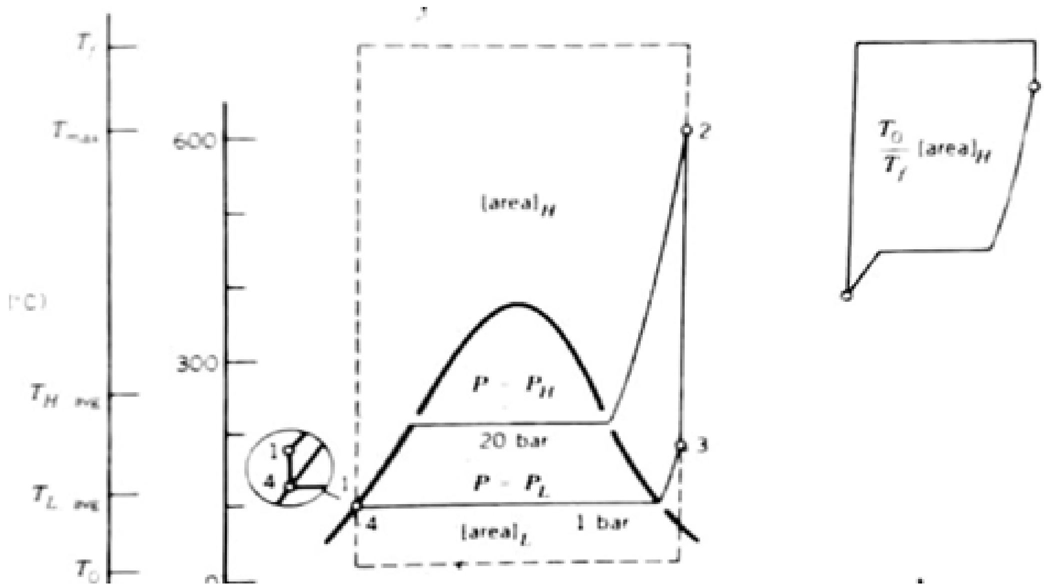

Figure 2.1: External Irreversibility in Ideal Rankine Cycle[2]

The maximum power producing by engine is given by,

$$W_{max} = Q_H(1 - \frac{T_0}{T_f}) \tag{2.17}$$

and

$$Efficiency = (1 - \frac{T_0}{T_f}) \tag{2.18}$$

But due to external Irreversibility the heat engine efficiency became,

$$Efficiency = (1 - \frac{T_{L,avg}}{T_{H,avg}}) \quad (2.19)$$

From figure it is clear seen that $T_f > T_{H,avg}$and $T_0 < T_{L,avg}$because the Irreversibility are restricted to the temperature gaps above$T_{H,avg}$a and below$T_{L,avg}$a. So, the efficiency is always less than the carnot efficiency. The size of relative two external Irreversibility can be calculated as,

$$Sgen, H = \frac{m}{T_f}[T_f(s_2 - s_1) - (\int_1^2 Tds)_{P=PH}] \quad (2.20)$$

$$Sgen, H = \frac{m}{T_0}[(\int_3^4 Tds)_{P=PH} - T_0(s_3 - s_4)] \quad (2.21)$$

By using this equations destruction work due to External Irreversibility calculate.

$$W_{lost} = T_0 S_{gen,H} + T_0 S_{gen,L} \quad (2.22)$$

2.2.2 Internal Irreversibility

In case of Rankine cycle the most of internal irreversibility found in boiler, super heater, re-heater, Expander and cooler. In boiler and super heater, a finite pressure drop occurs due to flow of high pressure working fluid.

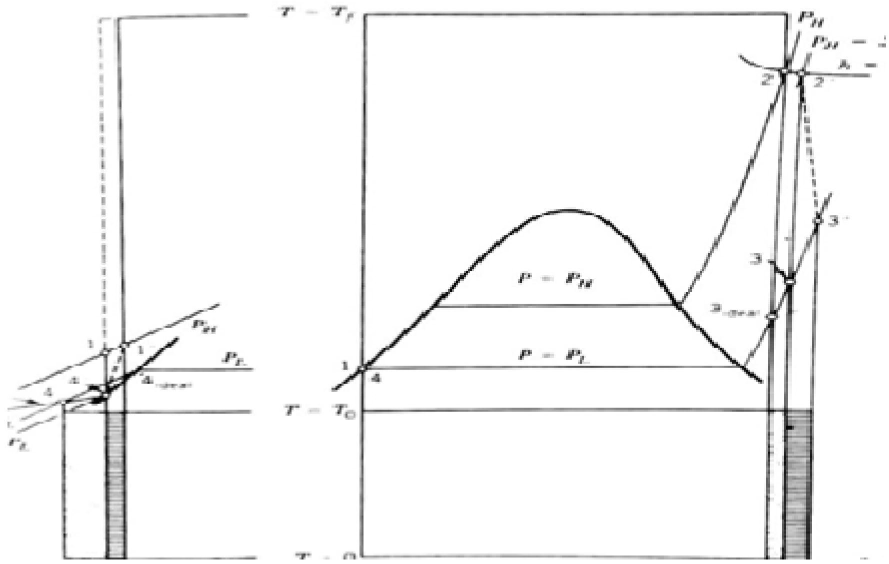

Figure 2.2: Internal Irreversibility in Rankine Cycle[2]

The entropy generation in heater while communicated with T_f reservoir is calculated by,

$$S_{gen,heater} = m(s'_2 - s_1) - \frac{Q_H}{T_f} \tag{2.23}$$

The loss of exergy in heater = $T_0 S_{gen,heater}$

In the isentropic expansion in expander, The loss of exergy = $T_0(S_3' - S_3)$

In the cooler, loss of exergy = $(\int_{3'}^{4} Tds)_{P=PL}$-$T_0(S_3' - S_3)$ +$T_0(S_3' - S_3)$

For the pump, loss of exergy = $T_0(S_1' - S_4')$

This Irreversibility is reduced by using Super heater, Re-heater and partial Condenser Vacuum. Due to use of re-heater cyclic efficiency increase by reduce the turbine exhaust moisture when T_{max} and P value fixed. Also turbine inlet temperature reduce otherwise costly blade material required. Use feed heating stages with turbine expander so it closed to reversible process. Recently Contact heaters, in which feed water stream is heated step by step are used in place of regenerator.

2.3 Energy conservation in Auxiliary system

In Industry for various applications, compressed air is majorly required so efficient compressor required. In power plant Compressed Air used as an Instrumental Air, Process Air, Conveying Air etc. The contribution of compressed Air system in Auxiliary Power Consumption would be in the range of 1 to 2 percent that will be issue specially for low and medium generation capacity plant. In Compressor only 10-15% input energy remain to do work and after distribution losses only 5 % energy Available. Many energy systems saying that with using proper technology and management power saving up to 10% in Compressor. Therefore, it is in the national interest that compressed air be generated and used with efficiency and economy, wherever possible. Because of major consumption in compressor Energy conservation required in Compressor. Based on National Productivity Council the scope in compressor system would be of about 25% to 30% by energy Conservation as experienced by power plants.

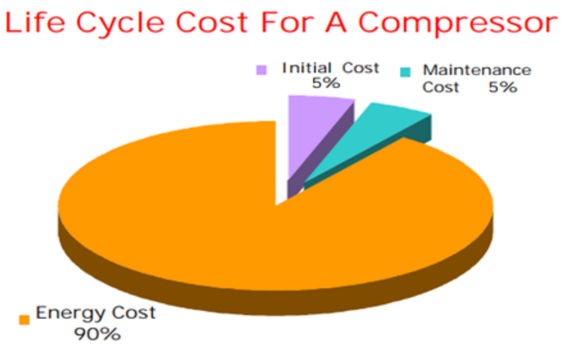

Figure 2.3: Life Cycle Cost of Compressor[18]

Following are the method to improve performance of Compressor:

- Vacuum air used in place of Plant Compressed Air.
- Reduce pressure drop in Compressed Air system.
- Periodical maintains required of motors and compressor.
- Identify the application for heat utilization by water, space heating and other liquid.
- Use alternative solution for Conveying System.
- Calculate load hours and unload hours.
- Required capacity compressor only used.
- Select most efficient and latest compressor technology for Automatic operation.
- Replace air filters regularly.
- Identify Air leakages, drains and piping infrastructure.

2.4 Recent work on Energy and Exergy Analysis

- Mert Gurturk, Hakan F. Oztop[3] present the paper on Circulating Fluidization Bed Combustion Boiler Co-generation plant. This paper given the solution for calculate chemical exergy of coal. Exergy balance equation given in this paper for all the component of Boiler. The energy and exergy efficiency calculated for all the components of Boiler and it was found that maximum exergy destruction occurs in combustion chamber is equal to 21789.39 kW because of entropy generation increase with low combustion efficiency fuel. Another reason is fuel inject from only one point if multiple feeder system is used that will create positive effect on combustion. Overall exergy efficiency of plant is 20%. Ash collect from hopper that will have certain amount of energy so with utilization of this energy performance increase.
- P. Regulagadda, I. Dincer, G. F. Naterer[5] published paper on Exergy analysis of thermal power plant with measured Boiler and Turbine losses. In this paper parametric study perform for various parameters for example when condenser pressure reducing plant efficiency increasing due to maximum expansion in turbine. Also maximum Irreversibility found in Boiler and Turbine that will be result in decrease exergy efficiency. At different pressure and temperature condition system performance carried out in this paper. After complete analysis it is found that plant Energy efficiency is 30.12% and Exergy efficiency is 25.38%.

- Raviprakash Kurkiya, Sharad Chaudhary[10] studied of various coal composition and give results of effect on Boiler Efficiency by carbon %, mass flow rate of coal, moisture %, Ash % and excess oxygen %. Efficiency increase with increase the % of carbon because with high calorific value coal consume also reduce. Energy efficiency decrease with increase in oxygen %, Ash % and moisture content. With this analysis the energy balance sheet prepared for various losses occurs in Boiler components. It shows that turbine has 30.18% efficiency, Boiler has 54% and condenser has 89% efficiency. This results give an idea where focus required to reduce the losses of Boiler components.

- Ompraksh prajapati, Dharmedra Kumar Jain[16] present the Energy and Exergy analysis of a 600MW of super thermal power plant. This is carried out on 1st law of thermodynamics approaches which is not difference between quantity and quality of energy, so the exergy analysis of the boiler component like boiler, turbine, condenser, Heat exchanger etc. This analysis gives a quantitative determine of quality of energy in terms of ability to produce work. In this analysis actual losses identified by energy and exergy balance equation for various components that will results in to improve the plant efficiency. Actual Irreversibility of each component find by exergy analysis that gives a real assessment of system. 2nd law carried out in this paper and justify possible efficiency improvement.

- Christian O. Osueke, Anthoni O. Onokwai, Adeyinka O. Adeoye carried out study of Energy and Exergy Analysis of a 75 MW plant in Huntley, The N.Z. Test were carried out, in both non-standard and designed modes of operation. Initially unit operating with the top heater at normal load with throttle control mode and after that operate without top heater with sliding pressure control mode at 150MW load. All the data were notes during heat rate acceptance test of the unit. In 1st case heat rate increase in steam cycle of 75.9kJ/KWh and that results in the increase in the exergy losses in condenser, Boiler and feed-water heaters from 53.9 to 56.99 % whereas turbine exergy losses reduced from 4.69 to 4.19 %. This paper concluded that the 1st law analysis resulted only in the increase in heat rate by 75.95 kJ/KWh while second law analysis react more important that would be resulted in the increase in low pressure turbine.

- Ashish M. Pullekunnel, Manish R. Moroliya[12] presented paper on Optimization of bed material consumption in CFBC boiler. This paper recommended for use of bed ash as bed material during boiler light up. There is no adverse effect on boiler efficiency by using bed ash as bed material that would be results in cost saving. There are basically two methods: Conventional method and Proportional method. Silica and alumina are generally used as bed material with small portion of other compounds. In conventional method at the time of cold light up whole furnace filled with bed material up to combustion zone. After coal feeding start for normal operation at that time some portion of bed material remove as ash by conveying system. And it is observed that ash contained a 1.5 to 2 % coal. In proposed method, during the research and analysis, it was found that the bed ash has almost comparable chemical and physical properties to that of the bed material used during light up of the boiler. Since, the bed material is automatically replaced with ash during operation.

- Manjunatha A., Basanagouda B. Patil, Sunil Chandra Mishra[15] studied on Oxygen Enrichment in CFBC boiler by Improvement of better combustion and reduce SOx and NOx. Increase the efficiency by reduces flue gas heat losses because the flue gas mass decrease as it leaves the furnace. There is less nitrogen to carry heat from the furnace. The oxy-fuel fired systems and certain burner can have achieved the lower levels of nitrogen oxide, carbon monoxide, and hydrocarbons by Improved heat transfer and temperature stability. Increasing the oxygen content allow the more stable combustion and higher combustion temperatures that can lead to better heat transfer. The productivity increase when a furnace has been converted to be oxygen enriched, throughput can be increased for the same fuel input because of higher flame temperature, increased heat transfers to the load, and reduced flue gas. Using oxygen-enriched combustion for specific applications may improve efficiency depend on the percentage of oxygen in the combustion air and the exhaust gas temperature.

Chapter 3

Energy Conservation in Auxiliary System

3.1 Power Saving opportunity in Compressor

To operate various pneumatic instruments, pneumatic ash conveying system and cleaning of plant compressor air is used. This requirement is fulfilled by operating two compressors. Atlas Copco compressor is used for 18 hours daily to supply air for operating conveying system. It is also used for 6 hours in night to provide air for cleaning of the plant. It is observed that out of 6 hours, 1 hour is loading time and rest of time is idle. To operate various pneumatic instruments 24 hours, air is supplied by Kaeser compressor. The third compressor named as plant air compressor (PAC) is available in the plant however it is not used for any application. As operating hours of Atlas Copco compressor in night time (6 hours) is only for one hour in load condition so it is not utilized to its fullest capacity and PAC compressor is remaining idle. Thus there is a need to optimize utilization of compressed air supply system to conserve energy and intern saving in cost. The two systems of utilization of compressed air are identified to optimize it usage. These cases are discussed in subsequent section in detail.

The another possibility is, the plant use Atlas Copco conveying compressor only for 18 hours for conveying system and PAC compressor use for remaining 6 hours for plant air. By doing this whatever energy save that will be mentioned in second case Load hours and Unload hours of compressor taken by observing compressor for 2 hours continuously up to 15 days and note down time by using stop watch.

The operating pressure range set of Atlas Copco compressor, PAC compressor and Kaeser compressor is 4.5 to 5 kg/cm2, 4 to 4.5 kg/cm2 and 5.5 to 6.5 kg/cm2 respectively. Performance comparison of various compressors are carried out based on its power consumption. The methodology used to determine power consumption is load unload current method []. The equation 24 is used to determine power consumption. The parameters of equation 24, like voltage, current and power factor are measured using digital power analyses. The consumption of current during load and unload condition for the different types of compressors are given in table 3.1. These values of current usage is utilized in subsequent section to determine power consumption of compressor as per usage. The voltage and power factor are found to be constant as mentioned in table 3.1.

$$P = \sqrt{3} * V * I * COS\phi \tag{3.1}$$

Table 3.1: Parameters of various Compressors

Compressors	Load Current,A	Unload Current,A	Voltage,V	Power Factor,ϕ
Atlas Copco	116	50	415	0.85
Atlas Plant Air	35	16.8	415	0.85
Kaeser	125	65.8	415	0.85

3.1.1 Modification 1 : Use of Kaeser Compressor to supply air for plant cleaning

To identify modification, the usage pattern of Atlas copco and Kaeser compressor during night time (6 hours) is studied. Based on study it is found that Atlas copco compressor operates for 1 hour under laoding condition and 5 hour under unloading condition whereas Kaeser compressor operates 5 hours under loading condition and 1 hour under unloading condition. It can be observed from table 3.1 that even in unloading operating condition compressor consumes power. Thus if Kaeser compressor is used to supply air for plant cleaning instead of Atlas copco compressor than it runs at full load condition for six hours and Atlas copco compressor remains in shutdown position. This strategy increases power consumption of Kaeser compressor however net power consumption reduces due to saving in power of Atlas copco compressor. This way it is possible to reduces energy consumption and electricity bill. The detailed data analysis of energy saving based on study are discussed below.

Power consumption for Atlas copco compressor calculated using equation 24 and data mentioned in table 3.1 for during loading and unloading operation is equal to 70.87 kW/hr and 30.55 kW/hr respectively.

The total power consumption considering 1 hour of loading and 5 hours of unloading operation is 223.62 kW.

Kaeser compressor during run at full load for almost 6 hours if it is also used for plant air.

Similarly consumption of the Kaeser compressor previous to modification is 422.02 kW and after modification (six hours loading time) is 458.22 kW.

Kaeser Compressor extra consumption due to supply plant air for cleaning is found as

36.2 kW.

Net saving in power is found as 187.42 kW per day.

Limitations of this modification is that when in some rare cases more number of valves need to open and close then compressed air supplied by Kaeser compressor after modification is found to be insufficient.

3.1.2 Modification 2 : Use of PAC Compressor to supply air for plant cleaning

As mentioned in section 3.1.2, on few occasions when load on Kaeser compressor compressor increases it may create problem for opening and closing of valves. This situation can not be tolerated as it affects functioning of various systems of power plant. Looking to table 3.1 it is found that current requirement for loading and unloading operating condition of PAC compressor is least among three. This is due to its low capacity however it is sufficient for cleaning of plant. Thus another modification is the use of PAC compressor instead of Atlas copco compressor to supply air for plant cleaning.

As PAC compressor capacity is low it is required to operate for 2 hours in loading and 4 hours at unloading condition.

Based on equation 24 and data of table 3.1, total power consumption of PAC compressor is found as 91.4 kW.

Net power saving due to this modification is found as 132.22 kW/ day. This is less than the modification 1. However, it is possible to implement as PAC compressor is remaining idle before modification.

3.1.3 Cost analysis of Compressors

The average rate of Electricity from Grid is equal to 6.5 Rs. per unit. The average rate of Electricity generation cost is equal to 3.8 Rs. per unit by considering basic cost and 4.9 Rs. per unit by considering Overhead cost.

In the first modification, the energy saving is equal to 187.42 kW per day that resulted in to cost of saving up to 918.46 rs per day and Rs. 3.35 lacs per year. In the second modification, the energy saving is equal to 132.22 kW per day that resulted in to cost of saving up to 647.98 rs per day and Rs. 2.37 lacs per year. Net difference between both of case is equal to 98725.20 Rs. per year.

But due to some technical reason the modification 1 is not implement by plant. After that suggestion of modification 2 to the energy manager, he referred this case and implemented this solution by permission of plant head. So after implemention of modification in the plant, company has profit of Rs. 2.37 lacs per year.

3.2 Energy conservation in Coal handling plant

The Boiler of design is such that the size of coal used should be less than 6 mm. Coal handling plant of 50TPH, produces such size of coal by crushing it using primary crusher and secondary crusher. The primary crusher reduces size of coal up to 50mm. Then secondary crusher further reduces size of coal around 6 mm. To supply only coal size less than 6 mm to boiler, coal coming from secondary crusher is filtered using vibro-screen. The coal with size of more than 6 mm again sent back to secondary crusher using bucket elevator. But as per practical analysis it is found that there is always phasing problem in bucket elevator. To over come issue these issues it is decided to install a modern coal handling plant of same capacity. In the new coal handling plant it is possible to develop coal of size around 6 mm using single crusher. When coal above 6 mm is removed by vibrato-screen but arrangement is made in such a way that it is not required to use bucket elevator to send it back to crusher. Thus new coal handling plant resulted in to reduction in power consumption due use of single crusher and elimination of use of bucket elevator. Energy conservation analysis to compare two coal handling plants are mentioned below. The power consumption of all motors used in plant can be determined using equation 25.

$$P = \sqrt{3} * V * I * COS\phi \tag{3.2}$$

3.2.1 Energy calculation for old Coal handling plant

In an old coal handling plant the coal sequentially passes through ground hopper, Vibrato feeder, Belt conveyor 1, Reversible belt feeder 1, Primary crusher, Belt conveyor 2, Reversible belt feeder 2, Secondary crusher, Vibrato-Screen, Bucket Elevator, Secondary crusher, Vibrato-Screen, Belt conveyor 3, Belt conveyor 4, Reversible belt feeder 5 and Coal Bunker. Out of these, equipment that are operated using electric motors are mentioned in table 3.2. In the old coal handling plant the power consumption of motors attached with number of elements is listed in table 3.2. The actual power consumption of each element is measured with the help of Clamp Meter. In table 3.2 the rated value of these motors are also mentioned along with actual values. Rated value means the maximum limit value of power. When power consumption increases than rated value the element may be tripped for safety of equipment and humans. For the old coal handling plant the total power consumption per hour is equal to 103.14 kW.

Table 3.2: Power consumption in different motor for old CHP

No.	Name of Motor	Rated value(kW)	Actual value(kW)
1	RBF-1	3.7	2.26
2	RBF-2	3.7	1.96
3	RBF-5	3.7	1.89
4	VF	0.51	0.51
5	BC-1	9.3	7.45
6	BC-2	9.3	6.78
7	Vibrato-Screen	15	7.69
8	BC-4	5.5	4.52
9	Bucket Elevator	5.5	4.28
10	BC-3	15	8.55
11	Primary Crusher	18.5	12.65
12	Secondary Crusher	75	44.6
Total	-	164.71	103.14

3.2.2 Energy calculation for new Coal handling plant

In the new coal handling plant the coal sequentially passes through Ground hopper, Vibrato feeder, Belt conveyor 1, Vibrato-Screen, {Belt conveyor 3(allow less than 6 mm)}, Crusher, Belt conveyor 4, Belt conveyor 2, Belt conveyor 1, Vibrato-Screen, Belt conveyor 3, RSC and Coal Bunker. In this plant the power consumption of motors attached with number of elements is listed in table 3.2. The actual power consumption of each element is measured with the help of Clamp Meter. In table 3.2 the rated value of these motors are also mentioned along with actual values. For the new coal handling plant the total power consumption is equal to 59.95 kW. The energy saving by installing new coal handling plant is found as 43.19 kW/hour. The coal plant is generally running 15 to 18 hours per day. Thus the energy saving per day considering average operating hours of 16. 5 is found as 712.64 kWh.

Table 3.3: Power consumption in different motor for new CHP

No.	Name of Motor	Rated value(kW)	Actual value(kW)
1	Vibrato feeder	0.5	0.49
2	BC-1	15	9.29
3	BC-2	5.5	3.85
4	Crusher	55	25.66
5	Vibrato-Screen	22	10.08
6	BC-4	2.2	1.47
7	BC-3	11	7.64
8	RSC-1	2.2	1.47
Total	-	113.4	59.95

3.2.3 Cost analysis of Coal handling plant

The total power consumption in old Coal handling plant is equal to 103.24 kW per hour. For the new coal handling plant the total power consumption is equal to 59.95 kW per hour. So, the Energy saving is equal to 43.19 kW per hour.

The coal plant is generally running 15 to 18 hours per day. So, the based on the average hours, Energy saving per day is equal to 712.64 kWh.

By considering Overhead cost of 4.9 Rs. per unit, the cost of saving is equal to 3491.94 Rs. per day and that resulted in to cost of saving equal to Rs. 12.75 lacs per year.

Chapter 4

Energy and Exergy analysis Captive Power Plant Components

4.1 Evaluate Boiler Efficiency and Exergy Analysis of Furnace

Boiler is a device which converters water in to steam using various types of fuel. The performance of boiler can be determined by knowing its efficiency. The efficiency can be measured using two methods (i) Direct method and (ii) Indirect method. Direct method evaluates boiler performance using on input and output energy quantities whereas indirect method evaluates using various losses occurring from boiler. The detail methodology of determination of boiler efficiency using direct and indirect method along with data of boiler used in present work is discussed as follows.

4.1.1 Direct Method

ASME PTC 4 or BS 2885 or IS 8753 describes method of evaluation of boiler efficiency using direct method. This method of is applicable for boilers fired with oil, gas, solid fuels. It is also applicable for different firing systems such as stoker, PFBC, FBC. Boiler direct efficiency is calculated using equation 26.

$$\eta = \frac{(Steamflowrate \times (steamenthalpy – feedwaterenthalpy))}{(Fuelfiringrate \times grosscalorificvalue)} * 100 \qquad (4.1)$$

Steam enthalpy and feed water enthalpy can be evaluated using steam table corresponding to pressure and temperature.

Values of boiler direct efficiency for different load conditions for steam pressure 103.73 kg/cm^2, steam temperature 494 ^{0}C, feed water temperature 149 ^{0}C, coal feed rate 20.13 TPH and GCV of coal 5298 kCal/kg is given in table 4.1:

Table 4.1: Direct Efficiency for Different Load condition

Steam Flow in TPH	141.4	135.9	133.7	131.2	129.4	124.1
Boiler Efficiency, η	84.02	83.06	81.43	74.8	69.95	66.2

This variation in boiler direct efficiency with respect to the steam flow increase with increase in quantity of steam. This rate of increase in efficiency shown in figure 4.1. So, for the effective utilization of boiler process plant operations maintain at full load condition.

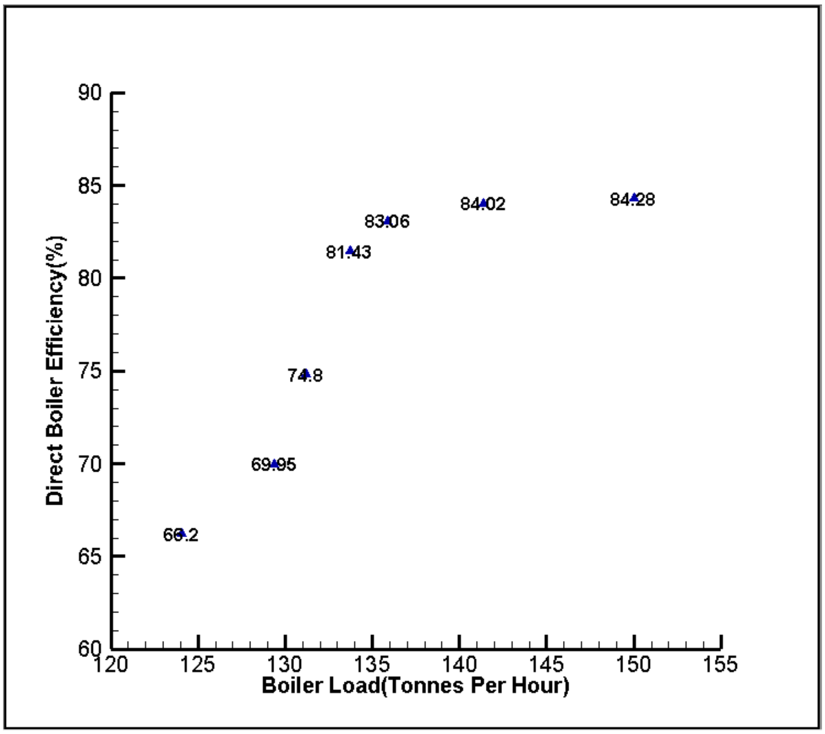

Figure 4.1: Variation in boiler direct efficiency with boiler load

4.1.2 Indirect Method

Direct method gives the values of efficiency and losses however it does not provide where these losses occurred in boiler. This limitation can be overcome by determining efficiency using indirect method. In indirect method various losses as a fraction of heat supplied are determined and its total values is subtracted from 1 to find efficiency.By knowledge of various losses, their is chance to increase efficiency by reducing losses.

Data required for this method are:

1. Ultimate analysis of fuel (C, H, O, N, S, Moisture, ash)

2. GCV of fuel, kcal/kg which varies from 4000 to 5500kcal/kg in present study.

3. Oxygen and CO in flue gas (% by vol.)

4. Flue gas temperature, Ambient air temp, humidity in air.

5. Combustibles (unburnt) in fly ash & bottom ash

6. Surface temperature of furnace

The value of composition of coal by ultimate analysis is given in table 4.2, when GCV of Coal equals to 4127 kCal/kg.

Table 4.2: Ultimate Analysis result of Coal

No.	Constituent	Percentage
1	Carbon	44.44
2	Hydrogen	3.13
3	Oxygen	12.71
4	Sulphur	0.26
5	Nitrogen	0.70
6	Moisture	30.00
7	Ash	8.76
8	Total	100

Boiler efficiency depends upon values of excess air supplied. If excess air supplied is higher than fuel consumption increases and if its values is found less than 1 than fuel is not completely burnt. Thus it is advisable to supply only that much excess air which is necessary to burn all fuel. Excess air supply and actual air supply can be determined using following method. As mentioned in table 4.2 oxygen needs to be supplied for reaction of Carbon, Hydrogen, Sulphur and Nitrogen. Calculation of this is mentioned below.

Combustion of Carbon:

$C + O_2 = CO_2$

12 + 32 = 44

0.444+1.184=1.628 kg/kg of fuel

Combustion of Hydrogen:

$H_2 + \frac{1}{2}O_2 = H_2O$

2 + 16 = 18

0.0313+0.2504=0.2817 kg/kg of fuel

Combustion of Sulphur:

$S + O_2 = SO_2$

32 + 32 = 64

0.0026+0.0026=0.0052 kg/kg of fuel

Theoretical Oxygen requirement for total Combustion,

$$O_2|_{Theoratical} = O_2|_C + O_2|_{H_2} + O_2|_S - O_2|_{Fuel} \tag{4.2}$$

Theoretical Oxygen requirement is equal to 1.3089 kg/kg of fuel.

Theoretical Air required by % of volume,

O_2+N_2= Air
23 + 77 = 100
1.309+4.382=5.691 kg/kg of fuel
Therefore, the Theoretical Air Required is equal to 5.691 kg/kg of fuel.
Excess Oxygen in flue gas = 2.82 %
% Excess Air supplied,

$$EAS = (\frac{O_2\%}{21 - O_2\%}) * 100 \tag{4.3}$$

The Excess air supplied is equal to 15.51%.
Actual Air supplied,

$$AAS = [1 + \frac{EA}{100} * TA] \tag{4.4}$$

Therefore the Actual Air Supply is equal to 6.573 kg/kg of fuel. The flue gas analysis results are shown in table 4.3 that will be helpful to calculate all losses of Boiler.

Table 4.3: Flue Gas Analysis results

No.	Constituent	Mass (kg/kg of fuel)	Mole. Mass	Mole (wet)	Mole (dry)
1	CO_2	1.628	44	0.037	0.037
2	$M.C. + H_2O$	0.5817	18	0.032	0
3	SO_2	0.0052	64	0.00008	0.00008
4	$O_{2\|ex}$	0.0282	32	0.0009	0.0009
5	$N_{2\|f} + N_{2\|th}$	4.389	28	0.1568	0.1568
6	$N_{2\|ex}$	0.1268	28	0	0.0045
7	$N_{2\|act}$	5.0612	28	0.1808	0
8	$Air_{\|th}$	5.691	-	-	-
9	$Air_{\|act}$	6.573	-	-	-
10		15.50%	-	-	-
	$\sum dry =$	6.1773	-	0.41	0.20

Loss due to dry flue gases,

$$L_1 = \frac{(m_{dfg} * Cp * (t_f - t_a))}{(C.V.of fuel)} * 100 \tag{4.5}$$

Loss due to dry flue gases is equal to 3.34 %.
Loss due to Hydrogen in fuel,

$$L_2 = \frac{(9 * H2 * 584 + Cp * (tf - ta))}{(C.V.of fuel)} * 100 \tag{4.6}$$

Loss due to Hydrogen in fuel is equal to 4.278 %.
Loss due to moisture content in fuel,

$$L_3 = \frac{(M * 584 + Cp * (tf - ta))}{(C.V.of fuel)} * 100 \tag{4.7}$$

Loss due to moisture content in fuel is equal to 4.54 %.

Loss due to moisture content in air,

$$L_4 = \frac{(AAS * Humidityfactor * cp * (tf - ta))}{(C.V.of fuel)} * 100 \tag{4.8}$$

Loss due to moisture content in air is equal to 0.266 %.

Loss due to unburnt Carbon particles,

Total heat loss due to unburnt C in total dry refuse=13.36 kCal/kg of fuel

$$L_5 = \frac{(TotalheatlossduetounburntCintotaldryrefuse)}{(C.V.of fuel)} * 100 \tag{4.9}$$

Loss due to unburnt carbon is equal to 0.179%.

Loss due to surface radiation and convection,

$$L_6 = 0.548 * [\left(\frac{Ts}{55.53}\right)^4 - \left(\frac{Ta}{55.53}\right)^4] + [1.975 * (Ts - Ta)^{1.25} * \sqrt{\frac{198.85 * Vw + 68.9}{68.9}}] \tag{4.10}$$

L_6= 10632.98 w/m^2

= 10632.98*0.86 KCal/m^2

= 9144.37 KCal/m^2

Total radiation and convection loss = 9144.37*90 = 822993.24 KCal/m^2

(4.11)

Loss due to radiation and convection is equal to 0.81 %.

Losses due to unburnt fly ash,

$$L_7 = \frac{(Totalashcollectperkgoffuelburnt * CVofflyash)}{(CVoffuel)} * 100 \tag{4.12}$$

Loss due to unburnt fly ash is equal to 0.002 %.

Losses due to unburnt bottom ash,

$$L_8 = \frac{(Totalashcollectperkgoffuelburnt * CVofbottomash)}{(CVoffuel)} * 100 \tag{4.13}$$

Loss due to unburnt bottom ash is equal to 1.2319 %.

Loss due to calcification of sorbet & sulphation gain,

Mass fraction of calcification & sulphation = 0

$$L_9 = \frac{(Ms)}{(GCV of fuel)} * 100 \quad (4.14)$$

Loss due to Calcification is equal to 0 %.

Loss due to moisture in limestone,

ML = 0

$$L_{10} = \frac{(Ml * \triangle H)}{(GCV of fuel)} * 100 \quad (4.15)$$

Loss due to moisture in limestone is equal to 0%.

$$Boiler Indirect efficiency = 100 – [L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8 + L9 + L10] \quad (4.16)$$

So, the Indirect Boiler efficiency is equal to 85.35 %.

This indirect efficiency varies with change in quality of coal used by plant. Generally, the indirect efficiency increase with increase in GCV of coal. Thus, as the carbon percentage in composition of coal increase the indirect efficiency also increases as shown in figure 4.2.

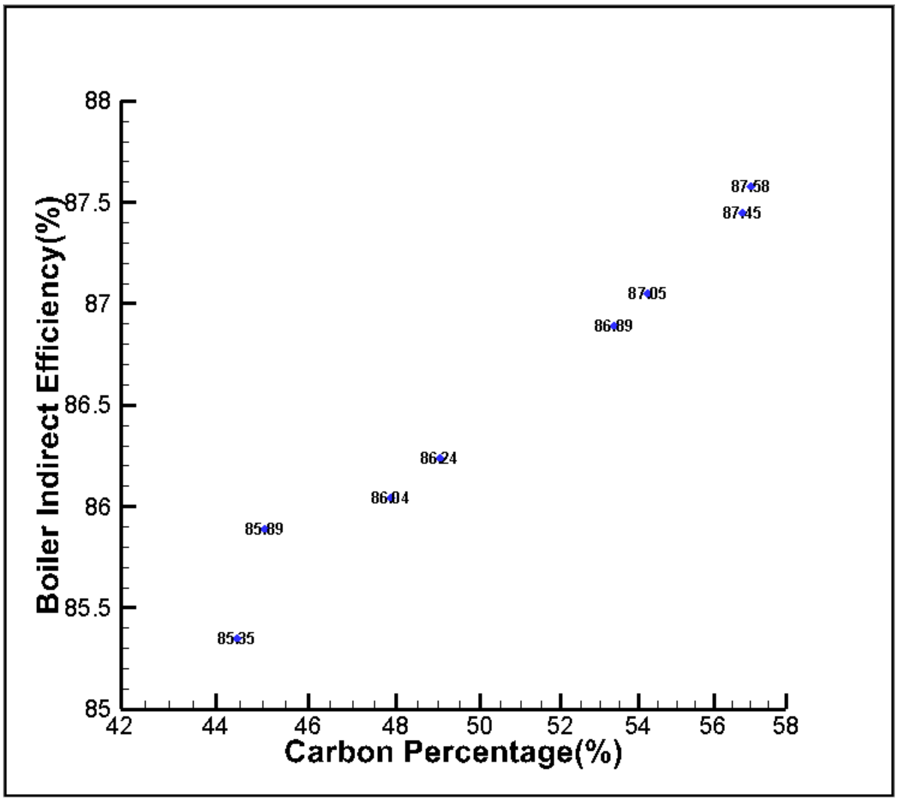

Figure 4.2: Increase in Indirect efficiency with increase in carbon percentage

4.1.3 Furnace Chemical and Physical Exergy Analysis

In case of furnace the chemical reaction occurs inside the chamber so for Exergy calculation the chemical Exergy also consider with physical Exergy. In the furnace, Inputs given are primary air, secondary air, saturated water and coal. The outcomes of furnace are steam and flue gas. Sometime bed material are drained from bottom of furnace for controling furnace bed temperature. But that will be not consider in exergy calculation because it is not necessary to drained bed regularly.

Chemical Exergy of Coal is given by,

$$\Psi_{coal} = 31183.16 * C + 21.95 * N + 11659.9 * H + 18242.9 * S + 13269.9 * O \tag{4.17}$$

The value of C,N,H,S and O is taken from table 4.3 and the chemical exergy of coal is equal to 101970.15 kW.

Physical Exergy of Steam,

$$\Psi_{steam} = m_s[(h - h_0) - T_0(s - s_0)] \tag{4.18}$$

The exergy of steam is equal to 41822.25 kW.

Physical Exergy of Air,

$$\Psi_{pa+sa} = m_{pa}C_{pa}[(T_a - T_0) - T_0 ln\frac{Ta}{T0}] + m_{sa}C_{sa}[(T_a - T_0) - T_0 ln\frac{Ta}{T0}] \tag{4.19}$$

The exergy of total air is equal to 1286.77 kW.

Physical Exergy of Water,

$$\Psi_{water} = m_w C_w[(T_a - T_0) - T_0 ln\frac{Ta}{T0}] \tag{4.20}$$

The exergy of water is equal to 10150.97 kW.

Exergy of Flue gas,

$$\Psi_{fg} = m_{fg}C_{fg}[(T_a - T_0) - T_0 ln\frac{Ta}{T0}] \tag{4.21}$$

The exergy of flue gas is equal to 24319.48 kW.

Exergy Balance Equation for Furnace is given as below Equation.

$$Exergyof(Coal + Air + Water) = Exergyof(Steam + Fluegas) + ExergyDestruction \tag{4.22}$$

Therefore, Total Exergy Destruction is equal to 30902.3 kW and the Exergy Efficiency is found to be 58.32 %

4.2 Turbine Performance and Exergy Analysis

Turbine is the very critical part of power plant. The performance of turbine is measured by heat rate, specific steam consumption, thermal efficiency and mechanical efficiency. However, the actual losses occurs due to improper insulation or due to internal Irreversibility that is not examined by these factor. So, for the complete analysis of Turbine the Exergy analysis has been carried out with the help of second law of thermodynamics. The Heat and Mass balance diagram for Condensate Turbine is given in figure 4.1.

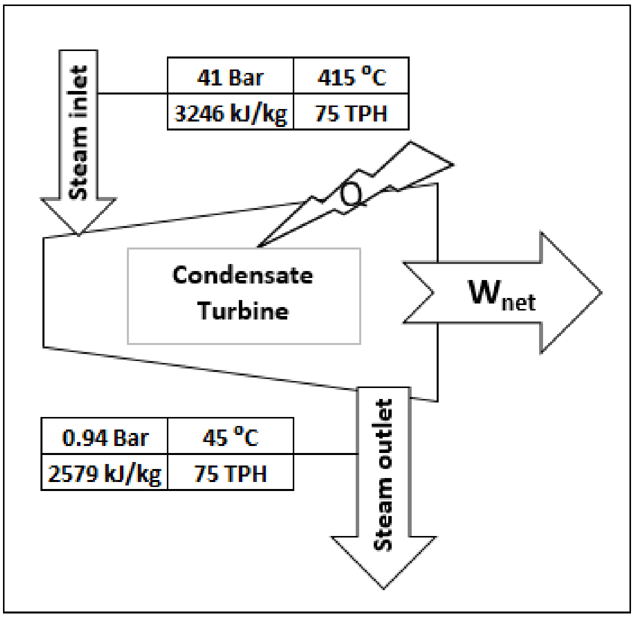

Figure 4.3: Condensate Turbine with HMBD Diagram

Heat rate of turbine is calculated by equation 48,

$$H.R. = \frac{((Steamflowrate * 1000 * Enthalpyatinletofturbine))}{(Steamturbineload * 1000)} \tag{4.23}$$

The heat rate of turbine is found equal to 3417.68 kCal/kWh.
Specific steam consumption is calculated by equation 49,

$$S.S.C. = \frac{Steamconsunption}{PowerGeneration} \tag{4.24}$$

The Specific steam consumption found equal to 4.25 kg of steam/MW.
Turbine Mechanical Efficiency is calculated by equation 50,

$$\eta = \frac{(Steamturbineload * 1000 * 860)}{(Enthalpyatinletofturbine * 1000 * Steamflowrate)} * 100 \tag{4.25}$$

It is found to be 27.16 %. According to design value, Efficiency should be 30% .

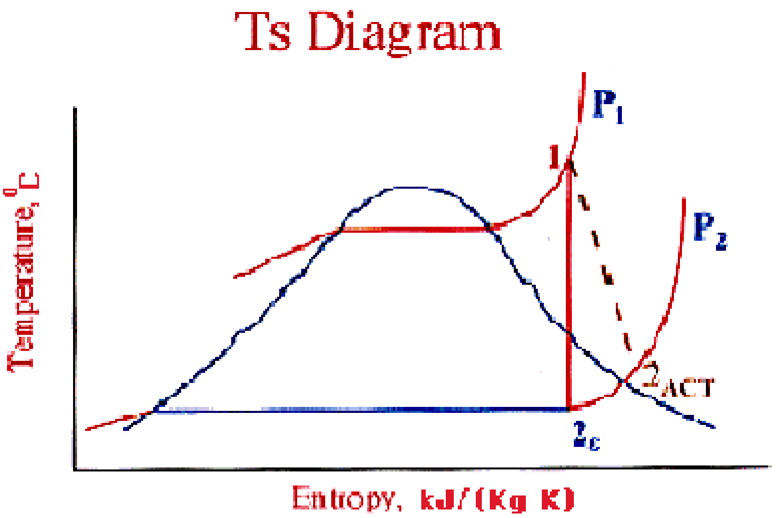

Figure 4.4: T-S diagram for Turbine Expansion

From Moiler Diagram shown in figure 4.2, Isentropic Enthalpy = 2210 kJ/kg
Isentropic Efficiency,

$$\eta = \frac{(Enthalpy at inlet of Turbine - Actual Enthalpy at outlet of Turbine)}{(Enthalpy at intelo f Turbine - Isentropic Enthalpy at outlet of Turbine)} * 100 \quad (4.26)$$

The isentropic efficiency is found to be equal to 67.29 %.

Due to unmatched design parameter of Boiler outlet(109 Bar) and Turbine Inlet(41 Bar) the plant has to been decided to change Turbine. So, Installed the Back pressure Turbine to reduce losses in PRDS system. The Heat and mass balance diagram with control volume shown in Figure 4.3.

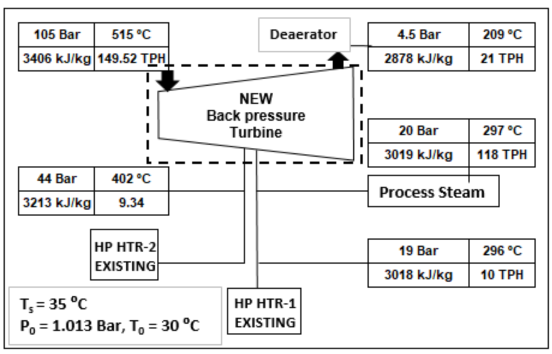

Figure 4.5: Control volume figure of BPSTG with HMBD diagram

Energy balance equation for turbine by considering Steady flow and neglecting K.E. and P.E. terms,

$$mh_1 + Q = mh_2 + W \tag{4.27}$$

Exergy at inlet,

$$B_{in} = \sum m_{in}[(h_i - h_0) - T_0(s_i - s_0)] \tag{4.28}$$

Exergy at outlet,

$$B_{out} = \sum m_{out}[(h_j - h_0) - T_0(s_j - s_0)] \tag{4.29}$$

Exergy balance equation for Turbine,

$$B_{in} - B_{out} - Q(1 - \frac{To}{Ts}) - W - I_{irrev} = 0 \tag{4.30}$$

Exergy Destruction is calculated by,

$$E_d = m * T_0 * S_{gen} \tag{4.31}$$

Exergy efficiency is calculated by,

$$\eta = 1 - \frac{E_d}{B_1} \tag{4.32}$$

The Exergy analysis result for both the Turbine shown in table 4.4.

Table 4.4: Result of Exergy analysis of both the Turbine

Type of Turbine	Heat loss(kW)	Exergy destruction(kW)	Exergy Efficiency(%)
Condensate Turbine	2475.5	7186.37	52.17
BPSTG Turbine	352.17	1662.35	69.61

4.3 Condenser Effectiveness and Exergy Analysis

Condenser is used for condensate the exhaust steam coming from the last stage of turbine. In condenser phase change process occurs and the remaining uncondensate gas extract through steam ejector system. The amount of condensate water collected in to hot well and transfer it again to the DM plant tank.

Effectiveness for condenser is calculated by,

$$\varepsilon = \frac{(Ms * (Hinlet - Houtlet))}{(Mw * Cpw * (Twout - Twinlet))} * 100 \tag{4.33}$$

It was founded to be 76.24 %.

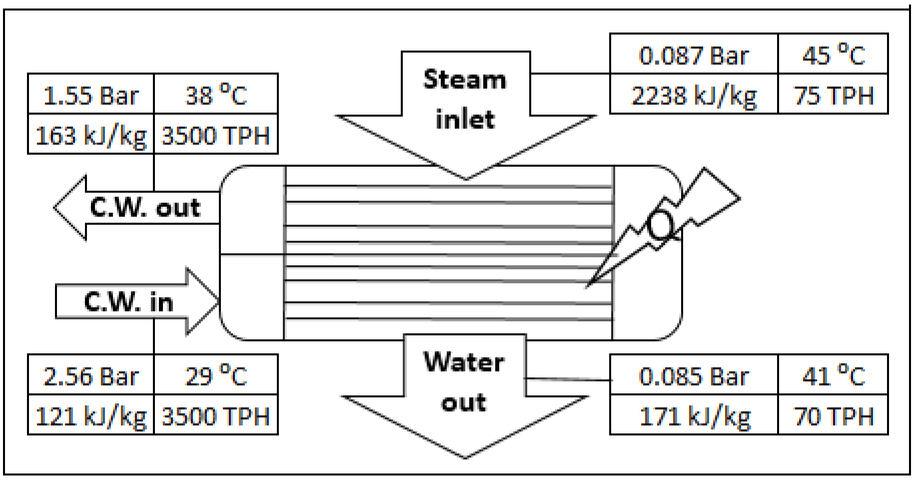

Figure 4.6: Condenser with HMBD Diagram

First law analysis for Condenser system:
Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1(h_1 - h_2) + Q = m_2(h_4 - h_3) \tag{4.34}$$

The heat loss occurs in condenser is equal to be 11693.70 kW.
Exergy balance equation for Condenser steady flow open system,

$$(B_1 + B_3) - (B_2 + B_4) - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.35}$$

The Exergy Destruction in condenser is equal to 3943.99 kW.

$$\eta = 1 - \frac{E_d}{(B_4 - B_3)} \tag{4.36}$$

Exergy efficiency of Condenser is equal to 52.17 %.

4.4 Boiler Accessory Effectiveness and Exergy Analysis

In the Boiler, Mounting and Accessory plays very important roles for effective and safe operation. Mounting is basically used for the safety of Boiler where's the Accessory is used for the increase the performance of Boiler. The heat energy generated by furnace cannot be utilized in single component. So, the Boiler accessories used for the complete utilization of flue gas energy step by step otherwise that should be loss in atmosphere.

4.4.1 Air Preheater Energy and Exergy Analysis

Air preheater used for the rise the temperature of primary air and secondary air that resulted in to constant combustion. In case of without Air preheater some of the fuel energy utilized for increase the temperature of air rather than to generate steam. In Air preheater the air is flow inside the tube and the flue gas flow from shell side because the soot blowing provided in shell side. The heat and mass balance diagram for air preheater shown in figure 4.5.

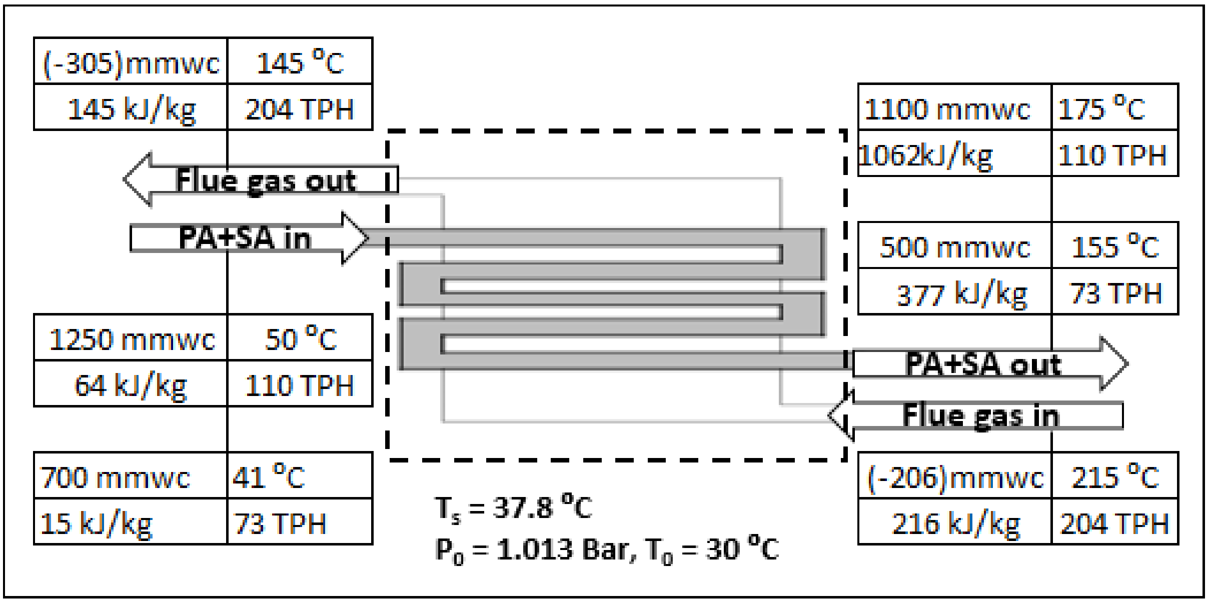

Figure 4.7: Initial Condition HMBD of Air Preheater

Effectiveness of Air Preheater,

$$\varepsilon = \frac{0.6 * Mpa * Cpa * (Tpaout - Tpainlet) + 0.4 * Msa * Csa * (Tsaout - Tsainlet)}{Mdf * Cdf * (Tdfinlet - Tdfoutlet)} * 100 \quad (4.37)$$

It is found 65.08 %.
First law analysis for open system,
Considering Steady flow and neglecting K.E. and P.E. terms,

$$0.6 * m_1 h_1 + 0.4 * m_2 h_2 + Q = m_3 h_3 \quad (4.38)$$

Exergy balance equation for Air preheater steady flow open system,

$$(B_1 + B_3 + B_5) - (B_2 + B_4 + B_6) - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \quad (4.39)$$

Exergy efficiency,

$$\eta = 1 - \frac{E_d}{(B_3 - B_4)} \quad (4.40)$$

Air preheater heat and mass balance diagram after modification shown in figure 4.6,

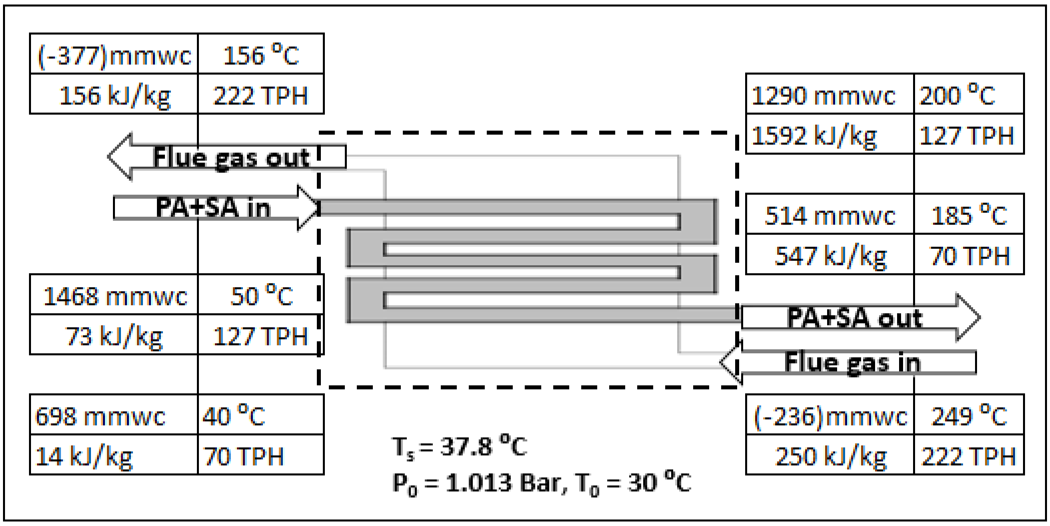

Figure 4.8: Modified Condition HMBD of Air preheater

By use of equation 63, 64 and 65 Re-calculate all these things. The Exergy analysis result for the both case of Air preheater written in table 4.5.

Table 4.5: APH Exergy result for both cases

Condition	Heat loss(kW)	Exergy destruction(kW)	Exergy Efficiency(η)
Before implementation	778.54	1026.35	55.90
After implementation	928.84	1523.96	58.42

4.4.2 Economizer Energy and Exergy Analysis

Economizer is used for the increase the temperature of feed water. Due to these the amount of sensible heat required in the Boiler furnace is reduced. So, the quantity of coal required is reduce. The heat and mass balance figure shown in figure 4.7.

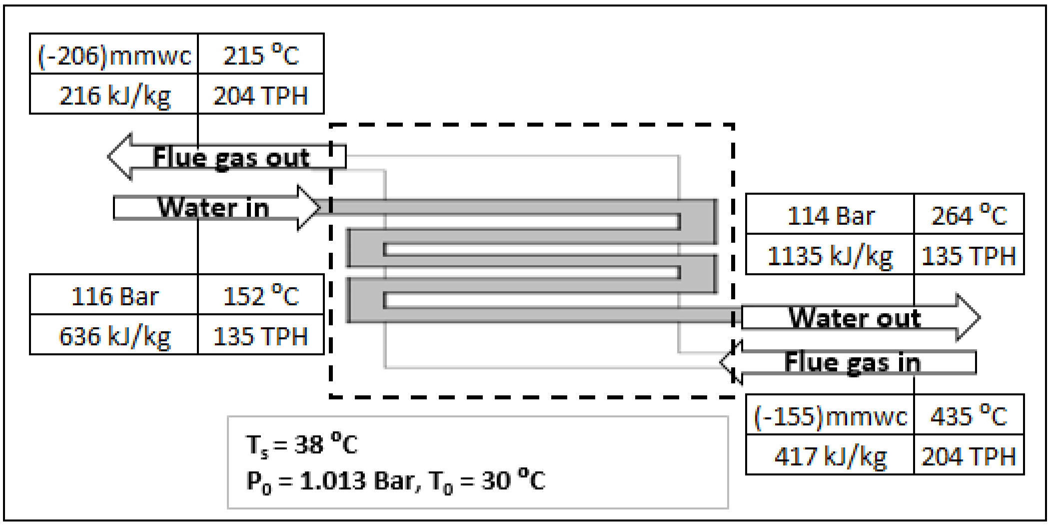

Figure 4.9: Initial Condition HMBD of Economizer

Effectiveness of Economizer,

$$\varepsilon = \frac{Mw * Cpw * (Twout - Twinlet)}{Mdf * Cdf * (Tdfinlet - Tdfoutlet)} * 100 \tag{4.41}$$

The Effectiveness of Economizer is equal to 70.4 %.
First law analysis for open system:
Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1(h_2 - h_1) + Q = m_2(h_3 - h_4) \tag{4.42}$$

Exergy balance equation for Steady flow open system,

$$(B_1 + B_3) - (B_2 + B_4) - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.43}$$

Exergy efficiency,

$$\eta = 1 - \frac{E_d}{(B_1 - B_2)} \tag{4.44}$$

The heat and mass balanced diagram of Economizer after implementation shown in figure 4.8.

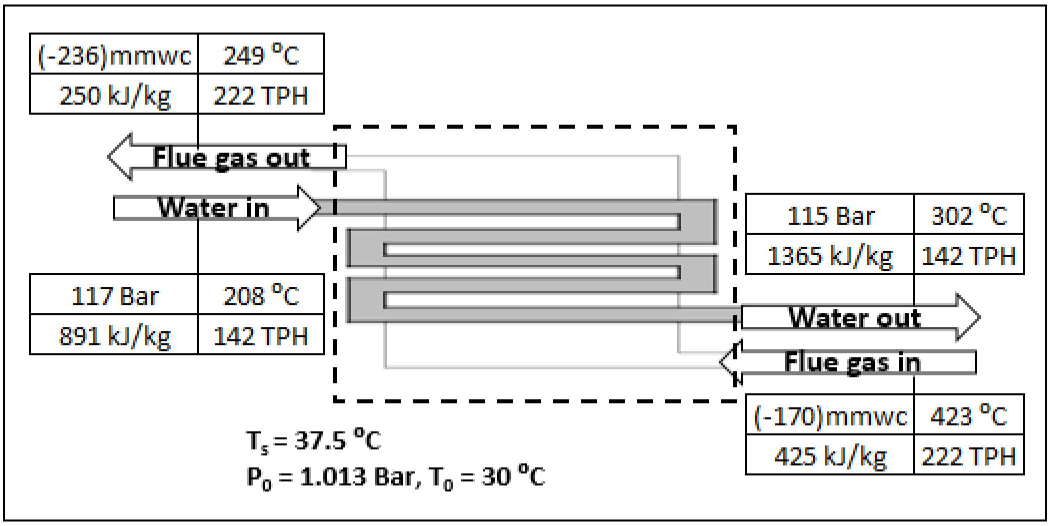

Figure 4.10: Modified Condition HMBD of Economizer

By use of equation 67, 68 and 69 Re-calculate all variable.Exergy result of Economizer for both case written in table 4.6.

Table 4.6: Exergy result of Economizer for both cases

Condition	Heat loss(kW)	Exergy destruction(kW)	Exergy efficiency(η)
Before implementation	3343.60	3591.44	62.23
After implementation	1565.23	2179.01	76.25

4.4.3 Primary Super Heater Energy and Exergy Analysis

Primary super heater used for converting the saturated steam into dry steam. The steam is passed through tube side and the flue gas is passed through the shell side. As per power plant concern the fluid which have more pressure is generally kept on tube side. The heat and mass balance diagram shown in figure 4.9.

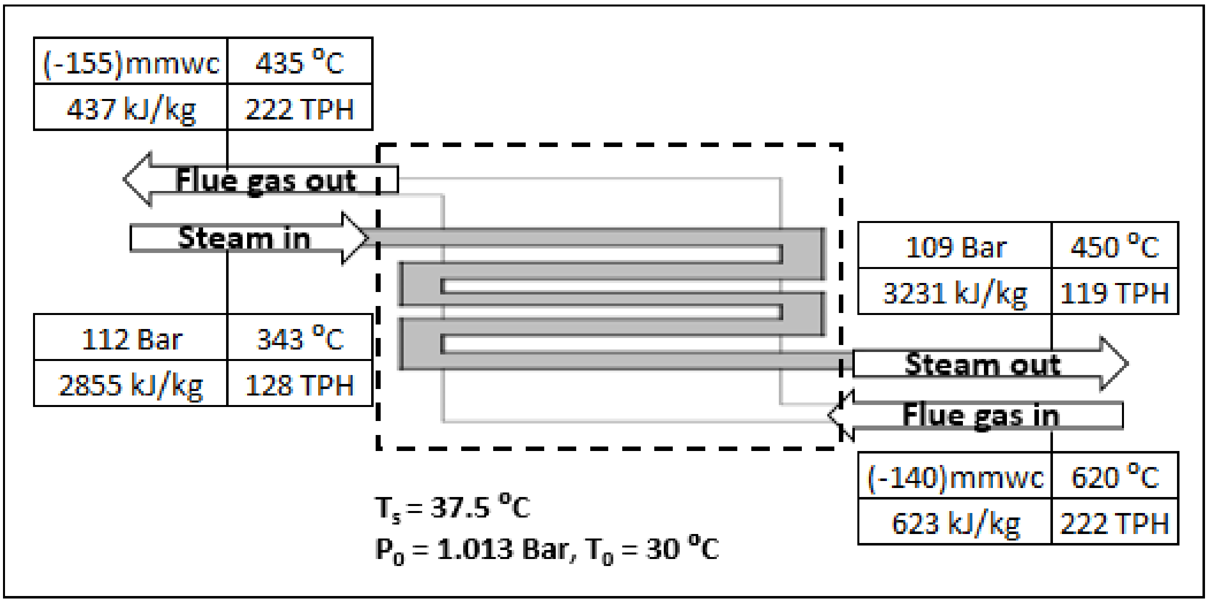

Figure 4.11: Initial Condition HMBD of PSH

Effectiveness of Primary Super Heater,

$$\varepsilon = \frac{Ms * Cps * (Tsout - Tsinlet)}{Mdf * Cdf * (Tdfinlet - Tdfoutlet)} * 100 \tag{4.45}$$

It is found to be 75.82 %.

First law analysis for open system:

Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1(h_2 - h_1) + Q = m_2(h_3 - h_4) \tag{4.46}$$

Exergy balance equation for Steady flow open system,

$$(B_1 + B_3) - (B_2 + B_4) - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.47}$$

Exergy efficiency,

$$\eta = 1 - \frac{E_d}{(B_3 - B_4)} \tag{4.48}$$

The heat and mass balance diagram for primary super heater after modification shown in figure 4.10.

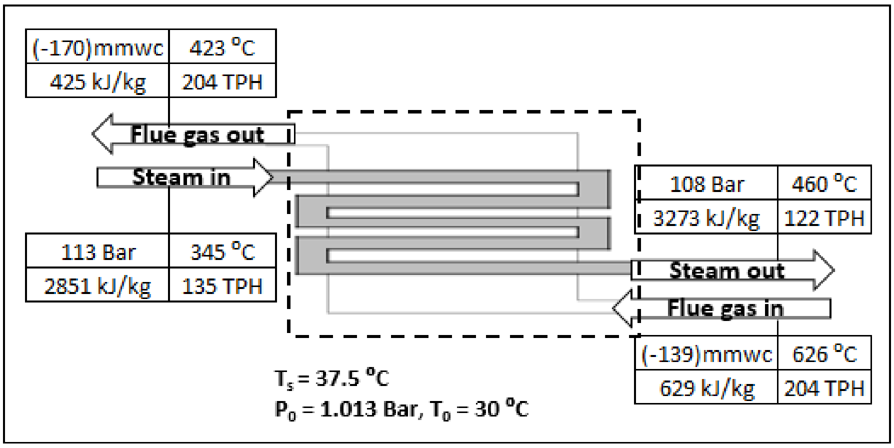

Figure 4.12: Modified Condition HMBD of PSH

By using the equation 71, 72 and 73 Re-calculate value of all variable. The Exergy result of primary super heater for both case shown in table 4.7.

Table 4.7: Exergy results of PSH for both cases

Condition	Heat loss(kW)	Exergy destruction(kW)	Exergy efficiency(η)
Before implementation	2546.42	1961.31	67.73
After implementation	2154.64	2629.96	74.19

4.4.4 Final Super Heater Energy and Exergy Analysis

Final super heater used for converting the dry steam into super heated steam. The steam is passed through tube side and the flue gas is passed through the shell side. Final super heater is used increase the degree of super heating. The heat and mass balance equation for Final super heater shown in figure 4.11.

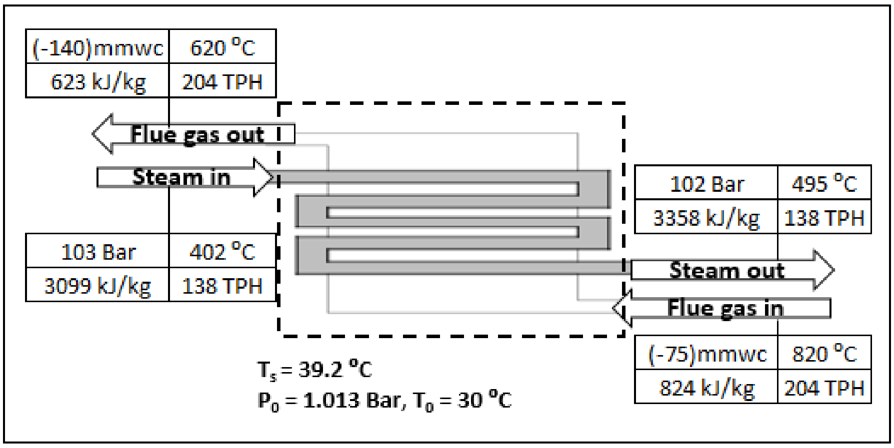

Figure 4.13: Initial Condition for HMBD of FSH

Effectiveness of Final Super Heater,

$$\varepsilon = \frac{Ms * Cps * (Tsout - Tsinlet)}{Mdf * Cdf * (Tdfinlet - Tdfoutlet)} * 100 \tag{4.49}$$

It is equal to 74.60 %.

First law analysis for open system:

Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1(h_2 - h_1) + Q = m_2(h_3 - h_4) \tag{4.50}$$

Exergy balance equation for Steady flow open system,

$$(B_1 + B_3) - (B_2 + B_4) - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.51}$$

Exergy efficiency,

$$\eta = 1 - \frac{E_d}{(B_3 - B_4)} \tag{4.52}$$

The heat and mass balance diagram for final super heater shown in figure 4.12.

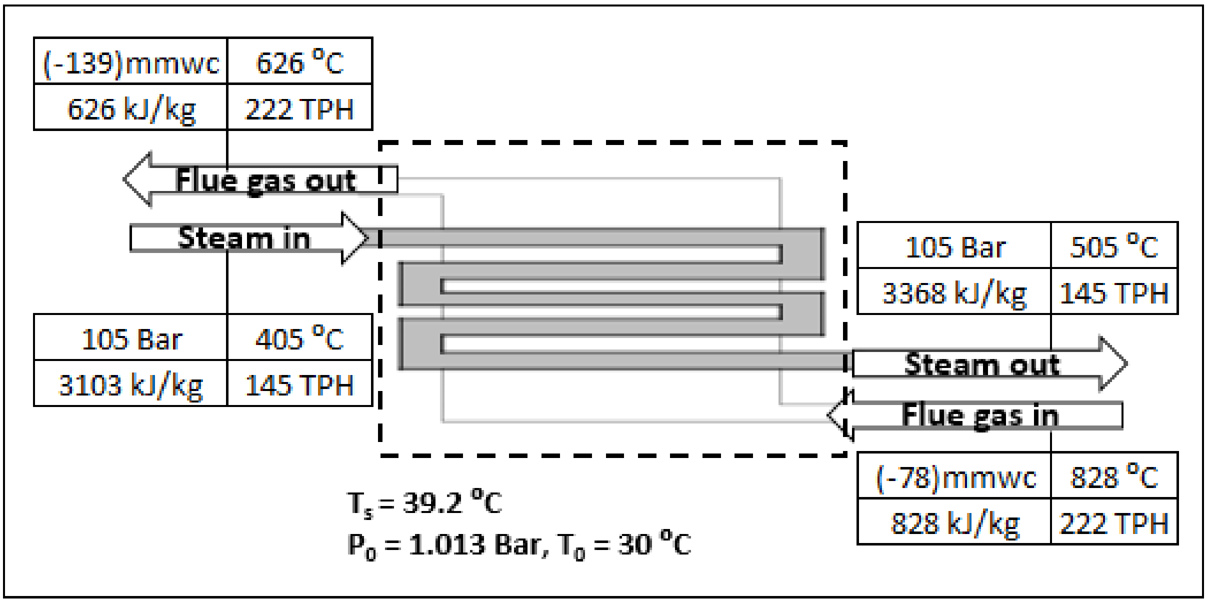

Figure 4.14: Modified Condition HMBD of FSH

By using the equation 75, 76 and 77 Re-calculate all the variable. The Exergy result of final super heater for both case written in table 4.8.

Table 4.8: Exergy result of FSH for both cases

Condition	Heat loss(kW)	Exergy destruction(kW)	Exergy efficiency(η)
Before implementation	2603.50	3448.38	61.86
After implementation	1850.97	2863.31	70.96

4.5 Cooling tower Performance and Exergy Analysis

Cooling tower is used for the decrease the temperature of cooling water which is coming from the condenser. The performance of cooling tower evaluated on the basis of Cycle of concentration, blow down loss, drip loss and evaporation loss. The efficiency of cooling tower depends on the atmosphere condition generally on wet bulb temperature.

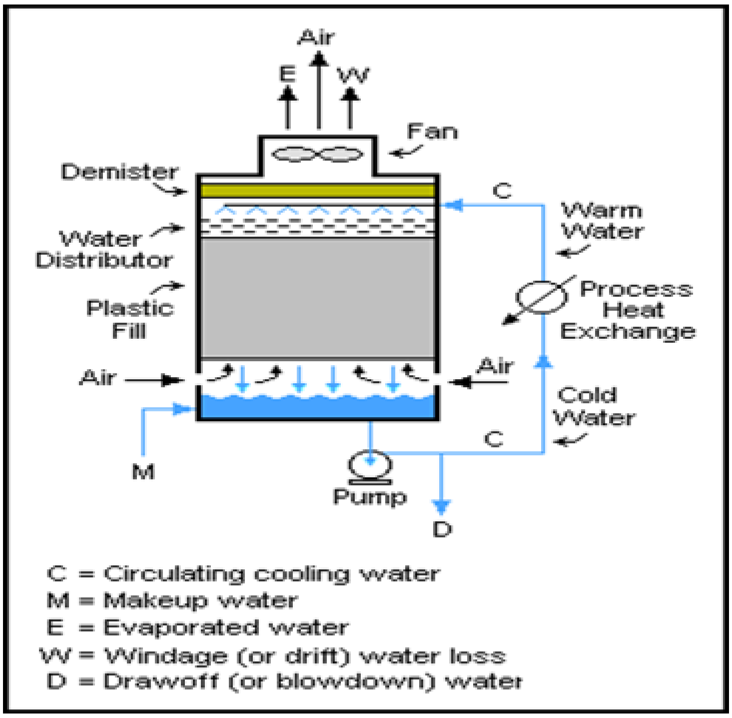

Figure 4.15: Cooling Tower with all type of losses

Cooling tower inlet temperature = 38^0C

Cooling tower outlet temperature = 29^0C

Wet bulb temperature = 25^0C

Range = cooling tower inlet temp – cooling tower outlet temp = 9

Approach = cooling tower outlet temp – wet bulb temp = 4

Cooling tower efficiency,

$$\eta = \frac{Range}{(Range + Approach)} * 100 \tag{4.53}$$

It is found to be 69.23 %.

C = circulating cooling water = CCW1+CCW2+ACW1 = 4500 m^3/hr

Drift Losses,

$$Df = 0.2 * C * 0.01 \tag{4.54}$$

It is found to be 9 m^3/hr.

Evaporation rate,

$$E = 0.00085 * R * 1.8 * C \tag{4.55}$$

Evaporation loss is found to be 61.58 m^3/hr.
Cycle of concentration,

$$COC = \frac{(Conductivity of Cooling Water)}{(Conductivity of Makeupwater)} \tag{4.56}$$

It is found to be 8.43 %.
Blow down/Draw off,

$$Bd = \frac{E}{COC - 1} \tag{4.57}$$

It is found to be 5.904 m^3/hr.
First law analysis for open system:
Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1h_1 - Q = m_2h_2 + m_3h_3 + m_4h_4 \tag{4.58}$$

The heat loss found in cooling tower is equal to 15796.61 kW
Exergy balance equation for Steady flow open system,

$$B_1 - (B_2 + B_3 + B_4) - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.59}$$

The total Exergy Destruction is equal to 1512.79 kW.

$$\eta = 1 - \frac{E_d}{B_1} \tag{4.60}$$

The Exergy efficiency is equal to 61.86 %.

4.6 Exergy Analysis of PRDS and Attamparator

PRDS means pressure reducing desuperheating system. PRDS is used for sync two unmatched parameter components by controlling pressure and temperature in power plant. Attamparator is used for desuperheating of steam to control the main steam temperature.

4.6.1 Exergy Analysis of PRDS 1

PRDS 1 is used for reducing pressure from 109 kg/cm^2 to 41 kg/cm^2.

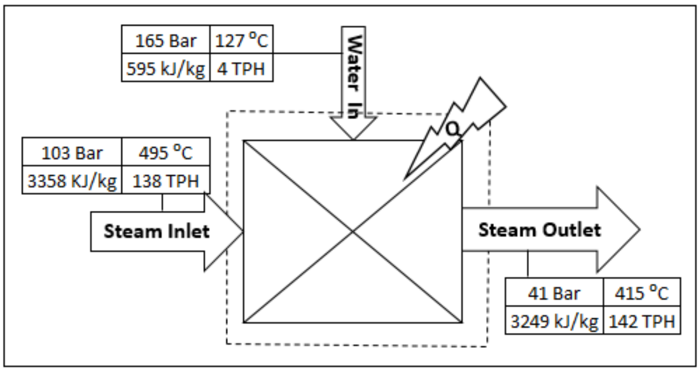

Figure 4.16: HMBD of PRDS-1

First law analysis for open system:
Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1h_1 + m_2h_2 + Q = m_3h_3 \tag{4.61}$$

The heat loss occurs in PRDS 1 is 294.62 kW.
Exergy balance equation for Steady flow open system,

$$B_1 + B_2 - B_3 - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.62}$$

Total Exergy Destruction in PRDS 1 is 5221.75 kW.

$$\eta = 1 - \frac{E_d}{(B_1 + B_2)} \tag{4.63}$$

The Exergy efficiency of PRDS 1 is equal to 90.23 %.

4.6.2 Exergy Analysis of PRDS 2

PRDS 2 is used for reducing pressure from 41 kg/cm^{2}to 2.5 kg/cm^2.

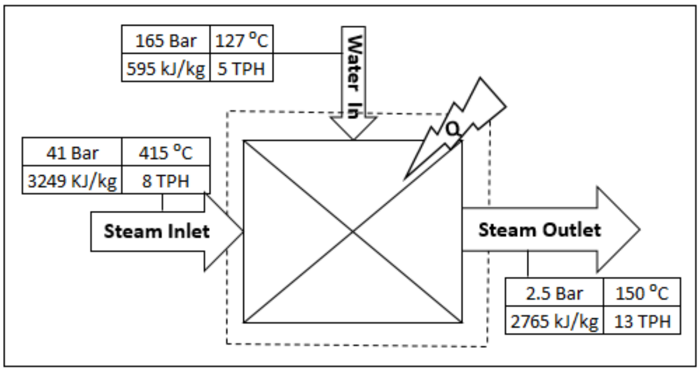

Figure 4.17: HMBD of PRDS-2

First law analysis for open system:

Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1h_1 + m_2h_2 + Q = m_3h_3 \tag{4.64}$$

The heat loss occurs in PRDS 2 is 174.62 kW.
Exergy balance equation for Steady flow open system,

$$B_1 + B_2 - B_3 - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.65}$$

Total Exergy Destruction in PRDS 2 is 2246.89 kW.

$$\eta = 1 - \frac{E_d}{(B_1 + B_2)} \tag{4.66}$$

The Exergy efficiency is equal to 81.23 %.

4.6.3 Exergy Analysis of Process PRDS

PRDS 2 is used for reducing pressure from 41 kg/cm^2 to 18 kg/cm^2.

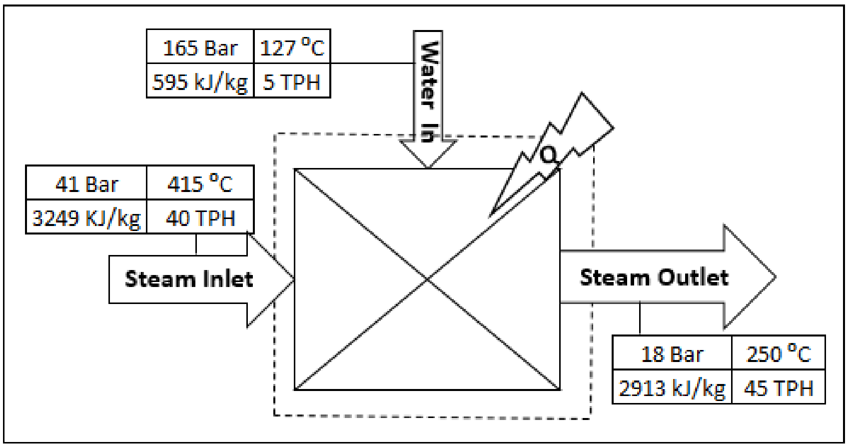

Figure 4.18: HMBD of Process PRDS

Surface Temperature of Process PRDS = 32 $^\circ$C
First law analysis for open system:
Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1h_1 + m_2h_2 + Q = m_3h_3 \tag{4.67}$$

The heat loss in Process PRDS is equal to 160.23 kW.
Exergy balance equation for Steady flow open system,

$$B_1 + B_2 - B_3 - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.68}$$

The Exergy Destruction in Process PRDS is equal to 886.59 kW.

$$\eta = 1 - \frac{E_d}{(B_1 + B_2)} \tag{4.69}$$

Exergy efficiency of Process PRDS is equal to 75.19 %.

4.6.4 Exergy Analysis of Attamparator 1

Attamparator 1 is used for reducing temperature from 456 $^\circ$C to 370 $^\circ$C. The heat and mass balance diagram for Attamparator 1 shown in figure 4.17.

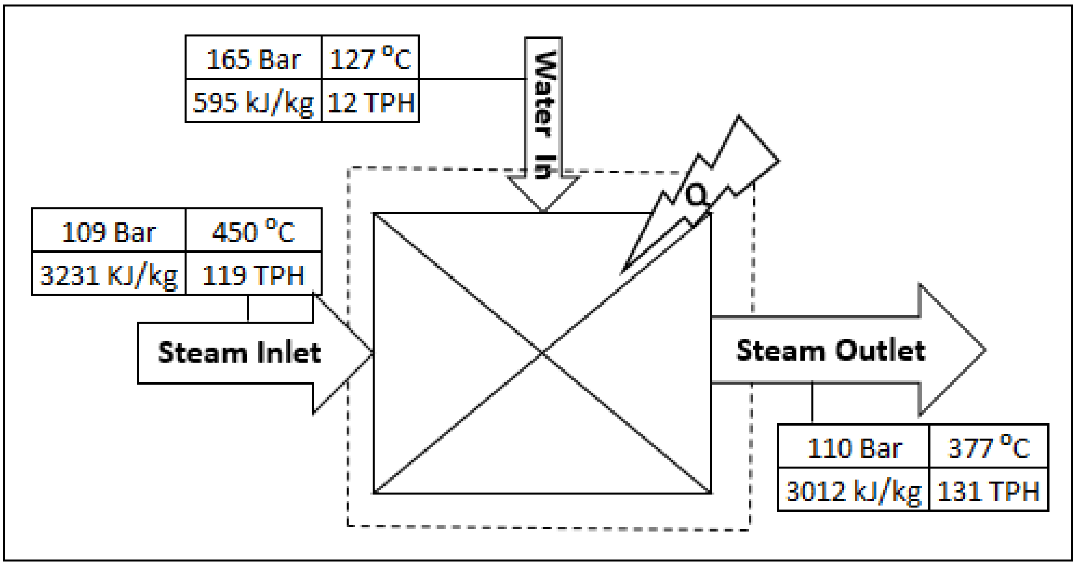

Figure 4.19: HMBD of Attamparator-1

Surface Temperature of Attamparator 1 = 37 $^\circ$C
First law analysis for open system:
Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1h_1 + m_2h_2 + Q = m_3h_3 \tag{4.70}$$

Exergy balance equation for Steady flow open system,

$$B_1 + B_2 - B_3 - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.71}$$

Exergy efficiency,

$$\eta = 1 - \frac{E_d}{(B_1 + B_2)} \tag{4.72}$$

After implimentation in plant their is certain changes in parameters that shown in figure 4.18.

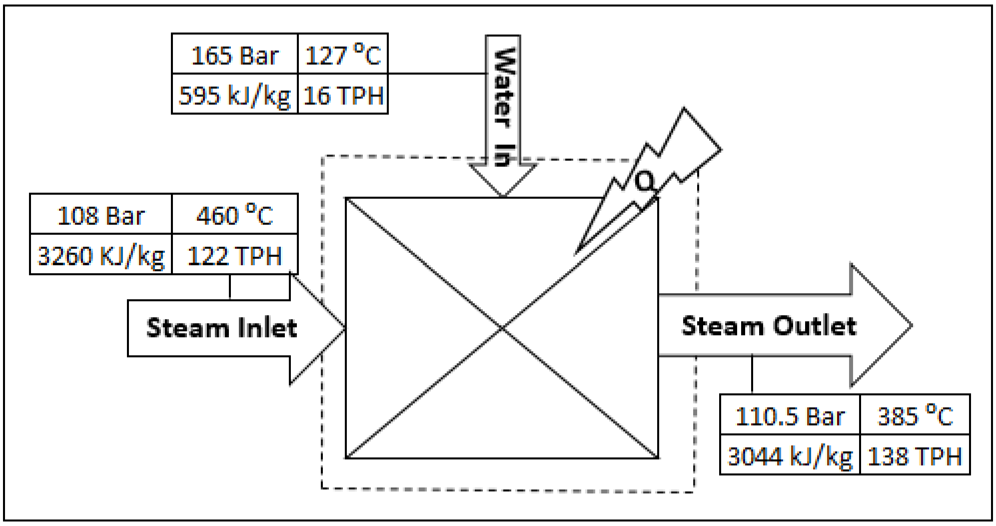

Figure 4.20: Modified HMBD of Attamparator-1

The results of Exergy analysis of Attamparator for both the cases shown in table 4.9.

Table 4.9: Exergy result of Attamparator 1 for both cases

Condition	Heat losses(kW)	Exergy destroyed(kW)	Exergy efficiency(η)
Before implimentation	745.14	510.55	98.84
After implimentation	985.87	2412.64	97.98

4.6.5 Exergy Analysis of Attamparator 2

Attamparator 2 is used for reducing temperature from 475 $^\circ$C to 390 $^\circ$C. The heat and mass balance diagram for Attamparator 2 shown in figure 4.19.

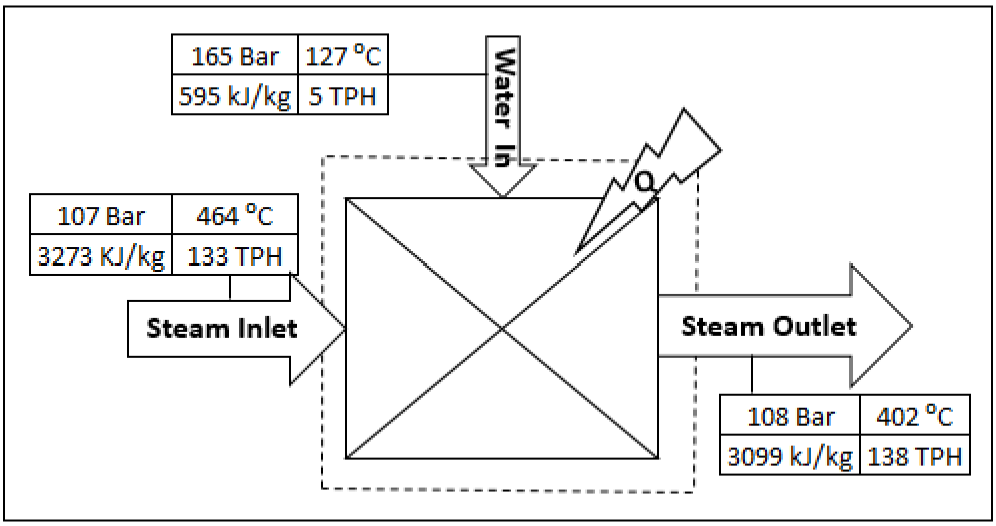

Figure 4.21: HMBD of Attamparator-2

Surface Temperature of Attamparator 2 = 39 $^\circ$C

First law analysis for open system:

Considering Steady flow and neglecting K.E. and P.E. terms,

$$m_1h_1 + m_2h_2 + Q = m_3h_3 \tag{4.73}$$

Exergy balance equation for Steady flow open system,

$$B_1 + B_2 - B_3 - Q(1 - \frac{To}{Ts}) - I_{irrev} = 0 \tag{4.74}$$

Exergy efficiency,

$$\eta = 1 - \frac{E_d}{(B_1 + B_2)} \tag{4.75}$$

After implimentation in plant their is certain changes in parameters that shown in figure 4.20.

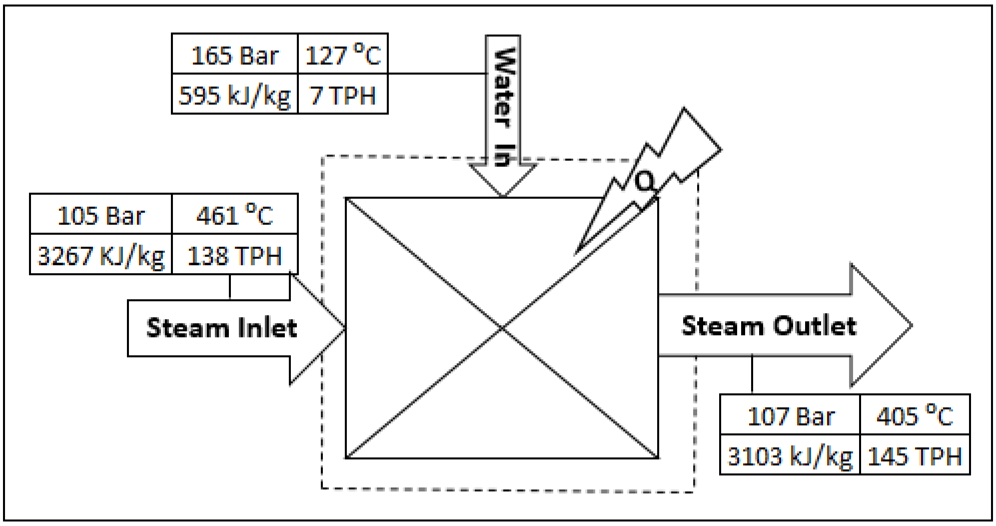

Figure 4.22: Modified HMBD of Attamparator-2

The Exergy result of Attamparator 2 for both cases written in table 4.10.

Table 4.10: Exergy result of Attamparator 2 for both cases

Condition	Heat loss(kW)	Exergy destruction(kW)	Exergy efficiency(kW)
Before implimentation	195.96	980.19	97.98
After implimentation	205.61	1141.47	97.76

Chapter 5

Result and Discussion

5.1 Heat losses and Exergy Destruction in Various Components

Heat losses in various components basically due to external Irreversibility like component without proper insulation, life of insulation over, highly conductive lines are used. In figure 5.1, the heat losses in various components shown. From this figure it's clearly seen that the major losses found in Boiler furnace (48%), Turbine (3%), Condenser (15%) and Cooling Tower (20%). In Boiler furnace heat loss is maximum because the number of manholes are not insulated as well as at some portion of furnace insulation damage. In case of Condenser and Turbine the heat loss is maximum because plant not use extraction system initially.

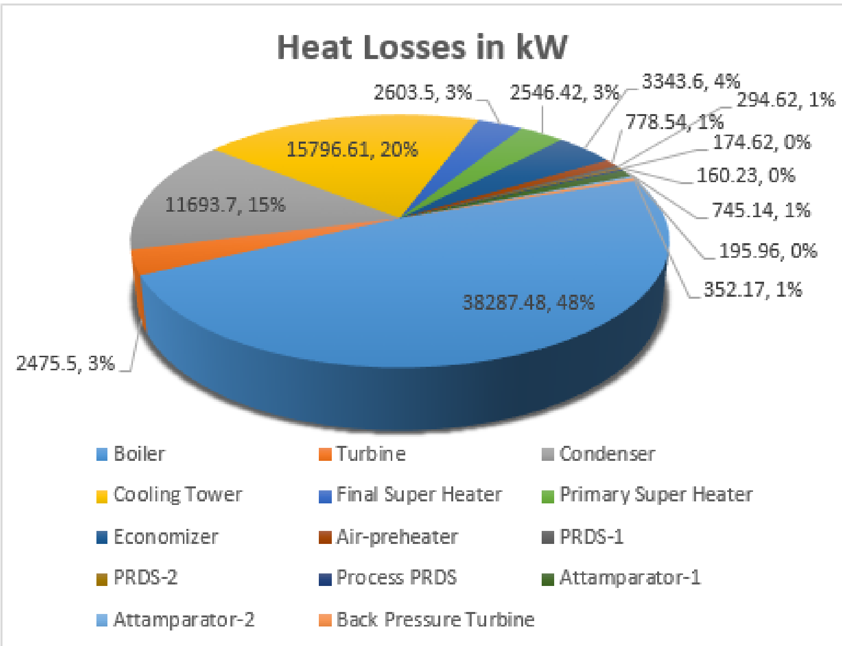

Figure 5.1: Heat losses in various components

The Exergy destruction in Components found by using second law of Thermodynamics. After analysis of plant the major exergy destruction found in the Boiler furnace (30902.3 kW), Turbine (7186.37 kW), Condenser (3943.99 kW), Economizer (3591.44 kW), Final Super Heater (3448.38 kW) and PRDS System (5221.75 kW) as shown in figure 5.2. The total Exergy destruction before modification is equal to 63418.9 kW. Due to unmatched parameter of Boiler outlet and Turbine inlet, the plant required additional system such as PRDS system. So after use of proper parameter of Turbine this destruction is eliminated.

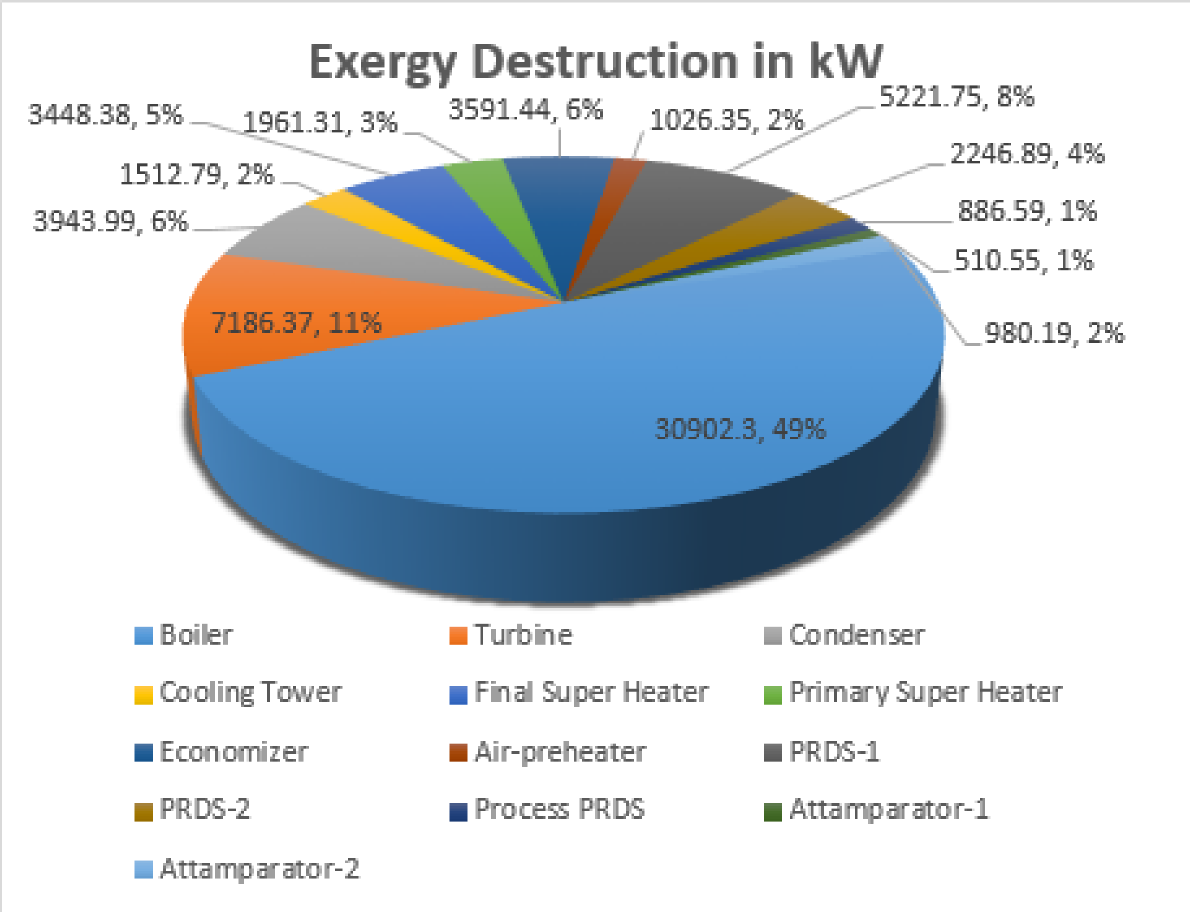

Figure 5.2: Exergy destruction in components before modification

The Exergy destruction in components after modification shown in figure 5.3. After modification the Back pressure Turbine installed. So, the condenser and cooling tower not required. Also Turbine is selected in such way that the design parameter of Boiler and Turbine matched. Due to this implimentation the additional system like PRDS system directly eliminated. So, the Exergy destruction in those components directly eliminated. The total Exergy destruction found in components is equal to 41210.6 kW.

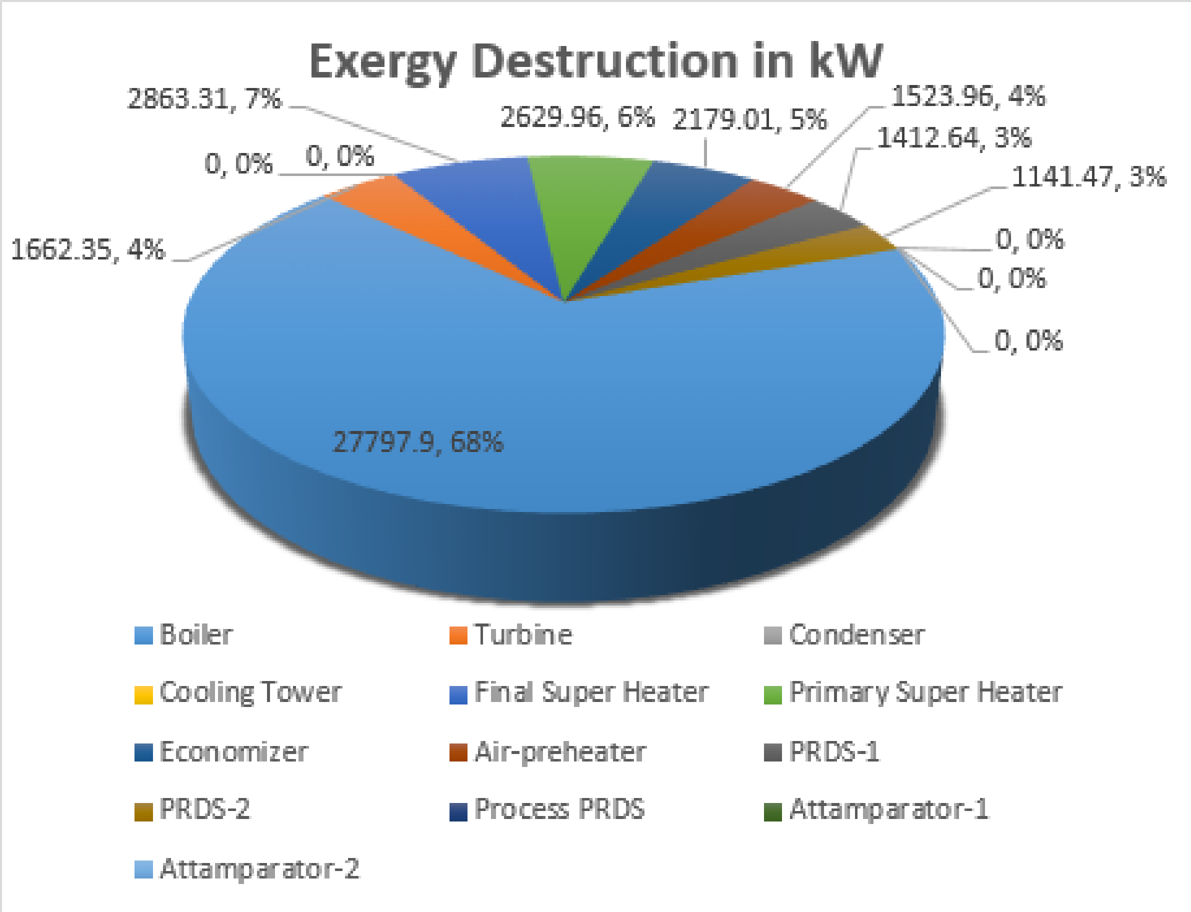

Figure 5.3: Exergy destruction in components after modification

5.2 Exergy Efficiency of Components

From Figure 5.4, it is clearly seen that the second law efficiency is always less the first law efficiency because the exergy factor being less than unity for process heat. Also the heat transfer between flue gas to air is less than the heat transfers between flue gas to water that is also prove by this analysis. Even heat transfer is maximum in case of Primary and Final Super heater because the high temperature gradient available from flue gas side. Turbine and Condenser has very low second law efficiency because plant does not use the extraction of turbine so more amount of heat energy is condensate without proper utilization. The condenser efficiency increase with decrease in condenser vacuum that is dependent on the turbine exhaust saturation temperature. This will be reducing by use of Extraction system.

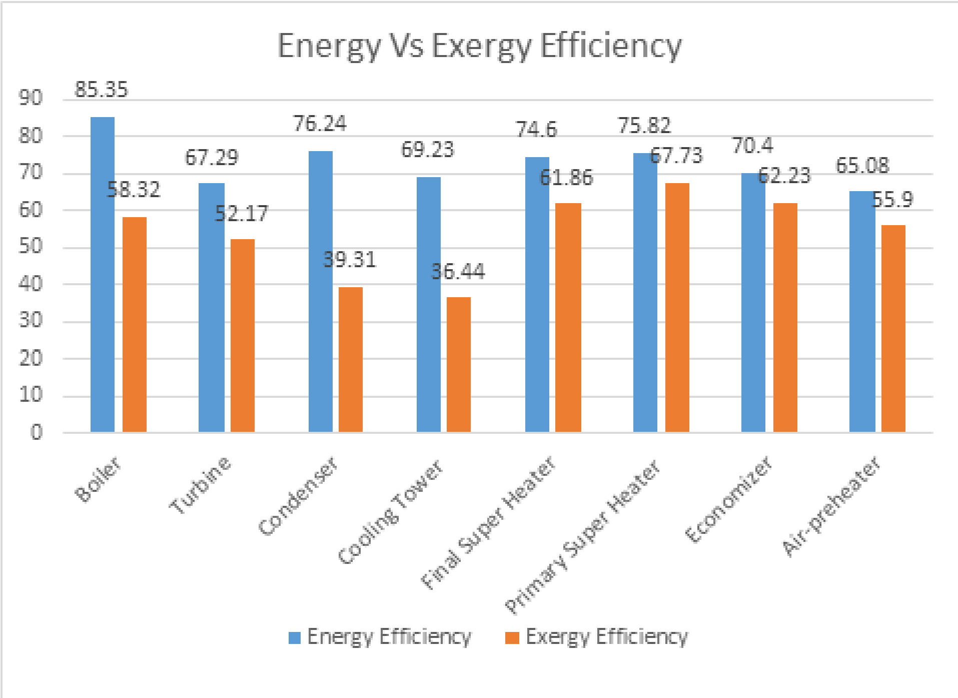

Figure 5.4: Comparison of Energy and Exergy Efficiency

Initially Boiler and Turbine had an unmatched parameter. So, the Boiler is not working at full load condition. After modification in the plant, the Boiler generally runs on the full load condition. So, all the components of Boiler generally runs on design condition. Also the insulation changes from some portion of components. Condensate Turbine replaced with Back pressure Turbine so the all energy going to Turbine is utilized. The improvement in Exergy Efficiency shown in figure 5.5.

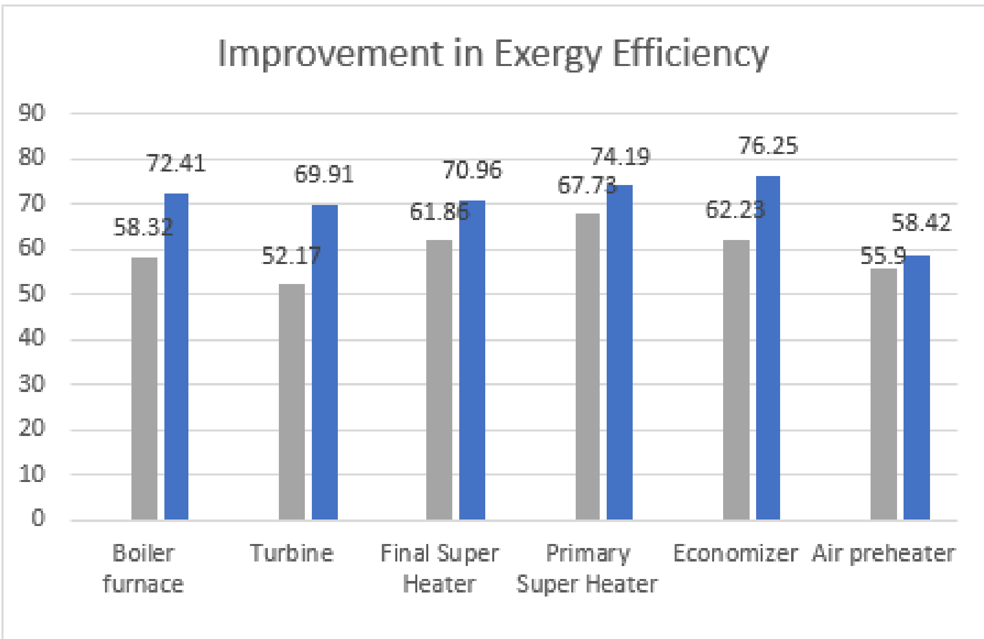

Figure 5.5: Improvement in Exergy Efficiency

5.3 Sankey Diagram and Grassmann Diagram

Sankey diagrams are the specific type of diagram for Exergy analysis, which put a visual emphasis on the major flows and transfer within a system. They are very useful in locating dominant contributions to an overall flow. Often, Sankey diagrams show conserved quantities within defined system boundaries. Sankey diagram shows the results of Exergy availability at each components. In plant the overall distribution of Energy can be identified from this diagram directly.

In figure 5.6, the amount of Exergy available at each components and how much Exergy is being utilized that drawn. In this case the Exergy added in Boiler furnace is equal to 29133.3 kW from the 60035.6 kW Available Energy. So, the large amount of Exergy destruction. Even in plant only one HP heater they were used. So, the Exergy available at the inlet of Boiler furnace is equal to 10527.1 kW. The Exergy utilized in this case is equal to 30361.2 kW from the available Exergy at outlet of Final super heater is equal to 53259.92 kW.

After modification in plant the whatever changes in Exergy Availability at each components that showed in figure 5.7. The Exergy added in Boiler furnace is equal to 28238 kW from the Available Exergy equal to 56035.9 kW. The total utilization of Exergy is equal to 55132.6 kW from the Available Exergy 56794.9 kW.

Grassmann diagrams are play very important role to show the Exergy analysis. The basic difference between Sankey diagram and Grassmann diagram is, the Sankey diagram just shows the value of Available Energy while in case of Grassmann diagram the Exergy destruction also shown in diagram.

The Grassmann diagram for initial condition shown in figure 5.8. The major Exergy destruction found in Boiler furnace due to chemical Irreversibility and major heat losses from outer surface. The PRDS system use initially due to unmatched parameter of Boiler and Turbine. Because of condensate Turbine the whatever Exergy available at the outlet of Turbine that directly condensate. Even due to use of numbers of PRDS system, the Exergy utilization cannot achieved properly that resulted in to high Exergy destruction.

Due to implimentation of new Back pressure Turbine in plant, the Exergy destruction in PRDS systems and Condenser directly eliminated. These resulted in to generation of more steam and power. The whatever changes of Exergy destruction in various components of plant that shown in figure 5.9. Due to Extraction system provided in Back pressure turbine the utilization of Exergy is maximum. Even in the other components of Boiler the amount of Exergy destruction reduce due to full load condition and changes of insulation.

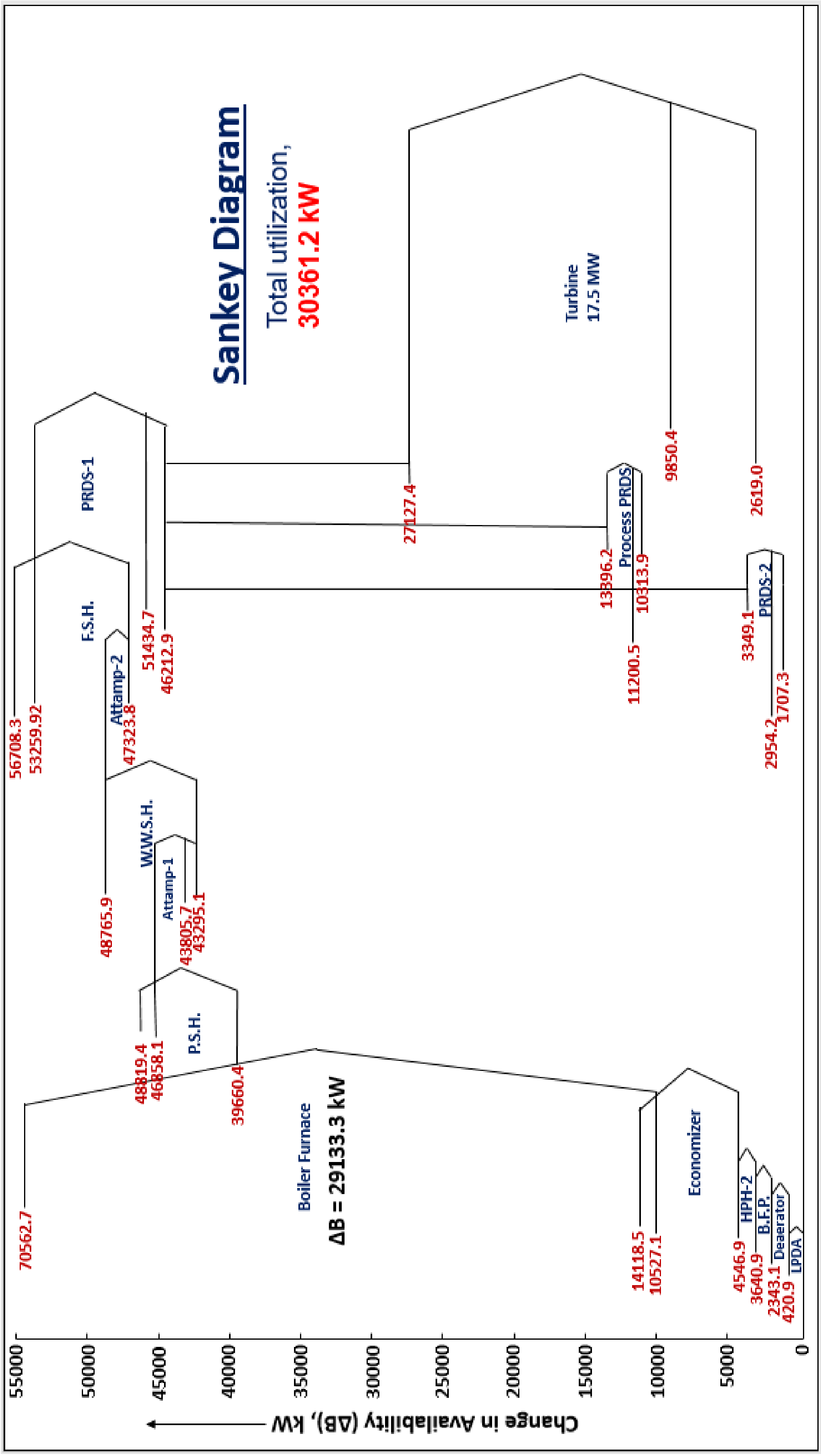

Figure 5.6: Sankey Diagram for Initial condition

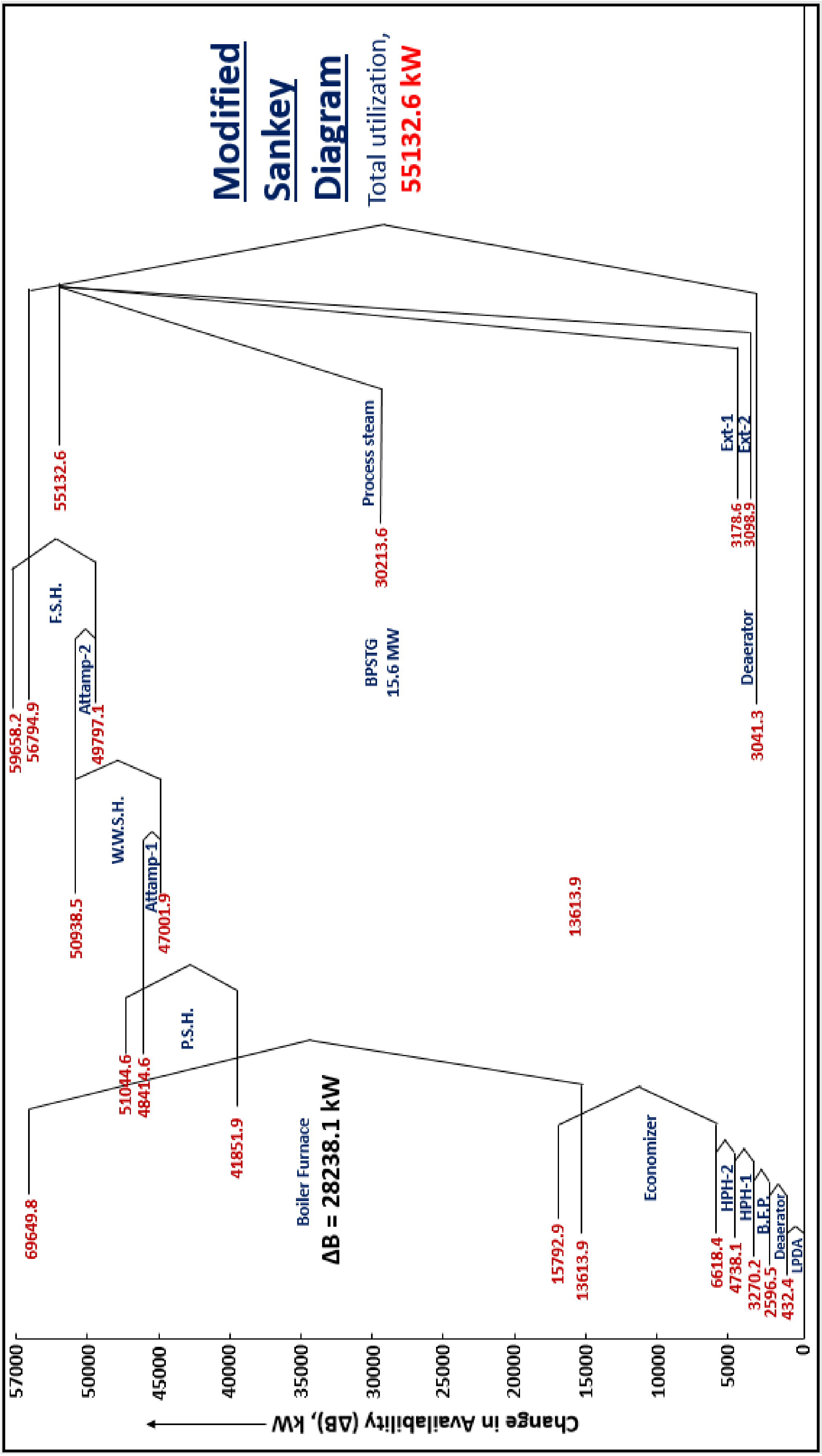

Figure 5.7: Sankey Diagram after modification

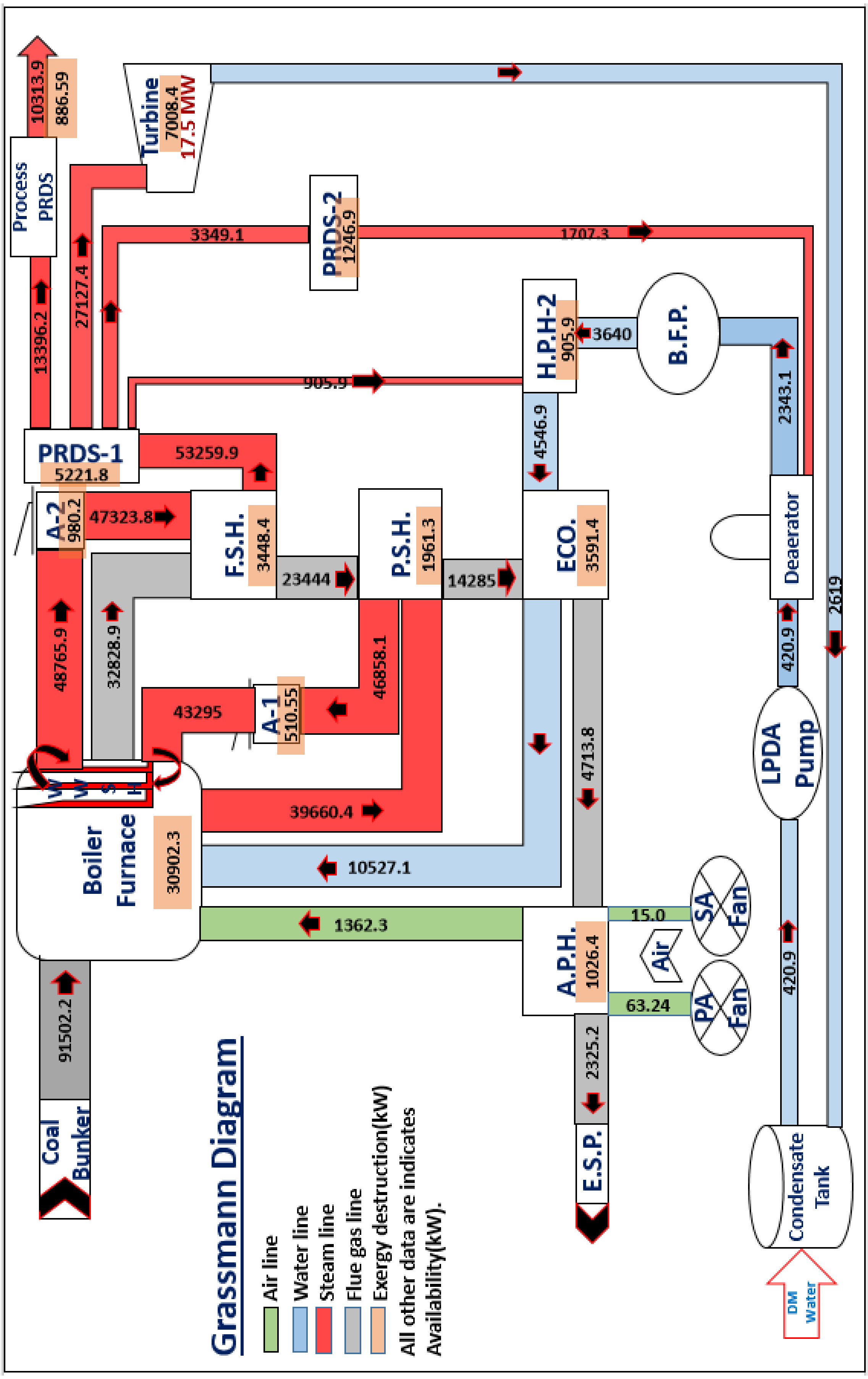

Figure 5.8: Grassmann Diagram for Initial condition

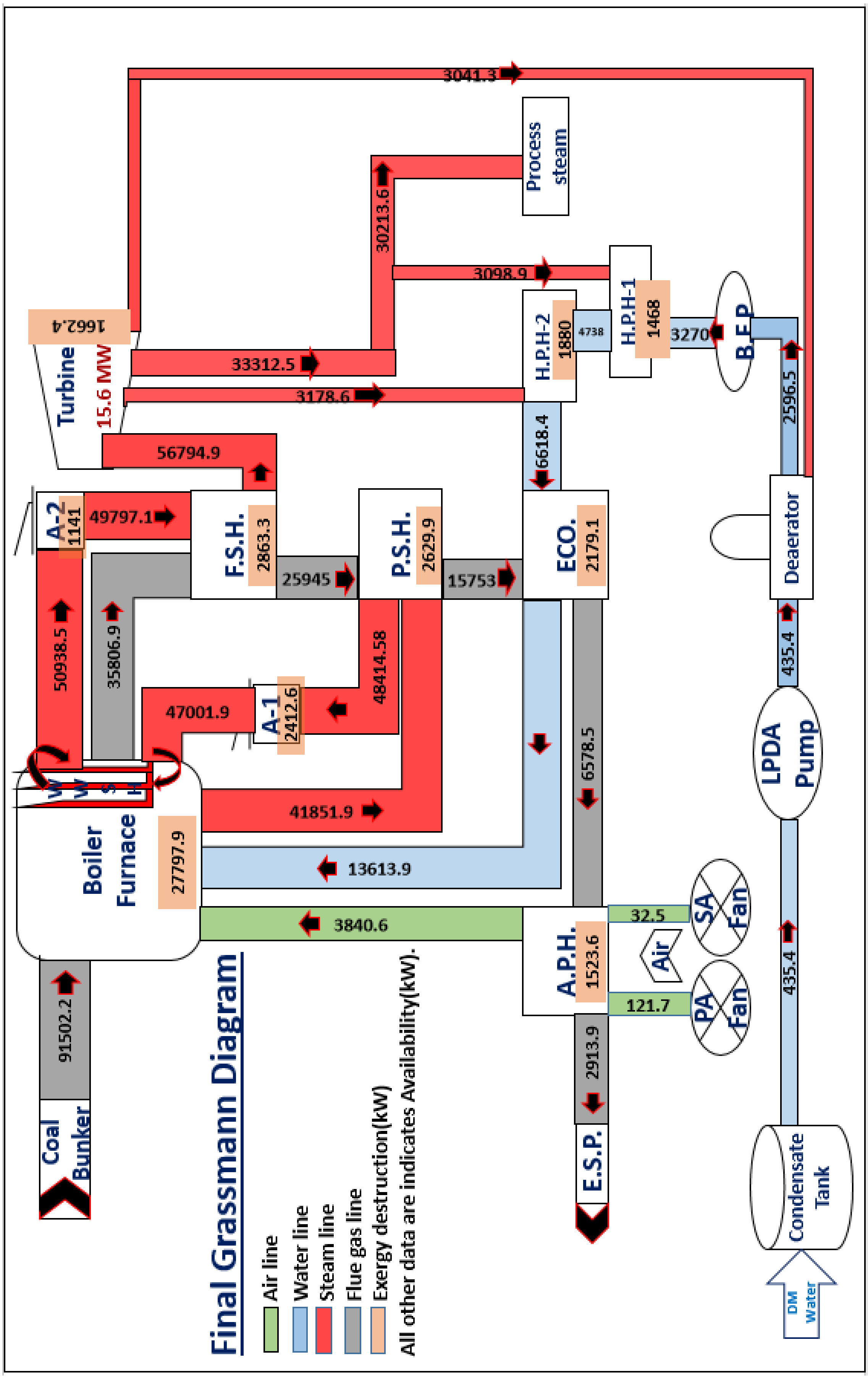

Figure 5.9: Grassmann Diagram after modification

Chapter 6

Conclusion and Future work

6.1 Conclusion

In this dissertation work, the Exergy Analysis and Energy Conservation has been carried out for various components of 150 TPH CFBC Boiler. Conclusion derived are listed below.

- Boiler performance evaluated using direct and indirect method. Direct Efficiency of boiler increase with increase in plant load. Indirect Efficiency depends on the quality of coal. The Indirect efficiency of boiler increases by increasing carbon percentage or by reducing moisture content in coal.

- For the Condenser, it was found that increase in condenser vacuum resulted in to reduced the condenser efficiency.

- The performance of Cooling Tower directly proposal to Wet Bulb Temperature.

- Major Exergy destruction occurs in the Boiler furnace compared to other plant components. This is due to irreversiblity in combustion reaction, more surface area of furnace and uninsulated surface of furnace. These results are shown in Grassmann diagram.

- Another major Exergy Destruction is found in Condensate Turbine which is coupled with condenser. This is because of not using extraction system though provided as per design and also due to loss of energy of the steam directly in condenser. Another issue with condensate turbine is that the working pressure of it is lower than the pressure at which boiler produces steam. To supply steam to turbine at its working pressure PRDS system is used. PRDS system has maximum second law efficiency but still it is taken as serious problem as it reduces pressure of steam. Thus energy of steam is lost without use. To over come this problem a new Back Pressure Turbine having working pressure similar to boiler is installed. This development eliminated use of PRDS system and energy and exergy destruction it. Also by use of new turbine condenser is not required and in turn cooling tower can also be eliminated. The replacement of turbine which does not have condenser coupled it with so the steam coming out from it is used for increasing temperature in deaerator. Thus loss in energy and exergy is recovered. Also as per design steam extracted from new turbine and send to HP heater 1. This increases the temperature at the inlet of economizer is increased from 152 ^{0}C to 208.6 ^{0}C. As per thumb rule increases in economizer inlet temperature by 30 ^{0}C leads to increase in direct efficiency of boiler by 1%. As in present case temperature rise is approximately 56 ^{0}C, the efficiency of boiler rises around 2%.

- Sankey and Grassmann diagram of power plant is prepared and based on studies of various modification in the plant, it is found that the steam utilization efficiency increases from 57 % to 97.1%. This also leads to increase in the exergy efficiency of the plant from 31.36 % to 45.53 %.
- From the first law and second law analysis of the plant, it was found that the second law efficiency is always less than the first law efficiency for any components.
- Three compressors utility to supply air in plant for various functions are optimized. This leads to saving in 48.26 MWh energy per year and Rs. 2.37 lacs per year in cost.
- Due to installation of new Coal Handling Plant, the requirement of electricity, space and need of number of labors reduces.This leads to saving in 260.11 MWh energy per year and Rs. 12.75 lacs per year in cost.

6.2 Future work

- To carry out the Energy Conservation study of Auxiliary systems such as PA Fans, SA Fans, ID Fans, Wall Seal Blower, Boiler Feed Pump etc.
- To carry out the calculation of economical thickness of insulation for replacement in certain places of plant.
- After modification in plant, the flue gas temperature rise from 120 ^{0}C to 139 ^{0}C. Some means needs to be determined to utilize this energy.

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Appendix

Gibb's free energy value by Michael J. Moran at Ambient condition.

Flue	LHV(kJ/mol)	HHV(kJ/mol)	$-\triangle G$(kJ/mol)
Carbon	241.8	285.9	237.2
Hydrogen	393.5	393.5	394.4
Methane	802.5	890.4	818
Ethane	1427.9	1559.9	1467.5
Propane	2044	2220	2108.4
Butane	2658.5	2878.5	2747.8
Pentane	3272.1	3536.1	3386.9
Hexane	3886.7	4194.8	4026.8
Octane	5162	5512.2	5307.1