Energy Audit of Coal Fired Thermal Power Plant

A Thesis

Submitted in partial fulfilment of
requirements for the degree of

Master of Engineering
in
Thermal Engineering

By

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July - 2018

CERTIFICATE

I hereby declare that the thesis report entitled "ENERGY AUDIT OF COAL FIRED THERMAL POWER PLANT" is an authentic record of my work carried out as requirements for the award of the degree of Master of Engineering in Thermal Engineering at TIET, Patiala under the supervision of Mr. Sumeet Sharma (Associate Professor, Mechanical Engineering Department), Dr. D.Gangacharyulu (Professor, Chemical Engineering Department). No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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ACKNOWLEDGEMENT

The work reported here was carried out under the guidance of Mr. Sumeet Sharma and Dr. D. Gangacharyulu. Their timely suggestions beamed a right direction to me. I gratefully acknowledge with profound sense of gratitude my sincere thanks for their inspiration, Persistent encouragement, invaluable guidance and providing me with an excellent atmosphere for doing research. Their advice on both research as well as on my career have been priceless. The opportunity, support, exposure and atmosphere provided by TIET, Patiala to carry out my studies are highly appreciated. The financial support provided by the SAI Lab and mechanical engineering department to carry out my studies is greatly appreciated.

I would also like to thank Er. Manjeet Singh, Er. Saurav Chandra, Er. Deepak Dhiman , Er. Prem Chand without whose help conducting the study at the plant would have not been possible. A special debt of gratitude is owed to the authors whose works I have consulted and quoted in this work. Last but not the least, I am forever grateful to my parents, family and friends for their unconditional support and best wishes.

Abhishek Kumar

Date:- 27/06/2018

ABSTRACT

An energy audit is feasibility study to establish and quantify the cost of various energy inputs to and flows within a factory or an organisation in a given period. Energy Audit of Coal Fired Thermal Power Plant has been considered out. The aim is to calculate all the losses and give measures to rectify them and calculate the economic benefits after taking measures of rectification of losses. The Energy Audit of NTPC Dadri is done. The plant is having capacity of 2649 MW from coal and 829 MW from gas-based station. More has been focused on heat losses in coal fired steam generator, economiser, air preheater and loss Marshal Yard to steam generator. After doing this study we came to know that boiler is having maximum losses followed by air preheater and economiser. The study is based on ASME BOILER TEST CODE method, BUREUEU OF ENERGY EFFICIANCY and GUDELINES FOR THERMAL POWER PLANT (INDO GERMAN ENERGY PROGRAM). Some national and international literature related to the Energy Audit is presented here and explained by giving there results. The methods used for efficiency of boiler is direct and indirect method thus there is also comparison and we can easily find out where the losses take place and where is the maximum possibility of energy savings. The second law efficiency of Economiser, Air Preheater are given here. The problem and limitations with available literature are listed here. From the investigation of this thesis, it is observed that the overall plant performance changes with the small variation in the output loads. From the calculation it can be easily concluded that the overall efficiency of the plant decreases with the decrease in the requirement of output load. Output Load of the thermal power plant depends on the demand of electricity. As the demand of electricity decreases, the output load of the thermal power plant decreases, and the overall efficiency of the plant is also lower because electricity cannot be stored so the plant is running on partial load. Now if the thermal power plant run at Full Output Load the overall efficiency of the plant is much higher. Boiler first law efficiency is 77.72 % and second law efficiency is 29.97%. Second law efficiency of economiser is 44.69 %. Second law efficiency of air preheater is 39.60 %.

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CHAPTER 1

INTRODUCTION

Systematic approach for decision making in energy management is done by the energy audit. The service to identify all the energy streams in a facility and balancing of total energy is done by energy audit.

As per **ENERGY CONSERVATION ACT 2001** energy audit is defined as 'verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefits analysis and action plan to reduce energy consumption.

1.1 NEED OF ENERGY AUDIT

Energy, labour and materials are the three top operating expenses found in the industry If check the priority to save 3 of them, energy audit is the best option for same output and quality but reduced input. The scope of improvement can easily given and understood by energy audit.

The preventive maintenance and quality control programs which are vital for production and utilising activities are done by positive orientation of energy audit. The energy cost, availability and reliability of supply of energy, appropriate energy mix, identification of energy conservation technologies is done by such audit programs.

The translation of conservation ideas into realities by leading technical feasibility with economic and other organisational consideration within a specified time is done by energy audit.

The energy consumption per unit of product output on to lower operating cost all is done by energy audit. Energy audit provides bench mark for managing energy in the organisation and also provide basis for planning a more effective use of energy throughout the organisation.

1.2 ENERGY WASTAGE IN PLANTS (REFERED FROM NTPC)

- Poor civil structures which allows less natural light to entre.
- Poor natural ventilation of air which will lead to mechanical ventilation and consumes more power.
- Poor insulation which leads to losses of heat.
- Poor handling of coal thus leads to more moisture in coal and leads to decrease value of GCV from marshal yard to boiler bunker.

- Conveyor belts are partially loaded thus more power consumption of motor is there because conveyor belts are at a BLF (belt loading factor) of 60%. Thus, this can be increased easily.
- Power factor of all the electric motors should be optimised.

1.3 BENEFITS OF USING ENERGY AUDIT (REFERED FROM NTPC)

- Reduces consumption charges drastically.
- Impact of operational improvements can be mentioned.
- Reduces specific energy consumption and operating cost.
- Identified energy losses for corrective actions.
- Improves overall performance of total system and profitability and productivity.
- Averts equipment failure.
- Estimates the financial impact on energy consumption projects.
- No extensive training or calculation involved.

1.4 OBJECTIVE OF ENERGY AUDIT (REFERED FROM NTPC)

- To minimise wastage without affecting production and quantity.
- To minimise investment.
- To go to sustainable development.
- Reduce idling time.
- To check power factor and correction factor possibilities.
- To explore possibilities of using chemicals for reduction in water spray.
- To maximising mechanical handling minimising bulldozing.
- To decrease the equipment failure rate.

1.5 TYPES OF ENERGY AUDITS

- **Comprehensive Audit**

  It is time consuming and expensive process because it is very much detailed.

- **Targeted audits**

  To provide detailed analysis and provide data of specific targeted projects.

- **Preliminary audits**

  It seeks to establish cost and quantity of each form of energy used in this energy audit.
  Collecting data
  Analysing data
  Presenting data

Establishing priorities and make recommendations

- **Walk through audit**
  This approach estimates the order of magnitude on energy consumption without involving rigorous estimations on calculation by using certain energy consumption equipment's.

- **Total system audit**
  This method requires rigorous data entry and analysis. This approach identifies area of improvement on energy quantity basis.

  - **Steam system audit**
    Making of balance of total system and analysis of steam system from steam generators and consumption data is analysed here. If identifies energy loss due to steam leakage and heat loss.

  - **Electric system audit**
    There are major energy consumers in process industries. The efficiency of total electrical system from electrical power consumption per day is checked in this type of audit.

  - **Cooling system audit**
    In this type of audit we calculate the cooling efficiency of the cooling tower. The impact of fouling or corrosion is identified for total system.

  - **Insulation audit**
    The process unit such as steam lines, tank insulation etc for improving the energy of complete system.

1.6 KEY INSTRUMENTS FOR ENERGY AUDIT ARE LISTED BELOW

 **Figure 1.1 Electrical measuring instrument**	**Electrical measuring instrument** Applied on running motor without stopping it. It measures instantly and can be operated very easily.

 **Figure 1.2 Combustion analyser**	**Combustion analyser** CO, O_2 & NO_X are measured by inbuilt chemical cells of this equipment.
 **Figure 1.3 Fuel efficiency monitor**	**Fuel efficiency monitor** Combustion efficiency is calculated by putting the value of CV of some common fuels.
 **Figure 1.4 Fyrite**	**Fyrite** The solution of flue gasses is drawn into frite. The amount of gas is generated by chemical reaction.
 **Figure 1.5 Contact thermometer**	**Contact thermometer** Flue gas, hot air, hot water temp is measured by inspection of probe into the steam.

 **Figure 1.6 Infrared thermometer**	**Infrared thermometer** This directly gives the temperature. It reads out when heat source is directed to it. Used to measure temperature of furnace.
 **Figure 1.7 Pitot tube and monometer**	**Pitot tube and monometer** Velocity of air in ducts is measured by dividing ducts into small parts and them taking average velocity.
 **Figure 1.8 Water flow meter**	**Water flow meter** Ultrasonic principle is used to measure water flow by no contact of the equipment with water.

 **Figure 1.9 Speed measurement**	**Speed measurement** Speed can be changed with belt slip and loading thus speed measurement is critical exercise. Direct access is possible by contact type instrument i.e tachometer.
 **Figure 1.10 Leakage detectors**	**LEAKAGE DETECTORS** Sometimes human cannot detect the leakage of compressed air and thus we use ultrasonic instrument to detect leakage.
 **Figure 1.11 Lux meters**	**LUX METERS** Electrical impulses which are calibrated as lux senses light output. Used to measure illumination levels.

(All pictures are taken from Bureau of Energy Efficiency)

1.7 ABOUT THE THERMAL POWER PLANT NTPC DADRI

National Thermal Power Corporation Dadri is a central government maharatna company and was established in 1975. The main motive of this company is to decrease the gap between consumption of electricity and the generation of it. The main idea behind establishing NTPC was to promote thermal power in India. Today NTPC is generating one fourth of total electricity generation of India by generating 40000 MW of energy. NTPC Dadri alone is generating 2649 MW of electricity from which 1820 MW is from coal and 829 MW from gas-based power plant. NTPC Dadri is divided into 3 parts Stage 1- 840 MW, Stage 2- 829MW and HVDC convertor station of 15000 MW. The coal fired power plant fulfil the requirements of NCR and northern grid with capital cost of 16.69 billion. The coal is transported by the means of railway transportation and the source of this coal is North Karanpura Coalfield of Bihar. NTPC Dadri burns 15000 MT of coal every day over 3.67 million annually.

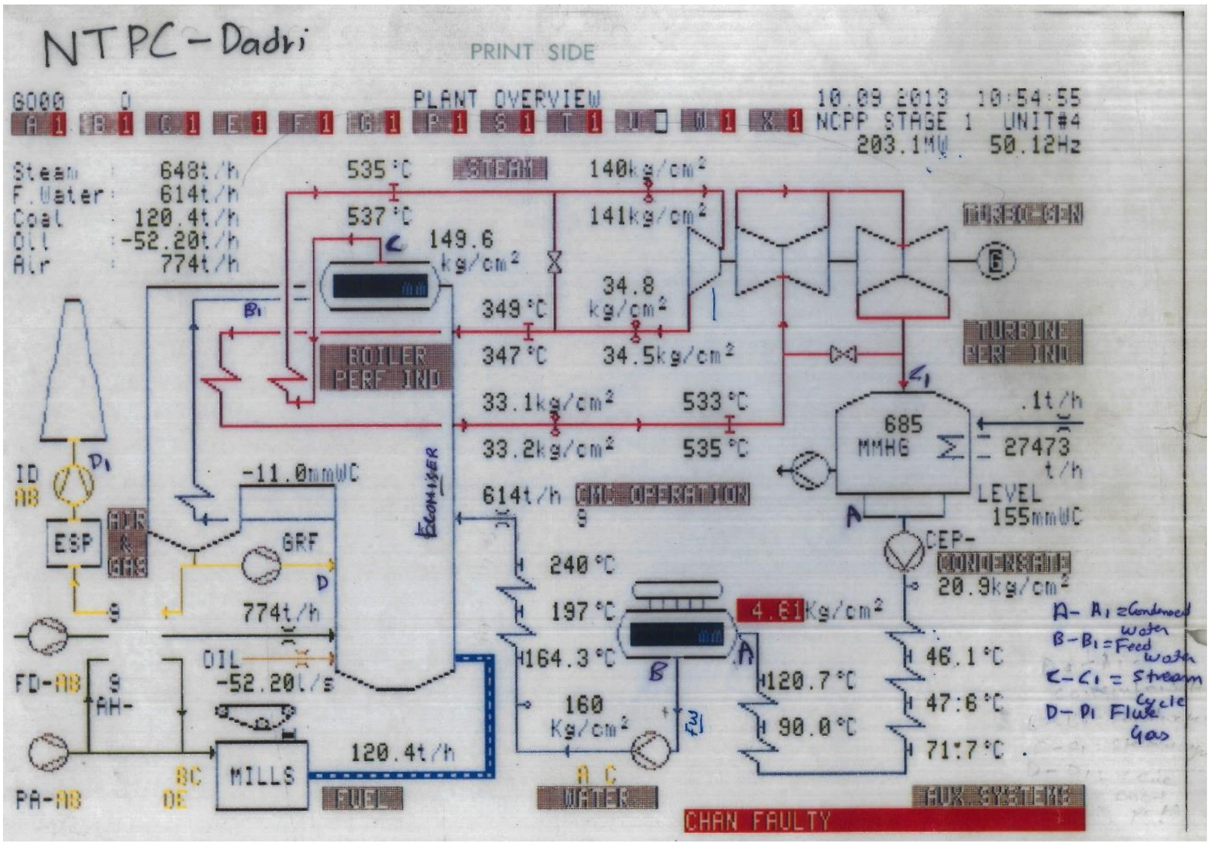


Figure 1.12 Plant layout of NTPC Dadri from NTPC Technical Diary

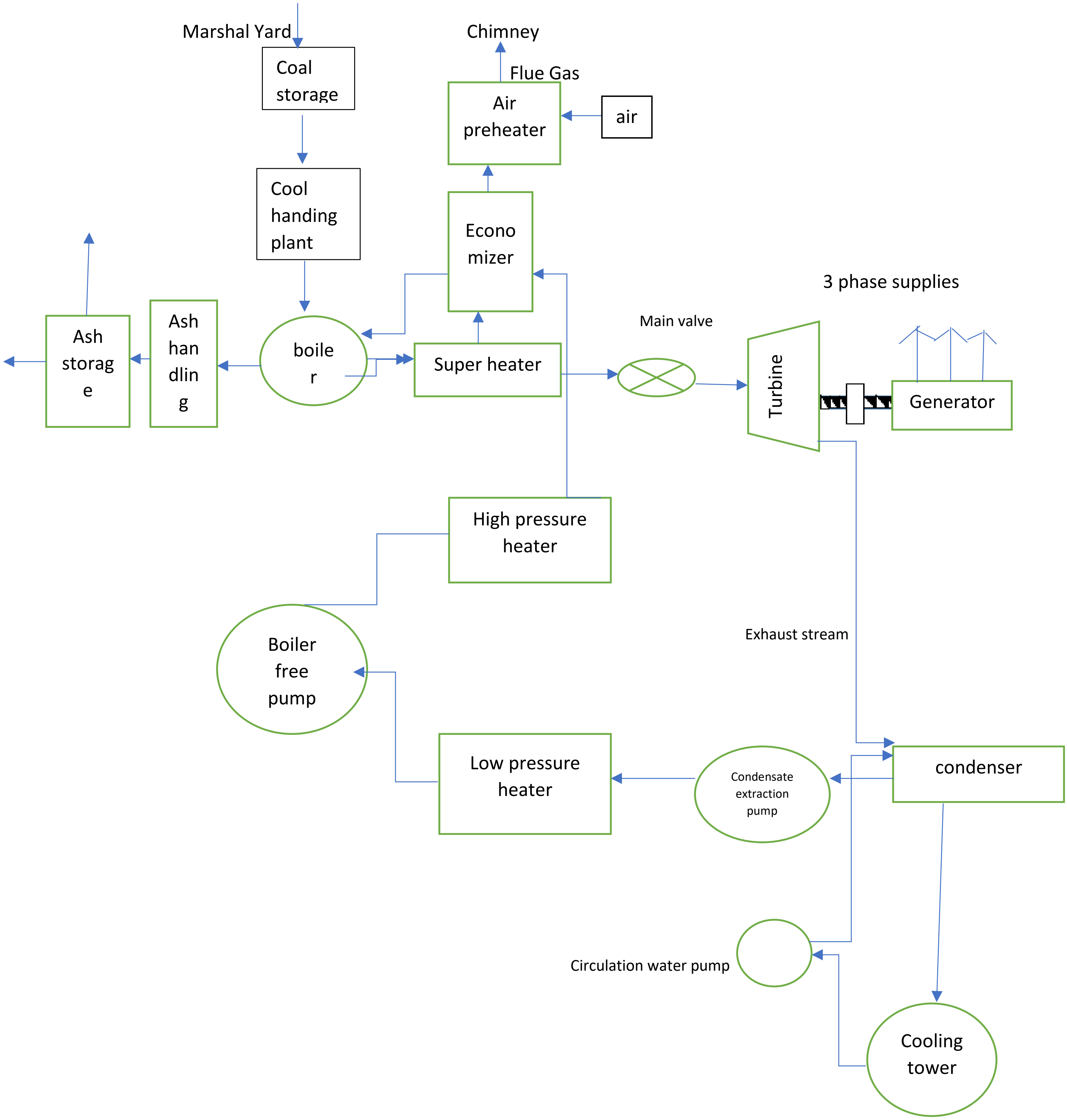


Figure 1.13 Block diagram of thermal power plant from NTPC Technical Diary

CHAPTER 2

LITERATURE SURVEY

The persistence of literature review is to:

- Place each effort in the framework of its influence to empathetic the investigation problem being considered.
- Recognize new methods to understand previous research. Expose any gaps that are in the **literature**

Kaya et al. [1] has done energy audit on steam generator using coal and gas as energies. The steam generator was run at 70 bar and 505 ˚C with capacity 10000 Kg/hr. The effectiveness of the steam generator was found by inspecting temperature, pressure & velocity. Chief losses were heat loss due to interaction of superficial and insulation, air seepage at gyratory air warmers.

Sulaiman , Fadare et al. [2] (done in the Southwest of Nigeria) has done exergy examination on the steam generator. The energy efficiency =72.46%. The exergy efficiency = 24.89%. Supreme energy devastation is in ignition chamber and then in heat exchanger of a steam generator. Actions to save energy originated are energy repossession from flue gas and use of adjustable speed driver's steam generators fans are measured into this.

Zheng et al. [3] To stock high temperature water in space heater heating structure centrifugal drive was used. The energy consumption was reduced by hybrid heating system(HHS). First replicas of mechanisms like heat drive was done. Secondly optimum procedure plan of least cost was recognized. Finally, yearly working charges of HHS was related with simple steam generator.

Dexter et al. [4] energy saving in boiler originators are attained by improved steam generator controls. It was done by replication and investigational study. Statistics which was accomplished was used to check difficulties in steam generator panels. The approaches of replication were very often authenticated. For enhancing the improvement of steam generator controls some exercises were done. As a conclusion of this paper we derived that 20% of our whole energy was protected. No one till now had done learning on this topic of control of steam generator can leads to betterment of energy savings. He had done study on 25 steam generator and he came to know that effectiveness of steam generator were unfortunate due to poor boiler operational controls.

Kumar TA. Chandramouli et al. [5] the energy effectiveness and exergy effectiveness were measured for his exercise and losses in exergy were measured. The whole plant was separated in three portions. The comprehensive steam generator assembly consumes 88% and flue gasses afterward its heat is expended by economiser and APH is 6.7%. The comprehensive plant exergy effectiveness is 31.15%. Most of the exergy is lost in furnace chamber. Turbine exergy loss is 8.4%. The exergy effectiveness of steam generator is 43.09%. The exergy effectiveness of plant is 29.29%.

Bakchoshesh et al. [6] his study was created on exergy effectiveness and energy effectiveness of the steam generator unit. The steam generator energy effectiveness was originated by him was 89.21% & exergy effectiveness was 45.48%. The divergence between exergy effectiveness and energy effectiveness was made by him. When segment of our extra air and stack temp. was reduced our plant, effectiveness is enlarged.

Sulaiman et al. [7] south west Nigeria was the place of his learning and energy effectiveness and exergy effectiveness was done on vegetal oil processing plant. This oil processing plant was having 2 steam generators, 1 generator and plant was having size of 100 T processing plant of crude oil into eatable vegetal oil. There manufacturing system were having of 4 chief portions neutralizer, bleacher, filter and deodoriser. For adapting the above progression 487.04 MJ/ton electric energy, thermal energy 95.23% & manual energy of 0.12% was used up. The device which was enchanting most of the energy input was deodoriser which was having 56.2% value. The plant was intense exergy effectiveness of 38.6% and the devastation originate in exergy was 29919 MJ. To rise the overall plant size the heating load of the steam generators is to be amplified.

Rashidi et al. [8] the study was done on the structure which was having binary reheat and turbine removal. The whole plant was having chief 3 apparatuses which were 3 high pressure turbines, 3 low pressure turbines and 1 deaerator. The complete learning was done to find the inclination of first law and second law efficiency of cycles. The comprehensive study of each of the constituent in the cycle was done and the key exercises done were exergy & irreversibility examination were accomplished. As a productivity of this we make the temperature continuous were over all thermal effectiveness and second law effectiveness of steam generator decreases. By considering the overhead we got supreme first law efficiency of LP & HP turbine.

Vuckovie et al. [9] cyclic use of power was finished in this energy audit. It is ideal for all the progressions. The progression of energy audit is very tough scheme but can be effortlessly done by energy investigation. The unconventional methods were created to check the left limits of the predictable energy investigation. The actual latent for checking the disadvantages and losses thus enhancement of these losses can be easily practised in energy audit. Most of the energy devastation is there boiler and furnace segment and thus most of the actions required to be taken are in boiler and furnace segment.

Naik et al. [10] The procedures for inspection of energy losses while entropy is produced and all the procedure which leads to improve the effectiveness and power output without cooperating the output excellence is done by energy audit. He has done study on the bio mass based steam power plant of 4.5 MW. As study based on calculation outcomes he find out that steam generator was having most exergy devastation. The plant was having quite good energy effectiveness which was around 18.25% & exergy effectiveness of the plant was 16.89%. The fuel used was rice husk. Comprehensive exergy investigation was done in this study.

Faaij et al. [11] the study of CO_2 capture and sequestration (CCS) are now measured the best expertise in biomass translation. As we all know the shortage of our fossil energies, so some actions must be taken so that sustainable development can be done. Thus, today the best way is using biomass in place of fossil energies. So, we had to make the biomass in most significant fuel for energy source as it is also eco-friendly. Thus, in current situation augmentation in biomass is 40 to 55 MJ per year. The major problem in biomass is how to make such a vast quantity of bio mass so that it can contest our contemporary prerequisite. The chief provider of bio-mass is sugarcane manufacturing.

Hupra et al. [12] the learning was based on the furthermost appropriate topic i.e. bed accumulation propensity of FBC (fluidised bed combustion) were checked by three adaptable procedures. The procedures used were standard ASTM ash synthesis test, compression done by sintering test, lab scale incineration test. The temperatures occupied for the procedure of diverse procedures were entirely different. For ASTM procedure temperature essential is 50 500℃, sintering test is 2040℃. The facts consequences were deliberated in this paper.

Backman et al. [13] the learning was founded on the behaviour of the ash in the testing of accumulation of the ash units in fluidised bed ignition chamber. To make this learning value it the author had taken 8 energies of dissimilar possessions so that their behaviour can effortlessly be verified and authenticated. There was a 5 KW fluidised bed ignition reactor and temperature of accumulation was restrained. For the learning SEM/EDS were characterised as they were patterned by bed models. As study was extra amplified to next level the data was taken from the phase illustrations and then he decided the behaviour of melting. As the behaviour was patterned he came to know that there was a layer of similar ash subdivisions. Then in additional study he determined that sulphur & chlorine were not found in accumulation. At last he settled that partial melting of bed elements is accountable for agglomeration.

Mekchilef et al. [14] in this study the author has clarified the basic supplies of maintainable expansion as we all know that the fossil energies such as oil, coal, normal gas are not last for extended years so their suitable use deprived of depletion is the major problem right now. The study for use of renewable capitals and ecological approachable events is done in this. According to this education there is actual great deprivation of carbon release i.e. as renewable capitals are used. The main cause of this study was decrease in use of carbon and to upsurge the use of biomass. As we all distinguish that due to soil erosion there is the requirement of swelling the bio mass practice to upsurge sustainable development.

Krishan Kumar et al. [15] according to this learning the chief arguments which can be easily premeditated by exergy examination is entropy generation, irreversibility, exergy loss & second law effectiveness. This study severely shows that the extreme exergy loss is there in furnace segment. In this learning thermodynamic study is done and real flow of exergy in cycle is premeditated. The chief reason of this study was to estimate the exergy effectiveness of steam generator i.e. 36.75% and the best outcomes were originate when bituminous coal was used. In this study he also determined the motive of above opinion i.e. little exergy devastation for high grade of coal. Exergetic effectiveness is 58.68% when the calorific value is 3500 KJ/Kg.

Saurabh Das, Manik Mukhargee et al. [16] in this learning we approved out the energy audit of 25 X 25 MW. The effectiveness of fan is 77.6%. Thus the performance of the fan is acceptable. The pull pressure of the FD fan is 114mm of WC which is higher side due to silencer. The learning was completed and originate the outcomes that when the size of the channel is enlarged then the current is even for the gas to stream and thus there will be very fewer pressure drop as pressure drop rises when there is interruption in the flow of the fluid. As by the above debate he determined that head loss and power consumption is very fewer. At latter cost advantage analysis and power consumption and energy preservation actions were given by him. Steam generator feed drive power consumption = 1189 KW, cold water pump =

1189.20 KW, ID fan=307.70KW, Net generation = 46.75 MW , Auxiliary power consumption= 4.31 MW.

Poddar, AC. Birajdar et al. [17] energy audit of steam generators was done and the consequences were authenticated. The value of boiler flue gas loss is 6.84%, due wetness in flue is 8.44%, losses due to unburnt carbon in ash is 0.8154%, losses due to practical heat carried out by gas is 3% the losses due to contamination & unaccounted losses are 1.22%, Total losses are 20.31% and the steam generation efficiency is 76.69%. The events given by him were the quantity of oxygen in flue gas at AH inlet should be compact, please guarantee the coal heat is not tilted as if the coal heat is tilted then there will high energy losses. The economiser fins tubes and seals of heat exchanger must be clean so that extreme heat transmission is there so that extreme heat of flue gas is transported to the feed water. There should be proper refinement so that stable air from FD fan can be easily feed.

Masitah, A.R.S, Mardiana I Ahmad et al. [18] the study is founded on the behaviour of heat exchanger and value of transmission of heat. He deliberate that the quantity of transmission in two air rivers will always be small when they are likened with the energy transported by bulk flow. He finds out that all the time the warmth conductivity in the plates is constant. The most stimulating comment was that the external temperature was continuous all over the flow. The results of this learning was that the heat transfer was78.3 to 611.4 W and lowest value was for 1 sec and uppermost value was for 3 seconds. The assumption was made that as the speed is straight comparative to heat transmission. When the temperature of the fluid was 20℃ heat transmission value was 407.6 W and it is at 28℃ heat transmission value was 156 W with continuous air speed 2m/s.

HA . Navano , L.C. Cobe Gas , Gomez et al. [19] in this learning we considered the presentation of our heat exchanger when the limit circumstances is known to us. The technique used to find the heat exchanger presentation is efficiency number of transmission unit. According to this investigation two approaches were found. First the computational technique and second one is for multifaceted geometries for which ENTU is not accessible. By the control of this effectiveness values for cross flow were estimated. According to practical he found that there is 10% difference between efficiency model forecast & actual formula.

Kartik,Silaipillayarputhur et al. [20] the learning was complete by the author for counter cross flow heat exchanger and discover out its midway thermal performance. The author found out that the expensive will change only the no. of licenses to get the certain release temperature. Normally met heat exchanger is used in this study.

Sadiq Elias Abdulllah et al. [21] the author has calculated the performance of cross flow H.E. The geometry of level surface is ($S_t/d = 1.77$) and ($S_l/d = 1.54$) affectionate index is 0.566 associated to 0.568 which is good. The endless value of 0.564 found to be as advanced as 0.429 this modification is due to the geometry preparation ($S_t/d = 2$) and ($S_l/d = 1.5$). He discovers out when Reynolds number growths pressure drop increases. Extreme power is consumed when nondimensional pressure drop upsurges.

2.1 IMPORTANCE OF THE PROPOSED PROJECT IN THE CONTEXT OF CURRENT STATUS

Many people have done this method of boiler efficiency i.e. **Energy in – Energy out= loss in boiler** in this method we cannot calculate where the losses are maximum and where we to make are efforts to save them.

In case of Economiser formula used = $\frac{\textbf{Water}\ \text{outlet temperature} - \text{Water inlet temperature}}{\text{Exhaust gas temperature} - \text{Water temp at inlet}}$

Very less research is done on energy audit of coal handling plant (CHP) but CHP is the most important part of coal fired thermal power plant because coal is black gold these days and it should be used correctly without any wastage and it is having many conveyor belts in it which are driven by electricity. On an average CHP consumes 1300 kW to 1600 kW power thus it is very important to calculate its losses and give measures to minimise them.

Very less research is done on exergy analysis to calculate 2^{nd} law of economiser.

The calculation of the boiler efficiency by method used in ASME PTC4, Fired Steam Generators and find methods to rectify them.

The energy audit of economiser is carried out by method of exergy analysis

I had done Energy audit of Coal handling plant also and not only calculate the losses, but I will also find measures to rectify them.

CHAPTER 3

METHODOLOGY AND CALCULATIONS

3.1 COAL HANDLING PLANT

The main objective of coal handing plant is to supply the appropriate amount of coal to the boiler bunker and store some amount of coal to the stack for the future purpose so that power plant can work all the time and no scarcity of coal is there. Coal is hard black or dark brown sedimentary rock formed by the decomposition of the plant material widely used as a fuel.

The coal particles are called coal lumps. They use E & F grade coals in India.

Coal can be transported in five different ways

1) Railways
2) Ropeways
3) Roadways
4) Waterways
5) Airway

The coal is transported to first crusher and the coal size is reduced to 300 mm.

The coal is then transported to second crusher and the coal size is reduced to 80 mm

Now the coal is feed to the 3rd crusher and the coal is 20 mm size.

After this process the coal is the coal is then transported to the pulveriser and then the coal is pulverised.

When the coal is full in bunker then the coal is transported to the stock pile and then the coal is stored in the stock pile.Coal handling plant is a plant in which the coal is handled from the receipt to the boiler bunker.

The main target of coal handling plant is :-

To receive, process, store and feed coal

Bunkering of coal

Unloading of coal wagon

Stacking of coal

Figure 3.1 Picture of Coal handling plant of NTPC Dadri picture clicked by me at site

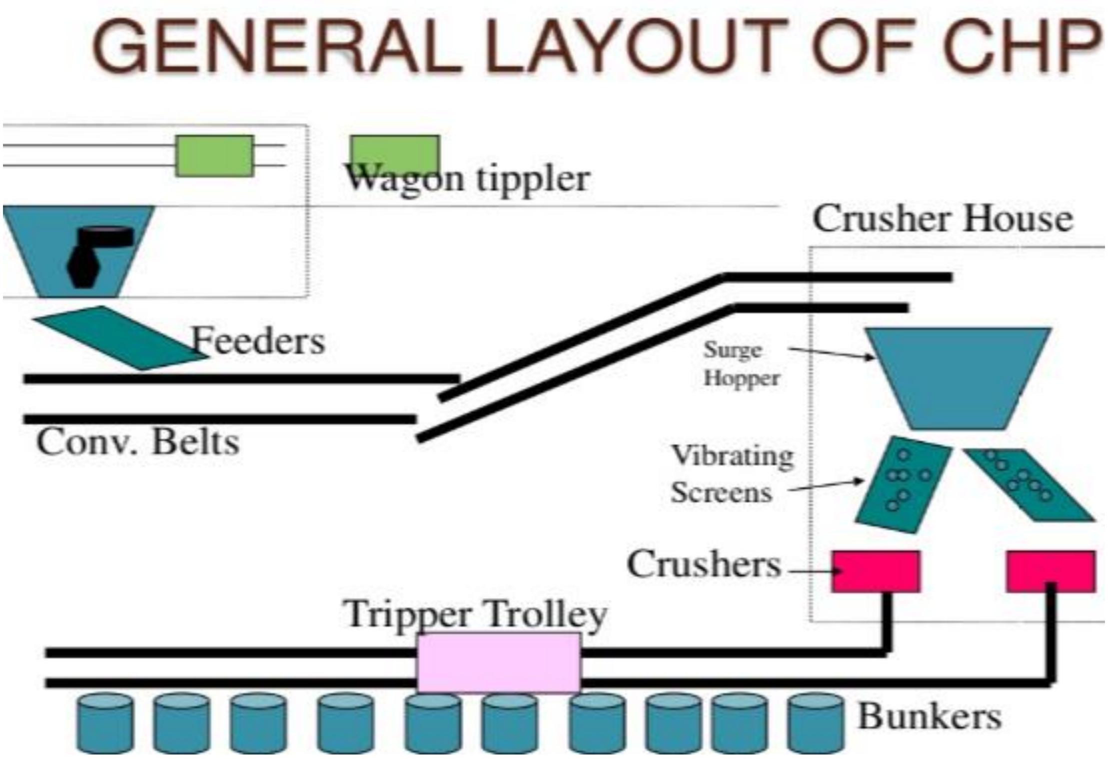


Figure 3.2 Block diagram of Coal handling plant from technical report of NTPC Dadri

Table 3.1 Coal handling plant readings

Item description	**Readings**
Input Size of coal in crusher	250 mm
Output size of coal in crusher	20 mm
Belt Loading Factor	**60%**
Amount of Coal in wagon	70 Tones
Coal stuck in clamps of tippler	10 kg
Total CHP motor consumption	1500 kW
Marshal yard CV	3500 to 4000 kJ/kg
Pulverised Coal CV	3300 To 3800 kJ/ kg

Formula used in ENERGY AUDIT OF CHP (method used here is method of NTPC)

Efficiency of crusher = $\frac{\textbf{Input size} - \textbf{Output size}}{\textbf{input size}}$ **X 100**

Air Losses = $\frac{\textbf{Weight of coal at starting of conveyour} - \textbf{Actual coal Feed}}{\textbf{Weight of coal at starting of conveyour}}$ **X 100**

Tippler Efficiency = $\frac{\textbf{Total amount of coal} - (\textbf{Amount of coal held in clamps} + \textbf{Dust of coal})}{\textbf{Tolat amount of coal}}$ **100**

Theft losses = $\frac{\textbf{Amount of coal initially} - \textbf{Amount of coal reached}}{\textbf{Amount of coal initally}}$ **X100**

Results of energy audit of CHP

Table 3.2 Coal handling plant results

Item description	**Efficiency%**
Efficiency of crusher	92%
Air Losses	36%
Theft losses	30%
CHP motor consumption	1500 kW
Oxygen losses in coal from marshal yard to pulverised coal	3.5 % to 4.5%

3.2 BOILER

Boiler is a pressure vessel in which firing energy is conveyed from furnace to the water in the water tank until the water changes its phase from liquid to vapour. The Water is a very convenient and inexpensive way for conveying heat. When water changes its phase from liquid to vapour by means of heat the volume is increased by 1600 times. This energy is conveyed in the complete cycle by radiation, convection and conduction.

The thermal efficiency is the amount of heat that is given and completely used to convert it to steam. There are two ways of checking the performance of boiler

1) **The direct method**

   In this method the heat acquired of the functioning fluid is balanced with the heat content of the coal.

   The direct method is also called the “INPUT- OUTPUT method” because in this method we consider the output i.e. water in vapour form and the energy input i.e. from coal for calculating the performance of the boiler.

   Advantage of direct method

   By this method we can calculate the performance of boiler in very less time.

   In this method we need very less computational variables.

   In this method we need very less number of equipment.

   Disadvantage of direct method

   In this method we cannot find out why the losses are there in the boiler, so we cannot find out how to rectify them.

2) **The indirect method**

   The indirect method is also known as heat loss method. In this method calculate the percentage of each loss which is there in the boiler and then we subtract it from total percentage of energy which is given to the boiler in form of input. We don’t calculate blow down losses in this method. The readings required for boiler performance calculations are: -

   1. Rate at which coal is fired
   2. Rate at which the stem is generated in the boiler
   3. Pressure of steam at the outlet of boiler

4. Temperature of steam at the outlet
5. Temperature of feed water at the outlet inlet of boiler
6. % of CO_2 present in Flue gas
7. % of CO present in Flue gas
8. Mean temperature of flue gas air-preheater
9. Ambient temperature
10. Humidity in ambient air
11. Surface temperature of boiler
12. Wind velocity around the boiler
13. Total surface area of boiler

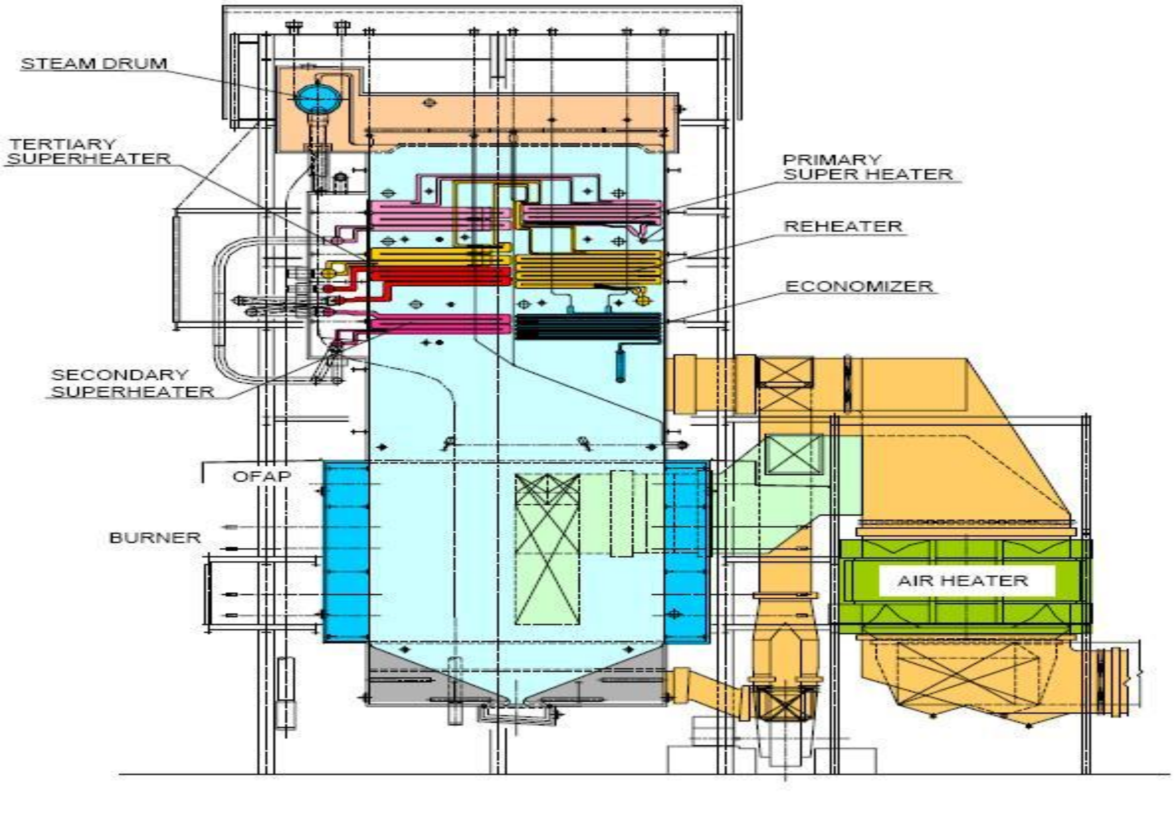
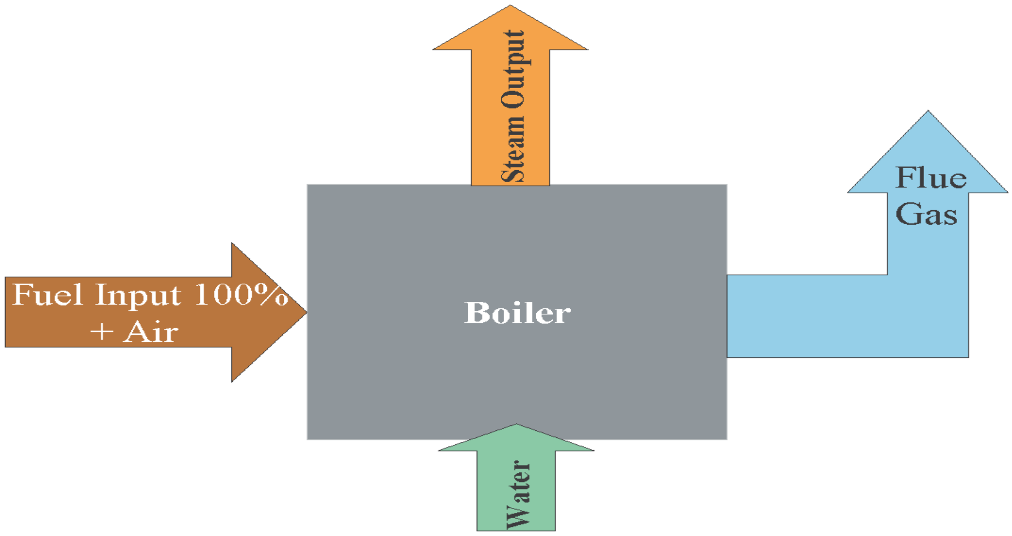


Figure 3.3 Pictorial description of boiler from NTPC Technical Diary

The direct Method (All readings are taken from NTPC Dadri**)**



$$\text{Efficiency} = \frac{\text{Heat addition to Steam} \times 100}{\text{Gross Heat in Fuel}}$$

$$\textit{Boiler Efficiency} = \frac{\text{Steam flow rate x (steam enthalpy} - \text{feed water enthalpy)}}{\text{Fuel firing rate x Gross calorific value}} \; x\,100$$

Figure 3.4 Explanation of Energy audit of boiler by direct method from Bureau of Energy Efficiency

Table 3.2.1 Energy audit of boiler by direct method

Parameters	**Quantity of steam generated per hour (Q)**	**Enthalpy of saturated steam in kJ/kg of steam (H_g)**	**Enthalpy of feed water in kJ/kg of water (H_f)**	**Quantity of fuel used kg/hr (q)**	**Fuel fired GCV kJ/kg**
Values	8 TPH	2782.8 kJ/kg	355 kJ/kg	1.34 TPH	17953 kJ/kg
Boiler Efficiency	Heat Outputx100/Heat Input = QX($H_g$$H_f$) x 100 /(q X GCV)				
Calculation	8X (2782.8355) X100/(1.34*17953)				
Result	**Boiler Efficiency = 80%**				

The Indirect Method Testing

We can calculate the performance of boiler by calculating all the losses happening in the boilers using the indirect method of testing. All the demerits of direct method can be compensated by this indirect method because in this method calculate the losses which are there in the boiler. We can obtain the efficiency percentage by just subtracting the percentage of losses from 100.

The most important merit of this method is that the mistakes made by us in calculation of losses don't affect our result of efficiency to greater extent.

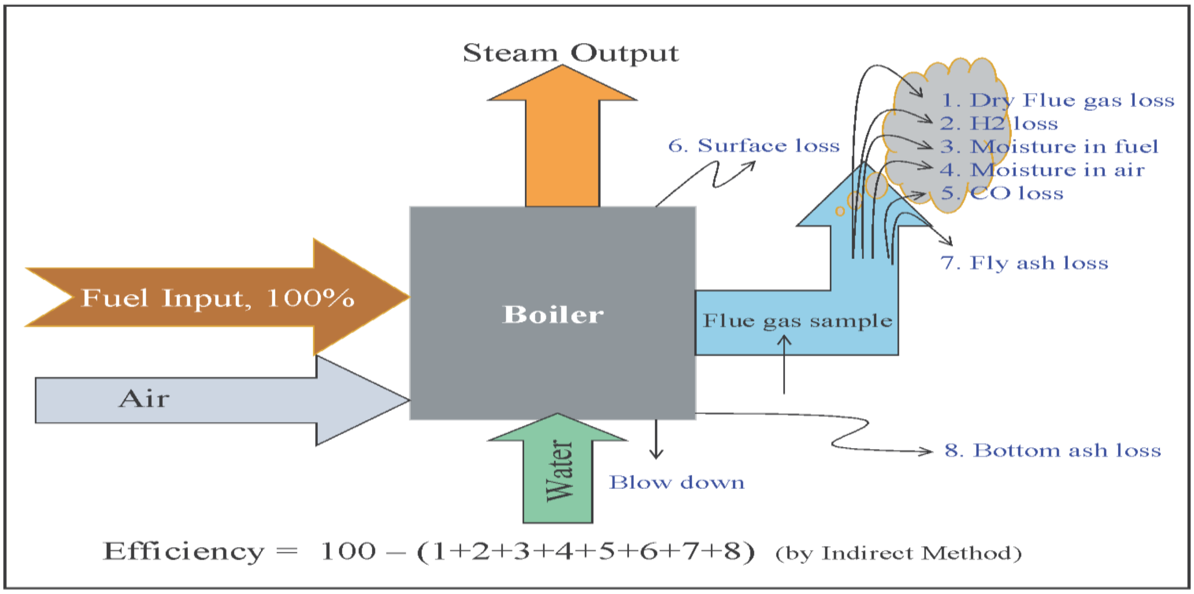


Figure 3.5 Explanation of Energy audit of boiler by indirect method from Bureau of Energy Efficiency

The following losses are applicable to liquid, gas and solid fired boiler

L_1. Loss due to dry flue gas (sensible heat)

L_2. Loss due to hydrogen in fuel (H_2)

L_3. Loss due to moisture in fuel (H_2O)

L_4. Loss due to moisture in air (H_2O)

L_5. Loss due to carbon monoxide (CO)

L_6. Loss due to surface radiation, convection and other unaccounted

L_7. Unburnt losses in fly ash (Carbon)

L_8. Unburnt losses in bottom ash (Carbon)

Boiler Efficiency by indirect method = 100 X (L_1+L_2+ L_3 + L_4+L_5+L_6 +L_7 +L_8)

Boiler Efficiency Calculation (ALL READINGS ARE TAKEN FROM NTPC DADRI)

1. Rate at which coal is fired = 272155 kg/hr
2. Rate at which the stem is generated in the boiler = 1315418 kg/hr
3. Pressure of steam at the outlet of boiler = 192 kg/cm^2(g)
4. Temperature of steam at the outlet = 540 °C
5. Temperature of feed water at the outlet inlet of boiler = 300 °C
6. % of CO_2 present in Flue gas = 3
7. %CO in flue gas = 0.22
8. Mean temperature of flue gas air-preheater inlet =330 °C, APH outlet = 180 °C
9. Ambient temperature = 30 °C
10. Humidity in ambient air = 0.0204 kg / kg dry air
11. Surface temperature of boiler = 78°C
12. Wind velocity around the boiler = 1.66 m/s
13. Total surface area of boiler = 147 m^2
14. GCV of fly ash = 525.2 kCal/kg
15. Ratio of bottom ash to fly ash = 9010

Fuel Analysis (in %) (done in SAI LAB TIET)

1. % of Ash in the fuel = 41
2. % of Moisture in the fuel = 13
3. % of Carbon in the fuel = 34.05
4. % of Hydrogen in the fuel = 3.05
5. % of Nitrogen in the fuel = 1.40
6. % of Oxygen in the fuel = 6.05

7. GCV of the fuel = 3401 kCal/kg

Step 1. Theoretical air required for combustion of coal in furnace

Theoretical air required for = **[(11.6 X C) + {34.8 X (H_2 X O_2/8)} + (4.35 X S)] /100**

complete combustion kg/kg of coal **[18]**

= **4.74 kg/kg of coal**

Step 2. % of Carbon dioxide present theoretically

% of Carbon dioxide present theoretically $= \frac{\text{Moles of C}}{\text{Moles of } N_2 + \text{Moles of C}}$

Moles of N_2 $= \frac{\textbf{Weight of } N_2 \textbf{ in theoritical air}}{\textbf{molar weight of } N_2} + \frac{\textbf{Weight of } N_2 \textbf{ in fuel}}{\textbf{Molar weight of } N_2}$

Where moles of N_2 = 0.135525

Where moles of C = 0.02837

$$(CO_2) = \frac{0.02837}{0.135525+0.02837}$$ **[18]**

= **17.30 %**

- **Step. 3 Excess of air Supplied to furnace**

Actual CO_2 measured in flue gas = 14.0%

$$\textbf{E. A} = \frac{O_2\%}{21-O_2\%} \; X \; 100$$ **[18]**

= 16%

- **Step. 4 To find actual mass of air supplied**

Actual mass of air supplied = {1 + EA/100} x theoretical air **[18]**

= 7.13 kg/kg of coal

- **Step. 5 To find actual mass of dry flue gas**

Mass of dry flue gas = Mass of CO_2 + Mass of N_2content in the fuel +Mass of N_2 in the combustion air supplied + Mass of oxygen in flue gas **[18]**

= 6.7765 kg/kg of coal

- **Step. 6 To find all losses**

1. **Dry flue gas losses: -**

Heat is vanished in the "dry" by-products of ignition, which is having only sensible heat because there was no change in state. The by-products of combustion of coal are carbon dioxide (CO_2), carbon monoxide (CO), oxygen(O_2), nitrogen (N_2) and sulphur dioxide (SO_2). Amount of SO_2 and CO are normally measured in terms of the parts-per-million (ppm) so heat loss can be ignored.

% Heat loss in dry flue gas (L_1) = $\frac{m X Cp\ X(T_f - T_a)}{\text{GCV of FUEL}}$ X 100**= 6.873 %**

Where,

L_1= % Heat loss due to dry flue gas

m = Mass of dry flue gas in kg/kg of fuel

= Combustion products from fuel CO_2 + SO_2 + Nitrogen in fuel +

Nitrogen in the actual mass of air supplied + $\mathbf{O_2}$ in flue gas.

(H2O/Water vapour in the flue gas should not be considered)

Cp = Specific heat of flue gas in kCal/kg°C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

([17], PAGE NO.211, POINT=60)

2. **Heat loss due to evaporation of water formed due to hydrogen in fuel (%)**

The amount of hydrogen is present in the fuel. When this hydrogen makes compound with oxygen it makes water. The water formed is in gaseous state because of high temperature of the boiler which leads to change in phase of the water. The change in phase of water leads to formation of steam and this steam is having very high temperature by very less entropy. The most relevant loss is about 11 % for natural gas and 7 % for fuel oil.

$$\mathbf{L_2} = \frac{\mathbf{9\ X\ H_2\ X\ \{584 + Cp(T_f - T_a)}}{\mathbf{GCV\ of\ FUEL}}$$

Where

H_2 = kg of hydrogen present in fuel on 1 kg basis

Cp = specific heat of superheated steam in kCal/kg℃

T_f = Flue gas temperature in℃

T_a = Ambient temperature in℃

Latent heat corresponding to partial pressure of water = 584

$$\mathbf{L_2 = 5.25\%}$$

([17], PAGE NO.211,POINT=61)

3.**Heat loss due to moisture present in fuel**

The water content which is present in the fuel when burned in the furnace is converted into the steam. The heat loss due to moisture is mainly comprised of three main components that is the heat needed to raise the temperature of the moisture to its boiling point, heat which is used to evaporate moisture and the superheating of the fuel so that the flue gasses can be reached to the temperature of the flue gas at the exit of the exhaust.

$$\mathbf{L_3} = \frac{\mathbf{M\ x\ \{\ 584+Cp(T_f-T_a)\}}}{\mathbf{GCV\ of\ COAL}}\ \mathbf{X\ 100}$$

where

M = kg moisture in fuel on 1 kg basis

Cp = Specific heat of superheated steam in kCal/kg°C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

Latent heat corresponding to partial pressure of water vapour = 584

$$\mathbf{L_3 = 3.41\%}$$

([17], PAGE NO.211,POINT=62)

3. **Heat loss due to moisture present in air**

There is some amount of water content in the air thus to remove this water in the air we have to super heat the air . The water content in the air leads to raise the temperature of the stack thus this is considered as a boiler loss. The water content which is present in the air when burned in the furnace is converted into the steam. The heat loss due to moisture is mainly comprised of three main components that is the heat needed to raise the temperature of the moisture to its boiling point, heat which is used to evaporate moisture and the superheating of the air so that the air can be reached to the temperature of the gas at the exit of the exhaust.

$$\mathbf{L_4} = \frac{\mathbf{AAS\ X\ Humidity\ factor\ X\ Cp\ X\ }(T_f-T_a)}{\mathbf{GCV\ of\ Fuel}}\ \mathbf{X100}$$

Where,

AAS= Actual Mass of air supplied per kg of fuel

Humidity Factor= kg of water/kg of dry air

Cp= Specific heat of superheated stem in kCal/kg℃

T_f = Flue gas temperature in ℃

T_f = Ambient temperature in ℃

$$\mathbf{L_4 = 0.28\%}$$

([17], PAGE NO.211,POINT=64)

4. **Heat loss due to incomplete combustion**

There is some incomplete combustion in the coal because there is less temperature required for the coal to burn completely. The components which are not burned completely and leads to in complete combustions are CO, hydrogen and various HC. We can only find out the amount of CO in boiler emission easily.

$$\mathbf{L_5 = \frac{\%CO\ X\ C}{\%CO + \%CO_2}\ X\ \frac{5744}{GCV\ of\ Fuel}\ X\ 100}$$

Where

L_5 = % Heat loss due to partial conversion of C to CO

CO= Volume of CO in flue gas leaving Economizer (%)

CO_2 = Actual Volume of CO_2 in flue gas (%)

C = Carbon content kg/kg of fuel

L_5 = 1.42% **([17,] PAGE NO.211,POINT=65)**

5. **Heat loss due to radiation and convection**

Although the boiler body is highly insulated but we all know that there is no such system which is ideal, and no heat is rejected to its surroundings so there are losses which are radiation losses and convection losses. As we are having some prerequisite knowledge of the boiler, so we can easily say that the radiation and convection losses for industrial fire tube boiler = 1.5 to 2.5% For industrial water tube boiler = 2 to 3% For power station boiler = 0.4 to 1%

$$\mathbf{L_6 = 0.548\ X\ [(\frac{Ts}{55.55})\text{^}4 - (\frac{Ta}{55.55})\text{^}4] + 1.957\ X\ (T_s - T_a)\text{^}1.25\ X\ \sqrt{[\frac{196.85\ Vm+68.9}{68.9}]}}$$

Where L_6 = Radiation loss in W/m^2

Vm = wind velocity in m/s

T_s= Surface temperature (K)

T_a= Ambient temperature (K)

L_6 = 409.99 Kcal/m^2

Total radiation and convection/ hour = L_6 X surface area of boiler = 60268.6

% Radiation = $\frac{\textbf{total radiation X 100}}{\textbf{GCV of coal X fuel firing rate}}$

%L_6= 0.397% **([17],PAGE NO.211,POINT=66)**

6. % Heat loss due to unburnt in fly ash

In fly ash there is some amount of carbon content thus we can easily find out that there are some losses in the boiler due to these unburnt losses. To calculate these heat losses, we must take the proximate analysis of the ash contents in the boiler. The amount of as made by the fuel should also be known

% Ash in coal = 11.93

Ratio of bottom ash to fly ash = 9010

GCV of fly ash = 542.25 kCal/kg

Amount of fly ash in 1 kg of coal = 0.1 x 0.1193

= 0.01193 kg

Heat loss in fly ash = 0.01193 x 542.25

= 6.498 kCal / kg of coal

% heat loss in fly ash = Heat Loss in fly Ash X $\frac{100}{GCV\ of\ COAL}$

L7 = 0.19 %

([17], PAGE NO.211,POINT=67)

8. % Heat losses due to unburnt in bottom ash

GCV of bottom ash = 769 kCal/kg

Amount of bottom ash in 1 kg of coal = 0.9 x 0.1193

= 0.10737 kg

Heat loss in bottom ash = 0.10737 x 769

= 82.56 kCal/kg of coal

% Heat loss in bottom ash = Heat loss in bottom Ash X $\frac{100}{GCV\ of\ coal}$

$\mathbf{L_8}$ **= 2.42 %**

Boiler efficiency by indirect method

= 100 - ($\mathbf{L_1}$+ $\mathbf{L_2}$ + $\mathbf{L_3}$ + $\mathbf{L_4}$ + $\mathbf{L_5}$ + $\mathbf{L_6}$ + $\mathbf{L_7}$ + $\mathbf{L_8}$)

= 100 - (6.873+ 5.25 + 3.41 + 0.28 + 1.42+ 0.397+ 0.19 + 2.42)

Boiler efficiency = 77.72% **([17]PAGE NO.211,POINT=61)**

Table 3.2.2 SUMMARY OF ALL THE LOSSES IN COAL FIRED BOILER

SUMMARY OF ALL THE LOSSES IN COAL FIRED BOILER	
Input/output Parameter	**% loss**
Heat Input	**100**
Losses in boiler	
1. Dry flue gas, $\mathbf{L_1}$	6.873
2. Loss due to hydrogen in fuel, $\mathbf{L_2}$	5.25
3. Loss due to moisture in fuel, $\mathbf{L_3}$	3.41
4. Loss due to moisture in air, $\mathbf{L_4}$	0.28
5. Partial combustion of C to CO, $\mathbf{L_5}$	1.42
6. Surface heat losses, $\mathbf{L_6}$	0.397
7. Loss due to Unburnt in fly ash, $\mathbf{L_7}$	1.19
8. Loss due to Unburnt in bottom ash, $\mathbf{L_8}$	2.42
Boiler Efficience = 100 - ($\mathbf{L_1}$+ $\mathbf{L_2}$ + $\mathbf{L_3}$ + $\mathbf{L_4}$ + $\mathbf{L_5}$ + $\mathbf{L_6}$ + $\mathbf{L_7}$ + $\mathbf{L_8}$) = 77.72%	

Second Law Analysis of Boiler

Exergy analysis has inspired the persons working in field of science to require some extra in-depth knowledge on the energy saving devices and to invent new techniques to rise the utilization of the gaining the victory on confined resources**.** Exergy analysis calculates entropy production, irreversibility percentage, exergy destruction & second law efficiency. The exergy destruction or irreversibility is highest in boiler**.** Thus, to know about authentic flow of exergy in the cycle thermal analysis & second law efficiency calculation is desirable**.** In this method of exergy analysis, we take operating conditions as mass and exergy balance. The exergy is maximum work which can be taken out from the system at ambient atmosphere. By doing this exergy analysis we can check where the losses are maximum, and we must make efforts to increase the performance of the system

Exergy destruction

Irreversibility's like surface roughness, merging, chemical reaction, heat transfer from some certain temperature difference, uncontrolled growth, unbalances compression or expansion consistently produce entropy & any change that produce entropy always destroys exergy. The exergy of the system and surroundings which very often be thought about the relation in degree unreachable system is constantly decreasing. The additional irreversible a system is, the greater the exergy destruction in the complete system. Exergy destruction is 0 in case of cyclic process. The exergy change of a system may be positive or negative in complete a method, but the exergy destruction will not be less than. Exergy analysis devote entropy formation, non-cyclic percentage exergy loss and second law efficiency. The exergy destruction or non-cyclic behaviour is highest in boiler as compared in all components of the coal fired thermal power plant. So, if we want to get the actual flow of exergy destruction in a complete system it is mandatory to have the knowledge of second law analysis of the complete system. In this method of exergy analysis, we consider we take operating conditions as mass and exergy balance. As a result, we find that maximum exergy destruction is in the combustion process. Some of the boiler parts are also having some major exergy losses.

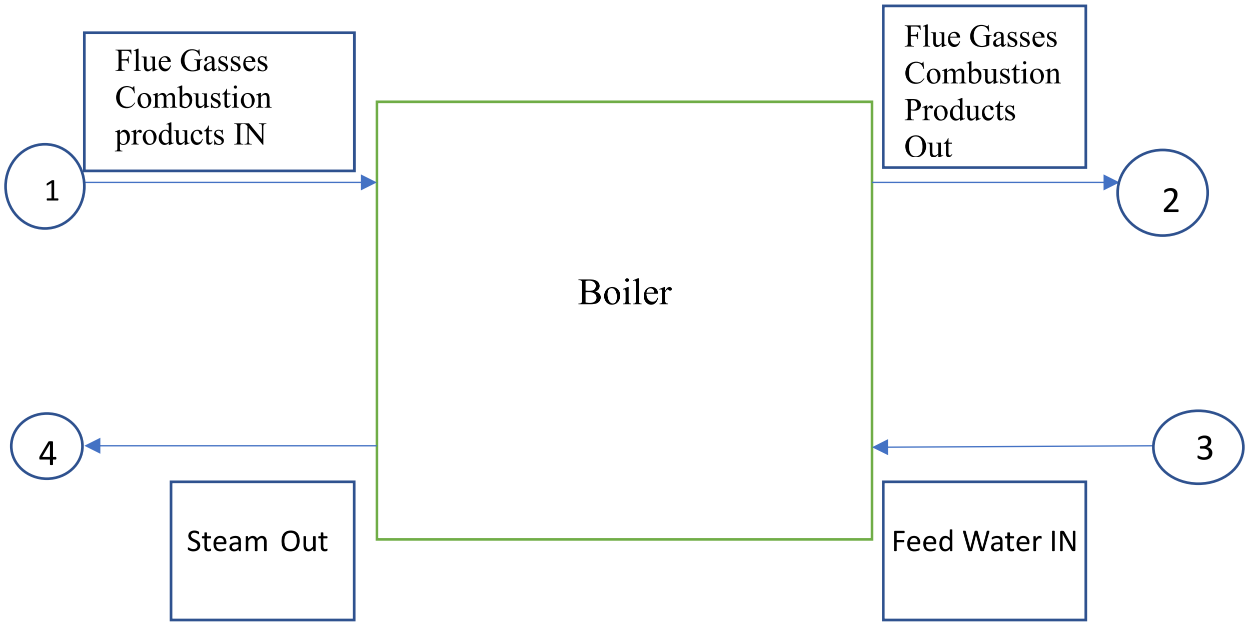


Figure 3.6 Explanation of 2nd law analysis of boiler

- **Equations (**All equations are taken from [19]**)**

net rate exergy is carried *into* the control volume. Between point 1 & 2;

$$\mathbf{m_1[ef_1ef_2]=m_1\ [(h_1h_2)T_0(s_1s_2R\ X\ ln\frac{P_2}{P_1})]}$$

net rate exergy is carried *into* the control volume. Between point 3&4;

$$\mathbf{m_3[ef_3ef_4]=m_3\ [(h_3h_4)T_0(s_3s_4R\ X\ ln\frac{P_4}{P_3})]}$$

Energy destruction**;**

$$\mathbf{E_d= m_1[ef_1ef_2] + m_3[ef_3ef_4]}$$

SECOND LAW EFFICIENCY OF BOILER

$$\boldsymbol{\varepsilon = \eta x\ [\frac{1-T_0\ /T_4}{1-T_0\ /T_1}]\ X\ 100}$$

Where: - ε = Second law effectiveness of boiler

η = First law efficiency of boiler

T_0 = Ambient temperature

T_1 = Temperature of Flue gasses at inlet of boiler

T_4 = Steam temperature at outlet of boiler

Readings

Table 3.2.3 Readings for Second law analysis of boiler

	Parameters	Values
m_1	Mass flow rate of combustion gasses INLET	176.397 kg/sec
m_2	Mass flow rate of combustion gasses OUTLET	201.597 kg/sec
T_1	Temperature of Flue gasses at inlet of boiler	873K
T_2	Temperature of Flue gasses at outlet of boiler	673K
T_3	Feed water temperature at inlet of boiler	573K
T_4	Stem temperature at outlet of boiler	813K
P_1	Pressure of Flue gasses at inlet of boiler	0.0098bar
P_2	Pressure of flue gasses at outlet of boiler	0.0098bar
P_3	Feed Water pressure at inlet of boiler	137.2bar
P_4	Steam pressure at outlet of boiler	188bar

On basis of above readings

- **Specific enthalpy**

Specific enthalpy has been calculated by **[19]**

$\mathbf{h_1}$= 899 kj/kg

$\mathbf{h_2}$ = 685 kj/kg

$\mathbf{h_3}$ = 1344 kj/kg

$\mathbf{h_4}$= 2464 kj/kg

- **Entropy**

Entropy have been calculated by **[19]**

s_1= 2.80 kj/kgK

s_2 = 2.51 kj/kgK

s_3= 3.25 kj/kgK

s_4= 5.1922 kj/kgK

Results

Table 3.2.4 Results of Second law analysis of boiler

Parameter	RESULT
Net rate exergy is carried into the control volume between point 1 & 2	395108.448 kW
Net rate exergy is carried into the control volume. between point 3&4	114581.45 kW
Energy destruction	280526.95 kWh

SECOND LAW EFFICIENCY OF BOILER= 29.97%

3.3 SECOND LAW ANALYSIS OF ECONOMISER

Economizer is an equipment which is used to decrease the energy consumption or to execute the purpose of preheating of water is then feed to the boiler. The device can also be used in power plant and heating ventilation and air conditioning. Economiser are called by this name because we use this device for enthalpy & increasing the efficiency of the boiler. Thus, economiser is a device which takes heat from the flue gasses to heat the feed water so that less energy is required to heat up the water in the boiler.

Now also the economiser is the most important part of the boiler system because it is the best way to reheat the water. Economiser also saves heat energy that the hot flue gasses to leave from the stack so that less thermal pollution takes place.

It gives more feed water temperature thus it lowers the thermal stress produced by the high temperature in furnace thus it indirectly increases the performance and life of boiler.

It uses waste heat from the gasses which will further passed from stack, so the overall coal required for combustion process is reduced.

It increases the evaporative capacity of the boiler.

Boiler require more powerful ID and FD fans because the economiser is in way of the flue gasses thus there will be pressure drop.

Economiser is a type of heat exchanger in which hot flue gasses gives heat to the water which is feed to the boiler to complete the process of boiling of water. So, if water at normal temperature enters the boiler drum more coal will be required to raise the temperature of the boiling water, so we use hot water thus less coal is required to heat the furnace. This process is call regenerative and reheating.

Thus, more the heat transfer more will be the efficiency of the economiser. So, we must make fins because the rate of heat transfer increase as we put fins in the pipes of economiser. Fins are there on the air side not on water side because heat transfer coefficient of air is very less than heat transfer coefficient of water. Thus, to increase overall heat transfer we make fins at air side. But in case of economiser of coal fired thermal power plant there is no need to make fins at the flue gas side because the temperature of the flue gas is very high, so heat transfer can easily be done, and second reason is because the flue gas is having carbon particles which will stuck in between the fins and the flue gas flow will be stopped because of chocking.

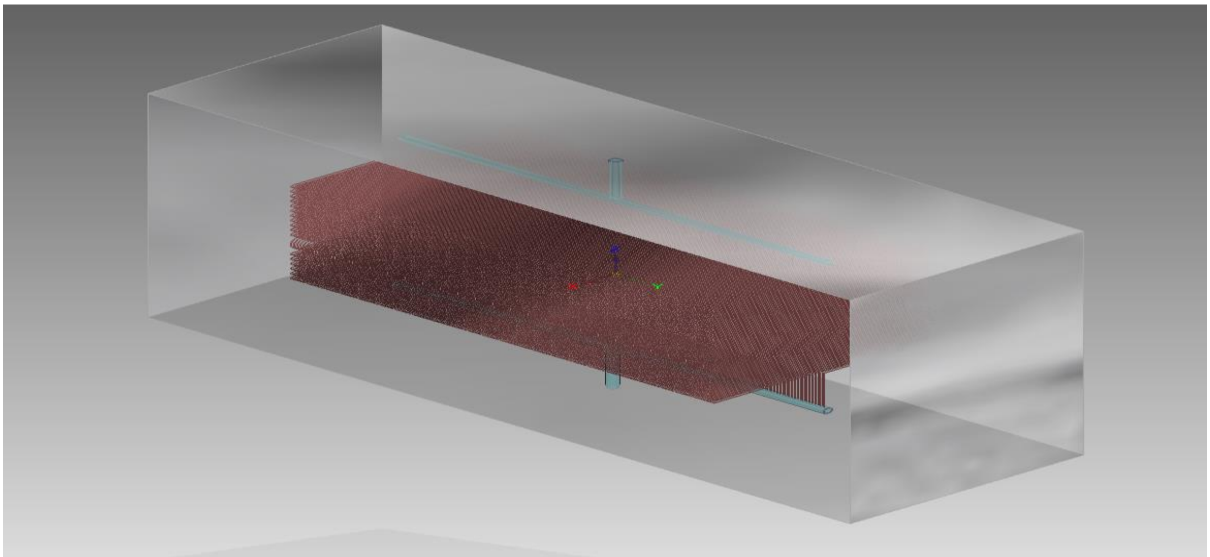


Figure. 3.7 3D rendered image of economiser made at ANSYS

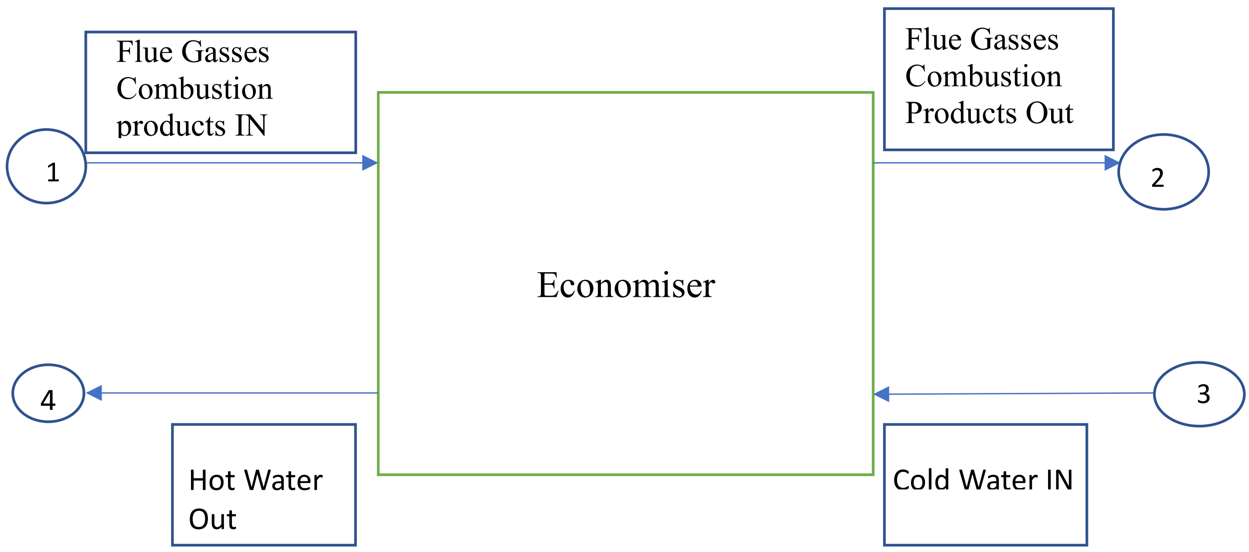


Figure 3.8 Explanation of 2nd law analysis of economiser

Readings

Table 3.3.1 Readings for Second law analysis of Economiser

	Parameters	Values
m_1	Mass flow rate of combustion gasses inlet	206.6 kg/sec
m_2	Mass flow rate of combustion gasses outlet	158.77 kg/sec
T_1	Temperature of Flue gasses at inlet of economiser	673K
T_2	Temperature of Flue gasses at outlet of economiser	613K
T_3	Cold water temperature at inlet of economiser	525K
T_4	Feed water temperature at outlet of economiser	623K
P_1	Pressure of Flue gasses at inlet of economiser	0.0019 bar
P_2	Pressure of flue gasses at outlet of economiser	0.0029 bar
P_3	Cold water stream water pressure at inlet of economiser.	166 bar
P_4	Feed water at outlet of economiser	156 bar

On basis of above readings

- **Specific enthalpy**

Specific enthalpy has been calculated by **[19]**

$\mathbf{h_1}$= 681.14 kj/kg

$\mathbf{h_2}$ = 617.83 k/kg

$\mathbf{h_3}$ **=** 1650.1 kj/kg

$\mathbf{h_4}$= 1610.2 kj/kg

- **Entropy**

Entropy have been calculated by **[19]**

$\mathbf{s_1}$**=** 2.52 kj/kg K

$\mathbf{s_2}$**=** 2.42kj/kg K

$\mathbf{s_3}$**=** 3.746 kj/kg K

$\mathbf{s_4}$**= 3.684** kj/kg K

Equations (All equations are taken from [19])

net rate exergy is carried *into* the control volume. Between point 1 & 2;

$$\mathbf{m_1 h_1\ [ef_1 ef_2] = m_1\ [(h_1 h_2) T_0 (\mathit{s_1} s_2 R\ X\ ln\frac{\mathit{P_2}}{\mathit{P_1}})]}$$

net rate exergy is carried *into* the control volume. Between point 3&4;

$$\mathbf{m_3 h_3\ [ef_3 ef_4] = m_3\ [(h_3 h_4) T_0 (\mathit{s_3} s_4 R\ X\ ln\frac{\mathit{P_4}}{\mathit{P_3}})]}$$

Energy destruction;

$$\mathbf{E_d = m_1\ h_1\ [ef_1 ef_2] + m_3 h_3\ [ef_3 ef_4]}$$

$$\mathbf{\eta = \frac{m_3 h_3\ [ef_3 - ef_4]}{m_1 h_1\ [ef_1 - ef_2]}}$$

RESULTS **Table 3.3.2 Results of Second law analysis of Economiser**

Parameter	RESULT
Net rate exergy is carried into the control volume. Between point 1 & 2	12.904 MW
Net rate exergy is carried into the control volume. Between point 3&4	6.247679 MW
Energy destruction	6.657

SECOND LAW EFFICIENCY OF ECONOMISER= 44.69%

3.4 3 SECOND LAW ANALYSIS OF AIR PREHEATER

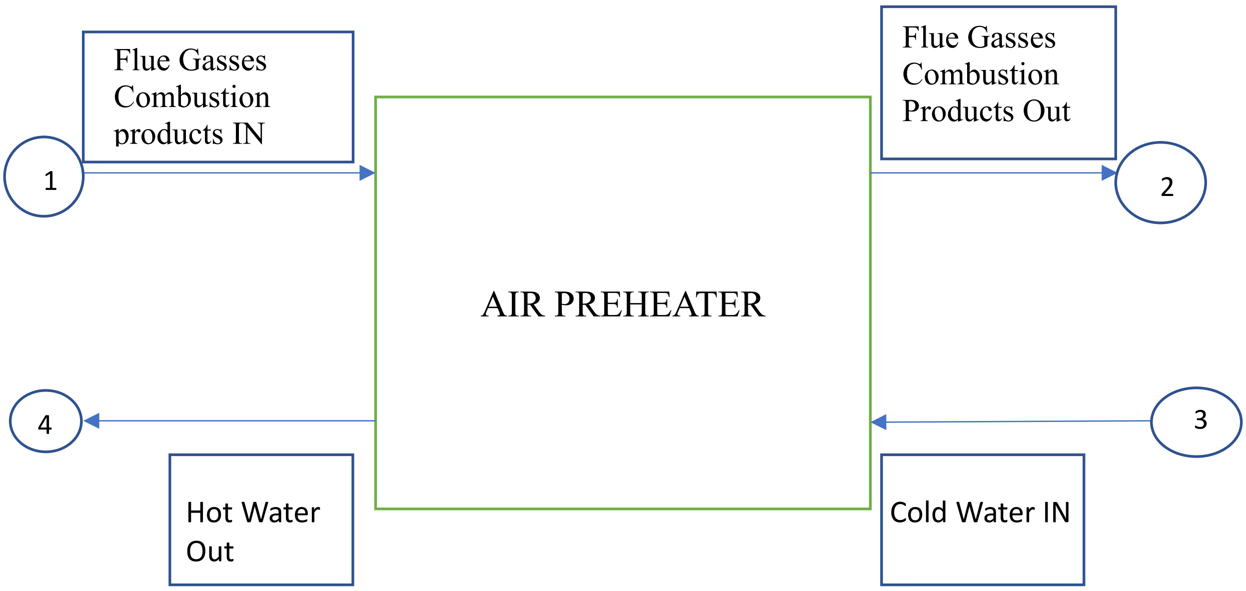


Figure 3.9 Explanation of 2nd law analysis of air preheater

	Parameters	Values
m_1	Mass flow rate of combustion gasses inlet	206.6 kg/sec
m_2	Mass flow rate of combustion gasses outlet	80 kg/sec
T_1	Temperature of Flue gasses at inlet of air preheater	613 K

T_2	Temperature of Flue gasses at outlet of air preheater	413 K
T_3	Air temperature at inlet of air preheater	303 K
T_4	Air temperature at outlet of air preheater	533 K
P_1	Pressure of Flue gasses at inlet of air preheater	0.0058 bar
P_2	Pressure of flue gasses at outlet of air preheater	0.0107 bar
P_3	Air pressure at inlet of air preheater	214.7 bar
P_4	Air at outlet of air preheater to furnace	196.13 bar

Table 3.4.1 Readings for Second law analysis of APH

Readings

- **Specific enthalpy**

Specific enthalpy has been calculated by **[19]**

$\mathbf{h_1}$= 617.53 kj/kg

$\mathbf{h_2}$= 411 kj/kg

$\mathbf{h_3}$**= 2742.1** kj/kg

$\mathbf{h_4}$ = 2794.2 kj/kg

- **Entropy**

Entropy have been calculated by **[19]**

$\mathbf{s_1}$= 2.42 kj/kg K

$\mathbf{s_2}$ = 22.01 kj/kg K

$\mathbf{s_3}$= 5.67 kj/kg K

$\mathbf{s_4}$**= 5.97** kj/kg K

RESULTS

Table 3.4.2 Results of Second law analysis of APH

Parameter	**RESULT**
Net rate exergy is carried into the control volume. Between point 1 & 2	4.257 MW
Net rate exergy is carried into the control volume. Between point 3&4	1.627 MW
Energy destruction	2.63 MW

SECOND LAW EFFICIENCY OF Air preheater= 39.60 %

3.5 CALCULATION OF RATE OF HEAT TRANSFER

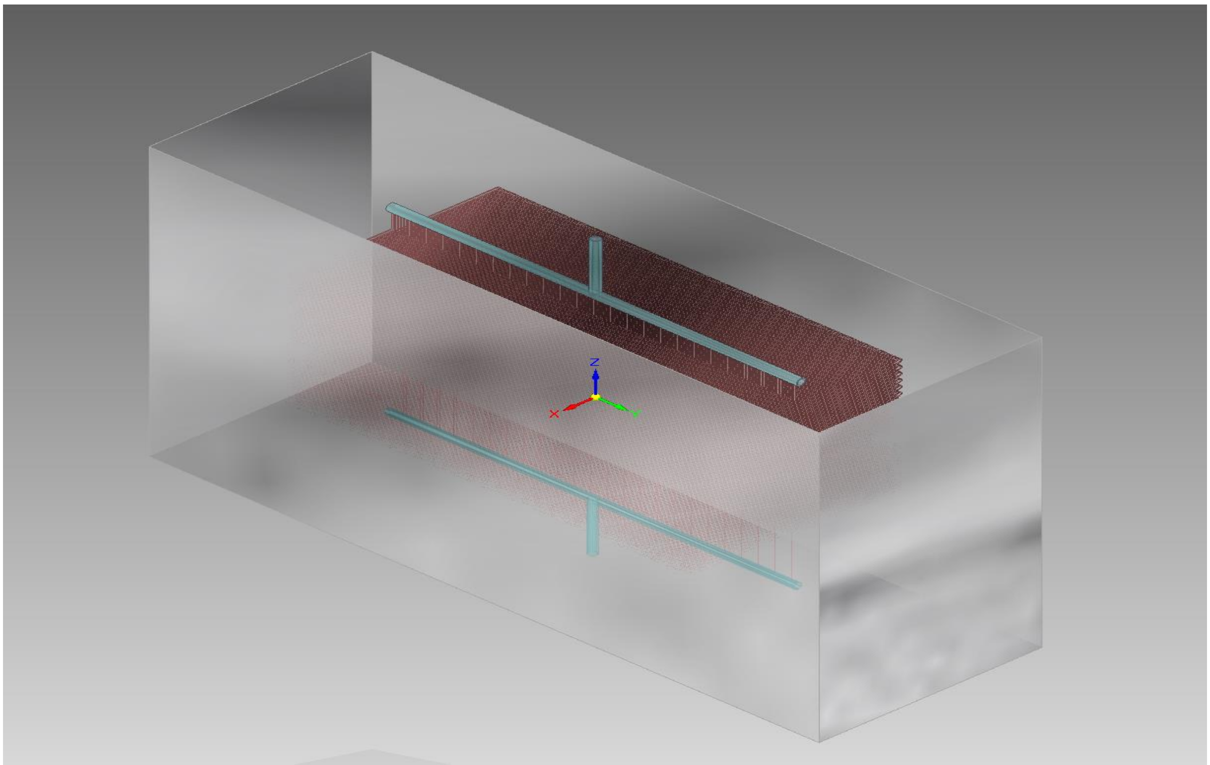


Figure 3.10 3D image of economiser made in ANSYS

Hot fluid inlet temperature = T_{hi} = 400℃

Hot fluid outlet temperature = T_{ho} = 340℃

Cold fluid inlet temperature = T_{ci} = 400℃

Cold fluid outlet temperature = T_{co} = 400℃

Mass flow rate of hot fluid = m_h = 206.6 kg/ sec

Mass flow rate of cold fluid = m_c = 158.75 kg/ sec

Specific heat of hot fluid = C_{ph} = 1064 J/ kg

Specific heat of cold fluid = C_{pc} = 5750 J/ kg

Longitudinal pitch = S_L= 0.0762 m

Transverse pitch = S_T = 0.103 m

Outer dia. = D = 0.0381 m

Inner dia. = d_i = 0.0345 m

Thickness of tube = t = 0.0053 m

No. of tubes = not = 145

Density of cold fluid = ρd = 803 kg/m^3

Viscosity of cold fluid = μd = 0.0001045 Pas

Density of hot fluid = ρD = 0.4856 Kg/m^3

Viscosity of hot fluid = μD= 0.00002932

Prandtl number of cold fluid at 301˚C = P_rd =0.902

Prandtl number of hot fluid at 301˚C = P_rD =0.902

Thermal conductivity of cold fluid = K_i = 0.6240 W/ mK

Thermal conductivity of hot fluid = K_0 = 0.0213 W/ Mk

Length of tubes = L = 12.143 m

Breadth of heat exchanger = B = 15 m

No. of passes = nop= 36

No. of tubes = NI = 36

Correction factor for cross flow heat exchanger

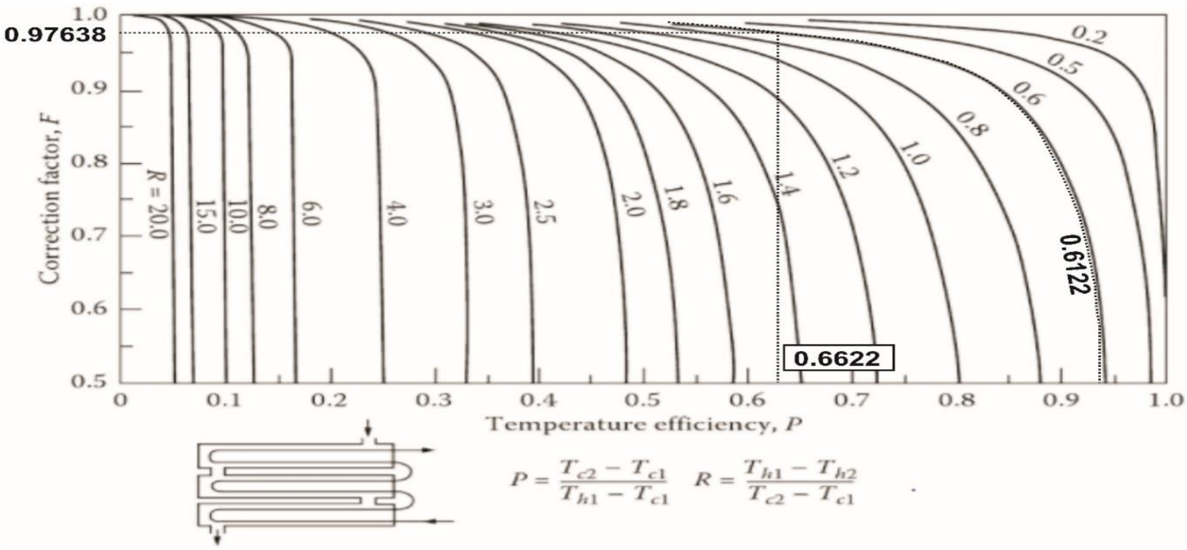


Figure 3.11 Correction factor for cross flow heat exchanger from Heat exchanger selecting & thermal design , Third edition by Sadik Kashap , Fig 2.9

P = $\frac{T_{c2}-T_{c1}}{T_{h2}-T_{h1}}$ = **0.6622** , **R** = $\frac{T_{h1}-T_{h2}}{T_{c2}-T_{c1}}$ = **0.6112**

F = Correction factor = f(P,R, flow arrangement) = **0.97638**

Where;

F = correction factor

P= effectiveness of heat exchanger, R = heat capacity of rate ratio

Friction factor for pressure drop for hot fluid (ff)

Red max= 222.7

$P_t = \frac{S_t}{D}$ = 2.7

Therefore, ff = 0.6

Correction factor for pressure drop hot fluid (X)

Red max= 222.7

$P_L = \frac{S_L}{D}$ = 2

$\frac{P_t}{P_L}$ = 1.35

X = 1

Thermal conductivity of carbon steel = k_t = 53.61

Average temperature of hot fluid (℃)

$T_{ha} = \frac{T_{hi} + T_{ho}}{2}$ = **370℃**

Hot fluid temperature difference (℃)

deltaT_h = T_{hi} T_{ho} = **60℃**

Heat load of hot fluid

Q_h = m_h x c_{ph} x deltaT_h = **13189344 W**

Average temperature of cold fluid (℃)

$T_{ca} = \frac{T_{ci} + T_{co}}{2}$ = **301℃**

Cold fluid temperature difference (℃)

deltaT_C = T_{ci} T_{co} = **98℃**

Heat load of hot fluid

$Q_c = m_c$ x c_{pc} x deltaT_c = **13189344 W**

Theoretical temperature of cold fluid outlet (℃)

$T_{cot} = m_C$ x C_{PC} x deltaT_C = **266.44 ℃**

Cold fluid mean temperature (℃)

$T_{cm} = \frac{T_{cot} + T_{ci}}{2}$ = **259.2℃**

Cross sectional area of tube (m^2)

$C_{ai} = \frac{\pi}{4}$ x (d_i) x (d_i) = **93482.01** m^2

Total cross sectional area (m^2)

$T_{Ai} = C_{ai}$ x not **= 0.5085** m^2

Mass flow rate per cross sectional area (kg/m^2. s)

$G_i = \frac{m_c}{T_{Ai}}$ = **312.1 Kg/**m^2**. S**

Reynolds number of cold fluid

$R_{ed} = \frac{G_i}{mud}\ x\ d_i$ = **1.0305 X** 10^5

Frictional factor of cold fluid

$f = (1.82 \text{ X} \log(R_{ed}) - 1.64)^2$ = **0.0026**

Nusselt number of cold fluid

N_{ud} = (($\frac{F}{8}$) x (R_{ed}) x P_{rd}) / (1.07 + (12.7 x (($\frac{F}{8}$)^ 0.5) x ((P_{rd})^ 2/9))1)) = **29.091**

Heat transfer coefficient inside the tube (W/m^2K)

$h_i = \frac{N_{ud}\ X\ K_i}{d_i}$ = **526** W/m^2K

Pressure difference in cold fluid inlet and outlet (Pa)

$deltaP_i = \frac{f\ x\ rho\ x\ v^2\ x\ L}{2\ \ d_i}$ = **1.2524 Pa**

Frontal area of heat exchanger (m^2**)**

TA_O = L x B x 0.5 = 2.0035 x 10^3 m^2

Velocity of hot fluid (m/s)

$V_O = \frac{mh}{TA_O\ x\ rhoD}$ **= 0.1281 m/s**

Staggered tube bank pitch (m)

$S_d = (S_L + S_t)$^ 0.5 **= 0.1281 m**

Maximum velocity (m/s)

$V_m = \frac{S_t}{2\ x\ (S_t - D)}$ **= 0.337003 m/s**

Reynolds no. of hot fluid

$ReD = \frac{rhoD\ \ X\ V_m\ X\ D}{muD}$ **= 212.6**

Nestle no. of hot fluid

NuD = 1.04 x $(ReD)^{0.4}$ x $(PrD)^{0.4}$ x $(\frac{PrD}{Pr\ S})^{0.25}$ = **7.68**

Heat transfer coefficient outside (W/m^2K)

$h_o = \frac{NuD \times K_o}{D}$ **= 4.29 W/m^2K**

Pressure difference in hot fluid inlet and outlet (Pa)

$deltaP_a = \frac{ff \times \rho D \times Vm \times Vm \times Ni \times L}{2}$ = **0.909 Pa**

Overall thermal coefficient of heat transfer (W/m^2K)

U_o = ((d_i x h_i x h_o x k_t) / ((D x h_o x k_t) + (d_i x h_i x k_t) + (t x D x h_i x h_o))) = **4.2547 W/m^2K**

Logarithmic mean temperature difference (℃)

$LMTD = \frac{((T_{ho} - T_{ci}) - (T_{hi} - T_{co}))}{\log((T_{ho} - T_{ci}) / (T_{hi} - T_{co}))}$ **= 67.219℃**

Outside area of tube (m^2)

A_o = p_i x D x L x not **= 1.739491** m^2

Inner area of tube (m^2)

A_i = p_i x d_i x L x not **= 1.5751** m^2

Rate of heat transfer (kW)

Q_o = U_o **X** A_o **X F X LMTD = 4.857 x** 10^3 **kW**

For program refer Appendix 1

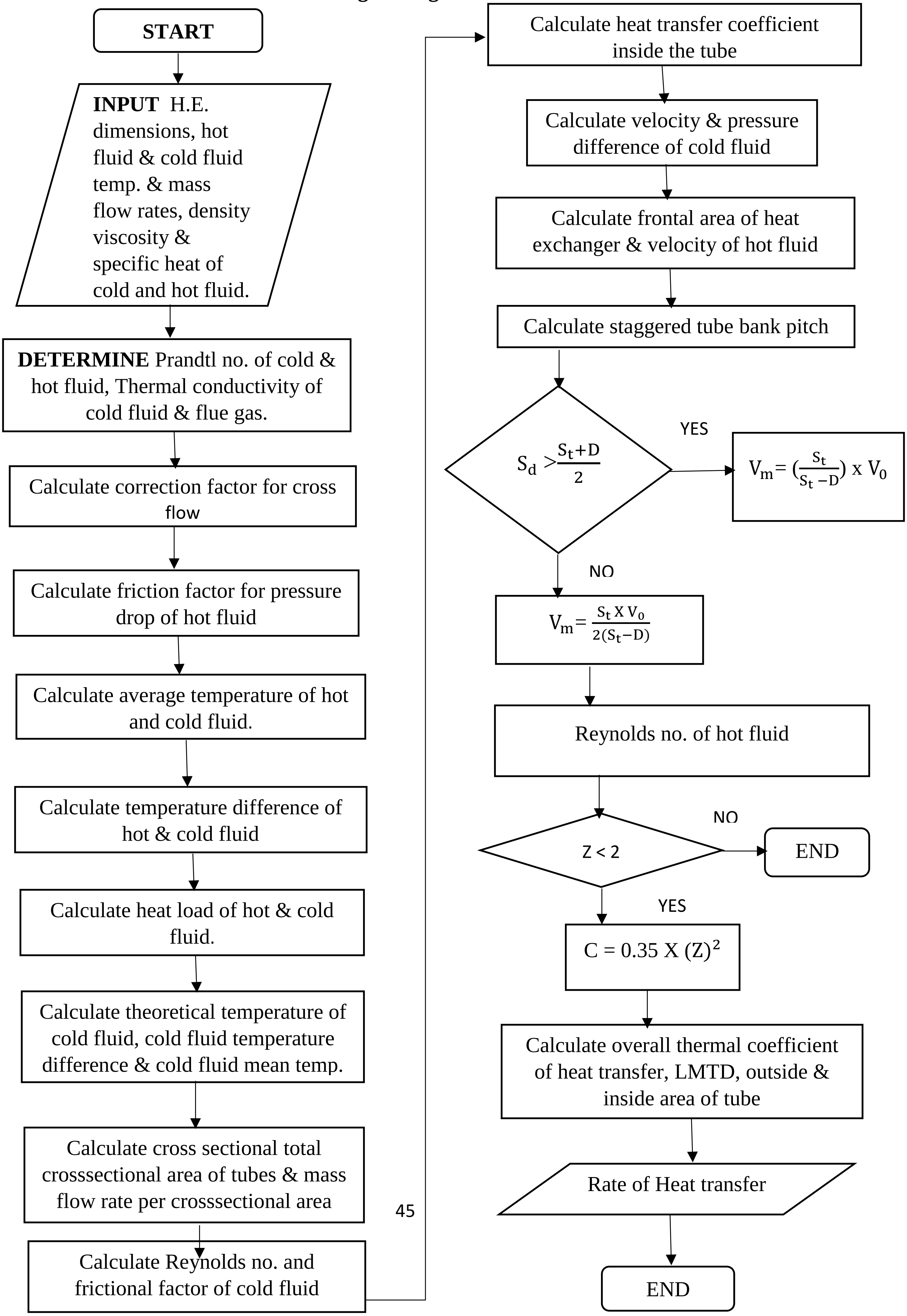
3.6 RATE OF HEAT TRANSFER OF APH

Q = m X C_p X delta T

= 25830 Kw

Rate of heat transfer of air preheater is very much high than Economiser. Thus, to make an economiser of same rate of heat transfer we need to make **3100 tubes** instead of **544 tubes.** Thus cost of making economiser will be **6 times** the construction of an economiser thus we do not use economiser in place of APH. This calculation is done in **MATLAB** and program is in Appendix 2 .We use air pre heater instead of this large economiser because it will occupy very large space and cost of construction is very high but it is one time investment .

3.6.1 Flow chart of heat exchanger design calculation



CHAPTER 4

ESTIMATION OF ENERGY SAVINGS

The method of energy audit we have used in this thesis is "DETAILED ENERGY AUDIT". The method of audit used here is the most detailed and time consuming one. This contains the use of devices to calculate the energy consumptions of all the equipment's in the thermal power plant. This energy audit exercise is a method to find out the wastage of energy in the thermal power plant and finding out the methods to rectify them.

4.1 PRILIMINARY AUDIT

To perform this preliminary audit a technical run survey was done. Based on knowledge collected and as per ASME standard a comprehensive survey was performed and the requirement of data to perform energy audit was given to all departments. These inputs from all departments gave assistance to get wastage of energy in all equipment and considering those equipment which have more energy wastage.

Based on above discussion within the plant we decided to consider Coal handling plant, Boiler, Economiser and Air pre-heater are having maximum energy wastage in thermal power plant.

4.2 COAL HANDLING PLANT

As we all know that coal is black gold these days, so we must use of this coal is in the most appropriate manner so that no wastage of coal takes place in the plant. So, we first checked all the components which there in coal handling plant are and then calculates the amount of coal which is wasted and then weighed.

1. The clamps to hold the wagon should be of different material so that reduction in size of clamps can be done and same strength can be obtained and as size is less thus less coal will be stuck at that part according to this loss in coal will be less.
2. To avoid air loss, we should cover the conveyer belt and don't let air to blow over it.
3. Water should be sprinkled time to time over the coal so that to avoid dust from the tippler and dust losses can be minimised.
4. The wagon containing the coal should be covered from the top to avoid theft losses.
5. The pneumatic valves to open the gates of the wagon to let coal to fall in the hopper in track hopper system should be perfect so that the wagons can be cleared in less time to avoid demerge cost given to Indian Railway by plant.

6. The CV of the coal from marshal yard to pulveriser is reduced by 200CV it can be avoided by keeping coal in less moist area.

7. CHP motor consumption is 1500 KW of total all motors, but this depends on full load, partial load or no-load condition. To avoid losses in MOTORS all motors should be always in full load condition so that the losses which are in no load condition can be compensated. We should also reduce idling time so that no-load condition can be avoided.

8. The coal used in power plat should always be washed coal so that minimum CV losses are there.

9. The circuit the use is very bulky and large because the stakes are at a distance from the furnace. They can be brought nearer thus very less no. of conveyor belts are there and subsequently less n. of motors to rum them and directly decreasing the auxiliary power consumption.

10. In CHP they are having closed rooms with less no. of windows and having concrete sealing at their top which are opaque. Thus, they can also use maxim no. of windows and can also give green sheet which is translucent in nature thus some amount of light can entre and reduces in electricity consumption. 11. Power factor of maximum motors in CHP was 0.6 to .07 thus can be improved up to 0.9 as BFP is working at .09 PF.

11. The opportunity of with compounds for dropping aquatic sprig should be there. Fraternization of biochemical composites in aquatic for clampdown of powder delivers ample improved atomisation of aquatic sprig by dipping shallow tightness which is not practised here.

12. Principle of ‘FIRST IN FIRST OUT’ in case of coal transportation SILO to HOPPER is used here which is very much efficient.

4.3 BOILER

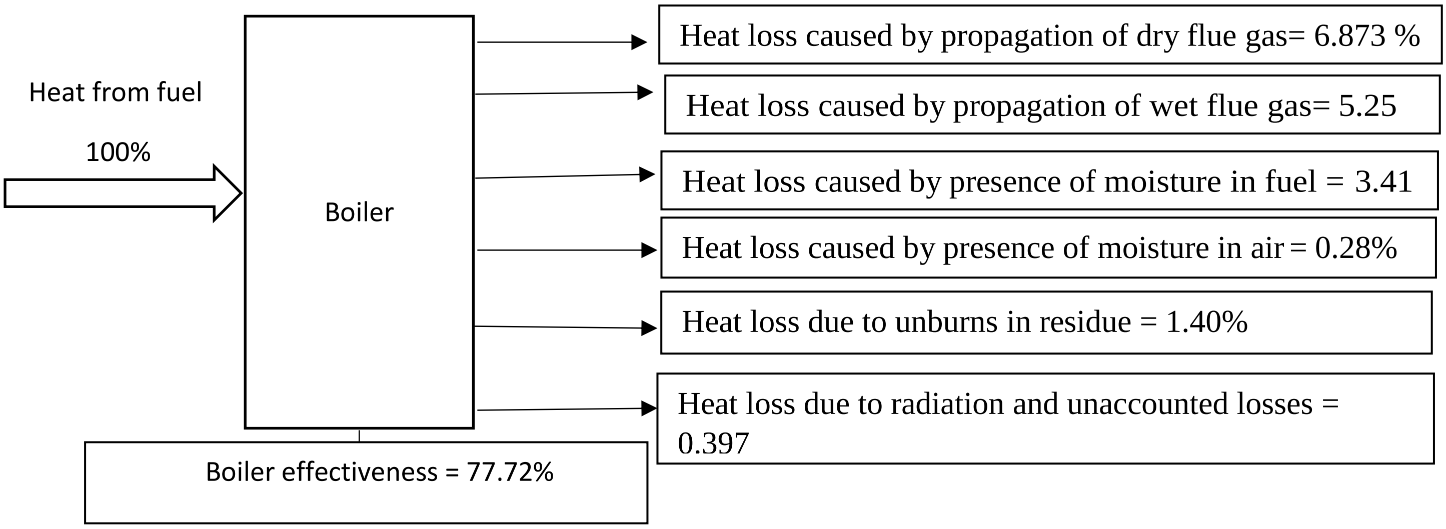


Figure 3.12 Results of boiler losses

- **Blow down**

  1% of blow down implies 0.17% heat added in the boiler. So, blow down should be adhered to the chemist requirement.

- **Soot blowing losses –**

  Superheated steam with high enthalpy is used for soot blowing.

  1% of steam required, contains 0.62% heat content. To make up the loss another 0.25% heat has to be added to feed water resulting in total heat loss of 0.87%.

  Frequency of soot blowing must be carefully planned.

- **High Dry flue gas loss**

  Air leakage through man holes, peep holes, bottom seals, air heater seal leakage, uneven distribution of secondary air, inaccurate sample/analysis, poor automatic boiler SADC, burner tilting poor O2 control.

- **Incomplete combustion**

  Poor milling i.e. coarse grinding, poor air/fuel distribution to burners, low combustion air temperature,low primary air temperature, primary air velocity being very high/very low, lack of adequate fuel/air mixing.

- **Radiation and convection heat loss**

  Casing radiation, sensible heat in refuse, bottom water seal operation, not largely controllable but better maintenance of casing insulation can minimize the loss.

4.4 ECONOMISER

Economiser is a type of heat exchanger in which hot flue gasses gives heat to the water air which is feed to the boiler to complete the process of boiling of water. So, if water at normal temperature enters the boiler drum more coal will be required to raise the temperature of the boiling water, so we use hot water thus less coal is required to heat the furnace. This process is call regenerative and reheating.

As we all know economiser is very important part of the boiler. Thus, more the heat transfer more will be the efficiency of the economiser. So, we must make fins because the rate of heat transfer increase as we put fins in the pipes of economiser. Fins are there on the air side not on water side because heat transfer coefficient of air is very less than heat transfer coefficient of water. Thus, to increase overall heat transfer me make fins at air side.

But in case of economiser of coal fired thermal power plant there is no need to make fins at the flue gas side because the temperature of the flue gas is very high, so heat transfer can easily be done, and second reason is because the flue gas is having carbon particles which will stuck in between the fins and the flue gas flow will be stopped because of chocking.

- **Pressure drop –**

  The pressure of water decreases at the outlet of the economiser thus this is not desirable because boiler is at higher level than economiser. Thus, more powerful Boiler Feed Pump should be used**.**

- **Performance**

  As economiser is a type of Heat exchanger thus its performance can be increased by just using more heat transferring material of tubes so that more and more heat of flue gasses can be transferred to feed water.

4.5 AIR PREHEATER

Air pre-heater is a type of heat exchanger in which hot flue gasses gives heat to the cold air which comes in the furnace to complete the process of combustion of coal. So, if air at normal temperature enters the furnace more coal will be required to raise the temperature of the furnace, so we use hot air which raises the temperature of the furnace automatically thus less coal is required to heat the furnace.

As we all know the APH is very important part of boiler system. The efficiency of this APH effects the performance of the boiler at very extent.

We checked the leakage in APH we must check the efficiency of the gas.

The air leakage is the amount of air passing through the air side to the gas side. As is due to wear and tear there is leakage in air from air side to gas side thus as the wear and tear increase the leakage increases. As the leakage of the air from air side to gas side increases the power requirements of draft fan increases thus more power is required and more use of electricity is required.

- **Air Infiltration**

  As air entering the APH is having some dust particles rather air is coming from filter but then also there are some dust particles thus will consume some heat of furnace.

- **Performance**

  As air preheater is a type of Heat exchanger thus its performance can be increased by just using more heat transferring material of tubes so that more and more heat of flue gasses can be transferred to air which is feed to furnace.

CHAPTER 5

ENERGY AUDIT

5.1 COAL HANDLING PLANT

1) Cost estimation of losses due to air

To avoid air loss, we should cover the conveyer belt and don't let air to blow over it.

Maximum capacity of coal can be in inlet = 1400 ton/hour

Actual feed to bunker = 900 ton/hour

500 ton/h coal is lost due to air losses

Present cost of 1 ton of coal = Rs 3210

Cost of 500 ton of coal = 3210 x 500

= 1605000 /-

2) Cost estimation of losses due to transportation of coal

The clamps to hold the wagon should be of different material so that reduction in size of clamps can be done and same strength can be obtained and as size is less thus less coal will be stuck at that part according to this loss in coal will be less.

Tippler losses = 10 Kg loss in clamps = 10 x 3.21

= 32.1 /-

In form of dust = 5 Kg = 5x 3.21

= 16.05 /-

Theft loss in wagon = Amount of coal feed in wagon = 100 ton

Amount of coal lest at last when it reaches the power plant = 70 ton

30 ton of coal is theft which cost = 30 x 3210

= 96300 /-

3) Cost estimation of losses due to non-opening of gates in track hoppers system

The pneumatic valves to open the gates of the wagon to let coal to fall in the hopper in track hopper system should be perfect so that the wagons can be cleared in less time to avoid demerge cost given to Indian Railway by plant.

Where the gate of wagon is not opened due to dust of coal complete wagon goes back to loss of coal in cost = 100 x 3210

= 321000 /-

4) **Cost estimation of losses due to idling time of the motor**

Motor at no load condition = 1 Kw

Motor at full load condition = 15 Kw

Thus, if no coal is being fetched then also 1 Kw power is being consumed by motor.

Motor consumes 1 unit of electricity in 1 hour

As if idling time is 1 hour daily then 1 unit of electricity is wasted daily

Per year 365 units is wasted

Which will cost = 365 x 8

= 2920 /-

5) **Cost estimation of losses due to opaque walls and excessive use of electricity** In CHP they are having closed rooms with less no. of windows and having concrete sealing at their top which are opaque. Thus, they can also use maxim no. of windows and can also give green sheet which is translucent in nature thus some amount of light can entre and reduces in electricity consumption. 11. Power factor of maximum motors in CHP was 0.6 to .07 thus can be improved up to 0.9 as BFP is working at .09 PF. In CHP where the officers sit there is very less number of windows and there are maximum opaque walls

1 tube light consumes 60/- in one month

30 tube lights are there in office = 30 x 60

= 1800/-

5.2 BOILER SYSTEM

1) **Cost of energy wastage by second law analysis of Boiler**

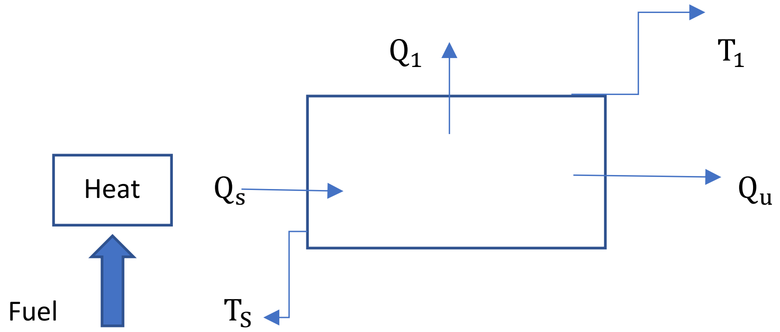


Figure 5.1 Energy distribution

Q_s = Rate of heat transfer receiving

T_s = Source temperature

Q_u = Delivery temperature

T_u = Delivery temperature

Q_1 = Rate of heat transfer to surroundings

T_1 = Temperature across the surface

Cost = CF X [1- $\frac{T_0}{T_1}$] Q_1

[1- $\frac{T_0}{T_1}$] Q_1 = Rate of energy destruction

CF = Cost decided by NTPC of 1 unit of electricity

Cost = 0.40 X 280526.95

= 112210.78 /-

2) **Cost of energy wastage by second law analysis of Economiser**

Cost = CF X [1- $\frac{T_0}{T_1}$] Q_1

[1- $\frac{T_0}{T_1}$] Q_1 = Rate of energy destruction

CF = Cost decided by NTPC of 1 unit of electricity

Cost = 0.40 X 6247.67

= 2499.068 /-

3) **Cost of energy wastage by second law analysis of APH**

Cost = CF X [1- $\frac{T_0}{T_1}$] Q_1

[1- $\frac{T_0}{T_1}$] Q_1 = Rate of energy destruction

CF = Cost decided by NTPC of 1 unit of electricity

Cost = 0.40 X 2680 =1072 /-

4) Loss in CV from marshal yard to pulveriser

The CV of the coal from marshal yard to pulveriser is reduced by 200CV it can be avoided by keeping coal in less moist area.

Marshal Yard CV of coal= 3760 CV

Pulverised coal CV = 3560 CV

Heat input is constant Qi = M X CV

M1 X CV1 = M2 X CV2

M1 X 3760 = 75.59 X 3560

$M1 = \frac{75.59 \text{ X } 3560}{3760}$

= 71.56 Kg / sec

Loss = 4.02 Kg/ sec

= 347.328 Ton / day

Cost of loss of coal = 3260 X 347.328

= Rs 115898

5) Blow down

1% of blow down implies 0.17% heat added in the boiler. So, blow down should be adhered to the chemist requirement**.**

Q = M X CV

= 75.59 X 3560

$= 269100.4 \text{ X } \frac{0.17}{100}$

Loss of Q due to 1% of blow down implies 0.17 % of heat loss = 457.4

New Q after loss = 269557.8

269557.8 = M X 3560

M = 75.71

More M required = 0.128 Kg/ sec

$\text{M per day} = \frac{0.128 \text{ X } 24 \text{ X } 60 \text{ X } 60}{1000}$

= 11.059920Ton / day

Cost of Q due to 1% of blow down implies 0.17% of heat loss = 11.0599 X 3260

= Rs 36052.992 /-

6) **Soot blowing losses**

Superheated steam with high enthalpy is used for soot blowing.

1% of steam required, contains 0.62% heat content. To make up the loss another 0.25% heat has to be added to feed water resulting in total heat loss of 0.87%.

Q = M X CV

= 75.59 X 3560

= 269100.4 X $\frac{0.87}{100}$

Loss of Q due to 1% of blow down implies 0.17 % of heat loss = 2341.173

New Q after loss = 266759.22

266759.22= M X 3560

M = 74.80 Kg/sec

More M required = 0.79 Kg/ sec

M per day = $\frac{0.79X\ 24\ X\ 60\ X\ 60}{1000}$

= 68.256Ton / day

Cost of Q due to 1% of steam required, contains 0.62% heat content. To make up the loss another 0.25% heat has to be added to feed water resulting in total heat loss of 0.87%.

= 3260 X 68.256

= 222514.56 / -

7) **Use of economiser in place of air pre-heater**

Q of air pre-heater = **25830 kW**

Q of economiser = 4857 kW

Rate of heat transfer of air preheater is very much high than Economiser. Thus, to make an economiser of same rate of heat transfer we need to make **3100 tubes** instead of **544 tubes.** Thus, cost of making economiser will be **6 times** the construction of an economiser thus we do not use economiser in place of APH. This calculation is done in **MATLAB** and program is in Appendix 2. We use air pre-heater instead of this large economiser because it will occupy very large space and cost of construction is very high, but it is one-time investment. The motor responsible for rotation of air preheater is of 11 kW, 415 V, 3 phase which moves at 1460 rpm but the cost of maintenance and working of this motor is very much less as compared to construct an economiser of such a big size,

CHAPTER 6

CONCLUSION & FUTURE SCOPE

From the investigation of this thesis, it is observed that the overall plant performance changes with the small variation in the output loads. From the calculation it can be easily concluded that the overall efficiency of the plant decreases with the decrease in the requirement of output load. Output Load of the thermal power plant depends on the demand of electricity. As the demand of electricity decreases, the output load of the thermal power plant decreases, and the overall efficiency of the plant is also lower, because electricity cannot be stored so the plant is running on partial load. Now if the thermal power plant run at Full Output Load the overall efficiency of the plant is much higher.

Rate of heat transfer of air preheater is very much high than Economiser. Thus, to make an economiser of same rate of heat transfer we need to make **3100 tubes** instead of **544 tubes.** Thus, cost of making economiser will be **6 times** the construction of an economiser thus we do not use economiser in place of APH. We use air pre-heater instead of this large economiser because it will occupy very large space and cost of construction is very high, but it is one-time investment. The motor responsible for rotation of air preheater is of 11 kW, 415 V, 3 phase which moves at 1460 rpm but the cost of maintenance and working of this motor is very much less as compared to construct an economiser of such a big size.

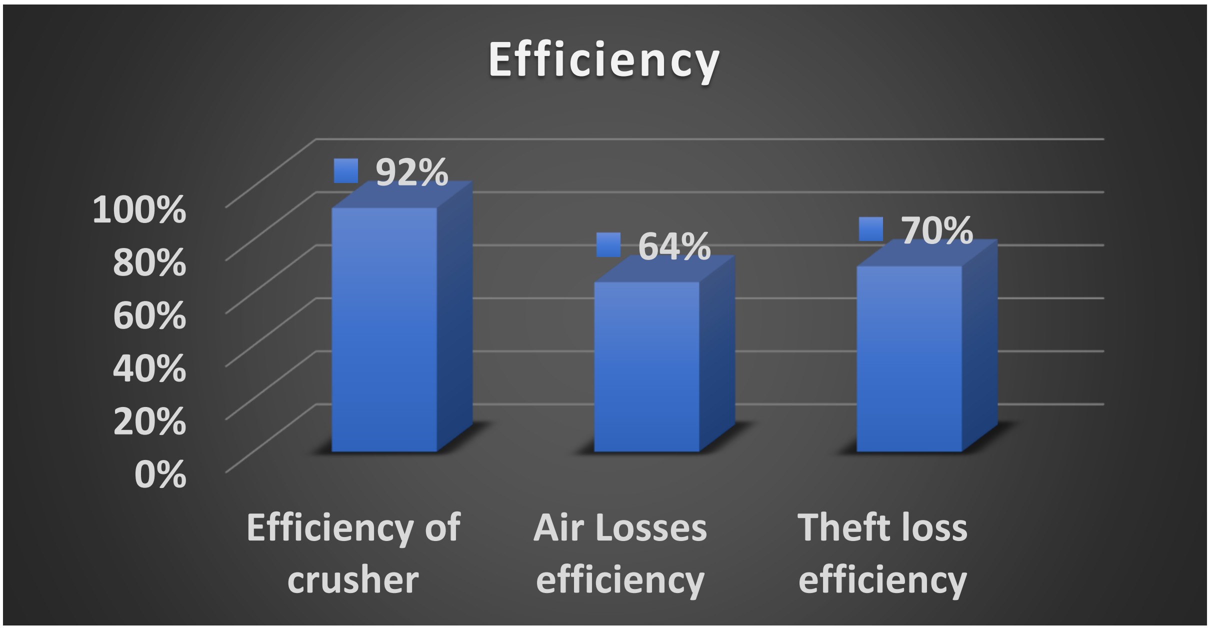


Figure 6.1 Coal handling plant results

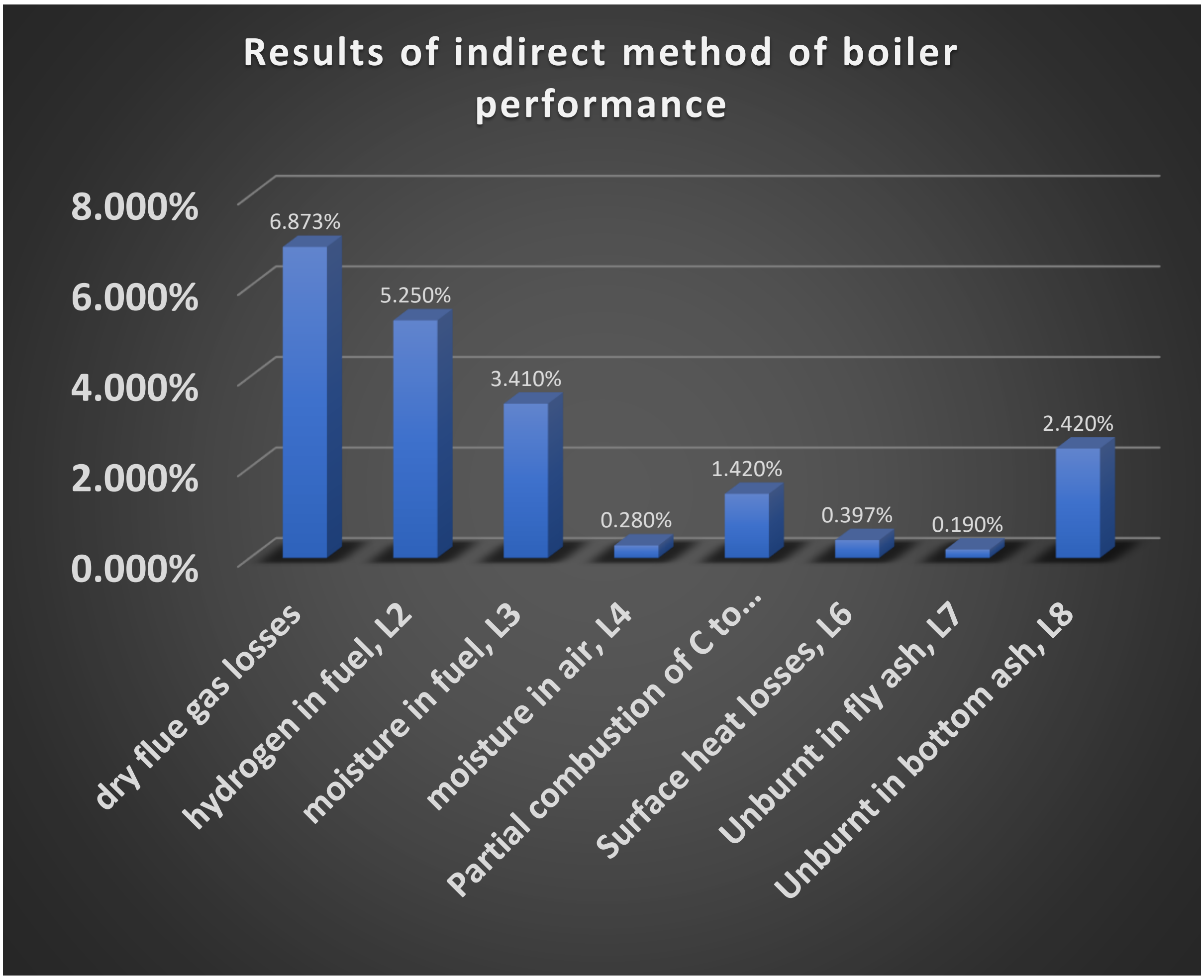


Figure 6.2 Boiler indirect results

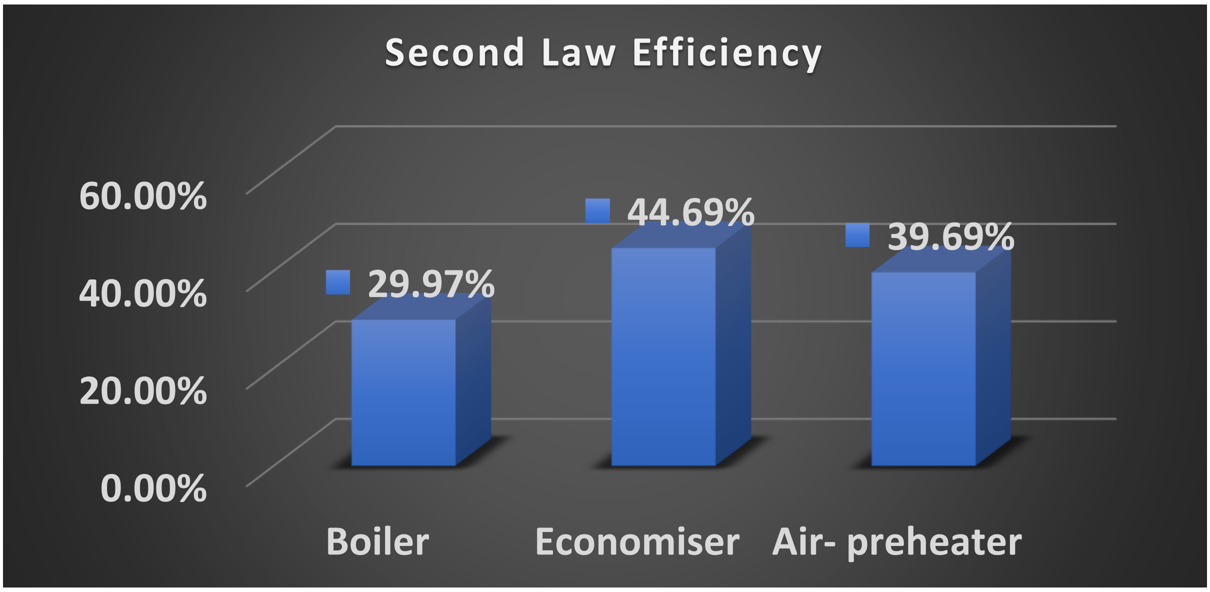


Figure 6.3 2nd law analysis results

6.1 CONCLUSION FOR IMPROVEMENT OF EFFICIENCY

1) The clamps to hold the wagon should be of different material.
2) To avoid air loss, we should cover the conveyer belt.
3) Keep coal in less moist area.
4) To avoid losses in MOTORS all motors should be always in full load condition so that the losses which are in no load condition can be compensated. We should also reduce idling time so that no-load condition can be avoided.
5) The circuit the use is very bulky and large because the stakes are at a distance from the furnace.
6) Maximum motors in CHP were having power factor between 0.6 to 0.07 thus can be improved up to 0.9 as BFP is working at 0.09 PF.
7) The possibility of using chemicals for reducing water spray should be there.
8) Principle of 'FIRST IN FIRST OUT' in case of coal transportation SILO to HOPPER is used here which is very much efficient.
9) 1 % of blow down implies 0.17% heat added in the boiler. So, blow down should be adhered to the chemist requirement.
10) Superheated steam with high enthalpy is used for soot blowing. 1% of steam required, contains 0.62% heat content. To make up the loss another 0.25% heat has to be added to feed water resulting in total heat loss of 0.87%. Frequency of soot blowing must be carefully planned.
11) Air leakage through man holes, peep holes, bottom seals, air heater seal leakage, uneven distribution of secondary air, inaccurate sample/analysis, poor automatic boiler SADC, burner tilting poor O2 control.
12) Poor milling i.e. coarse grinding, poor air/fuel distribution to burners, low combustion air temperature, low primary air temperature, primary air velocity being very high/very low, lack of adequate fuel/air mixing.
13) Casing radiation, sensible heat in refuse, bottom water seal operation, not largely controllable but better maintenance of casing insulation can minimize the loss.

6.2 FUTURE SCOPE

- CFD analysis of economiser can be done and rate of heat transfer of economiser can be validated by this method.
- Energy audit of all thermal insulations can be done.
- Losses in motors can be calculated.
- Energy audit of cooling tower can be done because was is wasted there which is very important.
- CFD analysis of APH can be done and rate of heat transfer can be calculated.

LIST OF PUBLICATIONS

1. A. Kumar, S. Sharma and D. Gangacharyulu "Energy Audit of Coal Fired Thermal Power Plant". Manuscript accepted & under process for publication in *International Journal of Engineering Research & Technology (IJERT).*
2. A. Kumar, S. Sharma and D. Gangacharyulu "Energy Audit of Coal Handling Plant". Manuscript accepted & under process for publication in *International Journal of Engineering Research & Technology (IJERT).*

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17. **ASME PTC4** 2008 Fired Steam Generators
18. Energy Performance Assements of boilers (**Bureau of Energy Efficiency**).
19. Fundamentals of Engineering Thermodynamics, **Michael J. Moran, Howard**

APPENDIX

Appendix 1

Matlab program for heat exchanger design

```
%%**********************************************%%
%% HEAT EXCHANGER DESIGN *********
%Input file variables.m
% created by : Abhishek Kumar
% Date : 21st Dec, 2017
%%setting
clc;
clear all;
%% Variable Declaration

syms Thi Tho Tci Tco Tcot hi l ho mh mc cph cpc vi vo nop vm L B LMTD Qh Qc Ki Ko Ui
Uo Sl St Sd D di cai TAi deltaPi deltaPo deltaTh deltaTc t not tha tca tcm rhod mud rhoD
muD Prd f Red Nud PrD ReD NuD Prs deltaPi deltaPo Gi C ;
fid = fopen('variables.m','r');
if(fid==-1) display('File Not proper'); return; end
format long
Thi= fscanf(fid, '%d',1); % Hot Fluid Inlet temperature (degree Celcius)
Tho = fscanf(fid, '%d',1); % Hot fluid Outlet Temperature (degree Celcius)
Tci = fscanf(fid, '%d',1); % Cold Fluid Inlet Temperature (degree Celcius)
Tco = fscanf(fid, '%d',1); % Cold Fluid Outlet Temperature (degree Celcius)
mh = fscanf(fid, '%f',1); % mass flow rate of hot fluid (kg/s)
mc = fscanf(fid, '%f',1); % mass flow rate of cold fluid (kg/s)
cph = fscanf(fid, '%f',1); % Specific heat of Hot fluid (J/kg)
cpc = fscanf(fid, '%f',1); % Specific heat of Cold fluid (J/kg)
Sl = fscanf(fid, '%f',1); % Longitude pitch (m)
St = fscanf(fid, '%f',1); % Transverse pitch (m)
D = fscanf(fid, '%f',1); % Outer Dia (m)
di = fscanf(fid, '%f',1); % Inner Dia (m)
t = fscanf(fid, '%f',1); % thickness of tube (m)
```

```
not = fscanf(fid, '%d',1); % Number of Tubes
rhod = fscanf(fid, '%f',1); % Density of cold fluid (kg/m3)
mud = fscanf(fid, '%f',1); % Viscosity of cold fluid (Pa.s)
rhoD = fscanf(fid, '%f',1); % Density of hot fluid (kg/m3)
muD = fscanf(fid, '%f',1); % Viscosity of hot fluid (Pa.s)
Prd = fscanf(fid, '%f',1); % Prandtl number of Cold fluid @ 301 C
PrD = fscanf(fid, '%f',1); % Prandtl number of Hot fluid @ 370 C
Prs = fscanf(fid, '%f',1); % Prandtl number of Cold fluid @ 266 C
Ki = fscanf(fid, '%f',1); % Thermal Conductivity of cold fluid (W/m.K)
Ko = fscanf(fid, '%f',1); % Thermal Conductivity of flue gas (W/m.K)
l = fscanf(fid, '%f',1); % Length of Tubes (m)
B = fscanf(fid, '%f',1); % Breadth of Exchanger (m)
nop = fscanf(fid, '%f',1); % number of passes
Nl = fscanf(fid, '%f',1); % number of rows of tubes
F = fscanf(fid, '%f',1); % Correction factor for cross flow
ff = fscanf(fid, '%f',1); % friction factor for pressur drop of hot fluid
X = fscanf(fid, '%f',1); % Correction factor for pressur drop of hot fluid
Kt = fscanf(fid, '%f',1); % Thermal COnductivity of Carbon Steel

L=l*nop;  % Total length of tube (m)

tha = (Thi+Tho)/2; % Average Temperature of hot fluid (degree Celcius)
deltaTh = Thi-Tho; % Hot fluid Temperature difference (degree Celcius)
Qh = mh*cph*deltaTh; % Heat load on hot fluid (W)

tca = (Tci+Tco)/2; % Average Temperature of cold fluid (degree Celcius)
deltaTc = Tco-Tci; % Cold fluid Temperature difference (degree Celcius)
Qc = mc*cpc*deltaTc; % Heat load on Cold fluid (W)

Tcot = Tci+(Qh/(mc*cpc)); % Theoretical temperature of Cold fluid outlet (degree Celcius)
tcm = (Tcot+Tci)/2; % Cold fluid mean Temperature (degree Celcius)
cai = (pi/4)*di*di; % Cross sectional area of tube (m2)
TAi = cai*not; % Total cross sectional area (m2)
```

```
Gi = mc/TAi; % Mass flow rate per cross sectional area (kg/m2.s)

Red = (Gi*di)/mud; % Reynolds number of cold fluid
f=(1.82*log(Red) - 1.64)^-2;  % Friction factor of cold fluid
Nud = ((f/8)*(Red)*Prd)/(1.07+(12.7*((f/8)^0.5)*((Prd^(2/9))-1))); % Nusselt Number of Cold Fluid

hi = (Nud*Ki)/di; % Heat transfer coeff. inside tube (W/m2.K)
vi = Gi/rhod; % velocity of cold fluid (m/s)

deltaPi = (f*rhod*vi*vi*L)/(2*di); % Pressure difference in cold fluid inlet and outlet (Pa)


%Outer Calculation

TAo = L*B*0.5; % Frontal area of exchanger (m2)
vo = (mh)/(TAo*rhoD); % Velocity of hot fluid (m/s)
Sd=((Sl*Sl)+(St*St))^0.5; % Staggered tube bank pitch (m)

if Sd>((St+D)/2)
   vm = (St/(St-D))*vo; % Max. velocity of hot fluid (m/s)

else
   vm=St*vo/(2*(St-D));

end

ReD = rhoD*vm*D/muD; % Reynolds number of hot fluid
Z=St/Sl; % Ratio of Pitches
 if Z<2
    C=0.35*(Z)^0.2;
 end
m=0.6;
```

```
NuD=1.04*(ReD^0.4)*((PrD^0.4))*((PrD/Prs)^0.25);  % Nusselt number of hot fluid

ho=NuD*Ko/D; % % Heat transfer coeff. outside tube (W/m2.K)

deltaPo = Nl*ff*X*rhoD*vm*vm/2; % Pressure difference in hot fluid inlet and outlet (Pa)

Uo=((di*hi*ho*Kt)/((D*ho*Kt)+(di*hi*Kt)+(t*D*hi*ho))); % Overall thermal coefficient of
heat transfer (W/m2.K)
Ui = (D*hi*ho)/((D*ho)+(di*hi)); % Overall thermal coefficient of heat transfer (W/m2.K)
LMTD=((Tho-Tci)-(Thi-Tco))/log((Tho-Tci)/(Thi-Tco)); % Log Mean Temperature
Difference (degree C)

Ao=pi*D*L*not; % Outside area of tube (m2)
Ai=pi*di*L*not; % Inner area of tube (m2)
Qo=Uo*Ao*F*LMTD; % Rate of heat tranfer (W)
```

Variable_eq.m file

```
400
340
252
350
206.6
158.75
1064
5750
0.0762
0.103
0.0381
0.0345
```

0.0053

544

803

0.0001045

0.4856

0.00002932

0.902

0.7533

0.852

0.6240

0.0213

12.143

15

22

66

0.97638

0.5

1

53.61

Appendix 2

```
%%*********************************************%%
%% HEAT EXCHANGER DESIGN *********
%Input file variables.m
% created by : Abhishek Kumar
% Date : 21st Dec, 2017
%%setting
clc;
clear all;
%% Variable Declaration

syms Thi Tho Tci Tco Tcot hi l ho mh mc cph cpc vi vo nop vm L B LMTD Qh Qc
Ki Ko Ui Uo Sl St Sd D di cai TAi deltaPi deltaPo deltaTh deltaTc t not tha
tca tcm rhod mud rhoD muD Prd f Red Nud PrD ReD NuD Prs deltaPi deltaPo Gi
C ;
fid = fopen('variables.m','r');
if(fid==-1) display('File Not proper'); return; end
format long
Thi= fscanf(fid, '%d',1); % Hot Fluid Inlet temperature (degree Celcius)
Tho = fscanf(fid, '%d',1); % Hot fluid Outlet Temperature (degree Celcius)
Tci = fscanf(fid, '%d',1); % Cold Fluid Inlet Temperature (degree Celcius)
Tco = fscanf(fid, '%d',1); % Cold Fluid Outlet Temperature (degree Celcius)
mh = fscanf(fid, '%f',1); % mass flow rate of hot fluid (kg/s)
mc = fscanf(fid, '%f',1); % mass flow rate of cold fluid (kg/s)
cph = fscanf(fid, '%f',1); % Specific heat of Hot fluid (J/kg)
cpc = fscanf(fid, '%f',1); % Specific heat of Cold fluid (J/kg)
Sl = fscanf(fid, '%f',1); % Longitude pitch (m)
St = fscanf(fid, '%f',1); % Transverse pitch (m)
D = fscanf(fid, '%f',1); % Outer Dia (m)
di = fscanf(fid, '%f',1); % Inner Dia (m)
t = fscanf(fid, '%f',1); % thickness of tube (m)
not = fscanf(fid, '%d',1); % Number of Tubes
rhod = fscanf(fid, '%f',1); % Density of cold fluid (kg/m3)
mud = fscanf(fid, '%f',1); % Viscosity of cold fluid (Pa.s)
rhoD = fscanf(fid, '%f',1); % Density of hot fluid (kg/m3)
muD = fscanf(fid, '%f',1); % Viscosity of hot fluid (Pa.s)
Prd = fscanf(fid, '%f',1); % Prandtl number of Cold fluid @ 301 C
PrD = fscanf(fid, '%f',1); % Prandtl number of Hot fluid @ 370 C
Prs = fscanf(fid, '%f',1); % Prandtl number of Cold fluid @ 266 C
Ki = fscanf(fid, '%f',1); % Thermal Conductivity of cold fluid (W/m.K)
Ko = fscanf(fid, '%f',1); % Thermal Conductivity of flue gas (W/m.K)
l = fscanf(fid, '%f',1); % Length of Tubes (m)
B = fscanf(fid, '%f',1); % Breadth of Exchanger (m)
nop = fscanf(fid, '%f',1); % number of passes
Nl = fscanf(fid, '%f',1); % number of rows of tubes
F = fscanf(fid, '%f',1); % Correction factor for cross flow
ff = fscanf(fid, '%f',1); % friction factor for pressur drop of hot fluid
X = fscanf(fid, '%f',1); % Correction factor for pressur drop of hot fluid
Kt = fscanf(fid, '%f',1); % Thermal COnductivity of Carbon Steel

L=l*nop;  % Total length of tube (m)

tha = (Thi+Tho)/2; % Average Temperature of hot fluid (degree Celcius)
deltaTh = Thi-Tho; % Hot fluid Temperature difference (degree Celcius)
Qh = mh*cph*deltaTh; % Heat load on hot fluid (W)
```

```
tca = (Tci+Tco)/2; % Average Temperature of cold fluid (degree Celcius)
deltaTc = Tco-Tci; % Cold fluid Temperature difference (degree Celcius)
Qc = mc*cpc*deltaTc; % Heat load on Cold fluid (W)

Tcot = Tci+(Qh/(mc*cpc)); % Theoretical temperature of Cold fluid outlet
(degree Celcius)
tcm = (Tcot+Tci)/2; % Cold fluid mean Temperature (degree Celcius)
cai = (pi/4)*di*di; % Cross sectional area of tube (m2)
TAi = cai*not; % Total cross sectional area (m2)
Gi = mc/TAi; % Mass flow rate per cross sectional area (kg/m2.s)

Red = (Gi*di)/mud; % Reynolds number of cold fluid
f=(1.82*log(Red) - 1.64)^-2;  % Friction factor of cold fluid
Nud = ((f/8)*(Red)*Prd)/(1.07+(12.7*((f/8)^0.5)*((Prd^(2/9))-1))); %
Nusselt Number of Cold Fluid

hi = (Nud*Ki)/di; % Heat transfer coeff. inside tube (W/m2.K)
vi = Gi/rhod; % velocity of cold fluid (m/s)

deltaPi = (f*rhod*vi*vi*L)/(2*di); % Pressure difference in cold fluid
inlet and outlet (Pa)


%Outer Calculation

TAo = L*B*0.5; % Frontal area of exchanger (m2)
vo = (mh)/(TAo*rhoD); % Velocity of hot fluid (m/s)
Sd=((Sl*Sl)+(St*St))^0.5; % Staggered tube bank pitch (m)

if Sd>((St+D)/2)
    vm = (St/(St-D))*vo; % Max. velocity of hot fluid (m/s)

else
    vm=St*vo/(2*(St-D));

end

ReD = rhoD*vm*D/muD; % Reynolds number of hot fluid
Z=St/Sl; % Ratio of Pitches
 if Z<2
     C=0.35*(Z)^0.2;
 end

m=0.6;

NuD=1.04*(ReD^0.4)*((PrD^0.4))*((PrD/Prs)^0.25);  % Nusselt number of hot
fluid

ho=NuD*Ko/D; % % Heat transfer coeff. outside tube (W/m2.K)

deltaPo = Nl*ff*X*rhoD*vm*vm/2; % Pressure difference in hot fluid inlet
and outlet (Pa)

Uo=((di*hi*ho*Kt)/((D*ho*Kt)+(di*hi*Kt)+(t*D*hi*ho))); % Overall thermal
coefficient of heat transfer (W/m2.K)
Ui = (D*hi*ho)/((D*ho)+(di*hi)); % Overall thermal coefficient of heat
transfer (W/m2.K)
```

```
LMTD=((Tho-Tci)-(Thi-Tco))/log((Tho-Tci)/(Thi-Tco)); % Log Mean Temperature
Difference (degree C)

Ao=pi*D*L*not; % Outside area of tube (m2)
Ai=pi*di*L*not; % Inner area of tube (m2)
Qo=Uo*Ao*F*LMTD; % Rate of heat tranfer (W)
display(Qo)
```

Variable_eq.m file

```
400
340
252
350
206.600
158.750
1.064
5750
0.0762
0.103
0.0381
0.0345
0.0053
3100
803
0.0001045
0.4856
0.00002932
0.902
0.7533
0.852
0.6240
0.0203
12.143
15
22
66
0.97638
0.5
1
53.61
```

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