Performance Analysis For Heat Recovery Components In Coal Or Biomass Fired Boilers

#1Mr.Amol Ghorpade, #2Vivekananda Navadagi, #3C Shriram Shastri

[1]Student M.E.(Heat Power)Savitribai Phule ,Pune university,DPCOE,Wagholi,pune
[2]Asst Prof . Savitribai Phule Pune University,DPCOE,Pune
[3]P.G. Coordinator Savitribai Phule Pune University,DPCOE,Pune.

Abstract:- Energy has become most basic need of today's fast moving world and it is used in almost all fields. Boiler plays important role in energy generation by producing steam, it was in 17th century when boiler revolution started and made its presence felt to everyone. Performance as boiler efficiency and evaporation ratio decreases with time due to poor operation, poor combustion, heat transfer fouling and maintenance. A deteriorating fuel quality and water quality also leads to poor performance of the boiler. Efficiency tests help us to know what the efficiency of the boiler is far from the best efficiency. Evaluation of the efficiency of boiler is a vital concept in any thermal power plant. Boiler is the heart of the power plant and for benefit of the plant there is a need to increase the efficiency of the boiler. The evaluation of boiler performance involves many complex factors, only a few of these factors are subject to precise analysis and many others are the result of data taken from operating units. The final selection of these surface arrangements represents a compromise on the designer's part in meeting performance requirements while controlling ash deposition, corrosion, and erosion.Current research deals with the Efficiency Assessment of Boiler.

Keywords: **Performance Analysis, Air Pre-heater, In-mold, Boiler efficiency**.

I. INTRODUCTION

Boiler is a most useful device for any developing industries to process & production. It is necessary to optimise for good boiler efficiency. The evaluation of boiler performance involves many complex factors, only a few of these factors are subject to precise analysis and many others are the result of data taken from operating units. Performance of the boiler like efficiency, evaporation ratio and different components reduces with time, due to poor combustion, heat transfer fouling and poor operation and maintenance. Deterioration of fuel quality and water quality also leads to poor performance of boiler heat recovery components. Efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency. Any observed abnormal deviations could therefore beinvestigated to pinpoint the problem area for necessary corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a pre requisite for energy conservation action in industry. Boiler are described depending upon their bed type and fuel used such asBed type: - Travelling grate boilers, Pusher grate boilers, FBC (AFBC & CFBC) etcFuel type: -Coal fired, Biomass fired, Spent wash fired etc. The purpose of the performance test is to determine actual performance and efficiency of the boiler and compare it with design values or norms. It is an indicator for tracking day today and season to season variations in boiler efficiency and energy efficiency improvements, so company felt need for performance measurement and optimization of boilers components such as furnace, economiser, air preheater etc. Demand for Spent wash fried boiler is increasing continuously as spent wash disposal is big problem for distiller business and it has lot many environment norms. So company is focusing on performance analysis and design validation of heat recovery components in boilers, for this actual site data collection is must

In collection of data first It is necessary to studythe General Arrangement Diagram (GA) &Piping and Information Diagram (P&ID) for each site, main purpose is to crosscheck the availability of readings/parameters which are required for performance analysis. Then prepare the data sheet for required parameter, also then arrange the instruments like Pressure gauge, temperature gauge, fittings, gas analyzer, dust load measurement instrument etc if required, to collect data which are not available at Digital control system (DCS) on site. Also it is necessary to collect fuel & ash samples to analysis there composition and properties.

II. LITERATURE REVIEW

Sachin M.Raut, Sanjay B. Kumbhare [1]

Present Research paper deals with Energy Performance Assessment of co-operative sugar mill's Existing boiler, with maximum continuous rating (MCR)-100 TPH and outlet steam parameter -110kg/cm2 and540°c and Bagasse used as a fuel.

Acharya Chirag, Prof. Nirvesh Mehta[2] This paper is concerned with calculating boiler efficiency as one of the most important types of performance measurement in any steam power plant. Thermal power plant converts the chemical energy of the coal into electricity.

Vikram Singh Meena1, Dr. M.P Singh [3]] This paper is concerned with Performance as boiler efficiency and evaporation ratio decreases with time due to poor operation poor combustion, heat transfer fouling and poor combustion and maintenance.

M.Nageswara rao[4] This project mainly deals with design, modeling and fabrication and cfd analysis of a shell and tube air preheater. Over all heat transfer coefficient of the shell and tube heat exchanger is based on the results of effectiveness-ntu approach and lmtd approach.

Nabil M. Muhaisen, Rajab Abdullah Hokoma[5] This paper is concerned with calculating boiler efficiency as one of the most important types of performance measurements in any steam power plant. That has a key role in determining the overall effectiveness of the whole system within the power station.

Prashant Kumkale, Dr.C.R.Sonawane [6]In this paper internal flow analysis of a super heater is done to study heat transfer characteristics of super heater of a boiler using a CFD (ANSYS-FLUENT) package. The CFD analysis provided fluid velocity, pressure, temperature, wall fluxes and especially we have concentrate on pressure drop from inlet to outlet of the super heater of a boiler.

STUDY OF AFBC AND CFBC BOILERS

In this chapter mainly AFBC and CFBC boiler information is provided with different fuel fired in it. Spent wash (distillery waste) is brown liquid waste water used as fuel in AFBC boiler. Due to strict environmental norms spent wash disposal has posed to be a major concern for the distilleries. Also the major portion of the coal available in India is of low quality, high ash content and low calorific value. The traditional grate fuel firing systems have got limitations and are techno-economically unviable to meet the challenges of future. Fluidised bed combustion has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits like compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SOx and NOx. The fuels burnt in these boilers include coal, washery rejects, rice husk, spent wash and other agricultural wastes. The fluidized bed boilers have a wide capacity range-1TPH to over 500TPH.Comparision of AFBC and CFBC is done separately.

Mechanism of Fluidised Bed Combustion:-

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream i.e. the bed is called “fluidised”. With further increase in air velocity, there ibubble formation, vigorous turbulence, rapid mixing and formation of dense defined as bed surface.

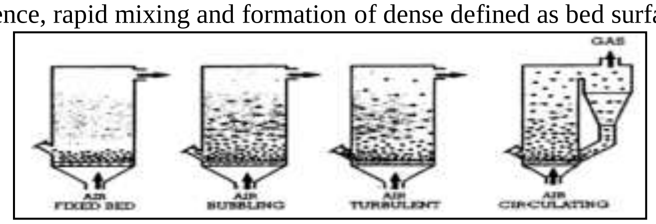


Fig 1 Mechanism of Fluidised Bed Combustion

The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid that is bubbling fluidized bed. At higher velocities, bubbles disappear, and particles are blown out of the bed. Therefore, some amounts of particles have to be recirculated to maintain a stable system such as circulating fluidised bed. This principle of fluidisation is illustrated in Fig . Fluidization depends largely on the particle size and the air velocity. The mean solids velocity increases at a slower rate than does the gas velocity. If sand particles in a fluidized state is heated to the ignition temperatures of coal and coal is injected continuously into the bed, the coal will burn rapidly and bed attains a uniform temperature. The fluidized bed combustion (FBC) takes place at about 840°C to 950°C. Since this temperature is much below the ash fusion temperature, melting of ash and associated problems are avoided.

Types of Fluidized Bed Combustion Boilers:-

1. Atmospheric Fluidized Bed Combustion System (AFBC)
2. Circulating (fast) Fluidised Bed Combustion system (CFBC)
3. PressurisedFluidised Bed Combustion System (PFBC)

III. DATA COLLECTION

Introduction:

Data collection is major part of my project work, it is basic requirement for checking performance of boiler and its components. First thing in data collection is to study the boiler general arrangement (GA) and process and information diagram (P&ID) for understanding actual locations of different components on site. Then made list of parameters that has to be collected from site, also studied the instruments needed for data collection. Then visited differentsites with commissioning engineer and collected required data. The data collected by me was very useful in company's perspective for different calculation and process.

Study of GA and P&ID

First step for data collection is to study the general arrangement (GA) and process & information diagram (P&ID) for boiler sites that has to be visited, from this we get clear idea of boiler components arrangement and their position on plant with proper elevations , so I was provided with latest revision of that boiler GA and P&ID. By studying GA I came to know all components and their position at actual site, and from P&ID it was clear about instruments placed at site for data collection with their position at different locations.

General arrangement (GA):-

In GA diagram we get clear idea of boiler and its parts. GA also tells us about locations and arrangement of all boiler parts such as Forced draft fan (FA), Secondary air fan (SA), Air Preheater (APH), Economiser (ECO) etc. In GA sheet we can get different views of boilers such as from boiler front, from boiler top and from elevation, these views shows exact parts of boiler and there arrangement. shows different arrangement of boiler with different
part and there proper locations.

Study of GA makes our work easy when we visit actual site locations and we directly know which part is at what location and whether that part is accessible or not. I studied GA for bagasse and spent wash fired boilers with different capacities, different steam temperature and pressure such as

Bagasse fired with Capacity= 1x80 TPH, steam pressure= 87 kg/cm^2, steam temperature= 515± 5 ˚C
b) Bagasse fired with Capacity =1x 135 TPH, steam pressure=110 kg/cm^2, steam temperature=540± 5˚C.
c) Spent wash fired AFBC boiler with 1x22.2 TPH capacity, steam pressure=44kg/cm^{2,} steam temperature 380˚C.
d) Coal fired CFBC boiler with capacity= 2x 330 TPH, steam pressure= 97 kg/cm2, steam temperature= 540˚C.

Process and Information Diagram (P&ID)

For P&ID it can be also called piping and information diagram. This diagram shows us how different part of boiler are connected with control looping system and further to DCS i.e. digital control system for continues monitoring at DCS section at site. By studying this diagram we get clear idea about what reading we get on DCS and what reading are not available at DCS, so we can check all looping among different parts and different sensors, indicators with their positions at actual site. It also consistsofdifferent symbols which make it easy to understand sensors positions and looping system. we can clearly see P&ID for air preheater (APH) where we see pressure and temperature transmitters which are put aside the duct and are looped with DCS for required readings. Fig shows some of the symbols which indicate the transmitter and other instrument for measurements at different locations. We start reading P&ID from FD and SA fan then moving with air flow in air preheater at its inlet along with flow we also check the available transmitters such as pressure, temperature, flow meter etc.Then from APH air outlet and inlet from economizer is been checked, further we follow air flow to furnace bed and over fire air nozzles. Then furnace exit gas temperature sensor is placed and looped to DCS. Then process flows from furnace outlet to super heaters then to boiler bank, till here we see for both water and gas flows but after boiler bank we mainly concentrate on flue gas flow and its temperature. Then flue gas moves to economizer section then to APH and then goes to stack.

PERFORMANCE ANALYSIS OF BOILER HEAT RECOVERY COMPONENTS

Mainly for performance analysis I am focusing on economiser and air preheater performance. My project aim is to check performance of these components with design values such as flue gas and water outlet temperatures for economiser and air temperature for air pre heater.

Performance calculations are typically used to establish one of three parameters: temperature, heat transfer surface area, or surface cleanliness. As in most thermal analysis problems, the evaluation of boiler performance is an iterative process. To evaluate flue gas and steam temperatures for a known boiler design arrangement, the surface area and surface cleanliness are normally known while the temperatures are assumed. The outlet temperature calculation updates subsequent iterations until convergence between assumed and calculated temperatures is achieved.

Table No. 1 for economizer data

Sr no	Economiser Parameter	Desin value	Site (ECO1)value	Site value(ECO2)
1	Inlet water temp(˚C)(t_1)	231	231	231
2	Outlet water temp(˚C)(t_2)	372	368	368
3	Inlet flue gas temp(˚C)(T_1)	511	476	476
4	Outlet flue gas temp(˚C)(T_2)	320	304	302
5	Water flow rate(kg/s)(m_w)	48.58	48.58	48.58
6	Water inlet pressure kg/cm^2)	111	112	112
7	Water outlet pressurekg/cm^2)	107	109	110
8	Flue gas temp drop(mmwc)	15	23	21
9	Total heating surface area m^2)	2274	2274	2274

-As per LMTD temperature calculations Method for Economiser 1 it is seen flue gas outlet temp = 308.66˚C, while design value is 320˚C so there is 3.3% difference between actual and design temperatures. Also water outlet temperature =378.6℃ , while design value is 372˚C so there is 1.77% difference between design value actual values. So, it is not necessary to change current design for economiser.
Similarly temperature where calculated for Economiser 2 and it was seen flue gas outlet temperatures = 307.2˚C, while design value is 320˚C so there is 4% difference between actual and design temperatures.

Validation of Air Preheater(APH) flue gas outlet temperature:

Table No. 2 APH data for performance calculation

Sr no	APH parameter	Design value	Site value	Desin value	Site value
1	Inlet air temp	32	32	32	32
2	Outlet air temp	240	213	275	240
3	Inlet flue gas temp	320	295	320	290
4	Outlet flue gas temp	152	145	152	145.6
5	Air flow rate	68.2	68.2	74	74
6	Flue gas flow rate	74	74	74	74
7	Air inlet pressure	1467	1463	1467	1459
8	Air outlet pressure	1410	1400	1410	1404
9	Flue gas pressure drop	65	70	65	70

10	Total heating surface area	8810	8810	7831	7831
11	Specific heat of air	1.05	1.056	1.07	1.071
12	Specific heat of gas	1.199	1.198	1.199	1.988

Results for APH:-

- As per above calculation method it is found out as site flue gas outlet temp = 147.5˚C while design value is 152˚C so there is 2.9% difference between design temperature.
- PA air outlet temperature = 255˚C as per design value it should be = 240˚C so there is 6.25 % difference between design value.
- SA side air temperature = 290˚C while design value is 275˚C there is 5.4% difference between design value.
- So, APH is working in good condition at site, there is no need for change in design for further projects.

IV. BOILER EFFICIENCY CALCULATION METHODS

The efficiency of a fuel fired boiler is quoted as the % of useful heat available, expressed as a percentage of the total energy potentially available by burning the fuel. This is expressed on the basis of gross calorific value (GCV) of fuel. Most standards for calculation of boiler efficiency, including IS 8753, ASME Standard: PTC-4 Power Test Code and BS845which are designed for measurement of boiler efficiency. Unvaryingly, all these standards do not include blow down as a loss in the efficiency determination process. Basically Boiler efficiency can be tested by the following methods:
1) The Direct Method: Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel fired.
2) The Indirect Method: Where the efficiency is the difference between the losses and the energy input.

The Direct Method:

This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. Fig 4.1 shows fuel and water as input parameter to boiler and the output of these parameters are steam and flue gas which accounts for boiler efficiency calculation by using direct method. This efficiency can be evaluated using the formula [1].

Efficiency of Boiler=$\frac{\text{heat output}}{\text{heatinput}} x100$...

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

The Indirect Method:

The efficiency can be measured easily by measuring all the losses occurring in the boilers using the principles to be described. The disadvantages of the direct method can be overcome by this method, which calculates the various heat losses associated with boiler. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. An important advantage of this method is that the errors in measurement do not make significant change in boiler efficiency. Fig 6.2 indicates clearly the different losses [1].
The various heat losses occurring in the boiler are:
The following losses are applicable to liquid, gas and solid fired boiler

L1- Loss due to dry flue gas (sensible heat)
L2- Loss due to hydrogen in fuel (H_2)
L3- Loss due to moisture in fuel (H_2O)
L4- Loss due to moisture in air (H_2O)
L5- Loss due to incomplete combustion i.e carbon monoxide (CO)
L6- Loss due to surface radiation, convection and other unaccounted*
*Losses which are insignificant and are difficult to measure

Heat Balance sheet for coal fired Boiler

Table no 2 Heat Balance Sheet for coal fired boiler

Input/output parameters	**% loss**
Heat Input = 20141.77 kJ/kg	100
Losses in boiler	
1. Dry flue gas (L1)	5.02
2. Loss due to hydrogen in fuel (L2)	4.69
3. Loss due to moisture in fuel(L3)	4.41
4. Loss due to moisture in air (L4)	0.21
5. Loss due to partial combustion of C to CO (L5)	0.05
6. Loss due to radiation(L6)	0.24
7. Loss due to unburnt in fly ash(L7)	0.075
8. Loss due to unburnt in bottom ash (L8)	0.74
Boiler efficiency (100-L1+L2+L3+L4+L5+L6+L7+L8)	**84.81%**

As per design efficiency calculated is = 86.17% and by manual calculations efficiency = 84.81%. So it is clear from boiler efficiency calculations that the CFBC boiler is working in good condition.

CFD SIMULATION FOR AIR PREHEATER (APH)

Computational Fluid Dynamics or CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer-based simulation. The technique is very powerful and spans a wide range of industrial and non-industrial application areas. From the 1960s onwards the aerospace industry has integrated CFD techniques into the design, R&D and manufacture of aircraft and jet engines. More recently the methods have been applied to the design of internal combustion engines, combustion chambers of gas turbines and furnaces. Increasingly CFD is becoming a vital component in the design of industrial products and processes. The ultimate aim of developments in the CFD field is to provide a capability comparable to other CAE (Computer-Aided Engineering) tools such as stress analysis code. In this chapter mainly Air preheater (APH) analysis is done using volumetric porosity concept, I have collected actual site data such as inlet and outlet flue gas temperature, pressure etc. so, it is necessary to compare actual data collected with CFD results.

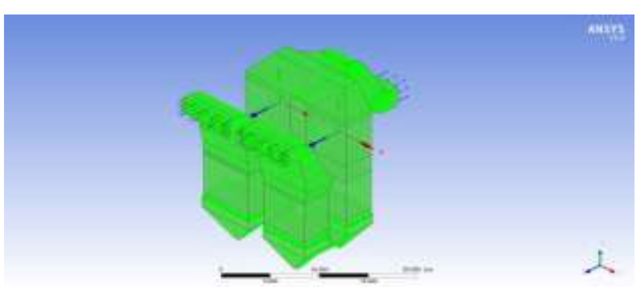
CFD Analysis for Heat Recovery System as Air Preheater (APH):

Heat recovery system play important role in enhancing the efficiency of any boiler, mainly APH and Economiser are used as heat recovery components. Before stating CFD analysis for APH it is necessary to know boiler type, design parameters, flue gas composition etc. Table shows design parameters for boiler which use this heat recovery system. The combustion of fueltakes place in the furnace by which tremendous amount of heat is generated as flue gas. This high temperature flue gas is passed over the panels, primary super heater, secondary super heater and convection bank to produce steam.

The geometry of the heat recovery system is modelled using Solid Works 14.0, the meshing is done using ANSYS ICEM 16.0 the analysis is done using ANSYS CFX 16.0. shows total APH geometry with primary and secondary side gas entry sections.

Meshing of APH

Meshing applied for this geometry was done in ANSYS ICEM 16.0 using tetrahedral meshing which is unstructured type meshing commonly used in Thermax company, as this type of meshing is fast and reliable for such huge geometry also it saves meshing time.



APH Isometric view

Flue gas parameters for APH Analysis

Table no. 4

Parameters	Units	Value
Gas flow rate	Kg/s	74.17
Inlet temperature	° C	295
Heating surface area PA side	m^2	8810
Heating surface .	m^2	7831

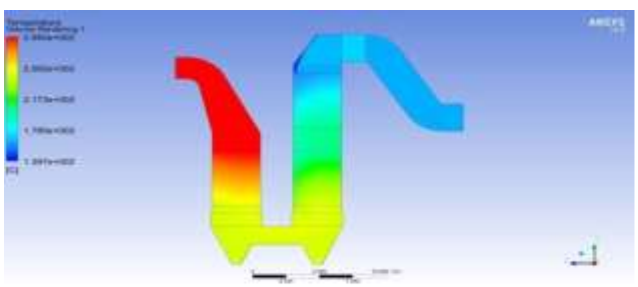
Heat Source Calculations for APH PA side Air

Table no.5

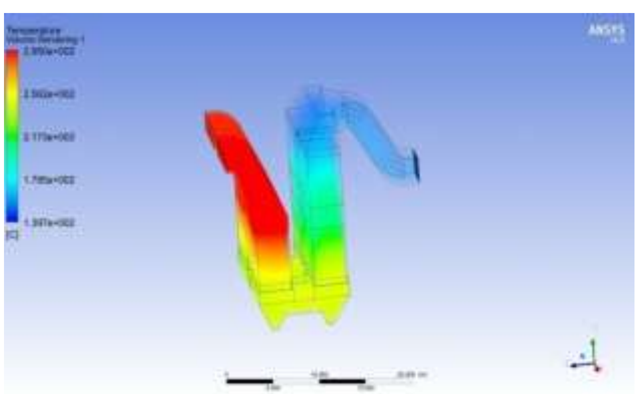
Module	**Mass of Air (kg/s)**	**Inlet Temp (^{0}C)**	**Outlet Temp (^{0}C)**	**Heat Source (kW)**
PA 1	68.2	32	104.8	5030.48
PA 2	68.2	104.8	177.6	5127.87
PA 3	68.2	158.7	240	4488.11

APH Analysis Results:

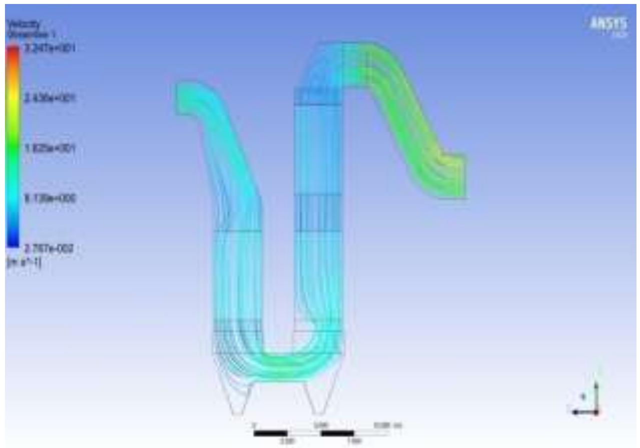
Main aim for doing CFD analysis for heat recovery components i.e. Air Preheater(APH) is to compare outlet flue gas temperature with actual site readings and with design value which obtain from program P140 used by company



Side view of APH Flue Gas Temperature Profile.



Isometric view of APH Flue Gas Temperature Profile.



Velocity Profile for APH

After studying the results obtained by the ANSYS CFX the following conclusions are drawn

1) The temperature drop obtained from the analysis for each module is also closer to the design values which mean the proper utilisation of flue gas heat is being take place in the system.
2) The pressure drop obtained from the analysis for each module is closer to the design values.
3) The velocity streamline for the heat recovery system shows the flue gas flow is uniformly distributed over the entire system.

V. CONCLUSIONS

In this project have drawn conclusion for performance analysis for Economiser and Air Preheater (APH) on temperature bases and then overall CFBC boiler efficiency using indirect method. This work was very useful for company i.e. data collection by monitoring actual site continuously for 8 hours also the performance checked for ECO and APH was useful to them in deciding the future design for such boilers. In future the performance can be checked using software techniques such as ANSYS, computational fluid dynamics (CFD).

1)For performance analysis of boiler i.e. overall boiler efficiency and its heat recovery components (economisers and air preheater), was checked mainly on temperature basis, the temperatures where calculated using NTU method for Heat Exchangers and then the site temperatures compared with design temperatures i.e. P140 temperatures values for economiser and air pre-heaters. It was clear from company that if temperatures matching within 5 to 8 % variation between actual and design value then the performance of components are ok.

2) In Economiser 1 it is observed 3.3% difference between design and actual temperature for outlet flue gas. Also 1.77% difference between design and actual temperatures for outlet water temperatures. So no change required for economiser 1 design.

3) In Economiser 2 it is observed 4% difference between design and actual temperature for outlet flue gas. So no change is required for economiser 2 design.

4) For Air Preheater (APH) is seen the outlet flue gas temperature variation for PA side and SA side is 2.9% compared between design and actual temperature. And for PA side air outlet temperature it is 5.9 % difference between design and actual temperatures. For SA side it is 5.3% difference between design and actual value.So, APH is working in good condition at site, there is no need for change in design for further projects.

5) Overall efficiency of boiler as per program is calculated as = 86.17% and by manual calculations the efficiency obtain is = 84.81%. So it is clear from boiler efficiency calculations that the CFBC boiler is working in good condition.

6) CFD simulation for Air Preheater (APH) is done using volume porosity method and the results obtain are compared with design value and actual site values shown in table

Compared Results using CFD, Design and actual site values

Parameters	**Units**	**CFD value**	**Design value**	**Actual site values**
Outlet Gas Temperature	^{0}C	139.7	152	145.6
Pressure Drop	Pa	598.2	637	686.4

Future scope:

In future the performance can be checked using software techniques such as ANSYS, computational fluid dynamics (CFD) for all boiler components. Also when the boilers are in shut down the condition of economiser and air pre-heaters can be checked i.e. rate of fouling on tubes can be seen and conclusion to be drawn out, also the sizing of tubes can be checked. This will help in obtaining better results and will help in deciding whether area provided while designing components is over design or under design. If sizing of tubes at desirable temperature difference are affecting then material properties of tube has to be studied. Also dust loading can be done at this site which gives clear idea for particular matter concentration in flue gas.

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