Optimization of Heat Transfer Coefficient of Air Preheater using Computational Fluid Dynamics

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Abstract— After studying literatures mentioned in the literature review chapter, it is understood that there are some gaps in design of shell and tube air preheater. The main aim of the project investigation is to modify the design of air preheater, mentioned in Das et al. [40] to increase its heat transfer coefficient and hence improving its performance and efficiency. The tubular preheater ducts for cold and hot air require more space and structural supports than a rotating preheater design. Further, due to dust-laden abrasive flue gases, the tubes outside the ducting wear out faster on the side facing the gas current. Many advances have been made to eliminate this problem such as the use of ceramic and hardened steel. This project also contains the method for calculating boiler efficiency using indirect method and reduce the losses in air preheater by changing the tube diameter of air preheater in ANSYS Fluent (CFD) software and validating its results from literature Das et al. [40].

Key words: CFD, ANSYS

I. Introduction

A primary air heater is a tubular air heater which is arranged in the form of cross-flow heat exchanger. Many primary air heaters are used in coal-fired power plants, Steel manufacturing industries, power plant etc. The cross-flow air heater is very popular due to its low cost and eases of cleaning, operating and maintaining. Normally, the heat exchanger (known as the primary air heater) is recovered heat from the high temperature flue gas to warm up the combustion air to ensure the coal is dried before transporting to the furnace. This heat exchanger is operated under high particulate conditions where fly ash from the combustion process tends to decrease its performance. Unfortunately, there is lack of data about the performance decreasing due to this condition.

For boiler & furnace air is a primary component. In each of this equipment, the ambient air is required to be heated up to high temperatures. Preheating the incoming air largely improves the thermal efficiency of the system, therefore, it increases the energy savings of the industry and as a results lower operating costs. In fact, every 220℃ rise in combustion air temperature increases the boiler efficiency by nearly 1%. Heat exchangers can be used to recover the heat from various processes to preheat the air. However, the heat transfer coefficient of air is low and hence, fins or extended surfaces are used to enhance the heat transfer. It is a common industrial practice to utilize the heat of exhaust gases or flue gases and process steam to preheat ambient air. Air pre-heater is the most common equipment responsible for deterioration in boiler efficiency and increase in auxiliary power consumption in ID (Induced draft), FD (Forced draft), and PA (Primary air) fans. [28]

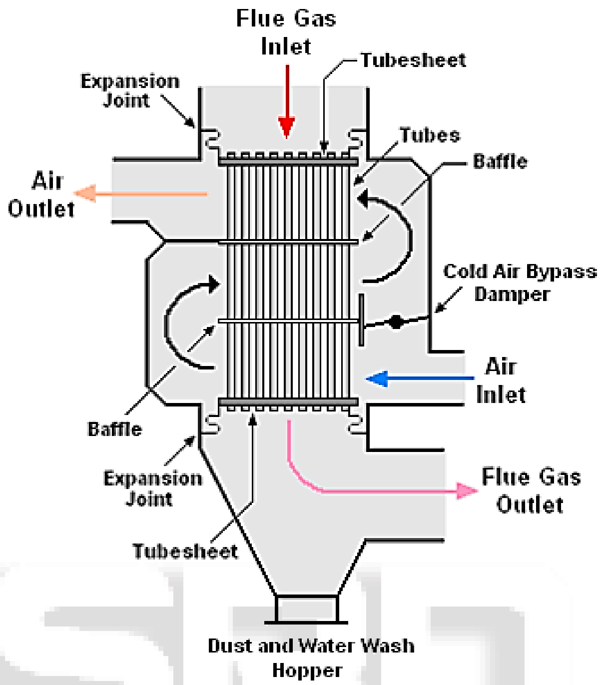

Fig. 1.1: Air Preheater [28]

An air preheater (APH) is a general term used to describe any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. They may be used alone or to replace a recuperative heat system

A. Types Of Air Preheater:

There are mainly two types of air preheater on the basis of operating principle.

1) Recuperative Air Preheater:

In such type of air preheater, heat is transferred continuously and directly through stationary, solid heat transfer surface which separate the hot flow steam from cold flow steam. The common heat transfer surfaces are tubes & parallel plates. [30]

a) Tubular Air Preheater:

In such type energy is transferred from the hot flue gas flowing inside thin walled tubes to the cold combustion air flowing outside the tubes. The unit is consist of nest of straight tube that are rolled or welded into tube sheets & enclosed in a steel casing or gas passing outside of the tubes & has both air and gas inlet & outlet openings.

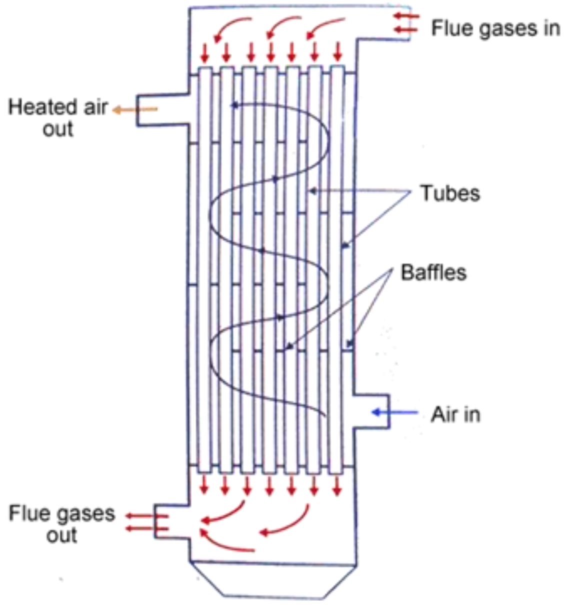

Fig. 1.2: Tubular Air Preheater [28].

2) Regenerative Air Preheater:

This type is relatively compact and are the most widely used type for combustion air pre heating in electric utility steam generating plants. Air to gas leakage can be controlled by cold presenting axial and radial seal plates to minimize gaps at the hot operating condition or using sacrificial material [28].

There are two types of regenerative air preheaters: the rotating-plate regenerative air preheaters (RAPH) and the stationary-plate regenerative air preheaters (Rothemuhle).

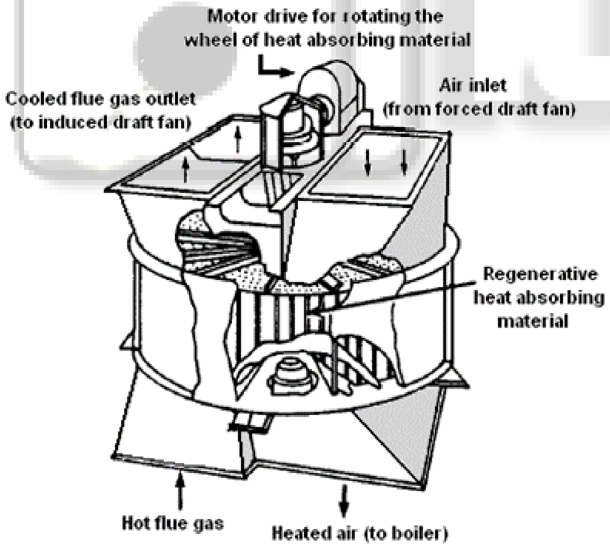

Fig. 1.3: Typical Rotating-plate Regenerative Air Preheater (Bi-sector type)

II. Literature Review

Dilip S. Patel (2015), The Ljungstrom air preheater is a regenerative type heat exchanger used for preheating the combustion air, mainly in steam power plant. The warm gas and cool air ducts are arranged to allow both the flue gas and inlet air to flow simultaneously through the air preheater. The hot flue gas heats the rotor material and as the rotor rotates, the hot rotor section moves into the flow of the cold air and preheats it. If the incoming air is not preheated, then some additional energy must be supplied to heat the air to a temperature required to facilitate combustion. Due to this, more fuel will be consumed which decreases overall efficiency of the power plant. In this paper different techniques used to optimize the process parameters of rotary regenerator are discussed.

Taware khushal (2015), In these result increase the efficiency of boiler by increasing no of tubes &adding super heater. Boiler efficiency also increased by reducing heat losses & increasing heat input. This heat input is increased by adding oxygen in the furnace area so more heat input is transferred to boiler process so increases the efficiency of boiler. By increasing length of tube boiler & adding super heater boiler gives max heat input to the process so increases ton capacity of boiler. In this way we get profit by increasing efficiency of boiler.

M.Nageswara Rao (2015), In these investigation the following points are concluded:

1) Thermal design of Air preheater model is cross verified by NTU method
2) Air and Gas outlet temperature from experiment are 47°C and 46°C which are close to that obtained by NTU method 43.66°c and 49.35°C 3. The difference in the temperature may be due to fouling in gas and distribution of flow due to vibration of the system

Chayalakshmi C.L (2015), The traditional method for calculation of boiler efficiency using indirect method involves complex mathematical equations, which is a tedious work for operation department people of an industry. Instead of manual calculation, the software system developed in this paper can be easily adopted which provides measurement and monitoring of various losses and boiler efficiency. In indirect method, no need to measure or monitor the parameters which are necessary for finding boiler efficiency and boiler design cannot depict its efficiency. As the performance evaluation of boiler is based on its boiler efficiency, finding boiler efficiency using indirect method is an easy task if the developed application software is used. The error between the boiler efficiency calculated using conventional method and the calculated using application software is very small. Calculation of boiler losses and efficiency is carried out using DASY Lab software package and tested with data obtained from industrial environment.

III. Methodology

A. Governing Equations of Fluid Flow and Heat Transfer:

Following fundamental laws can be used to derive governing differential equations that are solved in a Computational Fluid Dynamics (CFD) study [1]

- conservation of mass
- conservation of linear momentum (Newton's second law)
- conservation of energy (First law of thermodynamics)

In this course we'll consider the motion of single phase fluids, i.e. either liquid or gas, and we'll treat them as continuum. The three primary unknowns that can be obtained by solving these equations are (actually there are five scalar unknowns if we count the three velocity components separately)

- Velocity vector $\vec{V}$
- Pressure p
- Temperature T

But in the governing equations that we solve numerically following four additional variables appear

- Density ρ
- Enthalpy h (or internal energy e)
- Viscosity µ
- Thermal conductivity k

Pressure and temperature can be treated as two independent thermodynamic variables that define the equilibrium state of the fluid. Four additional variables listed above are determined in terms of pressure and temperature using tables, charts or additional equations. However, for many problems it is possible to consider ρ,µ and k to be constants and to be proportional to with the proportionally constant being the specific heat.

Due to different mathematical characters of governing equations for compressible and incompressible flows, CFD codes are usually written for only one of them. It is not common to find a code that can effectively and accurately work in both compressible and incompressible flow regimes. In the following two sections we'll provide differential forms of the governing equations used to study compressible and incompressible flows.

B. Heat Exchangers:

Heat Exchangers are classified according to their function and geometry:
Function:
Recuperative: two fluids separated by a solid wall
Evaporative: enthalpy of evaporation of one fluid is used to heat or cool the other fluid.
Regenerative: use a third material which stores/releases heat
Geometry:

1) Double Tube
2) Shell and Tube
3) Cross-flow Heat Exchangers
4) Compact Heat Exchangers

The heat transfer rate for most heat exchangers can be calculated using the LMTD-method (Log Mean Temperature Difference), if the inlet (T1) and outlet (T2) temperatures are known:

$$Q = UA\Delta\bar{T}$$

$$\Delta\bar{T} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)} F$$

Where, U = Overall heat transfer coefficient [W/m2-oC]
A = Effective heat transfer surface area [m2]
F = Geometry correction factor
$\Delta\bar{T}$ = Log mean temperature difference

C. Cross Flow And Compact Heat Exchangers:

- Cross-flow and compact heat exchangers are used where space is limited. These aim to maximize the heat transfer surface area.
- Commonly used in gas (air) heating applications.
- The heat transfer is influenced by whether the fluids are unmixed (i.e. confined in a channel) or mixed (i.e. not confined, hence free to contact several different heat transfer surfaces).
- In a cross-flow heat exchanger the direction of fluids is perpendicular to each other.
- In Compact heat exchangers, the heat transfer rate is directly related to pressure loss

D. Study Data:

This project work has been focused on the improvement in performance of Air Preheater resulting from by modified the existing design and reduction in various heat losses by changing air preheater parameters. By considering data referred by “Das et al. [40]”, was used indirect method for calculation. So, by taking a reference of this indirect method and analysis of various losses this research has been calculated. [24]

1) Water /Steam Parameters:

- Temperature & pressure measurement of water at economizer inlet and that of steam at boiler outlet.
- Steam flow rate(steam pressure, steam generation per hour)
- DM water quality.
- Feed water analysis.
- Fuel consumption rate per hour, humidity factor etc.

2) Fuel:

- Collection of fuel samples
- Ultimate analysis of the fuel(H2,O2,S,C, Moisture content, ash content)

3) Flue Gas/Ash Analysis:

- Collection of ash samples, for unburnt analysis.
- Online readings for flue gas analysis.
- Percentage of oxygen or CO2 in flue gas.
- Flue gas temperature in ℃(FGT)

4) Surface Condition:

- Measurement of surface temperature.

Other Data

- G.C.V of fuel in kcal/kg.
- Percentage combustible in ash (in case of solid fuel)
- G.C.V of ash in kcal/kg(in case of solid fuel)
- Ambient temperature in ℃ (Ta) and humidity of air in kg/kg of dry air.
- Data from heat recover device(if attach)

5) Experiment Data [40]:

Daily 3 shift wise boiler “log sheet” format.

S. No.	Parameters	Unit	Quantity
1.	Fuel	-	Indonesian coal
2.	Steam generation rate.	Kg/hr.	30,000
3.	Operating hour	hr/day.	24
4.	Steam pressure	Kg/cm^2	64.16
5.	Steam temperature.	℃	462.53
6.	Coal firing rate	Kg/hr.	1453
7.	G.C.V of coal	Kcal/kg.	5300
8.	Surface temperature.	℃	116.95
9.	Ambient temperature	℃	36.75
10.	Humidity factor.	-	0.021

Table 3.1: Data for Find out Boiler Efficiency.

S. No.	Parameters	Value
1.	Feed water temperature	160℃
2.	TDS	200PPM
3.	PH	7.1

Table 3.2: Feed water analysis from laboratory

S. No.	Parameters	Quantity
	C	36.4%
	H_2	2.9%
	N_2	1.1%
	O_2	4.5%
	A	38.6%
	M	15%
	S	1.5%

Table 3.3: Ultimate analysis of coal from laboratory:

S. No.	Parameters	Quantity
1.	Flue gas temperature	600℃
2.	% o_2 in flue gas	8.12%
3.	% co_2 in flue gas	11.6%
4.	% co in flue gas	0.42%

Table 3.4: Flue gas analysis with flue gas analyzer:

S. No	Parameters	Quantity
1.	G.C.V of bottom Ash	700 kcal/kg
2.	G.C.V of fly Ash	150 kcal/kg
3.	Bottom Ash to fly Ash ratio	45.55

Table 3.5: Ash Analysis

E. Modeling And Meshing Of Air Preheater:

Air preheater is modeled by using Creo Parametric 2.0. The Creo Parametric is the one of the most efficient modeling software which can use easily modeling and design the objects. After modeling the design of air preheater which can export this file into Finite volume method software because the modal is done for discretizing or meshing process.

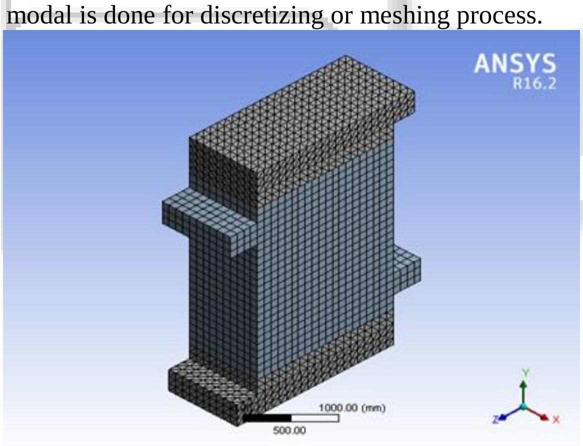

Fig. 3.1: Meshing view of Air Preheater (Isometric & Front View)

S. No.	Parameters	Symbol	Unit	Quantity
1.	Gas quantity	W_g	Kg/hr	54628.39
2.	Air quantity	W_a	Kg/hr	47,000
3.	Air inlet temperature	t_1	°C	36.75
4.	Air outlet temperature	t_2	°C	150.2
5.	Flue gas inlet temperature	T_1	°C	253.708
6.	Heat transfer	Q	KW	1488.55
7.	Flue gas outlet temperature	T_2	°C	156
8.	Density of flue gas	ρ_g	Kg/m^3	0.752
9.	Width of air preheater	W	m	2.82
10.	Depth of air preheater	D	m	2.286
11.	Specific heat of air	C_{pa}	Kcal/kg°C	0.2418
12.	Specific heat of gas	C_{pg}	Kcal/kg°C	0.2596
13.	Thermal conductivity of air	k_a	Kcal/mh℃	0.0253
14.	Thermal conductivity of flue gas	K_g	Kcal/mh℃	0.0303
15.	Viscosity of air	μ_a	Kg/mh	0.0723
16.	Density of air	ρ_a	Kg/m^3	1.287
17.	Viscosity of flue gas	μ_g	Kg/mh	0.0848

Table 3.6: Parameters for Air Preheater [40]

S. No.	Parameters	Unit	Value
1.	Tube side diameter	mm	63.5
2.	Tube thickness	mm	2.34
3.	Tube inside diameter	mm	59.42
4.	Tube material		Carbon steel
5.	Length of tube	mm	6200
6.	Perpendicular pitch (perpendicular to direction of air flow)	mm	85
7.	No. of tube wide	Nos	15
8.	No. of tube deep	Nos	50
9.	Parallel pitch (along the direction of air flow)	mm	85

Table 3.7: Air Preheater Geometry [28] [40]

S. No.	Parameters	Unit	Value
1.	Pressure at outlet	Gauge	0
2.	Velocity at inlet	m/s	15
3.	Wall		No slip & escape
4.	Default interior		Fluid (flue gas)

Table 3.8: Boundary condition for flue gas [28] [40]

S. No.	Parameters	Unit	Value
1.	Pressure at outlet	Gauge	0
2.	Velocity at inlet	m/s	6
3.	Wall		No slip & escape
4.	Default interior		Fluid (air)

Table 3.9: Boundary condition for air [28] [40]

IV. RESULTS AND DISCUSSIONS

A. Simulation Results:

The governing equations of the problem were solved, numerically, using a control volume method, and finite element volume (FEV) used in order to calculate the thermo physical properties. As a result of a grid independence study, a various grid size founded for different geometry to model accurately the flow fields described in the corresponding results. The accuracy of the computer model was verified by experimental result and improve the performance of air preheater. In present investigation various results, which are shown in table 4.1, 4.2 and 4.3.

S. No.	Tube Diameter mm	Flue Gas Flow kg/hr.	Flue gas Temp In	Flue gas Temp Out	Air Temp In	Air Temp Out	Pressure Drop Δp	Heat Transfer coefficient $w/m^2°$
1	43.5	54628	253.7	234.23	36.75	242.65	30.75	22.36
2	53.5	54628	253.7	237.97	36.75	239.56	32.98	21.89
3	63.5	54628	253.7	241.71	36.75	237.73	35.84	20.36
4	73.5	54628	253.7	243.56	36.75	235.27	37.44	19.79
5	43.5	54628	253.7	245.69	36.75	232.81	40.679	19.07

Table 4.1: CFD results for different tube geometry

S. No.	Tube Diameter mm	Flue Gas flow, kg/hr.	Flue Gas Inlet temperature °C	Air Inlet temperature °C	Gas side pressure drop Δp	Air side pressure drop Δp	Heat Transfer Coefficient $w/m^2°C$
1.	43.5	54628	253.708	36.75	30.75	34.98	22.36
2.	53.5	54628	253.708	36.75	32.98	25.84	21.89
3.	63.5	54628	253.708	36.75	35.84	20.19	20.36
4.	73.5	54628	253.708	36.75	37.44	18.36	19.79
5.	83.5	54628	253.708	36.75	40.679	15.97	19.07

Table 4.2: CFD results for different tube diameter parameter

Work	Tube Diameter (mm)	Flue gas outlet temperature °C	Air gas outlet temperature °C	Gas side pressure drop Δp	Air side pressure drop Δp	Heat Transfer Coefficient $w/m^2°C$
Das et al. [40]	63.5	156	150.2	35.25	20.78	20.25
Present ANSYS Fluent 16.2 Result	43.5	234.23	242.65	30.75	34.98	22.36
	53.5	237.97	239.56	32.98	25.84	21.89
	63.5	241.71	237.73	35.84	20.19	20.36
	73.5	241.71	235.27	37.44	18.36	19.79
	83.5	241.71	232.81	40.679	15.97	19.07

Table 4.3: Validation of results from Das et al. [40] and Present ANSYS Fluent result

B. Validation:

In this step all results are validated from Das et al. [40] and Present investigation results and concluded the results.

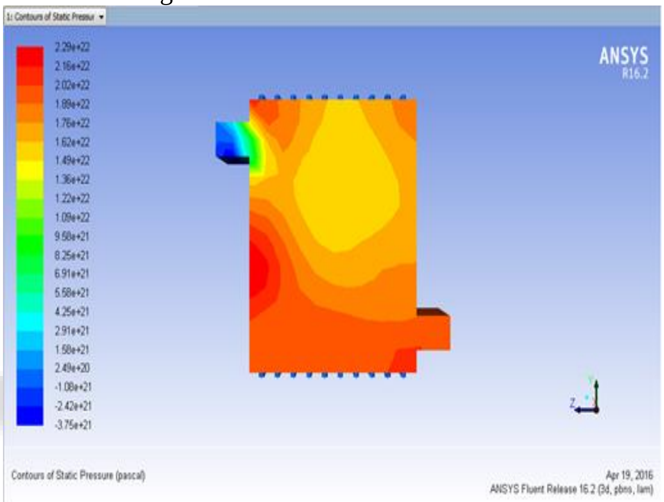

Fig. 4.1: Contour plot of Static Pressure in Air Preheater (Tube diameter 43.5)

Figure 4.1 shows the static pressure contour plotting of the air preheater. The pressure at the air inlet is more than at the air outlet.

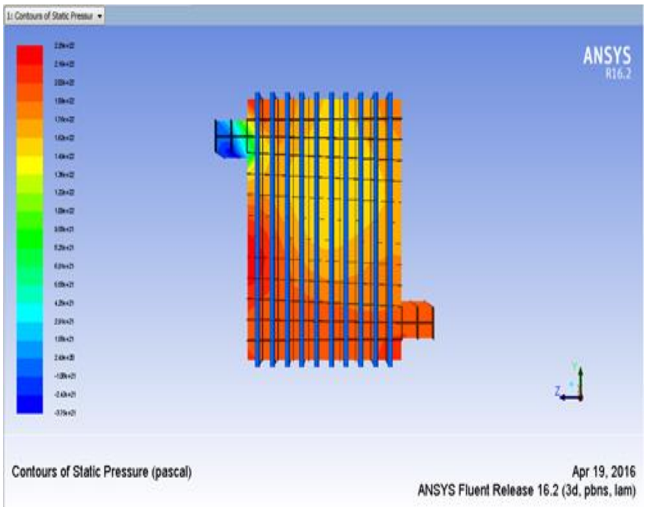

Fig. 4.2: Contour plot of static Pressure in Air Preheater (cross section) (Tube diameter 43.5)

Figure 4.2 shows the static pressure contour plotting of cross section of the air preheater.

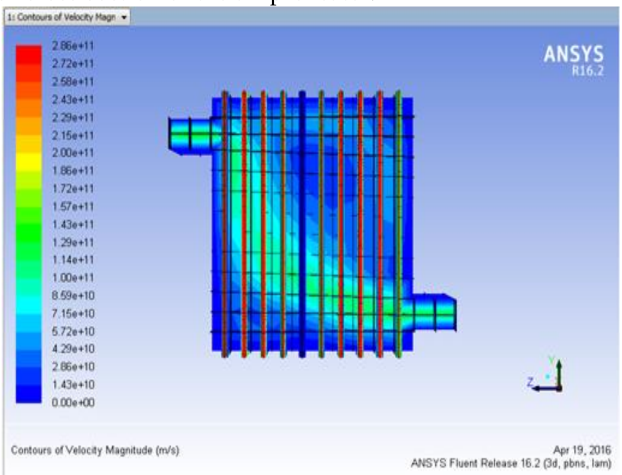

Fig. 4.3: Contour plot of Velocity magnitude in Air Preheater (cross section) (Tube diameter 43.5)

Figure 4.3 shows that the velocity contour plotting of the air preheater. The contour is shows that the flow of air in duct.

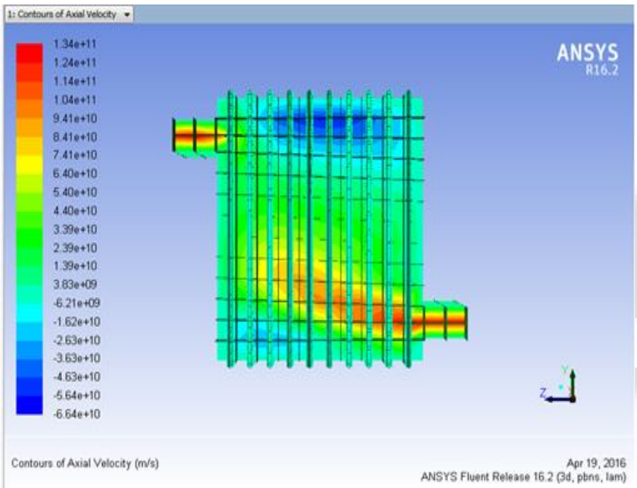

Fig. 4.4: Contour plot of Axial Velocity in Air Preheater (Tube diameter 43.5)

Figure 4.4 shows the axial velocity contours which is calculated by ANSYS Fluent software.

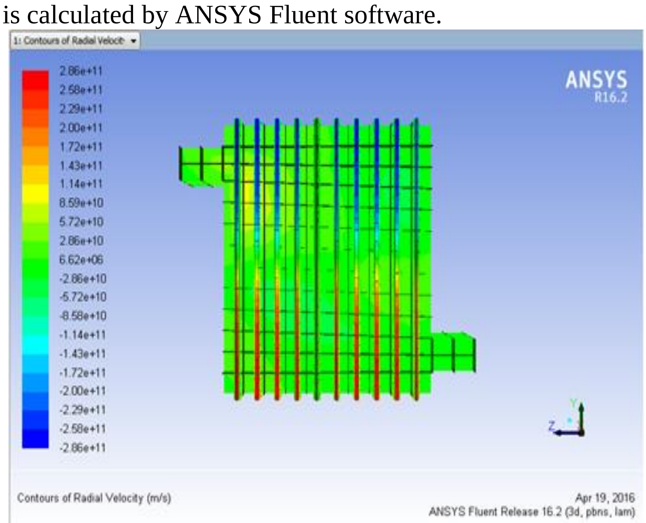

Fig. 4.5: Contour plot of Radial Velocity in Air Preheater (Tube diameter 43.5)

Figure 4.5 shows that the radial velocity contour plotting of the air preheater. The contour shows that the flow of air in duct and tube in radial direction.

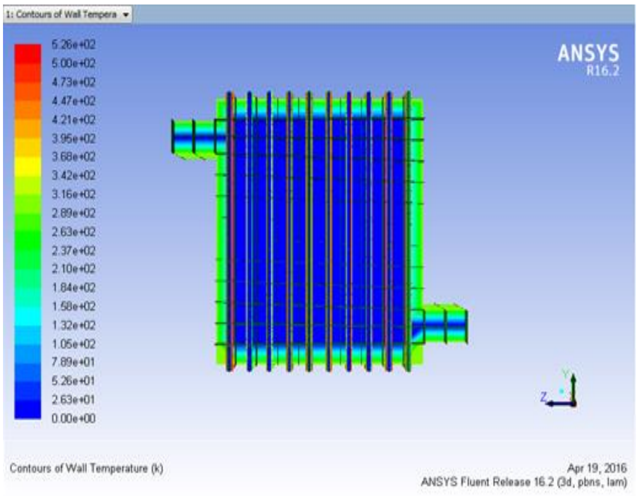

Fig. 4.6: Contour plot of wall temperature in Air Preheater (Tube diameter 43.5)

Figure 4.6 shows that the contour plotting of wall temperature on the duct and tube walls.

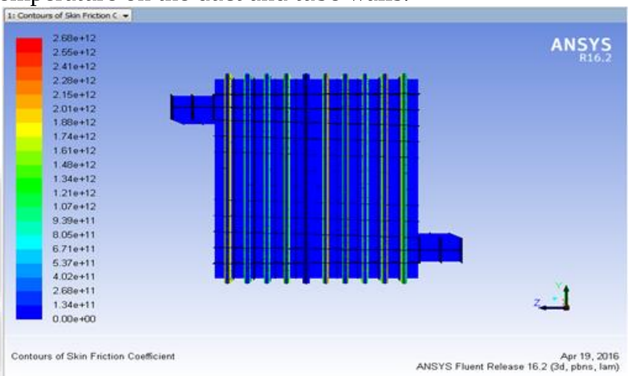

Fig. 4.7: Contour plot Skin Friction Coefficient in Air Preheater (Tube diameter 43.5)

Figure 4.7 shows that the skin friction coefficient contour plotting of air preheater. The figure indicates that the skin friction coefficient is very low, hence the generation of wall shear stress is also low for increasing heat transfer rate.

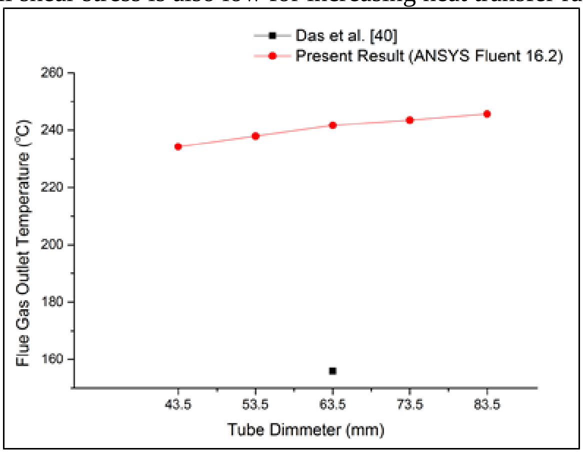

Fig. 4.8: Graph plotted between Flue gas outlet temperature and different tube diameter in Das et al. [40] and Present ANSYS Fluent 16.2 result

The figure 4.8 shows the graph between flue gas outlet temperature and different tube diameters. It indicates that when the diameter of tube decreases flue gas temperature also reduces.

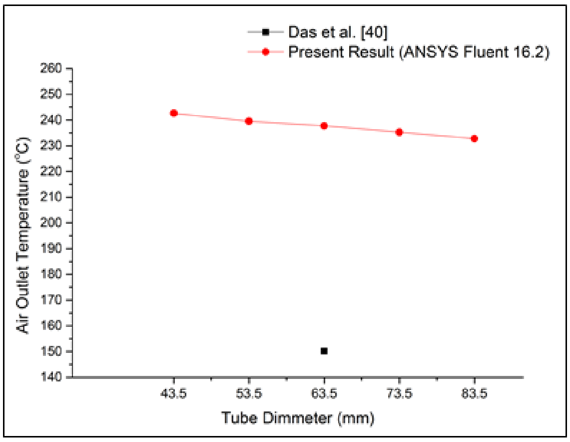

Fig. 4.9: Graph plotted between air outlet temperature and different tube diameter in Das et al. [40] and Present ANSYS Fluent 16.2 result

The figure 4.9 shows the graph between air outlet temperature and different tube diameters. It indicates that when the diameter of tube decreases air outlet temperature increases.

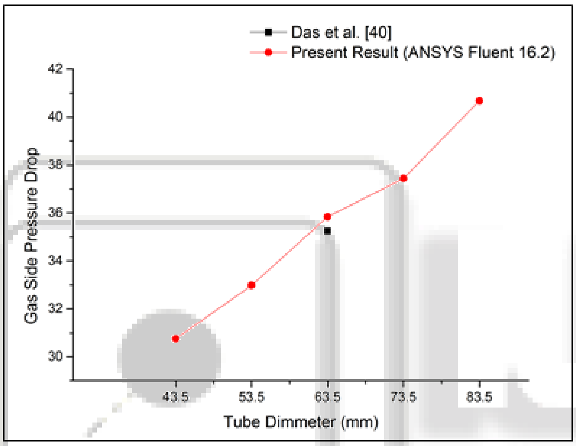

Fig. 5\4.10: Graph plotted between Flue gas side pressure drop and different tube diameter in Das et al. [40] and Present ANSYS Fluent 16.2 result

The figure 4.10 shows the graph between flue gas side pressure drop and different tube diameters.

It indicates that when the diameter of tube decreases flue pressure drop also reduces. In present investigation the flue gas side pressure drop is 12% less as compare to Das et al. [40].

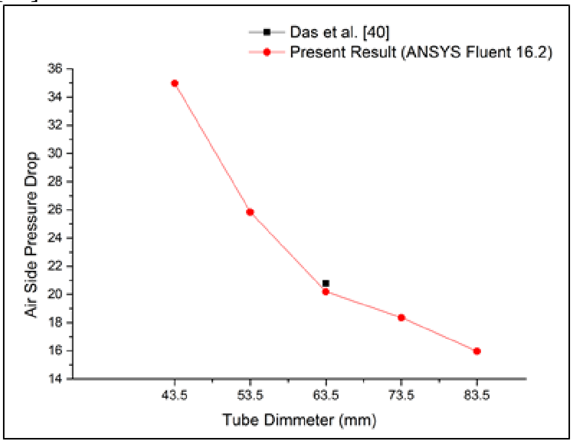

Fig. 4.11: Graph plotted between air side pressure drop and different tube diameter in Das et al. [40] and Present ANSYS Fluent 16.2 result

The figure 4.11 shows the graph between air side pressure drop and different tube diameters.

It indicates that when the diameter of tube decreases air side pressure drop is increased. Due to increase in air side pressure drop the performance of air preheater is improved. In present investigation the air side pressure drop is 40% more as compare to Das et al. [40].

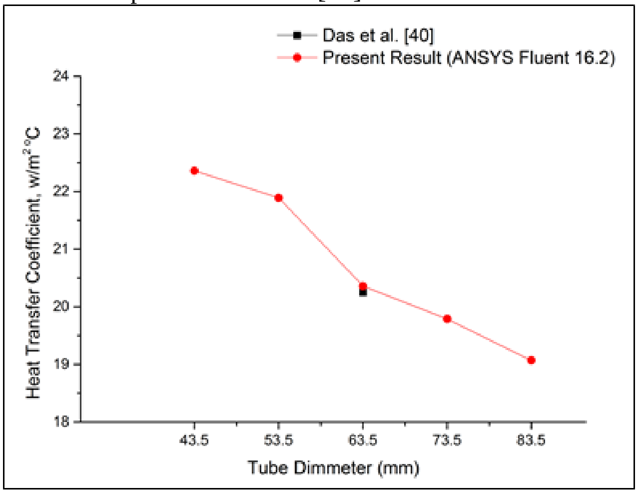

Fig. 4.12: Graph plotted between heat transfer coefficient and different tube diameter in Das et al. [40] and Present ANSYS Fluent 16.2 result

The figure 4.12 shows the graph between heat transfer coefficient and different tube diameters.

It indicates that when the diameter of tube decreases heat transfer coefficient is increased. The present investigation shows that the heat transfer coefficient has increased by 9% as compare to Das et al. [40].

Overall conclusion of the present investigation is that diameter of 43.5mm is more efficient for air preheater design than 63.5mm diameter as mentioned in Das et al. [40].

V. Conclusion

– In this thesis mainly focused on the of heat transfer coefficient and heat losses, and increase performance of the air preheater.
– Also in this thesis, an alternate design of Air preheater has been proposed by using change of air preheater tube parameter.
– Tube geometry is important design parameters of air preheater modules, since proper selection of tube diameter, thickness, number of tubes in parallel & perpendicular direction etc. results in optimum design of air preheater module.
– It concluded that when the diameter of tube decreases flue pressure drop also reduces. In present investigation the flue gas side pressure drop is 12% less as compare to Das et al. [40].
– It also concluded that when the diameter of tube decreases air side pressure drop is increased. Due to increase in air side pressure drop the performance of air preheater is improved. In present investigation the air side pressure drop is 40% more as compare to Das et al. [40].
– Screen covered many results has been founded to be best option in terms of overall size of the air preheater. It can be clearly seen from result tables that as change tube outside diameter from 63.5 mm to 43.5 mm, there is

saving of 6 to 7 % of tube material. Overall size of air preheater is reduced & results in compact design.

- When the diameter of tube decreases heat transfer coefficient is increased. The present investigation shows that the heat transfer coefficient has increased by 9% as compare to Das et al. [40].
- Overall conclusion of the present investigation is that diameter of 43.5mm is more efficient for air preheater design than 63.5mm diameter as mentioned in Das et al. [40].

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