Numerical Analysis of Rotary Air-Preheater for Different Operating Conditions

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Abstract- **Rotary air preheater is a kind of regenerative heat exchanger which helps in consuming waste heat energy contained in hot flue gas by transmitting this heat energy to the air which further enter in boiler furnace. While designing any engineering equipment energy consumption is one of the most important factors that is considered. Installation of rotary air preheater helps in saving up to 15% of fuel cost in power plant. Using ANSYS DESIGN MODULAR 3D modelling of rotary air preheater is done. The rotor is assumed to be made up of porous material and properties of material is considered to be constant. The flow directions of air and flue gas is in counter flow direction and there is separate passage for primary air, secondary air and flue gases. Earlier rotary air preheater is provided with opening angle of 50 degrees. the quality of coal was better as compared to today hence more quantity of coal needed to be fired. In order to overcome this problem, we increase the primary inlet angle from 50°to 80°.based on our result we found that as primary air opening angle increases then pressure drop gradually decreases which leads to increase in X-ratio. We also studied the effect of variation of RPM for different primary air inlet opening angle and found that there is no change in pressure drop.**

Keywords— Roatary Air-Preheater, thermal performance , Duct profile, Heat exchanger and X-ratio.

I. INTRODUCTION

In modern world energy shortage is one of the most important problem we are facing on. Hence the enhancement of energy conversion efficiency during the process of consumption of energy is of great significance and hence it attracted the global attention. In 1920, One of the methods which is used to recover essential energy in steam-based power plant called rotary air preheater is taken into use by Ljungstrom. energy is transferred from hot steam fluid to cold fluid by a rotating matrix made up of regular packed space plates. There have been many studies carried out about preheater efficiency, which consider the importance of effect of the air preheater on the efficiency of cycle. There is one publication, published by warren on Ljungstorm which says that Ljungstorm is a particular type of exchanger which exchange air to air and on the basis of experimental results, he confirmed that there is a reduction of at least 10% in fuel consumption in power plants. Rajan et al [1,2], the optimization of the pressure drops and increasing the inlet opening angle of RAPH helps in improving the X-factor of air pre-heater, also reduces the temperature of flue gas. There is another publication, carried out by Skiepko, [3] who investigated the effects of heat conduction in the matrix, matrix length and number of peclet on the preheater performance. There is one statement given by Worsoe-Schmidt [4] which states that it is observed efficiency of the exchanger is decreased by using separator, but we can't remove the separator because it is used to reduce the leakage in fluid. On the basis of various numerical analysis and several experiments, Sadrameli and Ghodsipour [5] carried out studies on the effects of matrix's rotational speed and mass flow rate on the performance of preheater and it was showed that effect of flow rate is more significant than the rotational speed. The basic application of RAPH is to recover waste energy from flue gas. The combustion air, heated by RAPH just not only enhance the combustion but also mandatory for drying and transportation, of pulverized coal. There are basically two types of air- preheater, regenerative and recuperative. The process in which heat is transferred between hot and cold fluid in a continuous process is called recuperative. In this there are tubular type air pre-heater and plate type air preheater. In regenerative type preheater, there is also exchange of heat is between the hot and cold fluid but it is not continuous. The various modification of design of Rotary air-preheater are widely used in modern power plant and enhance for fast heat transfer for boiler and condenser. RAPH perform better operation after modification in matrix shell for high rate of heat transfer. However, the pressure drop in rotary air-preheater in the matrix shell is higher for a higher loss consideration. So, an optimally design is needed to achieve the maximum heat transfer performance with heat loss and leakage air/pressure.

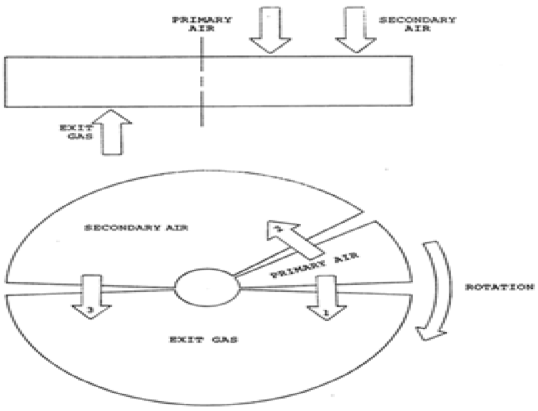

Fig. Typical Rotary air-preheater

Many a researcher broadly classified the RAPHs into following types;

Recuperative [6]-This unit may start operation with no leakage but leakage is observed as thermal and time cycles unites. Leakage can be controlled below 3percent with regular maintenance. You can determine approximate air heater leakage based on gas inlet and outlet analysis. Plugging and

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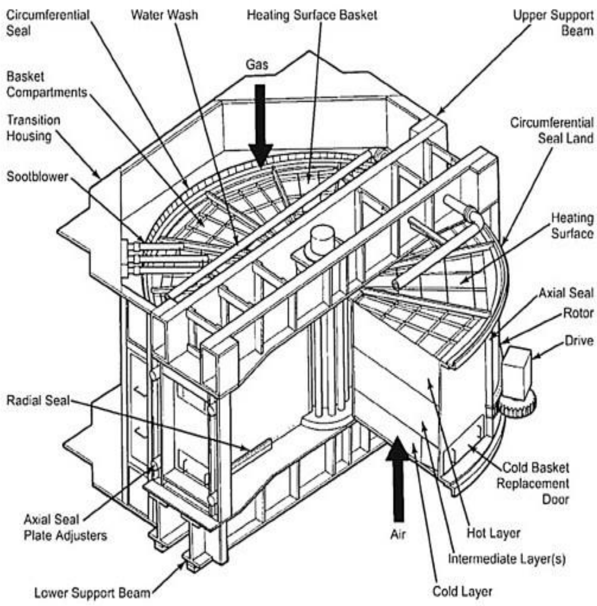
Erosion, When the high-speed dust particles move over materials, it removes its layers called it Erosion whereas closing down and fouling of heat transfer flow passage by gas is dominated with corrosion products and ash particles. Dangerous result of erosion is observed such as loss of heat transfer area, structural weakening and perforation of components. Erosion could be controlled by decreasing the velocities, clearing the affected material galvanization. The cold end flue gas temperature is drawn for acid due point in APH, as completed burnt of coal is done.

Regenerative [7] In that study, mainly two heating elements are used, either stationary or rotary. Wear and tear of the plates is reported as a primary problem and, high ash and silicon content is seen in dust laden incoming flue gases. Leakage of gases from gaps in the mid of stationary and rotary structures is reported as the secondary problem, it also affects the performance of APH to a larger extent. Seal is used in the APH for the stoppage of leakage. One more problem is seen as the deposition of unburnt particles on the surface of APH. Cold air and flue gases flow over unburnt deposits, ignition temperature is achieved along with sufficient amount of oxygen causes particles starts burning. Explosion may be possible inside of APH because of this. You can see Dew Point Corrosion in all.

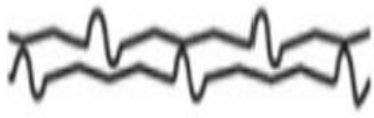


types of pre heaters. Dust laden flue gases contains sulphates and chlorides is coming out of the furnace. As soon as the flue gases reach to acid saturation temperature, condensation of sulphates and chlorides takes place in the form of sulphuric acid, hydro chloric acid etc. Condensation is seen on steel tubes and plates, the part of the tubes or plates which is encircled by acids is less oxygenated, behaves a anode while the parts which is not by acids behaves as a canoed.

Special class of heating element used in RAPH

DU CLASS (Double undulated): These class contains wavy nature. The main feature of this class is alternate stacking of undulated element sheets with sheets having both undulations and notches. the profile of Du class is shown below.

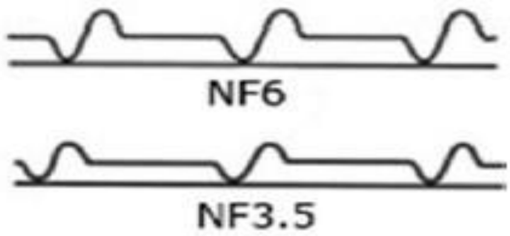
DN CLASS (Double notched): Fouling factor is highly reduced by using this type of plates. pressure drop and heat transfer characteristics is same to DU class.



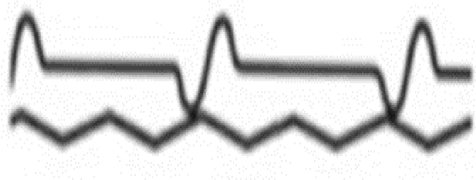
DL CLASS (Double notched loose packed): The profile is same as that of DN class. however, the element is hold loosely within the basket hence the element gets disturb back and forth at most 1 inch during soot blowing.

FNC CLASS (flat notched cross): Compared to DU type element these elements offer better thermal performance and lower pressure drop.

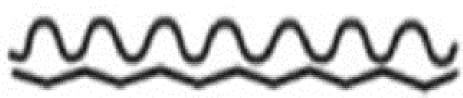
NF CLASS (notched flat): This type of plate consists of notched flat plate further followed by complete flat plate. most common type of NF class is NF6 and NF3.5 shown as below.



CLASS (Notched undulated): These are identical to NF series. The only difference between them is that NU class consists of undulated sheets while NF class consists of flat sheets diagram of NU class is shown below:



CU CLASS (Corrugated undulated): The element of cu is more open than DU. This profile is used in natural gas fired unit. The figure of cu profile is shown below.



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II. CORRELATION FOR ROTARY AIR-PREHEATER.

Many a Researcher have developed empirical correlation for classical or modified RAPHs. This correlation has been taken from [9].

$$\eta_r = \frac{1 - \exp[-NTU(1 - C_b)]}{1 - C_b \exp[-NTU(1 - C_b)]}\left[1 - \frac{1}{9C_r^{1.93}}\right]$$

NTU is called number of transfer unit and for hot & cold side it is given as follows-

$$NTU = C_a\left[\frac{4a_1 D_{dl} G}{\overline{\mu}_c(1 - x)\varepsilon}\right]^a \frac{L}{D_{dl}} \overline{Pr}^{-2/3}$$

$$NTU = C_a\left(\frac{4a_1 D_{dl} G}{\overline{\mu}_h x\varepsilon}\right)^a \frac{L}{D_{dl}} \overline{Pr}^{-2/3}$$

$$\eta_0 = \left[1 - \frac{(T_7 - T_1)(1 + X)B}{T_1 - BT_3}\right]\eta_v - \frac{B(1 + X)T_1 kR}{(T_1 - BT_3)(k - 1)c_p}\left[\frac{a_2^{(k-1)/k}}{\eta_{ff}} + \frac{T_6(a_3^{(1-k)/k} - 1)}{T_1\eta_{fd}}\right]$$

III PROFIT GAINED AFTER MODIFICATION OF RAPHS.

Modification of rotary air preheater results in saving of coal cost. Thus using rotary air pre heater helps in achieving economic benefit. Cost saved using RAPH per year is shown by the following numerical. For every20°c drop in a flue gas temperature, heat recovery leads to 1% boiler efficiency improvement. Benefits obtained using air preheater with steam generator are:

- Low grade fuel burn efficiently
- Coal saving
- Load on primary fan/blower is decreased
- Preheats the air for coal drying
- To increase up to 15% boiler efficiency is achieved by RAPH.

S. No.	Parameters	Before Modification		After Modification	
		Fan A	Fan B	Fan A	Fan B
1	Unit Load	250 MW		250 MW	
2	Fuel Consumption	148 T/Hr		146 T/Hr	
3	PA Fan Current	82 Amp.	81 Amp.	64 Amp.	61 Amp.
4	FD Fan Current	31 Amp.	33 Amp.	30Amp.	32 Amp.
5	ID Fan Current	170 Amp.	172Amp.	165 Amp.	159 Amp.

Analysis of Coal cost saving per hour

Mass flow of flue gas (FG) = 300 tons/hr.= 83.33 kg/sec
Temp of Flue Gas FG at inlet of air pre heater = 350 °C
Flue gas temp at air pre heater outlet =150 °C
1 Tons coal cost = Rs1400,
Average calorific value =3200 kcal/kg
Heat recovered from flue gases
= mfg*Cp*ΔTfg
= 83.33*1.13*(350-150)
= 18832.58 KJ/S
= 4505.40 kcal/s*3600
= (16.22*10^6kcal/hr.)/3200(avg. CV)
= 5068.57 kg/hr. coal req
= 5.06857*1400
= RS 7096.008 Rs /hr. (COAL COST)
= 7096.008*8000 (let it work 8000 hr./year)
= 5.6768crores/yr.

IV NUMERICAL ANALYSIS OF RAPHS.

After studying the basic steps in CFD to be followed is to analyze the fluid flow through rotary air pre-heater. Now we can start the analysis of heat transfer with actual data. In computational fluid dynamics we follow these steps. Pre-processing, CAD modelling, Meshing, Type of solver the basic purpose of CAD modelling is to design the air pre heater rotor. following are dimension of rotor.
Diameter of Rotor = 8.6m
Height of Rotor = 1.8m

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These rotors are is divided in three portions. One portion is for flue gas entry & exit. One portion for primary gas entry & exit, 3" portion for secondary air entrance at. Different openings of primary air have been analyzed. the modelling of CAD is done with the help of ANSYS DESIGN MODULAR.

CAD MODEL OF APH SHOWN BELOW:
CASE 1.
Primary air (PA) opening = 50°, Secondary air (SA) opening = 130° and Flue gas opening = 180°

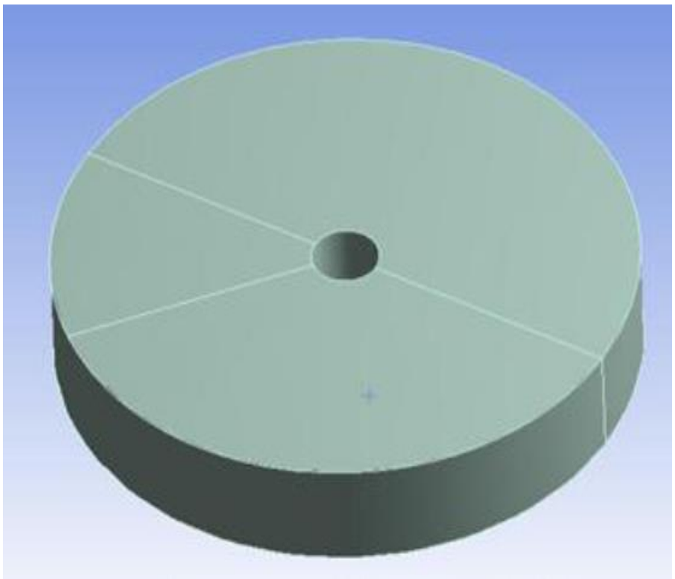

Fig: Modelling of 50° PA Opening Rotor

CASE 2
PRIMARY AIR (PA) OPENING = 60°, SECOUNDARY AIR (SA) OPENING = 120° and
Flue GAS OPENING = 180°

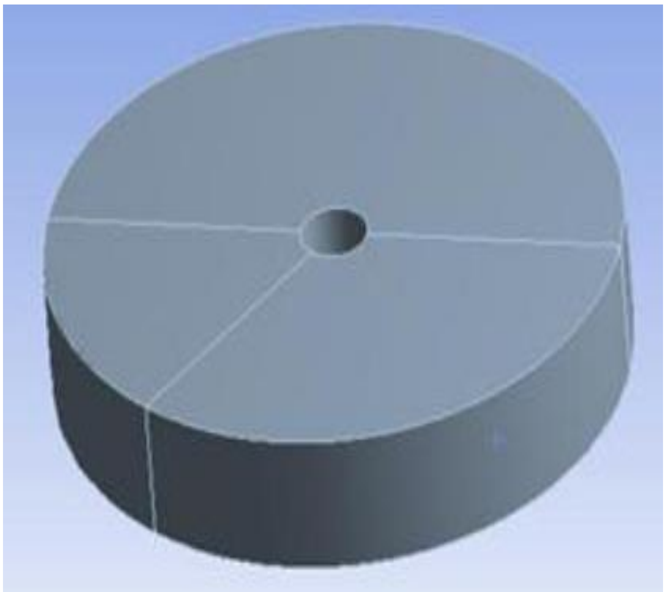

Fig: Modelling of 60° PA Opening Rotor

We generate mesh for all four-case using ANSYS ICEM, after CAD modelling. The best meshing rotary air pre-heater is hexahedral. This excellent meshing helps to obtain the best result after post processing to different operating conditions.
CASE 1(PA OPENING 50°)
MESH TYPE: HEXAHYDRAL
NO OF NODES: 16146
NO OF ELEMENTS: 13056

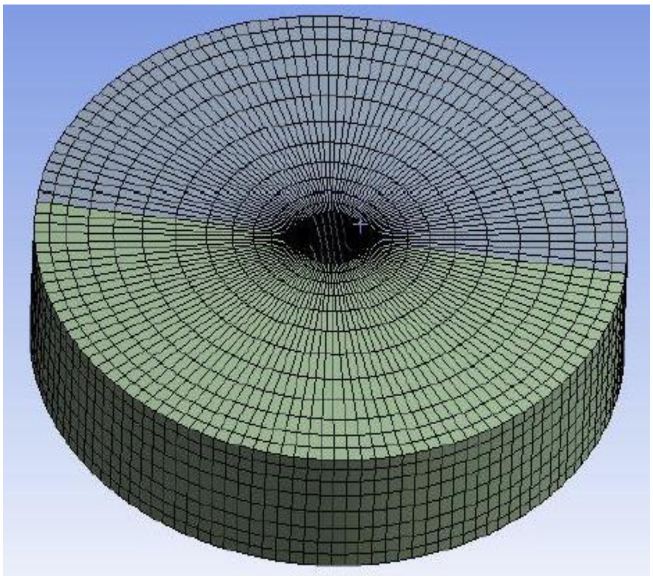

Fig: Meshing of 50° PA Opening Rotor

CASE 2 PA OPENING 80°
MESH TYPE: HEXAHYDRAL
NO OF NODES: 16263
NO OF ELEMENTS: 13152

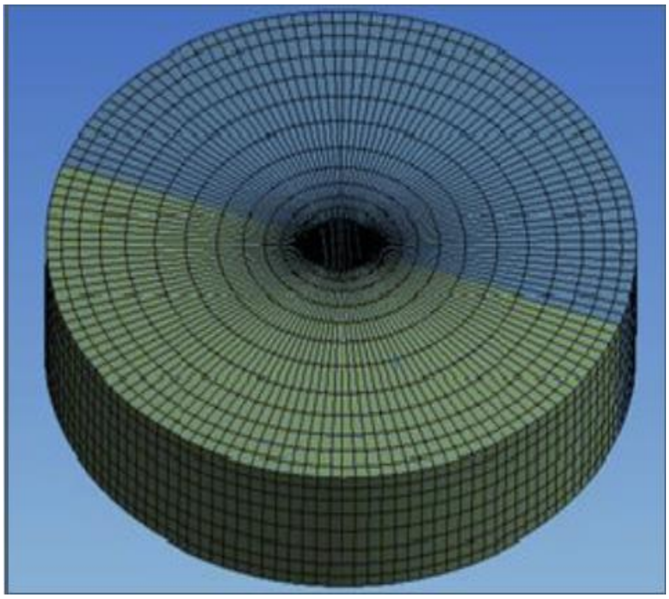

Fig: Meshing of 80° PA opening rotor

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In earlier part of study, we are optimizing the primary air opening angle for which pressure drop is minimum, based on study we found that near to 70° opening we get decrease in PA pressure drop optimum as further decrease in angle results lowering of primary air
temperature also.

Now we will vary RPM of rotor at 70° PA opening and observe the effect keeping other parameters same.

STUDY OF TEMPRATURE PROFILE

Figure which is given below shows the variation of temperature across air pre-heater for 2 different RPM values we observe very minute changes in temperature pattern. Almost negligible.

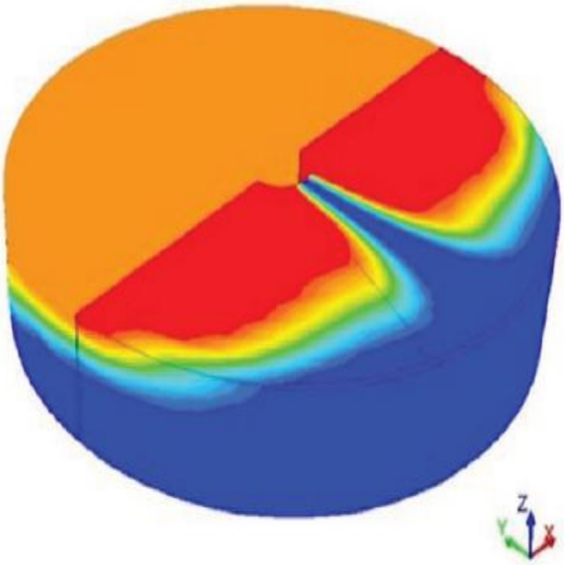

Fig**:** Temperature dist. at 1.5 rpm

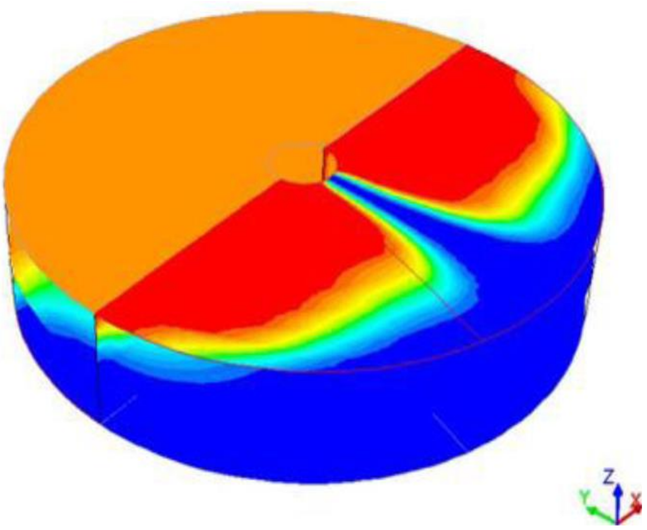

Fig**:** Temperature dist. at 2 rpm

Inlet conditions of Primary & Secondary air

Inlet Primary air		Inlet Secondary air	
Mass flow rate	36.11 kg/s	Mass flow rate	40.27 kg/s
Velocity for 50° PAopening	4.253765 m/s	Velocity for 130° SA opening	1.824557m/s
Velocity for 60° PAopening	3.544785 m/s	Velocity for 120° SA opening	1.976577 m/s
Velocity for 70° PA opening	3.038073 m/s	Velocity for 110° SA opening angle	2.15627 m/s
Velocity for 80° PA opening	2.658568 m/s	Velocity for 100° SA opening	2.37191 m/s

GAS SIDE EFFICIENCY AT DIFFERENT PA OPENING

Gas side efficiency is defined as the ratio of drop of Gas Temperature across the air heater, corrected for no leakage, to temperature head. Gas side efficiency is denoted by η.

$$\eta = \frac{Temperature\ Drop}{Temperature\ Head} * 100$$

S.NO.	ANGLE IN DEGREE	$\frac{T_{g,in} - T_{g,out}}{T_{g,in} - T_{air,in}}$	GAS SIDE EFFICIENCY
1	50	$\frac{623.15 - 395.944}{623.15 - 303.15}$	0.71001875
2	60	$\frac{623.15 - 394.3129}{623.15 - 303.15}$	0.7151159
3	70	$\frac{623.15 - 393.0736}{623.15 - 303.15}$	0.718988
4	80	$\frac{623.15 - 392.117}{623.15 - 303.15}$	0.7219781

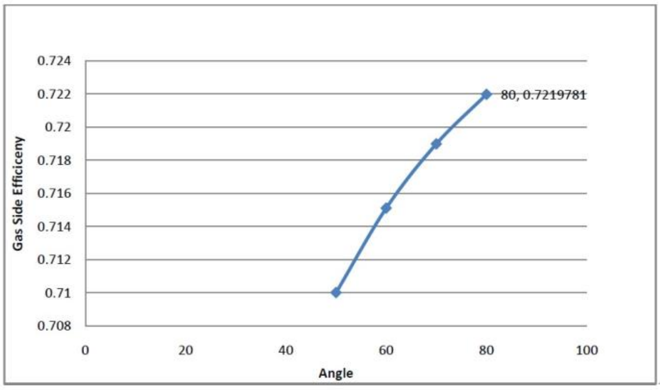

Fig: graph between gas side efficiency and PA opening

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Through the above graph we can conclude that when inlet angle of primary air opening increases from 50° to 80° gas side efficiency increases from 0.71 to 0.72.

X-RATIOS FOR DIFFERENT PA OPENING:

Heat capacity ratio of air passing through the air heater to that of flue gas passing through the air heater.

Mair out *Cpa*ATs=Mg*Cpg *AT

$$X - Ratio = \frac{T_{gas,in} - T_{gas,out}}{T_{air,out} - T_{air,in}}$$

X-Ratio depends on

- moisture in coal,
- leakage from the setting
- specific heats of air & flue gas

S.NO	PA OPENING ANGLE	$\frac{T_{g,in}-T_{g,out}}{T_{air,out}-T_{air,in}}$	X RATIO
1	50°	$\frac{623.14-395.944}{567.16-303.15}$	0.86009
2	60°	$\frac{623.15-394.3129}{560-303}$	0.888
3	70°	$\frac{623.15-393.15}{555.22-303}$	0.91300
4	80°	$\frac{623.15-392.15}{550.74-303}$	0.9316

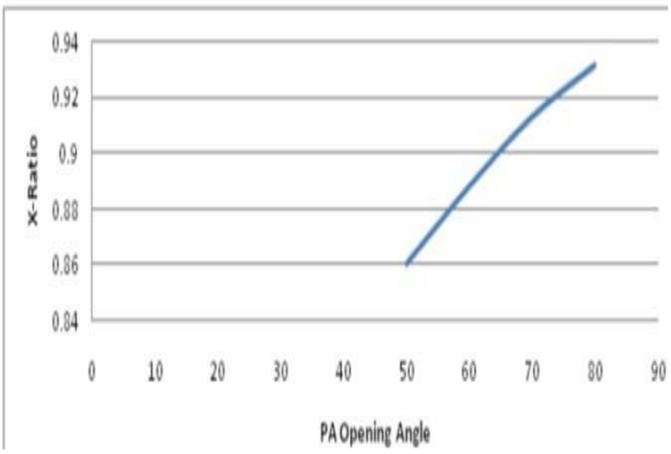

Fig: Graph of Variation of Xx -Ratio with PA Opening

Through the graph between X-ratio and different primary air opening angle we can conclude that when inlet angle of primary air opening increases from 50° to 80° X-ratio increases from 0.86 to 0.93.

Note-X-ratio does not provide a measure of thermal performance of air pre-heater, it gives indication of condition on which it operates. A low X-ratio indicates either excessive gas weight through the air heater or that air flow is bypassing the air heater.

A lower than designed X-ratio results into a higher than design gas outlet temperature& can be used as an indication of excessive tempering air to the mills or excessive boiler setting

V CONCLUSION

After analyzing the heat transfer between flue gas and air (primary as well as secondary) in tri-sector air pre heater using CFD analysis of fluid flow in ANSYS FLUENT software following conclusions can be drawn

1) We optimize the primary air inlet opening angle, based on our results we found that as primary air opening increases pressure drop across primary section of air pre heater is reduced significantly, as a result loading on primary air fan get reduced thus, we got margin on PA FAN. Now we are able to supply same mass flow rate of primary air at reduced primary fan electric consumption & also we are able to supply more amount of primary air for increase in boiler loading. The possible reasons behind reduction in primary air pressure drop is reduction in resistance across air pre heater, now same amount of primary air get more area to flow thus flow resistance reduced.
2) By increasing primary air opening thermal performance of air pre heater is improved, as flue gas temperature drop across air pre heater is increases with increased primary air opening angle
3) Gas side efficiency which is ratio of flue gas temperature and temperature head justify the improved performance, as gas side efficiency increases with increase in Primary air opening
4) Low value of X-RATIO than designed X-ratio indicates high flue gas exit temperature or air is By-passing the air pre heater.
5) In our case the value of X-ratio is good & it increases with increase in primary air inlet opening.
6) Increase in primary air opening angle lowers the pressure drop across primary section of air pre heater but it lowers PRIMARY AIR temperature also.
7) Primary air has two purposes i.e.; it absorbs the moisture in pulverized coal & it lifts the coal from mill brings it to boiler. For this reason, we get optimum results in between 70° to 80° primary air opening.
8) Temperature distribution of air pre-heater indicates highest temperature achieved neat to center of rotor and at cold end chances of corrosion is high thus suitable material selection is done with keeping this.

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