OPTIMIZATION OF PRIMARY AIR INLET OPENING OF TRI-SECTOR AIR PRE-HEATER FOR MINIMISING PRIMARY AIR PRESSURE DROP IN AIR PRE HEATER (APH) & TO STUDY THE EFFECT OF VARIATION OF RPM ON APH PERFORMANCE USING CFD ANALYSIS

M.TECH. DISSERTTION

by

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DISSERTATION REPORT

ON

OPTIMIZATION OF PRIMARY AIR INLET OPENING OF TRI-SECTOR AIR PRE-HEATER FOR MINIMISING PRIMARY AIR PRESSURE DROP IN AIR PRE HEATER (APH) & TO STUDY THE EFFECT OF VARIATION OF RPM ON APH PERFORMANCE USING CFD ANALYSIS

Submitted in partial fulfilment of the requirements for the award of degree of

MASTER OF TECHNOLOGY
IN
DESIGN ENGINEERING

Submitted By

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CERTIFICATE

This is to certify that the dissertation work entitled "Optimization of Primary Air Inlet Opening of Tri-Sector Air Pre-Heater for Minimising Primary Air Pressure Drop in Air Pre Heater (APH) & to Study the Effect of Variation of RPM on APH Performance Using CFD Analysis" by Mr. Mohit Rajput is a bonafide work completed under my supervision and guidance, and hence approved for submission to the Department of Mechanical Engineering, Malaviya National Institute of Technology in partial fulfillment of the requirements for the award of the degree of Master of Technology with specialization in Design Engineering. The matter embodied in this Seminar Report has not been submitted for the award of any other degree, or diploma.

(Dr.Himanshu Chaudhary)

Department of Mechanical Engineering,

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Place : Jaipur

Date : 30 June , 2016

Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled
"Optimization of Primary Air Inlet Opening of Tri-Sector Air Pre-Heater for
Minimising Primary Air Pressure Drop in Air Pre Heater (APH) & to Study the Effect
of Variation of RPM on APH Performance Using CFD Analysis" in partial fulfilment of
the requirements for the award of the Degree of Master of Technology in Design
Engineering, submitted in the Department of Mechanical Engineering, MNIT, Jaipur is
an authentic record of my own work carried out for a period of one year under the
supervision of Dr. Himanshu Chaudhary of Mechanical Engineering Department,
MNIT, Jaipur.

I have not submitted the matter embodied in this dissertation for the award of any other
degree.

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Mohit Rajput

Place : Jaipur
Date   : 30 June, 2016

<u>ABSTRACT</u>

TRI-SECTOR rotary air pre heater is a regenerative heat exchanger which utilises waste heat energy contained in hot flue gases (product of combustion) by transferring this heat to incoming air which is to boiler.

In this era of energy crises air pre heater becomes an essential part of thermal power plants, installation of air pre heater save up to 15 % of fuel cost in power plants.

In this study 3D modelling of tri-sector air pre heater done in ANSYS DESIGN MODELER, we assume rotor made up of pores material and properties of material as constant. Air and flue gases flows in counter flow directions & there is separate passage for primary air, secondary air and flue gases.

Earlier tri-sector air Preheaters is provided with 50° primary air opening in tri sector air pre heater based on the quality of coal (4000 to 4500 Kcal/kg) exists that time , but coal available today is of lower quality (3000 to 3500 Kcal / hr) thus more quantity of coal to be fired and for this more amount of primary air to be supplied to mills . this increased primary air flow results in high pressure drop across the air pre heater causes higher loading of primary air fans.

In order to overcome this problem we studied the effect of increase in Primary air inlet opening which minimises the primary air pressure drop across air pre heater. we taken 4 different primary air opening angles i.e $50°, 60°, 70° \& 80°$ and study its effect on primary air pressure drop and air pre heater performance.

Also we studied the effect of variation of rotor RPM for 70° primary opening on performance of Air Pre-heater.

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1. Introduction:

1.1   AIR PRE-HEATER OVERVIEW

Air Pre-heater is a kind of heat exchanger which is used to transfer heat from hot flue gases (hot fluid) to air (cold fluid) supplied for combustion. It is important auxiliary equipment in modern thermal plants and industrial process.

1.1.2   AIR PRE-HEATER CLASSIFICATION

Air pre-heaters broadly categorised into two categories

1. RECUPRATIVE TYPE(heat exchanger without storage)
2. REGENRATIVE TYPE(heat exchangers with storage)

In recuperative type air preheaters a solid wall partition   separates hot and low temperature fluid. The transfer of heat occurs due to conduction and convection through partition wall, the heat transfer consist of

- Convection between the hot fluid and the wall.
- Conduction by wall.
- Convection between wall and cold fluid.

Such types of heat exchangers are used when mixing between two fluids is undesirable. Majority of industrial application heat exchangers comes in this category.
Examples are:

- Steam coil air pre-heater (SCAPH)
- Tubular air preheaters.
- Plate type air preheaters.
- HPH & LPH

In Regenerative type air pre-heater matrix element (certain medium) is heated by passing hot fluid through it. Heat transfer takes place from hot fluid to matrix element, matrix element

accumulate heat in it. The heat thus stored here is further transferred to cold fluid by allowing it to pass over heated matrix.

In rotary air pre-heater matrix is made to rotate through hot flue gases and the cold air passages. Part of matrix which arrives in flue gas path get heated the same heated element when comes to cold fluid path during rotation delivers the heat to the cold fluid. Heat transfer process is transient in nature.

Examples: Ljungstrom air pre-heater.

Both the regenerator and the recuperative are surface type heat exchangers because heat transfer is linked with surface of solid.

Use of APH in boiler:
Benefits of using air pre-heater with steam generator are
- Fuel saving.
- Ability to burn low grade fuel effectively

Improved combustion results into very low carbon deposits that normally lead to fouling in furnace and thus limit boiler output.
For every 20 degree centigrade drop in flue gas temperature by heat recovery leads to 1% boiler efficiency improvement.
A boiler equipped with air pre-heater generates same amount of steam , compare to a large boiler without air preheaters . For coal fired furnaces, an air pre-heater system provides hot air for fuel drying.

1.1.3   USE OF AIR PRE-HEATER IN BOILER:

 Energy saving in 210 mw steam generator:
(Data Taken From Satpura Thermal Power Plant Sarni M.P. Ph-3 Unit No 8 APH)

Mass flow of flue gas (FG) = 300 tonnes/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 = mass*sp heat*temp. Difference =$m_{fg}*C_p*\Delta T_{fg}$

$= 83.33*1.13*(350\text{-}150)$

$=18832.58$ KJ/S $=4505.40$ kcal/s*3600

$= (16.22*10^{\wedge}6$ kcal/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 per year)

$=5.6768$crores/yr

Since 2 APH working for 210 mw unit

Total saving= 11.35 crores per year.

ADVANTAGES OF USING APH WITH BOILER:

- ABOUT 15% saving in fuel cost
- It preheats the air for coal drying.
- Enable burning of low grade fuel effectively.
- Save energy by waste heat utilization.

1.2   STEAM COIL AIR PRE-HEATER (SCAPH)

Steam coil Air Preheater (SCAPH) is used to protect the Cold End Heating Elements components of an Air Preheater from Low Temperature Corrosion. It is located in the cold air duct between the FD fan and the Air Preheater.

SCAPH is a Finned Tube heat exchanger. The straight finned tubes are welded to the steam inlet and outlet Headers. Steam passes through the tubes and the air flows over the fins. The heat is transferred from steam to cold air.

 Heated air entering Air Preheater maintains the Average Cold End Temperature is, higher than Acid Dew Point Temperature. Normally SCAPH will be in operation during boiler start-up and up to 30% boiler load. Required steam will be taken from auxiliary boiler / adjacent boiler in operation.

1.3 WORKING OF AIR PREHEATER BASED ON: REGENERATION

The Regenerative Air Preheater absorbs waste heat from flue gas and transfers this heat to the incoming cold air by means of a continuously rotating Heat Transfer Elements made up of specialised corton steel. These high efficiency elements are placed spaced and compactly arranged within 12 / 24 sector shaped compartments of a radially divided cylindrical shell called the rotor.

With duct connections at both of the ends, and it is adequately sealed by Radial & Axial Sealing members forming an Air Passage through one-half of the Pre-heater and the Gas Passage through the other.

As the rotor rotates, it rotate slowly the mass of heating elements and alternatively through the air and gas passages. The heat is absorbed by the element surfaces while passing through the hot flue gas stream, and which heat is later on transferred to the air, thus increasing the temperature of the incoming air.

1.4 DESIGNATION OF AIR PRE-HEATER:

27 SIZE NUMBER	VI VERTICAL INVERTED	M MODULAR

T TRISECTOR	1800 DEPTH IN mm
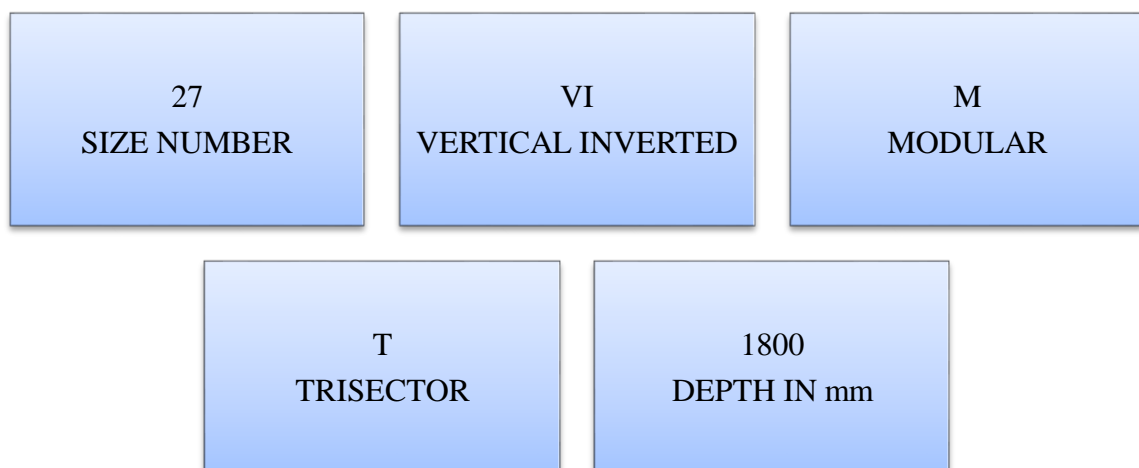
1.5 MAIN COMPONENTS OF ROTARY AIR PRE-HEATER:

Following are the various components of a air pre-heater:

a. Cellular & modular rotor,

b. Rotor housing & connecting plate,

c. Heating Elements Sealing system ,

d. Support Bearing and Guide Bearing,

e. Lubricating Oil circulation system,

f. Mechanism for driving with Auxiliary arrangement,

g. Access doors,

h. Observation ports & lights,

i. Cleaning & washing devices,

j. Rotor stoppage alarm,

k. Deluge system,

l. Element handling arrangement, and

m. Fire sensing device.

A. CELLULAR & MODULAR ROTAR:

Cellular Rotor: 12 to 24 sectors combined to form rotor. A central rotor post provided to rotor and cellular rotor shipped in separate pieces to be assembled at site for completeness of the rotor. The baskets containing heating elements are to be installed in the completed rotor at site.

Modular Rotor: The rotor is made up of 12 numbers of full sector modules that are attached are located adjacent to the rotor post are attached by pinned type joints. The modules consist of elements and shipped to site where erection is to done.

B. ROTAR HOUSING AND CONNECTING PLATES:

The Housing is octagonal in shape and consists of Main Pedestals, Side Pedestals, Housing Panels and Connecting Plates. Housing Panels, located between top & bottom plates, are the panel which form an integral structure to take loads, and also form a enclosure from a gas tight enclosure.

C. HEATING ELEMENTS:

Design of the air heater is provided with multi-layers of heating elements. The Cold End Elements made in form of basket and for easy removal and replacement from the sides. Hot End Elements can be taken away from the gas ducts at top position. Generally the Hot End & Hot Inter elements are of DU type and Cold end element is of NF type. The material for Hot End & Hot Inter is Carbon Steel and material for Cold End is Low Alloy Corrosion Resistance (Corten) Steel.

D. SEALING SYSTEM:

The rotor is divided into equal sectors each forming a separate air or gas passage through the rotor. Metal Seals of fixed leafy structure are Radially & Axially attached to the rotor structure between each sector. Radial Sealing Plates provides the sealing surfaces that divide the rotor into air and gas passages application.

The sealing system made up of Circumferential, Radial, Axial seal plate to Sector plate, and Rotor past seals designed to minimise leakage between the Gas & Air sides of the Regenerative Air Preheater.

The location of radial seals is at the edges of the radial division plates and bear against the Sector plates.

The Axial seals are located axially along the outer edges of the radial division plates and bear against the axial seal plates.

The Circumferential (or Bypass) seals are located in the housing around the periphery of the rotor and bear against the T bar attached to the periphery of the rotor.

The Axial seal Plate to Sector plate seals is attached to the axial seal plates and bear against the Sector plates.

E. SUPPORT BEARING AND GUIDE BEARING:

Spherical Roller Thrust Bearing Type is provided as support bearing and is located at the bottom Connecting Plate.

The Spherical Roller bearing type used as guide bearing and is located at the top Connecting Plate.

The Bearing Housings are designed to act as oil reservoirs for provision of integral oil circulation system.

F.   LUBRICATING OIL SYSTEM:

Both the Support & Guide Bearings are provided with independent recirculation of oil. Circulation of oil system contains Oil Pump, Oil Cooler, Pressure & Temperature Indicators and Flow Switches.

G.   DRIVING SYSTEM WITH BACKUP ARRANGEMENT IN CASE OF EMERGENCY

The drive system envisaged is of peripheral Pin Rack - Pinion Type. It consists of a two input Speed Reducer with built-in Over-Running Clutch, one Electric Motor for main drive, and an Air Motor which is used in case of emergency.

Normally drive is through the Electric Motor and in the event of tripping due to electrical fault , the Air Motor comes into operation automatically, compressed air being admitted through solenoid valve. The air line is fitted with necessary

H.   ACCESS DOORS:

A sufficient numbers of access doors are given, both at the inlet and outlet ducts and also in the housing panels for inspection and maintenance.

I.   OBSERVATION PORT & LIGHT

Observation Port & Vapour Proof Light are provided. There location is near to the air inlet portion to have a complete view of the Cold End Elements while in operation.

J.   CLEANING AND WASHING DEVICES

CLEANING DEVICES:

Twin nozzles are given in heat exchanger with Swivelling Arm type Power Driven Cleaning Device at gas outlet side, for on load cleaning of air heater elements.
The cleaning device unit is located on the housing wall with the swivelling arm nozzle transverse horizontally in an area across the radius of the rotor, a short distance away from the element packs.

Off-Load Water Washing Device:

Two fixed multi-nozzle washing pipes are fitted, one above and another at lower part of the rotor. Ends of the pipes where surface connection can be given are located adjacent to rotor housing.

K. ROTAR STOPPAGE ALARM

Rotor stoppage alarm is provided to indicate the slowing down of the rotor. This consists mainly of vane operated proximity Switch and Vanes, which are mounted on the Trunnion. Signals from the proximity switch is taken to customer DDCMIS at UCB to generate rotor stoppage alarm if the vanes fail to pass under the proximity Switch within the set time interval, to warn the operator that the rotor is slowing down.

L. DELUGE SYSTEM:

Two fixed multi-nozzle fire fighting manifolds are fitted to both ends of rotor .points on the terminal sides where surface connection can be given are located nearby to rotor housing. In case of extreme difficult situation caused by APH, all fire prevention mechanism and water washing manifolds must be used.

M. ELEMENT HANDLING ARRANGEMENT

Heat exchanger is provided with a Pulley Block operated by hand with Trolley for handling of hot end elements from inside of the Air Preheater to the Air Preheater operating floor.

N. THERMOCOUPLE FOR APH FIRE SENSING:

Thermocouple which comes under category of shell type elements placed at the Connecting Plate Centre Sections are arranged (in radial direction) in the air outlet & gas outlet ducts close to rotor face, such that there is a measuring point between each tangential walls of the rotor.

The increasing temperature, as a result of fire, causes instantly and repeatedly increase of the thermo-electric voltage and the signal released by thermocouple is given to customer DDCMIS at UCB for suitable alarm. If fire alarm sounds, then deluge system valves and water wash system valves shall be opened.

1.6 TRI-SECTOR RAPH

The tri-sector design permits a single rotary Regenerative Air Preheater to perform two functions: Coal Drying and Combustion Air heating.

As the name implies, the Tri-sector design has three sectors - one for flue gas, one for primary air (the air which dries the coal) and one for secondary air (the air which goes to the boiler for combustion).

With this design, if there is a large variation in primary air flow, there is relatively little effect on heat recovery since heat that is not recovered in the primary section can be picked up in the secondary section. This is a highly desirable feature, since it minimises heat losses when alternate fuels are burnt.

1.6.1 ADVANTAGES OF TRI-SECTOR AIR PREHEATERS

i. The addition of a primary section to form the tri sector design is a practical means of providing both primary and secondary air from a single Air Preheater.

ii. The tri-sector Air Preheater can supply the required primary air temperature. The secondary air section is located immediately following the flue gas section and ahead of the primary air section in the direction of rotation (reverse rotation).

iii. The tri-sector Air Preheater yields a more economical duct arrangement than separate primary and secondary Air Preheaters. Tri-sector heater requires just a single gas duct common for heating both primary and secondary air.

iv. It is flexible in meeting operational changes and is easily adaptable to varying coal moisture content, which is a highly desirable feature for Indian monsoon

v. A lower KW per ton of coal pulverized can be realised by the elimination of the hot air fan and / or exhauster conditions.

1.6.2 TRISECTOR APH RESULTS IN LESS TOTAL COST BECAUSE:

- By combining primary & secondary Air Heating systems in one unit, an appreciable saving is made in the plant space and structural requirements.
- Less electrical wiring & controls are required for the tri-sector Air Preheater arrangement.
- One set of Cleaning & Washing equipment including air and / or steam and water piping is required instead of two or more sets.

- Fewer expansion joints are required.
- Less insulation required.
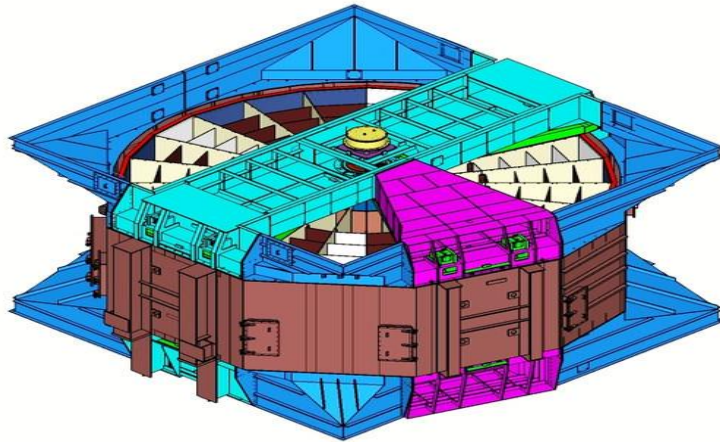
Fig 1.1 Rotor assembly

Fig. 1.2 Modular Rotor
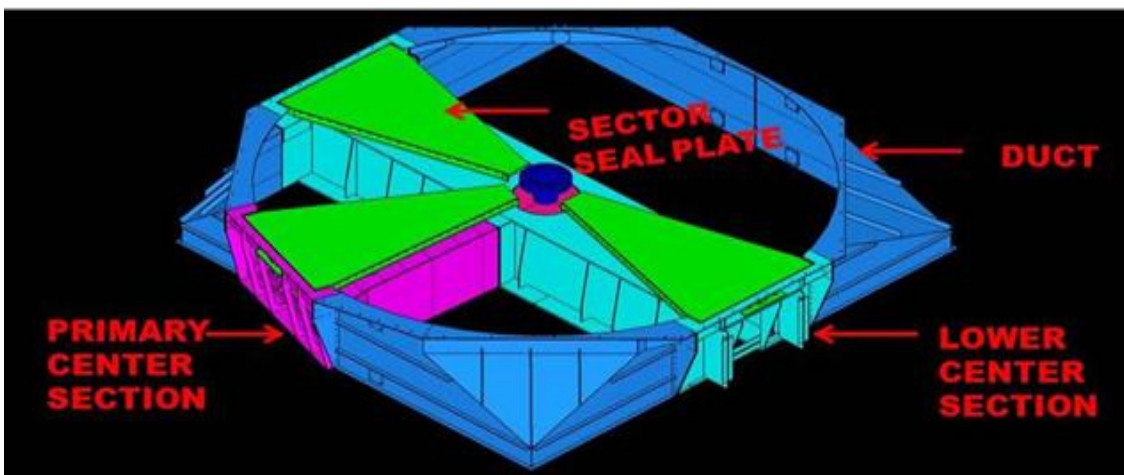
Fig 1.3 Sector seal plate
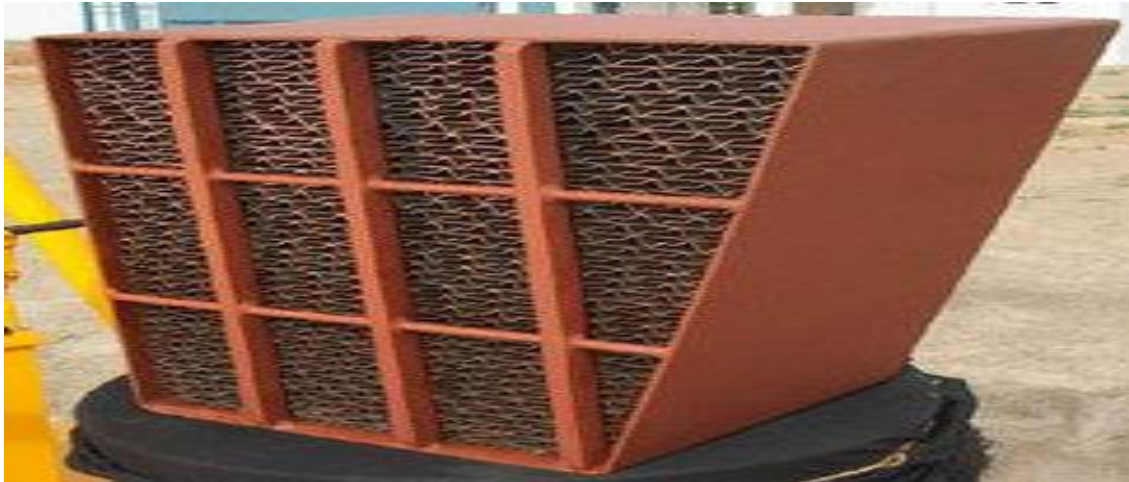
Fig. 1.4 Basket of heating element

1.7   FAN

'Fan' is one of the many types of turbo machines used for energy transfer. It can be defined as a rotating machine with an impeller having blades, which provides a continuous air flow. It is continuous because the flow at entry and exit and through the impeller is steady.

1.7.1   PRINCIPAL OF WORKING:

It is possible that energy transfer can be from the machine to the Flowing fluid or vice-versa. Fans, Blowers, Compressors, Pumps etc., fall into the category where transfer of energy takes place from the Machine to working Fluid, i.e. Mechanical Energy conversion takes place in the form of Energy associate with fluid. One fundamental Difference between Fans, Compressors& blower and Pumps is that the Pump handles liquid, whereas the others handle air or gas.

A turbine comes in category, where transfer of energy occurs through fluid to the prime mover. In different way, the Fans consume power as they rotate with the help of prime mover and energize the Flowing fluid whereas turbines rotates due to the fluid energy imparted to it and helps in generating power.

1.7.2   CLASSIFICATION OF FANS:

Fans are of two types

 i.   Axial flow

 ii.   Radial flow.

1.7.2.1 AXIAL FLOW FANS:

In axial flow fans the main flow is parallel to the axis of rotation of the fan both at entry and exit. Axial fans further divides in two groups

- Reaction type
- Impulse type

1.7.2.1.1 REACTION FAN:

Axial Fans (reaction type), maximum energy at outlet of the impeller is in the form of Energy resembles with pressure. It is called Degree of Reaction. It is expressed as

$$R = \frac{static\ pressure\ rise\ across\ impeller}{total\ pressure\ rise}$$

The pressure rise for an individual fan can be increased multi-fold by arranging two or more impellers in series in the same housing depending upon the requirement. This is called staging.

1.7.2.1.2 IMPULSE FAN:

In the impulse type fans, most of the energy coming out of the impeller is Kinetic Energy. It is converted into Pressure Energy in the Outlet Blades and the diffuser. Hence, these fans are called Impulse Fans.

1.7.3 RADIAL FANS:

Based on the arrangements of blade with respect to the direction of rotation of the impeller it is called Backward Curved, Forward Curved and Radial Bladed impeller.

```
                    ┌──────────────────┐
                    │    Radial fan    │
                    └──────────────────┘
           ┌───────────────┼───────────────┐
   ┌───────────────┐ ┌───────────────┐ ┌───────────────┐
   │ forward curve │ │ backward curve│ │ radial bladed │
   │(blade angle at│ │(blade angle at│ │(blade angle at│
   │  exit <90°    │ │  exit >90°    │ │  exit= 90°    │
   └───────────────┘ └───────────────┘ └───────────────┘
```
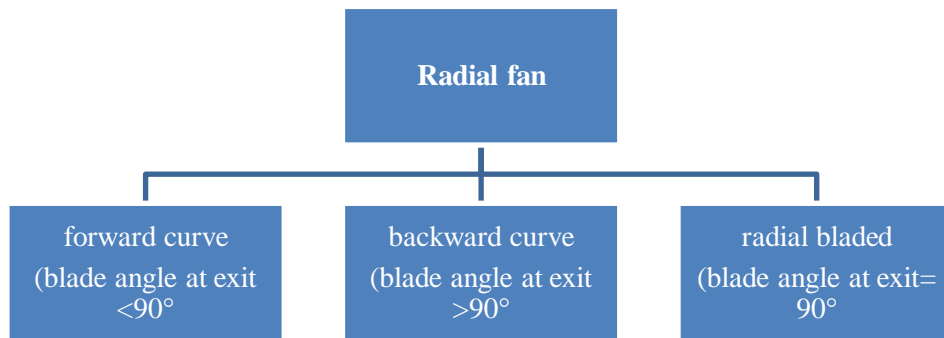
- Impeller consists of backward curve vanes are the most efficient among the three and hence mostly used.
- Forward Curved impellers have the overloading characteristic and are more power consuming. Because of the self cleaning characteristics of the Forward Curved Bladed impeller they are used in some ID application.

1.7.4   CLASSIFICATION OF FANS ON THE BASIS OF APPLICATION

1. **FORCED DRAFT FAN:** This is used for supplying secondary air to the furnace for combustion.
2. **INDUCED DRAFT FAN:** This create negative draft in the furnace which results suction of flue gases from the furnace through the system and delivers to the chimney.
3. **PRIMARY AIR FAN:** This supplies air to carry the fuel from the mills to the burners.
4. **GAS RECIRCULATION FAN:** This sucks the flue gas from the Boiler Second pass and delivers it to the bottom of the furnace helping steam temperature control when the boiler is oil fired one.

1.7.5   PARAMETERS FOR FAN:

Main parameters are mentioned below

1. Volume flow rate   : Q meter cube /sec

2. Differential pressure : H mmwcl

3. Temperature : °C degree centigrade

4. Density of medium : kg/ m^3

5. Medium handled : fresh air / flue gas

1.8 FLOW CONTROL:

Different types of control used for fans are:
   a. Damper control
   b. Inlet guide vane control
   c. Speed control
   d. Blade pitch control

DAMPER CONTROL:

This is least efficient of all the controls. Its actuation is done by servo motor.

INLET GUIDE VANE CONTROL:

This control is used invariably in axial impulse type (AN) fans and radial fans. This is more efficient than damper control.

SPEED CONTROL:

This is achieved either by a variable speed motor or hydraulic coupling.

Q is proportional to ND^3

H is proportional to N^{2}D^2

(Where Q is volume, H is pressure head, N is speed, and D is dia. of fan)

BLADE PITCH CONTROL:

This is the most efficient of all the controls. The blades of impeller are turns
During operation and hence the angle of entry is varied to vary the performance. The hydraulic servomotor helps in achieving the control with the help of an external oil system.

Table 1.1 Technical Specification of Fans Use in MPPGCL STPS SARNI Ph-3 Unit No-8,

1. Primary Air Fan (PA fan)

Type & size	Single suction radial flow
Flow discharge delivers	bottom horizontal
Medium handled	Atmospheric air
Location	Ground level
No off fan /boiler	2
Capacity	661 m^3/sec
Specific weight of medium	1.077m^3/kg
Total head developed	1375 mmwcl
Speed	1480 rpm
Temperature of medium	40 °C
Regulation of fan	Inlet guide vane control
Drive motor rating	1250 KW
Motor rpm	1480

2. Secondary Air Fan(Sa Fan)

Type & size	Axial reaction type
Orientation	Horizontal
Medium handled	Atmospheric air
Location	Ground level
No off fan /boiler	2
Capacity	110m^3/sec
Specific weight of medium	1.077m^3/kg
Total head developed	520mmwcl
Speed	1480 rpm
Temperature of medium	40 °c
Type of fan regulation	pitch control
Drive motor rating	750 KW

Motor rpm	1480rpm

3. **Induced Draft Fan (Id Fan)**

Type & size	Axial impulse type
Orientation	Horizontal
Medium handled	Atmospheric air
Location	Ground level
No off fan /boiler	2
Capacity	230m^3/sec
Specific weight of medium	0.765m^3/kg
Total head developed	350mmwcl
Speed	980 rpm
Temperature of medium	150°c
Type of fan regulation	pitch control
Drive motor rating	1300KW
Motor rpm	980rpm

2. LITERATURE REVIEW

2.1 INTRODUCTION

Many CFD analyses have been done over air pre-heater but there is no work is done on the primary air inlet opening of tri-sector is performed. There is need to optimise primary air inlet opening angle of an air pre-heater which minimise the primary air pressure drop. However, the following studies were useful in setting up proper CFD models for the purposes of this research.

I.   **Armin Heidari-Kaydan, Ebrahim Hajidavalloo:** "Three-dimensional simulation of rotary air preheater in steam power plant"

- rotor material is supposed as a porous media
- 3D simulation done.
- Impact of various parameters on APH performance is discussed.

II. **SreedharVulloju, E.Manoj Kumar, M. Suresh Kumar and K.Krishna Reddy: "**LJUNGSTORM air heater heating elements performance is analysed"

- In this research paper area of concentration was heating elements.
- They want to develop new element profiles which minimise the pressure drop across them.
- Two types of elemental profiles (flat notched cross & double undulated elements) studied in wind tunnel.
- Performance studied at different Reynold no. are done.

III. **Teodor Skiepko& Ramesh K. Shah:**"A comparative study of regenerator theoretical result with experimental results of air pre-heater operated in a thermal plant is carried out"

- Basic idea was to compare the result obtained by theoretical modelling with directly measured experiment data.
- Rotary air pre heater regenerative in nature it heat flow model involving longitudinal matrix heat conduction is formulated in the paper.
- The results representing temperature distributions of heat exchanging gases and continuously rotating matrix are illustrated by means of 3D charts.
- For the rotary air pre-heater having diameter 5.3 m ,variation of temperature throughout computed are compared with experimental data.

IV. **Bostjan Drobnic, Janez Oman & Matija Tuma: "**study of leakages in a rotary air pre-heater and heat transfer analysis using numerical modelling"

- Flue gas flow through pre-heater and adjoining channels is studied.
- Regenerative heat transfer and temperature profiles in matrix media is studied.
- An influence of leakage on performance parameters is studied.
- Dependence of parameters on seal setting is found.

V. **SANDIRA ELJSAN, NIKOLA STOSIC, AHMED KOVAČEVIĆ, and INDIRA BULJUBASIC:** "Optimization of working parameters of regenerative air pre-heater for improvement in energy efficiency of coal fired steam boiler.

- They vary the load at constant speed and observation recorded.
- Effectiveness is calculated for different operating parameters variation.

VI. **N. Ghodsipour &M. Sadrameli: "**There topic was experimental and sensitivity analysis of a roatary air pre-heater for flue gas heat recovery".

- Regenerator simulation is done by solving a developed mathematical model.
- Optimization is done with experimental designed method.
- Effect of dimensions less parameters on effectiveness of rotary air pre-heater is studied.
- Numerical results are obtained by solving continuity, momentum & energy equation.

- To obtain experimental results lab scale rotary regenerators is used.

VII. **Hong Yue Wanga, Ling Ling Zhaob, Qiang Tai Zhoub, ZhiGaoXub, Hyung Taek Kim :** "irreversibility of air pre-heater was analysed using exergy analysis"

- In air pre-heater, there are unavoidable losses in the form of leakage because of carry over and pressure differences.
- Irreversibility arises due to mixing pressure losses and temperature gradient.
- Second law of thermodynamics governs this analysis.
- Moto is to build relation between power plant efficiency and irreversibility arises from process in air pre-heater using exergy analysis.
- Effect of variation of principle design parameters on APH efficiency and exergy efficiency is studied.

VIII. **M. Zeng , L.X. Dua, D. Liao , W.X. Chu , Q.W. Wang, Y. Luo , Y. Sun:** They investigates pressure drop and heat transfer performance of plate fin iron air pre-heater by experimental and genetic algorithm method.

- Drop of pressure heat transfer characteristics of platen fin air pre-heater is experimentally studied.
- Critical Reynolds no for laminar to turbulence is calculated.

IX. **Hong Yue Wang , Ling Ling Zhao , ZhiGao Xu , Won Gee Chun , HyungTaek Kim :**They studied the heat transfer in tri sector air pre heater using semi analytical method.

- Temperature distribution in air pre heater is determined to avoid cold end corrosion.
- Semi analytical method is employed
- Main focus is on temperature change of fluid and temperature distribution of matrix.

X. **Kaushik Krishna , Rahul Ramachandran1 and P. Srinivasan :**There work is on heat transfer modelling and heat transfer in rotary regenerative air pre-heater.

XI. **H.Y. Wang a, X.L. Bi , L.L. Zhao , Q.T. Zhou a, H.T. Kim c, Z.G. Xu :**They studied thermal stress deformation using analytical method which based on temperature distribution of matrix in a rotary air pre-heater.

3. PROBLEM DETAILS

Earlier BHEL has provided 50° primary air opening in Tri sector Air Preheaters based on the quality of coal (4000 to 4500 Kcals/Kg) prevailed at that time.

But the coal available today is of lower quality (3000 to 3500 Kcals/Kg) which requires more quantity of coal to be fired.

This necessitates supply of more quantity of primary air to mills. Increased primary air flow results in higher-pressure drop across the air pre-heater leading to higher loading on PA Fans.

In order to overcome above problem we have to increase primary air opening from 50 degree to 60°, 70° & 80°.

Primary air fan loading restrict our ability to take higher load on increasing demand as for increasing demand more amount of coal is to be lifted from mill thus more primary air needed.

Initially our primary air inlet opening was 50° due to restriction in flow passage more pressure drop occurs it results high amperage rating of primary air fan thus limits ourselves to supply a fixed quantity of primary air at full amperage rating.

But for increasing demand we required more amount of air, as more air will lift more quantity of pulverised coal from mill to boiler thus more will generate and more steam formation would occurs which lead to increased power generation.

3.1: MODIFICATIONS REQUIRED FOR CONVERSION OF PRIMARY AIR OPENING FROM 50° TO HIGHER VALUES

- Replacement of primary centre section at hot and cold ends including sector plates.

- Replacement of Air side ducts of connecting plate assembly at hot and cold ends.

- Replacement of Air side housing panels.

- Replacement of hot end sector plates with roller supported type sector plates.

- Replacement of stationary spool assembly at hot and cold end.

- Modification in guide bearing assembly and supply of modified tracking arrangement for hot end sector plates.

- Supply of thicker rotor post seal with back-up ring.

- Modification of Air inlet & outlet ducts.

- Modification of dampers.

- Replacement of air side expansion bellows at the inlet and outlet of air pre-heater.

- Relocation of support beam on air side side-pedestal.

3.2: EXPECTED ADVANTAGES WITH THESE MODIFICATIONS:

- Reduced primary air pressure drop across air pre-heater.

- Reduced PA fan loading.

- Power consumption of auxiliaries get reduced.

- Reduced erosion in APH parts due to reduced primary air velocity.

- Improvement in mill air temperature.

3.3: PROBLEM SETUP:

 For study of effect of primary air inlet opening modifications we developed a 3D modal of tri-sector rotary air pre heater assuming rotor material as porous in ANSYS DESIGN MODELER. Four different models for four different primary inlet openings ($50°, 60°, 70°\&\ 80°$) are prepared. Dimensional parameters of air pre heater are 1.8 m height & 8.6m rotor diameter (this dimensions taken from STPS MPPGCL SARNI M.P PH-3 UNIT NO. 8 air pre-heater manual).

After modelling of 4 different cases, we start meshing of each case having different primary air inlet opening. Meshing is done in ANSYS ICEM CFD. Type of mesh is hexahedral.

After meshing we define setup which includes problem type, type of solver, physical model, material property, boundary conditions ,cell zone condition, operating conditions at inlet and outlet are defined. Above mentioned work comes in pre processing of problem.

After pre processing we select solution method, solution initialization is done & we run the solution.

It is followed by post processing process here we got results which can be interpreted in many forms like graph, animations, tabular data etc.

We also studied the effect of variation of RPM of air pre-heater on air pre heater performance. We take four different RPM values (1.5 rpm, 2 rpm, 3rpm, 4 rpm)

Same procedure as mansions above followed for each different RPM study.

3.4   OBJECTIVE

To optimise the primary air inlet opening which minimise the pressure drop across the air pre-heater and hence reduction in primary air fans loading.

To study the heat transfer through tri-sector air pre-heater & to determine temperature, pressure and velocity distribution across APH.

Also to study the effect of variation in rpm of rotor on APH performance.

4.   APH PERFORMANCE ANALYSIS

4.1   PERFORMANCE PARAMETERS

- Gas inlet outlet temp/pressure
- Temperature, pressure of Primary air at inlet /outlet
- Temperature, pressure of secondary air at inlet & outlet
- Temperature at inlet outlet of air preheating coil
- Gas inlet outlet analysis (wet/dry)
- Air / gas pressure differential

4.2   AIR HEATER PERFORMANCE INDICATORS

- Air-in-Leakage
- Gas Side Efficiency
- X – ratio
- Flue gas temperature drop
- Air side temperature rise
- Gas & Air side pressure drop

4.2.1   LEAKAGE:

Air heater leakage is inherent in all air - to - gas heat exchangers to varying degrees. Simply stated, the driving force that causes leakage is the difference in the static pressure levels between the air & gas streams.

In addition, the quantity of the leakage is dependent on the seal clearance and the length of the seals separating the two sides. Because of temperature difference is part of all

Air pre heater, deformation structure takes place resulting in clearances or gaps between seal and sealing surfaces.

4.2.1.1   DEFINATION OF LEAKAGE:

Direct leakage is the quantity of air that passes in to the gas stream between the seals and sealing surface as a result of the static pressure differential between the air and flue

gas. The degree of leakage through seals is directly proportional to the square root of the pressure differential and is also dependent on fluid density.

Entrained leakage is the quantity that is contained in the rotor as the rotor passes from the air side to the gas side and vice versa. The amount of this leakage varies with the geometry and speed of rotor
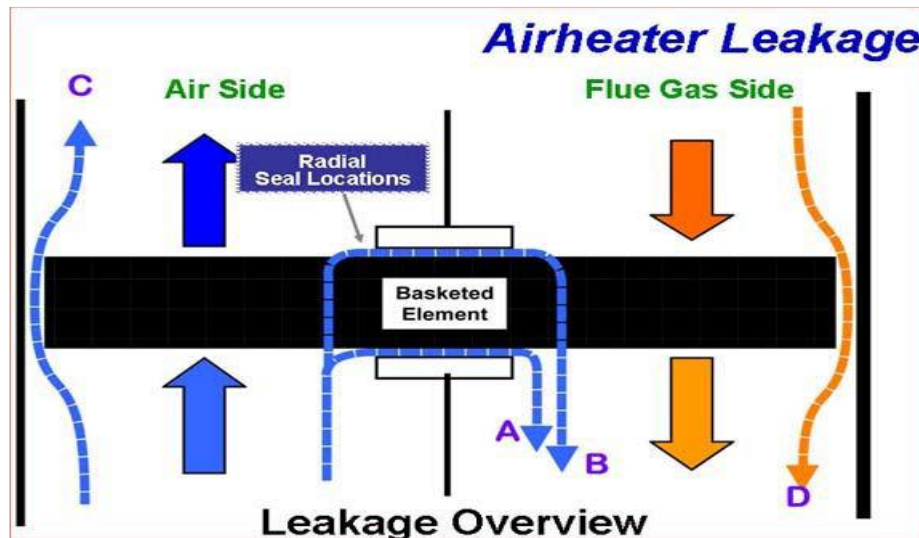
Four Leakage Paths in Air Heaters

Fig. 4.1 Leakage path on air pre-heater

Path A - Cold Air leaks to the gas side on Cold End,

Path B - Hot Air leaks to the gas side on Hot End,

Path C - Air Bypass through circumferential seals, and

Path D - Gas Bypass through circumferential seals.

Effects of Leakage:

Leakage whether direct or entrained has no effect on the heat transfer efficiency of the regenerative air pre-heater. There is no difference in the number of KCals transferred to the air stream from the gas stream because of leakage. However, the gas temperature leaving the pre-heater is diluted or decreased by 5 to 10°C by the mixture of the cooler air with the hotter gas stream.

% Leakage:

$$\% \, leakage = \frac{\text{Weight of Air leaking to gas side}}{total\,weight\,of\,gas\,entering\,APH}$$

$$= \frac{co_{2,in} - co_{2,out}}{co_{2,out}} \text{ x } 0.9 \text{ x } 100$$

$$= \frac{o_{2,out} - o_{2,in}}{21 - o_{2,out}} \text{ x } 0.9 \text{ x} 100$$

$CO_2 \& O_2$ mesurment preformed for flue gases.

4.2.2   GAS SIDE EFFICIENCY:

Ratio of   Temperature drop in gas side of air pre- heater, corrected for no leakage, to the temperature head.

$$Gas \ side \ efficieny = \frac{TEMPRATUREDROP}{TEMPERATUREHEAD} \text{x} 100$$

Where,

Temperature drop $= T_{GAS,IN} - T_{GAS,OUT} (no \ leakage)$,

Temperature head $= T_{GAS,IN} - T_{AIR,In}$

$T_{GAS,OUT}$ (no leakage) $=$ The temperature at which the gas would have left the air heater if there were no AH leakage.

$T_{GAS,IN} =$ Flue gas temperature to inlet of air preheater.

$T_{GAS,OUT} =$ Temperature of flue gas at outlet of air preheater.

$T_{IN} =$ Temperature of air at inlet of air pre heater

4.2.3   X-RATIO

Ratio of product of mass and specific heat of air goes into the air heater to the heat capacity of flue gas passing through the air heater.

$$M_{AIROUT} * C_{PA} * \Delta T_A = M_G * C_{PG} * \Delta T_G$$

$$\text{X-RATIO}=\frac{m_{airout}C_{pa}}{m_{gasin}C_{pg}} = \frac{T_{gasin}-T_{gasout}}{T_{airout}-T_{airin}}$$

X-Ratio depends on

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

Note: X-ratio does not provide a measure of thermal performance of the air heater, it gives idea of condition at which it operates. A very low value of X-ratio means more than sufficient gas weight through the air heater or that air flow is bypassing the air heater.

if value of X-ratio is low it means gas outlet temperature is higher than design condition & it indicates more than required tempering air to the mills or excessive boiler setting infiltration.

5.   CFD ANALYSIS OF ROTARY AIR PRE HEATER

5.1 COMPUTATIONAL FLUID DYNAMICS

Computational fluid dynamics(CFD) a computer-based simulation method for analysing heat transfer, fluid flow and related phenomena .CFD analysis of fluid flow and study of heat transfer in air pre heater is performed in this project..

The CFD based simulations find its uses in many areas of the fluid flow for example:-
- Vehicles designs for fluid flow streamlining.
- In chemical engineering to maximize the yield of their equipments.
- Architects engineers used to design the home for safe living.
- Weapons design and estimate the damage.
- Aerodynamics lift and drag i.e. in airplanes and wind mills.
- Analysis of fuel combustion in Power plants.

There are many benefits of selecting CFD over experimental setups as experiments costs directly increased with the how many configurations desired for testing, where as in CFD, a number of results can be produced at practically very low expenditure thus studies based on CFD to optimise the equipment are very inexpensive when they are compared to experiments.

This section briefly describes general concepts and theory related for using CFD to analyse fluid flow and phenomena of heat interaction in this project. Here we starts with review of things required for carrying out CFD analyses and processes to be followed , then the governing equations and turbulence models are summarised and finally a discussion of the discretization schemes and solution algorithms is presented.

5.2   CFD COMPUTATIONAL TOOLS

 In this section it is described about the CFD tools required for carrying out a simulation and the process one follows in order to solve a practical situation on CFD. One of prime requirement is hardware beside this and there are three other important elements used for processing CFD simulations:

1. pre-processor,
2. processor and
3. post-processor.

Availability of the number of commercial CFD software like Ansys CFX , Fluent, ACE, as well as a wide range of the suitable hardware and cost of it based on several difficulty of the mesh generation and size of the calculations.

For a simulation to get it run, there are three main elements which are required:

5.2.1   PRE-PROCESSOR:

A pre-processor is been used to define the geometry for the computational domain of interest and to generate the mesh of control volumes for calculations. Generally, the finer the mesh is in the areas of large changes, the more is the accuracy of the solution. Fineness of the grid also determines the computer hardware and the calculation time needed. Modelling for this project is done with DESIGN MODULAR of ANSYS, mesh generates in ANSYS ICEM CFD PAKAGE.

5.2.2   SOLVER:

The solver makes all the calculations by using the numerical based methods, which make use of either finite difference methods or finite element scheme or the spectral methods. Many CFD codes uses finite –volume method, which is the special finite difference method. Firstly fluid flow equations are to be integrated over the control volumes, then discritization of integral equation done (producing the algebraic equations through conversion of an integral fluid flow mathematical equations), and finally an iterative method is been used to solve the algebraic equations.

5.2.3   POST PROCESSING:

The post-processor will provide all visualizations for the results. Graph and charts or simulation is obtained here to understand the phenomena.

Problem- solving with CFD:-

A number of decisions has been taken earlier to set up the problem in the code made in CFD. Some of the decisions which is to be made can include.

- Decide the problems is 2D or 3D.

- Generate the geometry.

- Start geometry meshing & sizing of the elements.

- Boundary conditions are decided..

- Confirm the type of solution method either pressure based or density based.

- Initialized the problem

- Give the iteration number

- Converged to the problem

- Calculate the results.

5.3   CFD GOVERNING EQUATIONS:

Here governing equations used in CFD to mathematically solve for fluid flow and heat transfer are discussed, based on the principles of conservation of mass, momentum, and energy.

Conservation equations:

- Law of Conservation of Mass: Fluid mass is always conserved. (Equation 1)

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0.$$

- Newton's 2nd Law: The sum of the forces on a fluid particle is equal to the rate of change of momentum. (Equation 2)

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j}.$$

- First Law of Thermodynamics: The rate of head added to a system plus the rate of work done on a fluid particle equals the total rate of change in energy. (Equation 3)

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_j}{\partial x_i}\right).$$

The fluid nature described by the properties of fluid velocity vector **u** (with components u, v, and w in the x, y, and z directions), heat conductivity k, viscosity μ, pressure p, density ρ, and temperature T.

The changes in these properties of fluid can occur over time & space location. Properties are calculated for small fluid element, based on conservation laws ..These changes occurs due to the fluid flowing across the boundaries of the fluid element and this can also be due to sources within the element producing changes in properties of fluid . This is Euler method (following changes in the stationary mass while particles t are travelling through it) in contrast with the Lagrangian method (which follows the movement of a single particle when it flows through a series of elements).

5.4   FINITE VOLUME METHOD AND DIFFERENCING SCHEME

Continuity equation for mass conservation, equation for momentum conservation, and scalar transports equations are all equations integrated over all the fluid elements within a computational domain using CFD.

The FVM method is the particular finite differentiating numerical scheme it is most general and popular scheme which is used for the calculating the CFD codes. This part are elaborated the basic procedure of finite volume method that how to calculate the CFD codes.

In this method first create the system of algebraic equations by discretising the governing equations such as mass conservation equation, momentum equation, and scalar transport equation.

5.4.1   DIFFERENCING SCHEMES

The accuracy of the solution of the problem defines by the differencing scheme that is used for the discretization process. There are the different types of schemes that are available are as following: central scheme, upwind scheme, hybrid scheme, power law, and there are various type of higher order schemes. In this project the upwind differencing scheme are used for the calculation,

5.4.2   UPWIND DIFFERENCING SCHEME

The scheme for upwind differencing is designed to be capable of accounting for the directionality of flow. It is being used often in CFD codes for flow problems, which can't be calculated with the central differencing scheme. For the flow which is in one direction, for example let the flow is in positive x direction (with P node between West and East nodes), the property value achieved at the x face is now taken to be the same as the value achieved at the West node.

The scheme for upwind differencing is conservative, transportive and bounded. It is containing a first-order Taylor series truncation error, which results in the type of numerical error which is called false diffusion and (overestimation of diffusion) if the flow is not directly aligned with the grid and is causing a diffusion-like transported property distribution, even where there is no diffusion is actually occurring. Making a finer grid will improves the accuracy, but it is still the not perfect result. For more reliable results the upwind differencing scheme will not always be the best, and a higher order scheme for reducing discretization errors can be chosen instead.

5.5   SOLUTION TECHNIQUE

When discretised equations are created for each of the node in the computational domain, for using the relevant differencing scheme and modifying the first and last node to incorporate boundary conditions, the problem is ready to be solved using a solution techniche using matrix.

The TDMA (tri-diagonal matrix algorithm) is based on the forward eliminations followed by the backward substitution and various changes occurring are used together with a SIMPLE (or a variation) algorithm used for linking pressure to velocity.
Gauss-Seidel point iterative techniques shall be used for desired scaler property achieved by solving the system of linear algebraic equations. The solution algorithm SIMPLE (semi-implicit method for pressure-linked equations), used to solve for the velocity field in all the three directions and the pressure to be described in the next section.

[Hjertager, 2007] [Versteeg and Malalsekera, 2007]

5.6   SOLUTION ALGORITHMS

The desired value of scalar property at any point in the computational domain depends on the flow's direction and speed, this are solved in calculation process. To There are many algorithms available for this most common algorithms are SIMPLE   and PISO methods. Description of the SIMPLE algorithm given in this section and compares it to the PISO Algorithm . A short overview of the 'staggered grid' is also given.

In order to calculate the entire flow of field, the momentum equations in all three directions and the continuity equations must be solved simultaneously it contains velocity term and the pressure difference term. There is dependency between pressure and the three velocity components.

In cases where the pressure difference is already determined, discretization techniques can be used to obtain scalars. However, there is no transport equation for pressure only, and thus another method used to find pressure when the pressure gradient is not known.

If the flow is compressible, the transport of density is found using the continuity equation and a scalar property such as temperature is found by the combination of the momentum equations and equation for the energy. Pressure and density solutions are used for finding the pressure using the equation of state. In case of fluid compressibility condition density was not linked to pressure, a guess-and-check technique such as SIMPLE is required in order to solve the entire flow field.

5.6.1   THE STAGGERED GRID

The flow and relative transport equations are discretised. Then it must be decided where the velocity component values will be stored. If they are stored at the same nodes as pressure and other scalar variables, a particular problem of a 'checker-board' pressure field arises due to linear interpolation of pressure during the process of discretising the equations. It results in the pressure having discretised gradients of zero at all nodal points, and the discretised momentum equations are not properly representing the pressure.

To solve the 'checkerboard' problem, the velocity components can be defined at the faces, while scalar variables (i.e. pressure, density, temperature) are stored at the usual nodal points. This results in the scalar variable control volumes (sometimes called the pressure control volume) being different from the velocity control volumes, and realistic pressure gradient results.

5.6.2   THE SIMPLE ALGORITHM

The SIMPLE algorithm is a guess-and-correct technique to determine the values for pressure on a staggered grid. It is iterative and has to be done in the specific order when other scalars are also calculated. The procedure for the technique is shown in Figure 12, which is followed by a description of the steps in the algorithm.
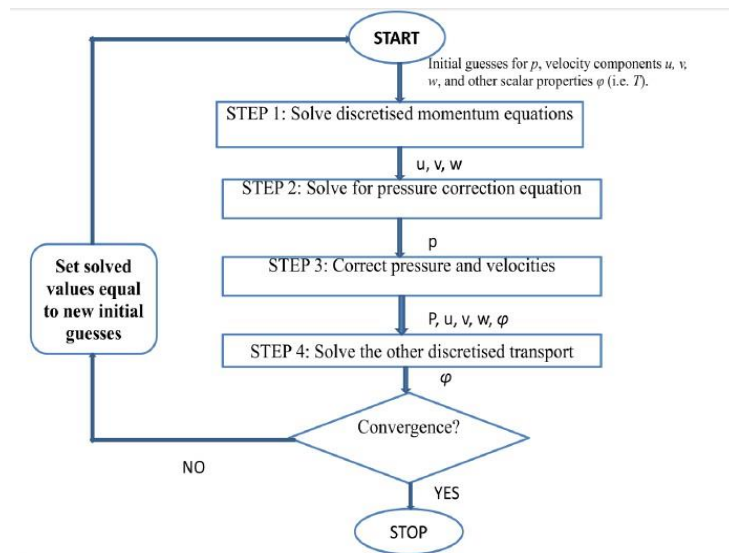
Fig. 5.1 The simple alogrithm

5.6.2.1   START

Estimate a starting guess for the pressure field p*.

5.6.2.1.1   STEP 1

Solve the discretised momentum equations for the velocity components, using the line-TDMA method, and based on the pressure guess p*. For a three-dimensional case as the one in this project, 6 discretised momentum balances are solved for each of the six

neighbours for node P (E, S, N, W, B, and T). This step results in finding values for u*, v*, w*, based on p*.

5.6.2.1.2 STEP 2

Solve for pressure correction equation to find the pressure correction p'. This is done With the discretised continuity equation by finding the mass imbalance b_p and between Total mass flow inflow and the total mass outflow of the six 'guessed' velocities (calculated based on the guessed pressure p*).

5.6.2.1.3 STEP 3

Correct the pressure and velocity components using the correction found in the pressure, here

Correction (p') is added to the initial guess (p*), to get the new pressure field p, or:

Equation 1 p = p*+ p '

This step of the SIMPLE algorithm results in calculated values for velocity components and pressure: p, u, v, w, φ*, after correcting the guesses, which satisfy the continuity Equation.

5.6.2.1.4 STEP 4

Solve the other discretised transport equations using the line-TDMA method to get calculated values for the remaining scalar variables φ.

5.6.2.2 CONVERGENCE

After step 4, the outputs are tested for convergence (meaning that the mass imbalance is very close to zero), and if this is not within the value required for convergence, the program loops back to the beginning, using the newly calculated pressure, velocity, and other scalar values as the next starting guess. The process continues until convergence occurs (iteration).

5.6.2.3 RELAXATION FACTORS

Often the pressure correction is too large, causing unstable calculations and divergence rather than convergence. Due to this problem, the iteration procedure must be slowed down to under-relax the pressure corrections. This is done by utilizing an under-relaxation factor α of between 0 and 1, which is multiplied by the correction factor so that only a fraction of the originally calculated correction factor is actually used in the calculation,   (for example with the pressure correction):

Equation 2 $p = p * + \alpha_p p'$

Under-relaxation factors are also used for the velocity components. Oscillatory or divergent solutions are a result of too large values for α , while very slow convergence results from too small of values for the under-relaxation factor. Therefore, the correct under-relaxation factor is important for a converged solution, but cannot be determined in general and must be determined for each specific CFD case.

There are also other versions of the SIMPLE method available: SIMPLER (SIMPLE-Revised) and SIMPLEC (SIMPLE-Consistent). The SIMPLER version involves using a discretised pressure equation rather than the SIMPLE correction equation used for pressure, while the velocity field is still calculated using
corrections. The SIMPLEC version omits terms from the velocity correction equation.

5.6.3   THE PISO ALGORITHM

The PISO (Pressure Implicit with Splitting of Operators) algorithm can be considered a continuation of the SIMPLE algorithm. PISO also involves making a guess for pressure, p*, and calculating the velocity components u*, v*, and w* based on this p*. There is a correction step to pressure and velocity fields, just as with the SIMPLE method. However, a second, additional, corrector step using the results from the first correction is carried out just after calculating the first correction. When the values for corrected
Pressure and velocity fields (now corrected twice) are determined; the other scalar transport equations are solved. The PISO algorithm requires more storage for the extra correction step, resulting in more computational resources needed.

Hjertager, 2007] [Versteeg and Malalsekera, 2007]

5.6.3.1   THE SEGREGATED METHOD:-

By using this method the governing equations solved properly in sequence that is segregated from one to other. Because of the non linear equation directs, several iterations must be performed for obtaining the converged solution. For obtaining the converged solution, the steps flow chart is illustrated below:-
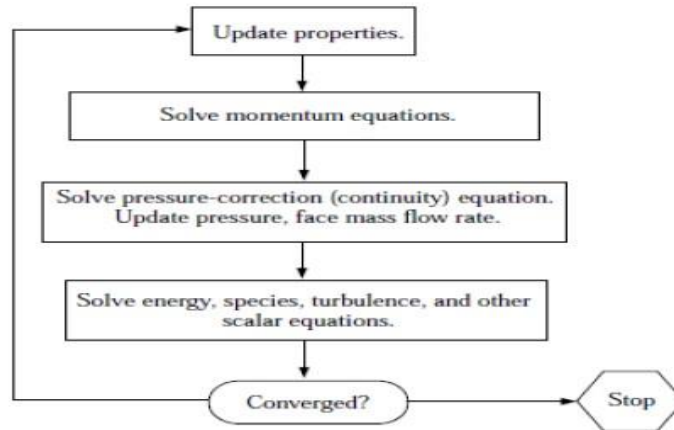
Fig. 5.2 The Segregated Method

5.6.4   COUPLED ALGORITHM:-

The coupled solver solve the governing equation of momentum equations, continuity equations, and energy equations and species transport simultaneously that is the coupled together The governing equation solve will solve the sequentially for the additional scalars (that is segregated from one to another and from the coupled set) using this Procedure described for the segregated algorithm in the above section. Because the Governing equations are non linear or coupled and then many iteration must be performed for the solution loop and then converged solution is done.

These given below steps are continued till the convergent criteria are to be done.
  i.   Based on the current solution the fluid properties are updated. If the calculation just started then the fluid properties will be updated, it is based on the initialized solution.

ii.   Solve the governing equation simultaneously like momentum equation, continuity equation and energy equations.

iii.   Solve the scalars variables such as turbulence, temperature, pressure and radiant, using the previously values of the other variables.

iv.   When the coupling inter phase is to be available in the problem then the source term in the proper continuous phase equations may be updated with the calculation of discrete phase trajectory.

v.   Then check for the convergence of the equation set is met.

The flow chart is given below with the steps that are included in Coupled Solution
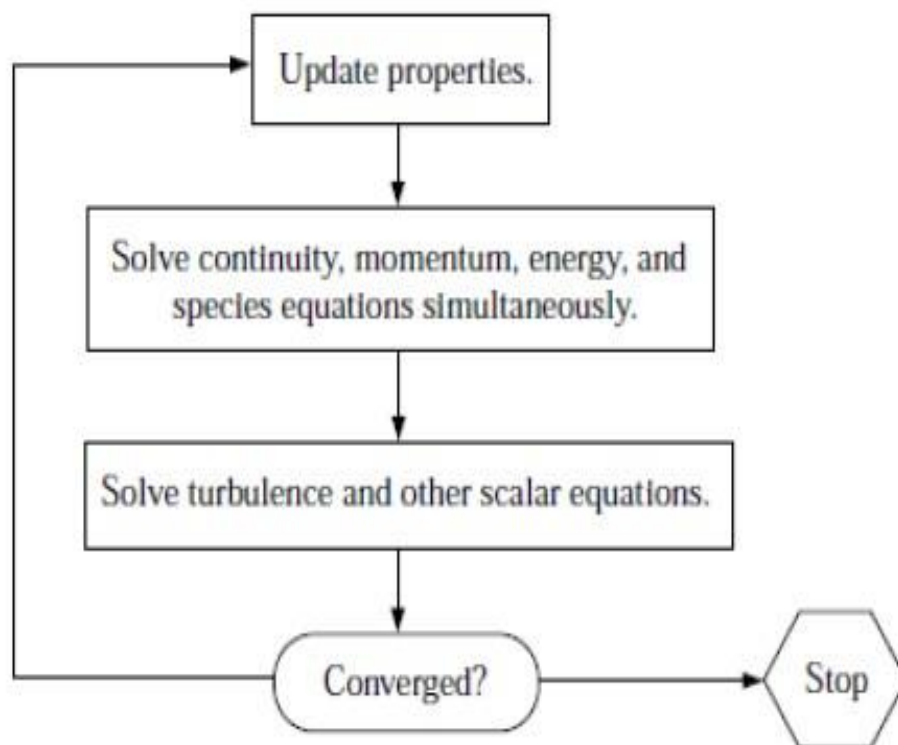
Fig. 5.3 Couple algorithms

5.7 SUMMARY OF SOLUTION ALGORITHMS

The SIMPLE algorithm is used for this project. It is a known algorithm and used in many CFD codes. SIMPLER can be used to use computer processing time more efficiently (even though there are more calculations) since it uses the correct value for pressure.

For certain types of flow, SIMPLEC and PISO can be just as efficient as SIMPLER. Which algorithm to use depends on the specific case being studied: the

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flow conditions, degree of momentum dependence and scalars, and the specific numerical schemes used.

It is assumed that the fluid includes flue gases and air passes through heating element matrix which is assumed as porous media. And properties of materials are also assumed to be constant.

5.8 BASIC STEPS TO PERFORM CFD ANALYSIS:

5.8.1 PRE-PROCESSING:

- **CAD Modelling:**
  Creation of CAD Model by using CAD modelling tools for creating the geometry of the part/assembly of which you want to do FEA.CAD model may be 2D or 3D.

- **Meshing:** Meshing is a critical operation in CFD. In this operation, the geometry in CAD is discretised into large numbers of small Elements and nodes. The arrangement of elements and nodes in space in a proper manner is called mesh. The accuracy for analysis and duration depends on the mesh size and orientations. With the increase in mesh size (increasing no. of element), the CFD analysis speed decrease but the accuracy increase.

- **Type of Solver**: Choose solver for the given problem from Pressure Based and density based solver.

- **Physical model**: Choose the required physical model for the problem i.e. laminar, turbulent etc

- **Material Property**: Choose Material property of flowing fluid.

- **Boundary Condition**: Define the desired boundary condition for the problem i.e. velocity, mass flow.

5.8.2 SOLUTIONS

- **Solution Method :** Choose the Solution method to solve the problem
- **Solution Initialization**: The solution is initialized to get the initial solution for the problem.
- **Run Solution:** The solution is run by giving no of iteration for solution to converge.

5.8.3 POST PROCESSING:

For viewing and interpretation of Result. The result can be viewed in various formats: graph, animation etc.

6. METHODOLOGY

After studying the basic steps in CFD to be followed is to analyze the fluid flow through tri-sector rotary air pre-heater**.** Now we can start the analysis of heat transfer with actual data. Following three steps are required to run the simulation.

6.1 STEP 1 PRE-PROCESSING:

It includes

- CAD modelling
- Meshing
- Type of solver
- Physical model
- Material property
- Boundary conditions

6.1.1 CAD MODELLING

In CAD modelling we designed air pre-heater rotor which consists of heating elements. The dimensions of rotor are:

Rotor dia.   : 8.6 m

Rotor height   : 1.8 m

These rotors are divided in three portions. One portion is for flue gas entry & exit. One portion for primary gas entry & exit, 3rd portion for secondary air entrance .different openings of primary air has been analysed.

CAD MODEL OF APH SHOWN BELOW:

CASE 1.

Primary air (PA) opening = 50°

Secondary air (SA) opening = 130°

Flue gas opening = 180°
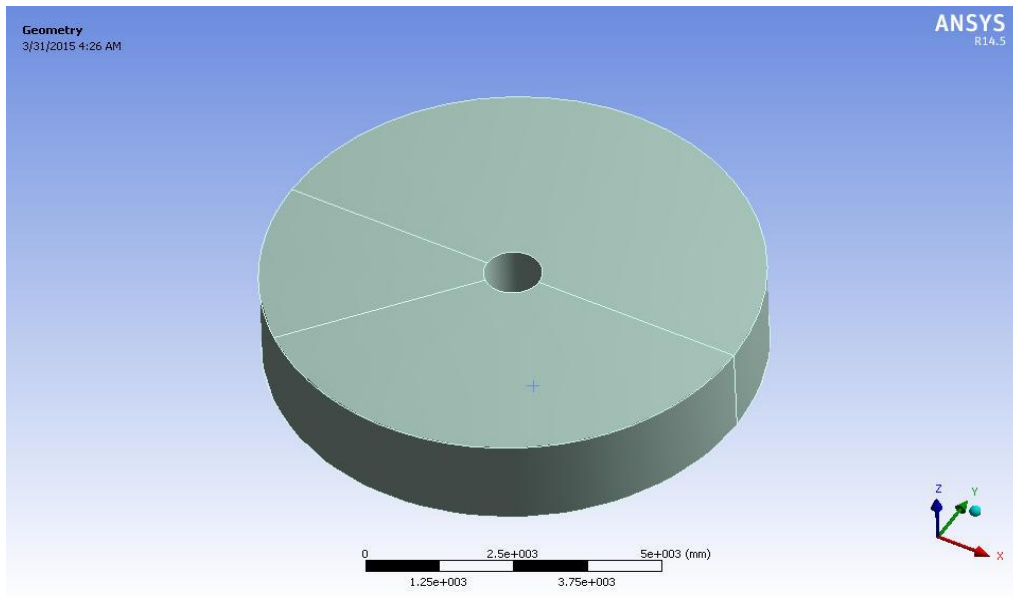
Fig. 6.1 modelling of 50° PA opening rotor

CASE 2

PRIMARY AIR (PA) OPENING = 60°

SECOUNDARY AIR (SA) OPENING = 120°

Flue GAS OPENING = 180°
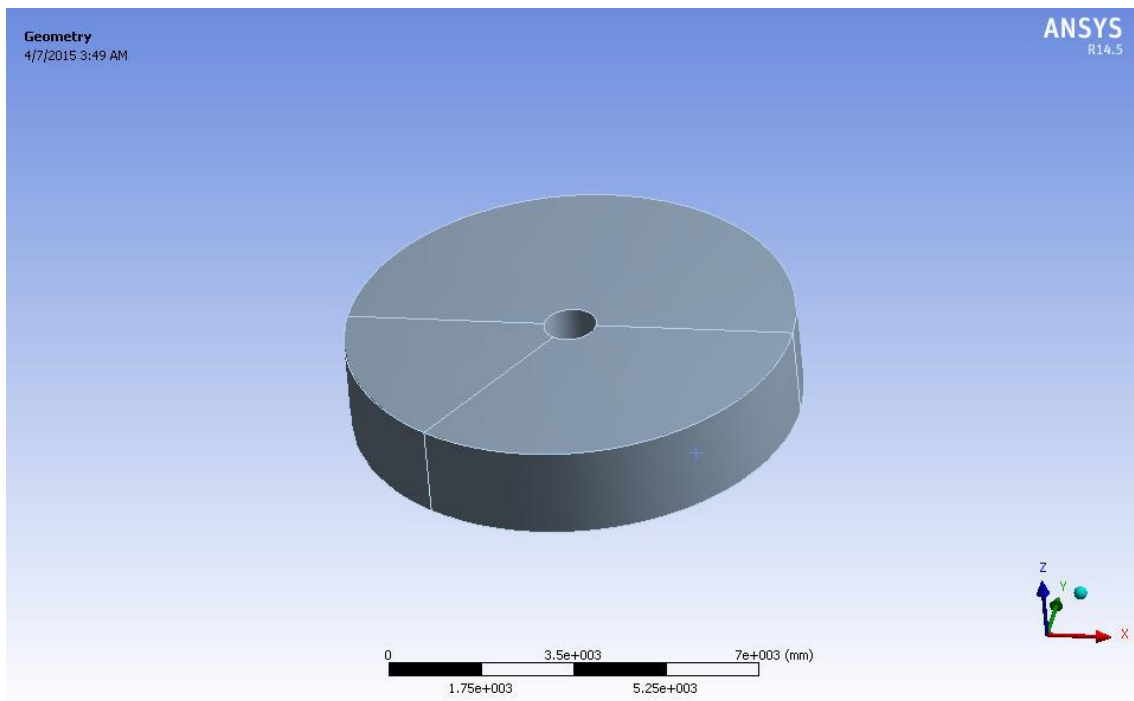
Fig. 6.2 modelling of 60° PA opening rotar

CASE 3

PRIMARY AIR (PA) OPENING = 70°

SECOUNDARY AIR (SA) OPENING = 110°

Flue GAS OPENING = 180°
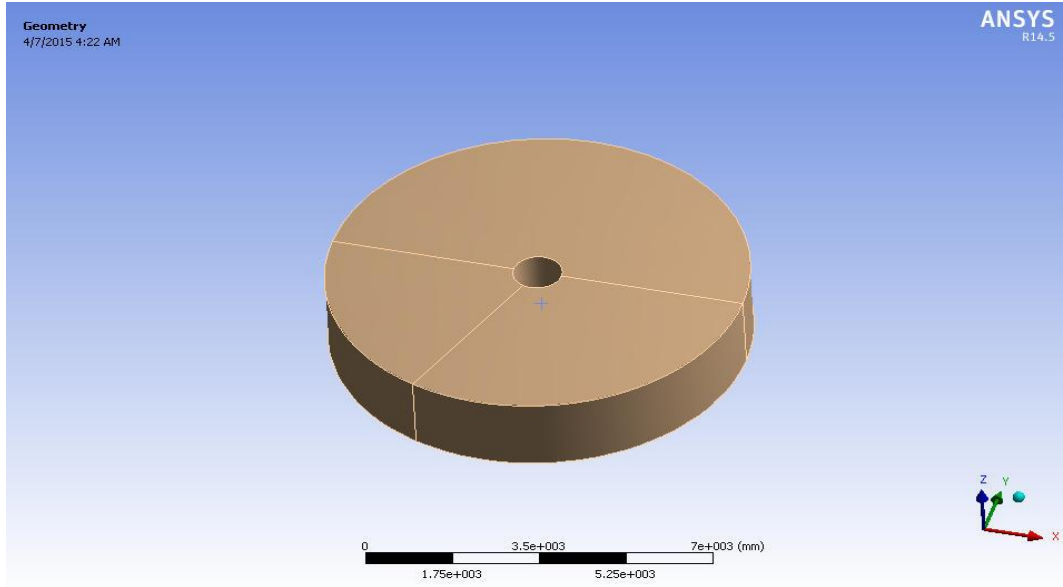
Fig. 6.3 modelling of 70° PA opening rotar

CASE 4

PRIMARY AIR (PA) OPENING = 80°

SECOUNDARY AIR (SA) OPENING = 100°

Flue GAS OPENING = 180°
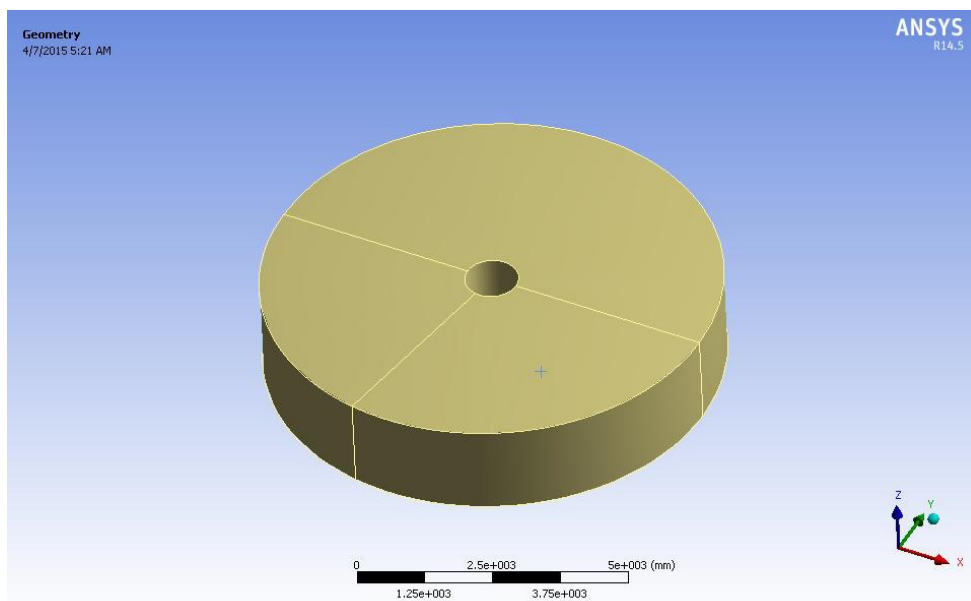
Fig. 6.4 modelling of 80° PA opening rotar

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6.1.2 MESHING

After CAD modelling we generate mesh for all four case using ANSYS ICEM.

CASE :1 PA OPENING 50°

MESH TYPE: HEXAHYDRAL

NO OF NODES: 16146

NO OF ELEMENTS: 13056
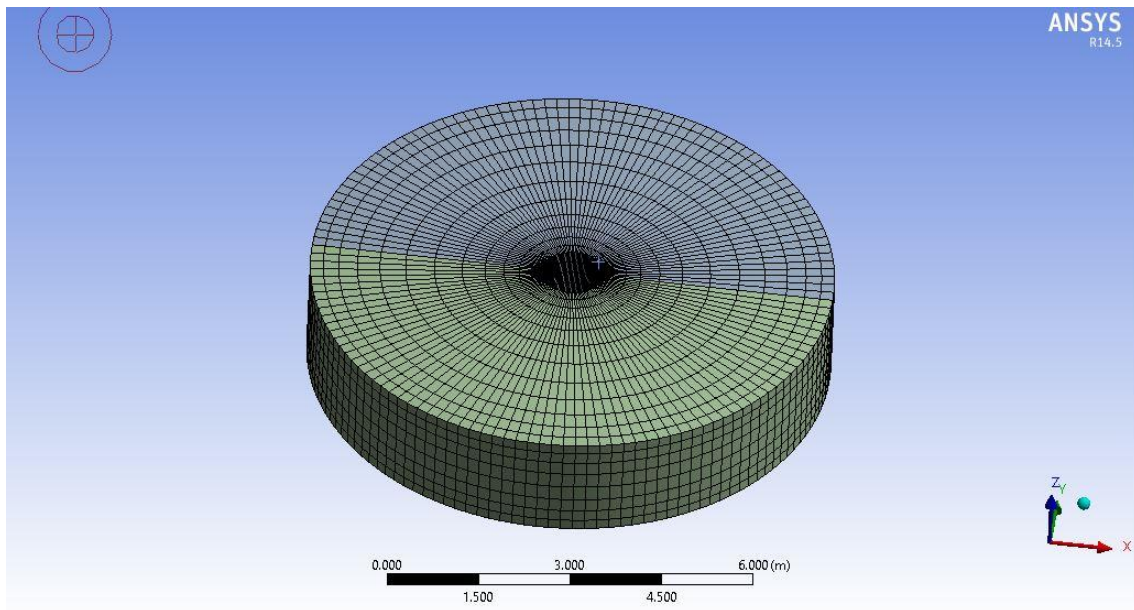
Fig 6.5 Meshing of 50° PA opening rotor

CASE: 2 PA OPENING 60°

TYPE OF MESH: HEXAHYDRAL

NO OF NODES: 16263

NO OF ELEMENTS: 13152
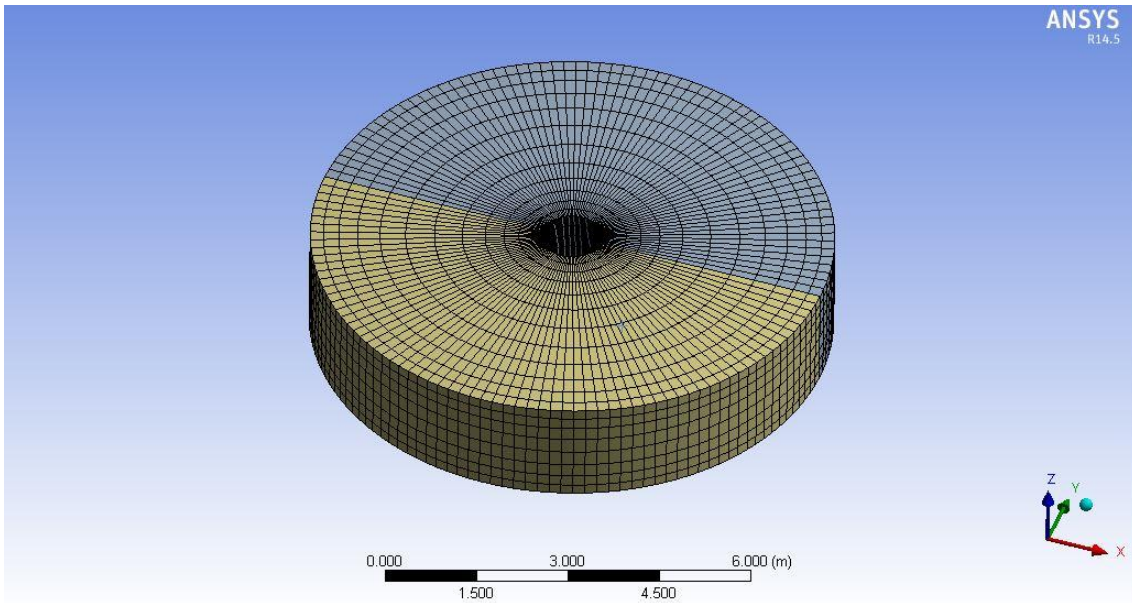
Fig 6.6 Meshing of 60° PA opening rotor

CASE 3: PA OPENING 70°

MESH TYPE: HEXAHYDRAL

NO OF NODES: 16263

NO OF ELEMENTS: 13152
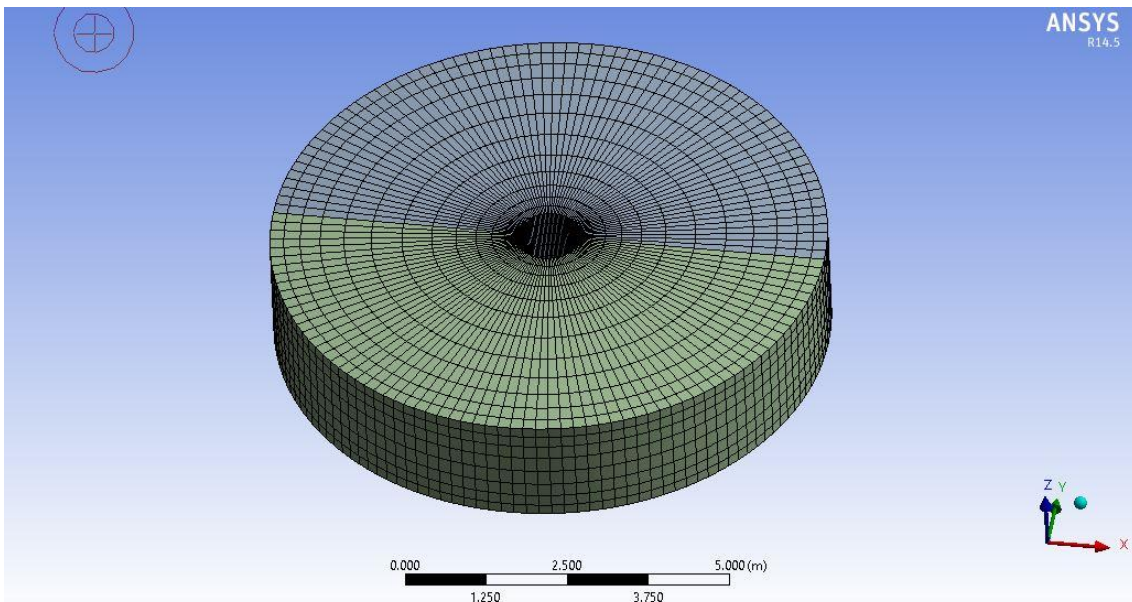
Fig 6.7 Meshing of 70° PA opening rotor

CASE 4: PA OPENING 80°

MESH TYPE: HEXAHYDRAL

NO OF NODES: 16263

NO OF ELEMENTS: 13152
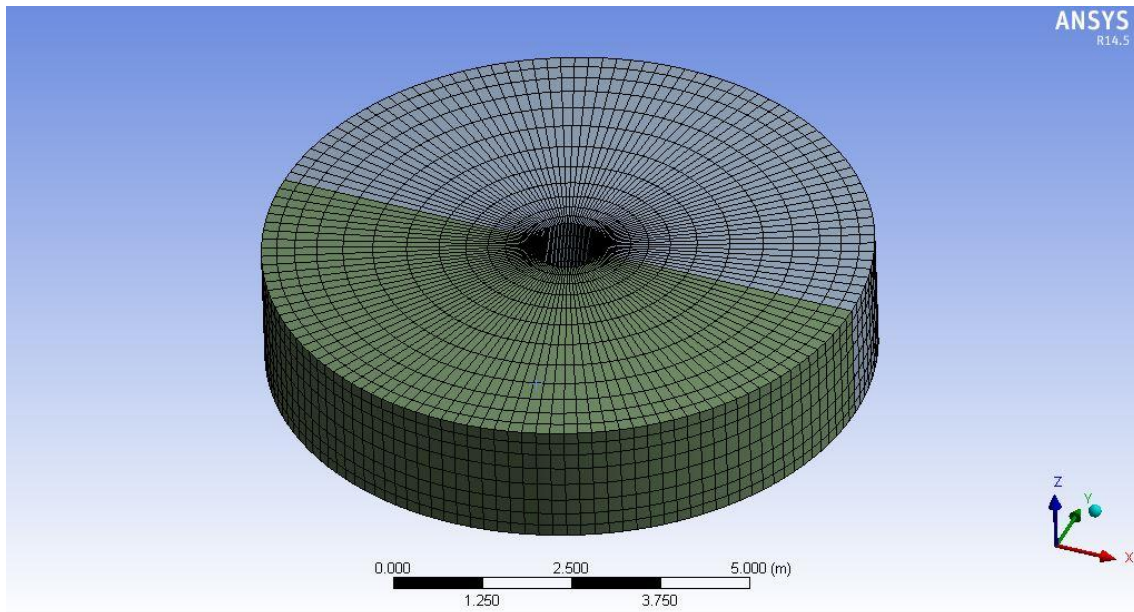
Fig 6.8 Meshing of 50° PA opening rotor

6.1.3 FLUENT SETUP: After mesh generation we define the setup in ANSYS FLUENT as:

- Problem type : 3D
- Type of solver : pressure based solver
- Physical model: viscous k$-\varepsilon$ two equation turbulence model, energy model.
- Material property:

    A. Properties of air:

    - Density : 1.067 kg/m^3
    - Specific heat c_p= 1.005 kj/kg k
    - Conductivity = 0.0271 W/mk
    - Absolute viscosity = 1.1983 *10^{-5} Pas

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- Kinematic viscosity = $14.55*10^{-6}\,m^2$/s

B. Properties of flue gas:

- Density : 0.6072 kg/m^3
- Specific heat c_p= 1.13 kj/kg k
- Conductivity = 0.0.06175 W/mk
- Absolute viscosity = $2.947*10^{-5}$ Pas
- Kinematic viscosity = $48.53*10^{-6}\,m^2$/s

C. Properties of carbon steel:

- Density : 7850 kg/m^3
- Specific heat c_p= 0.49 kj/kg k
- Conductivity = 54 W/mk
- Thermal expansion coefficient= $23.1*10^{-6}$ m/m°c

- **Cell zone condition:** For hot gas section porosity =0.80,

  For PA&SA section porosity =0.76
- **Boundary conditions:**

Operating pressure= 101325 pa

Inlet conditions:

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

Inlet flue gas mass flow rate: 83.33 kg/s

Inlet flue gas velocity= 4.791488 m/s

Turbulent intensity = 5%

Viscosity ratio = 10%

OUTLET:

- Pressure outlet: define same outlet conditions for all PA openings.

  Gauge pressure = 0 Pa

  Turbulent intensity = 5%

  Viscosity ratio: 10%

6.2   STEP 2: SOLUTION

- **SOLUTION METODS:**

  Pressure velocity coupling scheme – SIMPLE

  Pressure –standard

  Momentum – second order

  Turbulent kinetic energy (k)- second order

  Second order turbulent dissipation rate (ε)

  Energy – second order

- **Solution initialization**: initialise the solution to get the initial solution of the problem.

- **Run solution**: we run the solution by giving 1000 no of iteration for solution to converge.

6.3   STEP 3: POST PROCESSING:

For viewing and interpretation of result post processing is done. The result can be viewed in various formats like graphs, value, animations.

7.RESULT & DISCUSSION

7.1 INTRODUCTION:

This chapter presents prediction of possible heat transfer in tri sector air pre-heater based on the input parameters we provided in earlier section. This chapter presents velocity, temperature & pressure profile for heat transfer across rotor of air pre heater.

The data collected using ANSYS FLUENT 14.5 included the temperature data, pressure data and airflow velocity at the monitor point and the temperature distribution , pressure distribution and airflow velocity at all node points in the air pre-heater.

7.2.   ANALYSIS OF AIR PRE HEATER

7.2.1 Case 1: Temperature Analysis for 50° Primary Air Opening
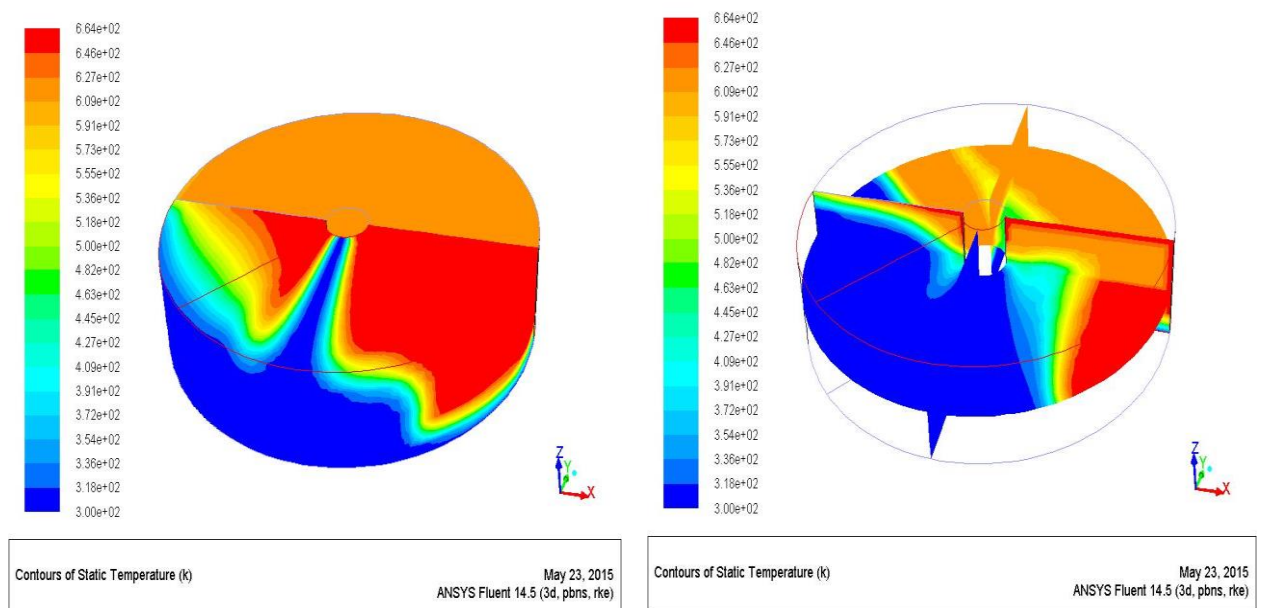
Fig. 7.1 50° PA OPENINGTEMP DIST.   fig. 7.2 50° PA OPENING Mid PLANE TEMP DIST
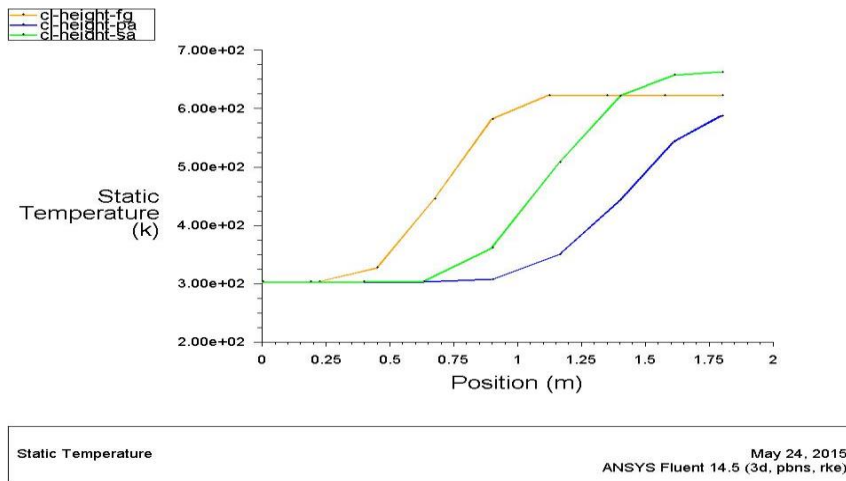
Fig. 7.3 PA,SA, flue gas temp variation along height

Above figure shows temperature distribution through the air pre heater at all points as well as variation of temperature at any section along the height.

i.   **Velocity Distribution for 50°Primary Opening:**

fig shown below are the vector plots of velocity which show the flue gases and PA& SA flow inside the air pre heater given inlet opening.
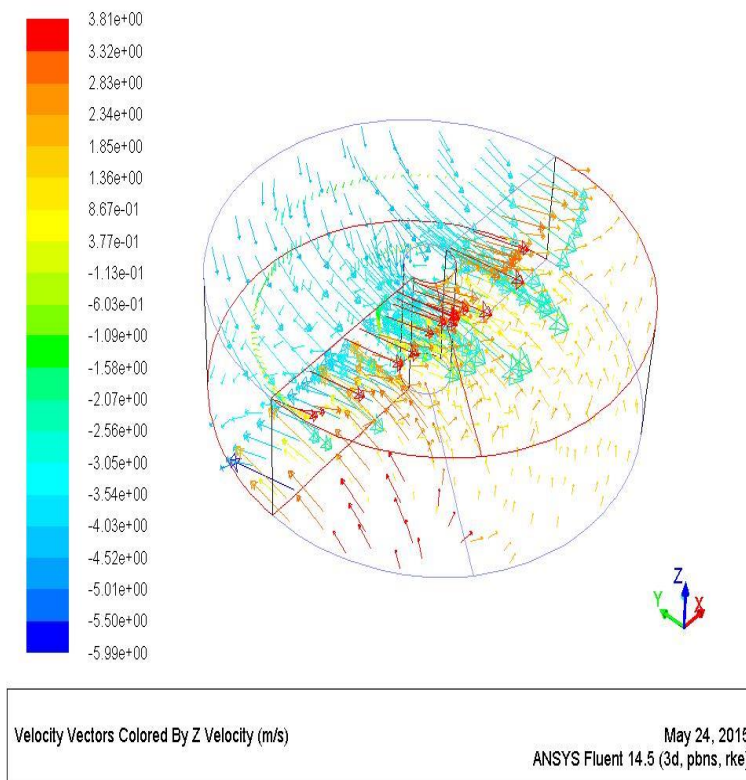
Fig. 7.4 50° Primary Air Opening velocity distribution at all points

50

Contours of Z Velocity (m/s)
May 24, 2015
ANSYS Fluent 14.5 (3d, pbns, rke)
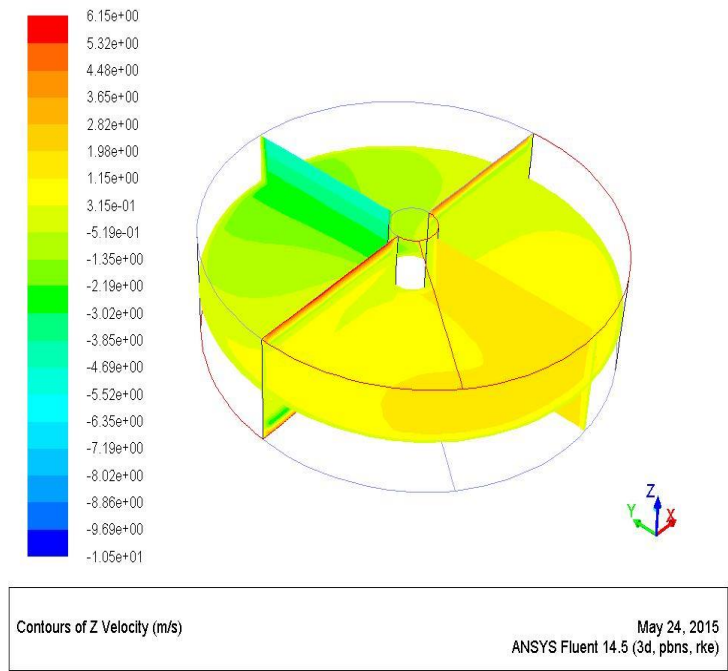
Fig. 7.5 50° Primary Air Opening velocity distribution at mid plane

Fig shown above shows the temperature distribution at mid plane of air pre heater. PA& SA portion starts gaining heat from flue gases as flue gases temperature lowers. Portion near to flue gas section gains temperature at faster rate.

Contours of Static Pressure (pascal)
May 24, 2015
ANSYS Fluent 14.5 (3d, pbns, rke)
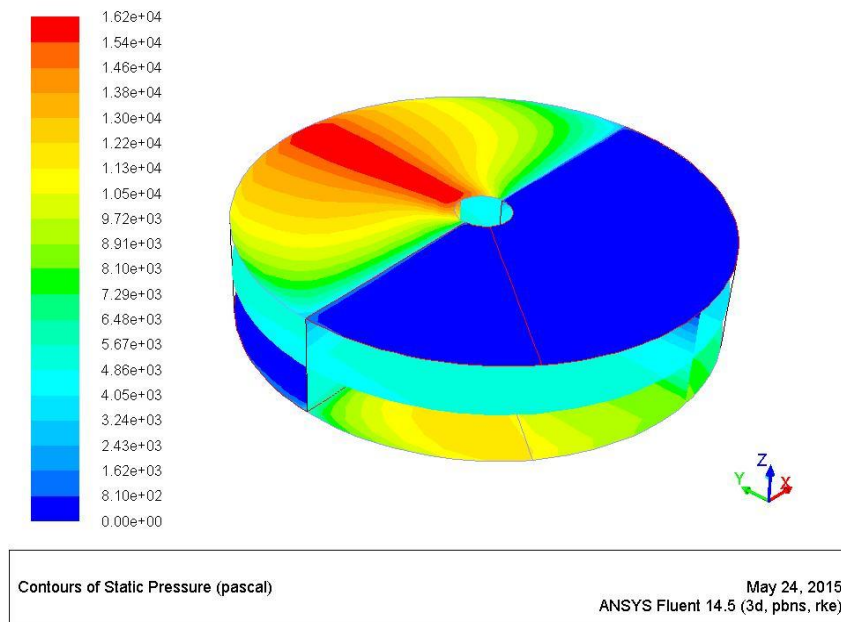
Fig. 7.6Above figure shows pressure distribution for 50° PA opening.

PA pressure drop across APH is 10451.13 Pa (gauge)

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7.2.2 CASE 2: ANALYSIS OF AIR PRE HEATER FOR 60° PRIMARY AIR OPENING

i.   Temperature Analysis of Air Pre Heater For 60° Primary Air Opening
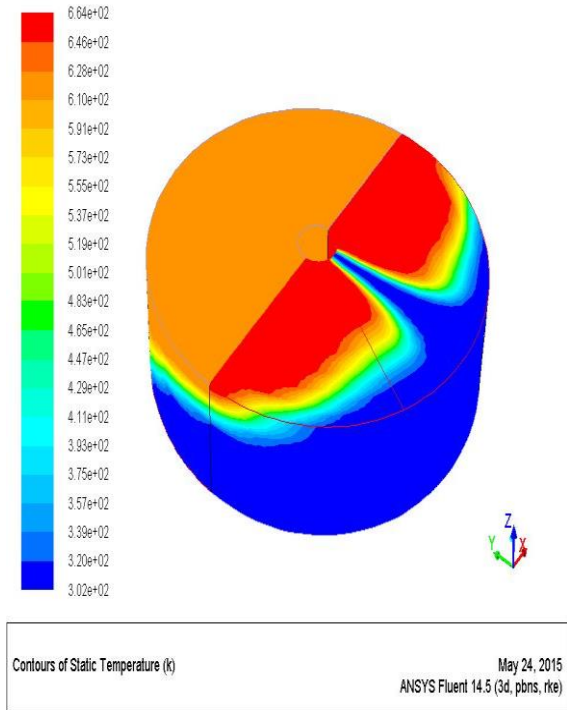
Fig. 7.7 temp dist. throughout
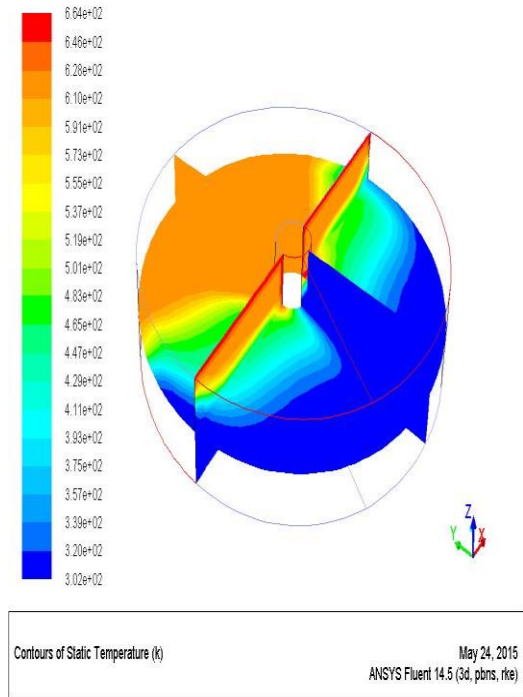
Fig. 7.8 temp. dist. at mid plane
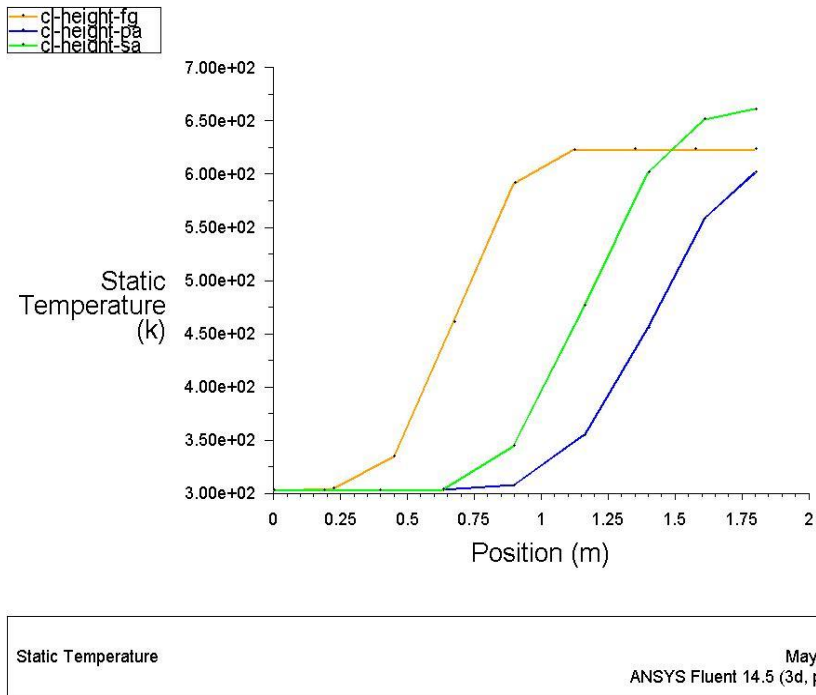
Fig. 7.9 PA, SA, flue gas temp. dist. along height

Diagrams shown above are plots of temperature distribution. 1st fig. Shows the overall temperature distribution across air pre-heater.

2nd diagram shows variation of temperature at mid plane it shows gain of temperature begins at area close to flue gas portion slowly to whole PA & SA portion.

3rd plot represents variation of temperature along the height.

PRESSURE DISTRIBUTION DIAGRAM FOR 60° PA OPENING.
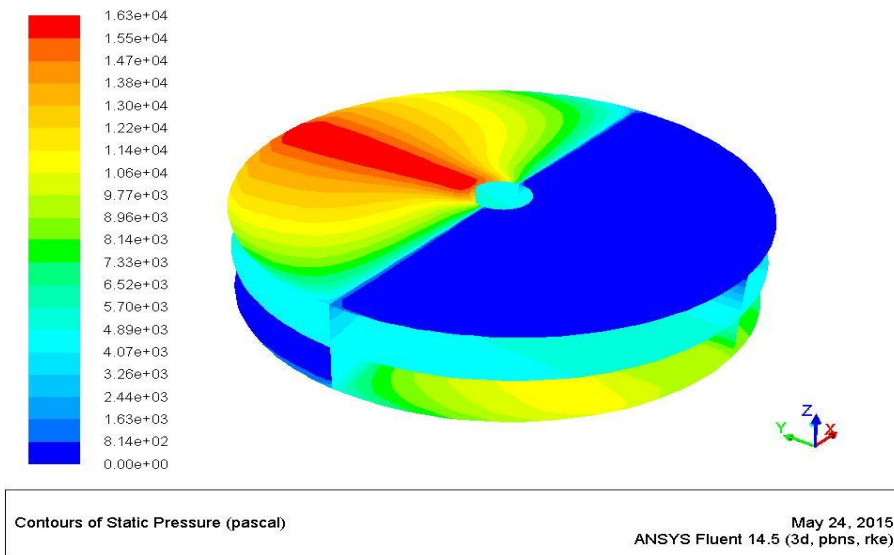
Fig. 7.10 Contour of static pressure for 60° PA opening

Above diagram is plot of gauge pressure. Bluish shade represents discharge to atmosphere .maximum pressure for flue gas is about 0.15bar gauge pressure at inlet. for PA& SA it is about 0.115 bar gauge pressure.

VELOCITY COUNTOUR FOR 60° PA OPENING.
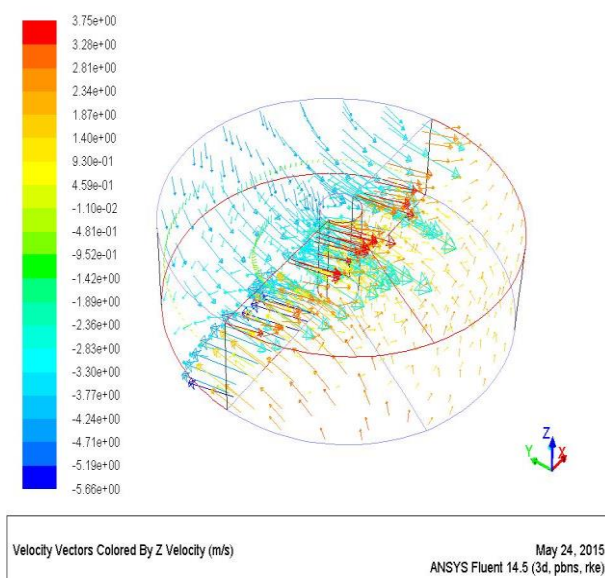
7.11 velocity contour along height
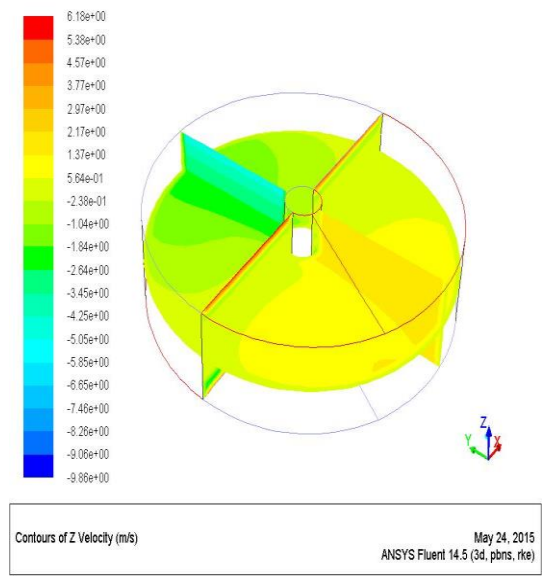
fig. 7.12 velocity distribution at mid plane

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Above plot represents velocity distribution at mid plane of air pre heater.

7.2.3 CASE 3: ANALYSIS OF AIR PRE HEATER FOR 70° PRIMARY AIR OPENING
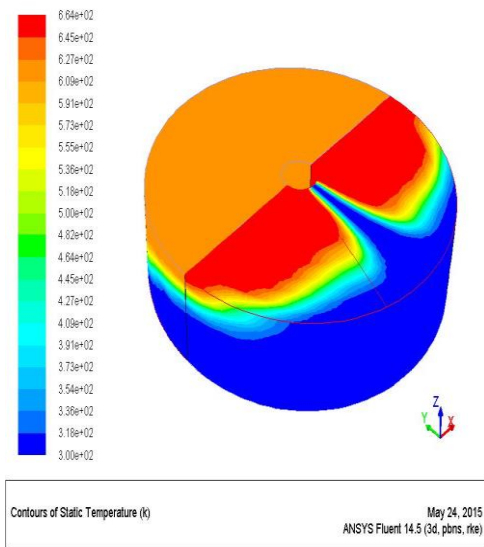
Fig. 7.13 Temp.dist. At all points   fig. 7.14 at mid plane dist of temp
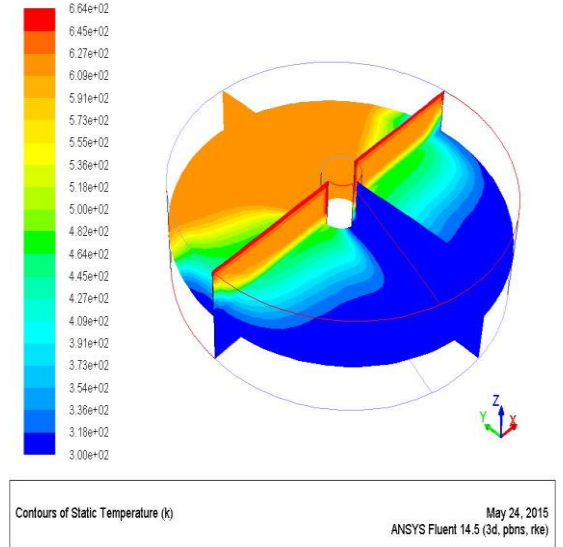
All 3 figures give complete picture of temperature distribution across air pre heater for 70° inlet opening.

Static Temperature

May 24, 2015
ANSYS Fluent 14.5 (3d, pbns, rke)
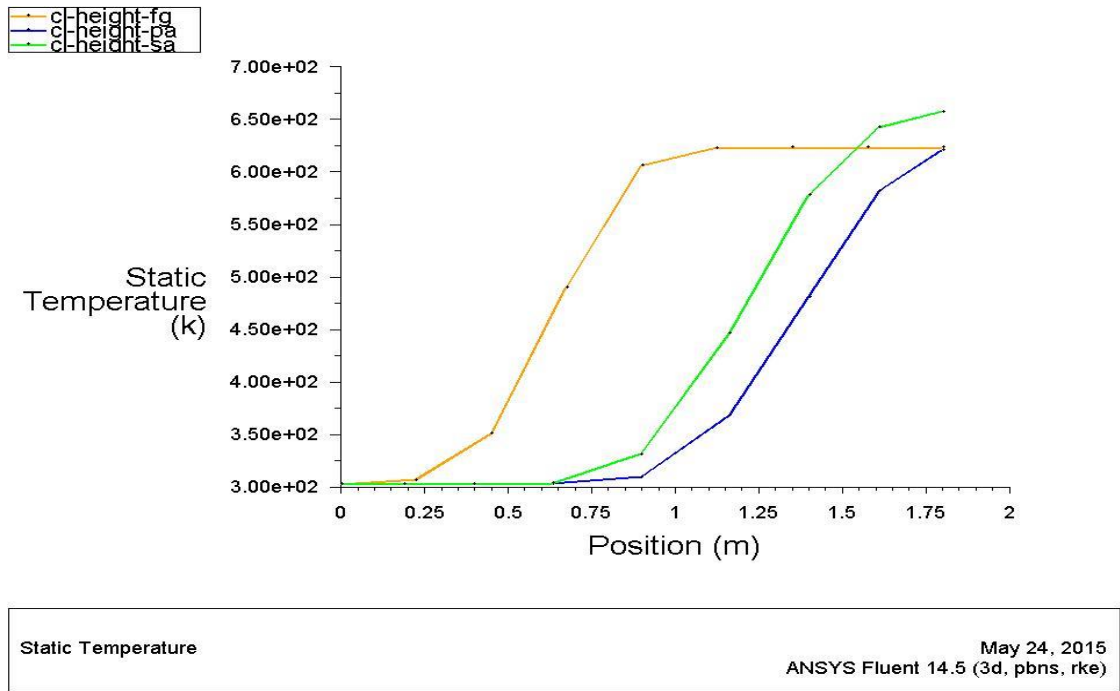
Fig. 7.15 PA, SA, FG temp. variation along height

VELOCITY COUNTOURS FOR 70° PRIMARY AIR INLET OPENING

Velocity Vectors Colored By Z Velocity (m/s)

May 24, 2015
ANSYS Fluent 14.5 (3d, pbns, rke)

Contours of Z Velocity (m/s)

May 24, 2015
ANSYS Fluent 14.5 (3d, pbns, rke)
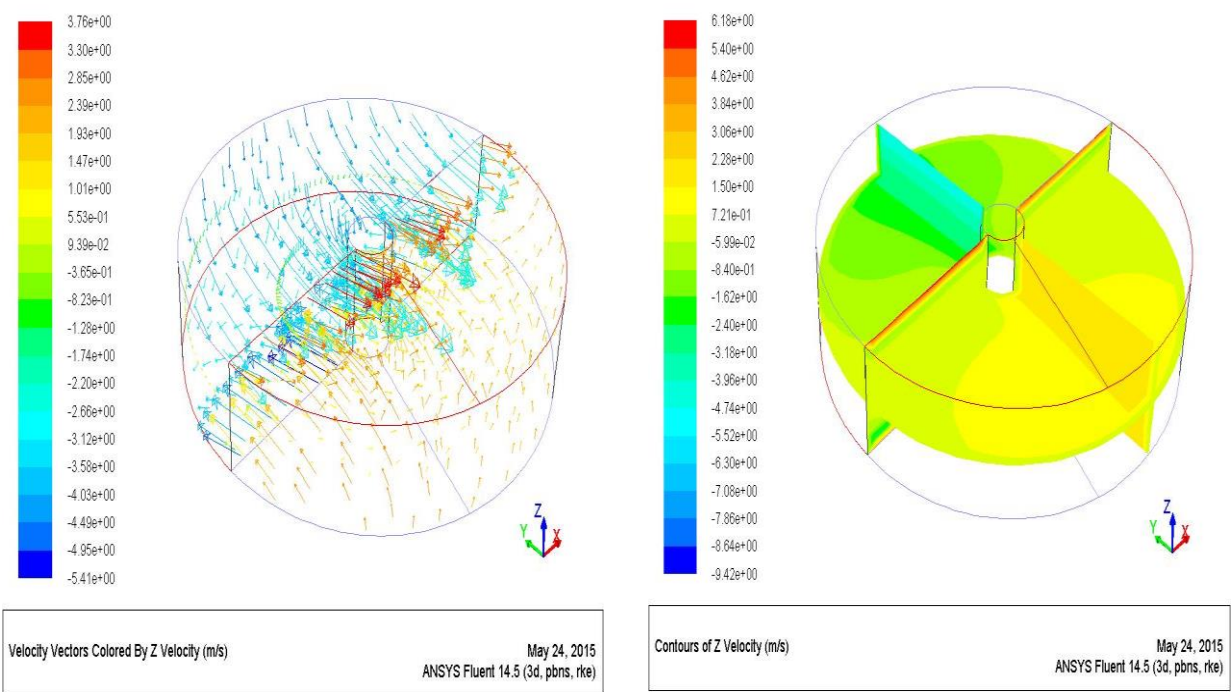
Fig. 7.16 velocity vector at all points   fig. 7.17 velocity dist. At mid plane

55

1st figure shows velocity vectors which gives idea about direction of flow along with magnitude.

2ndfigure shows velocity magnitude at mid plane.

Distribution of pressure for 70° PA opening
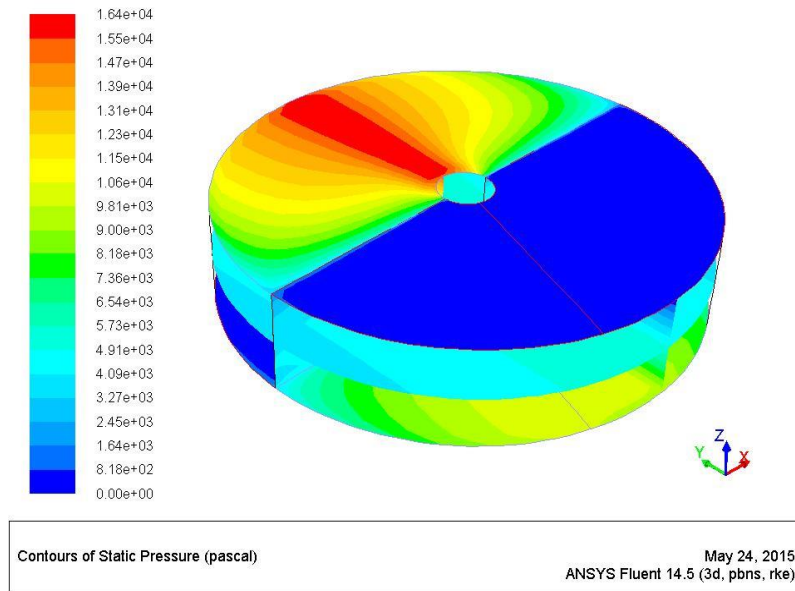
Fig. 7.18 Pressure distribution for 70° PA opening

7.2.4 CASE 4 ANALYSIS OF AIR PRE HEATER FOR 80° PRIMARY AIR OPENING.

- **Plots of temperature distribution**
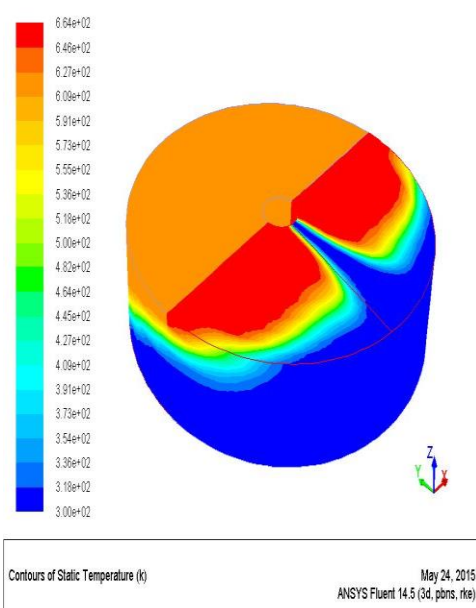
Fig.7.19 temp.dist.At all points   fig. 7.20 temp.dist at mid plane
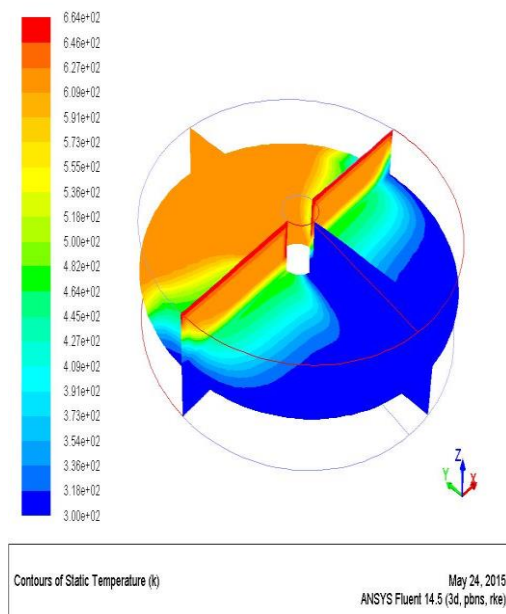
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Fig: 7.21 PA, SA & FG Variation along the Height

VELOCITY DISTRIBUTION ACROSS AIR PRE HEATER FOR 80° PA OPENING:

Primary air velocity at inlet= 2.658568 m/s, Secondary air inlet velocity = 2.37191

Flue gas velocity at inlet= 4.7915 m/s, vector plot show direction and distribution.
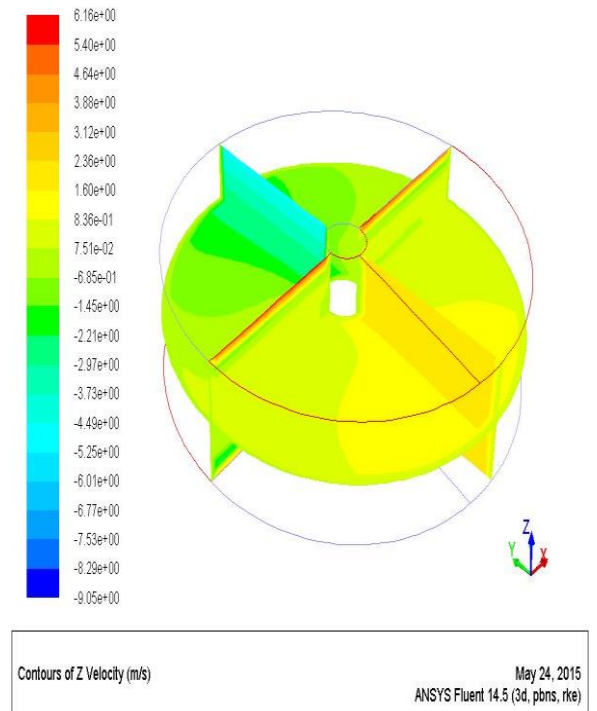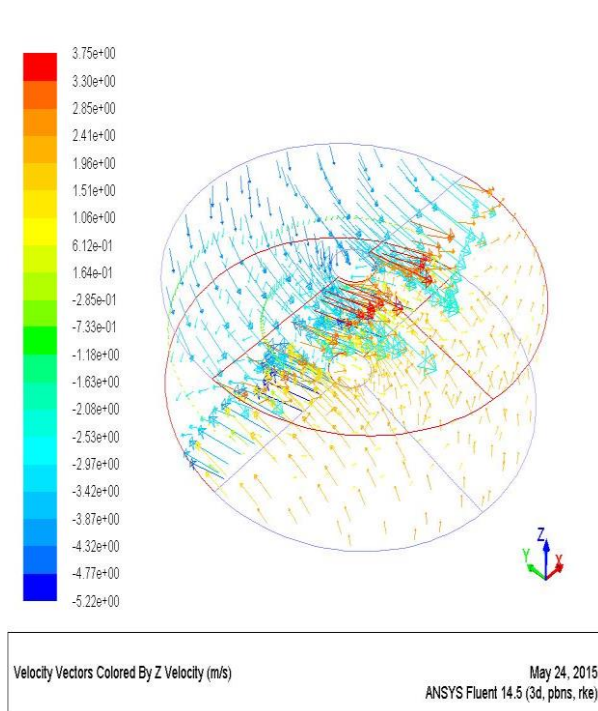
Fig.7.22 velocity vector plot at all points   **Fig. 7.23 velocity distribution at mid planes**

DISTRIBUTION FOR 80° PA OPENING
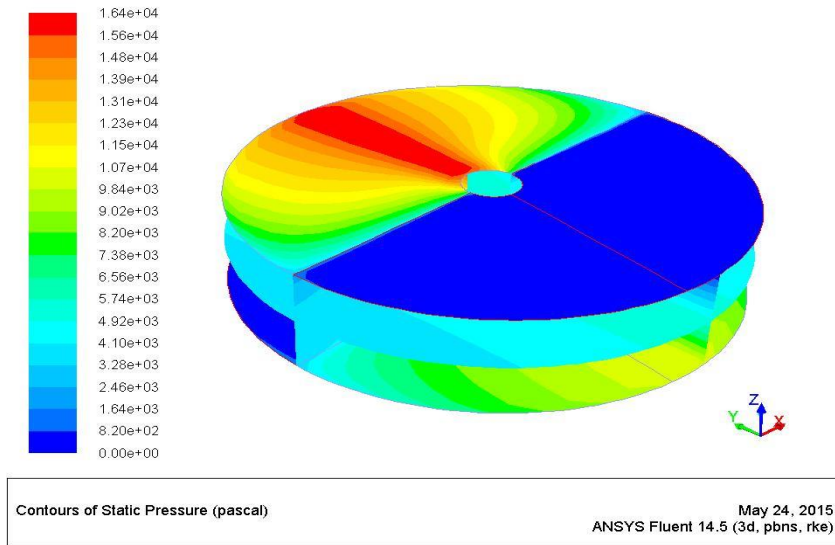
Fig. 7.24 Pressure contour for 80° PA opening

In pressure contour blue shed represents 0 gauge pressure (discharge to atmosphere),

PA pressure drop across APH= 8331.117PA

Table 7.1 input, output parameters after post processing

prim ary air angl e	primary / seconda ry air inlet temp k	primary air inlet vel	seconda ry air inlet vel	flue gas inlet vel	flue gas inlet temp k	primar y air outlet temp k	secon dary air outlet temp k	flue gas outlet temp k	primar y air gauge pressur e drop Pa
1.5 RP M									
50	303.15	4.2537	1.82455	4.79	623.1 5	598.9 2	535.4 0	395.94	10451. 13
60	303.15	3.5447	1.97657	4.79	623.1 5	589.4 3	531.5 5	394.31	9598.8 72
70	303.15	3.0383	2.15627	4.79	623.1 5	582.4 7	527.9 7	393.07	8899.7 451
80	303.15	3.0383	2.37191	4.79	623.1 5	573.1 1	528.3 7	392.34	8331.1 17

RESULTS OBTAINED AFTER CFD ANALYSIS

mass flow rate of primary air= 36.11 kg/s

mass flow rate of secondary air = 40.27 kg/s

mass flow rate of flue gas= 83.33 kg/s

NOTE: mass flow rate of flue gas, primary air, secondary air & their respective inlet velocity and inlet temperature values are taken from actual running parameters of rotary air pre heater operating at SATPURA THERMAL POWER PLANT MPPGCL SARNI M.P.

7.3   CALCULATIONS:

7.3.1 GAS SIDE EFFICIENCY:

Ratio of drop of Gas Temperature across the air heater, corrected for no leakage, to the temperature head.

$$= \frac{TEMPRATUREDROP}{TEMPERATUREHEAD} \text{ x } 100$$

Gas temperature drop= gas inlet temp – gas outlet temp.

Temperature head = gas inlet temp.- air inlet temp = 623.15-303.15 =320K

Table 7.2 gas side efficiency at different PA opening

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

Fig. 7.26 graph between gas side efficiency and PA opening

7.3.2   X-RATIO:

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

$$M_{AIROUT}*C_{PA}*\Delta T_A = M_G*C_{PG}*\Delta T_G$$

$$\text{X-RATIO} = \frac{m_{airout}c_{pa}}{m_{gasin}c_{pg}} = \frac{T_{gasin} - T_{gasout}}{T_{airout} - T_{airin}}$$

X-Ratio depends on

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

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

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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 infiltration.

Table 7.3 X-Ratio for different PA opening

S.NO	PA OPENING ANGLE	$\dfrac{T_{g,in}-T_{g,out}}{T_{air,out}-T_{air,in}}$	X RATIO
1	50°	$\dfrac{623.14-395.944}{567.16-303.15}$	0.86009
2	60°	$\dfrac{623.15-394.3129}{560-303}$	0.888
3	70°	$\dfrac{623.15-393.15}{555.22.303}$	0.91300
4	80°	$\dfrac{623.15-392.15}{550.74-303}$	0.9316

Fig. 7.27 Graph of Variation of X -Ratio With Pa Opening

Table 7.4 PA Pressure drop at different PA opening

S.NO	PA OPENING ANGLE	PRIMARY AIR PRESSURE DROP (IN Pa) Gauge pressure
1	50°	10451.13
2	60°	9598.872
3	70°	8899.7451
4	80°	8331.117
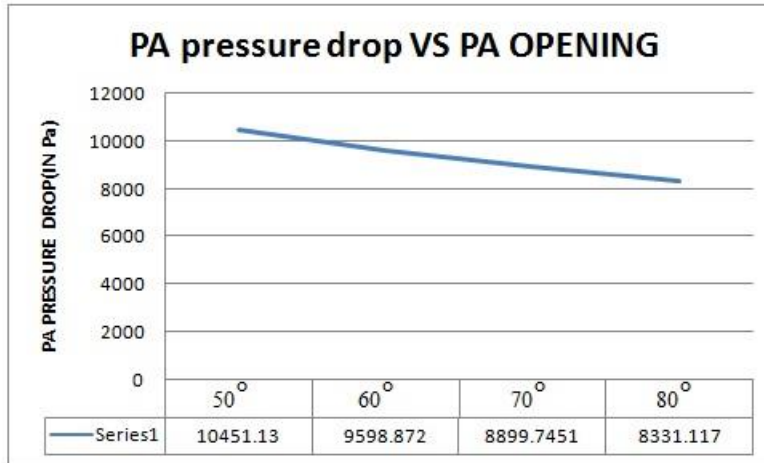
Fig. 7.28 Variation of PA opening with PA opening

7.4 STUDY OF VARIATION OF RPM ON APH PERFORMANCE

In earlier part of study we are optimising 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.

Here we are varying RPM of rotor at 70° PA opening and study the effect keeping other parameters same.

7.4.1 STUDY OF TEMPRATURE PROFILE

Figure shows the variation of temperature across air pre-heater for 4 different RPM values we observe very minute changes in temperature pattern. Almost negligible changes observed.
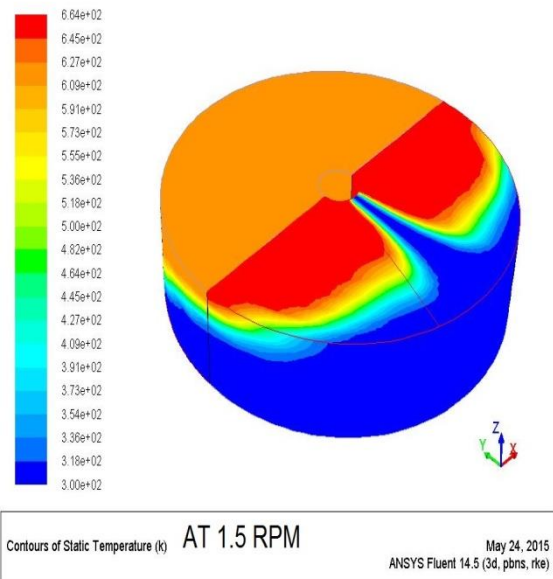
fig. 7.29   Temp dist at 1.5 rpm   fig. 7.30 Temp. dist. at 2 rpm
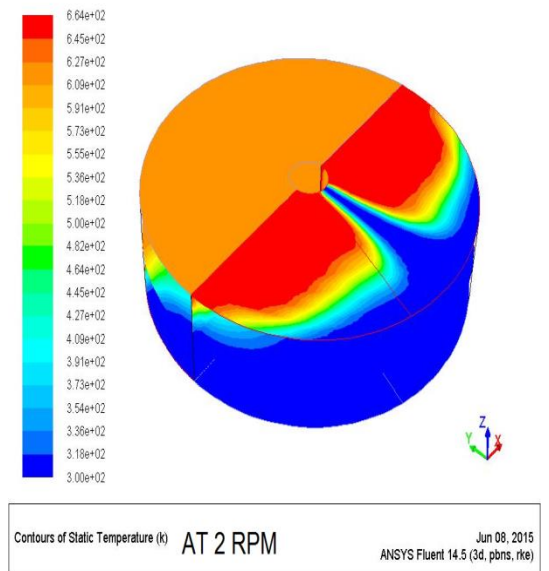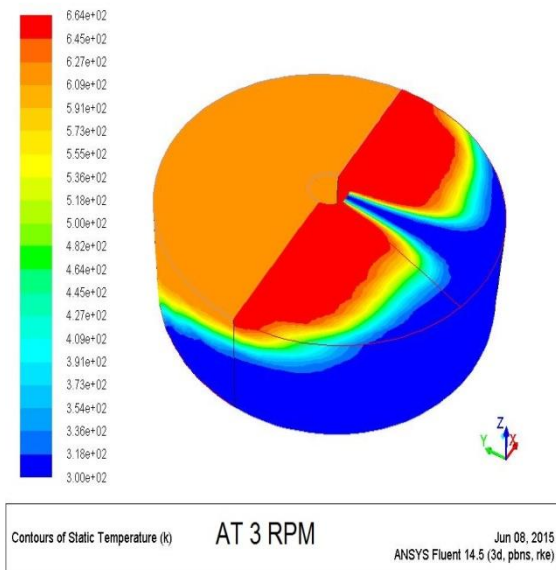
Fig.7.31 temp dist. at 3 rpm   Fig. 7.32 temp dist. at 4 rpm
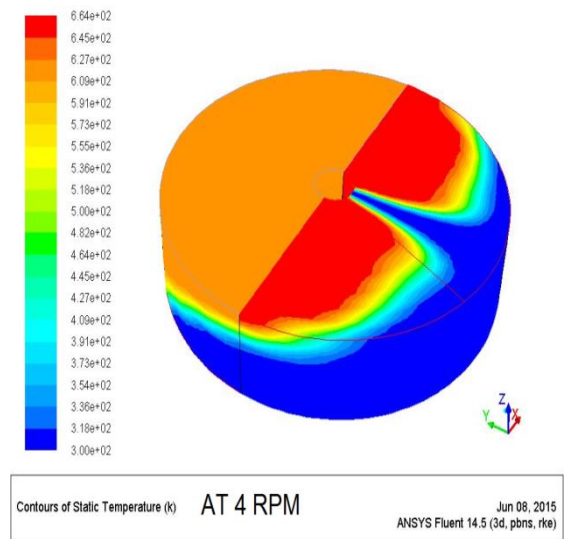
7.4.1.1 TEMPRATURE DISTRIBUTION AT MID PLANE WITH VARYING RPM:

These figure shows variation of temperature at mid plane of air preheater for 4 different rpm values, temperature changes are minute in all cases.
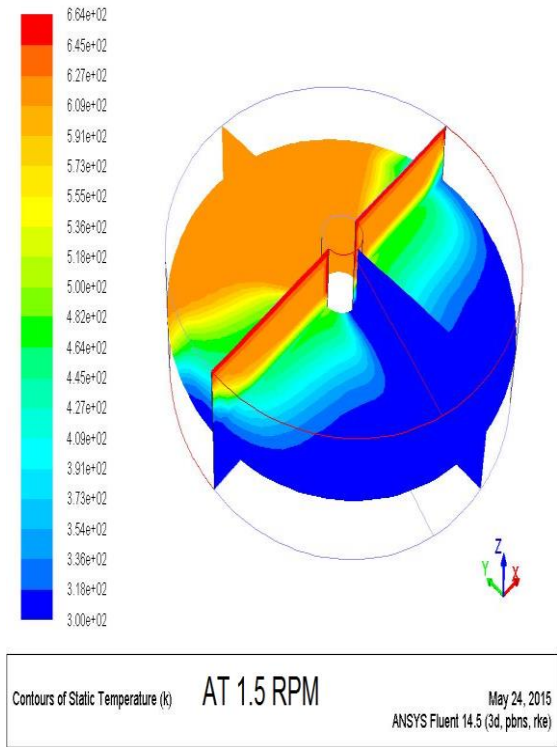
Fig. 7.33 mid plane temp. dist for 1.5 rpm
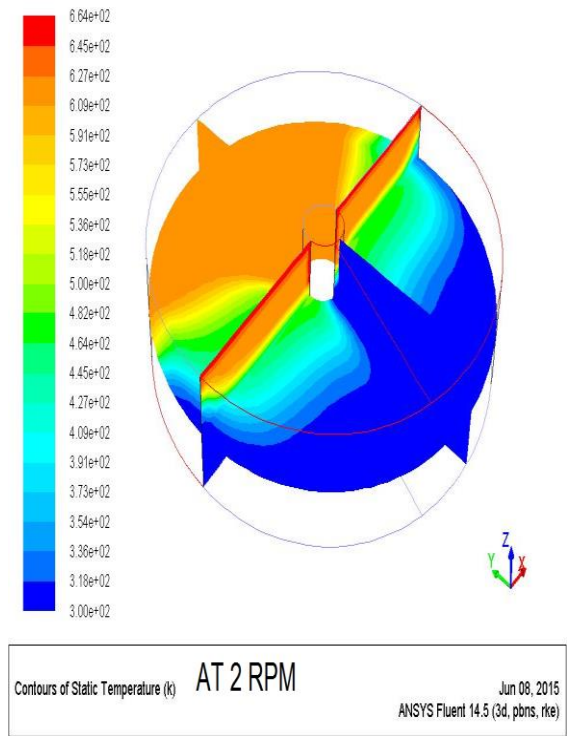
fig. 7.3 mid plane temp dist. For 2 rpm
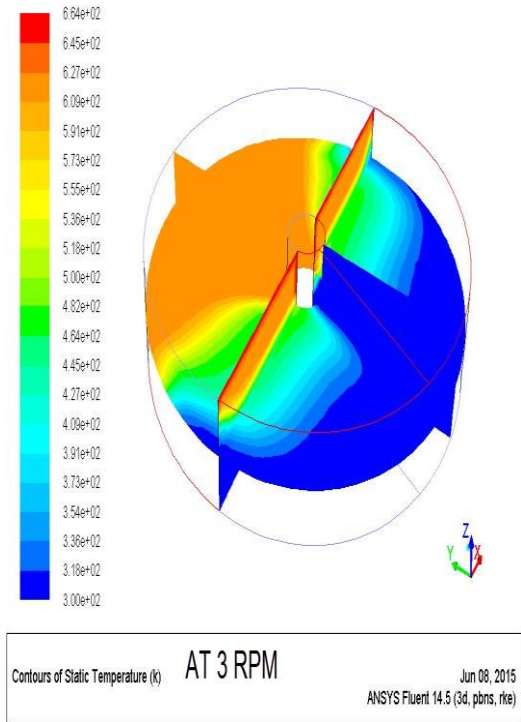
Fig. 7.35   mid plane temp dist at 1.5 rpm
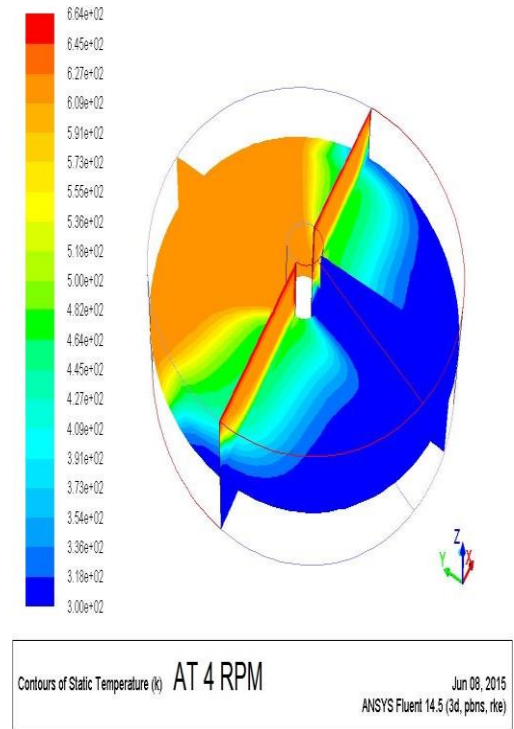
fig. 7.36 mid plane temp dist for 4 rpm

7.4.1.2 GRAPH OF TEMPERATURE DISTRIBUTION FOR DIFFERENT RPM:

In these graphs of temperature variation at mid section along the height is plotted for 4 different rpm values. red line shows variation of flue gas temperature, green line indicates SA temp variation, purple colour line shows variation in PA temp.
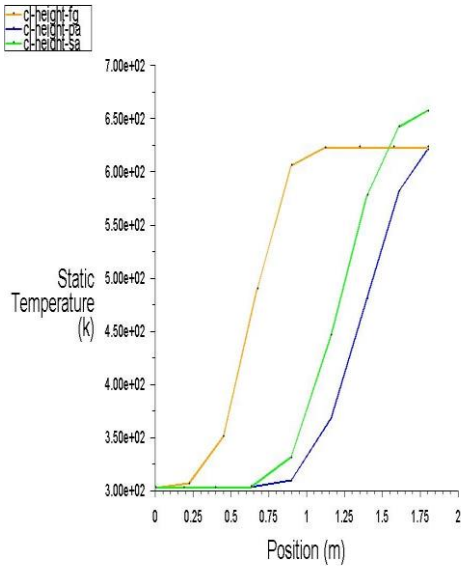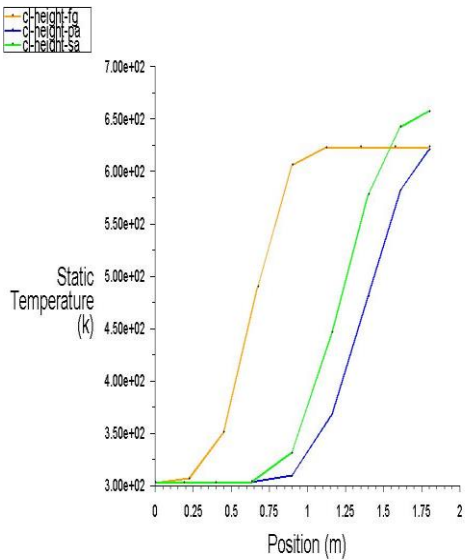

Fig. 7.37 variation of temp .with height for 1.5 rpm
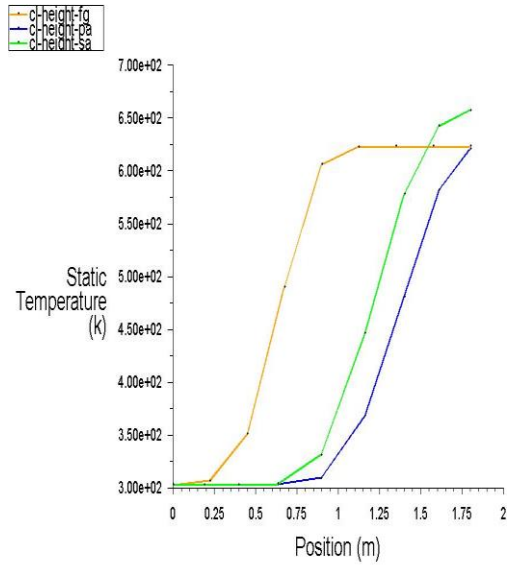
fig. 7.38 variation of temp. with height for 2 rpm.

Fig. 7.39variation of temp.with height for 3 rpm
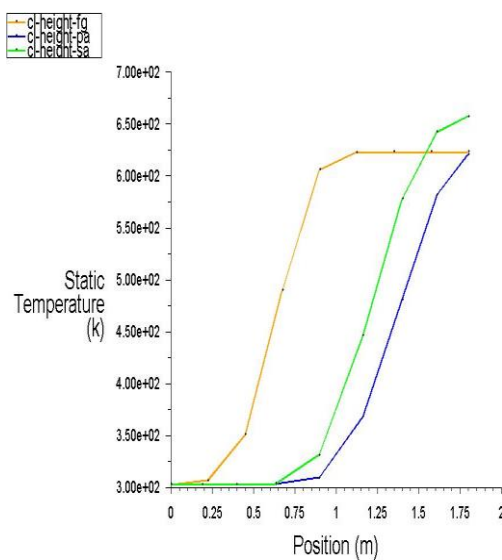
fig. 7.40variation of temp. with height for 4 rpm.

7.4.2 VELOCITY DISTRIBUTION FOR 4 DIFFEENT RPMS ACROSS APH

Velocity vector plots at different RPM values gives information regarding direction of flow with magnitude of velocity.

Primary air velocity at inlet = 3.038 m/s, secondary air velocity at inlet = 2.156 m/s
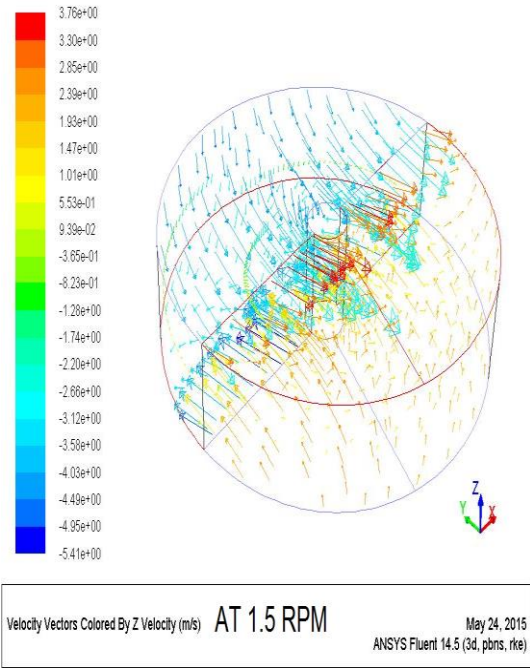
Flue gas velocity at inlet = 4.7915 m/s
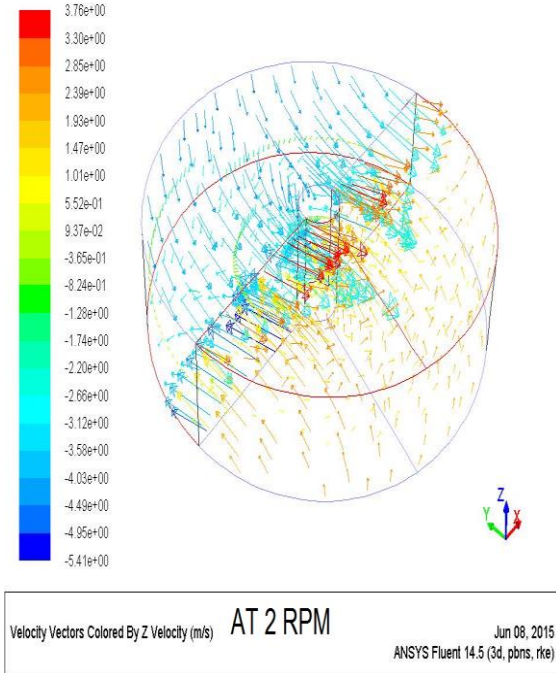

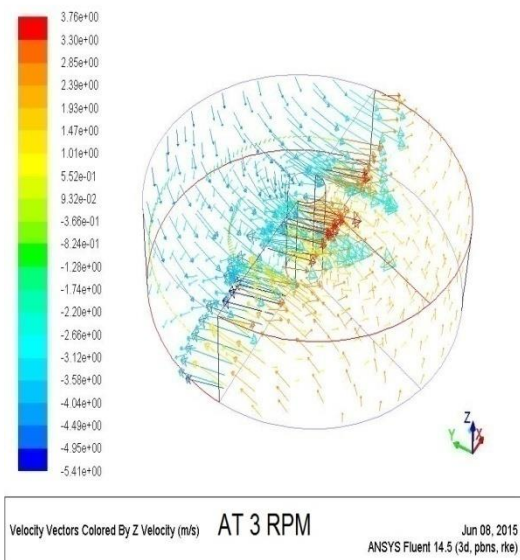Fig. 7.41velocity vector for 1.5 rpm

fig. 7.42 velocity vector for 2 rpm

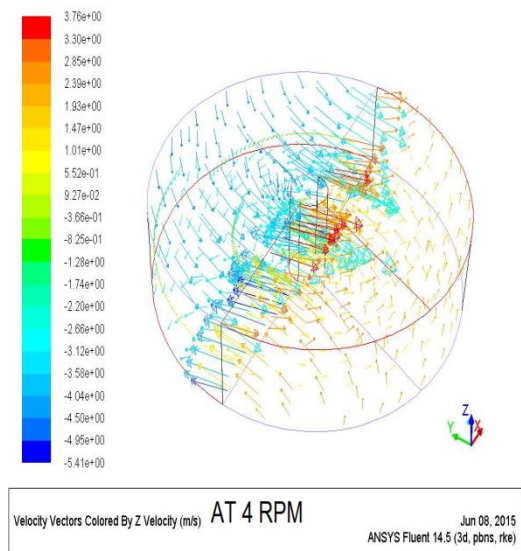Fig. 7.43   velocity vector for 3 rpm

fig. 7.44 velocity vector for 4 rpm

7.4.3 PRESSURE VARITION ACROSS APH FOR DIFFERENT VALUE OF RPM

By varying the RPM of air pre-heater no effect observed on pressure drop across air pre-heater .values of pressure drop remains constant .

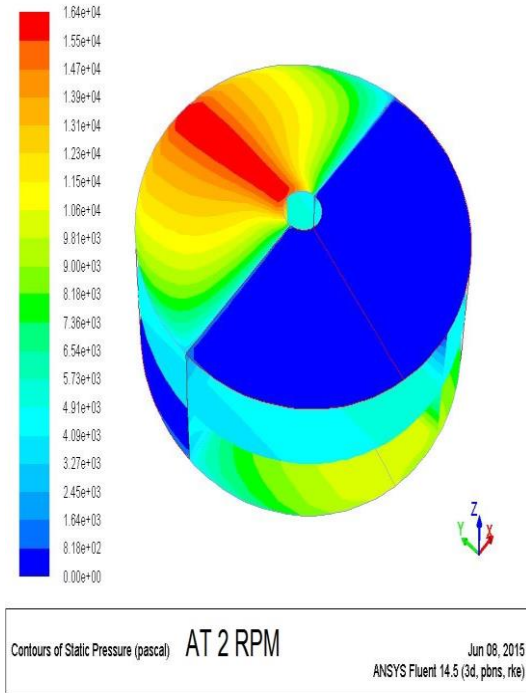Primary air pressure drop = 8898.96 Pa.
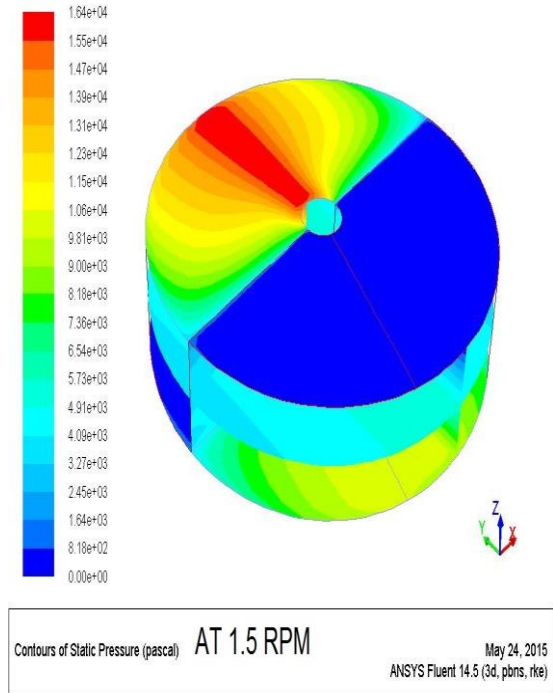

fig.7.45 pressure contour at 2 rpm
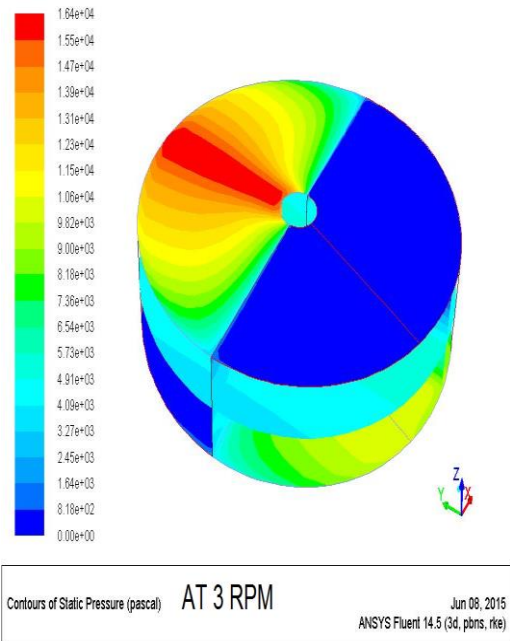

fig. 7.46 pressure contour at 1.5 rpm

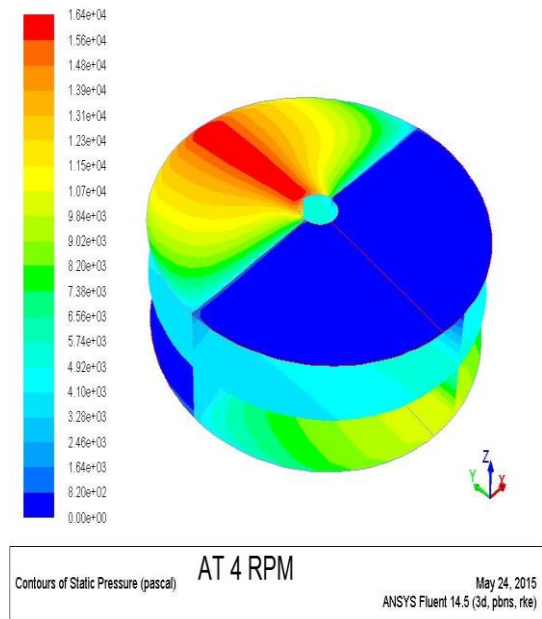Fig. 7.47 pressure contour at 3 rpm

fig.7.48 pressure contour at 4 rpm

Table 7.5 OBSERVATION TABLE FOR DIFFERENT RPM VALUES OF ROTOR

RPM	primary/ secondary air inlet temp k	flue gas inlet temp k	primary air inlet vel	secondary air inlet vel	flue gas inlet vel	primary air outlet temp k	secondary air outlet temp k	flue gas outlet temp k	primary air gauge pressure drop Pa
1.5	303.15	623.15	3.03837	2.15627	4.7915	582.4797	527.9769	393.0736	8899.7451
2	303.15	623.15	3.03837	2.15627	4.7915	582.4888	527.9773	393.0719	8899.7451
3	303.15	623.15	3.03837	2.15627	4.7915	582.5093	527.9803	393.0682	8899.7451
4	303.15	623.15	3.03837	2.15627	4.7915	582.5333	527.9869	393.0623	8899.7451

Table 7.6 X-RATIO CALCULATION FOR VARING RPM OF ROTAR

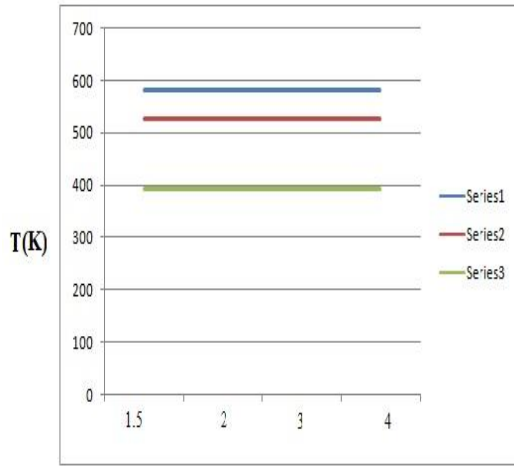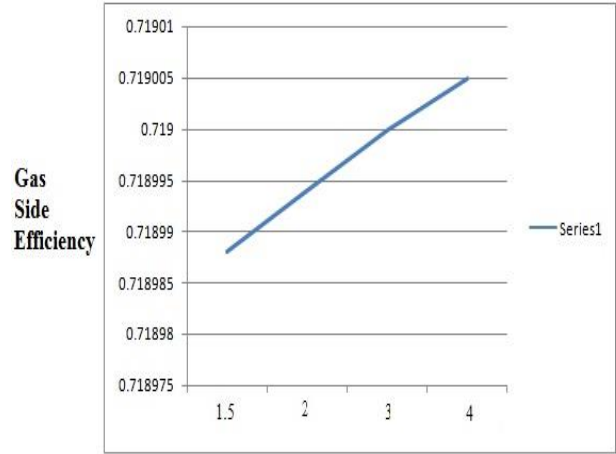|	RPM	$\dfrac{T_{g,in} - T_{g,out}}{T_{g,in} - T_{air,in}}$	GAS SIDE EFFICIENCY
1	1.5	$\dfrac{623.15 - 393.0736}{623.15 - 303.15}$	0.718988
2	2.0	$\dfrac{623.15 - 393.0719}{623.15 - 303.15}$	0.718994
3	3.0	$\dfrac{623.15 - 393.0682}{623.15 - 303.15}$	0.71900
4	4.0	$\dfrac{623.15 - 393.0623}{623.15 - 303.15}$	0.719005

Fig. 7.49 PA, SA& FG variation with temp

fig. 7.50 gas side efficiency variation with rpm

8. CONCLUSIONS

After analysing 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:

- We optimise 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.

- 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.

- 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.

- Low value of X-RATIO than designed X-ratio indicates high flue gas exit temperature or air is By- passing the air pre heater.

  In our case the value of X-ratio is good & it increases with increase in primary air inlet opening.

  Increase in primary air opening angle lowers the pressure drop across primary section of air pre heater but it lowers PRIMARY AIR temperature also.

Primary air has two purposes i.e. it absorb the moisture in pulverised 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.

▪ Temperature distribution of air pre-heater indicates highest temperature achieved near to centre of rotor and at cold end chances of corrosion is high thus suitable material selection is done with keeping this facts in mind.

8.1 EFFECT OF VARIATION OF AIR PRE-HEATER RPM ON APH PERFORMANCE.

We keep the primary air opening $70°$& varing the air pre heater RPM keeping other parameters same based on our study following conclusions can be drawn.

▪ Effect of variation of RPM on flue gas temperature ,primary air & secondary air outlet temperature is very less, we got almost linear variation there temperature with increase in RPM, but the trends are increasing in case of primary and secondary air.

▪ Primary air, secondary air & flue gas pressure drop across air pre heater is constant with increase in RPM of rotor.

▪ Air heater performance is slightly improved but not significant.

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