To optimize the design of the basket profile in Ljungstrom air preheater

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Abstract - *The Ljungstrom air preheater is a regenerative type of heat exchanger used for preheating the air, mainly in thermal power plant. The warm flue gas and cold air ducts are arranged to allow both the flue gas and air to flow simultaneously through the air preheater. The hot flue gas heats the rotating profile and as it rotates, the hot section moves into the flow of cold air and preheats it. In the present investigation, experimental data of air preheater has been collected from 70 MW Unit at KLTPS Panandhro. This complex geometry models of various element profiles were first developed in Pro-Engineering and then imported in ANSYS CFX to carry out the CFD analysis. The parameters like outlet temperature of Flue gas is obtained after precise CFD simulations for all the profiles. The analytical approach shows acceptably agreements with the experimental results. The efficiency study shows that the FNC profile is most efficient with the given operating conditions at the thermal Power plant.*

Key Words: *Ljungstrom air preheater, CFD, Element Profile, Thermal Power Plant, Efficiency*

1. INTRODUCTION

Air preheater is the device used to heat the air supplied for the combustion with the help of hot flue gases (Fig-1). The purpose of the air preheater is to recover the heat from the boiler flue gas which in turn increases the thermal efficiency due to reduction in the heat lost in the flue gas. As a result, the flue gases are conveyed to the chimney at a lower temperature allow a more simplified design of the conveyance system. It also allows control over the temperature of gases leaving the chimney to meet the emission regulations.

There are two types of air preheater in thermal power stations. In recuperative air preheater the heat exchange between the carrier and the air to be heated takes place continuously through the walls of the heating surface that separate them. In regenerative air preheater the heat exchange is accomplished by the alternate heating and cooling metallic or ceramic fixed or rotating surfaces of the preheater (Fig.-2).

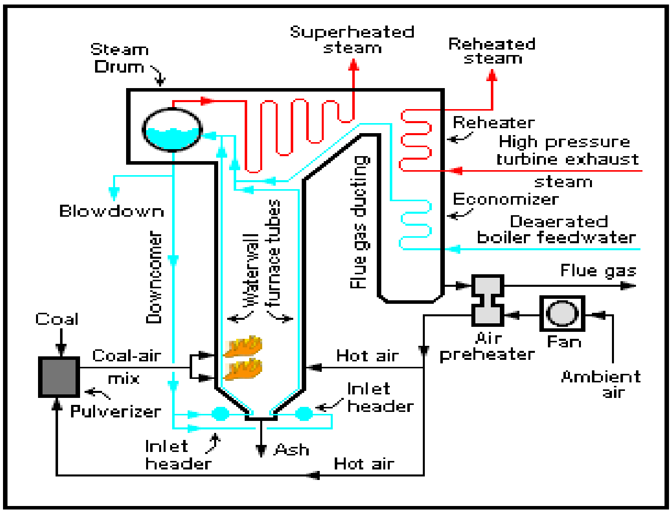

Fig -1: Layout of Steam Power Plant

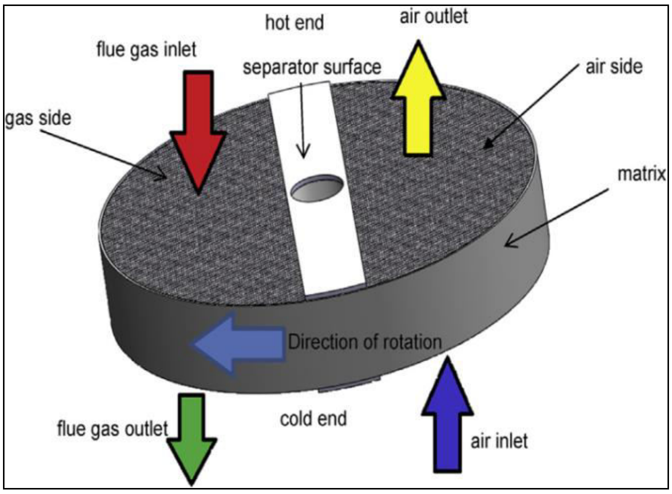

Fig -2: A view of rotary Air preheater

Rotary air preheater is one of the important energy recovery systems in the steam power plant which was first introduced in 1920 by Ljungstrom [1]. Warren published his studies on Ljungstrom air preheater and base on the experimental results confirmed a minimum reduction of 10% in power plants fuel consumption [2]. Sandira ELJSAN shows how operation parameters of a regenerative air preheater can be optimized to increase its efficiency and consequently the overall efficiency of a steam boiler [3]. Installation of air preheater reduces fuel consumption by as much as 25 %.

Armin Heidari-Kaydan, Ebrahim Hajidavalloo investigated RAH in 3-D and treating it as a porous media with the help of Fluent software [4]. They discussed the effect of parameters such as rotational speed of the matrix, fluid mass flow, matrix material and temperature of the inlet air on the performance of the preheater. Jonathan Dallaire also optimizes the thermal performance of a rotary heat exchanger as porous media [5]. They considered length and porosity as a variable. Two different porosity geometries have been investigated, a series of parallel channels and a packing of spheres. For numerical calculations finite volume formulation is used.

Sreedhar Vulloju tested air preheater elements using cold flow studies [6]. He proved that performance of Ljungstrom air preheater is dependent on the heat transfer element profiles. These profiles were tested using residual time test and Cold flow study. Theses performance was compared at different Reynolds numbers.

Saeid Jafari optimized operational conditions of the rotary regenerator using genetic algorithm optimization technique [7]. They took thermal effectiveness as objective function. Decision variables like volumetric flow rates of cold and hot air streams, matrix rotational speed, and heat transfer surface area were considered in his work. Sandira Alagi made use of the commercial CCM (computational continuum mechanics) solver to obtain results [8]. The results were displayed in the form of the temperature distribution within the preheater solid elements and fluid flow of both the hot combustion products and cold air. Hong Yue Wang employed semi analytical method to investigate the 3-D heat transfer of tri-sectional rotary air preheater [9]. The main focus was on the temperature distribution of the matrix.

2. HEAT TRANSFER ELEMENTS

Heat transfer element is the heart of the Ljungstrom air preheater. Different types of element profiles are currently available and in use.

1) NF - Notched flat:
Although relatively low in thermal efficiency, it's wide open configuration (axial oriented Notched sheet followed by a Flat sheet) makes NF element for coal fired units where condensation combines with ash resulting in plugging and corrosion. NF element is usually provided in the thicker 18 gauge steel for increased life (Fig-3).

2) ACE - Advanced clear element:
ACE design is the optimum solution for most air heater element problems in today’s power plant environment. ACE element not only provides a lower pressure drop than other available element, but its unobstructed flow pattern greatly reduces plugging from ash and enables the element to be easily cleaned throughout its entire depth with normal soot blowing (Fig-4).

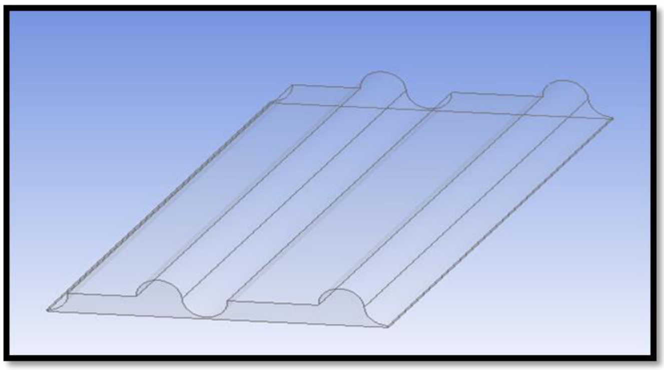

Fig -3: Modeling of NF Profile

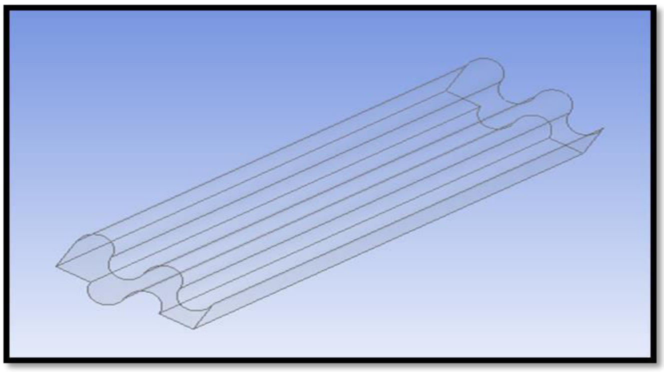

Fig -3: Modeling of Ace Profile

3) FNC - Flat Notched Crossed:
This element has higher thermal performance and lower pressure drop. It is mainly used in low fouling applications such as oil and gas since it is extremely difficult to clean (Fig.-5).

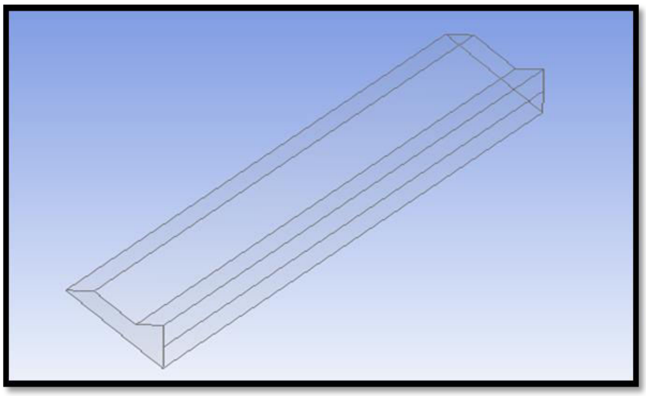

Fig -5: Modeling of FNC Profile

4) NU - Notched Undulated:
This profile is similar to NF but contains an undulated sheet in place of the flat sheet used in NF. NU has better heat

transfer characteristics than NF and can be used on applications where the potential for plugging is low (Fig-6).

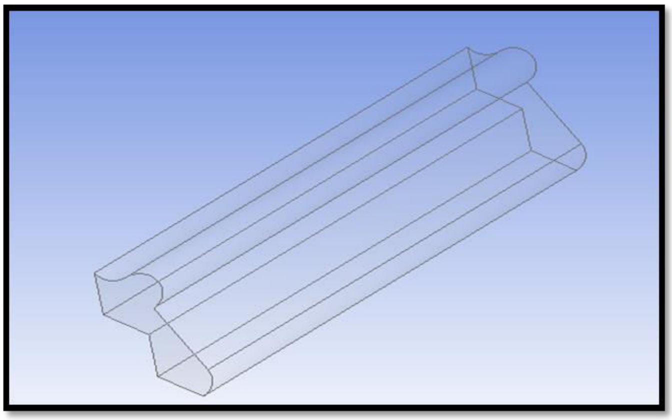

Fig -6: Modeling of NU Profile

5) CU - Corrugated Undulated:
This profile is typically used only in natural gas fired units. CU is a compact, exceptionally high thermal efficiency element but it has high pressure drop characteristics as well. This element is most suitable when used with the low density flue gasses produced when firing natural gas (Fig-7).

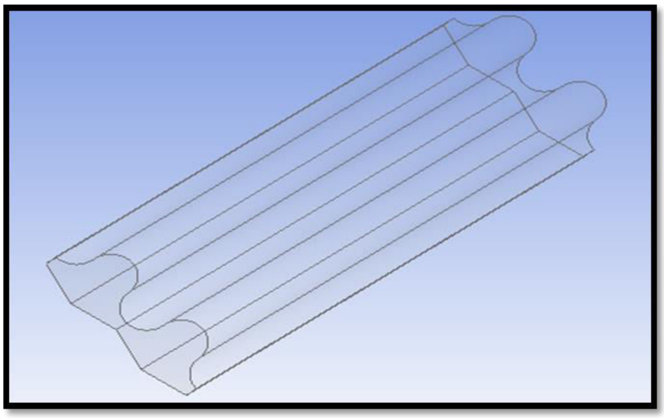

Fig -7: Modeling of CU Profile

3. EXPERIMENT MEASUREMENTS

IRJET In this paper, five types of profiles has been tested to evaluate efficiency. These profiles are namely,
(1) NF (Notched Flat) profile
(2) ACE (Advanced clear element) profile
(3) FNC (Flat Notched Crossed) profile
(4) NU (Notched Undulated) profile
(5) CU (Corrugated Undulated) profile

Generally these elements are made-up of corten steel. Corten steel has more erosion resistance, more corrosion resistance and high thermal conductivity.

Experiments were conducted at KLTPS (Kutch Lignite thermal power station) of GSECL.

Specifications of unit under study and Ljungstrom air preheater are as under;
Plant specification:

- Capacity - 70 MW Unit
- Turbine - 3000 rpm
- Frequency - 50 Hz
- Power factor - 0.8
- Ambient temperature - 40 ^{0}C

Rotary air preheater specification:

- Type - Ljungstrom regenerative
- Rotor rotation - 2 rpm
- Rotor diameter - 5.86 m
- Heating plate height-hot part-864 mm
- Cold part - 305 mm
- Heating plate thickness - 1 mm
- Plate material - Corten steel

Table -1: Average Values of Readings

Medium	Inlet temp.	Inlet Pressure	Outlet temp.	Outlet pressure
Air	315.55 K	2.0538 KPa	562.15 K	1.737 KPa
Flue gas	584.75 K	-0.5434 KPa	486.75 K	-1.5446 KPa

Table -2: Composition of Flue Gases

Sr. No.	Constituent	Weight percentage	Mole percentage
1	O_2	5%	4.35%
2	CO_2	10%	6.25%
3	CO	9%	8.70%
4	H_2O	13%	19.56%
5	N_2	63%	61.14%

Table -3: Properties of Flue Gas

Sr. No.	**Property**	**Value**
1.	Density	0.623 Kg/ m3
2.	Specific heat (constant pressure)	1.1798 Kj / Kg.K
3.	Thermal conductivity	0.04067 W / m.K
4.	Viscosity	0.026 Pa.s
5.	Enthalpy	280.37 Kj / Kg
6.	Molar mass	27.2324 g / mol

During experiment, sufficient numbers of readings were taken at inlet and outlet of the preheater. Temperature and pressure of both air and flue gas were taken at inlet and outlet. The average values of all the measurements were obtained and presented in Table-1.

The thermal power plant is using Lignite as a fuel. Composition of flue gas is shown in Table-2 and the property of the flue gas is present in Table-3.

4. FORMULATION

Efficiency of the air preheater is defined as the ratio of actual heat transferred to maximum possible heat transferred.

Efficiency = heat transferred/ Maximum possible heat transferred [4]

$$= \frac{m_{in,\ flue\ gas} \times c_{p,\ flue\ gas} \times (T_{in,\ flue\ gas} - T_{out,\ flue\ gas})}{m_{in,\ flue\ gas} \times c_{p,\ flue\ gas} \times (T_{in,\ flue\ gas} - T_{in,\ air})}$$

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

Where,

$m_{in,\ flue\ gas}$ = mass flow rate of flue gas at inlet

$c_{p,\ flue\ gas}$ = specific heat of flue gas at constant pressure

$T_{in,\ flue\ gas}$ = flue gas temperature at inlet

$T_{out,\ flue\ gas}$ = flue gas temperature at outlet

$T_{in,\ air}$ = air temperature at inlet

5. CFD ANALYSIS

Modeling of each profile was done using Creo Parametric. The geometry is then imported in ANSYS CFD for analysis. In a test case tetrahedral element are used in mesh with 199537 numbers of elements. Based on the literature review total energy model for heat transfer and k–epsilon turbulence model is used in the CFD analysis. The aim of the analysis is to find out outlet temperature of the flue gas. Boundary conditions used for analysis are shown in the Table-4.

Table -5: Boundary conditions

Boundary condition	Temperature	Pressure	Rotation
Inlet	584.75 K	-0.5434 KPa	2 rpm
Outlet	-	-1.5446 KPa	2 rpm

5.1 Grid Independent Test

Grid independence is the term used to describe the improvement of results by using successively smaller size for the calculations. A calculation should approach the correct answer as the mesh becomes finer. The normal CFD technique is to start with a coarse mesh and gradually refine it until the changes observed are smaller than a pre-defined acceptable error.

Three runs of the same problem chosen with very different mesh size. These show how well the software copes up with a changing scale and how very close it is to having grid independence (Chart-1).

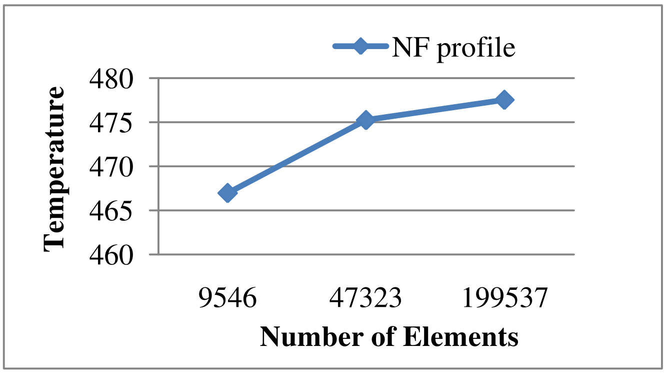

Chart -1: Grid independent test

6. RESULTS & DISCUSSIONS

Efficiency of NF profile obtained using experimental measurements and CFD analysis are 36.40% and 39.83% respectively. So, experimental and analytical results show good agreement.

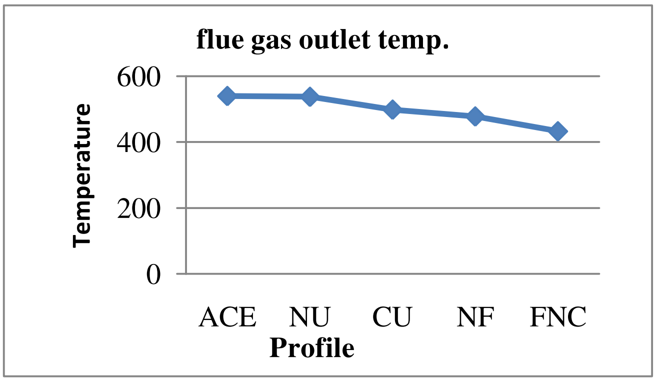

Chart -2: Flue Gas Outlet Temp.

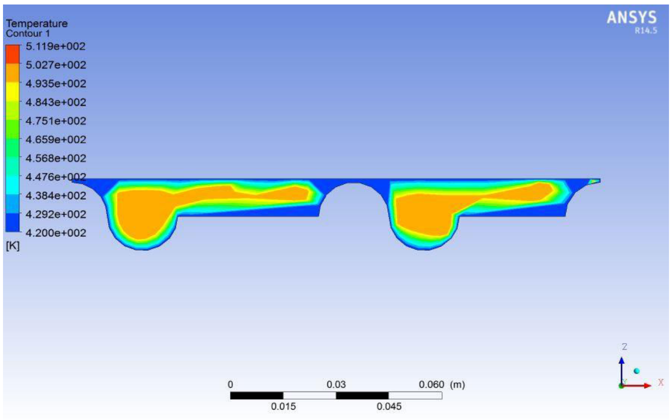

Fig -8:Temp. Contour for NF

Efficiency of APH depends on the flue gas inlet temperature, air inlet temperature and flue gas outlet temperature. But flue gas inlet temperature and air inlet temperature are fixed. So, efficiency is only function of the flue gas outlet temperature. Outlet temperature of different profiles calculated using CFD analysis is shown in Fig. 9. Temperature contours of flue gas at outlet for different profile is shown in Fig. 8-12. Efficiency for different types of profiles is shown in chart-3.

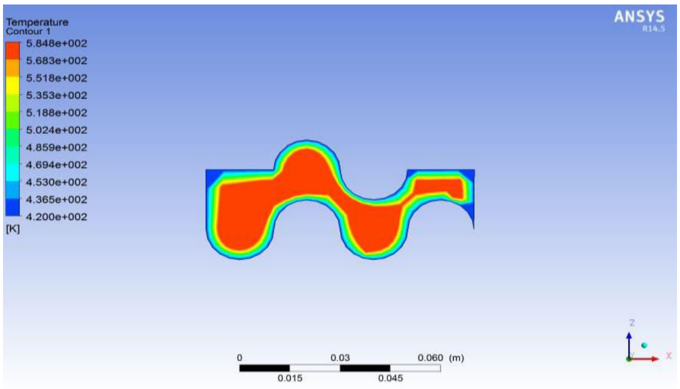

Fig -9:Temp. Contour for ACE

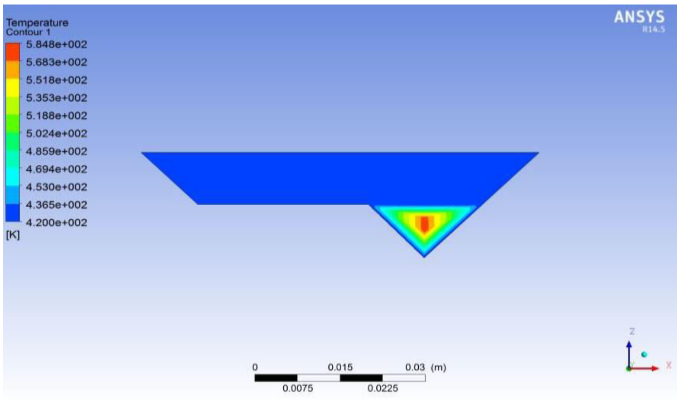

Fig -10:Temp. Contour for FNC

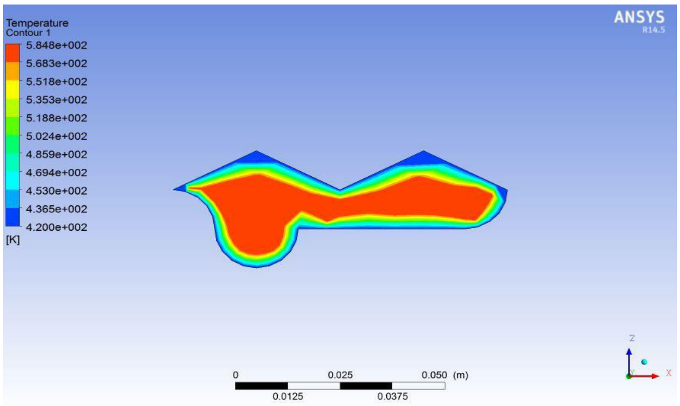

Fig 11:Temp. Contour for NU

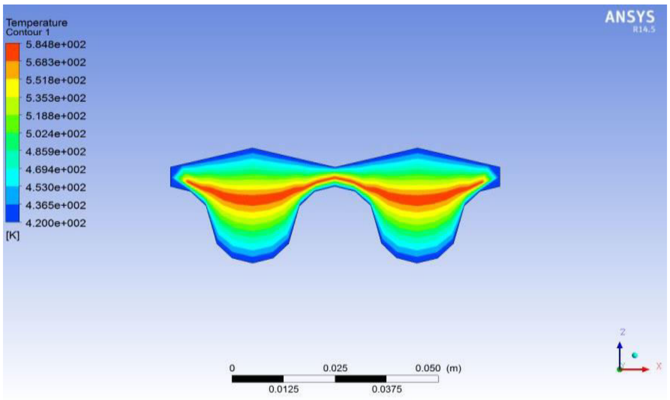

Fig -12:Temp. Contour for NU

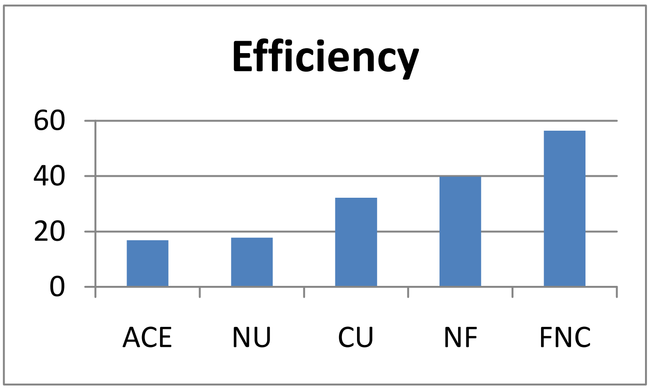

Chart -3: Efficiency for different profile

7. CONCLUSIONS

As a part of this research work, CFD analysis and experimental study were carried out to optimize the efficiency of air preheater element profile. Findings of the work are;

1) Heat transfer depends on the type of element profile used for air preheater.

2) NF profile is most efficient among all the profiles studied.

In future, this study can be applied to problems involving element profile in heat transfer. Material change can also be tested.

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