International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Analysis of Performance of Ljungstrom Air Preheater Elements

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Accepted 10 January 2014, Available online 01 February 2014, **Special Issue-2, (February 2014)**

Abstract

The Ljungström air pre-heater is a regenerative type of heat exchanger used for preheating the combustion air, mainly in thermal power plant. The warm gas and cool air ducts are arranged to allow both the flue gas and the inlet air to flow simultaneously through the air preheater. The hot flue gas heats the rotor material and as the rotor rotates, the hot rotor section moves into the flow of the cold air and preheats it. The performance of Ljungstrom Air Preheater is depended on the heat transfer element profiles. New profiles are being designed in such a way that these new profile elements must be improving the efficiency of Air Preheater. In this context, it is felt necessary to develop new element profiles with lesser pressure drops for efficient heat transfer with less power consumption to improve overall efficiency of thermal power plants. In this research paper, two types of element profile (Flat Notched Crossed & Double Undulated elements) are tested using cold flow studies with the help of wind tunnel and compared their performance at different Reynolds numbers.

Keywords: *Ljungstrom air preheater, heat transfer element profiles, cold flow studies, wind tunnel.*

1. Introduction

The overall efficiency of a thermal power plant is increased by preheat the air before supplied to combustion chamber. If the incoming air for combustion is not preheated, then some additional energy must be supplied to heat the air to a temperature required to facilitate combustion. Due to this, more fuel will be consumed which increases the overall cost and decreases the efficiency of plant. Generally the rotary regenerative air pre-heater (APH) (Ljungstrom) is more used than any other type of heat exchanger for comparable service. Proven performance and reliability, effective leakage control, and its adaptability to almost any fuel-burning process, are the basis for its preference. It is both designed and built to operate over extended periods with durable service. Simplicity of design also makes it easy and economical to maintain while in operation. For fossil fuel-fired power generators and industrial processes, the recovery of waste heat energy has proven to be one of the most effective ways to conserve fuel and lower operating costs. Fuel savings with the Ljungstrom APH are about 1-1½% for every 40°F to 50°F increase in combustion air temperature, depending on the application (11). They not only provide the highest fuel saving efficiency that is available, but their simplified design and operating integrity assure continuous reliable service throughout the life of the Plant. Heat energy is captured and transferred to incoming air for combustion before it is lost to the stack. The result is a substantial saving in fuel that would otherwise be required to bring the air up to combustion temperature.

A rotary regenerative APH consists of a central rotor which keeps rotating at a constant speed. The heat transfer surfaces which are referred to as matrix is attached to the central rotor. The APH is divided into two sectors. Hot flue gas enters from the top and leaves from the bottom in one sector; ambient air enters from the bottom and leaves from the top in the other sector. During the heating phase, the hot flue gas comes in contact with the matrix and transfers its thermal energy. Moreover, the temperature of the matrix keeps increasing continuously in the heating phase as it is always in contact with the hot flue gas. Once the matrix comes to the other sector on rotation, energy is transferred in the form of heat from the hot metal matrix to the ambient air. As a result, the metal matrix cools down and the ambient air gets heated and leaves from the top. This cycle keeps happening in an APH continuously and heat is alternatively stored and rejected by the matrix. Due to the continuous heating and cooling of the metal matrix, it is subjected to continuous thermal fatigue stress due to the temperature difference present between the heating and cooling cycle. It is crucial to identify the thermal fatigue stresses at different regions of the APH to predict the probability of a particular region to succumb before another. The research work aims to identify such regions by analyzing the three dimensional temperature profiles.
Fredrick Ljungstrom was the pioneer credited with coming up with the design for the APH. By the year 1926, the APH had become a part of many thermal power plants as a

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substantial amount of coal could be saved over a period of time. The first recognized work on the temperature distribution of an APH was done by Hausen and was used till 1948. Mondt provided an improvised model by taking into account the longitudinal conduction effects.

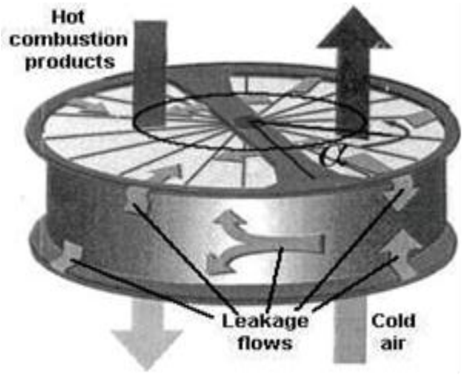

Fig. 1 Fluid flows in Ljungstrom Air Preheater.

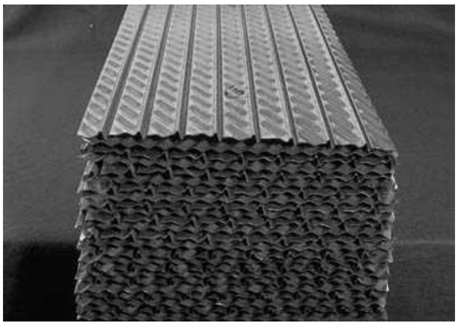

Fig. 2 Arrangement of heat transfer elements.

Lambertson came up with the complete solution for the temperature distribution for the APH in the hot and cold sectors. An axial stationary conduction model for the APH was developed by Bahnke and Howard. Lambertson, Mondt, Bahnke and Howard used the principles of finite difference method to treat steady-state behavior with respect to both finite rotational speed and finite longitudinal heat conduction in a solid. Leong and Toh developed software for the regenerator simulation using the _-NTU method. Beck extended Bahnke and Howard's solution with matrix surface effects on the regenerator performance.

2. Heat Transfer Elements

As the heat transfer element is the heart of the air preheater it is important to ensure that thermal and hydrodynamic data is reliable. The large numbers of element profiles are developed and available for use, four elements are currently available (Figure 3, 4, 5 and 6). The performance of all elements has been tested in the laboratories.

2.1 FNC - Flat Notched Crossed: This has the highest thermal performance, resulting in the shallowest heater for a given thermal duty. In addition the ratio of pressure drop per unit of heat transfer is lower than for any other element thus it will also have the lowest pressure drop.

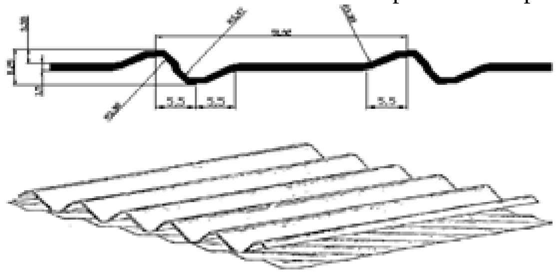

Fig. 3 FNC element profile

2.2 DU - Double Undulated: This is used in place of FNC for applications where the fuel ash is expected to be more erosive than normal or where there is a higher potential for fouling, eg. at the cold end. This is because a) the gas is less turbulent as it flows through the element thus reducing erosion.(b) because the passages through the element tend to prevent the energy of the air or steam used in soot blowing from dissipating, thus maintaining cleaning efficiency through the full length of the tier.

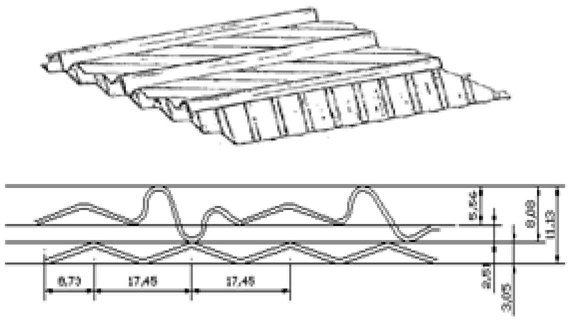

Fig. 4 DU element profile

2.3 CU - Corrugated Undulated: A more open element than DU but requires a greater depth and thus pressure drop for the same heat transfer. It also has a profile, which assists efficient cleaning.
2.4 NP - Notched Plate: The simplest element currently in use. Its low heat transfer properties, resulting in a deep rotor mean that it is seldom used nowadays**.**

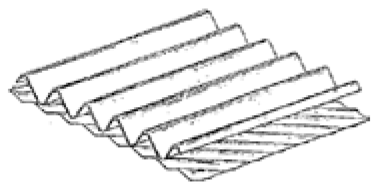

Fig.5 CU element profile

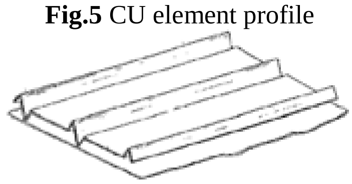

Fig.6 NP element profile

3. Types of Performance Tests

In this paper, two types of heat transfer elements namely (1) Flat Notched Crossed elements (Fig.3), and (2) Double

Undulated elements (Fig 4) have been tested to evaluate fluid flow parameters and heat transfer parameters. Based on comparison studies, the best performance heat transfer element has been obtained. Generally these elements are made-up of Corten steel. Because this material has more corrosion resistance, erosion resistance and high thermal conductivity.

The following two tests are conducted to determine the performance of heat transfer elements.

1. Residual Time Test
2. Cold Flow Studies.

3.1 Residual Time Test

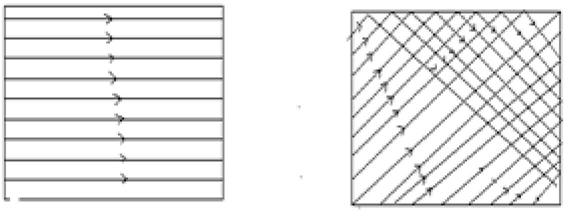

Fig.7 Air flow direction in DU & FNC element.

The time taken by air to travel from one end of element to other end is called Residual Time.

The Residual Time is generally directly proportional to length of air travel which is also directly proportional to surface area of element.

i.e $R_T \propto l_T \propto A$

Where R_T = Residual Time

l_T = Length of path of air travel

A = Contact of air surface area through element.

But $h \propto A$

Where h= Heat transfer co-efficient

If the length of path of air travel through the element is more, then the contact of air surface area through element increases and residual Time through the element is also increased. If surface area increases, then heat transfer co-efficient increases. So, If residual Time is more, elements have more heat transfer coefficient so these elements transfer more heat to medium or absorb more heat from medium and vice-versa. But, residual Time depends on the flow path of air through the elements. The flow of path of air through the DU and FNC element as shown in figure 7 and it shows that air flows in straightly through DU elements and cross flow takes place through the FNC elements. As FNC elements have more Residual Time compared to DU elements, FNC elements have more heat transfer coefficient than DU elements.

3.2 Cold Flow Studies

This test is conducted for two elements (DU and FNC) using Wind Tunnel to evaluate the fluid flow parameters like pressure drop, Reynolds Number, friction factor etc.

4. Experimental Setup

The following equipments are used to conduct the cold flow studies through the heat transfer elements.

4.1 Wind Tunnel: Wind Tunnel is a device in which a jet of air or any other suitable gas (Freon, Nitrogen, Steam etc.) of uniform properties across the cross-section is produced. This is used for aerodynamically testing the models under the given standard conditions. All Wind Tunnels are generally comprised of the driving unit, a settling chamber, an accelerating duct (contraction or nozzle), the test section and the diffuser.

The driving unit consists of the Fan, Blower or a Compressor, generally driven by an electric motor. The location of the driving motor depends upon the type of the tunnel. The flow from the compressor/blower or a fan is settled in a large chamber called the settling chamber; this is provided with wire gauges and arrays of honeycombs to straighten the flow and remove irregularities in it. On account of the very low velocities, near stagnation conditions exist in the settling chamber. This chamber supplies the flow to the contraction located downstream. This is carefully designed to accelerate the flow from the settling chamber to the test section velocity with minimum disturbance.

The contraction or the nozzle feeds the test section with a jet of uniform velocity. The model to be tested is fixed here with suitable supports. A transparent window of strong glass is often provided on one or both the sidewalls of the test section. This facilitates in handling the model and the instruments and also permits optical measurements in the flow over the model surfaces.

The diffuser collects the flow from the test section and raises the pressure of the air for discharging it to the atmosphere or the return circuit in case of a closed circuit tunnel. Boundary layer thickening and separation on account of strong pressure gradients in the diffuser should be minimized. The diffuser throat is often made flexible; this allows the throat to be varied for starting and running conditions. After starting, the diffuser throat area is reduced for optimum running conditions. If the jet from the diffuser is discharged into the atmosphere a distributor and a silencer are often used after the diffuser to reduce the noise level in the area. A suction type Wind Tunnel that was used in the experiment is shown in the Fig.8.

4.2 Velocity Measurement: The radial duct is an expanding passage in which the velocity of the fluid changes. Velocity of air flow is measured just before the test section using TSI hot wire electronic velocitymeter in the test section at 170 locations as average velocity is to be evaluated.

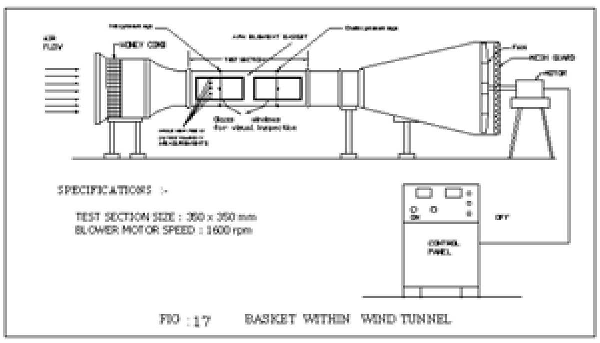

Fig.8 Wind Tunnel Setup.

4.2(a) TSI Velocity Meter: It is an advanced electronic model of a Hot Wire Anemometer. A hot wire anemometer consists of a tiny wire (d=0.005 mm) held between two prongs; it is heated (hence the term Hot-wire) to a given temperature by passing an electric current through it. When such a wire is introduced into the flow of a gas it cools down the hot wire to a lower temperature due to convective heat transfer from the wire element to the gas. By employing suitable electrical circuit the hot wire can be used in two ways.

1. Constant Temperature type: In this method, the temperature of the hot wire is maintained constant by changing (increasing or decreasing) the current flow in the wire. The different values of the current can be used to measure the gas velocities.
2. Constant Current type: In this type the current through the hot wire element is kept constant. Hence the temperature and the wire resistance changes with the flow velocity. A voltmeter (micro or macro) across the wire records the variation of the voltage with the gas velocity. The variation in voltage is calibrated to give the gas velocities.

To have accuracy in measurement, Velocity at 170 locations throughout the test section and their average was considered. The velocity probe was positioned with the help of Traverse mechanism. Experiments have been conducted for various speeds by placing elements such that the axis is in line with the tunnel axis. A typical flow diagram of Instrumentation is shown in the **Fig.8**. This instrument is also used to measure the temperature of air passing through the heat transfer elements.

4.3 Pressure Measurement: Pressure drop of air flow between inlet and outlet of test section is measured by using micromanometer.

5. Experimental Procedure

Flat Notched Crossed elements (860 mm length, 345mm width, 0.63 mm thick) were paired together in a housing former as shown in fig.2 to suit the wind tunnel test section dimensions. Proper sealing was provided to avoid leakages through side gaps. Velocity measurements were taken at the entrance section by providing 5 insertion points at equidistance in the plane perpendicular to the flow direction using traverse mechanism **(**Fig. 8).

Velocity measurements were carried-out for every 10 mm distance (345/10 = 34.5) in the plane perpendicular to air flow direction to the element basket at entry section.

Pressure tapping points in all the four planes of wind tunnel test section that were provided at the entry and exit sections of the basket for the measurement of pressure drop across the Air Preheater element basket.

Wind tunnel is allowed to run at desired rpm to commensurate the air flow through basketed elements by suction. In other words both inlet and outlet of basket constitute suction effect, simulating the conditions of flue gas passage through Ljungstrom Air heater using suction pressure by Induced Draft Fan in Thermal power plants.

In the same manner Double Undulated elements have been tested for performance evaluation.

5. Formulation

For a pipe the characteristic length is hydraulic diameter (D_h) which is calculated by the following formula**:**

$$D_h = 4 \times \frac{\text{Flow cross Sectional area}}{\text{Wetted perimeter}} \quad (1)$$

Density of air is calculated by using the following formula

$$\rho_{air} = 1.293 \times \frac{273}{(273 + t_{avg})} \ \text{kg/m}^3 \quad (2)$$

$$\text{Bed Porosity} = \frac{\text{Flow cross sectional area}}{\text{Total cross sectional area of box}} \quad (3)$$

Actual Velocity of air is calculated by using formula

$$v_a = \frac{\text{Average Velocity}}{\text{Bed Porosity}} \quad (4)$$

Reynolds number is calculated by using formula is

$$Rey = \frac{\rho\, v_a D_h}{\mu} \quad (5)$$

Where ρ = Density of air in kg/m^3

μ = Viscosity of air in pa,sec.

Friction factor is calculated by the following formula

$$\frac{\Delta p}{\rho} = \frac{f\, L\, v_a^2}{2\, g\, D_h} \quad (6)$$

Where Δp = Pressur difference in mmwc.

L = Length of test section in wind tunnel in m.

The fluid pumping power is calculated as follows

$$P = VI \quad (7)$$

Where V = Voltage in Volts

I = Current in amperes.

6. Results and Discussions

Hydraulic diameter of DU element is 8.2019 mm and hydraulic diameter of Flat Notched Crossed element is 8.334 mm. Thus, Double Undulated elements have slightly less hydraulic diameter than Flat Notched Crossed elements.

Flat Notched Crossed elements have more Residual time compared to that of Double Undulated elements. From this result, it is concluded that FNC elements have

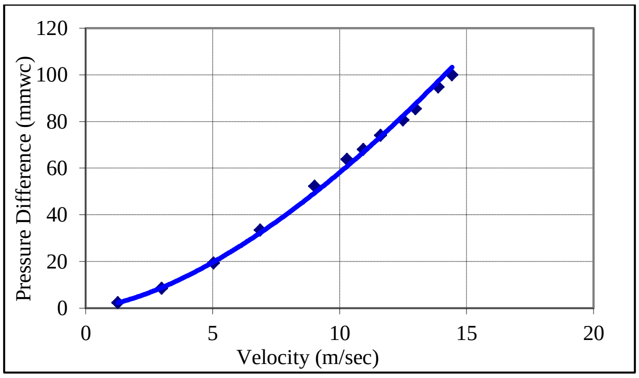

Fig. 9 Velocity Vs Pressure Difference (DU) more heat transfer co- efficient than that of DU elements.

The pair height of Double Undulated element is 11.125 mm and the pair height of Flat Notched Crossed elements is 10.26 mm. Thus, FNC elements have less pair height than DU elements.

31 pairs of heat transfer elements are placed in the test section of wind tunnel. The required volume of 31 pairs of DU elements is 0.1024 m3 and the required volume of 31 pairs of FNC elements is 0.0946 m3. For a given 31 pairs of elements, 7.57 percentage of volume decreases by using FNC elements instead of DU elements.

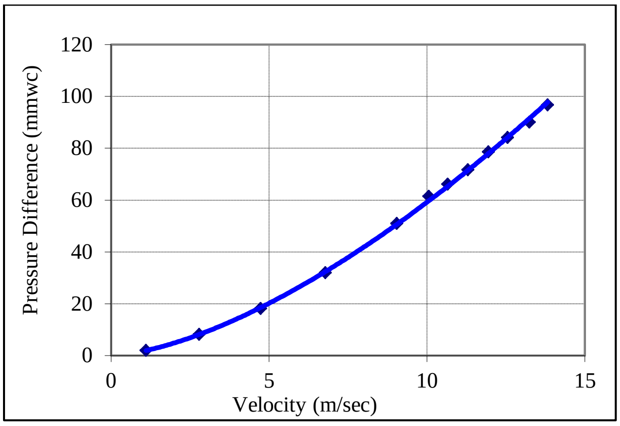

Fig. 10 Velocity Vs Pressure Difference (FNC)

The fig. 9 & 10 shows that velocity increases, the pressure difference through the elements also increases for both FNC and DU elements.

Comparison of pressure drops at various flow rates for both DU and FNC elements as shown in Fig. 11. In these fig., pressure drop increases with increase in velocity. The pressure drop in FNC elements is approximately equal to DU element from velocity 1.2 m/sec to 6 m/sec. The difference between the pressure drop of DU and FNC increases from velocity 6 m/sec to 14 m/sec. The fluid pumping power is directly proportional to the pressure drop in the fluid across element. The required fluid pumping power for DU elements at 1400 RPM is 5475 W. The required pumping power for FNC elements at 1400 RPM is 4420 W.

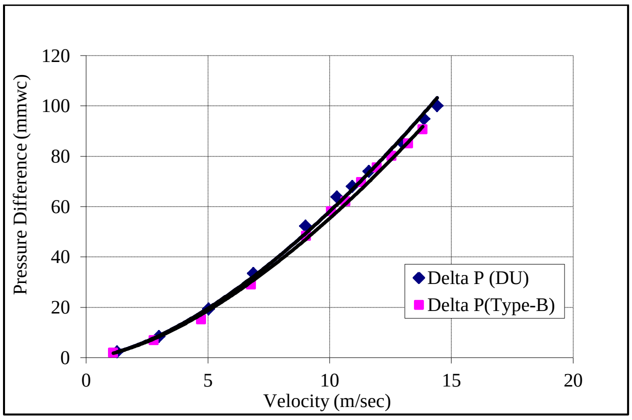

Fig. 11 Comparison of DU & FNC elements

Fluid pumping power decreases 19.3 percentage using FNC elements instead of DU elements at 1400 RPM.

7. Conclusions

From the tests carried out in the Wind Tunnel test facility to find out the performance of both DU and FNC elements, the test result reveals that;

1) It has been concluded that hydraulic diameter does not effect on the performance of Du and FNC elements as the difference between hydraulic diameter of DU and FNC is less.
2) The pair height for FNC elements is less than the pair height for DU elements. So, Flat Notched Crossed elements are occupied less volume than Double Undulated elements in a given number of pairs of elements. Thus, the size and weight of Air Preheater can be decreased using FNC elements instead of DU elements.
3) It is concluded that heat transfer co-efficient FNC elements is higher than DU element as The residual time for FNC elements is more than the residual time for DU elements .
4) The fluid pumping power is directly proportional to the pressure drop in the fluid across element. The fluid pumping power is less for FNC elements compared to DU elements.

From the above points, it has been concluded that the performance of FNC elements is more than DU elements.

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