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Design and Performance Analysis of Air Pre heater for Water Tube Boiler to improve its Efficiency

V. Karthikeyan, M. Sambathkumar, K. Arulkumar

Department of Mechanical Engineering, Excel Engineering College, Komarapalayam, Namakkal. Tamilnadu, India

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ABSTRACT

Air preheater is a heat transfer surface in which air temperature is raised by transferring heat from other media such as flue gas which is coming from boiler exhaust. The paper presents the design of regenerative –air preheater to designed to meet specific performance requirements, using the software application CFD (Computational Fluid Dynamics) / CADD. An analytical study was planned to find out the various heat transfer performance parameters like outlet and inlet air temperature of the air preheater and the boiler, Pressure drop inside the Air preheater and the boiler heat transfer coefficients, heat transfer rate, overall heat transfer coefficient and Velocity of the air and flue gas also Conduction and convection modes of heat transfer were found. These heat transfer parameters are critical in designing and functioning of the air Preheater and to calculate the efficiency of the boiler.

Keywords : CFD, Pre-heater, Regenerative, Boiler

I. INTRODUCTION

A high pressure water tube boiler is a type of boiler in which water circulates in tubes heated externally by the fire. Fuel is burned inside the furnace, creating hot gas which heats water in the steam-generating tubes. In smaller boilers, additional generating tubes are separate in the furnace, while larger utility boilers rely on the water-filled tubes that make up the walls of the furnace to generate steam. The heated water then rises into the steam drum. Here, saturated steam is drawn off the top of the drum. In some services, the steam will reenter the furnace through a super heater to become superheated. Superheated steam is defined as steam that is heated above the boiling point at a given pressure. Superheated steam is a dry gas and therefore used to drive turbines, since water droplets can severely damage turbine blades. Cool water at the bottom of the steam drum returns to the feed water drum via large-bore 'down comer tubes', where it pre-heats the feed water supply. To increase economy of the boiler, exhaust gases are also used to pre-heat the air blown into the furnace and warm the feed water supply. Such water tube boilers in thermal power stations are also called steam generating units. The older fire-tube boiler design, in which the water surrounds the heat source and a gas from combustion pass through tubes within the water space, is a much

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weaker structure and is rarely used for pressures above 2.4 MPa (350 psi). A significant advantage of the water tube boiler is that there is less chance of a catastrophic failure: there is not a large volume of water in the boiler nor are there large mechanical elements subject to failure.

An air preheater (APH) is any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. They may be used alone or to replace a recuperative heat system or to replace a steam coil. In particular, this article describes the combustion air preheaters used in large boilers found in thermal power stations producing electric power from e.g. fossil fuels, biomass or waste. For instance, as the Ljungström air preheater has been attributed worldwide fuel savings estimated to 4,960,000,000 tons of oil, "few inventions have been as successful in saving fuel as the Ljungström Air Preheater", marked as the 44th International Historic Mechanical Engineering Landmark by the American Society of Mechanical Engineers. The purpose of the air preheater is to recover the heat from the boiler flue gas which increases the thermal efficiency of the boiler by reducing the useful heat lost in the flue gas. As a consequence, the flue gases are also conveyed to the flue gas stack (or chimney) at a lower temperature, allowing simplified design of the conveyance system and the flue gas stack. It also allows control over the temperature of gases leaving the stack (to meet emissions regulations, for example).It is installed between the economizer and chimney.

II. Materials and Methods

Air Preheater tubes are essentially a type of heat exchanger tubes use for the purpose of heating air which is further used in other applications like Boilers, Dryers etc. An air preheater (APH) is a general term used to describe any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process . The air passing through the Air Pre Heater is heated by allowing the air to flow on the Outer Surface of the tubes which have a highly heated fluid flowing inside through them. The heat is exchanged over the surface of these tubes and which in turn raises the temperature of the Air flowing over it. The heat transfer can further be improved by use of finned tubes(increasing the contact surface area) .

Air preheater tubes are made from Cold Drawing process and are generally of Carbon Steel material. The application of these tubes is in an area where the tubes is not subjected to extremely high temperatures and pressures. Hence, the use of Carbon Steel tubes in applications for Air Preheater Tubes is generally preferable. There are various types of Air Preheaters; one of them widely used is Tubular Type Air Preheater. In this type of Air Preheater, straight tube bundles are used, which pass through the outlet ducting of the boiler and open at each end outside of the ducting,

The hot furnace gases pass around the air preheater tubes, transferring heat from the exhaust gas to the air inside the preheater. Ambient air is forced by a fan through ducting at one end of the air preheater tubes and at other end the heated air from inside of the tubes emerges into another set of ducting, which carries it to the boiler furnace for combustion. There are other Heat Exchangers like Regenerative Heat Exchangers, Recuperators, economizers which also make use of Air preheater tubes (Heat Exchanger Tubes)

Air preheater tubes manufactured by seamless Tubes are finding more and more application now a days because of higher reliability in seamless process.

Boiler Tubes are made from heat resisting carbon and low alloy steel which can withstand the loads at various pressures and temperatures. Boiler tubes are used for parts of energy type equipments such as boilers, super heaters, economizers, heat exchangers, etc. The tubes are manufactured as hot rolled or cold drawn with welded and seamless manufacturing process. Size and grades of tubes are decided by design of the boilers which are based on the type of fuel, temperatures, pressures and also the quantum of steam required.

Regenerative APH - In this, the heating elements are either rotary or stationary. The primary problem here is the wear and tear of the plates as the incoming flue gas is dust-laden having high ash and silica content. The second problem is the leakage of gases from gaps between the rotating and stationary structures, this leakage of gases affects the performance of APH to a great extent. Seals are provided in the APH to prevent the leakage. Another problem is the deposition of unburnt particles on the surface of APH. As the unburnt deposits meet flowing cold air and flue gas, the ignition temperature is reached along with sufficient amount of oxygen due to which the particles start burning. This also sometimes causes explosions inside the APH.

Dew Point Corrosion

Dew Point Corrosion is a problem generally seen in all kinds of air-pre heaters. The flue gas coming out of the furnace is dust-laden containing contaminants such as chlorides, sulphates etc. As the flue gas attains the acid saturation temperature, i.e. the temperature at which condensation of acids takes place, sulphates, chlorides etc. condensate in the form of acids such as sulphuric acid, hydro-chloric acid and other acids. The condensation takes place on steel tubes and plates, the portion of the tubes or plates which is surrounded by acids is less oxygenated, thus serving as anode while the portion which is not surrounded by acids is more oxygenated thus serving as cathode. This anode-cathode leads up to an electro-chemical cell, which in turn corrodes the base material. Recirculation of hot air in order to control cold end corrosion and ash fouling

Pressure drop

In recuperative air-preheaters, frictional loss during flow; inlet and exit shock losses as well as losses during return bends in flow passage contribute towards pressure drop. Pressure drop is directly proportional to the square of the mass flow rate of air.

Leakage

Recuperative units may begin operation with essentially zero leakage, but leakage occurs as time and thermal cycles accumulate. With regular maintenance, leakage can be kept below 3%. Approximate air heater leakage can be determined based on gas inlet and outlet oxygen (O2) analysis (dry basis).

Plugging and Erosion

Plugging is referred to as fouling and the closing down of heat transfer flow passage by gas which is enriched with ash particles and corrosion products, whereas erosion is the removal of a material layer because of high velocity dust particles. It usually occurs at the gas inlet where the velocity is high. The consequences of erosion are dangerous such as structural weakening, loss of heat transfer area and perforation of components, which may result in air to gas leakage. Erosion can be controlled by reducing the velocities, removing the affected material, galvanization or by using a sacrificial material. In an APH, the cold end flue gas temperature is designed for acid due point. Once the coal is burnt completely , sufficient alkaline fly ash is available which can absorb the acid

(H_2SO_4) thus preventing fouling, corrosion of air-preheater and ducting . If ash to sulphur ratio is more than 7:1 then, cold end fouling does not even occur at below 120 ºC temperature. The main requirements of an APH are high heat transfer rate, low pressure drop and low sensitivity to fouling. These features mainly depend upon the profile of heating elements used.

Thermal Conductivity

Thermal conductivity measures the ability of a metal to conduct heat. This property varies across different types of metal and is important to consider in applications where high operating temperatures are common. In pure metals, thermal conductivity stays roughly the same with increases in temperature. However in alloys the thermal conductivity increases with temperature.

Thermal Conductivity of Various Range of Metals

Common metals ranked by thermal conductivity		
Rank	Metal	Thermal Conductivity [BTU/(hr·ft·°F)]
1	Copper	223
2	Aluminum	118
3	Brass	64
4	Steel	17
5	Bronze	15

Experimental Set-Up Experiment Details

S. No	Details	APH Design
1	Hot End	0.6 mm, 762 mm or 0.8 mm, 300 mm Carbon Steel
2	APH Size	2000 (mm)
3	Hot Intermediate	0.6 mm, 762 mm, or 0.63 mm, 700 mm, Carbon Steel
4	Cold Intermediate	0.63 mm, 700 mm, Carbon Steel
5	Cold end	1.2 mm, 305 mm, Corten Steel or 0.8 mm, 300 mm, Corten Steel
6	Overall Height	1829 mm to 2000 mm
7	Sealing System	Single Seal or Double Seal
8	Heating Surface Area Provided	18497 sq. m per APH to 21629 sq. m per APH
9	Rotor Design	Modular
10	Capacity	4000 kg/hr
11	Primary Exchange r Material	Steel
12	Flow Rate (L/min)	140 L/min
13	Temperature	300 degree

Design of Air Pre-Heater

The Air Preheater designed for the analysis is the Recuperative Tubular type with the staggered tube arrangement. It consists of 1488number of steel tubes/pipes arranged in 32 rows, with 47 tubes in 1st row and 46 tubes in2nd row and soon.

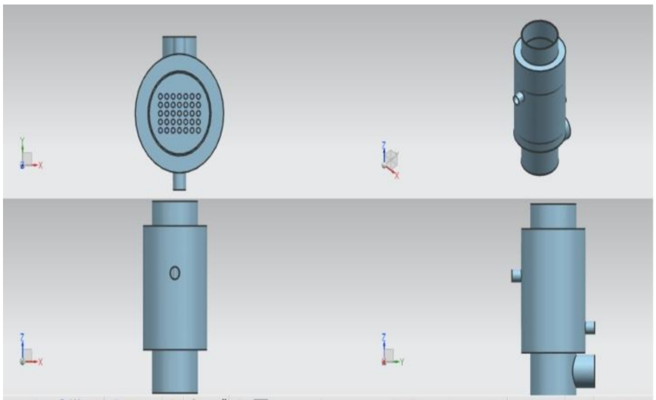

Fig. 1 Design of Air Preheater

Either side of the tubes is welded into the plate. It is designed such that air flows through the tubes and flue gas flows over the tubes heating the tube surface. The design of Air Preheater is done in SOLIDWORKS which is a comprehensive suite of computational fluid dynamics software for modeling fluid flow and other related physical phenomena.

III. Result and Discussion

Comparison of Air Leakage

As per this design and calculation it found that the leakage has been reduced considerably, so it is ensuring that heat transfer rate was increased. As shown in fig. 2

Before design Air leakage		After design Air leakage	
O_{2g1}	$5m^3$	O_{2g1}	$5m^3$
O_{2g2}	$3m^3$	O_{2g2}	$3.3m^3$

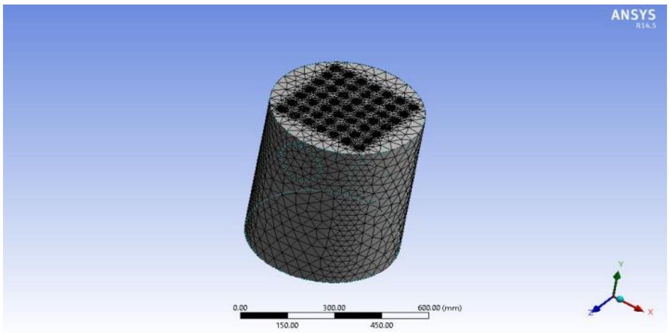

Fig. 2 meshing of tubes

Inlet and Outlet Temperature of Air

The analysis of input & output temp and calculation show that the output temp of gas is increased and flue gas were decreased. It is ensured the efficiency of the boiler was increased. As shown in fig. 3

Logarithmic Mean Temperature Difference

$$LMTD = \frac{\Delta T1 - \Delta T2}{ln(\frac{\Delta T1}{\Delta T2})}$$

Parallel Flow

$$= \frac{180-16.5}{(\frac{180}{16.5})} = 68.42$$

$Q_f = m_g C_{pg} (T_{fo} - T_{fi})$

$= 10.89 x 1.0995(170-210)$

$= 478.5 m^3/s$

$Q_{air} = m_a C_{pa} (T_{ao} - T_{ai})$

$=9.52 x 1.0294 (168.5-30)$

$= 1072.14 m^3/s$

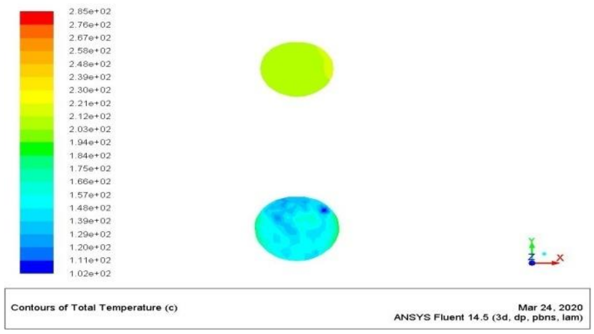

Fig.3 Inlet and Outlet Temperature of Air

Inlet and Outlet Temperature of Flue Gas

The overall heat transfer rate between the flue gas and air Shows that, Air heat is increased and flue gas heat is decreased. The analysis output and calculation is ensuring the same. As shown in fig. 4

$Q = u_o x \frac{\pi}{4} D^2 x l x 68.42$

$= 0.014 x \frac{\pi}{4} (24)^2 x 1.55 x 68.42$

$= 671.6 kw$

$Q = u_o x \frac{\pi}{4} D^2 x l x 68.42$

$= 0.925 x \frac{\pi}{4} (24)^2 x 1.55 x 68.42$

$= 44378 kw$

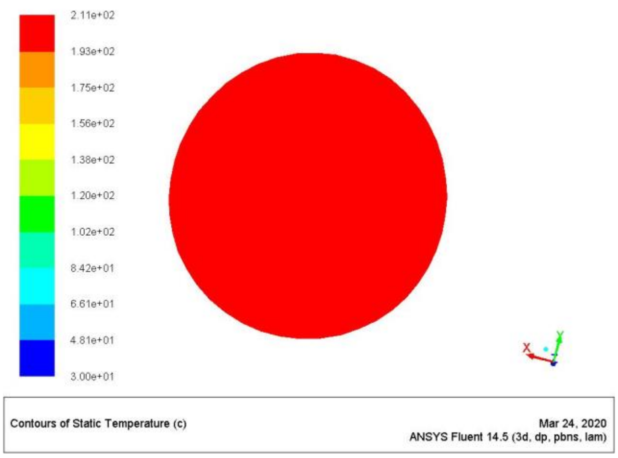

Fig. 4 Inlet and Outlet Temperature of Air

As per this data we can conclude that the heat transfer rate was increased, so it is showing that the boiler efficiency was increased through the air preheater.

IV. Conclusions

The Thermal performance of the air preheater and boiler is improved. From the design and analysis of Air Preheater, it can be concluded that the heat transfer performance parameters like outlet temperature of air Tao, outlet temperature of flue gas Tgo, overall heat transfer coefficient based on outside surface area Uo and rate of heat transfer Q obtained from analytical analysis are in good agreement with the corresponding values obtained from CFD analysis, with very little deviation. Hence it can be concluded that these design parameters of air Preheater met with the performance requirements as intended. It can also be concluded that the designed air Preheater serves the purpose of extracting heat from the flue gas of boilers, which can be used to preheat the air required for the combustion of the fuel in the boilers, thereby increasing thermal efficiency of the boiler, ultimately making a considerable contribution to improve the overall efficiency of fossil-fuel-fired power plants.

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