Performance Analysis of Radiant Super Heater in AFBC Boiler

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Abstract—The bed superheater of no. 4 of TNPL is subjected to the various problems like erosion, clinker formation, space constraint and frequent replacement of tubes. We have come up with a solution to overcome these issues by designing radiant superheater which involves the replacement of entire bed superheater and shifting it to the radiant zone where we don’t have a constraint of space and core temperature can be achieved. This greatly reduces the problem of frequent replacement of tubes and the increases the availability of superheater tubes to a great extent.

Key words: Reducing the problems in the boiler using radiant superheater.

NOMENCLATURE

FBC- FLUIDIZED BED COMBUSTION BOILER
AFBC- ATMOSPHERIC FLUIDIZED BED COMBUSTION BOILER
CFBC- CIRCULATING BED FLUIDIZED BED COMBUSTION BOILER
BFBC- BUBBLING BED FLUIDIZED BED COMBUSTION BOILER
PFBC- PRESSED FLUIDIZED BED COMBUSTION BOILER

Vg- VOLUME OF FLUE GAS
K- THERMAL CONDUCTIVITY
Re- RENOLDS NUMBER
NU- AVERAGE NUSSELT NUMBER
h- HEAT TRANSFER COEFFICIENT
U- OVERALL HEAT TRANSFER COEFFICIENT
f- CORRECTION FACTOR
MTBF- MEAN TIME BETWEEN FAILURE

1. INTRODUCTION

Atmospheric Fluidized Bed Combustion (AFBC) technology has the potential to use alternative fuel sources such as coal, wood, or waste, and is able to reduce and control nitrogen oxide (NOx) and sulfur dioxide (SO2) emissions. This report reviews AFBC technology for possible use in Army boilers in the size range of 20,000 to 300,000 lb/h steam.

AFBC involves burning sulfur-containing fuel particles suspended in an air stream, which causes them to behave like a fluid. The bed of particles is normally only about 10 percent fuel; the remainder is inert materials and sorbent (dolomite or limestone), which is used to capture up to 90 percent of the sulfur. This sorbent is continually injected into the bed while a gravity drain system withdraws spent material and ash particles.

[1] M.Hajee Mohamed, (mar 2015), focuses on the working principle of thermal power plant. In thermal power stations fuels are burnt and the resultant steam is used to drive the turbo generator. The pressure energy of the steam produced is converted into mechanical energy with the help of the turbine. Superheaters are used to heat the steam from the boiler and meanwhile the flue gases are let to the atmosphere through chimney. In India 65% of the total power is generated by thermal power stations.

[2] Dawid Taler and Jan Taler, (Jan 2009), describes the determination of the radiation heat transfer coefficient in radiation platen super heaters and on convective heating surfaces. It is determined on tube surfaces in convective evaporator, in a second stage convective heat super heater, and in platen super heater of a pulverized coal-fired boiler. In order to assess the accuracy of the achieved results, the flow of flue gas and the heat exchange were modeled using a commercial computational fluid dynamics program.

[3] V. Gnapathy (Jul 2001), outlines some of the
design considerations and performance aspects of superheaters which should be intrest to plant engineers.in packaged steam generators the vertical tube superheaters are replaced with inverted loop superheaters with is also common in HSRG’s. the performance is analyzed of the designed inverted loop superheater is calculated based on both design and off-design conditions, a final material is selection is made.

Atmospheric fluidized bed boilers consist of a chamber in which fuel is burned till being suspended in a gaseous mixture with inert material and sorbent. The sorbent most commonly reacts with SO2 released during combustion to form a solid sulfate material. The fluidized bed is maintained at 1400 to 150°F to maximize sulfur capture. This low temperature also reduces NOx emission while minimizing clinker formation. Although these characteristics are common to all fluidized bed boilers, the fuel and solvent feed systems, ash recycle/removal methods, and heat transfer surface vary. In this design of radiant super heater frequent replacement of tubes in a boiler can reduced.

2. FLUIDISED BED COMBUSTION BOILERS

A Packaged fluidized boiler concept has been introduced for the first time in the country in the range of 4 to 10 T/hr steam generation capacity. Fuel such as coal, lignite, spent biogases. Rice husk have been tried retrofit on FBC to existing boiler as a great potential. There are three types namely

1) Atmospheric Fluidized Bed Combustion System (AFBC)

2) Atmospheric circulating (fast) Fluidized Bed Combustion system (CFBC)

3) Pressurized Fluidized Bed Combustion System (PFBC).

3. ATMOSPHERIC FLUIDIZED BED COMBUSTION SYSTEM (AFBC) :

Fig. 1

When fluidization medium (limestone, sand etc.) placed on the distribution panel (perforated panel) is supplied with air from beneath, the medium floats in the air current within a specific range of the air speed, just as in a state of boiling. The layer of floating medium in this state is referred to as a fluidized bed. When coarsely-crushed coal is continuously supplied into the fluidization medium, which is heated in the air heating furnace to the ignition temperature of coal, the coal spontaneously starts burning. The furnace is turned off at this point, and while the coal keeps burning, coal supply volume is controlled so that the temperature of the fluidized bed stays at 760 to 860 deg.C. For recovering heat, the fluidized bed combustion boiler has heat exchanger tubes in its fluidized bed and convection section. The use of limestone as fluidization medium enables in-furnace desulfurization. Flue gas from the fluidized bed combustion boiler includes various unburned components, which are collected by the mechanical precipitator and burned in the after-burner furnace (CBC) to improve combustion efficiency.

[Features]
- In-furnace desulfurization Fluidized bed combustion boiler can remove SOx in the furnace while burning coal,using limestone as the fluidization medium.
- Use of various types of coalSince the fluidized bed combustion boiler ensures stable combustion at low temperature, as compared to the pulverized coal fired boiler, various types of coal can be used.
4. PROBLEMS PREVAILING IN EXISTING BOILERS

The problems occurred are: Clinker formation, Erosion, Space constraint, Frequent replacement of super heater tubes.

Before Implementation of Radiant Superheated

The bed superheater is one of the important accessories in fbc boiler. It is located inside the evaporator tubes, which are placed in the furnace bed. In the bed superheater even though the area is relatively less the heat transfer is more because it is located inside the furnace bed. The high velocity of air fuel mixture is very less about 2 to 3 years. The space availability in the furnace is very less. Bed superheater is placed in the bed of the furnace above the bed material, before the implementation of radiant superheater boiler is subjected to various problems such as clinker formation, erosion, space constraint and frequent replacement of tubes.

![Diagram of bed superheater](image)

**Fig. 2**

A. Clinker formation

It is a serious problem in the boilers of thermal power plants which results in forced outage for very long duration and generation loss. The removal of clinkers from the water wall and hopper of boilers is very difficult because clinkers are very hard lumps due to presence of metals in them. Main problem with conventional coal combustion is clinker formation. All coal contains non consumable components some of these components can melt at the temperature attain in the coal bed, when this happens clinker is formed.

B. Erosion

The combustion products of coal contain fly ash particles, which impinge on boiler tubes or fan blades and erode them. Fly ash erosion is the second most important cause for boiler tube failure. Tube failures by erosion in some cases account for about one-third of all tube failures in a boiler. Superheater tubes are just placed above the fuel grade. During combustion, the coal and the fuel gas upwards at the high velocity. This high velocity and high temperature coal particles and fuel gas impacts the bed super heater tube this impact of coal particles at very high temperature erodes the tubes.

C. Space Constraint

The bed super heater coils are placed inside the evaporator tubes, which are placed inside the furnace. The space inside the evaporator tube is very less. Therefore the inspection maintenance and replacement are difficult. This leads to frequent replacement, which make the space constraint.

D. Frequent Replacement of Super Heater Tubes

Due to erosion of super heater, the superheater coils need to the replacement very often. The clinker formation on super heater tubes leads to reduction in heated transformation rate. The replacement of super-heated tubes leads 2 months, for the boiler tubes has to be shut down for a long time.

4. SOLUTION FOR THE PROBLEM

After Implementation of Radiant Superheater

After the implementation of the radiant superheater, the bed super heater is removed and the radiant superheater is placed at the radiant
zone, where there is no constraint of space and increase the availability of superheater for easy replacement. The radiant superheater is located in a harsh environment, the furnace exit gas temperature is one of the most difficult parameters to estimate. Radiant energy varies as the fourth power of absolute temperature and hence a few degrees higher than estimate value can transfer significant amount of radiant energy to superheater, thus increasing the tube value and support temperature leading to failure, the super heater is located in a reason where it is.

5. DESIGN CALCULATION FOR RADIANT SUPERHEATER AND ITS FORMULAE:

**HEAT ENERGY REQUIRED:**

Heat energy required\(=V\Delta C_{ps}\Delta T\)

\[=1530.61*0.593*0.51*150\]

\[=70021\text{ kcal/hr}\]

**HEAT TRANSFER COEFFICIENT OF FLUE GAS:**

Volume of flue gas \(v_{fg}\)=122110 m\(^3\)/hr

\(T_a=820^\circ\text{c}\)

\(T_s=440^\circ\text{c}\)

Film temperature \(T_f=(T_a+T_s)/2\)

For the flue gas at 630\(^\circ\text{c}\)

- Kinematic viscosity \((U)=99.157*10^{-6}\text{ m}^2/\text{sec}\)
- Density = 0.3924 kg/m
- Thermal conductivity \((k_f)=66.99\text{ kcal/m hr}^\circ\text{c}\)
- Prandit number\((\text{Pr})=0.617\)
- Actual volume \(=112.488\text{ m}^3/\text{hr}\)

**CROSS SECTIONAL AREA OF THE FURNACE:**

<table>
<thead>
<tr>
<th>Width</th>
<th>3.886 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>9.256 m</td>
</tr>
<tr>
<td>Area</td>
<td>36.08151 m(^2)</td>
</tr>
</tbody>
</table>

**VELOCITY:**

- Maximum velocity \(=\frac{U*S_t}{(S_t*D)}\)

\[=4.6918\text{ m/s}\]

Reynolds number \((\text{Re})=\frac{U_{max}*D}{\text{density}}\)
Re = 2413.26
S/D = 0.152/0.051
= 2.98

**AVERAGE NUSSELT NUMBER:**

\[ \text{Nu}_b = c_1 \times (Re)^{n} \times pr^{0.33} \]

= 26.2648

\[ h_f = \text{Nu}_D \times k/D \]

**HEAT TRANSFER COEFFICIENT OF STEAM**

\[ \text{h}_f = \frac{\text{Nu}_D \times k}{D} \]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2.55 kg/m²</td>
</tr>
<tr>
<td>Kinematic viscosity</td>
<td>5.47 × 10⁻⁶ m²/sec</td>
</tr>
<tr>
<td>Prandtl number</td>
<td>1.15</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>24.8 × 10⁻³ kcal/m²/hr°c</td>
</tr>
<tr>
<td>Actual volume</td>
<td>4.516 m³/sec</td>
</tr>
</tbody>
</table>

**CROSS SECTIONAL AREA OF RADIANT SUPERHEATER:**

Cross sectional area of 
radiant superheater = \( \pi/4 \times D^2 \)

\[ = \pi/4 \times 0.042^2 \]

= 0.00178 m²

\[ \text{Nu} = (f/g) \times pr \times (mm/mw)^{0.33} \times Re^{0.67} \times (p_t^{0.67} - 1) \]

\[ \text{Mm} = \text{Dynamic viscosity at } T_m \]

\[ \text{Mw} = \text{Dynamic viscosity at } T_w \]

**HEAT TRANSFER COEFFICIENT OF STEAM:**

\[ \text{h}_f = \text{Nu} \times k/D \]

\[ h_s = \text{Nu} \times k/D \]

\[ h_s = 57963.158 \text{kJ/m²/hr°c} \]

**LMTD FOR PARALLEL FLOW:**

\[ \text{LMTD} = \Delta T_1 - \Delta T_2 / \ln(\Delta T_1 / \Delta T_2) \]

\[ \text{LMTD} = (T_{f1} - T_{s1}) - (T_{f0} - T_{so}) / \ln(1.07 + 12.7(f/8)^{0.67} - 1) \]

Where,

\[ T_{f1} = \text{flue gas inlet in radiant superheater}=820°c=T_1 \]

\[ T_{fo} = \text{flue gas outlet in radiant superheater}=640°c=T_2 \]

\[ T_{si} = \text{steam inlet in radiant superheater}=290°c=t_1 \]

\[ T_{so} = \text{steam outlet in radiant superheater}=440°c=t_2 \]

\[ \text{LMTD} = 338.61 \]

**Correction factor:**

form multipass cross flow heat exchangers

\[ R = \frac{(T_{f1} - T_{fo})}{(T_{so} - T_{si})} \]

\[ R = 1.2 \]

\[ P = \frac{(T_{so} - T_{si})}{(T_{f1} - T_{fo})} \]

\[ P = 0.28 \]

**Correction factor f = 0.045**

**TO FIND THE SURFACE AREA OF TUBES**

\[ Q = (U \times A \times L \times \text{LMTD} \times F) \]

\[ A = Q / (U \times \text{LMTD} \times F) \]

= 136.227 m²

**AREA (A) = 136.277 m²**

**TO FIND THE TOTAL LENGTH OF A TUBE:**

\[ L = A / (\pi \times D) \]

**LENGTH, L = 850 m**

**FIND THE LENGTH OF A SINGLE TUBE:**

Number of rows = 26

Number of tubes in each row = 12

Length of tube in one row = 850/60

Length of tube in one row = 33 m (approximately)

The obtained superheater’s area (136.227 m²) is greater than the bed superheater surface area (83 m²) which is sufficient for superheater steam generation.
MEAN TIME BETWEEN FAILURE:

BEFORE IMPLEMENTATION:

Failure rate = number of failures / number of operating hours
= 1 / (3*365*24)
= 3.8051 * 10^{-5}

Mean time between failure = 1 / failure rate
= 1 / 3.8051 * 10^{-5}

MTBF = 26280

AFTER IMPLEMENTATION:

Failure rate = number of failures / number of operating hours
= 1 / (25*365*24)
= 4.56621 * 10^{-5}

Mean time between failure = 1 / failure rate
= 1 / 4.56621 * 10^{-5}

MTBF = 219000

6. RESULTS AND DISCUSSIONS

by using the radiant superheater in afbc boiler instead of the bed superheater, we have increased the mean time between failure (MTBF) which is given as follows.

Before implementation= 26280
After implementation= 219000

1) Clinker formation

By replacing the bed superheater with the radiant superheater, the clinker formation is eliminated since there is no heat transfer.

2) Erosion

Since the superheater tube are located above the furnace bed, there is no change of high velocity air fuel mixture hitting the superheater tubes. The inspection and maintenance can be carried out quickly as compared to bed superheater.

3) Space constraint

By replacing the bed superheater with the radiant superheater, space taken by superheater is less.

4) Frequent replacement of superheater tubes

Since the life of radiant superheater is above the 25 yrs. So there is no need of frequent of superheater tubes.

7. REFERENCES:

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