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

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

Research Article

Mathematical Modelling of Reheater Section for Boiler Tube Leakage

Krunal P.Mudafale[Å*], Sandeep V. Lutade[Å] and Ashish Y.Pund[Å]

[Å]Department of Mechanical Engineering, DBACER,Nagpur University,Maharashtra,Idia

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

Abstract

The power plants are facing problem due to crisis in energy sector. The production rate of energy is insufficient in proportion with the demand. Due to over-load, power stations are running at their full capacity and hence, facing many technical difficulties. One such major difficulty arises due to boiler tube leakage in the thermal power stations. After the study of the problem at Bhusawal Thermal Power Station, it came to know that; most of the leakages are in the superheater and reheater section. Coal quality used at various thermal power stations has more ash content. Due to low quality coal, flue gases liberated from combustion of coal carries fly ash with it. After combustion flue gases passes over the economizer, superheater, airpreheater etc. Abrasive nature of coal may damage heat exchanger, which has hampered working of power station and overall efficiency of power station. So study of boiler tube leakage and finding the solution for the problem is need of thermal power station. The aim of the paper is to go for the study of BTL problem by considering the reheater section, which includes study of reheater section with its simulation by using mathematical model. It explains the fundamental physical processes that determine the interactions among the input and output variables. This model can simulate various operating procedures similar to those actually used in power plant operation. Hence, after simulation we can decide the behavior of reheater and hence diagnose operational faults, which cause the BTL problem.

Keywords: *Boiler Tube Failure, Reheater, Mathematical Modelling.*

1. Introduction

The power plants are facing problem due to crisis in energy sector. The production rate of energy is insufficient in proportion with the demand. Due to over-load, power stations are running at their full capacity and hence, facing many technical difficulties. One such major difficulty arises due to boiler tube leakage in the thermal power stations. After the study of the problem, it came to know that; there is a fireside leakage and sometimes waterside leakage. Coal quality used at various thermal power stations has more ash content. Due to low quality coal, flue gases liberated from combustion of coal carries fly ash with it. After combustion flue gases passes over the economizer, superheater, airpreheater etc. Abrasive nature of coal may damage heat exchangers. It has hampered working of power station and overall efficiency of power station. So study of boiler tube leakage and finding the solution for the problem is need of thermal power station.

The aim of the paper is to go for the study of BTL problem by considering the reheater section, which includes study of reheater section with its simulation by using mathematical model. It explains the fundamental physical processes that determine the interactions among the input and output variables. Simulation model of reheater offer a cost effective tool for studying the operating characteristics of the reheater. This model can simulate various operating procedures similar to those actually used in power plant operation. Hence, simulation of the reheater helps to understand the behavior of reheater.

2. Boiler Failure

Boilers are used to heat water for industrial purposes, and to produce steam in power generating plants. Steels, cast irons, stainless steels and high temperature alloys are used to construct various boiler components. Design defects, fabrication defects, improper operation and improper maintenance are some common causes for boiler failures. Elevated temperature and corrosion failures are common failure modes for boilers. Additionally, mechanical failures due phenomena such as fatigue or wear occur as well. Some of the most common failures modes for boilers used for steam generating include overheating, fatigue or corrosion fatigue, corrosion, stress corrosion cracking, and defective or improper materials.

Some of the common failures associated with the boiler are pitting, erosion, stress corrosion cracking, hydrogen damage, vibration, stress rupture, corrosion fatigue, caustic gouging, distortion, thermal fatigue, acid dew point corrosion, over temperature fatigue, maintenance damage, material flaw

3. Reheater

*Corresponding author: **Krunal P.Mudafale**

DOI: http://dx.doi.org/10.14741/ijcet/spl.2.2014.69

3.1 Introduction of Reheater

The modern boilers are having superheater and reheater arrangement. Reheater is a component of a steam-generating unit in which steam, after it has left the boiler drum, is heated above its saturation temperature. The amount of superheat added to the steam is influenced by the location, arrangement, and amount of reheater surface installed, as well as the rating of the boiler. The reheater may consist of one or more stages of tube banks arranged to effectively transfer heat from the products of combustion. Reheater is classified as convection, radiant or combination of these one of the most important accessories of a boiler is a reheater. It affects improvement and economy in the following ways.

- The reheater increases the capacity of the plant.
- Eliminates corrosion of the steam turbine.
- Reduces steam consumption of the steam turbine.

In order to resist metal temperatures above 600^0 C different types of materials are to be used for the tubes. The materials range from M.S., seamless carbon steel tubes to chromium molybdenum seamless alloy steel tubes to stainless steel tubes.

3.2 The reheating process

The reheating process is an important part of the steam generation and so a main part of the Rankin cycle of the power plant. In drum type boilers the steam flow leaves the drum at saturated temperature and then it is superheated in heat exchangers called Reheater. The live steam enters the turbines after the main steam valve.

The superheater heat exchanger surfaces are usually divided into two or three stages. Between the stages water sprayers (attemperators) are mounted to control the steam flow. The steam temperature controller defines the amount of the sprayed water. The live steam temperature (T1) determines the average temperature of the heat income ($\bar{T}_1$), which strongly influences the cycle efficiency, $\eta = 1 - T2/T1$, where T2 is the average temperature of the heat abstraction (*i.e.* condensation). Therefore regulation of live steam temperature is always an important question in the power plants. The three superheater stages are placed in a special order: the second stage is over the combustion chamber, followed by the third stage, and the final one is thefirst stage. This order has an important effect also on the modeling. The heat transfer at the second superheater stage is not only convective (from flue gas), but also radiative (from the combustion flame).

3.3 Design of Reheater

The location of reheater as almost standard based on the past experience. While finalizing the arrangement of reheater proper care should be given to the following areas:

- Spacing of tubes
- Fuel gas velocity

Proper spacing of tubes is provided to prevent ash build-ups in the narrow section. This tendency decreases with decreasing gas temperature. Hence the maximum transverse is given to for the platen superheaters, i.e. 450 mm and decreased to 225, 150, and 100 mm at appropriate stages.

Flue gas velocity is an important criteria in the design of superheaters. The heat transfer increases with increasing velocities. For coal fired boilers the advantage in the heat transfer due to the erosive tendency of the fly ash. For Indian coals a velocity 12 m/s is considered optimum.

3.4 Steam Temperature Control

The nominal control of reheat steam temperature is carried out by tilting the burners. The superheater steam temperature is controlled by spraying water. Other temperature control methods that are used according to the need and design are:

- Flue gas recirculation (used for oil and gas fired boilers)
- Gas by-pass or diverting dampers
- Non-contact type desuperheater
- Triflux type reheater
- Separate firing, auxiliary burners or twin furnace

3.5 Material Selection for reheater

The reheater material provided will be various grades. The material selection is done after finding out the mid wall temperature as well as the outer surface temperature at a number of points selected by experience in the reheater circuits. These temperatures are calculated considering all the possible heat contributions like

- Direct radiation from furnace
- Convection and Non-luminous radiation
- Front and rear cavity radiation

Careful consideration is given to the selection of thickness. The use of small thicknesses for these applications is avoided considering the erosion problems associated with our Indian coals. The materials used by BHEL in the reheater systems are of ASTM specification.

4. Simulation of Reheater

4.1. Need of Simulation

Why simulate?,is the question one should ask oneself before starting.

Answer: To get a better understanding of how things work and, when dealing with large complex machines, it is the only possibility for understanding how their components interact. How to foresee how a machine is going to react when being run in a new way, can preferably be obtained with the use of simulation.

When a model describes reality in a correct manner it is possible to determine how a machine is going to operate in different configurations. It can be used for optimization of the machine, where trying all the possible configurations in practice is too expensive and time consuming. Simulation models can also be used for training purposes, so that mistakes can be made without damage to hardware.

Power generation units have to be controlled properly to ensure continuous energy production. The energy engineer has, due to economic and environmental demands during the last decades, had to focus on improving efficiency and reducing the problems associated with the power plant.
Simulator is a powerful tool used to train employees to operate power plants. Computer runs the simulation with inputs from the operator and displays the results of the simulation.

4.2. Reheater Model

Models are developed for the reheater section by applying conservation of mass, momentum, and energy principles. The pressure drop and heat transfer coefficients are computed using empirical correlations. The choice of correlation is such that the rms error associated with it for a given flow situation is minimum. The following general assumptions are made in developing the boiler model.

- A lumped parameter approach is used in modeling the system.
- Any property of a component at a given cross section is suitably represented by a single effective value. For example, temperature of the steam at inlet to platen superheater varies across the cross section, but this is represented by a single effective inlet temperature. This allows working in one-dimensional framework.
- Feed water temperature is assumed to be constant.
- Heat transfer coefficients are determined from steady state operating conditions.

Now, by mass balance for reheater

$$\dot{m}_{si} - \dot{m}_{so} = \frac{V_s d\bar{\rho}_s}{dt} \quad \ldots\ldots 1$$

Where, $\dot{m}_{si}$ -Mass flow rate of steam at inlet of reheater

$\dot{m}_{so}$ -Mass flow rate of steam at outlet of reheater

$\bar{\rho}_s$ -Density of the steam at bulk temperature $\bar{T}$

Pressure drop in the reheater is calculated as,

$$P_{si} - P_{so} = \frac{f.\ell_h.m_{si}^2}{2dA^2\rho_{si}} \quad \ldots\ldots 2$$

Conservation of energy principle applied to reheater gives

$$\dot{m}_{si}.h_{si} + Q_{mw} - \dot{m}_{so}.h_{so} = \frac{V_s d(\bar{\rho}_s \bar{h}_s)}{dt} \quad \ldots\ldots 3$$

Where, h_{si} - Enthalpy of the steam at inlet to reheater

h_{so} - Enthalpy of the steam leaving reheater

Q_{mw} - Heat transfer rate from reheater tube metal to steam flowing inside the reheater

$\bar{h}_s$ - Enthalpy of the steam at the bulk fluid temperature.

The reheater tube metal energy balance equation is,

$$Q_{fm} - Q_{mw} = \frac{M_s C_s dT_m}{dt} \quad \ldots\ldots 4$$

Where, T_m - Tube metal temperature

M_s - Mass of reheater tubes

C_s - Specific heat of reheater tube metal

Heat transfer from flue gas to reheater tubes for radiant reheater is,

$$Q_{fm} = \sigma.A_r.\varepsilon_g.(\bar{T}_g^4 - T_m^4) \quad \ldots\ldots 5$$

And for convective reheater

$$Q_{fm} = h_o.A_o.(\bar{T}_g - T_m) \quad \ldots\ldots 6$$

Where, A_r - Radiant area

σ - Stefan-Boltzmann constant

ε_g - Emissivity of the gas

$\bar{T}_g$ - Average temperature of the flue gas

Convective heat transfer from tube metal to steam flowing is given by-

$$Q_{mw} = h_i.A_i.(T_m - \bar{T}) \quad \ldots\ldots 7$$

Where, A_i - Convective area

h_i - Forced convective heat transfer coefficient

Petukhov correlation, used for the calculation of heat transfer coefficient in in single phase flow is,

$$h_i = \frac{\left[R_e.P_r.(f/8).(k/d)\right]}{\left[1.07 + 12.7\left(P_r^{2/3} - 1\right).(f/8)^{0.5}\right]} \quad \ldots\ldots 8$$

$$m_g.C_{pg}.\left(T_{gi} - T_{go}\right) = h_o.A_o.\left(\bar{T}_g - T_m\right) \quad \ldots\ldots 9$$

Model takes inlet steam temperature, inlet steam flow rate, inlet temperature of the flue gas and mass flow rate of the gas as inputs. The outputs are various thermal parameters like main steam pressure, temperature, etc. Behaviour of the metal temperature to these inputs is governed by equation 4. Outlet temperature of the steam is calculated from total energy balance of the superheater. Response of the reheater to increase in mass flow rate of the gas can be shown. When the mass flow rate of flue gas increased, outlet temperature of steam should be increased. Increase in the flue gas flow rate increase the outer heat transfer coefficient. Hence overall heat transfer also increases. This increase in the overall heat transfer coefficient cause the increase in the outlet steam temperature. The simulation of this model can be performed using SIMULINK.

Conclusion

The only way to run the Power Station is adopting new technology, replacing damage parts and making the system more users friendly. The boiler tube leakage problem can be solved taking preventive measure or by modifying design condition. For this reason, simulation of the mathematical model of reheater can be helpful to diagnose the faults.The purpose of simulation of the base case (existing operation) is to evaluate the current operation of the reheater and verify the results with observations and data obtained under actual conditions. Results of this modeling could then be used to diagnose potential operational and design deficiencies and finally to correct these, with the most cost-effective changes.

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