CHAPTER 2

STUDY OF 210 MW BOILER SYSTEM

2.1 DESCRIPTION OF 210 MW BOILER

Detailed study has been carried out on a 210 MW boiler system with regard to model development, control and optimization. Figure 2.1 illustrates the schematic diagram of a boiler furnace in a 210 MW coal fired thermal power plant and depicts the path of combustion products. The boiler converts the chemical energy available in the fuel (coal) into internal energy of steam, the working fluid. The boiler feed water pumps deliver feed water to the boiler drum from where water is directed into the down comers and the circulating pumps located at the bottom of the boiler. The circulating pumps deliver the feed water to the distribution headers beneath the furnace sections. The water rises in the circuits, which are the vertical enclosing walls of the furnace. During combustion, the water walls absorb radiant heat in the furnace, boiling takes place and a water-steam mixture (saturated steam) enters the drum, while the saturated water leaves the drum and enters the down comers.

Saturated steam from the drum is further heated to the final required temperature of 540°C in the primary and secondary superheaters and fed in to the High Pressure (HP) turbine. After isentropic expansion there, the steam is reheated in the reheaters and fed into the Intermediate Pressure (IP) and Low Pressure (LP) turbines. The hot gases leaving the furnace transfer heat by radiation and convection to the Secondary Superheater (SSH), Primary
Figure 2.1 Schematic diagram of a boiler furnace in a 210 MW coal fired thermal power plant
Superheater (PSH) and the Reheater in succession. The hot gases before being sucked out to the chimney by the Induced draft (Id) fan, deliver heat to the feed water in the Economiser. The Forced draft (Fd) fan provides the required air for the combustion process. Desuperheating spray water is introduced between the primary and secondary superheater sections for control of main steam temperature. The furnace heat absorbed by the superheater or reheater is also controlled by tilting the burners or changing the pattern of firing by burner selection. Gas recirculation is used to increase the mass flow of hot gases through the superheaters as shown in Figure 2.1 by withdrawing some amount of gas from the gas outlet into a manifold around the bottom of the furnace chamber, thus tending to cool the walls and increase heat absorption by superheaters.

2.2 SUPERHEATING OF STEAM

The thermodynamic equilibrium temperature at which vapour (steam) and liquid (water) exist together at a particular pressure is called the saturation temperature ($T_{\text{Sat}}$). The corresponding pressure is called the saturation pressure ($P_{\text{Sat}}$). The difference between the enthalpies of the liquid and vapour at the saturation temperature is known as the latent heat of vapourization. In boiling and condensing systems, it is often convenient to use the saturation temperature as datum and refer other system temperatures to this datum. Fluid at a temperature higher than the saturation temperature is said to be “superheated” with reference to $T_{\text{Sat}}$.

During the phase change of a substance, an extra energy transfer is required to make the change in the molecular structure of the substance without changing the temperature. The energy quantity involved for water is given in
terms of its latent heat of vapourization as 970 Btu / lb. The phase change takes place at a constant temperature ($T_{\text{Sat}}$). Any additional heat input higher than the latent heat of vapourization has no effect on this temperature. Hence, it is not possible to raise the temperature of steam above $T_{\text{Sat}}$ inside the boiler drum/downcomer – water walls circuit with the application of higher heat input through combustion. Consequently, if we apply more heat input than what is required for the saturation condition, the steam pressure increases above $P_{\text{Sat}}$ with the steam temperature remaining constant at $T_{\text{Sat}}$. This is illustrated by the temperature – specific volume diagram for water in Figure 2.2.

In a thermal power plant, the highest work efficiency can be achieved by maintaining highest possible steam temperatures that the metallurgy of the plant is capable of withstanding (Francis G. Shinskey 1978). Therefore, the steam temperature and hence its enthalpy has to be elevated from $T_{\text{Sat}}$ to a higher value through superheating.

For example, the maximum allowable superheat steam temperature for a 210 MW boiler is 540°C at 178 ata pressure whereas the $T_{\text{Sat}}$ for this boiler is around 361°C. As this superheating is not possible inside the boiler drum, the saturated steam when it leaves the drum is captured and further heated to the required temperature in separate superheaters (PSH and SSH) with the help of the hot gases that exit from the boiler furnace. The steam that comes out of the SSH is known as the ‘main steam’.

2.3 CONTROL SYSTEMS

Boiler control systems have evolved over many decades. Today, all power plant boilers are equipped with Computerised Distributed Control
Figure 2.2 Temperature—specific volume diagram illustrating phase changes of water
Systems (DCS) that is functionally and geographically distributed. There are three basic objectives of boiler control system.

(i) To cause the boiler to provide a continuous supply of steam at the desired conditions of pressure and temperature
(ii) To continuously operate the boiler at the lowest cost for fuel and other boiler inputs, consistent with high levels of safety and full boiler design life
(iii) To safely start up, shut down monitor on-line operation, detect unsafe conditions and take appropriate actions for safe operation at all times

Boiler control is organized around three basic control subsystems:

(i) Master pressure control system
(ii) Drum level control system
(iii) Main steam temperature control system

2.3.1 Master Pressure Control System

The objectives of this control system are:

(a) To detect the change in load as reflected by the change in steam pressure and adjust the fuel flow to the boiler accordingly
(b) To maintain a safe relationship between the fuel flow and air flow by the lead-lag principle
(c) To automatically correct for variations in the calorific value of coal and other disturbances in the coal flow variator

(d) To maintain a set value of Oxygen in the flue gas, so that efficiency and safety of combustion process is ensured

(e) To ensure smooth and efficient response of steam generation during load variations and also during start-up and shutdown operations

The steam pressure decreases when the steam demand increases and vice-versa. The amount of variation and rate of change of variation in steam pressure reflect the load change. The master pressure controller generates a fuel demand signal for a given steam flow conditions, which forms the variable set point for the coal flow controller and also the air flow controller. During an increased load, the air is increased first and the fuel (coal) is allowed to increase subsequently. During a decreasing load, the fuel is decreased first and air is allowed to decrease subsequently. This is called the lead-lag system, which ensures that excess air is always available inside the furnace and hence the combustion is safe and complete. During any operating conditions, the change in the calorific value of the coal is determined by comparing the steam produced and the coal burned. If a change is noticed either due to change in calorific value or due to the reduced/improper coal flow through the coal feed variator, the speed of the variator is adjusted automatically so that the coal flow is sufficient to meet the steam flow condition. Oxygen is measured continuously and compared with the set point, so that the predetermined excess air is ensured. Any variation in the excess air is automatically corrected and controlled by adjusting the airflow through the Fd fan.
2.3.2 Drum level control system

The objectives of the drum level control system are:

(a) To maintain the water level inside the drum within the limits while meeting the steam demand of the turbine

(b) To vary the water flow into the boiler, as steadily as possible, in order to avoid thermal stress and undue fluctuations

(c) To keep the water flow at the theoretical value of steam demand during drum level ‘shrinkage’ and ‘swelling’ conditions

During start-up condition, the demand of feed water is limited and depends on the response of the boiler unit to increase the steam production. The steam flow and feed water flow measurements are not accurate enough for control purposes. Hence a single element (drum level measurement) control is used with a low load control valve. The differential pressure across the valve is maintained constant by adjusting the feed pump speed.

As load increases, the steam flow measurement and feed water flow measurement are used and a three element control system is adopted. The transfer from single element to three element can be manual (as decided by the operator) or it can be automatic. It should be ensured that the feed water flow is neither drastically increased nor drastically decreased during the transfer from single element to three element control. It is desirable to maintain the drum level at a higher value during start-up and increasing load conditions.
During decreasing load conditions, the drum level can be maintained at lower value. During a sudden increase in steam flow, the drum pressure will drop by giving out more steam flow. The drum level will apparently increase due to the drop in drum pressure. This is called the “swelling” of the drum level. The drum level controller will try to close the feed water valve, instead of opening. The steam flow measurement signal will call for opening the feed water valve. The net result should be made to open the valve. Similarly, when there is decrease in steam flow, the drum pressure will increase and the drum level will decrease. This is called the “shrinkage” of drum level. The feed water flow should be reduced in this case.

A sudden increase or decrease in feed water will produce thermal stress in the economiser and also disturbance in the heat absorption rate at economiser and air heater. This may in-turn affect the temperature at the mill outlet, which may in-turn disturb the flame conditions at the furnace. Hence, the feed water flow adjustment should be as smooth and steady as possible.

2.3.3 Main steam temperature control system

The objectives of the main steam temperature control system are

(a) To maintain superheated steam temperature at a predetermined value at various loads efficiently by spray water regulation

(b) To detect changes in the firing conditions in advance and make necessary adjustments in the spray water flow so that the temperature fluctuations are limited and ensure protection of superheater tubes
The superheater outlet steam temperature is controlled by spraying water on the left and right sides.

The primary benefit in constant steam temperature is in improving the economy of conversion of heat to mechanical power. Control capability increases the lower load temperature, resulting in the potential for higher thermal efficiency of the power generation process. In addition, maintaining a constant temperature minimizes unequal expansion or contraction due to unequal mass or material between the static and various rotating parts of power generation machines. This makes possible the use of smaller clearances and also results in higher thermal efficiency in the energy conversion process.