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Research paper

Operation of Reheat Steam Temperature Control Concept in Sub Critical Boiler: Operational Review Practices and Methodology

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Abstract

In subcritical boilers, spray water system and feed water flow are applied to control the superheated steam temperature. Meanwhile, for reheat steam temperature control, many methods are being adopted namely burner tilt, gas recirculation, and excess air and steam bypass as primary control and feed water is envisaged as an emergency control. In a large boiler operation, the boiler is operated in sliding pressure mode the cold reheat steam temperature is higher compared to constant pressure operation. To ensure the correct temperature control for reheat steam with high pressure, the right method and sufficient mechanism operating the boiler is required. In fact, spray is not used for reheat steam temperature control because the boilers are designed for constant pressure operation since the spray quantity required will be large for an impact on plant heat rate. The boilers used for this study were operated under sliding pressure mode; hence, reheat steam temperature control by spray is a common practice in subcritical boiler operations. This paper dealt with the advantages and disadvantages of using spray by looking at boiler performance for RH steam temperature control in lieu of other control mechanisms.

Keywords: *Subcritical boiler, Rankine cycle, Superheated Steam, Reheat Steam.*

1. Introduction

Thermal Power Plants (TPP) generate the largest total electricity power supply in the Asia Pacific region. A minimum improvement to raise the efficiency and heat rate could have a tremble effect on fuel saving and reduced greenhouse gas emissions. Therefore, every step should be taken to enhance the efficiency and heat rate of the steam power cycle (1, 2). Thus, it is important to achieve the best possible heat rate needed to reduce the fuel cost and hence, operators should try to maintain superheat and reheat steam temperatures at rated values to the extent possible. In subcritical boilers, SH steam temperature is maintained by coordinating feed water flow and the desuperheated spray water system (3). Practically, there are numerous operation methodologies used to control RH steam temperature, such as burner tilt, gas recirculation (GR) as well as excess air and steam bypass. For same cases, the RH desuperheated spray water system is preferred as it results in a simpler design and operation of the boiler and needs less maintenance as systems like burner tilt and GR fans, are eliminated (4, 5).
Therefore, an effective method for controlling RH must be determined in order to optimize the heat rate of the boiler. Besides, the understanding when applying each method is that the other parameters that affect the boiler must be taken into consideration (3, 6). The thermal power generation plant or thermal power station is the most conventional source of electric power. As mentioned earlier, the power generation process includes the process of energy transfer. The thermodynamic law and Rankine cycle are the main guidelines used when operating and maintaining the power plant process. The source of heat of a thermal plant is subjected to selected fuel as per plant design. Normally, the heat sources used in these power plants are nuclear fission or the combustion of fossil fuels such as solid fuel like coal, gas forms such as natural gas, and in liquid phase like oil or distillate. The working fluid flows around continuously in a closed loop of the Rankine cycle (4, 7, 8). Thus, it can be said that the waste heat's low temperature exits the system, which then allows the addition of higher temperature (heat) that is transformed into a useful product (power).

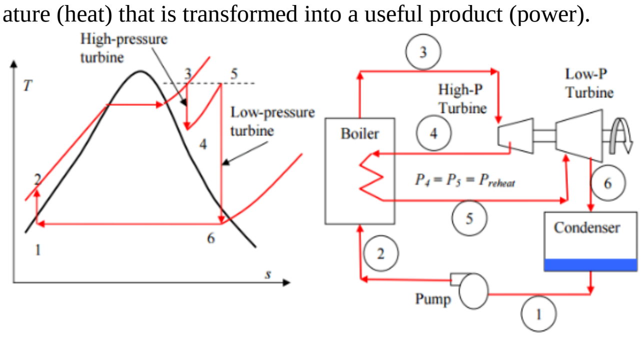

Figure 1.1: The T-S diagram process flow

Referring to Figure 1.1, the closed-loop cycle process involves the main equipment, such as the pump, turbine, boiler and condenser. The process in the T-S diagram involves temperature and pressure conditions. To describe the change of temperature to a specific entropy during the thermodynamic process, the cycle is translated into the T-S diagram or temperature entropy diagram. The diagram enlightens and visualizes the heat transfer during a process (4, 7, 8). The purpose of the ideal thermodynamic cycle is to transform the heat into mechanical work and the process is presented through the Rankine cycle. For an ideal Rankine cycle, the pump and turbine would be isentropic and generate no entropy; hence, maximizing the network output. From process 1 to 4, it is represented by vertical lines in the T-S diagram and more closely resembles that of the Carnot cycle. Table 1.1 describes the details of the Rankine cycle from process one to four. The Rankine cycle shown here prevents the vapour ending up in the superheated region after expanding in the turbine, which reduces the energy removed by the condensers (8). The actual vapour power cycle differs from the ideal Rankine cycle because of irreversibility in the inherent components caused by fluid friction and heat loss to the surroundings; thus, fluid friction causes a pressure drop in the boiler, the condenser, and the piping between the components (8).

Table 1.1: Rankine Cycle process

Process	Description
Process 1 to 2: Isentropic compression (Pump)	An isentropic process explains the compression process from a low to a high pressure by an external work force. The pump provides high pressure where the working fluid of the pump is working in it.
Process 2 to 3: Isobaric heat supply (Steam Generator or Boiler)	An isobaric process describes the form of superheated steam process by the heat source from the high temperature of working fluids. The saturated vapour is formed when the pressurised fluid enters a boiler with constant pressure and high temperature.
Process 3 to 4: Isentropic expansion (Steam turbine)	An isentropic process designates that the working fluid entropy remains constant throughout the process. The dry saturated vapours expand in the turbine and drive the turbine to work. The temperature of the working fluid entering the turbine decreases and the working fluid pressure drops. In the meantime, the condensation process takes place.
Process 4 to 1: Isobaric heat rejection (Condenser)	An isobaric process takes place when the pressure of the working fluid remains constant. The condensing cycle occurs when the wet vapour enters a condenser where it is condensed at a constant temperature. The end product is in the form of saturated liquid.

Boiler tube defect during operation must be avoided. As a transaction medium between two phases of steam and vapor, boiler is design to come out with high specification pressure and temperature. According to Jones (9), the boiler tube failures phenomena are unavoidable. There are a lot of factor that cause the boiler tube to fail. They are subject to potential degradation by a variety of mechanical and thermal stresses and environmental attack on both the fireside of the boiler. Boiler tube mechanical components can fail due to creep, fatigue, erosion, and corrosion (10). The categories of thermal fatigue classified are corrosion fatigue and thermal fatigue (5, 10, 11). In addition to the boiler tube fail factors, an erosion phenomenon is a metal removal caused by particles striking the metal's surface (5, 6, 12)

Normally, the steam temperature is controlled by spraying water into the steam between the first and second-stage superheater to cool it down. The water injection system is also known as the attemperator or desuperheater. The spray water comes from either the intermediate stage of the boiler feedwater pump (for reheater spray) or from the pump discharge, which is the superheater spray (4, 5, 13). Other methods of steam temperature control include flue gas recirculation, flue gas bypass, and tilting the angle so that the burners fire into the furnace. This discussion focused on steam temperature control through attemperation. The designs discussed were applied to the reheater and superheater, but only the superheater was mentioned for simplicity (8, 14, 15).

2. Problem Statement

Reheater Steam Temperature play a vital factor to gain desired heat rate for coal power plant. There are several mechanisms in order to control the Reheater Steam Temperature to ensure heat rate and efficiency can be achieved. In optimizing the boiler operation, heat transfer and plant efficiency, the right method must be choosing in controlling reheater steam temperature.

3. Research Questions

What is the effective method for controlling Reheater Steam Temperature and how the boiler response with every single method in order to optimise boiler operation.

4. Purpose of the Study

This study is made to review the suitable method available in one of the thermal coal plant located in Malaysia for controlling Reheater Steam Temperature which are Gas Recirculation, Desuperheated Spray Water, Burner Tilts and Excess Air.

5. Research Methods

In line with the objective, this study was carried out in a coal power plant in Malaysia. The plant was designed with a sub-critical, reheat and coal fired boilers with a nominal rated power output of 700MW and firmly commissioned in 2003.

System	Pressure	Temperature	Steam Flow
Main Steam	175 bar	540^0C	2213 t/h
Hot Reheat	38 bar	540^0C	1927 t/h
Condenser	70 bar	-	-

Attached to the boiler is the main components such as economiser, boiler drum, superheater and reheater, boiler circulation pump and safety valve. Table 3.2 present the main components attached to the boiler and its function.

Table 3.2: Main components and function

Main Component	Function
Economiser	To recover part of the heat remaining in the flue gas to raise the temperature of feedwater and thus increase the thermal efficiency of boiler
Boiler Drum	It is a vessel accommodating a mixture of water in liquid state and gaseous state. It also serves as a water reserve capable of accommodating any sudden variation in steam generation. The drum also serve to eliminate water droplets from the saturated steam on its way to desuperheaters
Superheater & Reheater	Is a heat exchanger which converts saturated steam into superheated steam.
Boiler Circulation Pump	To induced an 'assisted circulation' for faster start-up by forcing feedwater from the downcomer to the bottom header
Safety Valve	To protect the high pressure parts of boiler drum, superheater and reheater against over pressure

It is in this enclosure that the fuel is burnt and the main heat exchanger is used to generate steam. Each exchanger is generally composed of a bundle of tubes arranged in parallel between an inlet header and an outlet header. The water and/or steam flows inside the tubes while the hot combustion gases pass over the outside of the tubes. As a result, the process of heat exchange takes place which converts the feedwater into superheated steam, which is the main energy for turning the steam turbine. Within the enclosure is the heat exchangers which serve to vaporize the water and superheat the steam and they include:

- Economiser which absorbs heat and raises the temperature of the feedwater.
- Furnace wall tubes which vaporize the water via convection and radiant heat exchange.
- Superheaters which superheats the steam through:
    - Low Temperature Superheater of platen, convectional type

  - Intermediate Temperature Superheater of pendant, radiant type
  - High Temperature Superheater of pendant, radiant type
- Reheater which superheats the HP turbine exhaust steam through:
  - Low Temperature Reheater of the pendant/vertical loop, convectional type
  - High Temperature Reheater of the pendant/vertical loop, convectional type

The technical specification of the boiler includes the specification of the main-steam piping, cold reheat steam piping and hot reheat steam piping that followed the ASTM standard (13). The boiler concepts were the two-pass type boiler and drum with control circulation. It was designed for steady state operation, two-shifting transient operation, frequency response, load cycling, load rejection and overload operation, in line with other operational requirements. The specifications were captured during the commissioning of the boiler using designed coal, shown Table 3.3.

Table 3.3: Operational parameters of the boiler

Parameters	Operating value
Superheated steam flow	2390 t/h
Cold reheat steam flow	2065 t/h
Coal flow	341 t/h
Drum Pressure	19.60 MPa
Steam pressure at Superheated outlet	18.22MPa
Superheated steam temperature	543°C
Water temperature at economiser outlet	277°C
Cold Reheat Steam temperature	333°C
Steam temperature at reheater outlet	541°C
Gas temperature at air heater inlet	375°C
Gas temperature at air heater outlet	133°C
Secondary air temperature at air heaters outlet	349°C
Primary air temperature at air heaters outlet	356°C
Secondary airflow to the burners	1,547 knm^3/h
Primary airflow to the mills	575.9 knm^3/h
Total combustion air flow	2,123 knm^3/h
Excess air at economiser outlet	21%
Oxygen content at economiser outlet	3.6%
Flue Gas Flow at Air Heater Outlet	2783 knm^3/h
Flue gas temperature air heater outlet	130°C
Flue gas flow (approx.)	944 kg/s
Feed water temperature	272.3°C
Coal flow	89 kg/s

The power plant process is described in Figure 3.1. From raw water, water is quality is achieved throughout water treatment plant process at Water Treatment Plant (WTP) before being supplied to the condenser hot well system. Water from hot well is ejected and fed to the feed water system by the condensate extraction pump (CEP). After the ejector exits, the feed water passes through the gland steam cooler, and the low-pressure heater (LP1). From there, the outlet of the low-pressure heater 1 (LP1) goes to low pressure heater 3 (LPH3) before entering into the feed water system. The feed water system line begins from the deaerator system to the feed water stop valve. The system's function is to feed water to ensure a balanced boiler drum level during the steam evaporation process. The boiler feed booster pump suctions from the deaerator storage tank and discharges it into the associated boiler feed pump. The boiler feed pump (BFP) discharges it into a common header that routes the feed water to high pressure heater 5 (HP5) and then to the high pressure heater 7 (HP7). Then, the feed water flows through the tubes of the HP feed water heaters and passes to the boiler economizer. Water from condensate system passes through the economizer and goes into the boiler drum through the boiler tube. There is a close circuit system with continuous circulation of water between the drum and the water walls and part of the feed water is converted into steam. Through the boiler drum, the steam is separated and supplied to the super heater and boiler condenser sections. The super-heated steam produced in the super heater then enters into the turbine through the turbine stop valve and then rotates the electrical generator. After expansion occurs in the turbine the exhaust steam is condensed in the condenser and used for the closed cycle, as showed in Figure 3.1. (7, 12)

Figure 3.1: (See Appendix – A)

6. Findings

The discussion refers to the method applied at this power station to control reheat steam temperature in a subcritical boiler. The boiler is sub-critical, reheat, single drum, radiant and convectional two-pass type superheat, with controlled recirculation.

6.1 Desuperheaters of the Superheater and Reheater

There are four desuperheaters installed on the high-pressure steam circuit. Two desuperheaters were installed between LTS and ITS and two others between the ITS and HTS exchangers. This arrangement provides a two stages, water spray injection capability, with left/right side controls. The spray device consists of a tube fitted with a series of holes. The tube is installed transversely in the piping and the holes are orientated in the direction of the fluid. The water spraying reduces the temperature of the steam coming from the LTS or ITS when necessary and maintains the temperature at the HTS outlet at a designated value (9). As for the reheater, two desuperheaters were installed in the cold reheat piping, upstream of the inlet header in the reheater piping. The spray water injection was meant for emergency use in case of high steam temperatures at the HTR outlet. The spray water is taken from the boiler's feed water pump discharge for the superheater circuits. For the reheater circuit, the spray water is taken from the intermediate stage of the feed water pumps.

Figure 6.1: (See Appendix – B)

6.2 Burner Tilt

Proper operation of burner tilts on tangentially fired boilers is crucial for controlling fuel combustion and final steam temperature, as well as minimizing NOx formation. In addition, the operation of burner tilt affects the flue gas temperature (FEGT) of the boiler. According to Yuan, Cheng, Zhong and Chen, 2013, the furnace FEGT is one of the important parameters for the combustion control of large coal-fired units (16). In fact, higher FEGT affects the main and reheat steam temperatures, which results in a loss of unit economy. The study purposely catered for the problem of main and reheat steam temperatures that is lower than the design values. The results showed that by increasing the tilt angle from 0° to 25°, the FEGT had grown by 65K from 1442K to 1507K, while the burnout degree decreased slightly from 99.96% to 99.33%. At same time, the high temperature area near the water wall decreased, which indicates that the slagging tendency on the water wall can be reduced. A tilting angle of more than 16° was enough for raising FEGT and improving the main and reheat steam temperatures.

For this study, tilted burners were installed at the corner of the tangential fired boiler, while the flame was adjustable by operating the tilt. During the operation, the burners could be tilted up or down in unison in all the four corners in order to move the fire ball inside the furnace either upwards or downwards to change the furnace absorption. To meet the temperature, when RH temperature is lower than the rated value, burners are tilted up to reduce the furnace absorption and increase the furnace outlet temperature. As more heat is now available for RH pick up, RH temperature could be maintained. When RH temperature is more than the rated value, the burners are tilted downwards.

Figure 6.2: (See Appendix – C)

6.3 Gas Recirculation

For this study, the gas recirculation method was referred to as the flue gases recirculation operation. Flue gas is diverted from a location downstream in the main boiler bank and mixed with the combustion air from the forced draft fan. This flue gas process circulation is called the Flue Gas Recirculation (FGR) system. At some thermal power plants, flue gas is mixed with the over fire air system. The recirculated flue gas takes the place of greater amounts of excess air that the stoker would normally use to keep the burning fuel bed cool in order to avoid clinkering and grate overheating. The FGR system allows the cooling and the combustion requirements of the forced draft air to be "de-coupled". The cooling effect comes from the moisture and CO2 contained in the flue gas. The flue gas has a greater heat capacity than air so it carries more heat away from the fuel bed and reduces peak temperatures by as much as 250° F. The total air requirement for fuel combustion can be achieved throughout the FGR system, which come from fuel bed cooling. Moreover, the FGR system allows the stoker boiler to operate at very low excess air levels. 15% - 20% percent excess air operation is easily achieved with the FGR system. This reduction in excess air reduces the velocity of the flue gas in the boiler and therefore, reduces the amount of fly ash that is entrained in the gas stream exiting the boiler.
Operationally, one part of the flue gas outlet ID fan, which is about 10 % of the total induced air, is sent back to the furnace bottom. This circuit is used for loads higher than 40%. The flue gas flow is controlled by control dampers at an increasing flow rate according to the steam flow from 50 up to 200 knm3/h. The inching dampers at the ID fan discharge are partly closed to insure sufficient differential pressure between the discharge ID fan and the furnace bottom. The flue gas's recirculation flow influences the furnace temperature as well as the superheater and reheater exchanges. The flue gases emitted from each ID fan discharge are collected from a common duct, isolated by two motorized dampers. This main line is fitted with a flue gas recirculation flow measurement device and then divided into four individual lines to the boiler bottom, each with a control damper

Figure 6.3: (See Appendix – D)

6.4 Excess Air

The extra air used is called excess air and this excess air ensures that there is enough air for a complete combustion in the boiler. Excess air is expressed as a percentage of the required theoretical air. However, to ensure the complete fuel combustion in the boiler, it is important to have excess air. In fact, the excess air increases the amount of oxygen during the combustion as well as the fuel combustion (14, 17). As for this case study, the operating value for excess air was 21%, while oxygen was 3.6 % at the economizer outlet. The control of the secondary airflow was obtained by adjusting the FD fan inlet vanes. The correct excess air was maintained automatically for total combustion of oil or coal at any load. Basically, the complete mixing of flue gas outlet and oxygen refers to the precise or stoichiometric amount of air required to completely react with a given quantity of fuel. In practice, conditions for combustion are never ideal, and additional or "excess" air must be supplied to completely burn the fuel. The correct amount of excess air is determined by analysing flue gas oxygen or carbon dioxide concentrations.
Analysis of the flue gas leaving the boiler should be monitored as it is an indication of complete combustion and economical operation. A common location, used in practice, for the analysis of the gas leaving the furnace, is the economizer outlet duct. The best percentage of excess air used for different evaporation rates is controlled automatically, but may be adjusted according to the nature of the fuel, the actual conditions of the fuel burning equipment and other factors. The presence of carbon monoxide (CO) in the fuel gas indicates incomplete combustion and requires excess adjustment. Portable, calibrated and reliable apparatus should be used when analysing the flue gas, even if other operating instruments are provided. The analysis should include the determination of CO, CO2 and O2 content in the flue gas (2, 11).
The boiler is equipped with an automatic firing control system. As the boiler load demand changes, the coal flow is adjusted to balance the required heat input. The oil flow is controlled by the operator. The combustion airflow is then adjusted to correspond to the actual calorific load (coal and oil), and is corrected by the oxygen content in the flue gas to achieve the required amount of excess air (2). This system provides a performant combustion and boiler load control. Nevertheless, it is recommended that the operators frequently monitor the combustion parameters, in order to prevent any deviation on the firing systems caused by abnormal conditions. During steady operations, parameters such as fuel flow, combustion airflow, the oxygen and carbon monoxide content in the flue gas, should be recorded several times during the day and compared with typical figures. Visual verification of the flame and analysis of unburned carbon content in the residual ash, are also important tasks that shall be performed periodically.

7. Conclusion

By looking at the available method to control the superheated and reheater temperature, there is a need to study the factor could influence to choose the right method during boiler in operation. Besides, boiler parameters, material and operating procedure of the boiler must take into account during the selection of method. However, the desuperheater or namely as spray water system is the last option to cater the high temperature at superheater temperature and reheater temperature. This method involves with water injection which is sourcing from the feedwater system. Spraying mechanism operation is applied during the superheater system put in service and its will perform in such quenching phase. Operator must able to make decision and take fast response on handling the high temperature. Failed to do that can affect the boiler tube performance which is tube overheating.

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Appendix - A

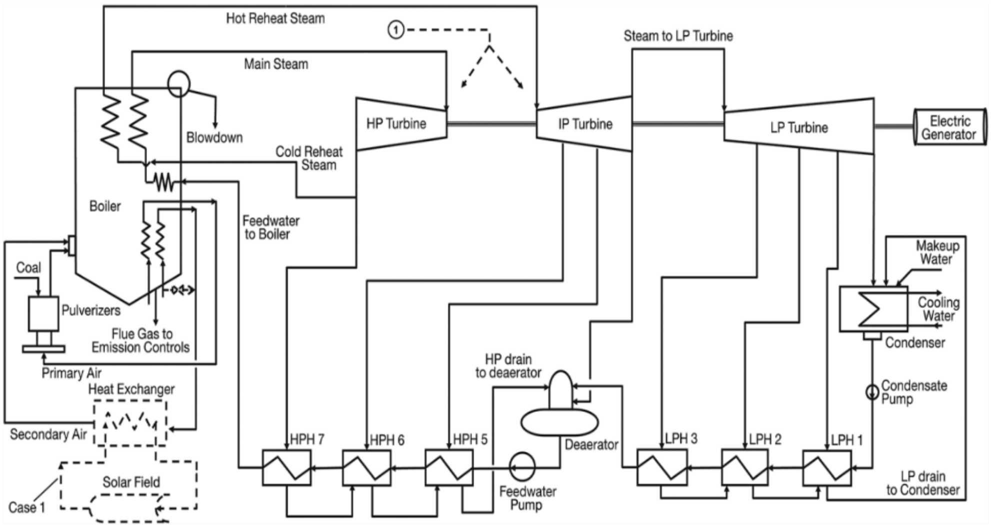

Figure 3.1: Schematic Diagram Power Plant Process

Appendix - B

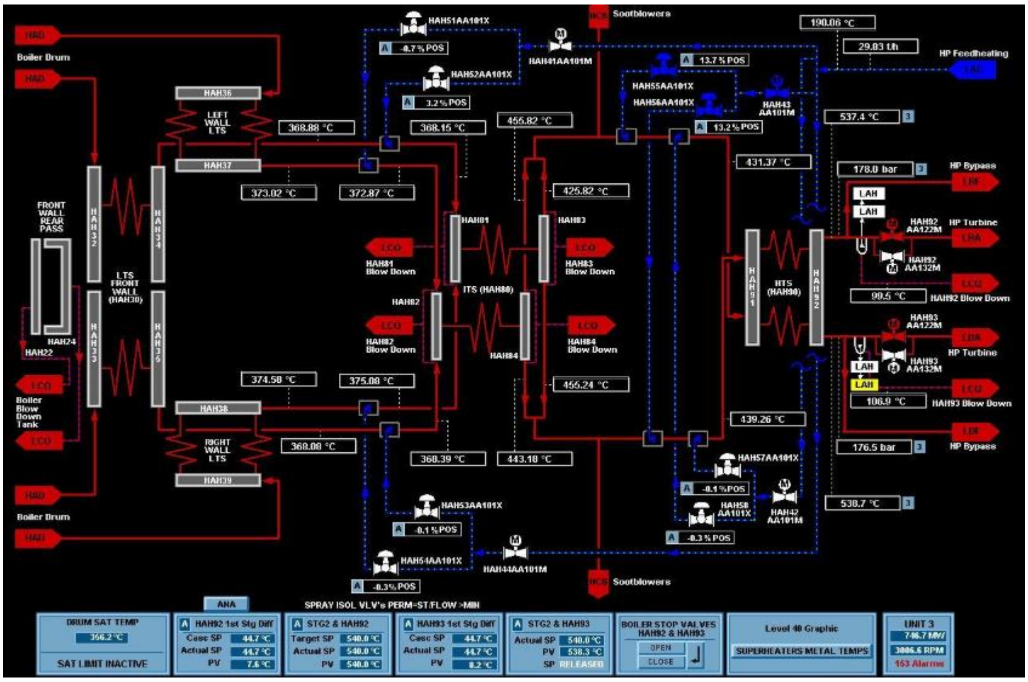

Figure 6.1: Desuperheaters Circuit

Appendix - C

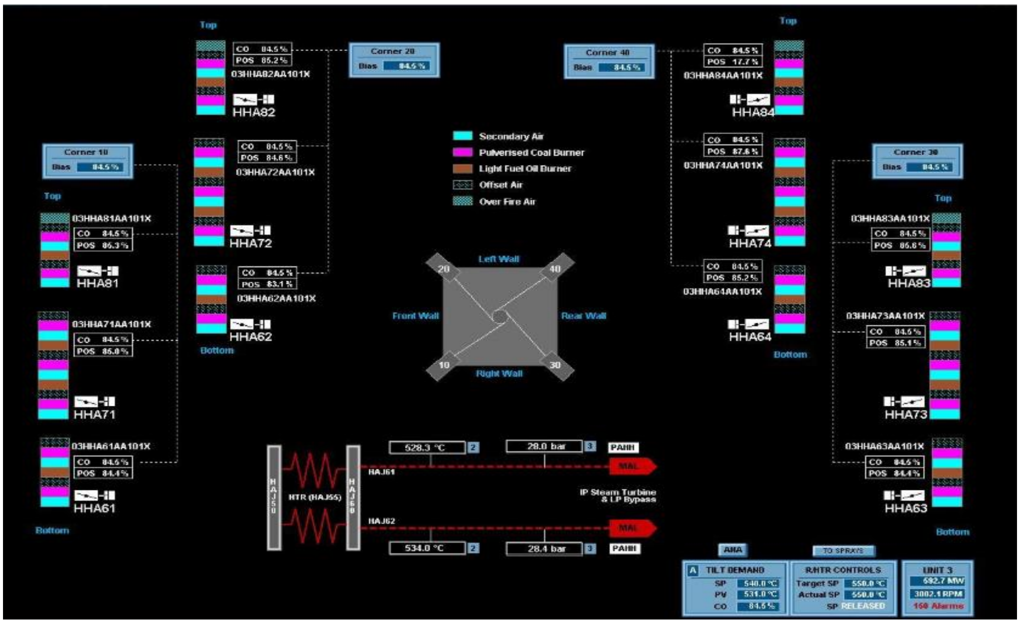

Figure 6.2: Burner Tilt Position

Appendix - D

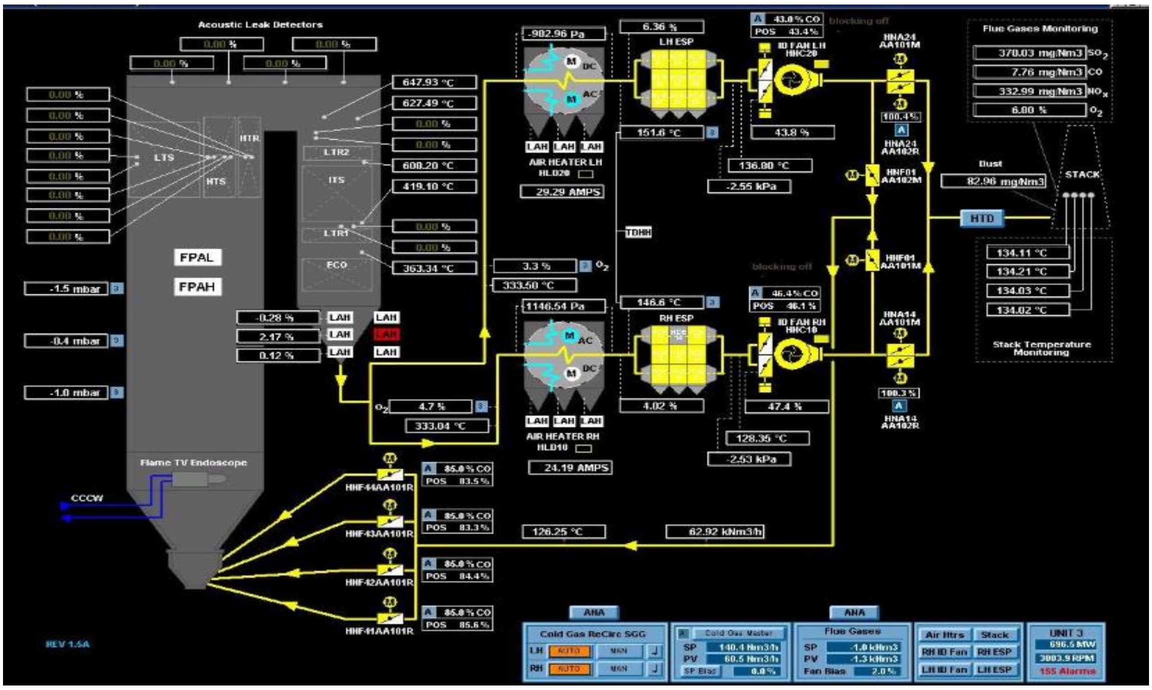

Figure 6.3: Gas Recirculation Position