A Review on Optimization of Combustion

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Abstract— Optimization of Combustion in pulverized coal fired boiler is more important to improve the performance of power plant. The objective of the work is to optimize the combustion in pulverized coal fired boiler in order to improve the boiler efficiency and reducing coal consumption and net heat rate heat of the plant. The study involves boiler performance testing by controlling secondary air supply using dampers & Air fuel ratio and improvement in boiler efficiency and reduction in consumption rate will be calculated.

Key words: Optimization, pulverised, Combustion , Boiler, Air/Fuel Ratio

I. Introduction

Optimization of combustion is very important ant activity to be carried out in any boiler for achieving best thermal performance of boiler, Optimizing the combustion in furnace means that fuel and air distribution are well tuned such that they mix and the best flame temperature and carbon burn out are achieved. Fields trials are needed to optimize the fuel and air regimes for a particular firing system and boiler to achieve the optimum level so that fuel is completely burn to carbon dioxide to minimum level of carbon monoxide and also with which there is not heat loss due to much excess air. The study of coal analysis i.e. proximate & ultimate analysis is carried out Also review of the topic is carried out after studying related research papers. Now in the future, optimization of combustion can be carried out using parameter like secondary air damper control & burner tilting angle also showing comparison & calculation of boiler efficiency. The main objective of the project is to optimize combustion in such a way that it results into Improvement in boiler efficiency and reduction in heat rate.

II. Combustion

Combustion is the high temperature oxidation of the combustible elements of a fuel with heat release. The combustible elements in coal and fuel oil are carbon, hydrogen and sulfur. The basic chemical equations for complete combustion are

$$C + O_2 \longrightarrow CO_2$$

$$2H_2 + O_2 \longrightarrow 2H_2O$$

$$S + O_2 \longrightarrow SO_2$$

When insufficient oxygen is present, the carbon will be burned incompletely with the formation of carbon monoxide.

$$2C + O_2 \longrightarrow 2\,CO$$

In order to burn a fuel completely, four basic conditions must be fulfilled:

(1) Supply enough air for complete of fuel.
(2) Secure enough turbulence for through mixing of fuel and air.
(3) Maintain a furnace temperature high enough to ignite the incoming fuel air mixture.
(4) Provide a furnace volume large enough to allow time for combustion to be completed.

Apart from adequate air supply, the three T's, viz., time, temperature and turbulence have to be kept in mind while designing a furnace. Combustion may be said to hinge upon the word MATT- M is for mixture (turbulence), so that the fuel molecules meet the oxygen molecules, A is for the proper air-fuel ratio in order to support combustion, one T is for temperature, and the other T is for time. Since the complete mixing of the fuel and air is virtually impossible, excess air must be supplied to ensure complete combustion. The greater is the rate of mixing or turbulence, the lower would be the excess air required.

A. *Stoichiometric Air:*

The ultimate analysis of the fuel is given by

$$C + H + O + N + S + M + A = 1.0$$

Oxygen needed for the oxidation processes can be calculated as follows:

C	+	O_2	=	CO_2
12 kg		32 kg		44 kg
1 kg		2.67 kg		3.67 kg
C kg		2.67C kg		3.67C kg
$2H_2$	+	O_2	=	$2H_2O$
4 kg		32 kg		36 kg
1 kg		8 kg		9 kg
H kg		8H kg		9H kg
S	+	O_2	=	SO_2
32 kg		32 kg		64 kg
1 kg		1 kg		2 kg
S kg		S kg		2Skg

Oxygen required for complete combustion of 1 kg fuel is

$$W_{O2} = 2.67C + 8H + S - O$$

Where O is the oxygen in the fuel, C is the carbon content, H is hydrogen and S is Sulphur. Air is contains 23.2% oxygen by mass. Therefore theoretically air required for complete combustion of 1 kg of fuel. Complete Combustion of fuel cannot be achieved if only the theoretical or stoichiometric air is supplied. Excess air is always needed for complete combustion. It is expressed as a percentage or by the use of dilute coefficient. The percent excess air supplied air is

$$\%\ \text{excess air} = \frac{WA - WT}{WT} \times 100$$

Where W_A is actual amount of air supplied for complete combustion of 1 kg of fuel. The dilution coefficient, d, is given by

$$d = \frac{WA}{WT}$$

The percentage of excess air varies between 15 and 30% for most large utility boilers.

B. *Control of Excess Air:*

Proper control of the right amount of excess air maintains optimum combustion efficiency. Amounts of CO_2 and O_2 in combustion gases are indexes of excess air. The desirable CO_2 level depends on the fuel and the optimum excess air for the furnace. Desirable O_2 values depend much less on the type of fuel. This makes O_2 measurement the preferred method for combustion control. If the measured O_2 content is more than that desired, the air supply is to be reduced. If the O_2 measured is less than that desired, air supply is to be increased.

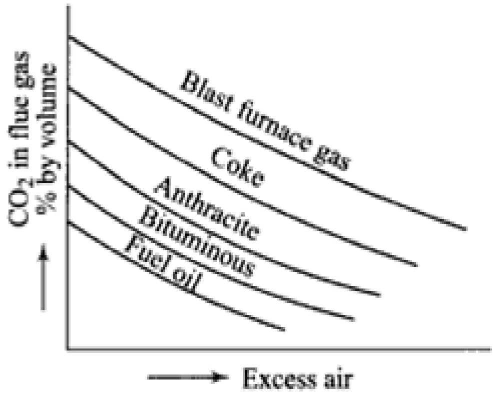

Fig. 1: Variation in flue gas with fuels and excess air

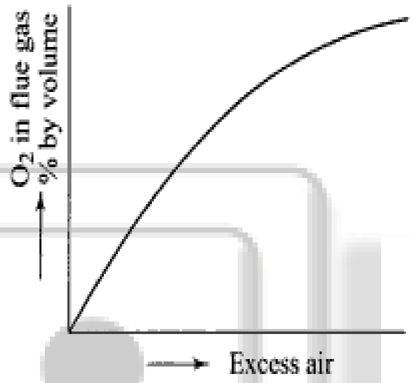

Fig. 2: Variation in flue gas with excess air

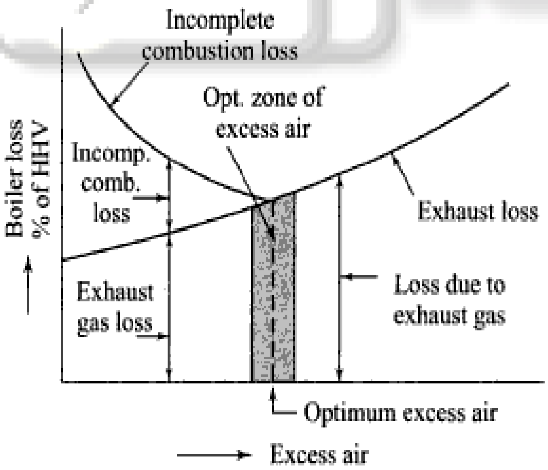

Fig. 3: Optimum excess air for maximum combustion efficiency

Boiler lossesare estimated as outlined in different outputs. The excess air is then adjusted by controlling air supply to show the optimum value of excess air for best combustion efficiency is then ascertained. The excess air can also be determined using the following relation.

III. PULVERIZED COAL FIRED BOILER

The first commercial application of pulverized coal firing for steam generation was made in the early 1920s. Since then it has become almost universal in central utility stations using coal as fuel. Coal is first ground to dust like size and powdered coal is then accepted in a steam of air to be fed through burners into the furnace, the volatile matter is distilled off and this reduces the coal particles to minute sponge-like masses of fixed carbon and ash. The volatile gases mix with the oxygen of the air, get ignited and burn quickly. Oxygen of the hot air reacts with the carbon surface to release energy. Proper burning of fuel needs the supply of correct proportion of air, mixing of fuel and air, high temperature, and adequate time to complete combustion reactions. The ash resulting from combustion (i) partly falls to the furnace bottom and (ii) the rest is carried in gas steam as fly ash to flue-gas outlet, or (iii) is deposited on the boiler heating surfaces. Modern central station boiler furnaces have water-cooled walls that form component of the heat-absorbing surfaces in steam generations.

Technical specification of pulverized coal fired boiler and its accessories are given in Table 1

Boiler type	**Tangentially coal fired, water Tube, natural circulation**
Fuel	Fuel Indian Bituminous Coal
Generation Capacity	Upto 210 MW
Furnace Type	Fusion Welded Panels
Low Temperature Superheater	425 ºC
Platen Superheater	515 ºC
Final Superheater	540 ºC
Reheater	300 to 540 ºC
Economizer	245 to 280 ºC
Air Preheater	300 to 336 ºC

Table 1: Technical Specifications of Boiler used at Stage-II of WTPS

The concept of burning coal that has been pulverized into a fine powder comes from the belief that if the coal is made fine enough, it will burn almost as easily and efficiently as a gas. The feeding rate of coal according to the boiler demand and the amount of air available for drying and transporting the pulverized coal fuel is controlled by computers. Pieces of coal are crushed between balls or cylindrical rollers that move between two tracks or "races." The raw coal is then fed into the pulverized along with air heated to about 330 °C from the boiler. As the coal gets crushed by the rolling action, the hot air dries it and blows the usable fine coal powder out to be used as fuel. The powdered coal from the pulveriser is directly blown to a burner in the boiler.

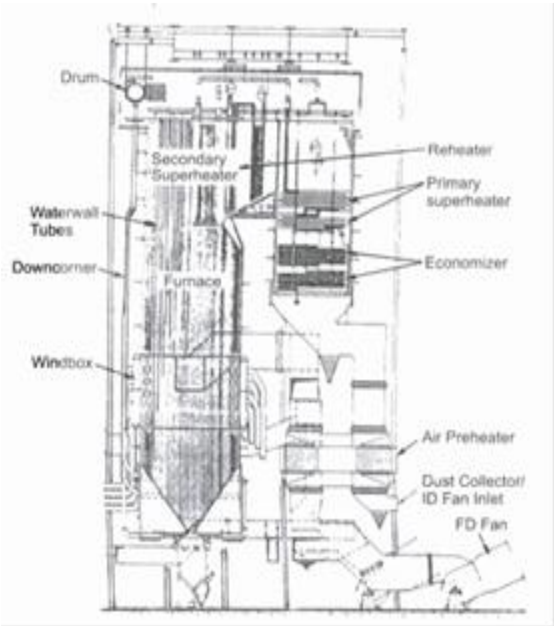

Fig. 4: General Arrangement of Pulverized Coal Fire Boiler

To burn pulverized coal successfully, the following two conditions must be satisfied:

(1) Large quantities of very fine particles of coal, usually those that would bypass a 200 mesh sieve must exist to ensure ready ignition because of their large surface-to volume ratio.
(2) Minimum quantity of coarser particles should be present since these coarser particles because slagging and reduce combustion efficiency.

IV. COAL ANALYSIS & COAL FLOW BALANCING

A. *Coal Analysis:*

This is the easier of two types of coal analysis.

B. *Proximate Analysis:*

This is the easier of two types of coal analysis and the one which supplies readily meaningful information for coal's use in steam generators. The basic method for proximate analysis is given by ANSI/ASTM Standards D 3172. It determines the mass percentages of fixed carbon, volatile matter, moisture, and ash. Sulfur is obtained m a separate determination. Fixed carbon is the elemental carbon that exists in coal. In proximate analysis, its determination is approximated by assuming it to be the difference between the original sample and the sum of volatile matter, moisture, and ash. The volatile matter is that portion of coal, other than water vapor, which is driven off when the sample is heated in the absence of oxygen in a standard test (up to 1750°F or 7 min). It consists of hydrocarbon and other gases that result from distillation and decomposition. Moisture is determined by a standard procedure of drying in an oven. This does not account for all the water present, which includes combined water and water of hydration. There are several other terms for moisture in coal. One, inherent moisture, that existing in the natural state of coal and considered to be part of the deposit, excluding surface water. Ash is the inorganic salts contained in coal. It is determined in practice as the noncombustible residue after the combustion of dried coal in a standard test (at 1380°F). Sulfur is determined separately in a standard test. Being combustible, it contributes to the heating value of the coal. It forms oxides which combine with water to form acids. These cause corrosion problems in the back end of steam generators if the gases are cooled below the dew point, as well as environmental problems.

C. *Ultimate Analysis:*

The proximate analysis of coal does not give any idea about the suitability of coal for the purpose of heating. It is not possible to find out the calorific value of coal with the help of proximate analysis. To find out the chemical analysis of coal, like carbon, hydrogen, oxygen, nitrogen, sulfur and ash, ultimate analysis of coal is generally used.

Proximate Analysis %		**Ultimate Analysis %**	
Moisture	8.86	Moisture	8.86
Ash	37.12	Ash	37.12
Volatile matter	23.3	Hydrogen	2.92
Fixed carbon	30.6	Total carbon	39.08
		Nitrogen	1.82
		Sulphur	0.56
		Oxygen	9.64

Table 2: Proximate and Ultimate Analysis

D. *Coal Flow Balancing:*

The first step in optimizing combustion system performance is balancing the air and fuel flowing through each of the coal pipes, i.e the pipes that convey the air/fuel mix from the pulveriser to the individual burners in the furnace wall. Also necessary is information on the properties of the coal traveling through the pipes, such as fineness data. Fuel fineness and distribution are prerequisites to achieving the best furnace effectiveness for low-NOx burner performance, slagging, and steam cycle performance. When fuel and air are flowing through the pipes to each burner equally, and the quality of the fuel is within specific guidelines, then the system is balanced. These measurements play a crucial role in adjusting fuel and air flows to balance the flow, fuel fineness, and air/fuel ratio across all of the plant's coal pipes.

Characterizing air and fuel flow requires carefully collecting a number of measurements, including pipe static pressure, pipe temperature, dirty air velocities, fuel flows from each individual coal pipe, individual pipe velocities, total pulveriser fuel flow, and total air flow entering the mills. The following discussion focuses on the importance of an accurate and standardized coal pipe sampling methodology.

E. *Clean Air Flow Test:*

Clean Air flow test in milling system is carried out to check air flow variation between the pulverised coal pipes of a mill is within allowable limit and thereby to ensure that correct size orifices are installed in coal pipes for equalizing the air flow. A clean air test is conducted to balance the system resistance of each burner line leaving each pulveriser. This measurement is made with no coal flowing into the pulverizes. The clean air test conducted on each coal pipe is completed by multiple point measurements using a standard pitot tube. The velocities of the 12 point averages are then plotted on a graph for ease of analysis. Clean air tests must be conducted under steady state conditions with completely stable system temperatures. Select a Coal Pipe of average length, and insert the Pitot tube to the center of the pipe and adjust the air flow to produce the calculated pilot tube differential pressure. Velocity profile in each coal pipe shall be obtained by traversing the pilot tube at two directions, 90^0 apart at the center of equal areas. Record mill air temperature, mill air flow, mill differential pressure at control room. If control room indications not available, suitable measuring arrangements to be made at local. In clean air test, +/- 5% deviations of airflow are satisfactory.

F. Dirty Air Flow Tests:

In Dirty air test, dirty air velocities are measured in each fuel line to determine airflow and coal flow in each fuel line. The approach to measure dirty airflow in coal pipes (fuel and air) is to assemble a dirty airflow test kit and an isokinetic coal sampling test kit to collect representative fuel samples for coal fineness analysis. Isokinetic sampling collects particles flowing into the sampler at the same velocity as the coal flowing through the pipe. Prior to inserting the pitot tube into the flow, ensure the manometer is level and has been zeroed. Install a dustless connector at the ball valve outlet to ensure coal containment in coal transport pipe during traverse. Insert the dirty air probe through the dustless connector. Open the ball valve fully while inserting the dirty air probe and place the probe on the first measurement point. Allow the manometer reading to stabilize, record the data and move to the next measurement point. Repeat this process for all 12-test points on the particular port. Prior to moving to next test port, disconnect the tubing from the probe, blow the sensing lines and repeat the traverse on the remaining ports. Measure and record static pressure and temperature reading for each coal transport pipe using the static pressure probe. Before inserting the probe in the coal pipe, static pressure sensing line is connected to one side of the manometer. The tube on the other end is pinched to prevent blowout of manometer fluid during insertion of the probe. The thermocouple is attached for measurement of temperature. Calculate velocity in each fuel line and ascertain dirty air balance. The dirty air balance should be expressed as a deviation from the mean velocity of all the pulverizes individual coal transport pipes.
An isokinetic sampling can be used to sample coal fineness in a coal pipe. Insert the probe into the dustless connector, open the ball valve, and slide the probe in to the first port. Turn on and adjust the aspirating air and start the stopwatch. Sample each traverse points for 5 seconds. Upon completion of the last traverse point, cut off the air, and remove the probe. Repeat the process for second port on the pipe.

V. PARAMETERS FOR OPTIMIZATION OF COMBUSTION

Using These Following three Parameters are going to optimize combustion in boiler:

- SADC Damper
- Burner Tilt Angle

A. SADC Damper:

Combustion air requirement for soot particles is fulfilled by secondary air. Secondary air fans are used for this, discharge of which is connected to air pre heaters, where air temperature is increased to 325 ^{0}C. These air then flows to wind box, from where it is admitted to the furnace through damper called secondary air dampers. The main function of SADC Control is to regulate the supply secondary air into the furnace through wind box. The required secondary air comes from FD Fan. By varying the supply of secondary air we can optimize combustion in boiler.

Secondary air is another stage of supply of air to the combustion chamber, it is provided to complete the combustion which is initiated by primary air. It is injected into the combustion chamber of boiler with sufficient pressure to produces turbulence required for proper mixing in combustion and so complete combustion is possible.

B. Burner Tilt Angle:

Burner tilting device is use to move the fire wall inside the furnace in upper and downward directions. The main function of burner tilting is to maintain reheat temperature. It can be tilted 10^0 upward and 10^0 downward. In tilted burner arrangement, the burning fuel in a corner fired boiler forms a large swirling fireball which can be moved to a higher or lower level in the furnace by tilting the burners upwards or downwards with respect to a mid position. The repositioning of the fireball changes the pattern of heat transfer to the various banks of super heater tubes and this provides an efficient method of controlling the steam temperature, since it enables the use of spray water to be reserved for fine-tuning purposes and for emergencies.

In addition, the tilting process provides a method of controlling furnace exit temperatures. With such boilers, the steam temperature control systems become significantly different from those of boilers with fixed burners. The boiler designer is able to define the optimum angular position of the burners for all loads, and the control engineer can then use a function generator to set the angle of tilt over the load range to match this characteristic. A temperature controller trims the degree of tilt so that the correct steam temperature is attained.

Tilted burners are generally used in tangential fired furnace. In tilted burners, the burner can be move up word or down word and accordingly change the heat transfer in furnace. When the reheat steam temperature is above the rated value, the burner moves downward which reduces the heat absorption and the temperature start to reduce. On other hand for lower steam temperature the burner moves upward. The different position of burners.

VI. CONCLUSION

A review of Combustion optimization in pulverized fuel fired boiler lead to reduction in coal consumption rate and net heat rate of the plant. Auxiliary power consumption which is mainly utilized in running boiler feed pumps, coal mills, etc also reduces. Efficiency of the boiler is increased. Over and above losses due under performance of boilers and downtime cost reduces drastically which will increase utility of the plant and hence revenue generation also increases.

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