Name: Rashid Yasin Shaikh

Email: rashid_y_shaikh@yahoo.com

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MONITORING OF STACK GAS TEMEPRATURE, O2 and CO_2 in Flue GAS

1. Introduction

The considerable rise in electricity demand throughout the world has resulted in enormous increase in power plant size installation and in their size. The expansion coupled with escalating cost of fuel, has imposed a urgency to ensure that the power plant is operated and maintained as near to optimum conditions as possible. One must know the causes of poor efficiency and tools to rectify these trends.

Figure 1 shows the typical power plant boiler. The Boiler is a natural circulation, single drum radiant heat, and balanced draft type with tilting tangential burners. Flue gas path is from radient superheater, reheater, final superheater, low temperature superheater and economizer. Then flue gas flows through airpreheater in which primary and secondary air is heated.

For the fuel savings in boilers, we have to lower stack gas temperature and excess air. This is not surprising because stack gas temperatures are usually higher than necessary due to scale and soot build up, or overfiring or air leakage in Airpreheater. Excess air is also higher than necessary since boiler operators tend to increase it for complete combustion and to avoid smoke generation. Most operators cannot operate at an ideal excess air level because there is no O_2 monitoring equipment or oxygen trim installed.

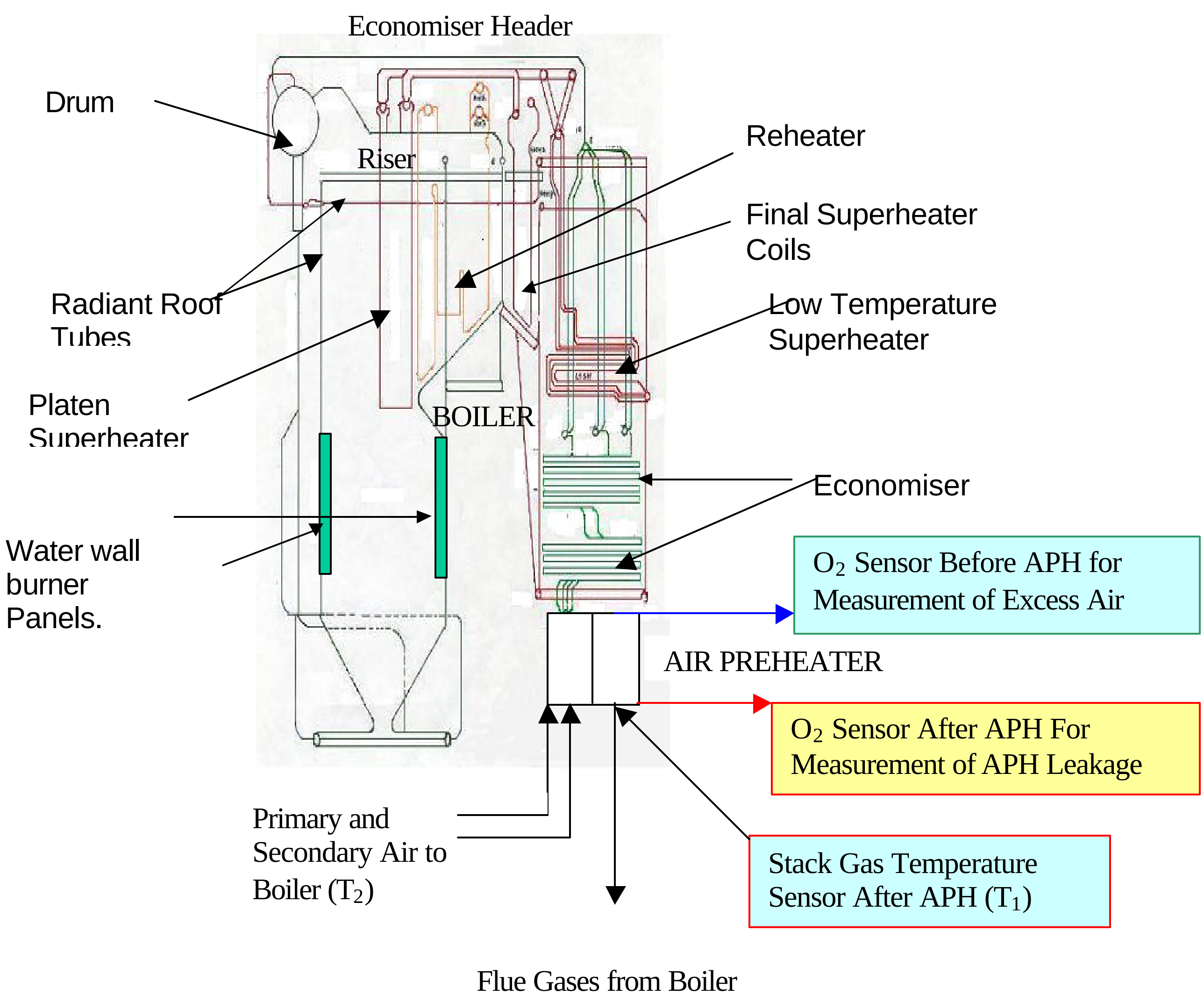

Fig.1 Schematic of Boiler

2. Boiler Efficiency

The efficiency of a boiler is dependent upon the efficiency of combustion and the heat transfer within the boiler. Boiler efficiency is calculated by Heat loss method as

BOILER EFFICIENCY = 100 – VARIOUS HEAT LOSS

Following are various boiler losses

1. Unburnt carbon loss
2. Dry Flue Gas Loss
3. Moisture in fuel
4. Hydrogen in fuel
5. Moisture in Air
6. Unburnt Gas Loss due to Carbon Monoxide
7. Specific Heat Loss from Bottom Ash and Fly Ash
8. Radiation and Unaccounted Loss
9. Radiation to Furnace Bottom
9. Heat Credit due to Mill, Primary Air Fan, Forced Draught Fan, Circulating Water Pumps

Input parameters affecting boiler efficiency are

Proximate Analysis of Coal
Ultimate Analysis of Coal
Heat Create in Boiler due to Mill, Circulating Pumps, Fan Power.
Gross Calorific Value of Coal kcal/kg
Carbon Monoxide CO ppm
Carbon in Bottom Ash Hopper
Carbon in Fly Ash %
Oxygen (O2) in Flue Gas before Airpreheater %
Oxygen O2 in Flue Gas outlet after APH %
Flue Gas Outlet temperature after Airpreheater T_1
Air Inlet Temperature to Airpreheater $\mathbf{T_2}$
Ambient Air Deg. C
Relative Humidity
kg of water/kg of dry air

3. Effect of Stack Gas Temperature on Boiler Efficiency

The causes of High Air preheater gas outlet temperature are:

a. APH scaling or ineffective soot blowing.

b. Holed and torn element at cold ends, due to corrosion.

c. Scaling of boiler.

d. Excessive air supply to boiler.

e. Film boiling due to poor circulation in boiler.

f. Low feed water temperature.

g. Poor milling and longer burn-off times of coal.

h. Use of higher elevation burners at low loads.

i. Excessive firing.

j. Air ingress into furnace.

Stack Gas temperature affects following losses in Boiler.

3.1.Dry Flue Gas Loss

T_1 is temperature of flue gas after APH. T_2 is temperature of Primary and Secondary air to APH.

Dry flue gas loss depends upon

a. Quantity of dry combustion gases

b. Temperature rise between FD Fan inlet and gas exit temperatature

c. Mean specific heat of flue gases (constant pressure)

Dry Flue Gas Loss = $\dfrac{100\times(\frac{C\%}{100}+\frac{S\%}{267}-CinAsh)}{12(CO2+CO)}\times 30.6\times(T_1-T_2)$ kJ/kg of coal

3.2 Loss Due To Hydrogen and Moisture In Fuel

Loss Due to Moisture in Fuel

$$=\frac{9\times Hydrogen+Moisture}{100}\times[1.88\times(T_1-25)+2442+4.2\times(25-T_2)]\text{ kJ/kg of Coal}$$

3.3. Moisture In Air

Weight of flue gas = Total Air at APH outlet

Weight of flue gas = $\text{Stiochomet ric Air} * (1 + \frac{\text{ExcessAira tAPHoutlet \%}}{100})$

Moisture in dry air (kg of water/kg of dry air) is calculated from psychometric chart by using Dry Bulb Temperature (DBT), Wet Bulb Temperature (WBT) and Relative Humidity.

Moisture in air loss = $WeightOfFlueGas \times \frac{kgofwater}{kgofdryair} \times 2 \times (T_1 - T_2)$

3.4. Specific Heat Loss Of Fly Ash

Specific Heat of Fly Ash = 0.836 kJ/kgK

Loss = $\frac{FA\%}{100} \times \frac{Ash\%}{100} \times SpecificHeatofFlyAsh \times (T_1 - T_2)$ kJ/kg of Coal

Hence the monitoring of Stack Gas Temperature is important from the point of Boiler Efficiency.

4. Location of Stack Gas Temperature Measurement

The common equipments in thermal power plants to increase the thermal efficiency are economizers, superheaters and air preheaters. The Heat carried away with the flue gases is partly recovered in economizers and air preheaters

So after airpreheater, flue gases are exhausted to atmosphere through chimney and it is waste energy. So upto airpreheater, the heat carried away by flue gases is utilized.

We know that boiler efficiency is defined as the heat added to the working fluid (Steam and Water) expressed as percentage of heat in the fuel being burnt. In the boiler, we are utilizing the heat in the fuel upto air prehater only.

Hence the location of stack gas temperature for measurement is after air preheater as shown in Fig.1. By measuring stack gas temperature after air preheater we can predict boiler efficiency.

5. Excess Air

More air than theoretical air is required for complete combustion. Less excess air means incomplete combustion. Too much excess air means large heat is dissipated to the chimney. Optimum air is that which reduces the sum of these two losses to minimum. The combined effect of excess air on dry flue gas loss, unburnt carbon (in ash) loss and unburnt gas loss due to incomplete combustion loss is plotted in Fig.2. There is only one value of excess air which gives maximum efficiency. The method of determining of excess air is by the analysis of the flue gas.

In Appendix 1, figures of changes in dry flue gas loss, unburnt gas loss and unburnt carbon (in ash) loss with excess air is shown.

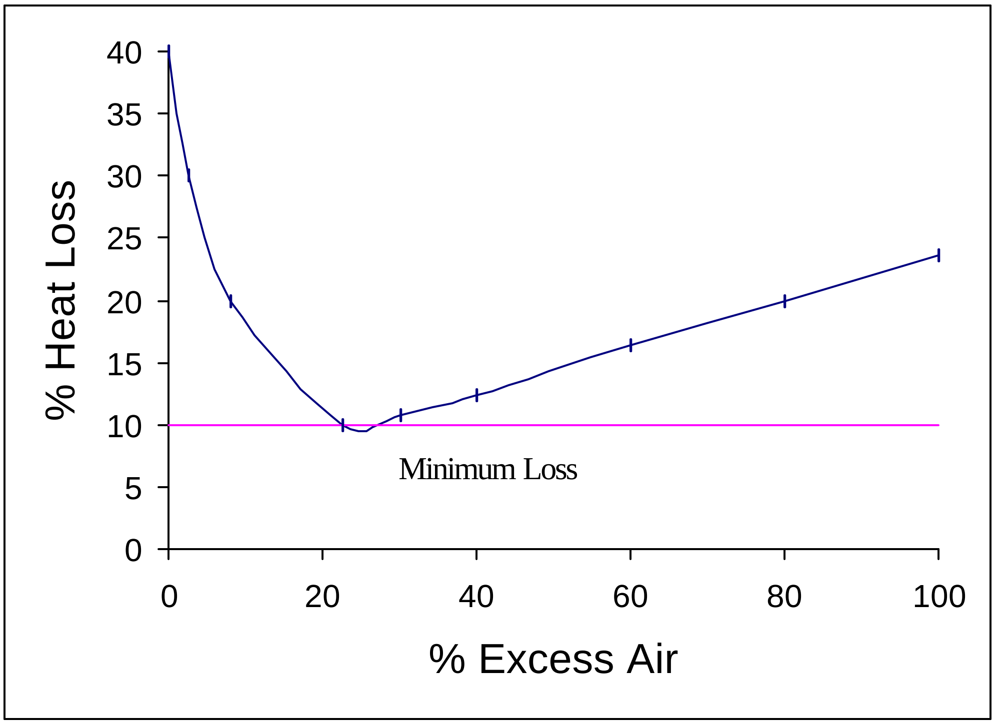

Fig.2 Excess air vs Heat Loss

The purpose of gas analysis is to determine the concentration of one or more components of a gas mixture. In steam power plants, the objective of gas analysis is to keep the concentration of CO_2 and O_2 as minimum as possible therefore constant recording of these components in exhaust gases is necessary. The recording of these components helps in improving the efficiency of steam generation, and for safe continuous and proper plant operation.

Excess Air is monitored by measurements of CO_2 and O_2 measurements.

5.1 Excess Air by CO_2 Monitoring

The excess air reduces CO_2 % and thus following relation exists. The quantity of excess air present in a boiler may be determined from knowledge of the CO_2 % present and the theoretical maximum CO_2 % for the fuel.

$$ExcessAir = \frac{TheoreticalCO_2\,\%}{ActualCO_2\,\%} - 1$$

Theoretical CO_2 % for various fuels is given

Theoretical CO_2 % for Various Fuels	
Fuel	CO_2 % by Volume
Natural Gas	11.7
Fuel oil	15.3
Bituminous Coal	18.6

In Appendix-1, variation of CO_2 % with Boiler load is shown.

Fig.3 shows the variation of excess air with CO_2 %

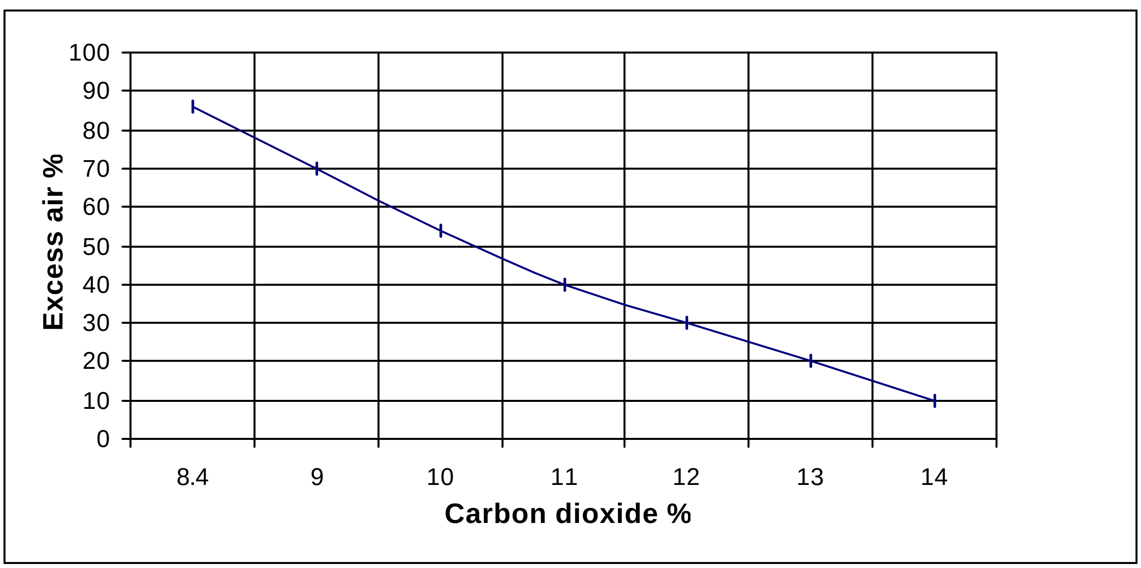

Fig.3 Variation of Excess air with CO_2 %

5.2 Excess Air by O_2 Monitoring

Excess Air can also be calculated by using formulae,

$$ExcessAir\% = \frac{O2\%atAPHInlet \times 100}{21 - O2\%atAPHInlet}$$

In Appendix-2, variation of O_2 and CO_2 for Coal and Oil Fuel has been shown.

Fig.4 shows the variation of excess air with O_2 %

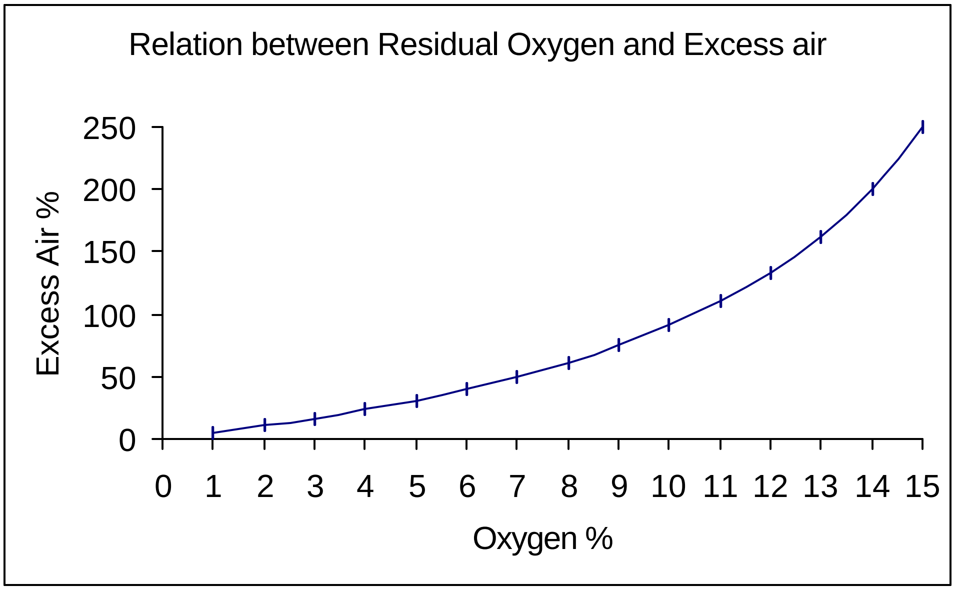

Fig.4 Variation of Excess air with O_2 %

6. Best Solution to Measure O_2 or CO_2 in The Stack Gas

The method of determining the quantity of excess air is by the analysis of flue gas. In the past it was common to do this by measuring CO_2 % content of the flue gas. However the CO_2 % indication has several limitations

1. It is not a direct measure of excess air.

2. The indication is affected by the Hydrogen/Carbon ratio. For example this ratio is different for fuel oil and coal. Thus 10% CO_2 means some excess air with oil firing and different excess air with coal firing.

The most common method used for measuring CO_2 content in flue gases is hot wire thermal conductivity gas analysis cell. If appreciable H_2 is present in flue gases then reading of CO_2 % based on thermal conductivity of CO_2 content of the gases may be inaccurate. This type of instrument relies on the fat that the proportion of H_2 present is small and constant.

3. Another important consequent of the gas is water vapour, the thermal conductivity of which is approximately same as for CO_2 . Therefore the effect of variation in water vapour should be eliminated by either drying or saturating the gas sample before analysis.

4. As the excess air is reduced, the CO_2 % increases until the CO_2 is maximum. Further reduction of excess air results in decreasing of CO_2 as shown in Fig.5. This may be interpreted as if the excess air has been increased

5. With most CO_2 analysers, it is necessary to withdraw a sample of gas from the measuring point for external analysis. This results in practical problems such as cleaning of filters at the probe end and condensation in sample carrying pipe.

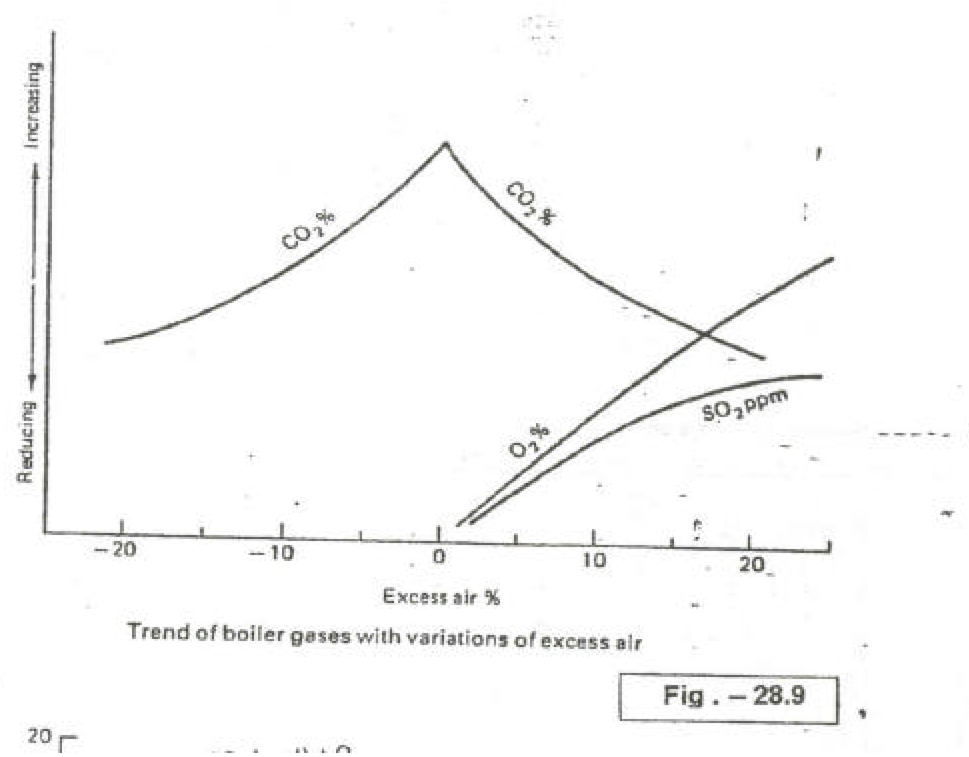

Fig.5 Trend of Boiler Gases with variations to theoretical Air

If instead of CO_2, an indication of O_2 is provided then the relationship between excess air and percentage of oxygen in flue gas is almost constant whatever the type of fuel. Oxygen analysis are ideal for use in boiler automatic control schemes for 'Oxygen Trim Control". The advantage of Zirconia Oxygen Analyser is that it dispenses with the necessity to withdraw a gas sample for analysis external to the boiler. The accuracy and reliability are very good.

Because of the drawbacks in CO_2 measurement, Oxygen O_2 level can only tell the operator what the boiler efficiency level is, since the efficiency level is directly related to excess air fed to the combustion chamber.

Since % of O_2 is more reliable and fundamental guide to the excess air for combustion, the best solution to predict excess air in stack gas is the measurement of O_2.

7. Location of O_2 Sensor

Excess Air is monitored by measurement of O_2 at air preheater inlet (Economiser Outlet) as shown in Fig.1.

The reasons to select APH inlet (Economiser Outlet) location for O_2 measurement are

1. Due to air leakage across the air heater seals, we can't correctly measure the excess air at air preheater outlet as show in Fig.1.
2. If we measure O_2 above burners location near Platen Superheater, we will get clear picture of excess air in combustion zone of boiler. By measuring difference of O_2 at air preheater inlet (Economiser Outlet) and O_2 in Combustion Chamber, we can find out Tramp Air through peepholes of Boiler or ant leakages into boiler. But measurement of O_2 in Combustion Chamber is very costly. Other disadvantage is that we can't predict complete combustion of fuel in boiler by monitoring of O_2 in combustion Chamber.

O_2 sensor should be placed before Air preheater inlet (Economiser outlet).

Appendix-1

Fig. 6 shows the changes in dry flue gas loss, unburnt gas loss and unburnt carbon (in ash) loss with CO_2 variation.

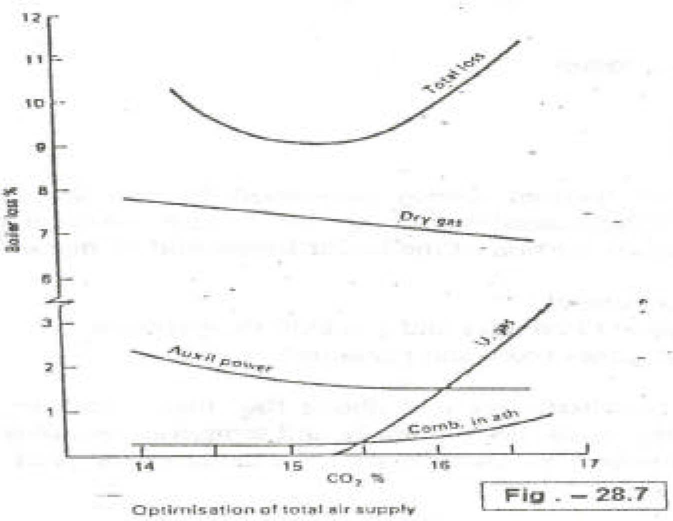

Fig.6 Variation of Boiler Losses with CO_2

Fig.7 shows the variation of CO_2 % with Boiler load.

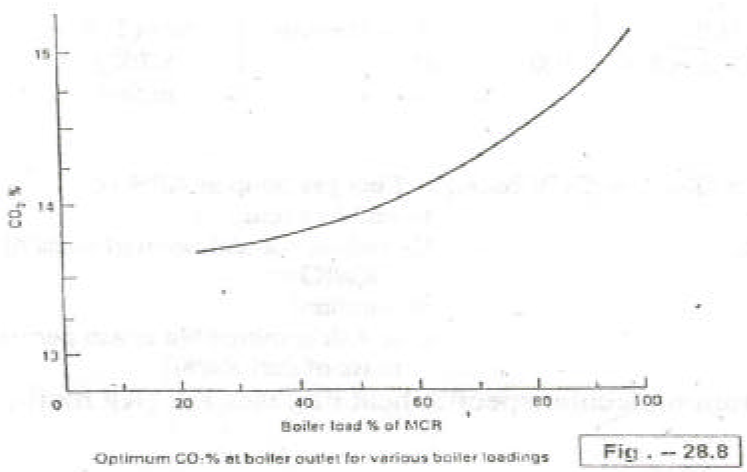

Fig.7 Variation of CO_2 with Boiler Load

Appendix-2

Fig.8 shows the variation of O_2 and CO_2 with excess air.

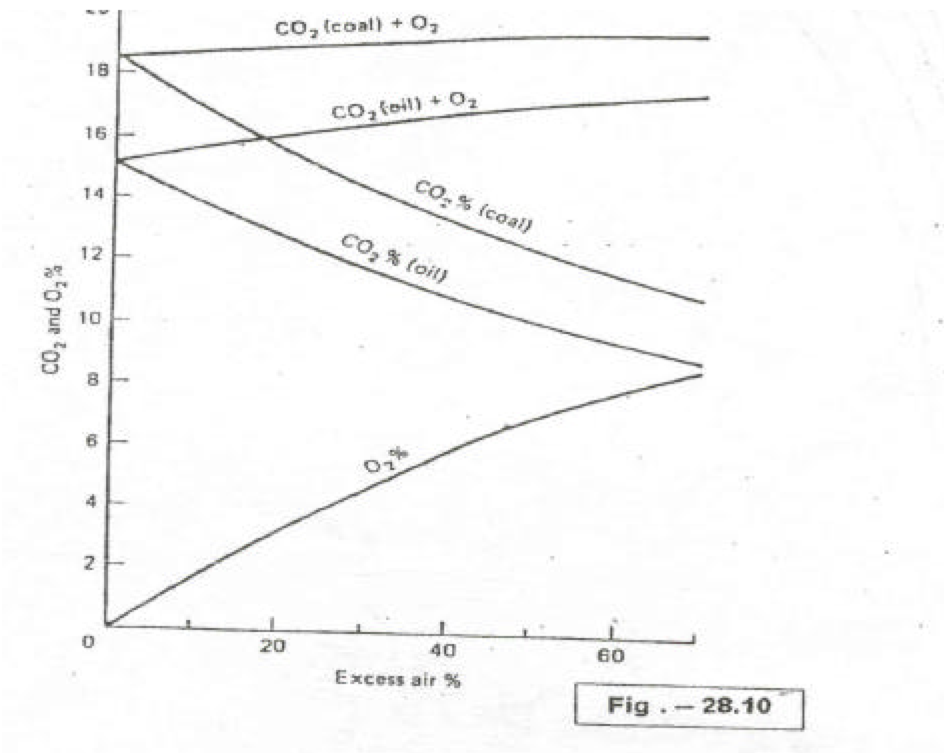

Fig.8 Variation of O_2 and CO_2 with excess air