



**Article for Issue # EE 05**  
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**Monitoring and controlling the stack gas temperature of a combustion process as well as oxygen (O<sub>2</sub>) in the stack gas are the minimum requirement to check on unnecessary fuel consumption. Rules of thumb are that reduction of 20°C of stack gas temperature will reduce fuel consumption by 1%. Reduction of 1% of O<sub>2</sub> in the stack gas will reduce fuel consumption by between 0.5% and 1% depending of the fuel fired. Questions are:**

- a. Where would you measure the stack gas temperature and why do you recommend this location, in the system.
- b. Which is the best solution to measure either O<sub>2</sub> or CO<sub>2</sub> in the stack gas and why is it the best solution.
- c. Where would you place the O<sub>2</sub> sensor and why do you select this location.

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# 1. A Brief Introduction to Stack gas and Combustion process

## 1.1 Stack gas

A complex phenomena of combustion of any fuel with the oxygen inside the combustion chamber results in the formation of a number of gases, which are to be thrown out into the atmosphere through a stack. These gases combined together are called the flue gas or the Stack gas.

The Constituents and percentage composition of various gases in the Stack gas depends on the type of fuel fired inside the combustion chamber. The various types of fuel may be Coal, Naphtha, Natural gas , Municipal Wastes, Wood Products, etc.

But the main constituents or the general constituents of any Stack gas are

Oxygen

Oxides of Sulphur

Oxides of Nitrogen

In a Coal fired power Plant, where the Stack gas also contains fly ash particles, it is absent in case of gas fired plants and so on.

Here the main topic of concern is the presence of Oxygen in the Stack gas as far as the Constituent of Stack gas is concerned.

## 1.2 Importance of Stack gas

The two major characteristics of Stack gas, that is presence of **Oxygen** and the **temperature** of Stack gas plays a very vital role in deciding the pattern of Fuel consumption in a power plant.

This makes it an important point in the Monitoring and Control of these two parameters from the view point of Efficiency of the Plant, or in other words the Profitability of the Plant.

## 1.3 Stoichiometric Ratio

As we know that for complete combustion of any fuel, a definite amount of oxygen is required, as per the chemical combustion equation. For e.g., the combustion of any coal will require a definite amount of air for conversion of all its carbon constituents into carbon dioxide. As the chemical process of converting carbon into carbon

dioxide is an exothermic reaction, it is necessary to see that there is no under combustion of coal. Only then it is possible to extract the full heat of the coal.

If the process of incomplete combustion occurs, then the reaction of formation of carbon monoxide occurs, which is an endothermic reaction and hence there is a consumption of heat, which is released by the exothermic reaction. This ultimately leads to the net loss in the heating value, ultimately affecting the **FUEL CONSUMPTION**.

Combustion of Coal



If proper amount of oxygen is not supplied, some of the carbon tends to less oxygen and the result is

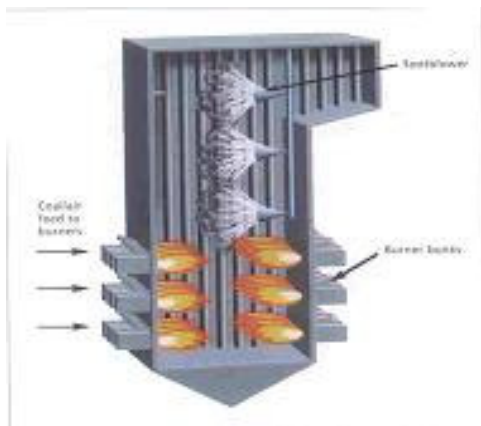


For convenience we define the “stoichiometric air” as the air to fuel ratio, AF (kg air/kg fuel), and the excess air factor as

$$EA = \frac{\text{Mass of air (kg) supplied for combustion of one kg of fuel}}{\text{Stoichiometric air (AF)}}$$

The AF is a property of a fuel that can be calculated from the ultimate chemical composition of the fuel.

### Parameters Controlling during Combustion Process in a Pulverised Coal fired Power Station Boiler.



A typical pf Fired power station boiler is represented here. Banks of pf burners , fed with combustion air and pf from the milling and distribution systems, fire into the boiler. The boiler is lined with heat exchanger tubes that convert water into steam to drive the steam turbine. Banks of heat exchanger tubes are also positioned at the exit of the boiler in order to gain the maximum possible efficiency from the heat produced in the combustion process.

The parameters that will determine the combustion operation of a pf boiler, which is directly related to Fuel Consumption, includes:

Primary air:pf ratio  
Secondary air distribution  
Burner tilt ( on tangentially fired boilers)  
Mill firing pattern.

In practice , these parameters are altered, during boiler operation to control combustion conditions.

Primary air: pf ratio - Change coal feed rate,change primary air fan speed  
Secondary air distribution- Damper positions adjustment  
Burner tilt - Auto or Manual alteration  
Mill firing pattern - Alteration of the individual mill feed rates to sets of burners.

In order to maintain the Optimum Combustion efficiency, and hence save costs on fuel combustion, it is essential to monitor and control the Stack gas parameters , mainly OXYGEN and TEMPERATURE.

The operation of the plant and its output depends, therefore, on the accuracy of the temperature measurement of critical parts of the plant, such as the exhaust gas of the power station.

Q.No. a . Where would you measure the stack gas temperature and why do you recommend this location, in the system.?

**Answer:**

**Why to Measure?**

**Reasons:**

**For its impact on Boiler Efficiency**

**For its Impact on Electrostatic Precipitator performance in a coal based thermal power plant**

**Impact on Boiler Efficiency**

Stack gas temperature plays a vital role in determining the boiler efficiency in a power plant.. Higher is the exhaust temperature ,higher is the Stack gas loss. That means lower boiler efficiency and higher fuel consumption for the same output.

Since the Stack gas loss is a function of Exit Stack gas temperature ( as shown in the figure No.2), its measurement and overall its measuring point is of utmost importance.

The heat loss with the Stack gas , constitutes the largest portion of boiler losses, or we can say highly responsible for increase in fuel consumption; which in turn depends upon

### Quantity of Dry combustion gases

Temperature rise between FD fan inlet ( ambient air) and gas exit temperature

Mean specific heat of flue gases

### Dry Flue Gas Loss

$$\text{Dry Flue Gas Loss} = \frac{100 \times \left( \frac{C}{100} + \frac{S}{267} - C_{inAsh} \right)}{12(CO_2 + CO)} \times 30.6 \times (T_1 - T_2)$$

Dry Flue Gas Loss can also be calculated by using equation

$$= \frac{11 \times CO_2 + 8 \times O_2 + 7(CO + N_2)}{3 \times (CO_2 + CO)} \times 1.01 \times \left( \frac{C}{100} + \frac{S}{267} - C_{inAsh} \right) \times (T_1 - T_2) \text{ kJ/kg of coal}$$

Alternatively :-

Dry Flue gas loss % =  $K \times (T-t)$  (on GCV basis)

Where ,  $K =$

- 0.68 for anthracite
- 0.63 for bituminous
- 0.70 for Coke
- 0.56 for fuel oil.

$T =$  Stack gas temperature

$t =$  ambient temperature

With this explanation, it is quite clear that measuring the Stack gas temperature before air preheater has no relevance with the boiler efficiency because it has relevance when it passes through Air preheater. And after that it does not perform any useful work.. However for checking the performance of Air preheater, the temperature measurement may be provided before air preheater also.

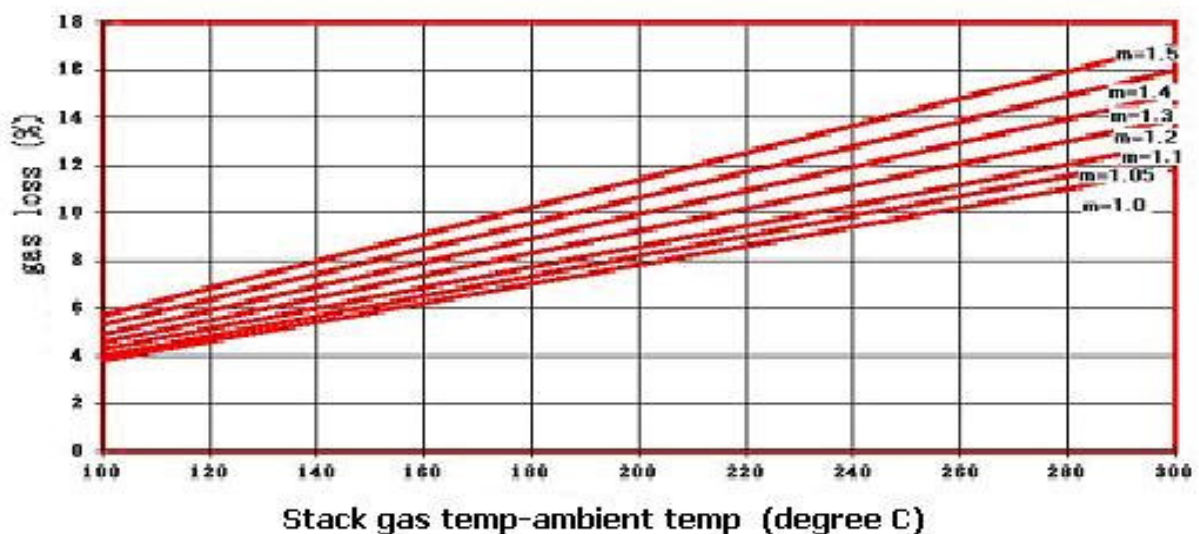


Figure No 2

## 2. Impact on Performance of Electrostatic Precipitator in a Coal based thermal Power Plant.

The flue gas entering the ESP displays severe SO<sub>2</sub>, **temperature**, and resistivity stratification that are consistent with the rotation of the air preheater (Figure No 3). The gas channels between plates in the ESP behave as discrete units with different sensitivities to changes in **flue gas temperature** and SO concentration. The air preheater is responsible for the **temperature** and SO stratification observed at the ESP inlet, resulting in an ash resistivity increase and reducing ESP collection efficiency. The result is higher particulate penetration and opacity. Hence the Measurement of Stack gas temperature is essential to survive in under the stringent environmental norms imposed on the power stations.

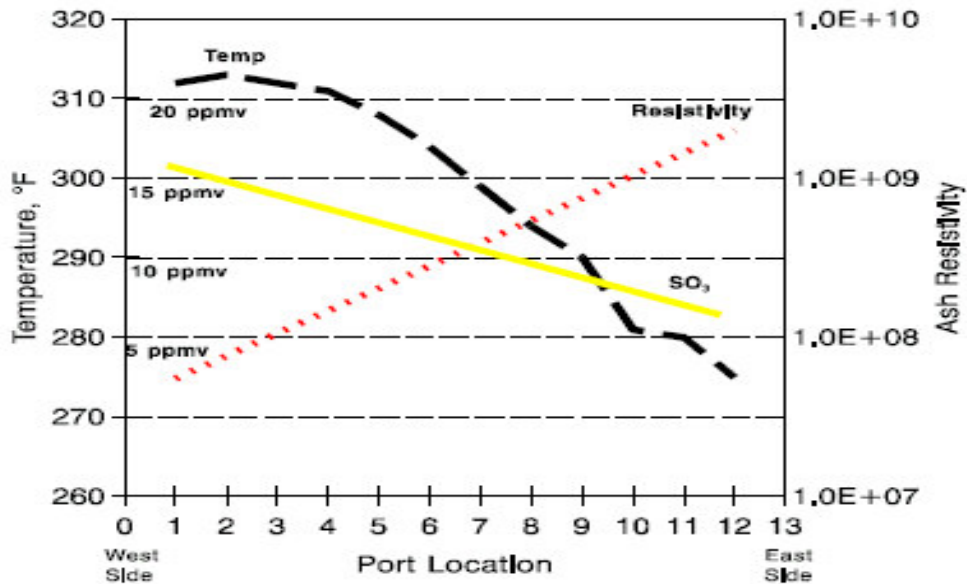


Figure No. 3

### Where to Measure Stack gas temperature?

#### Stack gas Temperature Monitoring Point should be at the Air Preheater Outlet

All the Calculations related to efficiency in a coal based thermal power plant, as seen above, is done with the temperature of Stack gas, till it does some work.. When the Stack gas leaves the air preheater, it does no further useful work. However it is at a considerably higher temperature than ambient, so it carries valuable heat to the chimney to be disbursed to the atmosphere.

**So the point after Air preheater is the most important point of measurement for Stack gas temperature.**

Another point that cannot be overlooked is the relationship of this temperature with the efficiency of Electro Static precipitator, in a coal based thermal power plant. A typical air preheater gas outlet temperature on a modern boiler is around  $130^{\circ}\text{C}$  , which corresponds to the dew point when there is 10 PPM of  $\text{SO}_3$  in the flue gas. So, if the proper temperature monitoring is not done before the stack gas enters the Electro static precipitator, there is chance that, under certain circumstances, this exit Stack gas temperature may come down to form the acidic substances, leading to lot of corrosion in the duct as well as in the ESP.

Also the efficiency of Electrostatic Precipitator goes down with the increase in Stack gas temperature entering into the ESP. If gas temperature is higher than the designed, the gas volume also increases and results in lowering of efficiency.

The design of a precipitator depends on the velocity of a particles of dust effectively traveling towards the collecting electrode. By effective means the particles may be collected and entrained in the gas stream before it is finally trapped. This velocity is known as effective migration velocity ( $w$ ).

With the increase in temperature of the Stack gas leaving the Air preheater and entering the ESP, the gas volume flow rate also increases and hence is the increase in the effective migration velocity, which reduces the efficiency of Electrostatic precipitator.

Thus it is clear that at the exit of Air preheater, the temperature of Stack gas has great relevance.

**So in my view, the best point for the measurement of Stack gas temperature is the outlet of Air Preheater.**

Q.No. b Which is the best solution to measure either $\text{O}_2$ or $\text{CO}_2$ in the stack gas and why is it the best solution.?
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#### **Relevance of Measurement of $\text{O}_2$ over $\text{CO}_2$**

- **$\text{O}_2$  gives instantaneous & clear indication of Combustion Status**
- **$\text{O}_2$  control can be optimised with CO monitoring, for optimum combustion environment**
- **$\text{O}_2$  level also gives the indication of creation of acid smuts.**

In a boiler, the first and foremost point is to ensure complete combustion of the fuel fired. Once the combustion is complete, there is no need for more air in the furnace. Carbon dioxide is the result of complete combustion. Once the combustion is complete, and still the air is increasing, carbon dioxide formed will only get diluted and its measurement will not reflect instantaneously whether the combustion has been complete or not.

In a practical furnace, it is impossible to obtain complete combustion of any fuel with only the theoretical quantity of combustion air, as it would require every molecule of fuel and oxygen to be in exactly the right place at the right time, so what would actually happen is that some of the fuel would have an ample supply of oxygen and the rest not enough. Consequently, carbon monoxide and hydrocarbons would appear in the Stack gas and the combustion would be inefficient, because heat release from the fuel would be incomplete.

To ensure that all combustibles meet with a sufficient supply of oxygen, excess air is supplied to the boiler. This enables all the available carbon to burn to carbon dioxide., hydrogen to water vapour and sulphur to sulphur dioxide, thus releasing the maximum possible heat. On the other hand, if more excess air is supplied, greater is the flow of stack gas to the chimney, carrying considerably amount of heat with it, as well as diluting the heat from combustion process.

### **Excess air in Combustion ( O<sub>2</sub> in the Stack gas)**

Although the theoretical calculation of combustion process gives a figure of Stoichiometric fuel air ratio for complete combustion of fuel, the safe and efficient operation of the burners in a boiler or furnace is of paramount importance to the overall operation of the boiler. Loss of individual flamees can lead to unburnt fuel being fed into the boiler, resulting in the accumulation of potentially explosive fuel/air mixture. So a definite amount of **EXCESS AIR** cannot be avoided to ensure the proper and efficient combustion process. This excess air is reflected in terms of **Oxygen** in the Stack gas.

Thus, although excess air is necessary , every effort is made to keep it as small as possible. Normal quantities are:

Pulverised Coal	20%
Fuel Oil	2%
Natural Gas	8%

This excess air , along with the other components of stack gas ( product of combustion of fuel), results in the loss called Flue or Stack gas Loss. Since to provide the safe operation of boilers, this excess air cannot be avoided, the question now arises as **How much excess air is permissible ?**

Here we take the **example** of a Pulverised coal fired , tangential fired Coal burners.

As per the recommendation of different OEMs, this value differs with the nature of fuel fired and the type of combustion chamber. In a pulverised coal, tangentially fired boiler, the recommended value is 2% to 3% of oxygen at the exhaust, which is equivalent to 15 to 20% of excess air. This Oxygen percentage is measured before Air Pre heater inlet. This  $O_2$  is used for finding the excess air as

$$\text{Minimum\_Oxygen\_required} = y = \left( \frac{C\%}{1200} + \frac{H\%}{400} + \frac{S\%}{3200} - \frac{O\%}{3200} - \frac{C_{inash}}{12} \right)$$

If  $x$  is excess air in Stack gas

$$O_2\% = \frac{xy}{\frac{C\%}{1200} + \frac{S\%}{3200} + 3.76 \times (1+x) \times y + xy}$$

By using this equation we can find excess air % and total air required as

$$\text{TotalAir Required} = \text{MinimumAir Required} \times \left( 1 + \frac{x\%}{100} \right)$$

$$\text{ExcessAir} = \text{TotalAir Required} - \text{MinimumAir Required}$$

Excess Air can also be calculated by using formulae,

$$\text{ExcessAir}\% = \frac{O_2\% \times 100}{21 - O_2\%}$$

In fact, although there is a minimum value recommended by the OEMs, it is better to have a monitoring system for Monitoring of CARBON MONOXIDE also. And the Oxygen monitoring and control should be done in association with Carbon Monoxide. There is no meaning of Monitoring of Oxygen alone. It is observed in a power plant that as the oxygen percentage goes down a certain value, there is tendency of rise in the value of carbon monoxide, which indicates that the process of incomplete combustion has started. It is at this moment that the Monitoring and control of excess air (or oxygen) is required to avoid this phenomenon. A balance between these two values, will optimize the combustion process, which will result in optimum fuel combustion. Hence Monitoring of both Oxygen and Carbon Monoxide is essential, and not only Oxygen.

The flue gas produced by burning any fuel completely but with only the theoretical quantity of air will contain a characteristic percentage of Carbon Dioxide. For example, if pure carbon were so burned, then all the carbon would be oxidized by combining with all of the oxygen present. Hence, the oxygen in the combustion air would become carbon dioxide in the flue gas, so the volume of  $CO_2$  would be 21%. Adding excess air will cause oxygen to be present in the flue gas and quantity of  $CO_2$  will be reduced because of dilution by the extra oxygen and nitrogen.

In fact,

$$\text{Excess air} = (\text{Theoretical CO}_2 \% / \text{Actual CO}_2 \%) - 1$$

The theoretical CO<sub>2</sub> is the value obtained when the fuel is burned completely without excess air.

Approximate theoretical values of CO<sub>2</sub> for various fuel.

Bituminous Coal	18.6%
Fuel Oil	15.3%
Natural gas	11.8%

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So , if coal is burned with 15% CO<sub>2</sub> , then the excess air Quantity will be:

$$\frac{18.6}{15.0} - 1 = 0.24 \text{ or } 24\%$$

Fuels containing hydrogen or hydrocarbon gases have a lower theoretical CO<sub>2</sub> % than carbon. This is because the oxygen supplied to burn the hydrogen forms water, leaving the nitrogen to dilute the flue gases formed from the carbon.

So it is a standard practice to **use zirconia oxygen analysers (as mentioned under answer of Qustion No. C of this paper) instead of CO<sub>2</sub> instruments**, with the considerable advantage that there is no necessity to withdraw a gas sample from the boiler for analysis. Instead, the zirconia probe operates by direct insertion into gas stream, and its electrical output is a function of the Oxygen in the stack gas.

**BOILER EFFICIENCY = 100 – VARIOUS HEAT LOSS**

Following are various controllable 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. Heat Credit due to Mill, Primary Fan And Forced Draught Fan
- Out of the various losses, the two concerned losses for the related topic will be considered.

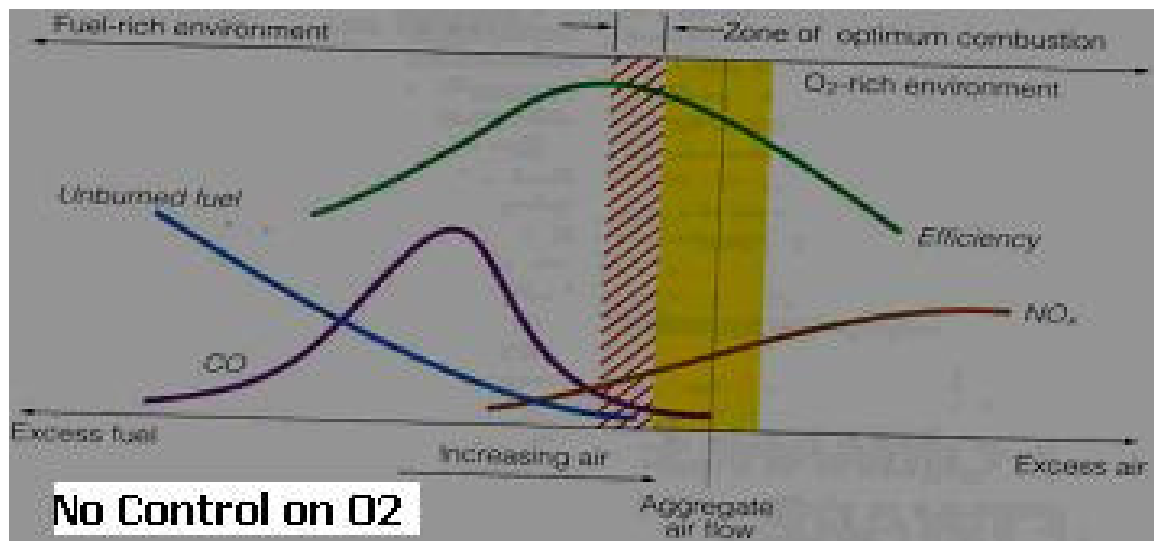
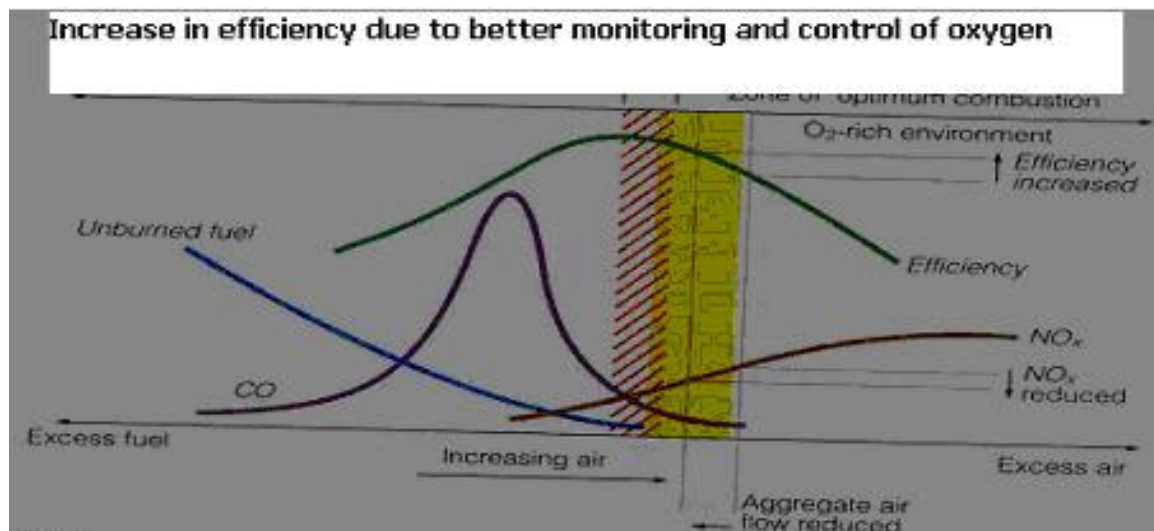
If the temperature is assumed to be constant, the Dry Flue gas loss will increase with the increase in excess air, as the total mass of stack gas increases.

On the other hand, if the excess air is less than the required quantity, there will be

### Unburnt Gas Loss Due To Carbon Monoxide (Incomplete Combustion)

Loss due to incomplete combustion =  $\left(\frac{C}{100} - C_{inAsh}\right) \times \frac{7}{3} \times \frac{CO}{CO_2 + CO} \times 23620$  kJ/kg of Coal. (23620 kJ/kg is the calorific value of CO) which will lead to more fuel consumption for the same boiler output

The effect of tight and efficient Oxygen monitoring and control on boiler efficiency (hence fuel consumption) is very well reflected in the given graphical representation



Hence we can conclude that measurement of Carbon dioxide in the stack gas will not take us to any conclusion instantaneously. On the other hand, the measurement of oxygen and Carbon monoxide will immediately lead us to conclude the behaviour of combustion. If the behaviour of the combustion process is known immediately, it will give the operator a bigger hand in controlling the combustion with the best optimisation of both the values of Oxygen and carbon monoxide.

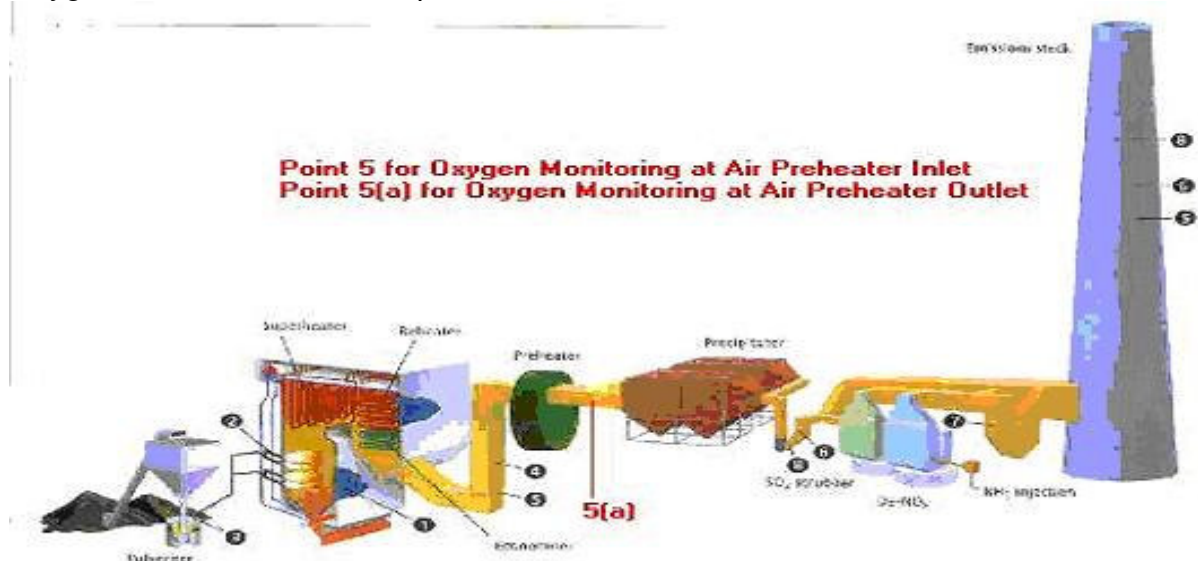
**The best solution is to measure O<sub>2</sub> and CO in the Stack gas as compared to CO<sub>2</sub>.**

**Q.No. C Where would you place the O<sub>2</sub> sensor and why do you select this location.?**

## **OXYGEN IN STACK GAS**

### **C.1 Common Monitoring Point for O<sub>2</sub> and its Control**

Generally the main points of measurement are Exit of Economiser and inlet of Air Preheater for O<sub>2</sub>  
Oxygen measurement at Air preheater Inlet and Outlet.



Economiser oxygen (O<sub>2</sub>) (and Carbon monoxide levels (at ID fan outlet)) is measured using sampling probes at the economizer exit. The gas temperature at the economizer is low enough, and the conditions benign enough, to make accurate measurements. The measured levels can be looped back into the combustion control system. If CO levels are having a rising trend, for example, then the excess air in the boiler is increased by adjusting the secondary air damper.

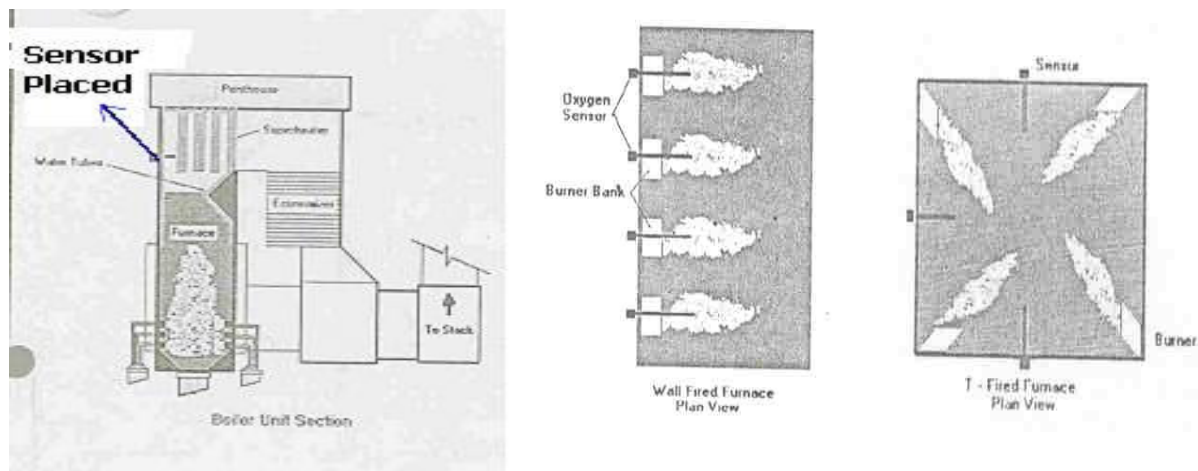
Oxygen Measurement at the Air Preheater Outlet alone do not reflect the excess air in the Boiler. So this point of measurement for controlling the combustion is of no meaning. However, there is a requirement of Measurement of oxygen at Air preheater outlet also, as this will reflect the leakages through the seals of APH from the airside to the gas side. If the difference of Oxygen at inlet and Outlet is more than the permissible value, then it will be reflected through the loading of Fans, which will indirectly contribute towards the losses, ultimately leading to More Fuel Combustion.

## C2. BEST or Recommended Monitoring Point for O<sub>2</sub> and its Control

Normally, Furnace O<sub>2</sub> level is measured periodically if there is suspicion of a flame impingement problem in the boiler. However, generally there is no online measurement of furnace O<sub>2</sub> level made, due principally to the aggressive gas conditions.

With the most utility units, excess air control is achieved by determining O<sub>2</sub> levels at the economizer outlet. Since the units are normally run under negative furnace draft, air can infiltrate through leaks in the boilers, ductwork, or expansion joints. This air in-leakage can result in a bias in the excess O<sub>2</sub> control circuit, giving indication of sufficient O<sub>2</sub> when, in fact, the opposite condition may be true. Enough air infiltration can lead to improper air to fuel ratios, poor combustion, and corrosive damage if a reducing atmosphere prevails.

Therefore the sensor **should be located** in the furnace where the combustion is complete. The locations preferred are in the superheater section of the boiler. Proper installation of the sensor will insure its performance. By using multiple sensors in the combustion zone, operations will be able to divide the boiler in to zones for burner balancing and tuning. This will pin point problem areas in the furnace and help to eliminate hot spots that cause tube failures. The big advantage in Tangential-fired units is the ability to center the fireball. Continuous oxygen monitoring will improve efficiency and reduce the possibility of unnecessary fuel consumption.



## Case Study

### High Temperature O<sub>2</sub> measurement improves Boiler performance

Organisation: North Indiana Public service Company (Nipsco)- Unit No 7 & 8  
(Reference- Power Magazine)

**The problem.** Unit 7 & 8 are Babcock & Wilcox Co (Barberton, Ohio) coal fire steam generators with Cyclone burners. Unit 7 is a 175-MW drum boiler, Unit 8 a 340-MW once through boiler. As with most utility units, excess-air control was achieved by determining O<sub>2</sub> levels at the economizer outlet. Since both units are normally run under negative furnace draft. Air can infiltrate through leaks in the boilers, ductwork, or expansion joints. This air in-leakage can result in a bias in the excess-O<sub>2</sub> control circuit, giving indication of sufficient O<sub>2</sub> when, in fact, the opposite condition may be true.

Enough air infiltration can lead to improper air-to-fuel ratios, poor combustion and corrosive damage if a reducing atmosphere prevails. Also, the O<sub>2</sub> probes and analyzers on unit 7 & 8 became increasingly unreliable. Repairs to maintain the economizer –outlet system had become excessive and costly. The result? The O<sub>2</sub> control system often operated with one or more probes out of service, making it more difficult for the operators to monitor and maintain excess-O<sub>2</sub> levels, which led to a lack of confidence in the system.

To solve the problem of biased excess air readings, Nipsco started experimenting with the permanently installed high-temperature O<sub>2</sub> probes in the upper furnace of unit 7. These criteria were established as a basis for purchase of new system:

- Low maintenance requirements.
- Continuous operation in the furnace section of boiler.
- Improved probe life with a one-year minimum desired.

A system that appeared to meet criteria was a zirconium oxide cell mounted in a silicon carbide tube. This type of probe had seen service in the glass and steel industries, but not in utilities. The probe is said to offer several advantages:

- High temperature operation, from 1200F to 2900F.
- Fast response.
- No sensor calibration required & No heater calibration or failure.

**Probe Operation:** The high temperature capability of the new O<sub>2</sub> probes allows their permanent installation in a area of the furnace other than economizer outlet. The high temperature is exposed to reference gas (instrument air) on one side of the cell, process gas on the other. Zirconia oxide cells behave as solid-state electrolyte at high temperatures in the presence of a catalyst. Under isothermal conditions, and when O<sub>2</sub> partial pressures differ on either side of the cell, an emf inversely proportional to O<sub>2</sub> content in the process gas is developed.

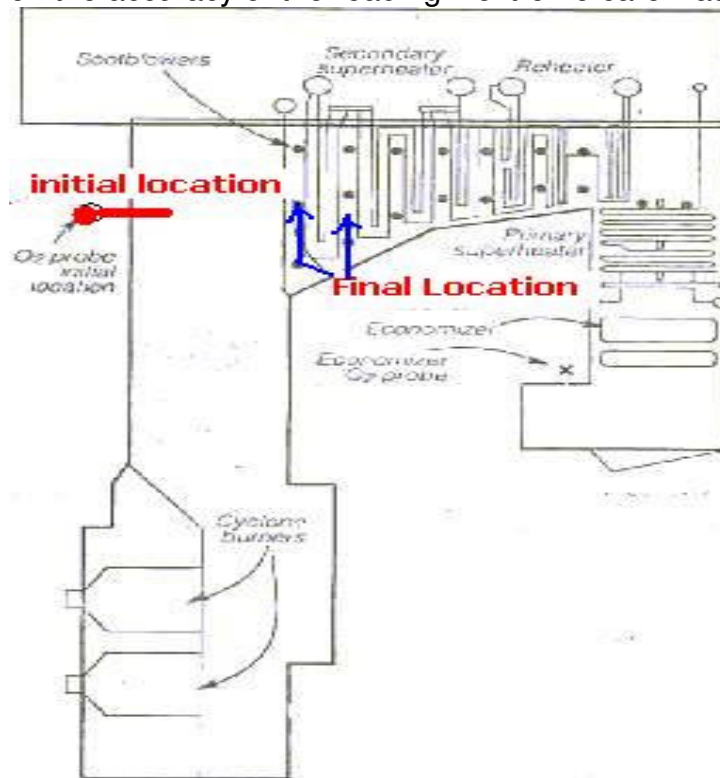
Proper functioning of the zirconia oxide cell is achieved above a minimum recommended temperature of 1100F. Because the old probes (also zirconium oxide cells) had to operate at temperature of 850F or less at the economizer outlet, a

heater assembly and temperature controller were required to maintain cell temperatures greater than 1100F. Since heaters aren't required with the new high temperature probes, calibration requirements are eliminated.

**Probes testing :** At unit 7, two high- temperature O<sub>2</sub> probes were initially installed in the inspection ports on the front wall of the furnace with a monitor for each installed at an elevation 88ft below the probes in the burner control cabinet room. Although performance was satisfactory at the first, two months later one of the probes failed, breaking of at a point beyond the inside of the front wall tubes. It was decided that excessive amounts of slag collection on the probes had caused the failure, rather than stress caused by constant vibration experienced at this location.

The next step was to install a probe with a stainless steel protection tube, instead of the standard silicon carbide tube, to see if it could better withstand the extreme conditions in the furnace. After only three days of operation this probe failed-an excessive amount of the slag had accumulated on its tip. The other probe failed after four months of continuous operation. The cause again appeared to be from slag.

Since probe performance otherwise was satisfactory, an outer protection tube was added to increase longevity. The longest achievable run with this added protection was only a probe life of the three months. The outer tube also had an adverse effect on the accuracy of the reading if extreme care was not taken in its installation.



#### Improved final Location

Obviously, the location of the probes had to be changed. At the front wall of the furnace, operation was completely unpredictable, rendering the probes unsuitable for use in an automatic control system. A location in Unit 7 that could greatly improve the service life of the high temperature O<sub>2</sub> probes appeared to be in the superheater area of the boiler convection pass. Rather than being exposed to harsh environmental conditions in the open area of the furnace, the probes would have maximum protection with the secondary pendant tubes. Consequently four O<sub>2</sub> probes were installed in the secondary superheater section of the furnace – 2 in each wall side.

A potential risk in putting them there was they would be close to sootblowers. After the probes were in service, the soot blower nearest each probe was operated. It was found that soot blower operation would not damage the probes. The O<sub>2</sub> system could now be monitored to evaluate the performance and longevity of the probes.

The bottom line: Initial trial on Unit 7's high temperature O<sub>2</sub> system show that the probes have good potential for application to utility boilers. The knowledge gained from this trial was put to good advantage when a high temperature O<sub>2</sub> system for unit 8 was installed; including four probes in the pendant reheat area of the convection pass. After continuous operation for over a year, none of Unit 8's probes have failed.

**Results to date have shown differences of O<sub>2</sub> measurements taken at economiser of 0.4% to 2.5% when compared to the high temperature probe readings. Probe performance has been so successful that the economiser O<sub>2</sub> system will be phased out at Nipsco. Also, operator confidence in O<sub>2</sub> measurement of Stack gas has been restored.**

## References

Power Magazine  
O&M manual  
CEGB Manual  
Literature of Oxygen sensor

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## Brief about High Temperature O<sub>2</sub> Sensors

Although, with the development in technology, now it is feasible to monitor oxygen percentage in the Combustion chamber, close to the source of combustion. One of these sensors comes with a brand name of OXYFIRE



**OxyFire Sensors:** Typically used in a coal-fired power boiler, the high temperature, in-situ oxygen sensor is generally installed in the boiler water-wall, above the nose arch and above each of the burner banks. This configuration allows the boiler operators to center the fireball in the radiant zone and "balance" the boiler.

Typically installed above the slag line, the sensors give the boiler operators a unique perspective on the combustion process, eliminating the typical "air infiltration" that confuses "low temperature" sensors located in the back pass.

Benefits from using Marathon Sensors' Combustion Optimization System to "trim" the draft are:

**Balanced boiler - Centering the fireball  
Reduces over-all maintenance costs**

**Providing the operators with this type of information allows them to do their job more efficiently, eliminates CO (carbon monoxide) pockets, and helps in achieving "lowest cost" megawatts.**

This in-situ oxygen sensor measures oxygen concentrations directly in the "high heat" zones of high temperature furnaces, boilers and incinerators. They are intrinsically safe, requiring no electrical input power, and generating only a low millivolt output.

**The main features and Performance advantages are:**

- Available in a number of standard lengths up to 48" (1200 mm)
- Field performance can be easily verified using integral calibration gas port
- "B", "S", and "R" thermocouples are available
- Alumina, Silicon Carbide, HR160 Alloy and Zirconia protection sheaths are available
- **CE Marked and TUV Certified**
- **Intrinsically Safe** per EN50 014 (1977) clause 1.3
- Temperature Range: 1200 °F to 3000 °F (649-1648 °C)
- Robust design eliminates "auxiliary sheaths" required on lower quality products
- Proven track record: used in more furnaces, boilers and incinerators than all other high-temp probes combined.
- No drift or accuracy problems common to "side hole" probes.
- High quality construction eliminates the need for cooling air - one more failure point in low-end designs
- Patented "boot" provides fast response while protecting the outer electrode and preventing the accuracy problems that plague foil-based electrodes.
- Proprietary, application-specific installation configurations maximize life and accuracy in high-slag environments

- Machined 6061T6 aluminum head provides air tight enclosure for electrical connections
- Classified configurations available

### Comparison of Sampling type sensors with High temperature sensors.

There are two major types of oxygen analysers, being used in the power industry.

#### Sampling type ( extractive)

#### Low/high temperature in-situ sensors.

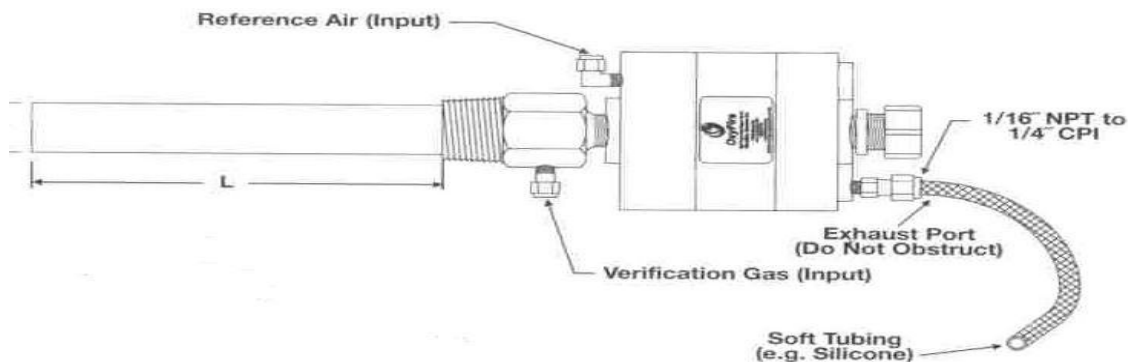
But the excessive maintenance limits the usefulness and reliability of the extractive units. Heaters, pumps, sample lines, and cells require continuous attention. Regular calibration services are a must. The filter system of the pumps must be cleaned periodically due to moisture and ash in the hot gases.

The low temperature in-situ unit is a direct reading sensor without pumps and sample lines. Temperature limitations of the sensor require that it be installed in an area downstream from the combustion zones. Then the measurement includes the combustion oxygen plus all air in leakage in the ductwork. This does not allow the accuracy required for very efficient tight control. Maintenance is also required because of heaters and regular calibration services.

The **High Temperature** in situ sensors do not require pumps, heaters, filter system, calibration, etc..

These sensors help in maximizing Combustion efficiency and reduce Fuel Cost. They provide dependable and verifiable oxygen measurement in the fossil fuel fired environment found in most steel, glass, power generation, petrochem and petroleum refining, as well as kilns and incinerator applications. As these sensors are operating close to the source of combustion, response to combustion atmosphere change is instant and precise and there is no need for the compensation of an extractive or heated system.

#### Operation of the sensor.



This sensor works by precisely measuring the net concentration of oxygen in a process; i.e. the amount of oxygen that remains after the combustion is completed. At its core is the platinum coated zirconia cell, which measures the emf potential in mill volts, that is generated by the diffusion across the cell wall, and is logarithmically proportional to the oxygen concentration. Also there is the required “B” type (or R and S type) thermocouple, which provides the sensor temperature needed for O<sub>2</sub> calculations.

The voltage produced also depends on the temperature at which the sensor operates (furnace gas temperature). It is calculated by [Nernst Equation](#)

$$E = 0.0215 \times T \times \ln \frac{\text{Oxygen}_{(reference)}}{\text{Oxygen}_{(process)}}, \text{ where}$$

E = Sensor output in mill volts

T = Sensor temperature in degrees Kelvin

O<sub>2 (reference)</sub> = Oxygen concentration on the inside surface of the sensor – typically ambient air

O<sub>2 (process)</sub> = Oxygen concentration on the outside surface of the sensor – furnace atmosphere.

With a known percentage of oxygen (reference air) on one side of the cell, the voltage (mV) generated will be proportional to the concentration (% to PPM) of oxygen on the opposite side (furnace atmosphere or other process gas). A thermocouple built into the probe provides an output, which is proportional to the temperature of the cell. The cell typically uses ambient air, which contains 20.9% oxygen as reference gas. When the reference gas composition is constant and the temperature of the cell is known, the oxygen level in the furnace atmosphere or the process gas can be determined by solving the Nerst equation manually or in the instrument itself.

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