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Introduction:

A Boiler or a Heater is a device that extracts energy in the form of heat from Fuel through a combustion process. There are three types of Heaters a) Natural draft b) Forced Draft and c) Balanced draft. In the Natural draft heater the combustion air is drawn into the furnace by natural convection and therefore little control on Air/Fuel ratio. In the forced draft furnaces, air is supplied by a blower and suitable control devices control the combustion air. In the balanced draft heaters even though the combustion air is controlled the induced draft in the post firing stage needs a better management to control the air ingress into the heater. In all the cases it is a Herculean task to measure and control the air, which is required for the combustion.

Same way controlling the stack temperature to the minimum possible extent without initiating low temperature corrosion is an issue, which requires clear understanding. Both these problems are addressed in this paper with an attempt to clarify how to control and improve the heater efficiency.

Efficiency:

The calculation of combustion efficiency is based upon three factors:

1. Chemistry of fuel
2. Net temperature of stack gases
3. The percentage of O2 or CO2 in the stack gases.

Eyeballing the flame for color, smoke and shape is not sufficient to maximize the efficiency.

The efficiency of any system is normally measured by ratio of useful work done to the energy spent. However in the combustion system the efficiency is calculated by subtracting the flue gas losses from 100% or maximum efficiency. The reason being the issues related to the accuracy of measuring devices like Flow, temperature and velocity. This is further getting complicated when different type of fuel is handled. The quality of fuel is worsening with the advancement in the refining technology. The quality of fuel is not consistent. The most commonly used fuel in India is Furnace oil. The Cadrason carbon

Residue content varies from 6 to as high as 13% in the furnace oil. Also integration of operating unit with the heaters to utilize the waste streams generated in the process open up the avenue for using multi fuel of varying heating value.

As it is impossible to keep a track on all the above factors, the efficiency of Boiler or Heaters is calculated based on indirect method by measuring O2 in the stack and Stack temperature.

Which is the best way to measure Excess Air?

For any process to achieve the completion one reactant should be in excess. The same is applicable to combustion process. The Air is supplied in excess to the fuel to complete the combustion process. Now the question comes how much excess? Whenever we say excess, it should be at optimum level. This optimum will vary depending on the system design, operational methods and the type of fuel handled.

Combustion is the release of energy in the form of heat through the process of oxidation. The energy is stored in the bonds of the carbon-based fuel that are broken down during combustion. The goal is to maximize the heat and that can happen when the combustion process is tightly controlled.

<u>Complete combustion</u>

Carbon + Hydrogen + Oxygen + Nitrogen → Water + CO2 + Nitrogen

<u>Incomplete Combustion</u>

Carbon + Hydrogen + Oxygen + Nitrogen → Soot+ Water + CO2 + CO+ Nitrogen

Perfect combustion is the process of burning fuel without excess combustion air. This process should develop the "*Ultimate CO2*" amounts in the combustion process.

Ultimate CO2 values

Fuel	CO2 max
Natural gas	11.70%
Propane	13.70%
Fuel oil # 2	15.70%
Fuel oil # 5	16.30%
Bituminous Coal	18.50%
Anthracite	19.90%
Coke	20.60%

You may note that the “Ultimate CO2 value” varies depending on the type of fuel used. This due to varying carbon content in the Fuel. However the practical CO2 values in the Flue gas are found to be much less than these numbers depending on the amount of Excess Air.

With 20% excess air the CO2 values in the flue gas for different fuel are:

Fuel	CO2
Natural gas	10.50%
Propane	11.50%
Fuel oil # 2	12.00%
Fuel oil # 5	13.00%

As the excess air supplied to achieve the complete combustion dilutes the CO2 level in the flue gas, gives us no idea whether the combustion is complete when you compare them with ultimate CO2 values. If at all we consider controlling the excess air by measuring CO2 in the flue gas, it needs to be supplemented with measurement of Carbon monoxide (CO). We need to have two different sensors for measuring CO and CO2 in the flue gas.

Figure 1 illustrates, the same CO2 reading can be obtained on both sides of stochiometric mixture. Carbon dioxide alone cannot define proper excess air operation of fuels. A check also must be made for the presence of oxygen, which confirms operation with excess air.

The flue gas also to be checked for presence of Carbon monoxide (CO).

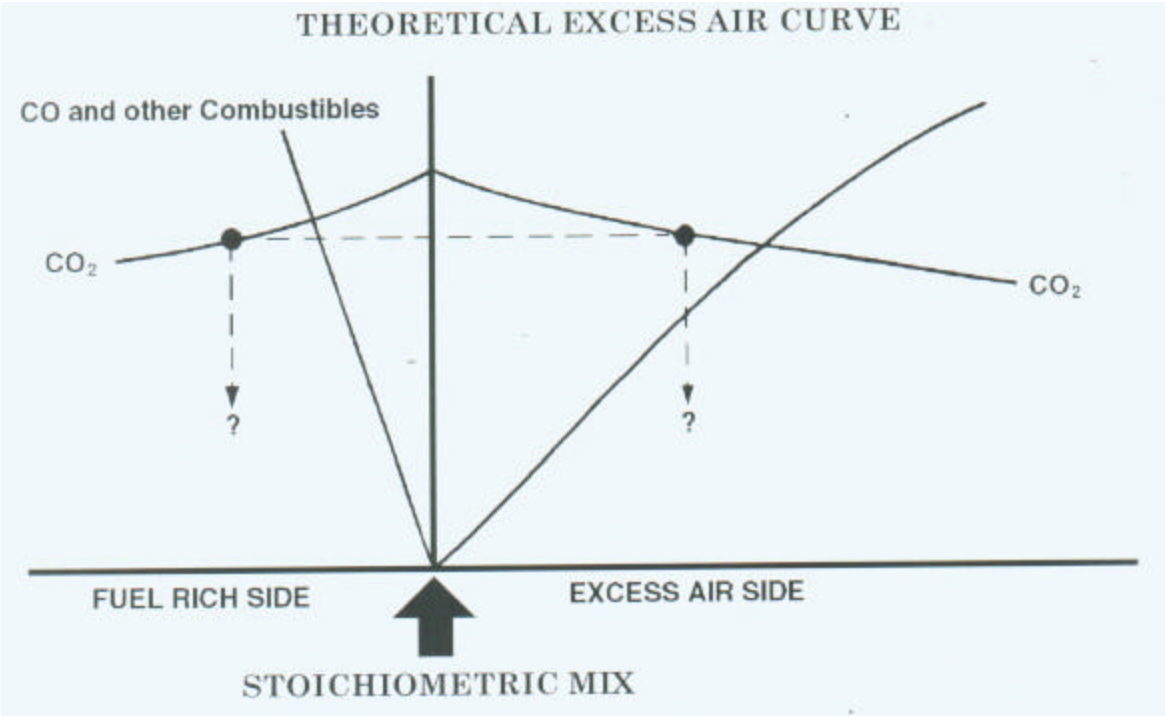


Figure 1

The natural gas has methane and along with inert gases such as Nitrogen and CO2. The CO2 content also varies with the source. Hence when the natural gas is used as fuel the CO2 in the natural gas also will end up in the stack indicating high CO2. This will totally mislead the operating personnel.

In normal operation we donot check the carbon content of fuel. As the fuel quality is also not consistent it is impossible to operate based ultimate CO2 values. As discussed earlier the modern units are utilizing all the wastes generated in the process as fuel. When multi fuels are used we are not sure on the maximum CO2 content what we should have in the stack.

For these good reasons, it is normally not recommended to use CO2 analyzer to limit the excess air.

The Oxygen measured in the flue gas is the direct measure of excess air. However it is not that simple as the air ingress at the point of measurement may totally mislead. A leak proof Oxygen analyzer installed in the heater will overcome this problem. A properly maintained oxygen analyzer is the best way to measure the Excess air in the Heaters or Boilers.

Where to measure the Oxygen?

There are two types of air entry into the system:

1. The Combustion air supplied to the burners
2. The air ingress into the system through the inspection doors, Inlet/outlet pipe entry points, the leaking auxiliary systems such as air pre-heater etc.

The air supplied in excess for complete combustion escapes through the chamber of the heater or boiler. Some of the combustion takes place after the burner at high radiation temperature. The carbon burning takes place as long as the temperature is > 600 C. The combustion process terminates when the gas gets cooled around this temperature. This will be the point to measure the oxygen, which is escaping in the flue gas. The end of the combustion chamber in case of boiler and top of Radiation section in heater are the ideal locations. They are normally operated at a temperature of 600 C to 900 C. Subsequent to this section normally heat recovery systems are added where mechanical opening are kept for inspection purpose. Air ingress is cannot be not avoided at these locations. Any leak in air tubes of air pre-heater or the convection section entry and exit point of heaters is the potential points for air ingress. Measuring Oxygen at these locations may show very high Oxygen, which will totally mislead. Hence the Oxygen to be measured at least 6 inches below such mechanical opening in the heater.

However it is to be noted any air ingress in these heat recovery sections also will reduce the overall efficiency of the system as the air at ambient temperature gets heated up to the stack temperature.

Hence measurement of Oxygen to be done as follows:

a. At the end of combustion chamber or the top of ration section (Arch) where the gas temperature is around 600 C. This will indicate the excess combustion air supplied.
b. Measure of Oxygen at the inlet and outlet of every heat recovery systems such as convection; air pre-heaters will indicate the air ingress in to the system.

Where to measure the Stack Temperature?

As highlighted the other source of energy loss is the high temperature flue gas leaving the stack. The minimum the temperature you reach the maximum is the efficiency. What is the possible minimum temperature attainable? The temperature at which, the acid condensation take place. It is called acid dew point. If the stack gas is cooled below the acid dew point then corrosion will occur. The acid dew point changes with respect to sulfur content in the fuel. If the sulfur is high, the acid dew point is high. To avoid corrosion problems we normally operate the stack 10 deg C higher than the acid dew point.

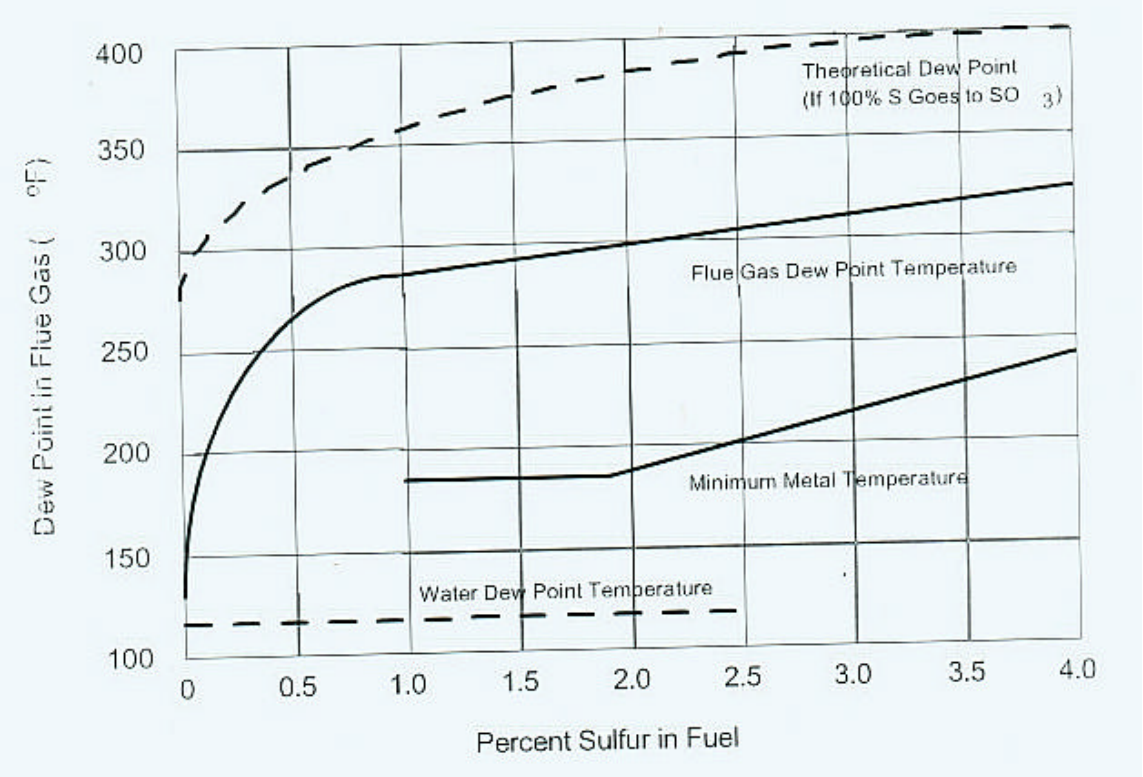
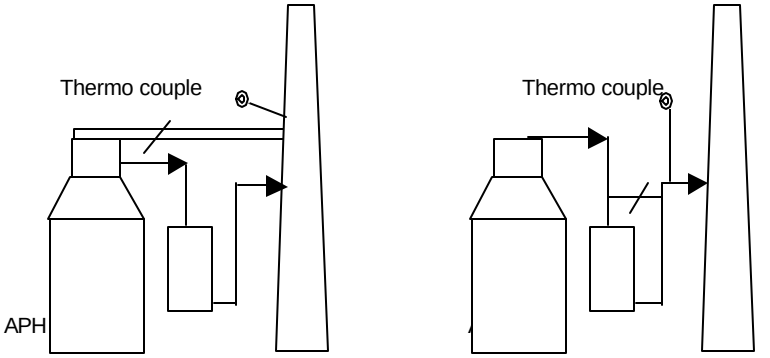


Figure-2

We need to locate the temperature-measuring instrument at right location. Normally the heat recovery systems are normally provided with bypass arrangements to carryout on line maintenance. Such bypass either directly route the hot gas to the stack or at the outlet of heat recovery systems. Depending upon the arrangement, the entry to the stack may be one or two. If the entry to the stack is single, then just the inlet of stack is the coldest point of the system and the temperature measurement to be done at that location. If the stack entry is more than one as detailed below, then the thermo couple should be ideally located in the stack at the downstream of the top most entry



Single Entry Stack **Double Entry Stack**

Figure-3

The idea is in case the bypass damper passes the same can be detected by the temperature measuring device in the stack, which otherwise normally measure the flue gas temperature leaving the heat recovery system.

Conclusion:

As it is complex to understand the chemistry of combustion and it becomes complicated with multiple fuels burning arrangement, the

best way to measure the Excess air is by installing Oxygen analyzer at the end of combustion chamber where the temperature is above 600 C.

The stack temperature is to be measured at the inlet of stack where single duct entry is the arrangement and in the stack at the down stream of top most duct entry where multiple ducts are entering the stack.

Even though the measurement at the above location maximizes the efficiency of the Boiler or Heater, it is essential to keep watch on air ingress at the down stream of combustion section to avoid heat loss to the stack.