THERMOX® Application Note

AMETEK® PROCESS INSTRUMENTS

Process Heaters, Furnaces and Fired Heaters

Improving Efficiency and Reducing NOx

PROCESS OVERVIEW

A process heater is a direct-fired heat exchanger that uses the hot gases of combustion to raise the temperature of a feed flowing through coils of tubes aligned throughout the heater. Depending on the use, these are also called furnaces or fired heaters. Some heaters simply deliver the feed at a predetermined temperature to the next stage of the reaction process; others perform reactions on the feed while it travels through the tubes.

Process heaters are used throughout the hydrocarbon and chemical processing industries in places such as refineries, gas plants, petrochemicals, chemicals and synthetics, olefins, ammonia and fertilizer plants. Some plants may have only two or three heaters while larger plants can have more than fifty.

Most of the unit operations in these plants require fired heaters and furnaces. These operations include:

- Distillation
- Fluidized Catalytic Cracking (FCC)
- Alkylation
- Catalytic Reforming
- Continuous Catalyst Regeneration (CCR)
- Thermal Cracking
- Coking
- Hydrocracking

Figure 1. Process Heaters

Typical process heaters can be summarized as follows:

- Start-Up Heater — Starts-up a process unit where it is required to heat up a fluidized bed of catalyst before adding the charge.
- Fired Reboiler — Provides heat input to a distillation column by heating the column bottoms and vaporizing a portion of it. Used where heat requirement is greater than can be obtained from steam.
- Cracking Furnace — Converts larger molecules into smaller molecules, usually with a catalyst (pyrolysis furnace).
- Process Heater — Brings feed to the required temperature for the next reaction stage.
- Process Heater Vaporizer — Used to heat and partially vaporize a charge prior to distillation.
- Crude Oil Heater — Heats crude oil prior to distillation.
- Reformer Furnace — Chemical conversion by adding steam and feed with catalyst.

Many refineries use light ends (e.g. refinery gas) from the crude units and reformers as well as waste gases for heater fuel. Natural gas is often blended with waste gas and the other off-gases as the primary fuel for heater processes. Residual fuels such as tar, pitch, and Bunker C (heavy oil) are also widely used.

The process heater shown below is a natural draft unit with inspiration type burners. Combustion air flow is regulated by positioning the stack damper. Fuel to the burners is regulated from exit feed temperature and firing rate is determined by the level of production desired.

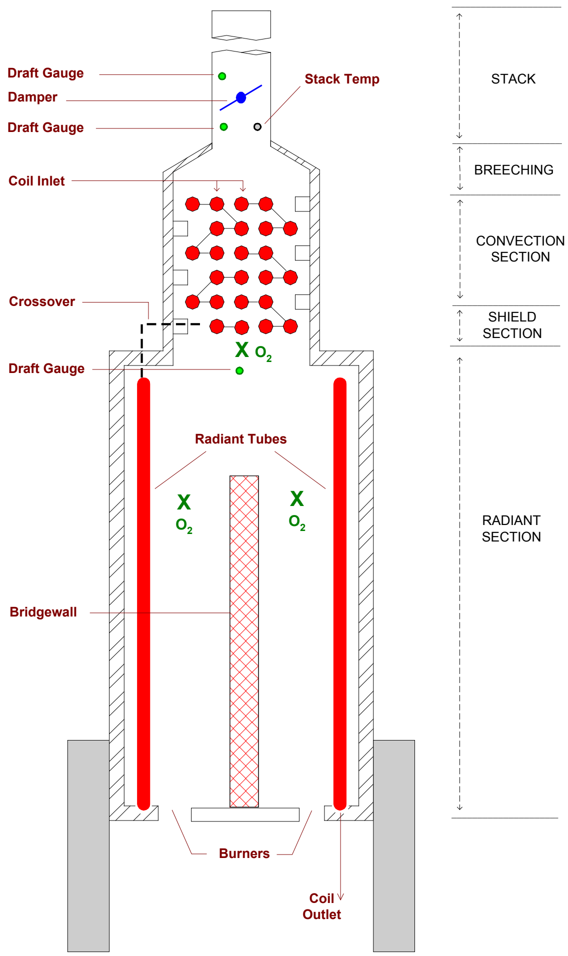
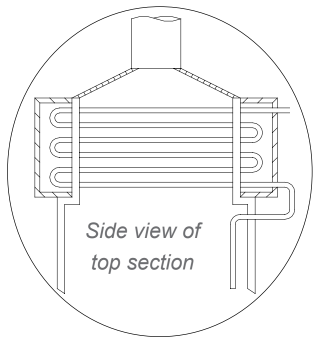


Figure 2. Sections of a process heater.

Radiant Section

The radiant tubes, either horizontal or vertical, are located along the walls in the radiant section of the heater and receive radiant heat direct from the burners. The radiant zone with its refractory lining is the costliest part of the heater and 85% of the heat should be gained there. This is also called the firebox.



Convection Section

Rather than hit the radiant section directly, the feed charge enters the coil inlet in the convection section where it is preheated before transferring to the radiant tubes. The convection section removes heat from the flue gas to preheat the contents of the tubes and significantly reduces the temperature of the flue gas exiting the stack. Too much heat picked up in the convection section is a sign of too much draft. Tube temperature is measured in both convection and radiant sections.

Shield Section

Just below the convection section is the shield (or shocktube) section, containing rows of tubing which shield the convection tubes from the direct radiant heat. Several important measurements are normally made just below the shield section. The bridgewall or breakwall temperature is the temperature of the flue gas after the radiant heat is removed by the radiant tubes and before it hits the convection section.

Measurement of the draft at this point is also very important since this determines how well the heater is set up. Excess draft, either positive pressure or negative pressure, can lead to serious problems.

This is also the ideal place for flue gas oxygen and ppm combustibles measurement.

Breeching Sections and Stack

The transition from the convection section to the stack is called the breeching. By the time the flue gas exits to the stack, most of the heat should be recovered and the temperature is much less. From a measurement point of view, this location places fewer demands on the analyzer but is much less desirable for the ability to control the process. Measurement of stack emissions for compliance purposes is normally made here.

The performance objectives of process heaters are similar to those of other process units:

- Maximize heat delivery of the process-side feed while minimizing fuel consumption.
- Maximize heat delivery with varying fuel quality.
- Minimize heater structural wear caused by operation.
- Minimize stack emissions (heat, CO, NOx).
- Maximize safety integrity levels.

Proper monitoring and control brings benefits and avoids problems in the following areas of heater operation:

Energy Savings

All process heaters consume large amounts of fuel to produce the necessary heat that must be transferred to the material brought into the furnace.

Energy costs represent up to 65% of the cost of running a chemical/ petrochemical/refining complex. Furnace and heater fuel is the largest component of this cost. In the past, there was little reason to seek efficiency improvements as waste fuel was cheap and the excess was often flared. Today many of the refinery processes require hydrogen, and a lot of the hydrogen-rich off-gases, which were previously used as heater fuel, are now needed to meet this demand. Natural gas, which is very expensive, is used to make up shortfalls. Therefore the more energy that can be squeezed from existing plant fuels, the less supplementary natural gas is required.

Correct use of gas analyzers can conserve the amount of fuel used and maximizes heater efficiency.

NOx Reduction

A significant fraction of NOx produced annually can be attributed to the chemical/ refining industry and stringent emission limits require greater control of NOx and other stack components. Operating the heater at optimum efficiency, with low excess air firing using oxygen and ppm combustibles, is the simplest and least expensive way to reduce NOx emissions.

Product Quality

Temperature control of the process tubes and reactions is critical in reforming and cracking operations.

Since flaring is no longer permitted, gases with widely varying calorific content are now used as fuel for the heaters. This leads to large variations in heat delivered in the radiant section, and therefore, to greater demands on control of the product or feed temperature.

Safety

No information or incorrect information from a poorly placed analyzer can lead to unsafe operation of heaters from air leaks, tube leaks, and fuel or burner problems. Purge-down and light-off cycles require special care and warrant methane monitoring in addition to oxygen and ppm combustibles.

Heater and Tube Life

Incorrect operation leads to premature failure, structural damage or tube leaks due to flame impingement, secondary combustion and flue gas leaks.

FACTORS AFFECTING PROCESS HEATER OPERATION

Process heaters offer particular challenges for measurement and control due to:

- High temperature in the radiant zone where measurement is desired.
- Multiple burners.
- Multiple radiant zones (cells).
- Widely varying fuel calorific value.
- Low investment in heater optimization.

A review of the factors affecting process heater performance will be useful . This includes draft, burner operation, combustion efficiency and NOx production.

For optimum operation, excess oxygen in the flue gas entering the convection section should be minimized and there should be a very small negative pressure at the convection section inlet.

Correct Draft

Refer to Figure 3. Stack dampers and secondary air registers affect the draft and both adjustments are related. The hot gas pushes so that the pressure is always greatest at the firewall. The stack draft pulls and when correctly balanced the pressure at the bridgewall should be close to zero or very slightly negative.

A process heater operating properly will also have a zero, or slightly negative draft, at the shield section. The firebox will be slightly positive (+0.5 to +2.0 “ water column (wc)) and the stack will have a range of -0.5 to -1.0” wc.

Excessive draft, either positive pressure or negative pressure, can lead to severe problems in the convection section.

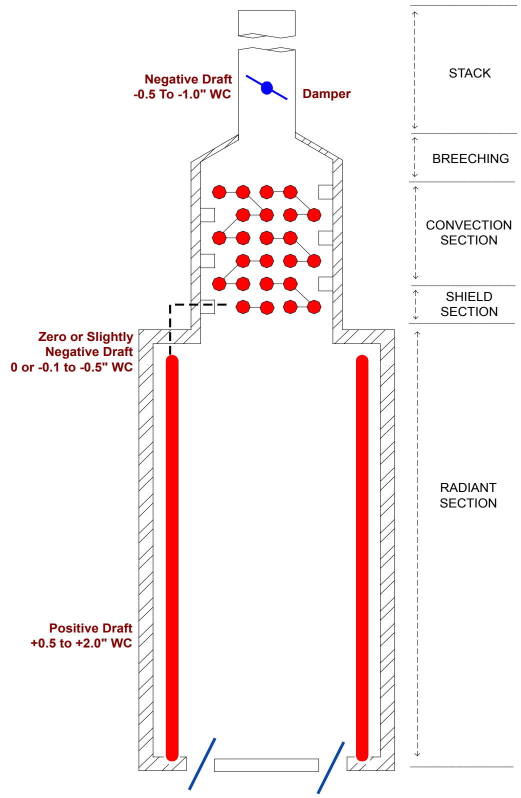


Figure 3. Correct draft

Excessive Draft — Positive Pressure Created

In Figure 4, the air registers are wide open and the damper mostly closed. This generates a positive pressure which forces flue gases outward through leaks in the convection section leading to serious structure damage, as well as heat loss.

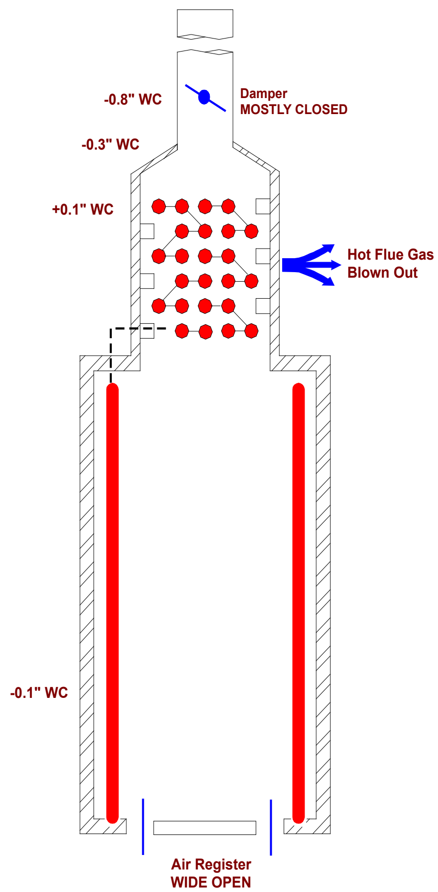


Figure 4. Excessive positive draft

Excessive Draft — Negative Pressure Created

In Figure 5, the air registers are mostly closed and the stack damper is wide open leading to a high negative pressure in the convection section. Cold ambient air is sucked in through leaks in the convection section leading to erroneous oxygen readings, as well as heat loss. In addition the excessive draft causes tall flames which can reach the tubes resulting in serious damage.

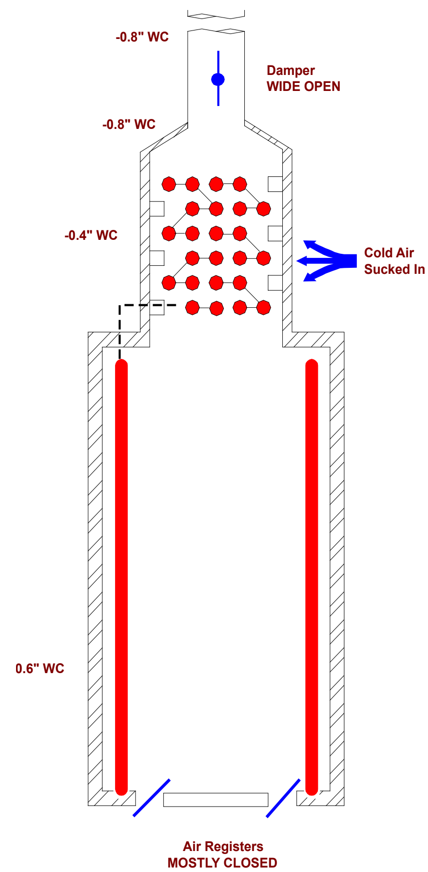
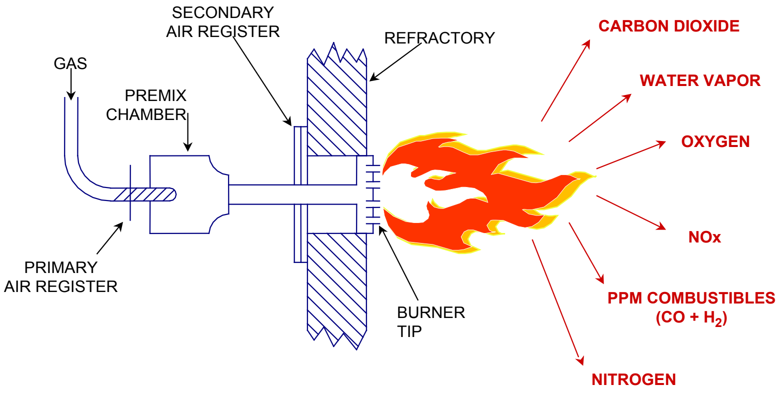


Figure 5. Excessive negative draft

Combustion Efficiency and NOx Reduction

The burners on a process heater premix the fuel with the primary air which is aspirated into the burner by the fuel gas flow (see Figure 6). The primary air flow should be maximized without lifting the flame off the burner. The pressure of the fuel gas supply is important since low gas pressure degrades performance. Most of the air (as primary air) is delivered to the burner along with the fuel. Secondary air is introduced and adjusted with the registers. Too much or too little secondary air gives poor combustion.



CORRECT COMBUSTION AIR

- Good flame length
- Maximum flame temperature

Figure 6. Burner with correct combustion air.

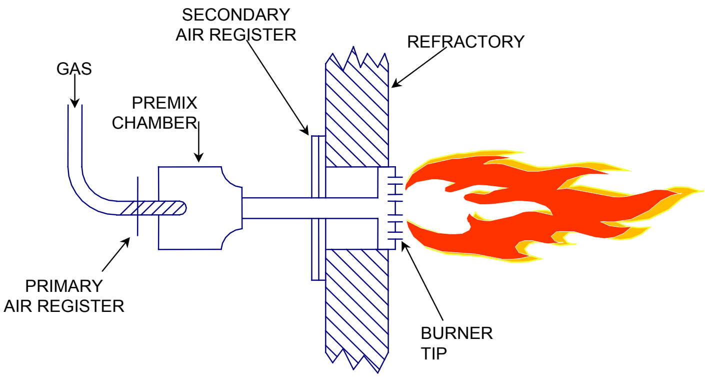
Stoichiometric Combustion

Under ideal conditions, fuel combines with exactly the right amount of oxygen to allow complete combustion. There is no unburned fuel and no excess oxygen. This is called stoichiometric combustion. In the simple case of methane burning in air, this can be written as

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Real combustion applications are more complicated because some excess air is always needed to ensure complete combustion of the fuel. Otherwise, significant amounts of CO are produced, reducing efficiency and increasing pollution levels.

Incomplete combustion occurs when not enough combustion air is supplied to burn all the fuel completely. The large amount of CO and H_2 formed as a result of the incomplete combustion makes the burner extremely inefficient (Figure 7). This reduces the flame temperature and might encourage the operator to increase fuel flow thus making matters worse. This condition may not be noticed because leakage in the convection section can hide insufficient air getting to the burner. Completion of combustion in the convection section results in heater damage.



INSUFFICIENT COMBUSTION AIR

- Long flame
- Cooler temperature
- Very little NOx
- Very inefficient

Figure 7. Burner with insufficient combustion air.

Normally, six to ten thermocouples report the temperature stratification across the radiant section and this temperature profile of the radiant zone is used to determine the burner air/fuel ratio and to balance multiple burners. A visual observation of the flame is used to adjust the flame color and flame height based on the fuel pressure. After checking to see what type of temperature pattern is generated at the bridgewall, the burners can be adjusted accordingly. Once the flame is set correctly, the damper is adjusted for the correct draft. Finally, the secondary air supply is adjusted to give the desired oxygen reading or O_2 setpoint.

When set correctly, and with good air-fuel mixing, the burner will produce the maximum flame temperature in a compact flame. The less secondary air that is needed, the better the efficiency. At optimum efficiency, the flue gas will contain a minimum of oxygen together with levels of combustibles (CO and H_2) in the 100 to 200 ppm range and a minimum of NOx.

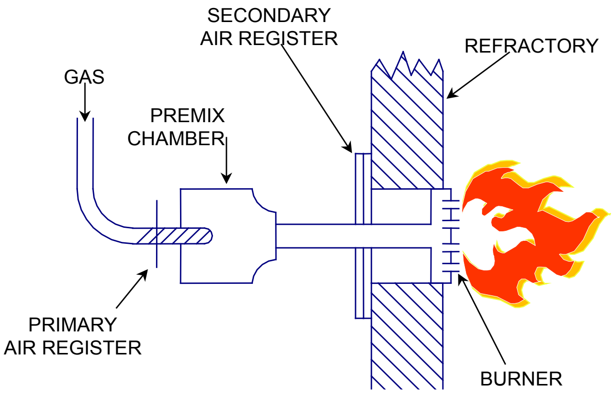


Figure 8. Burner with too much combustion air.

TOO MUCH COMBUSTION AIR

- Short flame
- Cooler temperature
- Wasted heat
- Increased NOx

NOx Production

Too much combustion air reduces flame temperature and drops efficiency (Figure 8). In most applications this is the biggest source of heater inefficiency and NOx production. The high temperature in the flame and radiant section, together with combustion turbulence at the burners, causes dissociation of air molecules. The nitrogen and oxygen atoms combine to form nitric oxide (NO) and nitrogen dioxide (NO_2), together known as NOx. The more combustion air, the more oxygen is available to produce NOx. Conversely the less oxygen the less chance of NOx formation (Figure 9).

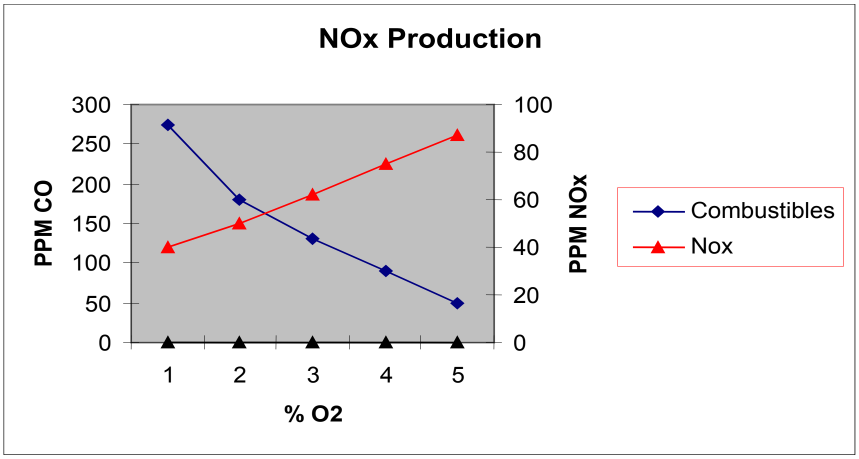


Figure 9. An example showing how NOx production increase with increasing excess air.

The Importance of Oxygen and Combustibles

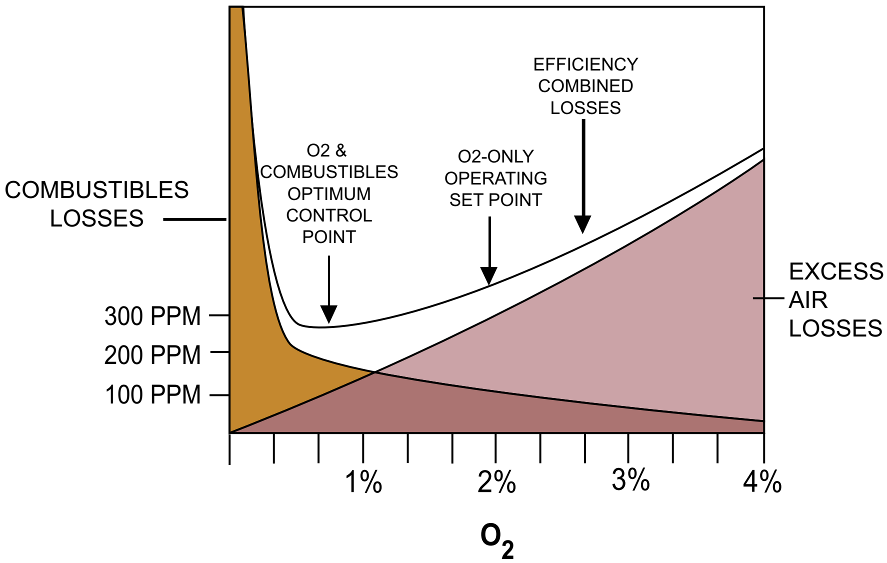


Figure 10. Determining optimum O_2 setpoint.

Reducing the excess air or oxygen to the minimum safe level is the most important step in reducing energy consumption. There is no single O_2 level that is right for all heaters. The optimum oxygen level depends on the load, the burner design, the type of fuel, and the burner performance.

Refer to Figure 10. Reducing oxygen while measuring the ppm combustibles allows the correct operating point to be determined. The actual value will depend on the variables mentioned previously and should be determined for each individual analyzer placement point. Without combustibles, it is not possible to find the optimum setpoint, since you cannot know when to stop reducing the combustion air. With the combustibles detector, the oxygen can be reduced safely until the combustibles starts to increase. This is the correct value for that heater.

Combustibles has always been an important part of our combustion control strategy. Thermox used the term “combustibles” in 1975 to refer to the incomplete products of combustion in flue gas, primarily carbon monoxide and hydrogen. The detector is not designed to measure unburned fuel such as methane. Many operators have previously used percent level combustibles which is good for detecting serious process upsets or for precipitator protection, but has no benefit for optimizing combustion efficiency. For this, a reliable ppm combustibles measurement is needed.

The latest generation of Thermox ppm combustibles detectors, perfected during 20 years of research and development, offers excellent reliability and performance.

It is often thought that the oxygen measurement from a zirconia probe will also indicate when there is insufficient excess air. This is because any combustibles present will burn on the cell and reduce the displayed oxygen accordingly. While this is correct, the drop in oxygen only becomes significant when a major upset occurs. For example, a 2000 ppm (0.2%) level of combustibles or CO in the flue gas will reduce the O_2 value by only 0.1%. A drop in oxygen from 3.0 to 2.9% will not be treated as significant by an operator. A reading of 2000 ppm on the combustibles detector at the same time would certainly be noticed, and acted upon.

Why CO Measurement is Not Sufficient

Although AMETEK does offer an infrared CO analyzer, a CO specific measurement is not a good choice for process heaters for a number of reasons.

1. Refinery fuel gases and other fuels used for process heaters have a varying H_2 concentration and that is a critical component that must measured to achieve good heater efficiency.
2. The temperature limitations on infrared CO analyzers require installation after the convection section or in the stack. Improper burning or poor fuel quality can cause afterburning in the convection section which leads to convection tube bundle plugging and tube overheating. The IR analyzer mounted in the stack reading only CO will not pick this up.
3. The response time of an extractive CO analyzer on a sampling system is too slow.

Analyzer location issues are discussed in more detail in the following sections.

Location

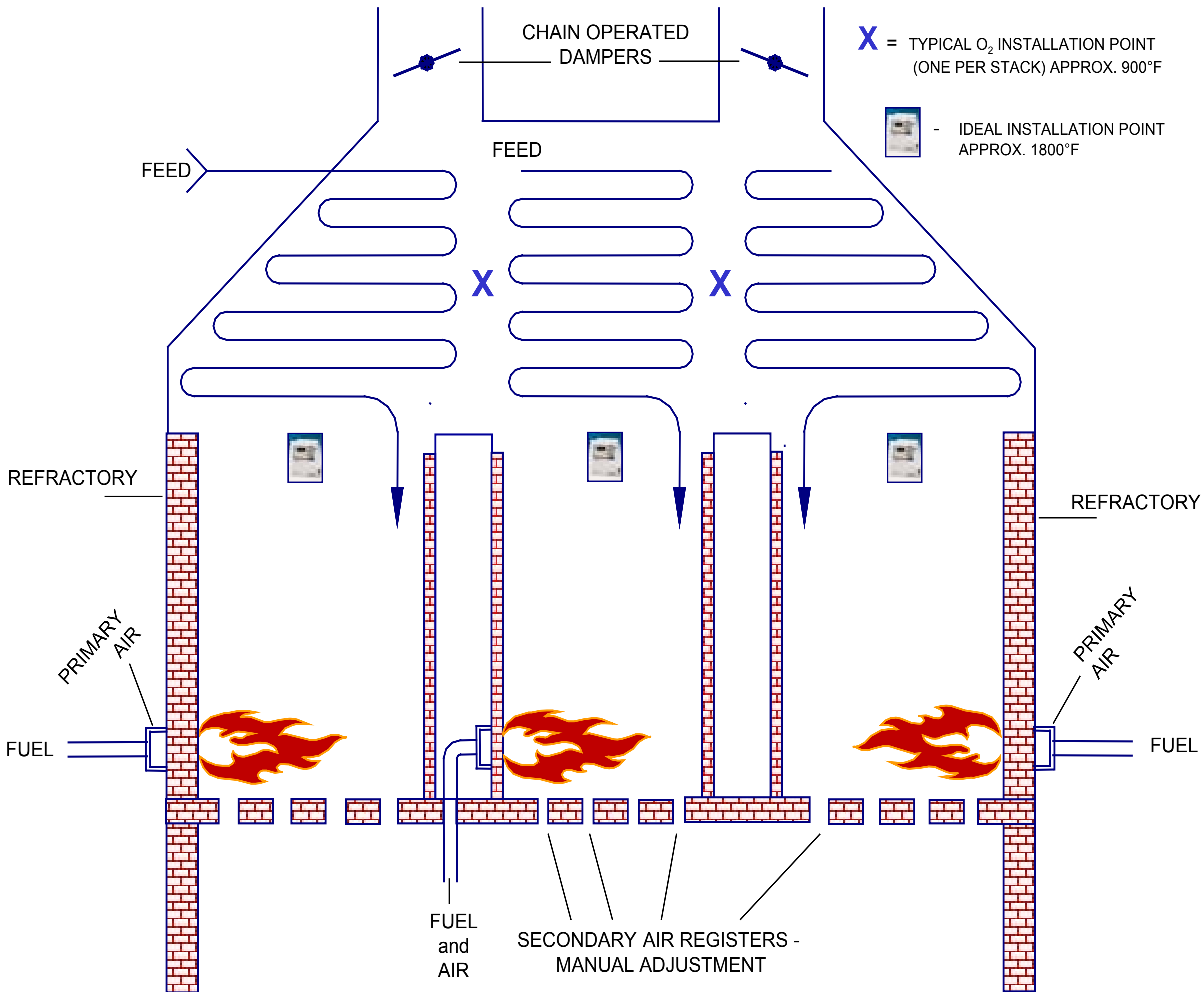


Figure 11. Cabin furnace with three cells.

A process heater is a complex combustion device with many variables to take into consideration. Control of the temperature of the feed inside the tubes relies greatly on precise control of the combustion process. Many heaters, reformers, and furnaces have multiple burners with two, three or more radiant sections (or cells). Proper control of the heater requires knowledge of the oxygen and combustibles levels of the flue gas as well as draft and temperature data. However, location of the oxygen analyzer greatly affects the validity of the measurement for control. It is almost impossible to operate a heater efficiently, effectively and safely with an oxygen measurement taken from the convection section or, even worse, from the stack.

Figure 11 shows a cabin furnace with three separate radiant zones but many configurations exist. Most often the measurement is taken from the convection section (position X). How is it possible to relate an oxygen measurement from the convection section to what is happening in the burner zones? Answer: It is not. Moreover, leaks of air in the convection section will give erroneous oxygen readings and can mask problems in the burner zone. Ideally, the oxygen and combustibles should be measured in the firebox for three reasons:

1. To avoid erroneous readings caused by air leakage in the convection zone.
2. Combustibles in the flue gas will continue to burn on the hot tubes of the convective section and will not show the correct values at this location.
3. To be able to relate to the burners from that zone only.

It is quite common for one or more

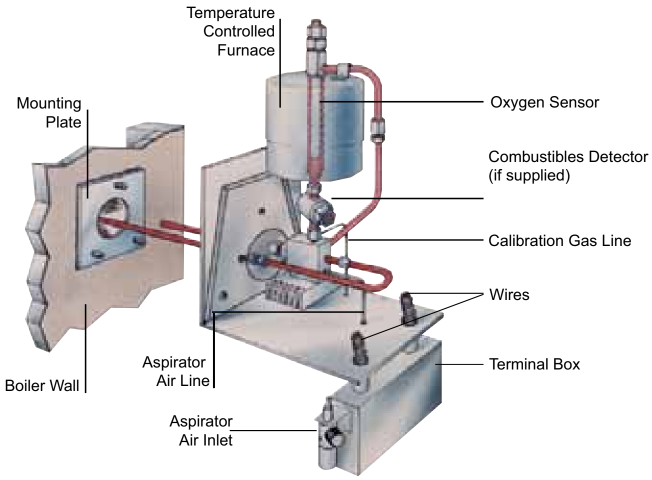


Figure 12. Close-coupled O_2 / combustibles analyzer.

Response

The response time of an analyzer is not measured by the time it takes to react to calibration gas, but rather by its reaction to a process step change. Calibration gas is forced to the analyzer under pressure reaching the measuring cell very quickly so that all analyzers appear to be fast during calibration. The time it takes for the flue gas to get to the cell, on the other hand, depends upon the design of the system. When comparing analyzer response times, make sure you are looking at "process response", not response to calibration gas.

The close-coupled extractive WDG-IVC mounts directly to the process flange and is heated to maintain all sample wetted components above the acid dewpoint. An air-operated aspirator draws a sample into the analyzer and returns it to the process. A portion of this sample rises into the convection loop past the combustibles and oxygen cells and then back to process. This design gives a very fast response and is perfect for process heaters.

The broad definition of the word "insitu" refers to an analyzer directly mounted to the process flange, rather than a remote location, with a sample conditioning system. "Insitu" can also refer to the distinction of whether the zirconia cell is located inside or outside of the flue gas duct.

For low temperature (1250°F/677°C max.) locations, you can use a WDG-Insitu, with the zirconia cell residing in the flue gas stream. This type of analyzer has a slower response since it depends on diffusion of the flue gas to the cell, rather than on induced flow.

A by-pass or cooling extension tube is often used for installation of insitu analyzers at higher temperature locations because of the probe temperature limit. In this configuration, it acts as a close-coupled extractive analyzer but with a slower response time.

High temperature insitu analyzers, heated by the process and requiring a minimum process operating temperature of 1200°F (648°C), are available from some manufacturers. These have a slightly faster response time than standard insitus but tend to break more easily. They also cannot generate any process information during heater start-up. Both process-heated and self-heated insitus can measure only oxygen.

Methane Detection During Start-up

As an additional precaution during the purge-down and light-off cycle, the methane detector will detect any natural gas or other fuels which have leaked into the firebox and could cause an explosion. If the heater is started up only rarely, the methane detector would have limited use. When a heater or boiler is started-up frequently, then the methane measurement gives additional peace of mind. Thermox offers a combination O_2, combustibles and methane analyzer. The methane part is used only during the purge-down/light-off cycle with natural gas-fired heaters. Once lit, the oxygen and combustibles measurements are used for optimization.

Portable Versus Fixed (Dry Versus Wet O_2)

It is not a good idea to use the oxygen value determined from a portable analyzer as the set point for the fixed oxygen analyzer. The portable, typically fuel cell or paramagnetic based, measures on a dry basis since the water must be removed before the sample is analyzed. The fixed analyzer, normally zirconium oxide based, measures the flue gas as is, including the water and thus measures on a wet basis. The dry reading is always higher than the wet and the difference can be significant. When measuring a flue gas containing 20% moisture in the flue gas and 3% O_2, the fixed analyzer will read 3%, whereas the portable will read 3.75%. Neither is right or wrong. They are just different ways of looking at the same thing and in fact this principle is used to measure flue gas moisture.

However, a setpoint value determined using the protable analyzer will not be the same as that determied using an in-situ measurement.

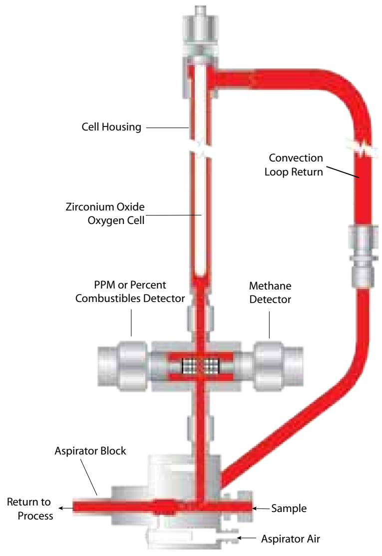


Figure 13. Convection loop of WDG-IVCM - O_2, combustibles and methane analyzer.

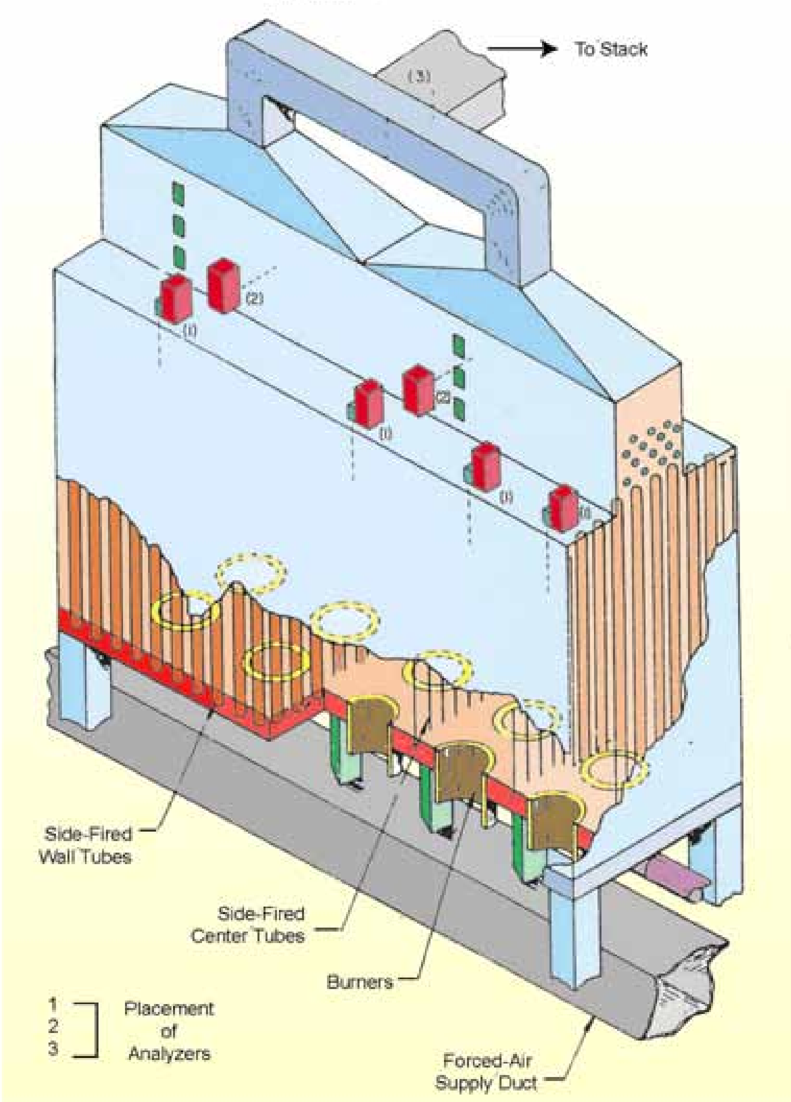


Figure 14. Cabin furnace showing possible placement of analyzers.

Figure 14 shows a cabin furnace with possible locations of the analyzers.

The ideal locations are at the positions marked (1). At least one analyzer should be used for each radiant zone. In this case the probes are installed vertically going down into the firebox, but it is also possible to locate them with horizontal probes and with the analyzer mounted lower down on the furnace wall. Angled mounting is sometimes necessary. Depending upon the length of the cell, more than one analyzer may be required to get a representative measurement.

Position (2) is much less desirable because the probe is now in the convection section. Air ingress tends to cause the readings to mask any burner problems if using oxygen only, but at least this will be picked up by the combustibles detector (make sure you have it!). This location gives no information on the cells, but rather some average of all the flue gas from that half of the cabin. Proper control of the furnace cannot be obtained with this approach. Comparison between (1) and (2) will give information on air leakage and if analyzers already exist at (2), they can be used for this purpose. Typically these are low temperature analyzers that anyway cannot be used in position (1).

Position (3) should be used only for stack emissions measurement and should never be used for heater control.

Thermox oxygen analyzers are designed for direct installation at the high temperature radiant section, typically 1500 - 2000°F (815 - 1093°C). A wide range of options is available, including hazardous area and floor mount versions. All parts are easily accessible and the analyzer can be serviced without having to take it off the flange.

Suggested Manual Trim of a Fired Heater

1. Adjust primary air on the burner for proper flame height and color at the operating fuel gas pressure.
2. Adjust the stack damper to the recommended - 0.1” wc draft at the entrance to the convection section, with secondary air registers open.
3. Trim the secondary air registers to the lowest excess oxygen level up to, but not exceeding, the ppm combustibles operational limit as dictated by plant personnel/ or experience.
4. Readjust stack damper and secondary air registers as necessary to maintain convection section draft and minimal radiant section oxygen with a safe level of combustibles.
5. Set up the heater using oxygen and combustibles. The heater is now controlled on oxygen, and the combustibles detector is used to watch for process upsets and burner performance over time. This is your window into the process.
6. A 100 ppm combustibles level can achieve maximum fuel efficiency as well as minimizing emissions, without sacrificing safety.

Not all heater situations can be improved with the above suggestions. Other classes of problems include:

Heat release-limited

The burner capacity limits furnace duty. An increase of gas pressure, or possibly increasing the burner orifice can increase capacity. High hydrogen content in the fuel gas can cause this.

Draft-limited

With the damper and registers wide open, there is still insufficient air. Air leakage into the convection section will not permit secondary air to enter the heater. Convection section tubes could also be partially plugged. Increasing secondary air opening size may remedy the situation.

Heat absorption-limited

The product can not obtain the target temperature. Add convective tubes, increase product mass velocity through tubes, adjust for dense flame.

CONCLUSION

Heater operators often feel that they need only to maintain thermal objectives and this can be done by controlling the excess air using an oxygen-only analyzer. Or if there is no automatic trim on the heater, that Oxygen-only is sufficient. As we have shown, this is a misconception and even the smallest heater absolutely needs Oxygen and ppm combustibles. Slugs of waste gas with poor BTU value can hit the burners at any time and cause major and rapid changes to the combustion parameters.

Measuring oxygen and ppm combustibles provides benefits far in excess of the analyzer(s) installed cost.

1. Improves efficiency - typically 3-5% fuel savings.
2. Reduces emissions - 15-20% NOx reduction is possible.
3. Identify problems due to air leaks.
4. Identify problems due to tube leaks.
5. Monitor burner performance.
6. Maintain product quality.
7. Improve heater and tube life.
8. Critical units such as reformers require multiple measuring points to provide sufficient information for proper process control.

Thermox oxygen and combustibles analyzers can help meet heater performance objectives with minimal investment cost. Even older heaters with manual secondary air adjustments can benefit from optimization made possible by reliable oxygen and combustibles measurements from the correct location.

All analyzers are available with a separate control unit to be located up to 1000 ft. (300 m) from the sensor, or as smart sensors (IQ versions). The smart sensors have all the electronics built into the sensor and are accessed via a handheld IQ Link or the LinkBus.

The AMETEK LinkBus RIMS (Remote Instrument Monitoring System) provides the customer with plant-wide PC access to process analyzers using the existing web browser or through Fieldbus™, Modbus™ protocol-based DCS systems. The LinkBus system is available for IQ and 2000 controller-based Thermox flue gas analyzers, the 4000 and 880 Series photometric analyzers and the 5000 Series moisture analyzers. Easy access to analyzer information and trend data allows the maintenance department to make the most efficient use of limited resources and to determine process problems versus invalid analyzer data. The system can be configured by the user to allow third party access to factory personnel in order to provide expertise to assist in troubleshooting. The elimination of routine maintenance visits allows focused attention where it is most needed. Enhanced reliability and improved analyzer performance both lead to tighter process control.

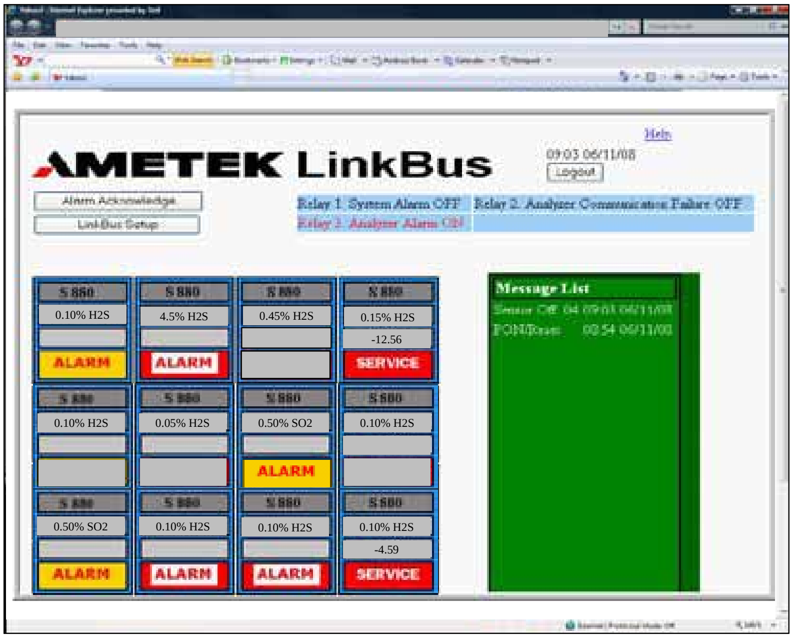


Figure 15. LinkBus RIMS multiple analyzer view page

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