EXPERTS IN COMBUSTION CONTROL

EXPERT PAPER

A COMPARISON OF GAS ANALYSIS TECHNOLOGIES AVAILABLE FOR EFFICIENT AND SAFE COMBUSTION IN CONTROL FIRED HEATERS

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Fired heaters are integral to hydrocarbon processing (HP). Specifically designed for the reaction of fuel and air to produce extremely high gas temperatures, heaters transfer this energy to potentially highly flammable process fluids via heat exchangers. They consume large quantities of fuel, produce large quantities of emissions and are a potential safety hazard to personnel and plant. However, they are currently irreplaceable within many HP processes – so they warrant the highest levels of understanding and care in their operation and control.

Recent improvements in burner technology to reduce NOx emissions require closer monitoring of the process, as newer burners often operate under narrower process control conditions than older, larger nozzle diameter gas burners. Demands have also grown on plant operators to improve safety practices, increase plant efficiency and reduce environmental emissions. As a consequence, more accurate and reliable instrumentation is required to support the control of the process.

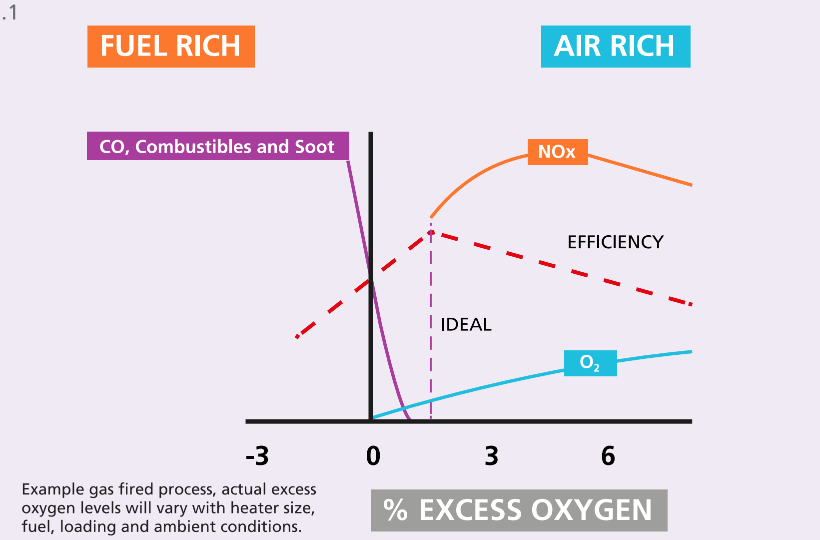
New and improved technologies are available to control fired heater combustion with ever greater accuracy and reliability, but the correct selection and effective use of these technologies requires understanding of a complex and delicate process.

THE PRINCIPLES OF EFFECTIVE COMBUSTION CONTROL IN FIRED HEATERS

The cornerstones of a well–controlled combustion process are optimized air–to–flue ratio and efficient fuel consumption. Before analyzer technologies were developed to measure excess air in the products of combustion, fired heaters were run in conditions of high excess air. Although this meant inefficient and costly fuel consumption, it was the only way to avoid the creation of low–oxygen, fuel rich conditions that could lead to a potentially dangerous explosion.

The introduction of Zirconium Oxide technologies in the late 1960s allowed engineers to obtain reliable and continuous measurements of excess air, enabling them to reduce the air-to-fuel ratio closer to that of the theoretical stoichiometric combustion mix. Unfortunately, the reduction of excess air poses a new problem: the nearer the process moves to the tipping point at which incomplete combustion takes place, the potential to move from safe to unsafe operating conditions increases, as well as the speed at which these transitions can happen (fig.1).

fig.1



Example gas fired process, actual excess oxygen levels will vary with heater size, fuel, loading and ambient conditions.

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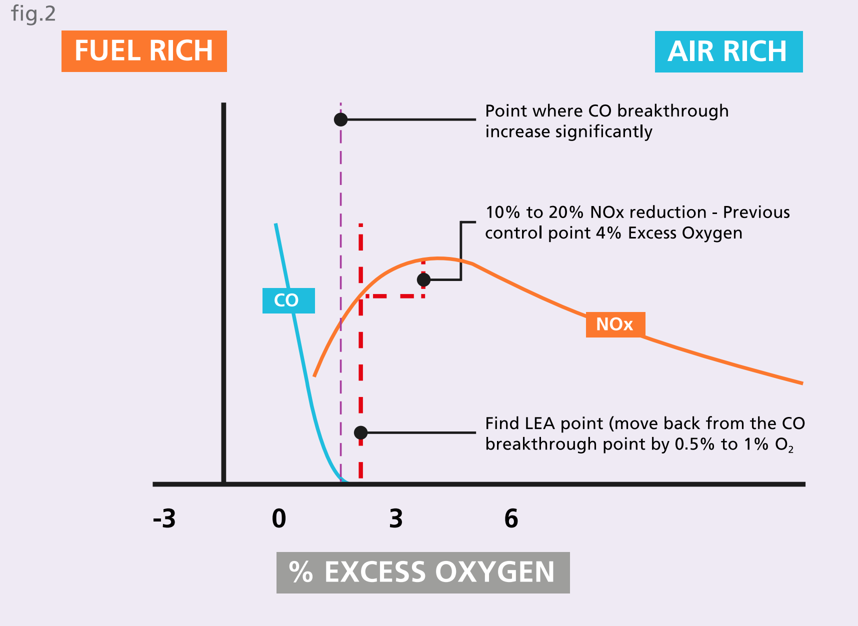
The control and safety systems that run fired heaters must therefore perform an extremely complicated balancing act. It is often not enough to just increase excess air levels when incomplete combustion is detected, as the complex interactions of oxygen and unburned fuel can lead to flammable mixtures igniting further down from the burners. Such conditions can lead to a number of negative process control conditions, including excess heat at the process tubes, which causes damage and leaks; carbon deposits on the process tubes, which decreases efficiency and heat transfer; and, in extreme cases, potentially dangerous combustion events can occur.

However, if a process problem is detected either by analytical instruments or other safety devices, it is inadvisable to simply switch off the fuel supply to the burners. Abrupt stops, restarts and light off conditions are the most common time for furnace incidents to occur. It is safer to bring the process carefully and correctly under control than to fully shutdown and restart the process and, as such, good quality and comprehensive analysis of the products of combustion, or lack of, is vital.

Despite the risks, there are measureable rewards for operating fired heaters at Low Excess Air (LEA) levels. In LEA combustion control the lowest level of fuel is consumed and the products of combustion are cooled the least by unused excess air. The cost benefits of these efficiencies are considerable, with just a single percentage saving in fuel enabling savings of many tens or even hundreds of thousands of dollars per year. Controlling air levels just above the point at which incomplete combustion starts also enables the 'cleanest burn', helping plants meet environmental emissions requirements. This in particular reduces the emission of NOx, created when unused oxygen reacts with nitrogen from the combustion air, which will be produced even by low NOx burners if they are not run as lean as possible (fig.2).

with burner inefficiencies preventing stoichiometric combustion levels being reached.

fig.2



A competent LEA combustion process – running at approximately 2.5-5% excess air or 0.5-1% oxygen above the point at which unburned fuel in the form of carbon monoxide starts to breakthrough – can be maintained and controlled at the most efficient running point. If the process is run with too little air, the products of combustion will contain unburned fuel which is wasted and passed into the atmosphere. As soon as there is not enough air to allow full combustion of the fuel, the process will quickly degenerate into an unsafe condition. Pockets of carbon monoxide, and possibly hydrogen and methane, can travel through the process, causing localized hot spots as they ignite and produce higher emissions of gases such as carbon monoxide. These effects begin to manifest at less than 10-15% excess air or 2-3% oxygen in the flue gas,

Excluding extractive techniques used for portable gas analyzers and some highly specialist fixed gas analyzer applications, there are currently two very different technologies available to measure the level of unused oxygen in the fired heater combustion process. Zirconium oxide cell technologies – commonly known as Zirconia – have been established for more than 50 years, but have recently been challenged by the introduction of Tunable Diode Laser (TDL) analyzers. Both offer distinct advantages and disadvantages in their usage, so it is extremely important to understand their respective qualities to deduce which is most suitable for an application. Neither offers a 'one-size-fits-all' solution, but there are notable advantages to be gained by using them as complementary techniques.

ZIRCONIUM OXIDE: OPTIMUM TECHNIQUES FOR OPTIMUM OXYGEN CONTROL

Zirconia is a proven technology that measures oxygen on a 'wet' basis, enabling the sampling and direct analysis from the hot, wet and often corrosive products of combustion. This avoids added complexities and reliability issues associated with a sample conditioning system, while readings do not have to be converted from dry–basis to wet–basis, which can be a cause of inaccurate readings. Furthermore, Zirconia technology is an inherent partial pressure measurement, which allows the percentage oxygen measurement to be made independent of temperature and pressure.

Zirconia analyzers are broadly split into two types: close–coupled extractive analyzers and in–situ analyzers. The most effective and reliable method for using Zirconia technology in process control is within a close-coupled extractive analyzer system, where a sensor enclosure is installed to the side of the process. This enclosure is heated above the gas dew point and contains the zirconia sensor connected to the process via a sample probe. The enclosure also normally contains an aspirator driven by compressed air, or occasionally nitrogen, which is used to extract the sample from the process.

SERVOTOUGH FluegasExact 2700
The FluegasExact 2700 enables the sampling and direct analysis from hot, wet and corrosive combustion products.

As this type of system can be installed close to the burners, the 'lag time' for oxygen analysis – the measurement delay due to sensor response – is minimized, giving operators a comparatively short response time. Detailed burner performance can be also monitored by installing multiple analyzers across banks of burners; this is especially important in fired heaters where low NOx burners are fitted, as the burners are notoriously difficult to evaluate through visual inspection as the flame is non–luminous. The outputs of these analyzers can then be averaged to give oxygen trim control. Many systems also offer the option of fitting an additional carbon monoxide or combustibles catalytic sensor. This offers additional diagnostic benefits for process and burner optimization, including providing early indications that excess air levels are too low, or that a bank of burners is incorrectly set–up, adversely affected by other burners or suffering from nozzle blockage.

Flame traps should always be specified when choosing this type of analyzer system to prevent the sensors from becoming a source of ignition back to the process. Care should then be taken to ensure that the flame traps have little effect on measurement lag times. High flow close-coupled extractive analyzers – analyzers that aspirate over 1l/min of sample from the process – can suffer from considerable sample lag times, as the pressure drops across flame traps at high flow rates causes reductions in sample flow. For added measurement certainty, it is recommended that analyzers are specified where the calibration gases supplied to the instrument can verify the whole of the system's performance, inclusive of the probe inlet to the analyzer, sensors and the aspirator outlet.

With in-situ analyzers, the zirconia sensor is situated at the end of a probe that is inserted into the hot products of combustion. While relatively simple and cost-effective to install, the sensor is directly affected by the process temperature variations and limited in absolute operational temperature. The mechanical requirements of higher-temperature operation – effectively making the analyzer operate like a diffusion-based, semi-close couple extractive analyzer – are complex, with bulky assemblies that incur high installation overheads.

Critically, when flame traps are fitted to an in-situ technique, the lag time can be up to several minutes or more, which many engineers will consider too risky for safe control. Problems can be compounded by probe installation points: if placed too far from the burners to limit process temperature effects on the sensors, then both air ingress into the flue and delays caused by the distance from the burners can weaken the ability to control the process efficiently and safely. The longer the analysis lag time and greater the air ingress, the further the process excess oxygen levels have to be controlled away from the ideal LEA point, as a high safety margin is then required to prevent incomplete combustion. As a consequence, engineers must have a clear understanding that their processes will be compromised by the potential shortcomings of in-situ techniques, regardless of the initial installation cost benefits they offer.

TDL TECHNOLOGIES: A COMPLEMENTARY TECHNOLOGY TO OPTIMIZE PROCESS

A major development in gas analysis techniques has been the introduction of Tuneable Diode Laser (TDL) technologies. Enthusiastically received by engineers and plant operators, a range of different technology integrations are now available from multiple manufacturers. Yet while TDL offers distinct advantages in the measurement of multiple gas types, it also has operational limitations which make its use in fired heaters a complementary technique rather than a complete replacement for other technologies.

TDL consists of a tunable diode laser light source, transmitting optics, an optically accessible absorbing medium, receiving optics and detector. TDL technologies are particularly suitable for in–situ cross stack measurements, with a typical cross stack system consisting of the laser emitter module and receiver mounted across the process pipe line or flue stack. The gas concentration information is held in the gas absorption line shape, which is obtained by scanning the laser wavelength over the specific absorption line. This causes a reduction of the measured signal intensity, which is detected by a photodiode and then used to determine the gas concentration. Being a spectroscopic absorption measurement technique, TDL effectively counts molecules (or number density of molecules) that fall within the beam. Within a certain gas mix, the number density for a fixed percentage composition is strongly pressure and temperature dependent according to the universal gas laws. Therefore external temperature inputs are required to enable the analyzer to derive an accurate percentage oxygen measurement.

SERVOTOUGH Laser 3 Plus Combustion
Compact TDL combustion series measures O_2, CO and CH_4 offering unique features and low cost of ownership.

There are primarily two cross–stack TDL technologies in use: Direct Absorption Spectroscopy (DAS) and Wavelength Modulated Spectroscopy (WMS). DAS is the first generation technique of TDL absorption spectroscopy, providing measurements from a relatively crude approximation of the area under the absorption curve generated by the laser scan.

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Today, few analyzer manufacturers use this approach to measurement analysis, as DAS yields a relatively noisy signal which compromises measurement accuracy. DAS is also limited due to the broad absorption line shape, with measurement data contained within the "wings" of the absorption curve, hence a proportion of the absorption data is not scanned and cross interferences from background gases, molecular interactions and environmental fluctuations can be difficult to correct. While the disadvantage of the DAS technique is generally not significant in relation to oxygen analysis, for all other gases it is a limitation to measurement accuracy.

WMS is a sophisticated evolution of the DAS technique, which takes a measurement of the second harmonic of the absorption curve. This yields a very sharp absorption curve with all measurement data contained within the laser scan width and very defined turning points which are easily computed, allowing an accurate evaluation of the area under the absorption curve. By delivering excellent cross interference rejection, precise temperature and pressure correction and low noise measurements, the greater accuracy and stability given by the WMS measurement means it is consequently the most commonly used TDL measurement technique. TDL–based systems appear an ideal choice for in–situ cross stack measurements in process and combustion control applications. As there is no physical or mechanical interaction with the process – other than molecular absorption – they offer a highly stable base line measurement, with a long interval between calibrations and a fast response measurement in hot, wet, corrosive and dusty process conditions. TDL technologies therefore appear highly attractive on both maintenance and performance grounds, but the technology has potential disadvantages when compared to zirconia for a process control measurement.

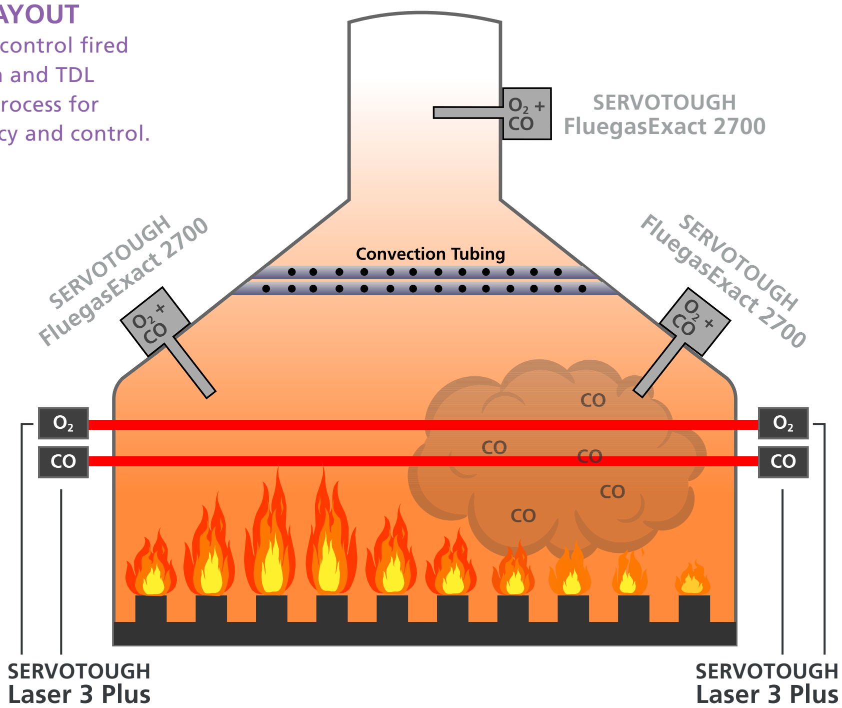
For oxygen analysis, TDL offers an average path measurement across all burners, while zirconia analyzers can be used to measure a particular section of burners by their ability to sample a single point. As TDL purchase and installation costs are between three to five times that of a zirconia installation, multiple zirconia analyzers can be purchased for an equivalent amount that can be used to both gain an average measurement and the single point measurements for burner diagnostics. TDL is also susceptible to a range of environmental factors which must be compensated for, including path length variation, window purge gas effects, optical interferences and temperature and pressure changes. For a WMS instrument an error of approximately +/– 5% of reading is normal, while for a DAS measurement the error can be considerably higher.

Problems can also arise in the fitting of optical windows between both the source and the process and between the detector and the process. These windows must remain clean at all times, which can only be achieved by purging the dead space with a gas that will not interfere with the measurement. For an oxygen measurement this precludes the use of compressed air, so nitrogen is used as the purge gas. As this is normally consumed at a rate of 20l/min to 50l/min for each side of the TDL, depending on process gas velocity, it makes operation and maintenance prohibitively expensive when compared with zirconia techniques, unless the process is too corrosive or dust laden for a zirconia analyzer to operate reliably.

There is also no way of calibrating a measurement without removing both the TDL source and detector and fitting a fixed length calibration cell. Even with the calibration cell fitted, which is usually one meter in length, a true calibration is difficult to achieve accurately as process path lengths typically vary from 5m to 20m long. The instrument must apply correction factors to compensate for the calibration cell path length and process path length differences.

TYPICAL FURNACE LAYOUT

Ideal analyzer layout for control fired heaters, utilizing Zirconia and TDL technologies across the process for maximum safety, efficiency and control.



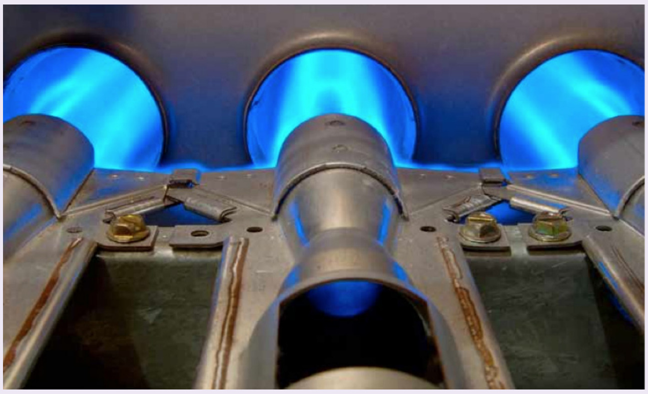
TDL delivers greater advantages in the measurement of carbon monoxide, with the fast response and specificity of TDL enabling carbon monoxide breakthrough to be monitored accurately. While it is not generally advisable to use carbon monoxide breakthrough as part of the process control loop, it can act as a secondary and complementary measurement to the oxygen measurement, assisting LEA optimization and introducing a further level of process safety related diagnostics. Carbon monoxide measurement using TDL also avoids the problem of high sulfur levels inhibiting catalytic sensors, while the ability to use compressed air as a purge gas removes the prohibitive costs associated with using TDL for an oxygen measurement. But as TDL offers an average path measurement, rather than a point measurement, a catalytic measurement of carbon monoxide combined within the same analyzer as the zirconia oxygen measurement gives a enhanced, cost-effective diagnostic capabilities for burner efficiency.

Possibly the most significant application for TDL in fired heater processes lies in the ability to integrate the technology into flameout protection, specifically the measurement of methane in natural gas burners. If TDL is installed so that a burner flameout can be detected quickly, it enables greater flexibility and response to control and shut down processes.

A further advantage of a methane optimized measurement is that a single TDL monitor can obtain further data to monitor carbon monoxide and moisture levels. In normal operating conditions no carbon monoxide or methane should be present in the process, so moisture analysis is particularly useful as it serves as a reference peak in the same laser scan cycle to prevent laser drift and loss of laser line lock.

CONCLUSION

In a typical fired heater, the optimum analytical techniques for process control, efficiency, safety and emissions reduction are a mix of Zirconia and TDL technologies applied to specific locations.



A minimum of two zirconia analyzers placed at the top of the radiant section, or at the very least bottom of the convective section, is essential: analyzers at these locations will minimize lag times and air ingress, enabling an average measurement and providing back-up when one analyzer requires maintenance. For LEA operation, a combustibles sensor combined with the zirconia analyzer is a very cost effective choice, the installation of which will support process safety procedures and site safety regulations. The addition of an integrated flow alarm also enables preventative maintenance.

Levels of carbon monoxide and water within the radiant section can be effectively measured by TDL in conjunction with Zirconia for oxygen. For flameout protection and diagnostics, and for added combustibles breakthrough analysis, an additional combined CO/methane TDL can be used. This TDL should be located as close to the burners as physically possible.

While TDL will continue to improve, it is not yet ready to completely displace the older technologies of Zirconia and catalytic sensors within combustion control. Within the short to medium term, it seems more likely that its introduction will trigger a new generation of zirconia and catalytic sensor improvements and analyzer developments. This competition between technologies will ultimately benefit process engineers and operators, as it will help generate new, cost effective and reliable instrument solutions.