Beyond detection

Anu Mahesh and Arshawn Mohseni, Yokogawa, USA, discuss how tunable diode laser spectroscopy can be used to revolutionise safety on the holistic management of fired heaters in fertilizer plants.

The global fertilizer industry serves as a foundational pillar for high-yield modern agriculture, supplying the nutrients needed to feed billions. This sector's vast operations depend on complex chemical transformations driven by fired heaters – key equipment used to supply process heat for producing ammonia, urea, and nitrate fertilizers. These heaters, often operating around the clock, are not only some of the largest energy consumers in industrial facilities, but also carry significant safety risks due to their reliance on large volumes of combustible fuels and high-temperature environments. As the industry faces new regulatory scrutiny, cost pressures, and societal expectations for safety, adopting advanced technologies in combustion monitoring and burner management is more important than ever.

The role of fired heaters and burner management systems

Fired heaters in fertilizer plants are essential for driving endothermic reactions such as steam methane reforming (SMR), which underpin the synthesis of ammonia and nitrate-based fertilizers. These units utilise burners that mix fuel – commonly natural gas – with combustion air, producing the high temperatures

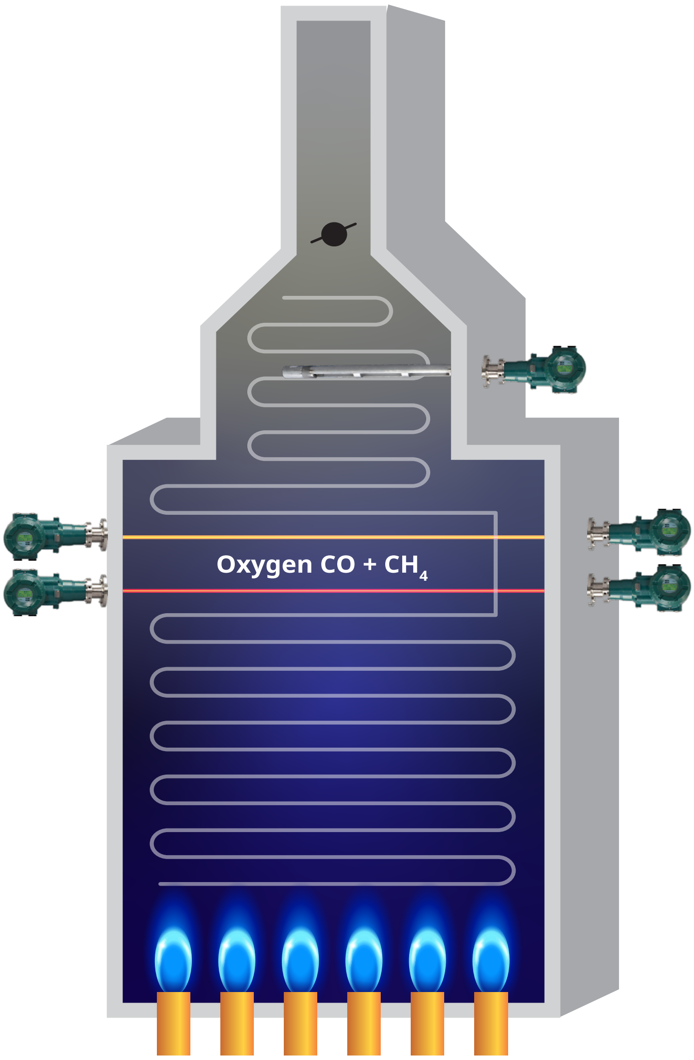

Figure 1. TDLS8000/8200 Series installation type by model.

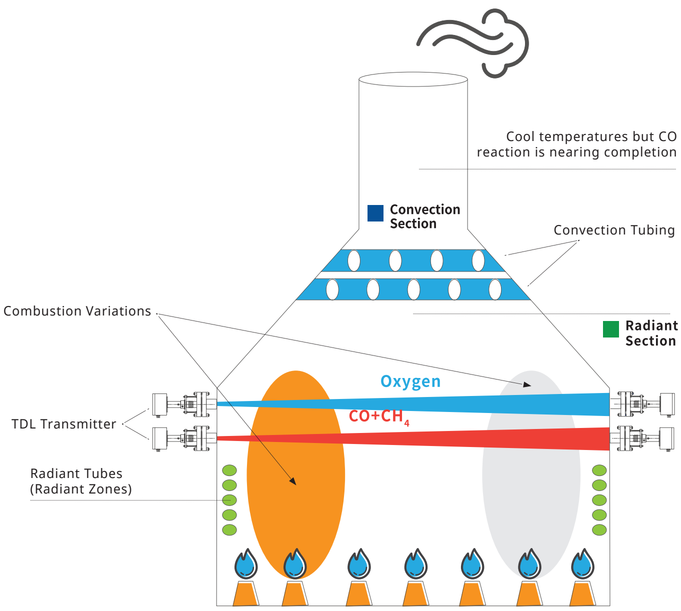

Figure 2. How a fired heater works: a properly designed system with TDLS enables control at the operational limit. Such a system is able to measure both the upper and lower conditions in a fired heater by simultaneously controlling the fuel and air supply based on fast sample intervals – typically less than five seconds.

necessary for reacting feedstocks. Ensuring these reactions proceed safely and efficiently is no small task, as improper air-fuel mixtures, undetected flameouts, or residual combustibles all hold the potential for catastrophic incidents.

An industry practice for overseeing and protecting fired heaters is the burner management system (BMS). The BMS ensures that fuel is introduced only under safe conditions, that burners ignite in the correct sequence, and that any deviation – such as a flameout, purge failure, or excess combustibles – triggers a rapid shutdown. Its sequence of interlocks and permissive signals is designed to protect personnel and process integrity.

Central to the BMS's efficacy are reliable, timely measurements of essential combustion gases. The system relies on oxygen (O_2) monitoring to verify sufficient air for safe combustion and detect whether a non-combusted (fuel-rich) or unsafe (too lean) state exists. Some systems further incorporate carbon monoxide (CO) and methane (CH_4) monitoring to identify incomplete combustion or dangerous build-up of fuel prior to ignition. However, the accuracy, speed, and reliability of these measurements can be compromised by the limitations of conventional sensor technology, posing a persistent risk for North American fertilizer producers.

Limitations and hazards of traditional combustion gas analysis

Historically, the most common O_2 measurement devices have been zirconium oxide probes, which use high-temperature sensors to detect oxygen concentration in exhaust or process streams. While proven in many applications, these legacy analysers introduce notable risks in fired heaters. First, their hot probe elements operate significantly above the ignition point for methane. This means that if a burner does not light properly or if there is a poor purge – or worse, a leaking fuel valve – a residual build-up of natural gas could contact the glowing hot sensor surface, acting as an unintended ignition source. There are documented examples in the chemical and fertilizer industries demonstrating that such scenarios can result in explosions, severe injury, and major plant outages.

Zirconia probe location can further impair rapid, accurate measurement. These sensors are typically installed downstream from the radiant section, in the convection section, which can introduce response delays of 30 seconds or more due to the time it takes flue gases to reach the probe. In a fast-unfolding hazardous situation, such as a sudden flameout or runaway combustion event, this lag can hinder the BMS from acting before unsafe conditions escalate. Additionally, because the probe is situated in the convection section, it is more susceptible to artificially elevated oxygen readings caused by tramp air ingress. Moreover, probes are susceptible to drift, corrosion, and fouling, resulting in unreliable combustion data just when it is needed most.

Traditional analysers also lack pre-ignition gas detection capability, meaning the BMS is 'blind' to the presence of hazardous fuel concentrations within the heater prior to startup. As a result, dangerous situations can go unrecognised until ignition is attempted – a leading factor behind so-called 'huffing' explosions and more severe plant incidents.

A paradigm shift in safety

Tunable diode laser spectroscopy (TDLS) has emerged as a game-changing technology in fired heater operation and BMS performance, offering a step-change in both safety and efficiency. Unlike point probes, TDLS systems transmit a precise laser beam across the process gas stream – usually through the radiant section of the fired heater – with specific wavelengths that are tuned to match gases such as O_2, CO, or CH_4. By measuring the reduction in laser intensity at these wavelengths, the TDLS system calculates the real-time concentration of these combustibles, providing fast, direct, and non-contact measurement.

TDLS offers several fundamental improvements over legacy analysers:

- No ignition hazard: with no heated or electrically energised components in direct contact with process gases, the risk of the analyser itself igniting unburned fuel is eliminated.
- Instantaneous, in-situ measurement: TDLS delivers results in less than two seconds, offering true real-time monitoring vs the lag-prone readings of conventional sensors.
- High specificity and accuracy: TDLS is more robust to cross-gas interference and more enduring to water vapour, particulates, or unknown hydrocarbons, ensuring data quality even under challenging conditions.
- Multi-gas capability: the same system can monitor O_2, CO, and CH_4, allowing for richer process safety strategies – such as 'methane permissive' logic to block ignitions if hazardous methane is detected pre-start.

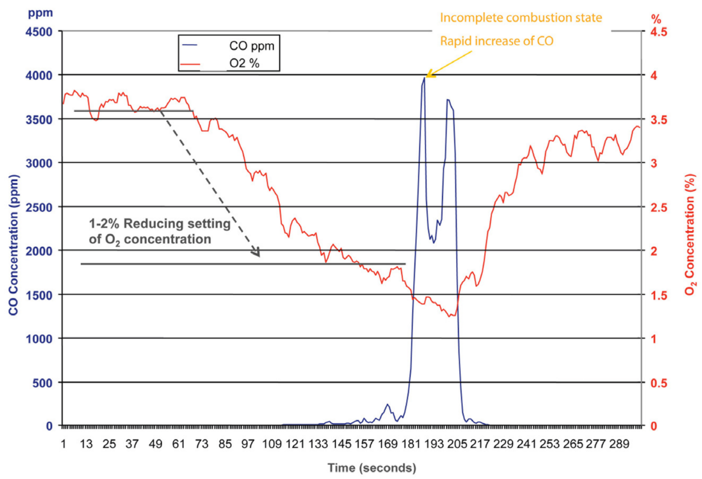

Figure 3. O_2 and CO concentration changes in a combustion furnace at low oxygen concentration operation.

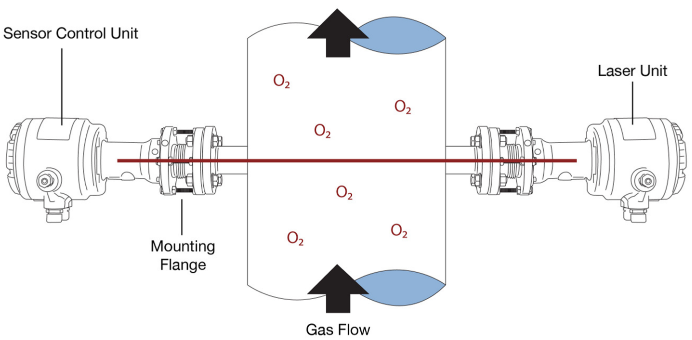

Figure 4. Installation example of the TDLS8000.

How TDLS transforms burner management system functionality

A BMS's decision-making capabilities and responsiveness improve dramatically when enhanced by TDLS real-time data. During normal operation, continuous O_2 monitoring enables fine-tuned control of the air-fuel ratio, so that excess oxygen can be safely minimised. This reduces fuel costs and NO_x emissions while keeping the heater away from fuel-rich, dangerous conditions. Should a deviation occur, such as a fall in oxygen or an unexpected rise in combustibles, the BMS can immediately respond – cutting fuel supply, shutting down burners, or issuing operator alarms to prevent a hazardous event.

Most importantly, during heater start-up and purge phases, TDLS offers a vital safety advantage over older technologies: methane permissive detection. By detecting residual CH_4 before auto-ignition, the BMS can halt the next ignition cycle, raise an alarm, and prompt operator intervention if hazardous fuel levels are detected. This functionality serves as a direct safeguard against 'huffing' explosions – minor gas ignitions that have the potential to escalate into far more dangerous incidents.

During stable operation, CO monitoring with TDLS allows detection of incomplete combustion at its earliest onset. Operators or advanced process control (APC) loops can adjust air supply proactively, maintaining efficiency while ensuring that flue gases remain within safe, low-CO limits. If excessive combustibles are detected traveling downstream into the convection section, this early warning reduces the risk of afterburning, overheating, and tube failure – improving equipment life and reducing unplanned downtime.

Safety, economic, and sustainability benefits for the fertilizer sector

The direct and indirect advantages of integrating TDLS into fired heater safety systems are profound. Most obviously, personnel safety is greatly enhanced. Eliminating a major ignition source within the process gas flow and enabling reliable detection of hazardous conditions gives operators and emergency systems the data they need to enact protective actions with confidence and speed.

Efficiency gains are equally compelling. By permitting safe reduction of excess air, TDLS boosts fired heater fuel economy – lowering operational costs at a time when energy prices are volatile and margins tight. The reduction in excess air also means a cut in NO_x formation and supporting the industry's shift toward sustainable operations. This technological advancement thus serves corporate social responsibility goals.

Asset reliability – as measured in mean time between failures (MTBF), turnaround intervals, and the rate of unplanned shutdowns – is also strengthened by TDLS. With accurate, responsive gas analysis, heaters can be operated closer to their optimal setpoints, avoiding hot spots, temperature cycling, and chemical damage that shorten tube and refractory lifespan. This means longer asset lives, more predictable and less frequent maintenance scheduling, and lower life-cycle costs – advantages that directly impact the bottom line.

From a process control perspective, TDLS can easily be integrated with distributed control systems (DCS) and advanced BMS logic for plant-wide digitalisation, supporting further adoption of predictive maintenance and operator training technologies that are now sweeping the industry.

Compliance and best practices in fired heater safety

The regulatory landscape for fired heater operation has evolved steadily, with updated standards specifying new requirements for safety instrumentation, operator training, and risk mitigation. Organisations such as National Fire Protection Association (NFPA) have released rigorous codes (NFPA 85, 86, 87), and OSHA mandates process hazard analyses (PHAs) and robust management of change (MOC) programmes.

TDLS technology aligns directly with these enhanced compliance requirements:

- Supports rapid detection and response to hazardous gases, reducing PHA-identified risks.
- Enables more thorough heater purging and start-up checking, which is increasingly demanded by insurance underwriters and safety consultants.
- Provides high-integrity data for incident investigation and continuous improvement programmes.

Industry best practice now dictates regular review of sensor placement, diagnostic routines, and integration strategy, ensuring that new technologies such as TDLS are leveraged to their full safety and operational potential.

Overcoming implementation challenges

Transitioning from legacy zirconium oxide analysers to TDLS-based measurement does entail careful project management. Initial considerations include:

- Defining optimal sensor installation points within the radiant section, ensuring full cross-sectional measurement for representative gas analysis.
- Seamless integration with existing control and safety systems, whether as a retrofit in brownfield plants or as part of new project specifications.
- Operator training to understand TDLS functionality, interpret real-time gas data, and correctly respond to system alarms or safety interlocks.

Fortunately, modern TDLS systems are designed for easy installation and commissioning, with maintenance requirements significantly lower than that of traditional probes. Their digital connectivity and diagnostics further ease integration with plant digitalisation initiatives.

The future: TDLS as part of holistic fired heater management

As fertilizer plants evolve towards smarter, more autonomous operations, TDLS will play an ever more central role in the holistic management of fired assets. By delivering actionable insights in real time and supporting advanced control strategies, these analysers help stabilise process temperatures and emissions, facilitate continuous improvement, and make plants more resilient to both internal and external risks.

Recent innovations are pushing TDLS beyond just safety, enabling finer control over temperature uniformity across the heater, improved mixing, and automated condition-based maintenance. As operators retire and are replaced by a new generation of less-experienced staff, the dependability and clarity of TDLS data become even more valuable in avoiding human error and sustaining best practices.

In coming years, as environmental performance, cost efficiency, and operational excellence remain top priorities, the adoption of TDLS in fired heater management will be not just a compliance box to be ticked, but a strategic investment with far-reaching operational and reputational benefits.

Conclusion

Fertilizer manufacturing in North America and worldwide is entering a new era – one defined by advanced safety expectations, stricter environmental mandates, and the relentless pursuit of operational excellence. Fired heaters, indispensable as they are, represent a persistent risk and a significant lever for improvement. By moving beyond legacy sensor technologies and adopting TDLS, the industry can make decisive gains in safety, efficiency, and cost control.

TDLS not only eliminates ignition risks and measurement delays but also delivers the precision and responsiveness needed for 21st century burner management. It provides plant operators, engineers, and safety professionals with the tools necessary to protect personnel and maximise asset value. As the fertilizer industry seeks to feed a growing world both safely and sustainably, TDLS stands out as a key enabling technology – transforming fired heater performance from a perennial headache into a source of competitive advantage and reliability. WF