

Fired Heaters in the Process Industries

Optimizing Operations and Minimizing Emissions

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KEY TAKEAWAYS

- ✓ Fired heaters have potential for improvement for many areas, ranging from safety to energy efficiency.
- ✓ Particularly during startup and shutdown, a fired heater represents a huge safety risk.
- ✓ Using excess air in the combustion process increases safety but also increases emissions and decreases efficiency.
- ✓ Controlling the fired heater at the edge of the safe operating envelope with minimum excess air can maximize ROI.
- ✓ Allowing the combustion process to recover from disturbances makes CombustionONE a trip prevention solution.
- ✓ CombustionONE has been proven to increase fuel efficiency, increase productivity, reduce NO_x and CO₂ emissions, and improve fired heater safety.

Part 1 Introduction



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Fired heaters have potential for improvement in many areas such as safety, energy efficiency, asset performance, asset lifespan, and emissions reductions.

The process industries, which include chemicals, metals and mining, oil and gas, petrochemicals, pulp and paper, and refining, are very energy-intensive. In these industries, fired heaters are the largest energy consumers and represent a tremendous opportunity for energy savings. Often referred to as a boiler or furnace, a fired heater is a heat exchanger that transfers heat from fuel combustion to process fluids that flow through tubular coils within an insulated enclosure. In refineries, the most energy intensive fired heaters are thermal cracking furnaces, alkylation furnaces, catalytic reformer units, catalytic hydrocracking heaters, and steam methane reformers.

Fired heaters have potential for improvement in many areas such as safety, energy efficiency, asset performance, asset lifespan, and emissions reductions.

Particularly during startup and shutdown, a fired heater presents a major safety risk. Poor controls or lack of accurate monitoring of live conditions such as excess fuel levels within the fired heater could result in an explosion.

Erring on the side of safety, operators often attempt to minimize that risk by using excess air in the combustion process. However, this decreases fuel efficiency and leads to higher CO₂ and NO_x emissions.

Less than optimal controls could also result in failures in the process equipment and reduced asset lifespans.

By deploying contemporary measurement and control technologies in conjunction with updated operation and maintenance procedures, fired heater users can realize significant improvements in energy efficiency, safety, asset performance and asset lifespan.

New developments in process instrumentation and analytical technologies have proven to enhance optimization of industrial fired heaters resulting in:

- Increased energy efficiency
- Protection of equipment and component investments
- Reduction of unscheduled production downtime
- Reduction in operation and maintenance costs (OPEX)
- Reduction in Total Cost of Ownership (TCO)
- Improvement in production quality and management of quantity
- Production effectiveness and repeatability
- Safety improvement
- Asset performance management improvement



Part 2 Key Aspects Influencing Fired Heater Control

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Yokogawa created a process simulator to test the key aspects influencing fired heater control and to evaluate potential improvements.

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Key considerations in fired heater operations include excess air control, fuel composition changes, downstream pressure and temperatures, feed composition and rate, and heat distribution between the convection and radiant sections.

EXCESS AIR CONTROL

The heater efficiency is strongly dependent on the excess air volume. Therefore, operators should optimize excess air to increase system efficiency. To ensure complete combustion, operators should provide more combustion air than is theoretically required for heaters. This tactic helps ensure safe boiler operation.

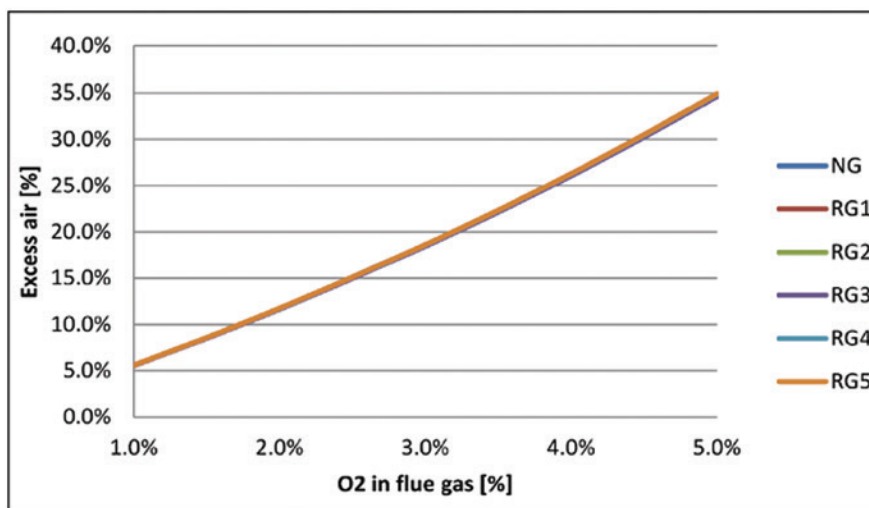


Figure 1 – Excess air for different fuel gas composition

Since Tunable Diode Laser Spectroscopy (TDLS) technology is capable of measuring the amount of oxygen directly in the radiant section of a fired heater on a two-to-four second cycle, the reference used in this study was the amount of O₂ instead of the excess air. Normally, there is a slight variation of excess air for different fuels, but the

differences between maximum and minimum values for selected gases is below 1 percent and that could be mitigated (Fig. 1).

As shown in Figure 2, radiant efficiency correlates closely with the amount of excess air. Operators should optimize excess air to increase system efficiency and, for safety purposes, should provide slightly more combustion air than is theoretically required. However, observation shows that it is sometimes too much, as the density of the fuel gas is not always readily available to the operator. A combustion process should have a balance between losing energy from using too much air (lean mode), and wasting energy from running in too much fuel mode (rich mode).

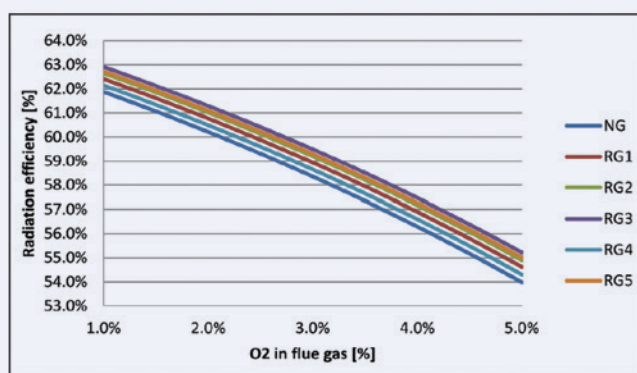


Figure 2 – Radiant efficiency for different fuel gas composition

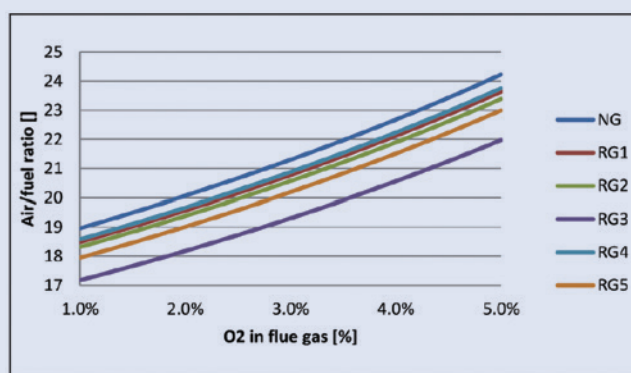


Figure 3 – Air to fuel ratio for different fuel gas composition

The best combustion efficiency could be achieved at the optimum air to fuel ratio and controlling this provides the highest possible efficiency. The air to fuel ratio is burner specific and should be set by correctly taking into account the heater, fuel composition and specific operational conditions.

FUEL COMPOSITION CHANGES

One major factor affecting fired heater performance is that refineries often use a mixture of natural gas and refinery gas as fuel. Refinery gas is a mix of gases generated during refinery processing. The composition of this gas fluctuates a lot and is strongly dependent on the composition of the crude oil and the refinery processes. Common components include butane, butylene, methane, ethane, and ethylene. To evaluate the potential impact of fuel composition fluctuations, the simulator used natural gas and evaluated five different mixtures (Table 1).

	NG	RG1	RG2	RG3	RG4	RG5
LHV. kJ/Kg	49,332.8	48,966.5	48,707.5	46,332.8	48,812.1	48,273.0
H2 mole content %	0.0	22.0	27.0	39.0	11.0	37.6
THC H/C ratio	3.978	3.556	3.111	3.087	3.788	3.519
TCW C/F	0.738	0.715	0.754	0.669	0.718	0.648
Density, kg/m ³	0.678	0.665	0.834	0.716	0.669	0.558

THC H/C ratio represents total hydrocarbons ratio of atoms of hydrogen on carbon

TCW C/F ratio represents total carbon weight on total fuel weight (gram mole weights)

LHV Low heating value in kJ/Kg

Just for reference and comparison pure methane has a density 0.668 kg/m³ under normal temperature and pressure conditions (defined as 20°C and 1 atm (14.7 psia.))

Table 1 – Specification of selected gases for simulation

DOWNSTREAM PRESSURE AND TEMPERATURE

In a process unit such as a tower, which is downstream of the first heater, a higher temperature increases the pressure in the process and, in return, influences evaporation inside the heater tubes, thus causing an additional disturbance to combustion control.

FEED COMPOSITION AND RATE

The increasing popularity of blending has demonstrated that a transition from one crude type to another poses problems. Scheduling could influence the feed rate with changes made in very small steps.

When the feed is in line with desired throughput, variation of the outlet temperature and the behavior of the process flow distribution controller could cause additional disturbances. Variations in the inlet temperature of the feed could cause even further disturbances. It is not uncommon to see fluctuations between 10 and 16 °C (18 to 29 °F). Any overheating of the outlet coil temperature has a significant impact on the fuel consumption and leads to reduced efficiency. Altogether, it impacts the stability and safety of the operation and energy efficiency of the entire process.

HEAT DISTRIBUTION BETWEEN THE CONVECTION AND RADIANT SECTIONS

For fired heaters such as vacuum heaters or thermal cracking heaters, it is mandatory to take into consideration the correct heat distribution and, as a result, the temperature distribution along the tubes in the radiant and convection sections (Fig. 4).

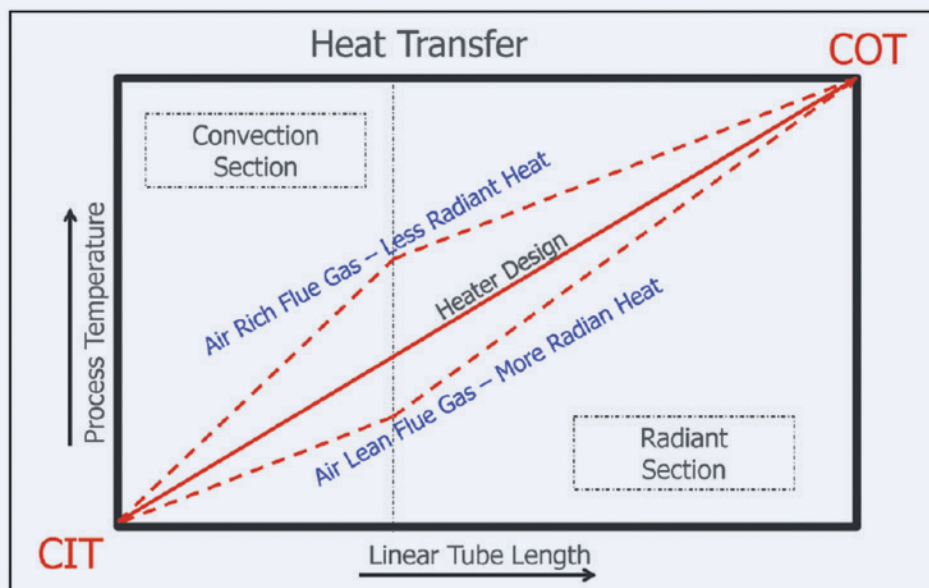


Figure 4 – Temperature profile inside the tubes for different operation conditions; CIT - Coil inlet temperature, COT - Coil outlet temperature



The higher volume of excess air results in higher absorbed heat in the convectional section and thus increases the crossover temperature. If the same amount of heat transfers in the radiant section, this results in a higher coil outlet temperature (COT). Assuming the COT will remain the same, automatic fuel input should adjust the fuel accordingly.

Consequently, there is a higher Tube Metal Temperature (TMT) in the convectional section near the crossover, but it is also valid for radiant tubes and sometimes it could be above the design value. Tubes and tube supports are designed to the minimum thickness to be cost competitive, as the alloy tubes are typically very expensive. The design thickness depends on the design temperature profile. Higher temperatures require thicker tubes.

If a furnace is running with higher excess air, the temperature profile will change and result in premature coking in the tube or thermal cracking will start prematurely, thus creating an over-cracking condition. Tubes and tube hangers exposed to higher temperatures could prematurely fail. Therefore, it is very important to maintain the design TMT profile.

Monitoring the TMT creates a robust control to prevent overheating and assists the plant operator in planning necessary maintenance if any of the unavoidable situations causing overheating occur. Those would include feedstock/steam failure, restricted process flow or burner misalignment. The tube temperature can be controlled to prolong tube life.

Part 3 CombustionONE Solution for Fired Heater Operations



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A three-tiered approach allows fired heater operators to focus on the most appropriate improvement aspects.

CombustionONE is a comprehensive approach that includes hardware, software, and turnkey project services. It combines Yokogawa's expertise in all areas of measurement, particularly Tunable Diode Laser Spectroscopy (TDLS), with control applications, optimization, and lifecycle maintenance and support to revolutionize the way operators manage their fired heaters and combustion processes.

CombustionONE uses an analysis of existing loop control structures and surrounding conditions. Based on empirical and theoretical experience, it allows the fired heater control process to be finely tuned.

A three-tiered approach allows fired heater operators to focus on the most appropriate improvement aspects. CombustionONE solution tier levels include Measurement, Control, and Optimization.



COMBUSTIONONE MEASUREMENT CAPABILITIES

Often, fired heater operators need only to add measurements such as coil and tube temperatures or replace aging instrumentation. CombustionONE measurement capabilities include comprehensive instrumentation with particular emphasis on Tunable Diode Laser Spectroscopy (TDLS) for fast and accurate post-combustion gas analysis.

Post-combustion composition measurements are very important. Industry groups such as API 556 have recognized that the traditional approach to O_2 content measurement in combustion gases using zirconium oxide probes presents a safety hazard because they operate above the CH_4 ignition temperature. Since these probes cannot be located in high temperature radiant sections, they do not provide proper measurements in non-homogenous combustion gases. When placed after the convection section or in the stack, they often add long measurement delays that could be arbitrarily skewed by tramp air. Not only does the zirconium oxide technology present a potential safety risk, it contributes to excessive fuel consumption, excessive emissions, and decreased production.

In contrast, a TDLS analyzer installed in the radiant section provides near real-time O_2 and CO measurements that are not skewed by tramp air. Depending on the fired heater application, additional live measurements by the TDLS analyzer could also include CH_4 and NH_3 .

In addition to TDLS, CombustionONE could include instrumentation for measurement of burner balancing, fuel density, fuel flow and stack flow, wind compensation ring for stabilized stack flow measurements and Continuous Emissions Monitoring (CEMS).



COMBUSTIONONE CONTROL CAPABILITIES

For control applications, CombustionONE can work in conjunction with existing combustion controls and burner management applications or replace outdated equipment as needed. Control capabilities include advanced combustion controls with cross limited CO/O_2 , improved burner management, patented stack flow wind compensation and user interface updates such as graphics, historian and performance reports.

Yokogawa services include installation on either a Yokogawa or third party control system or safety instrumented system, electrical and mechanical installation services, etc. Yokogawa also maintains a staff of subject matter experts who can provide complete automation and safety system consulting.



COMBUSTION ONE OPTIMIZATION CAPABILITIES

A variety of transformation capabilities allow fired heater operators to take multiple steps that are well beyond improvements in measurement and control. Optimizations could be any combination of the following:

- Feedwater pH optimization
- Ammonia slip optimization
- Combustion optics
- Turbomachinery controls
- Plant master and energy optimization
- Startup/shutdown procedural automation to simplify operations and improve safety
- Digital twins and full plant performance improvement analytics
- Operator training simulators
- Remote diagnostics via secure cloud
- Full plant performance improvement analytics, before and after implementation



Part 4 Addressing Key Factors for Fired Heater Operation Using CombustionONE

COMBUSTIONONE FOR IMPROVED TEMPERATURE CONTROL

Improved measurements for pressure and temperature coupled with tighter controls have allowed CombustionONE to address three of the key factors:

- Downstream Pressure and Temperature
- Feed Composition and Rate
- Heat Distribution between Convection and Radiant Sections

By reducing the fluctuation of the outlet temperature (Fig. 5), the safety margin in maintaining the stability of the downstream process could be increased. Consequently, it was possible to reduce the set

point of the outlet temperature to reach the same safety margin without influencing the downstream process. Such action will result in reduction in fuel consumption, while increasing the efficiency of the heater.

Substantially fewer trips and increased asset life result from

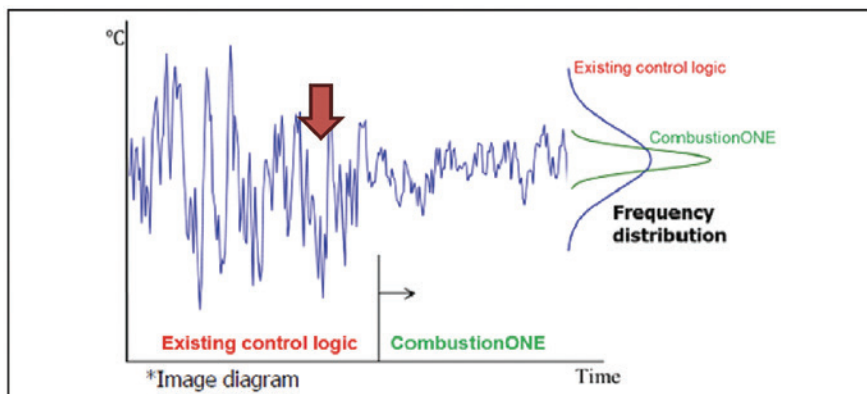


Figure 6 – Benefits of decreasing the magnitude of fluctuation of coil outlet temperature.

stabilized coil outlet temperature and O₂ content in flue gas. For fired assets such as steam methane reformers, which utilize catalyst in the tubes, avoiding trips can be critical to extending the life of the catalyst and delaying an extremely expensive catalyst change turnaround.

Well balanced burners reduce maintenance costs and allow longer run times between turnarounds. Balancing the burners and stabilizing the coil outlet temperature equalize the load and reduce aging of all radiant section components.

Reduced coking results in fuel savings and maintenance cost reductions. Stabilized combustion reduces tube deposits, which accelerate at high temperatures. By smoothing out temperature peaks, fired asset operators reduce the amount of decoking that is necessary and maintenance time required.

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Operating the fired heater at the edge of the safe operating envelope with minimum excess air will bring tangible benefits.

COMBUSTIONONE EXCESS AIR CONTROL

Operating the fired heater at the edge of the safe operating envelope with minimum excess air will bring tangible benefits. These translate into cash and the return on investment (ROI) can easily be calculated, thus justifying the investment in safety improvements.

As proven by more than ten European installations, the level of oxygen was reduced to 1% in flue gas for refinery gas and 2% for a combination of oil and gas. As a consequence, the consumption of the fuel was reduced between 0.6 to 4.2%, depending on the heater design and actual operating conditions. Usually, the concentration of oxygen in flue gas is kept between 2.5 to 3.5%, but there are cases where the heaters are operated above 4%. Additional savings could be generated by stabilization of COT. Experience shows that an additional 2–6% of the fuel consumption savings can be achieved (Fig. 6).

Note: Varying fuel composition makes it difficult to maintain low O_2 operation. The CombustionONE approach proved that this difficulty can be overcome.

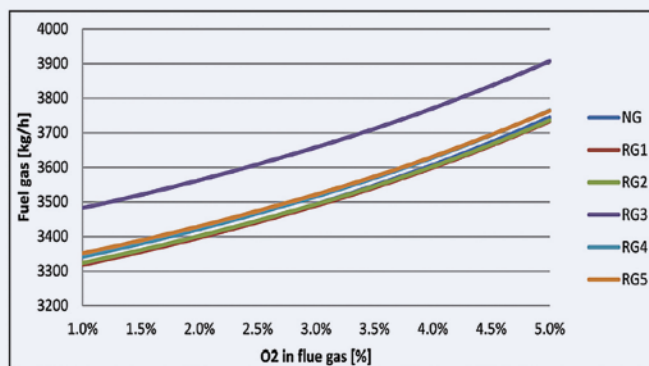


Figure 6 – Fuel consumption based on different fuel gas compositions and O_2 concentrations in fuel gas

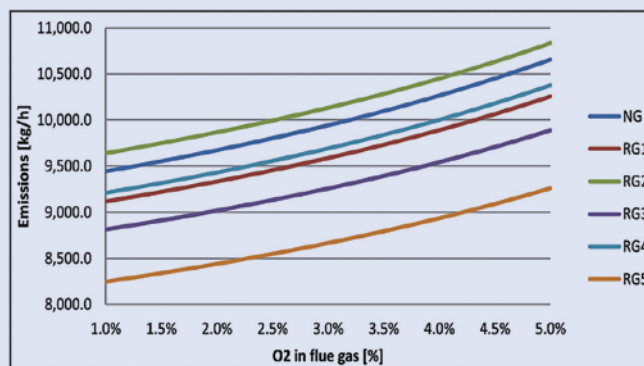


Figure 7 – CO₂ emissions based on different fuel gas compositions and O_2 concentrations in fuel gas



Tight excess air control also provides for significant emissions reductions. Reduced NO_x emissions will decrease the load or even eliminate the need for an SCR, and the corresponding ammonia injections.

Considering the price of 6 Euro/t of CO₂ emission, it would be possible to reduce emission by 1.5 t/h for this specific simulated case, resulting in more than 70,000 Euro p.a. In the simulations performed, savings were generated in the range of 0.8–2.5 t of CO₂ for natural gas and fuel oil, stemming from a reduction in excess air and reduced fluctuation of the coil outlet temperature (Fig. 7).

COMBUSTIONONE FOR FUEL COMPOSITION CHANGES

A real-time heating value estimate enables continuous bias of the air/fuel ratio to stabilize combustion and heat transfer into the tubes. This significantly eases fired asset operation while minimizing the thermal stresses on the tubes, even under conditions such as wide swings in demand or fuel heat value.

COMBUSTIONONE FOR FUEL COMPOSITION CHANGES

Last, but not least, CombustionONE was shown to enable safety improvements through the following measures:

- Detection of potential fuel leakage from burner firing valves
- Detection of failures of pilot burners
- Replacement of flame of sensor by utilizing TDLS or failure of flame sensors
- Trip prevention
- Reduction of the risk of liquid in gas piping
- Alarm derived from liquid level in fuel gas plant.

Part 5 APC vs. CombustionONE

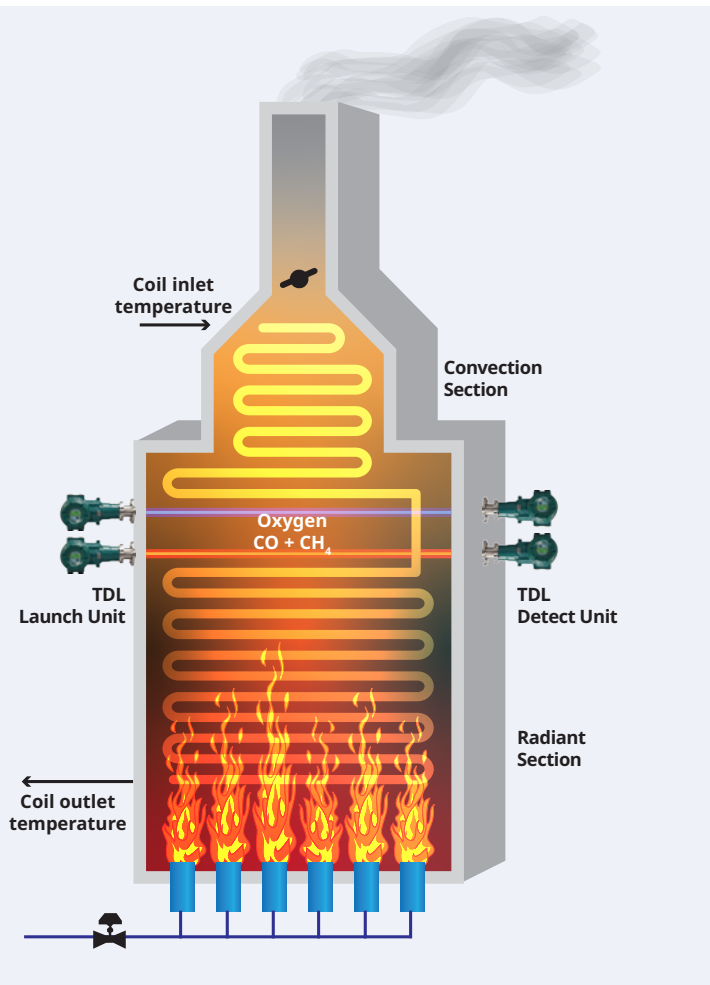


Figure 9 – Schematic example of utilization of Yokogawa TDL technology

In many cases, similar benefits could be achieved using Advanced Process Control. Based on Yokogawa's experience, the implementation of APC is more time consuming and requires higher investment. Additionally, special attention has to be paid to the cycle time, which could result in the necessity for rapid disturbance response (e. g. CO excursion) on heater performance.

The major differentiation factor between APC and CombustionONE is the increased safety of the fired heater by running it at the edge of the safe operating envelope with minimum excess air. Running at low O_2 without CO results in less combustion air (low excess air) being used, and less stack loss results in higher efficiency with the ultimate aim of reducing the risk of tripping. Tripping causes thermal shocks to heater components, which can increase the probability of component failures.

CombustionONE keeps focus on the following operating parameters/situations:

- Burner pressures, tube skin temperatures, furnace draft, O_2 , CO, fuel, air
- Automatically handles damper failure and potential operator mistakes
- Fuel valve failure

If burners are air-limited, higher throughput is possible with low excess air.

Part 6 Conclusion



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CombustionONE has also been proven to increase fuel efficiency, increase productivity, reduce NO_x and CO₂ emissions, reduce SCR ammonia injection, and increase asset and catalyst life spans.

While controlling the coil outlet temperature under a variety of dynamic conditions provides many benefits to fired heaters, CombustionONE is able to do much more. As a trip prevention solution, it allows the fired heater combustion process to recover from any disturbance by slightly changing parameters based on predefined logic and monitoring the progress of recovery. Otherwise, the typical recovery procedure should a trip occur would take a minimum of 12–24 hours, resulting in loss of production.

CombustionONE has also been proven to increase fuel efficiency, increase productivity, reduce NO_x and CO₂ emissions, reduce SCR ammonia injection, and increase asset and catalyst life spans. Operating the fired heater at the edge of the safe operating envelope with minimum excess air provides tangible benefits that maximize the return on investment (ROI).

Experience shows that it is important to combine the simulation results and the operation specifics during fine-tuning of the control system. An extra step is taken to evaluate the design of loops, to come up with the best result and operating performance for the fired heater in question. In properly selected heaters it was possible to achieve an ROI within two years.

