

## DUPLEX™: LESSONS LEARNED AND ROADBLOCKS OVERCOME TO ITS SUCCESS

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**Abstract:** Duplex™ is an innovative combustion technology that has been successfully implemented in a variety of industrial applications including refinery process heaters, once-through steam generators, enclosed flares and boilers. The technology provides unparalleled environmental and process performance characteristics to those of conventional low NO<sub>x</sub> (LNB) and ultra-low NO<sub>x</sub> (ULNB) burners. The development and implementation of the technology in refinery process heaters has evolved into ClearSign's Plug & Play™ ("PNP") platform, an easily retrofittable system to replace existing burners that can deliver NO<sub>x</sub> performance below 6 ppm (corrected to 3% O<sub>2</sub>) and operate at higher volumetric furnace heat densities when compared to LNBs and ULNBs. The development of PNP has yielded unique developments not only about those typically encountered in combustion systems such as kinetics, fluid dynamics and heat transfer, but also other sciences such as CFD modeling, materials, diagnostics and controls. The paper gives insight into the evolution of the technology driven by industry feedback and market requirements as well as provides an update on its unique performance characteristics, latest field installations and industry acceptance of the technology.

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### 1. Introduction:

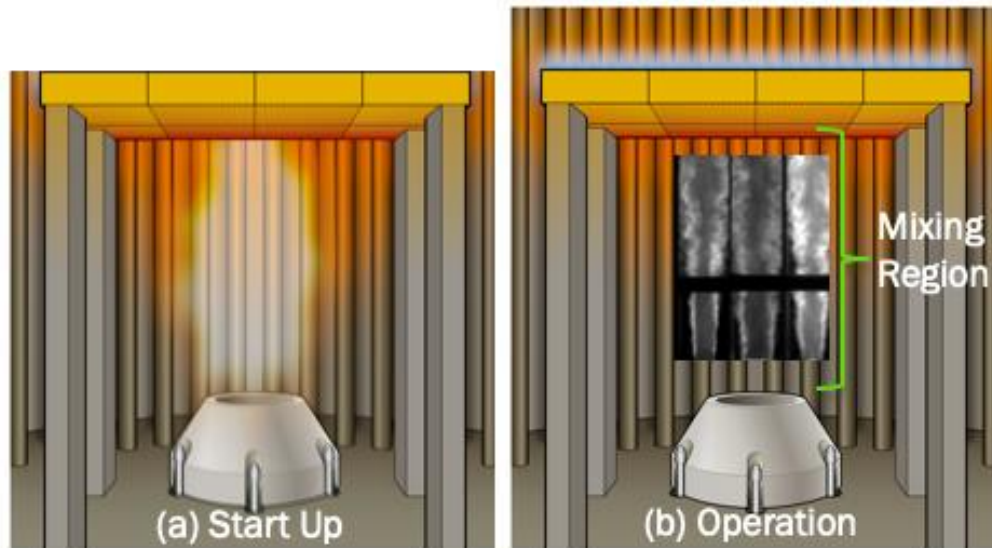
Since the introduction of ClearSign's Duplex technology in early 2013, end users in even the strictest regulatory environments have been offered a burner solution to meet their ultra-low emissions needs. Duplex is capable of achieving nitrogen oxide (NO<sub>x</sub>) emissions levels below 6 ppm (corrected to 3% O<sub>2</sub>), while also eliminating flame impingement on process tubes and enhancing radiant heat transfer. These ultra-low emissions levels are achieved without the use of external flue gas recirculation, steam injection, high excess air, or catalysts/reagents. The novel technology has been successfully demonstrated in Once-Through-Steam-Generators (OTSGs), refinery process heaters, boilers, and enclosed ground flares up to 70 MMBtu/hr in capacity.

Duplex has continuously evolved over the past several years, with its developments driven by end user feedback, operator behavior, and market requirements. To this day, Duplex employs a high-temperature porous ceramic surface located a prescribed distance from the fuel/air injection place. In this zone, fuel and air thoroughly mix and entrain internal flue gases. The resultant mixture provides a relatively homogenized, and diluted, reactant flow which is ignited and stabilized by the hot Duplex surface.

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Until recently, the sequence to arrive at “main burner operation” (i.e. Duplex operation) was rather unique in the industry, requiring a warm up period in order to preheat the porous ceramic surface. Once the warmup period was complete, the flame would “transition” from being anchored near the fuel/air injection plane to stabilizing on the Duplex surface itself (see Figure 1). Operational permissives were established to ensure this transition was completed safely and reliably.



**Figure 1 - Prior Duplex operation modes.**

Recently, ClearSign’s Duplex has evolved once more, incorporating design changes that simplify the technology while simultaneously improving operational requirements thereby aligning the operation with standard burner technology making it more familiar to operators running legacy process burners and/or equipment.

## **2. Technology Development**

Duplex was publicly introduced in 2013 solely as a retrofit concept attached to an OEM burner. Straight-channel, or “honeycomb”, ceramic tiles were mounted above the burner block, while minor modifications were made to the OEM burner tips and manifolds to allow for warmup and “transition-to-Duplex” modes. At the time the development of the technology was constrained by the intention that it would be something to add to installed burners and was therefore dependent on other burner vendors necessitating that the designs were totally generic.

Only through removing the constraints and many “What ifs” did the true discovery of Duplex unfold - a groundbreaking burner technology all of its own, with no dependency on another burner manufacturer. By designing

new ways to anchor and destabilize a flame for warm up periods Duplex evolved into a fully functioning burner technology and new performance benefits became accessible. At its core, a custom fuel tip arrangement and monolith of ceramic honeycomb tiles proved capable of achieving unprecedented emissions, without requiring any nonstandard operating conditions, and could be installed in practically any configuration known in the industry: natural draft, forced draft, up-fired, side-fired, heavy fuels, low BTU fuels, etc.

The second major evolution to Duplex came by way of the Duplex Plug & Play™ platform (Figure 2 below). With this configuration of the technology, the entire Duplex ceramic structure (flame holder), pilot, ignition system, fuel and air delivery are arranged as a complete unit like a conventional burner. The high temperature ceramic structure is further sized to fit through an existing burner opening in a heater floor. This required a design overhaul to support the ceramic tiles appropriately. With these changes, Duplex was capable of being installed entirely from outside a heater, much like conventional burners. At the same time, ClearSign had spent significant resources on understanding material sciences and improving the robustness of the ceramic materials, since they formed the backbone of the technology. Developments in the porous ceramic geometry enabled exceptional longevity and robustness of the flame stabilizing structure. The new material offered a crack propagation-resistant design while the change in material enhanced both the maximum use temperature and thermal shock resistance. This second-generation Duplex gained significant attention in the industry.



**Figure 2: Duplex Plug & Play™ Burner.**

Duplex Plug & Play has proven sub-6 ppm NO<sub>x</sub> emission performance (with many cases below that), compact flame profiles, and versatile burner design that can accommodate a wide variety of fuel blends. With installations ranging from pure natural gas firing to refinery fuel blends with up to 70% hydrogen by volume to heavy fuels (see Table 1 below), the developments to the technology had proven successful. Equipped with a foundation of field data across process heaters, enclosed ground flares, and once-through-steam-generators, product development at ClearSign was refocused to enhance the simplicity ease of use of this new burner technology with an ultimate goal of providing a like-for-like replacement of traditional burners from an installation and operations perspective.

**Table 1 - Fuel capabilities of Plug & Play.**

Fuel Blends			LHV (Btu/scf)
Natural Gas (vol. %)	Propane (vol. %)	Hydrogen (vol. %)	
100	0	0	922
30	40	30	1313
60	15	25	980
30	10	60	680
20	0	80	404

The third and most recent evolution of Duplex was a result of a focus on ease of use and normalizing the technology. A continuous and elevated pilot was added to the design to obviate the transition mode. Instead, Duplex now follows a conventional burner startup sequence; pilot light off, pilot verification, and main burner (i.e. Duplex) firing. The sequence is identical to conventional or low NO<sub>x</sub> burner technologies, making its operation feel very familiar to operators. Duplex operation, and unprecedented emissions performance, is achieved in mere seconds.

One final element added during the last development cycle was the simplification of the Plug & Play design. With several field installations of the Duplex technology, many design variables are now better understood, allowing a higher degree of standardization and a simpler design. This has enabled faster installation times, a smaller inventory of spare parts, and reduced maintenance. Finally, this simplified and standardized burner configuration has been consolidated into a “ClearSign Core™” enabling this technology to be embedded into burners, flares or combustors of traditional OEM companies’ products.

**3. Case Study**

In June 2019 ClearSign commissioned a 15 MMBtu/hr Plug & Play burner in an up-fired process heater at a California refinery (Figure 3). Emissions targets mandated by the local air quality district are 6 ppm NO<sub>x</sub> and 50 ppm CO, both corrected to 3% stack O<sub>2</sub> (dry). The installation is an upgrade from the previously installed ClearSign 8 MMBtu/hr Plug & Play burner [Ref. Oil & Gas Journal, April 2019, pp. 54-57] which was an interim solution while ClearSign

completed the design of the larger capacity system. The 15 MMBtu/hr burner now allows the heater to fire up to its maximum rated duty of 15 MMBtu/hr, a firing rate the heater had not achieved in decades. The burner incorporates all the features of the latest evolution of Duplex as described in the previous section, with its operation identical to conventional or other low-NOx burners. The burner employs a ClearSign-proprietary continuous pilot, a series of lattice members that provide robust flame stabilization, and porous ceramic surfaces that create a three-dimensional high-temperature flame zone. The high heat flux from the porous ceramic surfaces combined with the high reaction rates in the flame zone result in a very compact flame thereby completely eliminating any flame impingement on process tubes to enable increased process throughput when needed.

As required by the operators, the burner operation is fully-automated. The heater PID control modulates the firing rate as needed based on the process outlet temperature.

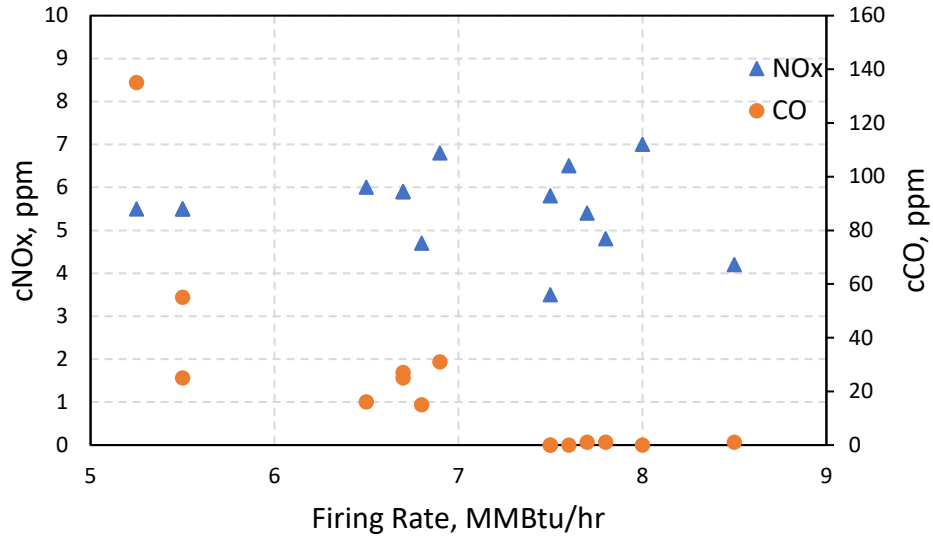


**Figure 3: Refinery Process Heater (left) and ClearSign Plug & Play Burner (right).**

Since commissioning in late June 2019, the burner operates in compliance with sub-6 ppm NOx emissions and sub-50 ppm CO emissions across its range of operation (See Figures 4 and 5 below).

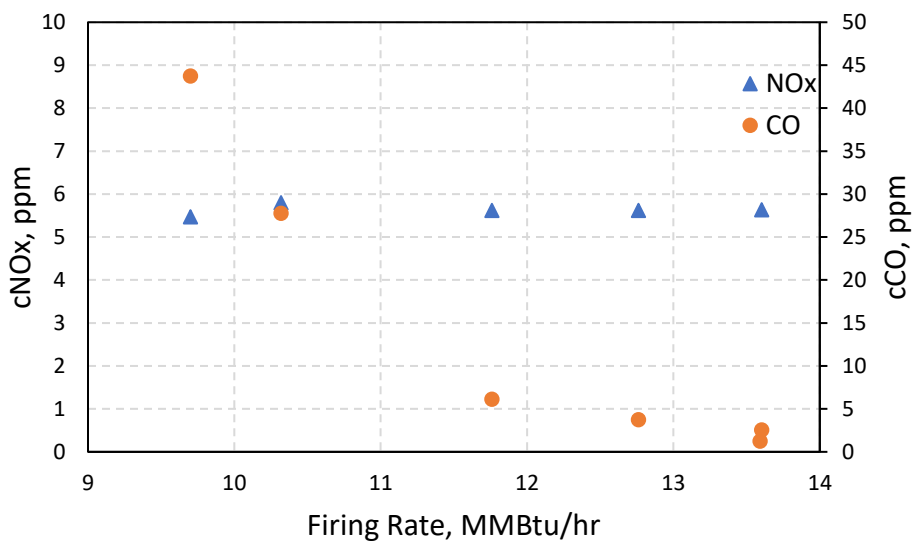
Figure 4 shows the NOx and CO emissions results for the initial 8MMBtu/hr burner while Figure 5 details the corresponding 15MMBtu/hr results. For the initial burner, it can be shown that NOx emissions (corrected to 3% O<sub>2</sub> dry) were relatively constant at 5ppm +/- 2ppm with CO emissions dropping from roughly 130ppm to zero as the burner capacity was increased as expected. The higher CO at the lower firing rates were due to the low bridgewall temperatures, often below 700 °F stemming from the reduced combustion intensity existing within the furnace. NOx

performance is relatively flat due to the competing effects of increased mixing and entrainment of FGR (which would reduce NO<sub>x</sub>) as fuel capacity increased versus higher heat densities (heat release per unit volume) which would elevate NO<sub>x</sub> formation.



**Figure 4: Emissions Performance (corrected to 3% O<sub>2</sub>) for the 8 MMBtu/hr Burner.**

As the customer demands dictated, a larger burner was developed using the same scaling laws as used for the smaller capacity burner and is shown (Figure 5) to yield similar NO<sub>x</sub> performance - around 5ppm. CO is much reduced due to the overall higher heat density existing in the furnace that would more effectively oxidize the CO to CO<sub>2</sub> as reflected in the higher Bridgwall temperatures (~1000 °F).



**Figure 5: Emissions Performance (corrected to 3% O<sub>2</sub>) for the 15 MMBtu/hr Burner.**

The upgraded burner now meets all of the refinery's production needs - lower firing rates for dehydration and capacities up to 15 MMBtu/hr for fractionation cycles - all while maintaining compliant emissions.

#### **4. Conclusions**

ClearSign's Duplex Plug & Play technology has continuously evolved to address a multitude of performance, installation, operability and customer requests. There have been many developments over the years, some familiar to burner manufacturers and others unique to this innovative technology. With the latest developments (improved ceramics and elevated pilot), the Plug & Play technology now operates like conventional burners while delivering exceptional emissions performance around 5 ppm. These design changes have already been successfully implemented in an up-fired process heater located in one of the strictest regulatory areas in the world (Southern California), achieving sub-6 ppm NOx emissions at firing capacities up to the heater's 15 MMBtu/hr nameplate capacity. ClearSign is now, more than ever, better poised for rapid deployment of the technology into regulated emissions zones into a myriad of market verticals.