THE CLEARSIGN CORE™ BURNER: TECHNOLOGY DEVELOPMENT AND FIELD RESULTS

Jeff Lewallen, Venkatesh Iyer, Donald Kendrick, Steve Sock
ClearSign Technologies Corp., 12870 Interurban Ave S, Seattle, WA 98168
AFRC 2021 Industrial Combustion Symposium

I. Abstract

At the 2019 AFRC Industrial Combustion Symposium, ClearSign introduced the ClearSign Core brand name to clearly differentiate our current Ultra Low NOx burner technology from earlier versions of our product and to describe how it will be supplied as the "core" inside established OEM burner manufacturers products. The ClearSign Core burner represents the commercial version of our Ultra Low NOx product and it provides greatly simplified burner operation and a wider range of burner stability across varying fuel compositions and operating conditions. This operational performance improvement has been achieved without sacrificing the proven sub-5ppm capable NOx performance of our technology.

The modifications made to our earlier technology eliminate the original, but non-industry standard start up sequence, so now burner operation is fully aligned with our customers' expectations and similar to other standard industry burners. This modification did present some technical challenges to provide the standard wide ranging operating performance expected from typical burners. These have now been overcome through extensive efforts conducted in 2020, initially in our Seattle, Washington R&D center, and subsequently in full scale factory test equipment in Tulsa, Oklahoma, including multi-burner configurations. The resulting ClearSign Core burners now achieve single digit NOx and operate just like conventional burners widely in use today. ClearSign Core burners have now been installed in multiple industrial facilities generating real world feedback and confirmation of tested performance.

The subject paper will provide insight into technology development process, especially the burner modifications associated with modifying the operating range while maintaining NOx performance. Test data from lab and factory testing will be shared, as will real operating results and lessons learned from field installations and case studies.

II. Introduction

ClearSign has been developing and supplying Ultra Low NOx combustion products to industry since 2013 and this past year marked a significant milestone with the advancement of the ClearSign Core technology for three unique product applications. These applications are:

- Process Burners,
- Enclosed Combustors,
- Boiler Burners.

In the past year, ClearSign has developed and applied our ClearSign Core technology to each of these products and has successfully delivered, installed and commissioned field equipment using this improved version of our technology.

III. Technology Development

The ClearSign Core technology represents the culmination of developing our Ultra Low NOx burner technology that has been presented previously to the AFRC and delivered to more than 15 customers in 4 different product applications. In addition to these customers, many industry experts were shown the technology and their feedback was solicited. One of the most common comments was that the operating sequence of the legacy version of the technology was not aligned with industry standards, presenting a potential barrier to utilization. ClearSign listened to this feedback, modified the technology to operate like existing equipment, and rebranded the resulting product as ClearSign Core.

The ClearSign Core technology is a substantial improvement over legacy versions of our technology because our current products that incorporate this technology operate very similarly to conventional burners commonly in use today. This improvement was accomplished by the addition of an industry standard pilot to the burner located near the flame stabilization feature, thereby enabling easy light off in line with conventional burner operating procedures and common safety systems and devices. In addition, this change resulted in improved burner stability during both typical and abnormal operating conditions, but this addition was not without challenges however, as the addition of the pilot contributed significantly to the NOx emissions of the modified burners. Additional proprietary features were subsequently developed in order to maintain the consistent single digit NOx performance of our original technology.

Initial development and testing of the ClearSign Core technology was conducted in two unique pieces of lab equipment at ClearSign's Seattle, WA research and development center. Research and development for process burner applications was conducted in an upfired, natural draft test furnace capable of 5 MMBTU/hr maximum heat release. This furnace is equipped with a mutli-fuel blending manifold and testing was conducted on a wide range of fuels, from 100% natural gas, to heavier fuel gas blends containing up to 50% propane, and on lighter fuel gas blends containing up to 80% hydrogen. In this way, the ClearSign Core process burner has been developed for a range of fuel compositions commonly found amongst industry users. Furthermore, the technology can be tailored to suit applications ranging from extremely low HHI (<60,000 Btu/ft^2) to over 500,000 Btu/ft^2 by altering the location of the fuel injection nozzles, height of the flame holder, and coverage area of the flame holder.

Upon completion of the process burner development and testing in Seattle, ClearSign worked with its new partner, Zeeco, to fabricate and test the process burner in two different full scale industrial test furnaces at Zeeco's facility in Broken Arrow, OK. One furnace is a large single burner furnace, and the other is a multi-burner furnace. The multi-burner testing was especially important in order to ensure that burner to burner interactions, even is the burner spacing is less than current API recommendations, would not affect burner performance or stability. In addition, factory acceptance testing for multiple third party customers has been conducted at this same site for burner sizes ranging from 2 MMBtu/hr to over 10 MMBtu/hr.

In parallel with the process burner development, ClearSign also conducted similar testing for a different burner application – fire tube boilers. Also located in the Seattle lab, ClearSign has a 125 HP commercially available fire tube boiler with a maximum heat release of 5.2 MMBTU/hr. As with most fire tube boilers, this equipment uses a single, horizontally fired, forced draft burner located within a narrow diameter fire tube inside the boiler.

Finally, ClearSign recently added a third piece of commercial scale test equipment to our Seattle research and development center which is a small enclosed combustor with a heat release of up to 0.65 MMBTU/hr. This was added to test emissions of a ClearSign Core technology burner for application without any process heat removal that helps reduce NOx formation.

Upon successful development and testing of burners for each of these applications, ClearSign successfully delivered, installed, commissioned and tested this equipment for clients at their operating facilities.

IV. Process Burner Case Study

In September of 2020, ClearSign was awarded a contract to supply three ClearSign Core process burners to a confidential client in greater Los Angeles. This client had an existing vertical cylindrical process heater with conventional Ultra Low NOx burners that could not meet the new emissions required by the local regulator. Since the newly required emissions were so low (7 ppm NOx, corrected to 3% excess O_2), an SCR was originally considered for the project to meet this NOx requirement, however, upon learning about the ClearSign Core technology and its best-in-class process burner NOx performance, the client elected to pursue a burner replacement project using the ClearSign Core process burners.

The heater is equipped with three upfired, natural draft burners that have two separate fuel streams. The main fuel is pipeline quality natural gas, while the secondary fuel stream is a recovered off gas from the process with a heating value similar to propane. The maximum heat release per burner is 4.2 MMBTU/hr.

ClearSign fabricated the test burner and successfully conducted a factory acceptance test in November of 2020. Final fabrication of the three burners was then completed and burners were shipped to the site in February of 2021. Burners were installed, commissioned and successfully tested in March of 2021, and the unit was turned over to the client. See Figure 1, for a photo of the burners installed in the furnace and Figure 2 for a graph of the field recorded NOx emissions against operating O_2 levels, showing a wide range of operating flexibility for emissions compliance. A third-party source test was conducted in April of 2021, and the measured NOx emissions at full firing rate was 6.25 ppm NOx, corrected to 3% excess air, thus meeting the required 7 ppm NOx guarantee. The source test has been submitted to the local regulatory authority for their final review and acceptance.

Figure 1 – Installed ClearSign Core Process Burners

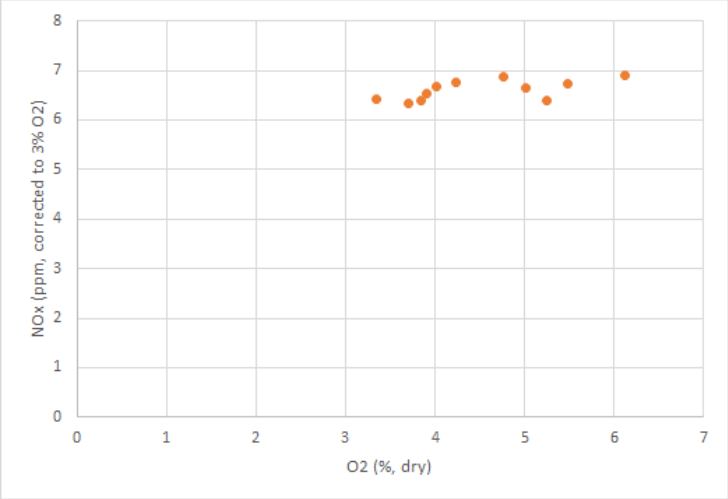

Figure 2 – Corrected NOx vs Operating O_2

V. Enclosed Combustor Case Study

Earlier in 2020, ClearSign and its partners were awarded a contract from a small oil producer in the Signal Hill area of greater Los Angeles, CA, near Long Beach. This operator had four individual well sites for crude oil production that produced small amounts of associated off gas in such small quantity as to be uneconomic to recover. This operator historically disposed of this gas with traditional elevated flares, but new regulations from the local authority now require extremely low emissions from such operations. As a result, the ClearSign Core technology was selected to use in new Ultra Low NOx enclosed combustors at these sites.

These sites were disposing of well-head gas at volumes ranging from 2.5 to 30 MSCFD. The heating value of the gas ranged from 1452 to 1752 BTU/scf HHV, depending upon the site. Emissions required were sub 15 ppm NOx, and sub 13 ppm CO, corrected to 3% excess O_2. In addition, no visible flames or emissions were permitted.

ClearSign and its partners designed and supplied four separate enclosed combustors for these sites, including the burner, flare stack, fuel gas train, burner management system, and controls. The combustors were installed between June and November of 2020, and emissions tests were passed for each unit. Emissions for all units were sub 10 ppm NOx and sub 10 ppm CO, both corrected to 3% excess O_2. Emissions for the largest unit are presented in Figure 3.

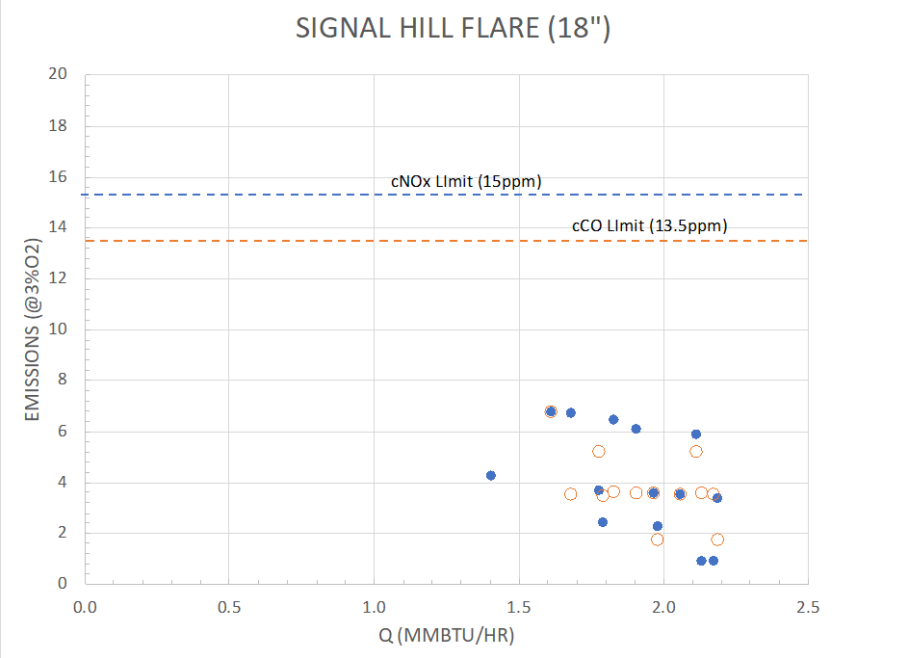

Figure 3 – NOx and CO emissions and limits vs. heat release, corrected to 3% O_2

VI. Fire Tube Boiler Burner Case Study

ClearSign has partnered with California Boiler, a large boiler service company in California, to commercialize a complete ClearSign Core fire tube boiler burner product line, with sizes up to 60 MMBTU/hr. The first field installation of this product occurred on a rental boiler at California Boiler's shop in Visalia, CA in August of 2021. This is the first of multiple ClearSign Core fire tube boiler burners to be installed on California Boiler's rental boilers for use in California.

The initial unit is a commercially available, 125 hp 2-pass, fire tube boiler. The maximum burner heat release is 5.2 MM BTU/hr. Local emissions regulations for this size equipment are sub 5 ppm NOx, corrected to 3% excess O_2. For boilers larger than 20MMBTU/hr, the NOx limit drops to 2.5 ppm. As a result, ClearSign's target for all ClearSign Core fire tube boiler burners is to be sub 2.5 ppm NOx. In addition, the burners were designed to work with standard available fuel gas pressure, to meet sub 50 ppm CO, and achieve 3:1 turndown. Expected emissions of the ClearSign Core fire tube boiler burner can be controlled simply by adjusting the operating excess O_2 in accordance with Figure 4, allowing the burner performance to be tuned on site to meet local NOx emissions requirements across a fairly wide operability range.

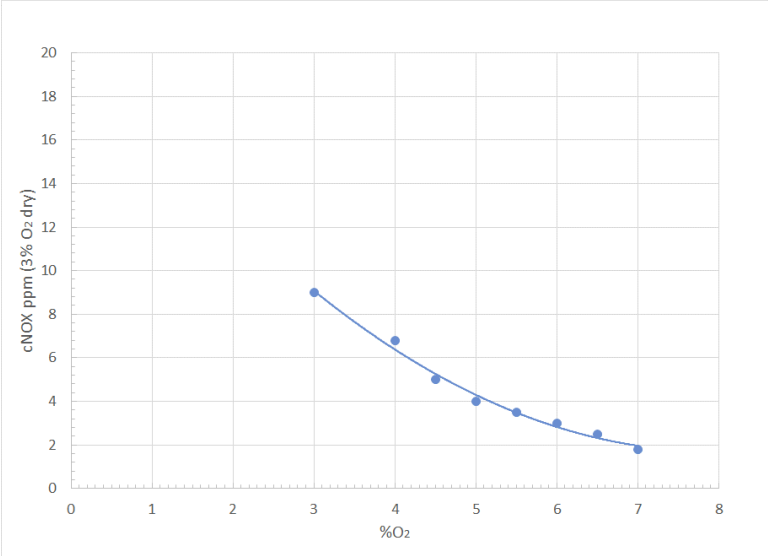

Figure 4 – Corrected NOx emission vs. operating O_2

On August 20 a third party source test company visited the site to confirm emissions of the burner. The burner successfully met the local regulatory requirement for NOx and CO across the full 3:1 turndown and is now available for rental in the region. Measured NOx performance was as low as sub 2 ppm NOx corrected to 3% excess O_2 for this burner at full firing rate. A third party customer has been identified and the boiler is scheduled to be shipped and installed at that site in September. Concurrently, a 500 HP (20 MMBTU/hr) burner has been fabricated and shipped to the site for installation and testing through October.

VII. Conclusions

In 2019, ClearSign made the decision to continue to invest in, and further improve a successful product in order to accommodate our customers' desires of having the product operate similar to equipment with which they and their staff were already familiar. As a result, an extensive development program was embarked upon involving five unique pieces of large-scale test equipment at two different sites across three different product applications. Within the past year, ClearSign Core products were successfully installed at operating facilities for each product application, thereby confirming the success of the development program.