EC SENSOR™: FLAME SAFETY AND FUEL SAVINGS INTEGRATED INTO ONE SYSTEM

Robert Geiger, Jackson Pleis, Donald Kendrick, Steve Sock, Jim Deller
ClearSign Combustion Corp., 12870 Interurban Ave S, Seattle, WA 98168
AFRC 2019 Industrial Combustion Symposium

Abstract. Safety is the most important consideration in the operation of any combustion system. To that effect, operators of combustion equipment monitor the presence of a flame in various ways. The most common flame monitoring sensors include flame rods, infrared scanners and ultra-violet scanners. Although these systems have gained wide industry acceptance, in some instances they may suffer from disadvantages related to longevity, reliability or unexpected nuisance shutdowns. A system that eliminates these disadvantages would be highly beneficial. Monitoring the flame alone does not yield information about stoichiometry of the fuel-air mixture. Fuel-air ratio control is generally accomplished by measuring the oxygen concentration in the stack. To accommodate proper fuel-air mixing in diffusion-style burners and avoid carbon monoxide emissions, 15%-20% excess air (3%-4% excess O2 in the stack) is commonly the set point. Unfortunately, furnaces with multiple burners can only perform global control, leaving the potential for individual burner fuel-air ratio conditions that highly deviate from the global set point creating the potential for unsafe and fuel inefficient conditions. This can happen in natural draft furnaces because of wind conditions or improper air register positioning and can be an even bigger problem in forced draft furnaces with common air plenums where air flow maldistribution is not uncommon. ClearSign Combustion Corporation has developed the EC Sensor (Electrical Capacitance Sensor), a highly-reliable, innovative monitoring and diagnostic system that integrates the capability of continuous flame monitoring while measuring fuel-air ratio at the same time. The sensor incorporates ClearSign's patented technology on the use of electric fields in combustion systems that discriminates flames from other burners and does not require immersed probes in the flame, adjustments in the field of view or reliability on infrared or ultraviolet radiation.

1. Introduction

Industrial burners must be robust and reliable to ensure safe operation and efficient utilization of fuel. However, unforeseen conditions often occur during normal burner operation. Some examples include variations in fuel composition, clogged nozzle, mechanical failures, pressure variations, and operator error. With the increasing adoption of Ultra-Low NO_x burners, such unforeseen conditions tend to have a more significant impact on burner operation. As such, the need for new and improved methods of flame monitoring is crucial.

Flame detection sensors typically fall into one of three categories: optical, thermal, or electrical. The various sensors developed within these categories have their own pros and cons. Optical techniques are the most widely used sensor for flame detection. They provide a quick response and are fairly robust. Optical sensors rely on the light emitted from a flame (natural chemiluminescence) measured at a specific range of wavelengths, either Ultraviolet, Visible, or Infrared. These sensors require an unobstructed line of sight of the flame, have limited viewing angle (solid angle) and have difficulty differentiating between flames in multi-burner configurations. The most common thermal technique is a thermocouple, which detects a flame by directly measuring the heat release (temperature) of the flame. This technique is slower than optical techniques and requires the sensor be in or near the flame; they can therefore have a rather short lifetime. The most common electrical sensor is a flame rod. A flame rod detects a flame by exploiting the asymmetric conductivity property of a flame. In other words, a flame acts like an electrical rectifier when an AC signal is applied. Flame rods provide a robust flame presence signal and can differentiate between flames in multi-burner units. However, flame rods must be placed within the hot zone of the flame and can therefore have short lifetimes and poor reliability.

When it comes to flame safety for industrial burners, optical sensors have been the dominant choice and have been developed the most. New optical techniques are being developed that incorporate intelligent algorithms to analyze the optical signals of a flame and obtain more information about the combustion process. With advancements in UV scanners and the use of fiber optics, devices are getting close to measuring both the pilot and main flame. However, the issues with dust and debris still exist along with erroneous background radiation which can cause “false positives”.

Electrical techniques for flame monitoring have been largely underdeveloped. While flame rods are the most developed electrical technique for flame detection other electrical techniques are rarely mentioned. The electrical characteristics of a flame can actually offer a lot more detail about the combustion process, more than simply flame presence. This is because the chemical ionization process of a flame depends on the operating conditions of the flame. Therefore, by measuring various electrical properties of the flame it becomes possible to characterize key flame characteristics, such as equivalence ratio, Wobbe index, Lean Blowout (LBO) and even the level of turbulence. This additional information can be used not only to detect the presence of a flame, but also to optimize the process of a burner and/or entire furnace system operation. Furthermore, these electrical measurements can be made using sensors located outside of the hot zone, therefore improving their lifetime as compared to a flame rod.

2. EC Sensor

The electronics for the electrical sensor developed by ClearSign can accurately measure electrical properties of a flame. The basic configuration consists of two sensing electrodes situated at the periphery of a flame. The electrodes are connected to the EC Sensor electronic enclosure with two shielded cables. This configuration can be adapted to work in a variety of configurations including standard pilots and burners within boilers, process heaters, flares, and more. To explore the capabilities of the sensor, two test configurations were used. The first test configuration was a smaller electrode configuration used with a pilot/burner and the second was a larger scale, more generic burner solution. Both configurations used the data monitoring and collection system shown in Figure 1. This box was designed to be deployed in the field for real world testing. It consists of the EC Sensor electronics, a data logging system, and an LTE Cellular Modem to allow for remote monitoring and control.

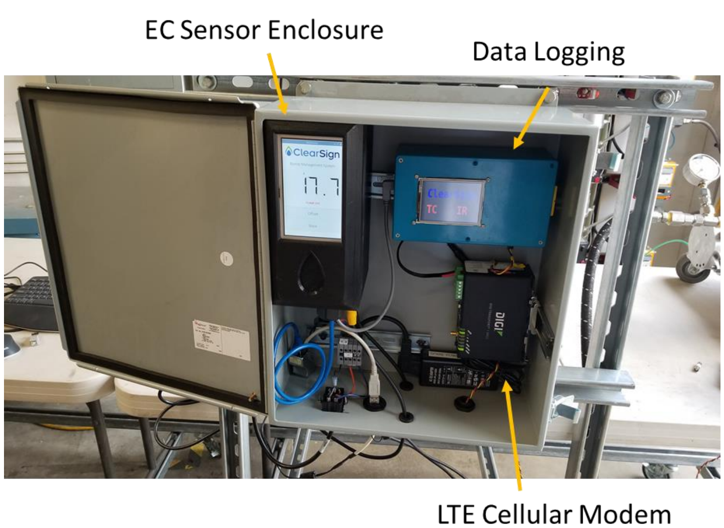

Figure 1 EC Sensor Electronics with data logging and remote monitoring for field installations.

2.1 Pilot/Burner

Initial sensor testing was carried out on a pilot burner developed by ClearSign. The burner is a swirl stabilized burner with a variable area venturi for varying the primary air educted by the fuel jet, Figure 2. The burner is mainly operated with natural gas at around 1 MMBtu/hr. Conical sensor electrodes are situated at the exit of the burner throat. The electrodes are connected to wires that run down the coaxial tube to the back of the burner where the electronics can be housed, making the burner completely self-contained. The electronics also include an igniter that utilized the EC Sensor to ensure the pilot remains ignited or shuts down the fuel after a 3 second no flame signal.

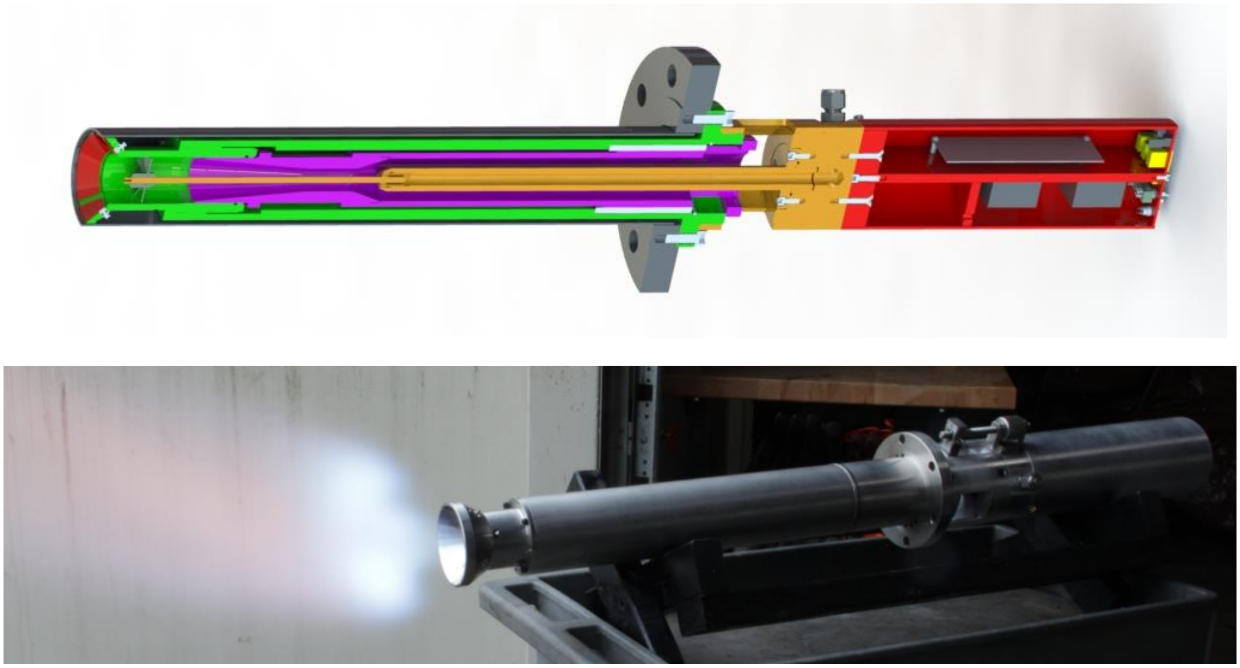

Figure 2 Test pilot burner designed with integrated EC Sensor.

The objective of the initial testing was to determine the robustness and speed of the EC Sensor as a Flame On/Flame Off detector. For this testing the EC Sensor, data from the sensor is plotted in real time using a software package developed by ClearSign. The sensor can acquire data at very fast rates, (10 kHz). Faster sampling rates are possible but are not of value for industrial burner applications. An example of the data produced by the EC Sensor while varying the firing rate is shown in Figure 3. Flame On and Flame Off responses were seen to be on the order of a few milliseconds. This response time seen by the sensor is the same as the actual ignition/extinction speed of the flame. In other words, the sensor provides a real-time measurement of the flame.

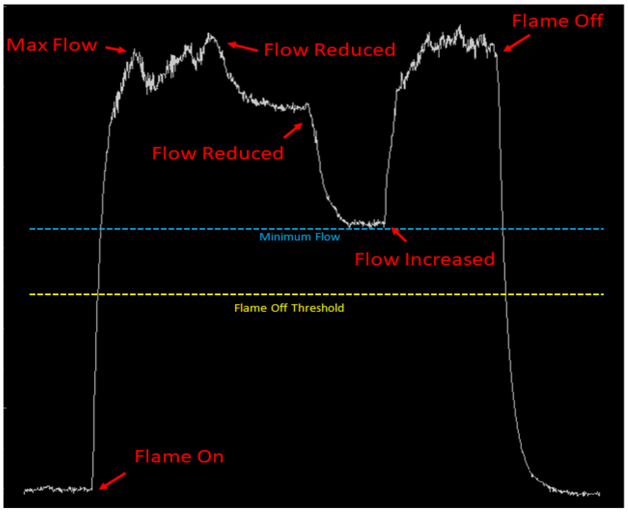

Figure 3 Flame On/Flame Off testing over a range of firing rates.

The signal produced by the sensor is sensitive to the firing rate of the burner, as seen in Figure 3. To use the sensor as a flame detector it is important that a threshold can be set, at which a clear Flame On/Flame Off signal can be produced. To ensure that a such a threshold can be set, the firing rate was varied over the largest feasible range for the burner [50 kBTU/hr to 1 MMBtu/hr]. From Figure 3 it is clear that a suitable threshold exists for flame detection. Furthermore, these results illustrate a unique ability of the sensor to provide additional information about the combustion process.

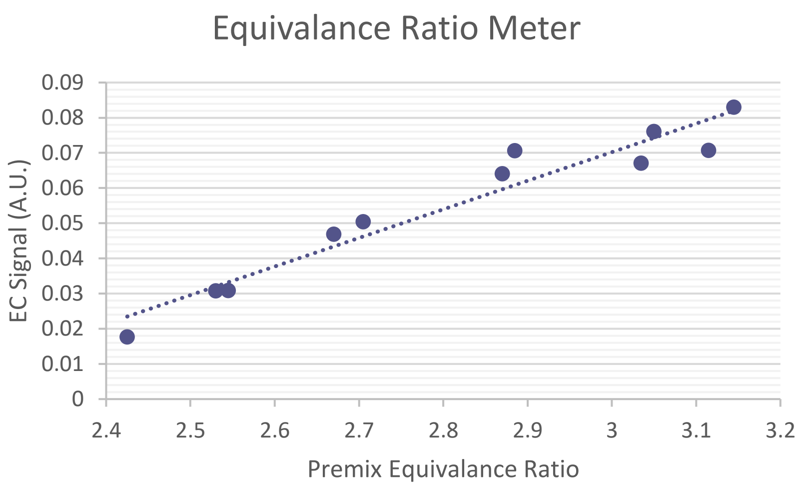

Figure 4 Calibration curve for equivalence ratio of burner.

The signal produced by the EC Sensor varies with the firing rate of the burner. Furthermore, the signal also depends on the equivalence ratio. This was tested using the burner and adjusting the variable area of the venturi, which altered the amount of air being educted. By measuring the flow rate of this primary air, the signal could be correlated to the equivalence ratio at a constant firing rate, Figure 4. A series of these calibration curves can be generated for different firing rates and fuels. This data can then be used to provide additional information about the operation of the burner which can be used to optimize it.

2.2. Burner

Figure 5 Generic burner EC Sensor electrode configuration.

The tests with the previous pilot/burner used sensor electrodes which were integrated with the pilot/burner; however, it is also possible to use larger electrodes for more standard burner applications for a retrofit application. To demonstrate this a new configuration was designed for a generic burner, Figure 5. This configuration is similar to the previous design; however, the electrodes were made much larger so as to fit within the throat of a burner tile. The electrodes are connected to wires that are fed through the furnace floor and out to the same electronics shown in Figure 1.

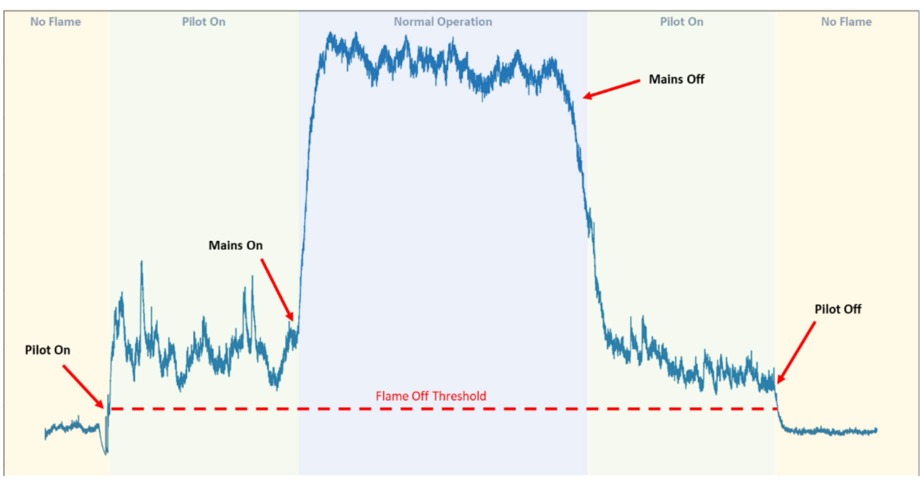

Figure 6 EC Signal produced from the generic burner electrode configuration for 1) no flame, 2) pilot on, and 3) normal operations.

Overall burner capacity tests have been carried out up to 5 MMBtu/hr. An example of the data collected from the generic burner electrode configuration is shown in Figure 6. The signal is initially at a baseline level. The pilot is then ignited, which causes a slight dip in the signal. The signal then rises to the pilot signal level above a set flame off threshold value shown as a dotted red line in Figure 6. After a brief warm-up period the main risers are opened, and normal burner operation begins. Once the mains are ignited the signal rises significantly above the pilot signal level to the normal operation level. There is a very clear distinction between each of these three regimes: no flame, pilot on, and normal operation. Once the mains are closed again, the signal drops back down to the pilot signal level. Finally, the pilot is turned off and the signal drops past the flame off threshold and back to the baseline signal.

3. Discussion

Flame detection and monitoring are two critical aspects of industrial burner operations. The ability to accurately detect flame presence is crucial for safety, while monitoring burner operation can provide valuable information that can be used to optimize the process. Of the available techniques, optical sensors are the most widely used and developed. Currently, there is a substantial opportunity to further develop electrical methods of flame detection and monitoring. ClearSign is actively pursuing this category of flame sensors.

The EC sensor developed by ClearSign has be developed and thoroughly tested in several applications. With a pilot type configuration, the EC sensor can provide a robust Flame On/Flame Off signal similar to a flame rod. A major benefit for this type of sensor is that it does not require putting metal electrodes in the flame. Instead, the sensor electrodes can reside on the perimeter, near the flame zone. This promises to make the sensor more robust, having a longer lifetime, and provide better reliability. Furthermore, when integrated with a pilot, flame detection can be accomplished locally, providing detection of only that pilot. It is not influenced by other nearby burners. When the sensor is integrated across an entire burner, the sensor can provide clear distinctions between the pilot flame and the main burner.

Beyond acting as a simple Flame On/Flame Off device, the sensor can also provide additional key information about the combustion process. The simplest use case of the signal would be to monitor the health of a burner. By monitoring the signal under normal operating conditions and deviations from that signal can be a key indication that something might be wrong with the burner and it should be investigated (plugged tips, fuel leaks, etc.). It was also demonstrated by using the pilot configuration that a calibration curve can be created which correlates the sensor signal to the equivalence ratio. Such calibration curves can be created for specific processes and firing rates. This calibrated information can then be used to help optimize the process. This optimization can be done both manually, by an operator, or even automated with an active feedback control system.