CLEARSIGN EYE™: PILOT SENSOR

Robert Geiger, Donald Kendrick, Jim Deller, Robert Culverhouse, Steve Sock, Jared Simon
ClearSign Combustion Corp., 12870 Interurban Ave S, Seattle, WA 98168
AFRC 20202 Industrial Combustion Symposium

Abstract. Clearsign Technologies Corp. has developed and tested a novel, capacitive based flame sensor for use on existing burners in a variety of industrial combustion applications including process burners, boiler burners and flares. ClearSign has developed two probe designs. The first probe design is compatible with existing burners and can leverage the existing flame rod port. The second design requires minimal modifications to the pilot mounting plate and has the additional capability of being removed without removing the pilot. Competing devices used for decades are frought with several drawbacks. Unlike a flame rod, the ClearSign detector is removed from the hot combustion environment, thereby exhibiting increased life, and is impervious to flase readings that are susceptible to traditional electrical, thermal, and optical strategies. Further, the technology can be extended to measure fuel-air ratio and other key flame "health" parameters. The new sensor, trademarked as the ClearSign EYE® , has been tested in various configurations, and under a range of operating conditions and disruptive events simulating real life situations known to degrade competing technologies. This paper discusses the engineering and testing done at ClearSign's R&D Center resulting in a new commercially available product.

1. Introduction

ClearSign Technologies has developed a new method of flame detection for industrial burner applications. After exploring all available technologies numerous shortcomings of these technologies were identified. The goal of this new flame detector is to provide a more robust alternative to currently available technologies. The ClearSign solution aims to be a reliable, long-life, low maintenance flame detector. This was accomplished by using a new electrical technique to be discussed in more detail in the next section. When choosing a flame detector, the combustion engineer is faced with several choices. Flame detection technologies typically fall into one of three categories: 1) Optical, 2) Thermal, or 3) Electrical. Each of these stretgies will be discussed below.

Optical sensors cover a wide range of frequencies including Infrared, Visible, and Ultraviolet. Optical sensors have seen substantial improvements over the years. These improvements are not so much related to hardware improvements, rather they are related to software and how the actual signals are analyzed. Many optical sensors are now available which incorporate multifrequency analysis to provide a more reliable detection. Optical sensors have the benefit of remote detection; they do not need to be in proximity with a flame to detect it. However, they do require a clear line of sight which can sometimes be problematic. Furthermore, optical sensors can produce false positives. This can occur if they pick up either ambient light or the light emission from neighbouring flames, as in a multi-burner configuration. They can also produce a false negative if the optical path is obstructed (ie. soot on debris on view port), or if the light of the flame is not within the detectable wavelength of the sensor (ie. excessive hydrogen compared with pure natural gas).

Thermal flame detection techniques generate electrical signals based on the temperature of a probe, such as thermocouples or thermistors. Unlike optical sensors, thermal techniques require immersing the probe into the hot environment of the flame. Using this method to detect flames has several downsides. In applications where fast response times are needed, thermal techniques are typically not the best choice. For accurate flame detection, the probe must be heated to a certain threshold temperature before providing a flame on signal; subsequently, the probe must be cooled below that threshold to provide a flame off signal. The cooling process in particular may be quite slow, especially in a heat-soaked furnace. Furthermore, immersing metallic probes within or nearby a flame leads to rapid deterioration and therefore lifetime and reliability challenges.

Flame rods are the only technology available that falls into the electrical category. This technique works by immersing a probe within a flame and driving an alternating electrical signal through it. This technique relies on the fact that a flame naturally contains charged particles (electrons and ions), which make it electrically conductive. In this way, the flame becomes a part of an electrical circuit which includes the flame rod, the flame, and the pilot itself. This circuit behaves differently when the flame is present than when it is not, therefore providing a method to detect flame presence. Like the thermal methods, this technique requires immersing a metalic probe within the flame, leading to rapid deterioration. Depending on the application, flame rods can have lifetimes spanning from just a few weeks to a few months. Furthermore, flame rods can be finicky for two main reasons. First, they are dealing with very small currents (microamps). These currents must be amplified, and this process can be prone to electrical noise and therefore false readings. Second, as mentioned the flame becomes part of the circuit. If the flame rod loses contact with the flame, the sensor will provide a flame off signal. Similarly, if the flame loses contact with the pilot, it can also provide a flame off signal. Finally, the flame rod needs sufficient grounding surface area that can result in additional unwanted metal, where it is co-located. Even with these drawbacks, the flame rod has found abundant use throughout industry and in many applications, even despite the significant shortcommings, is considered the standard.

2. Flame Sensor Development

Recognizing the widespread usage of flame rods, and their many drawbacks, ClearSign set out to develop a more reliable, long lifetime, low maintenance, electrical flame sensor. The principal behind the flame rod is not a bad one. The fact of the matter is that flames do possess unique electrical properties that can be exploited to measure the presence of a flame. The core problem with flame rods is that they must be immersed and in constant contact with the flame. Therefore, to improve upon the flame rod technology, ClearSign developed a method to measure the presence of a flame without the need for flame immersion.

2.1 A New Technique: Proof of Concept

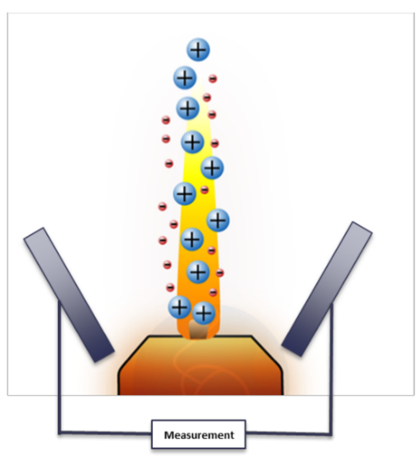


Figure 1 Flame detection using two capacitively coupled probes

The electrical properties of flames have been thoroughly studied at ClearSign and are well known. To detect a flame without immersing probes, the idea of capacitive coupling was explored, Figure 1. This technique requires the use of two capacitively coupled probes to be in proximity to the flame. This technique could allow for detecting a flame from a distance. To explore this concept further, ClearSign engineered a test burner specifically designed as a proof of concept, Figure 2.

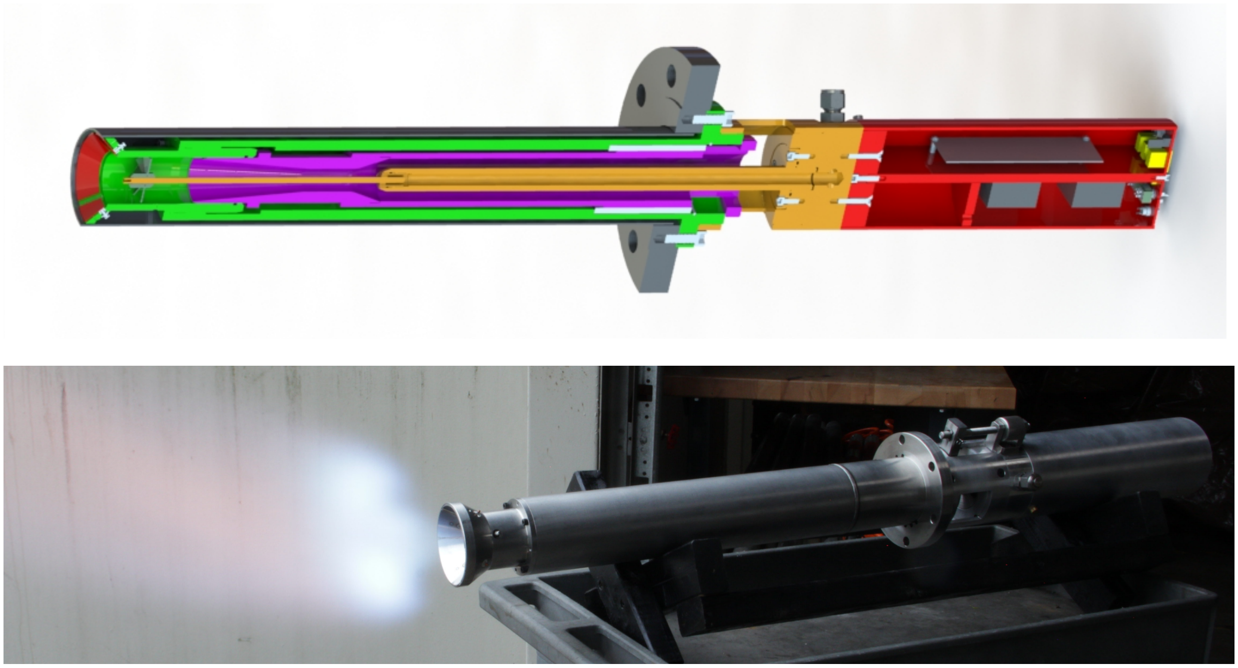


Figure 2 Proof of concept burner with integrated flame detector

The test burner incorporated electrodes situated at the tip of the burner. These electrodes were connected to wires running internally down to the base of the burner. The wires terminated at the electronics located at the base. The electronics work by sending an electrical signal to one of the electrodes (ie, transmitting electrode) and receiving the signal on the other (ie, receiving electrode). The burner is swirl stabilized and the flame lifted beyond the exit of the burner, Figure 3(a).

(a) (b)

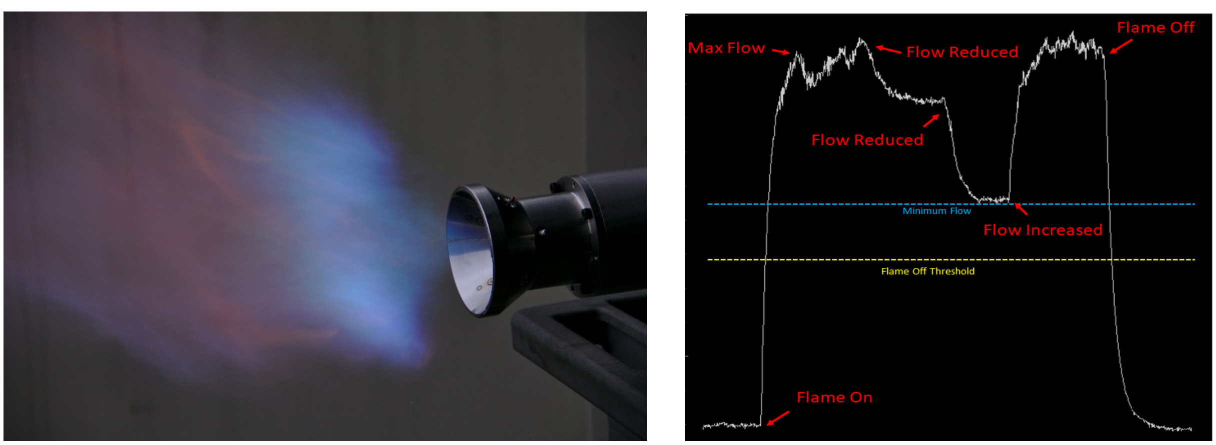


Figure 3 (a) Proof of concept burner firing, (b) Example output measurements showing the capability of high-resolution measurement of ion concentrations within the flame.

The measurements obtained from the proof of concept burner demonstrated that the technique was able to detect the presence of the flame with very high fidelity. Beyond simply detecting the flame, the sensitivity was such that accurate measurements of flame characteristics could be measured, Figure 3(b). The ability of this sensor to measure flame characteristics is attributed to the fact that the ion concentration of the flame is dependent upon various characteristics of the flame, including firing rate, equivalence ratio, and fuel composition. Because the sensor is making a measurement of the ion concentration it is able to detect these changes in flame characteristics. This capability has the potential to lead to future product developments at ClearSign.

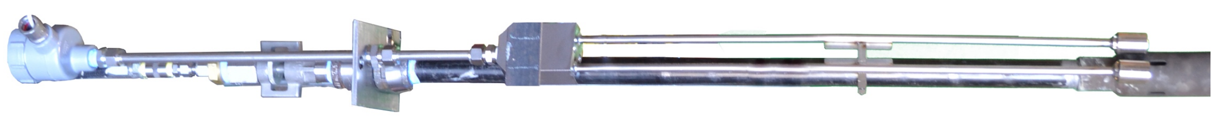
The proof of concept successfully demonstrated the ability of the new flame detection technique. It showed that two capacitively coupled electrodes, situated outside the flame zone, were able to make high fidelity measurements of a nearby flame. With the success of the proof of concept, ClearSign set out to create a product that could be a direct replacement for a flame rod.

2.2. ClearSign EYE - Flame Rod Replacement

While the proof of concept provided an ideal configuration for testing the new flame detection technique, as a product it is not very practical. It would require either customizing every existing pilot or providing an entirely new pilot to customers. Instead, ClearSign engineered and developed a product that could be directly used in place of an existing flame rod.

A key difference between the configuration of a flame rod and the ClearSign EYE is the need for two probes for the EYE as compared with a single probe for a flame rod. The engineering goal was to create a product that could be easily retrofitted onto existing pilots. To accomplish this, ClearSign developed two different configurations, Figure 4. The 2-to-1 probe configuration can be installed through the preexisting flame rod access port located on the pilot mounting plate. This configuration does not require any modifications to the pilot or the pilot mounting plate, Figure 4(a). The 2-probe configuration provides two separate probes, each having their own feedthrough on the pilot mounting plate. This configuration requires minimal modification to the pilot mounting plate to accommodate the additional probe feedthrough. The 2-probe configuration has the added benefit of being simple to remove, avoiding the need to withdraw the pilot itself.

(a)



(b)

Figure 4 Two configurations for the ClearSign EYE: (a) 2-to-1 probe configuration with single feedthrough on the pilot mounting plate, (b) 2-probe configuration with two feedthroughs on the pilot mounting plate

Another improvement the ClearSign EYE has over typical flames rods is a more robust mounting solution. Flame rods typically have exposed ceramics that are used to isolate the flame rod at the mounting brackets, Figure 5(a). These ceramics are fragile and prone to cracking. Once the ceramic breaks, the flame rod must be replaced. The ClearSign EYE avoids this issue by having no exposed ceramics. The mounting brackets clamp directly onto the metal tubes, Figure 5(b).

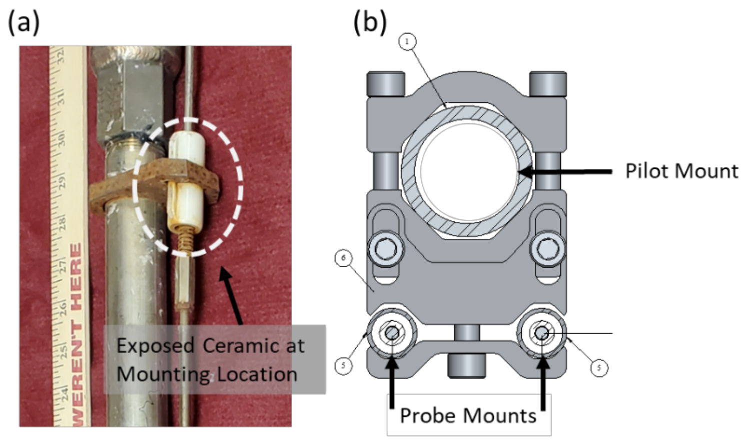


Figure 5 Mounting configuration for (a) flame rods and (b) ClearSign EYE

There are two electronic modules incorporated into the design that allow the ClearSign EYE to function, Figure **6**. One of these electronic modules is located at the base of the probe within an NEMA 4 rated enclosure. This electronic unit is passive and controlled by the second electronic control module, which can be remotely located likely within or nearby the burner management system. The control module provides several indicator lights including a power light, status light, flame on/off indicator, flame intensity meter, and two error lights for diagnostics. The controller module has a terminal block which provides the same outputs expected from a flame rod module such as a 4-20 ma output and dry contact relays. The unit also provides a reset button on the front for diagnostics and additional functionality. The control unit allows for customizing the delay time for the flame off signal.

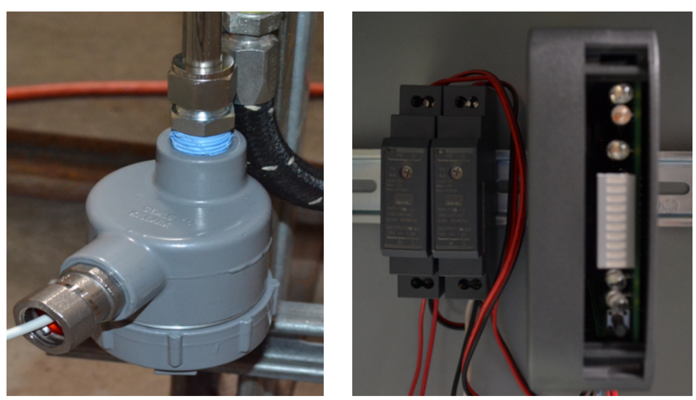


Figure 6 **ClearSign EYE electronic modules: (Left) An electronic module (not visible) within a NEMA 4 rated enclosure connects to the probe and sends a 6-wire cable bundle out through conduit to the controller, (Right) the controller located in or nearby the burner management system panel.**

To prepare this product for commercialization it was tested in environments simulating real life conditions. This testing was carried out in ClearSign Technologies test furnaces as well as outdoors under sever wind and water.

To ensure the sensors could detect a flame over the entire firing rate of the pilot, the pilot pressure was varied from as low as 2 psig to as high as 40 psig. The tests provided a strong signal over the entire stable operating range. At 40 psig the flame became unstable and the signal obtained flickered, synconized with the unstable flame. This would sometimes lead to a flame off signal if the instability was too large. A robust signal was detected as the fuel pressure was decreased to 2psig but not below this level as no flames issued form the pilot's "weep" holes, the circumferentially orientated holes near the base of the pilot tip.

The next series of tests ensured consistent and reliable operation and overall mechanical robustness by repetatively cycling the unit. The pilot was ignited, flame verification was achieved and then the pilot was shut off. This process was repeated a minimum of 5 times per test without issue.

A thermal test as shown in Figure 7 was then conducted. Since the components are stainless steel, they are able to withstand elevated temperatures. This was a worst case scenario test and meant to ensure the technology did not exhibit the same issues as its predecessor (flame rods). For this test, the sensor and pilot burner were placed in an enclosed heater to simulate standard operating conditions. The temperature did not have any impact on the performance or reliability of the sensor. With the pilot operating at maximum rate, the highest temperature recorded on the top of the electrode was approximately 330F, well below the maximum use temperature of the stainless.

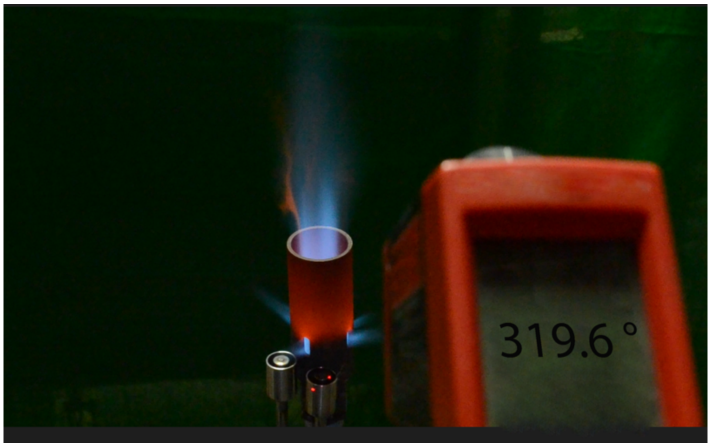


Figure 7 Thermal testing showing the temperature measurement of the ClearSign EYE probes at the location indicated by the two red dots.

Environmental tests were designed to ensure the system was capable of operating in conditions of extreme precipitation. A focussed stream of water was sprayed over the sensor from the probe down to the electronics with no adverse impact on operation. This was carried out both prior to firing the pilot and while the pilot was firing. By wetting the entire system prior to firing, the test demonstrated that the system is water tight and is not expected to fail in wet conditions. Furthermore, the sensor was able to provide a reliable flame on signal while firing the pilot with water being direct sprayed at it.

3. Discussion

Pilot flame monitoring technology has not advanced significantly to meet users growing reliablity expectations. The current technology suffers from operational inefficiencies due to frequent failures or environmental conditions. Operators tend to have a negative opinion about flames rods, however they are the best available option on the market and have become the standard for many applications. Most have created preventative maintenance programs around the known failure mechanicsms of existing products. The ClearSign EYE was designed to eliminate the reliability issues surrounding legacy pilot monitoring products. The ClearSign EYE product has been engineered to directly replace a flame rod, providing the same electrical outputs and same mounting requirements. It has been thoroughly tested for robustness and reliabaility. ClearSign is currently seeking opportunities for field testing, which is seen as the final stage of commercializing the product.