Flame Detection Solutions for Hydrogen Fueled Combustion

A Hydrogen flame detection performance evaluation of the Chentronics® iScan3® Flame Scanner.

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Abstract

As combustion energy market demands shift to an increase in Hydrogen fuel use, the ability to monitor flame remains a key requirement in the safe and robust operation of industrial burners and combustion turbines. Optical Flame Scanners used to monitor flame must detect the light spectrum produced by Hydrogen combustion, which differs from commonplace Hydrocarbon fuels such as Natural Gas, oil, and coal. The iScan3 series flame scanners by Chentronics are optimized for a wide variety of these fuels.

To the eye, Hydrocarbon fuels such as Natural Gas and propane burn in deep blue flame colors while oils, coal, and biomass tend to burn in bright yellows and orange or a mix thereof. Hydrogen combustion differs; it often burns in a slightly visible pale blue or is invisible to the eye altogether.

As Hydrogen often burns nearly or completely invisible to the eye, a common question arises – will my Flame Scanner see Hydrogen flame as well as it sees Hydrocarbon flame?

Chentronics iScan3 Single-Burner (SB) and Multi-Burner (MB) flame scanners are designed to detect these difficult to see flames in the out-of-the-box base configurations.

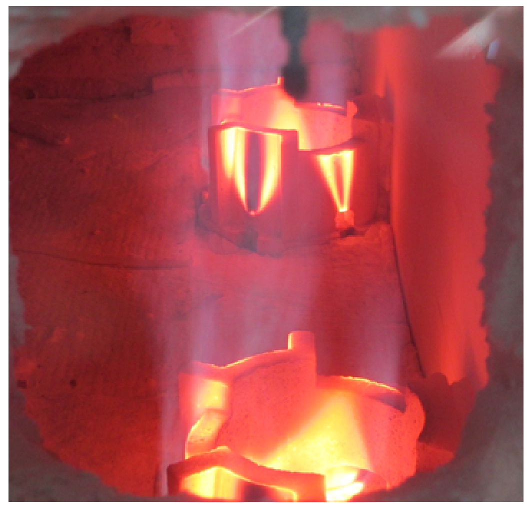

Fig. 1
Example Hydrogen Flame

Fig. 2
Example Hydrocarbon Flame

Background

Flame Light Spectrum

Hydrocarbon (CxHy) fuels such as Natural Gas and Hydrogen (H2) produce a flame light spectrum that includes content outside the visible range. This includes 250-400 nm Ultraviolet (UV) and 700-1000 nm Infrared (IR) content. Chentronics iScan3 flame scanners are tuned to UV/IR sensitivity and can detect both Hydrocarbon and Hydrogen flames.

Flame Signal

The flame light intensity sensed is converted to a voltage signal called flame signal, shown in **Figure 4**, which is then input into a processor. The iScan3's processor analyzes the content of the flame signal by examining its strength, frequency spectrum (flicker), and other characteristics to robustly determine if a flame is present.

Gain

To facilitate flame detection over a large flame light intensity dynamic range, variable amplification of the flame signal is incorporated into the iScan3's sensing circuits. The amount of amplification is called gain and it determines the strength of the flame signal resulting from the amount of flame light available to the sensor.

iScan3 flame scanners utilize an automatic gain control feature that allows self-adjusted amplification to achieve ideal flame signal strength level, thereby facilitating easy and dependable flame detection. SB model iScan3 flame scanners are factory set for automatic gain control. MB model scanner gain is manually set by the user, normally during a burner commissioning process. However, the automatic gain control feature, including gain limits, may be enabled as needed to support variable burner operating conditions. The high gain capability of the iScan3 allows it to detect small flames.

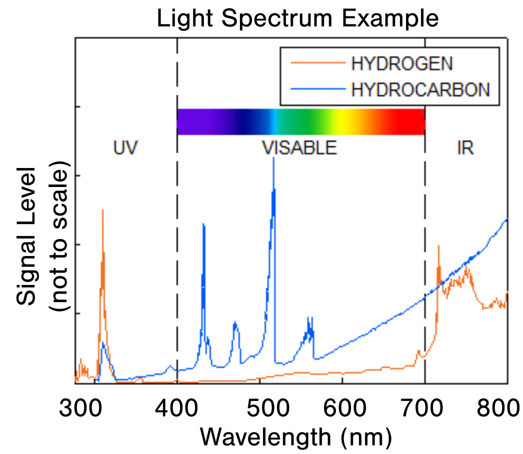

Fig. 3
Hydrogen and Hydrocarbon flame light spectrum

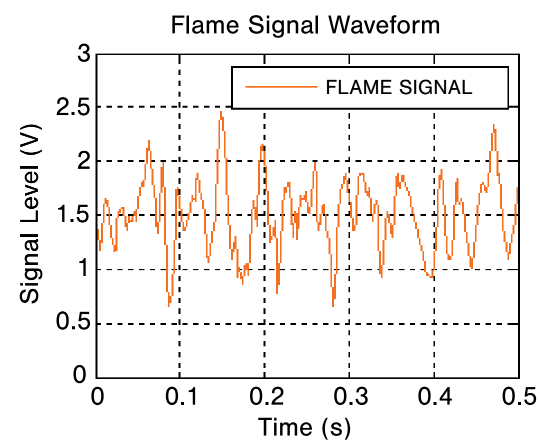

Fig. 4
Example Flame Signal voltage waveform

Flicker Spectrum

Flicker spectrum, shown in **Figure 5**, represents the strength (power level in dB) of the flame signal over its frequency range. As a fuel burns turbulently, light intensity is produced in a range of periodic frequency content. The flame signal content produces a distinguishable frequency spectrum which is typically in the range of 0 to 250 Hz and is naturally occurring in the form of pink noise.

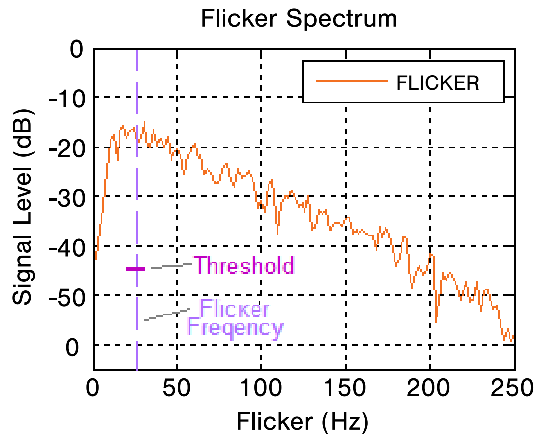

Fig. 5
Flicker Spectrum

Flicker Frequency

Flicker frequency is a particular frequency of interest in the flicker spectrum. Signal level at this frequency must exceed a certain value, called threshold, as part of the flame on detection affirming analysis. Flicker frequency and threshold settings are therefore chosen where the flicker spectrum contains significant signal level. Example flicker frequency and threshold are depicted in **Figure 5**.

SB model iScan3 flame scanners are factory configured to 26 Hz flicker frequency and -45 dB signal threshold. MB model scanners may be tuned for the burner application at hand. Configuration is typically performed during a burner commissioning process.

Pink Noise

There are several types of naturally occurring noise signals such as white, pink, and blue noise. Pink noise is the term for a type of frequency spectrum wherein signal power decreases as frequency (f) increases with a 1/f proportionality. When describing a general flame characteristic, this noise is often also referred to as flicker noise. The flicker spectrum shown in **Figure 5** exemplifies the pink noise / flicker noise general form.

A Comparative Test: Hydrogen Flame Detection vs Natural Gas Flame Detection

An investigation of the Hydrogen detection capability of the iScan3 flame scanner was carried out at the University of Applied Sciences and Arts Northwest Switzerland, Combustion Research Laboratory (FHNW), in March 2023. Flame detection tests were conducted at similar power level on a Natural Gas fired turbine burner and a Hydrogen fired turbine burner. Additionally, flame detection tests were conducted on the Hydrogen burner from viewpoints along the length of the flame spanning from root to end.

Each burner was mounted to a comprehensively instrumented test frame system that monitors and records combustion data including compositions, temperatures, and flow rates, etc. Analytics provided by the system calculated burner operating characteristics such as operating power level. Each burner was fired into a glass cylinder where the resulting flame was visually observed, and flue gas was monitored and vented.

Two iScan3 flame scanners, "Scanner A" and "Scanner B", were affixed perpendicularly to the burner axis and directed to view flame through the glass cylinder as shown in **Figure 7**. The iScan3 positions were adjusted to viewpoints along the flame length as necessary to achieve best flame detection results. Each iScan3 was connected to a data acquisition system where flame sensor data including flicker spectrum, flame strength, and gain level, etc. was recorded and analyzed.

The iScan3 were each tested in the base SB configuration. The SB model incorporates automatic gain control and is pre-tuned for plug-and-play ease of use in single-burner flame detection applications. No additional settings, filters, or accessories were used to enhance the incoming signal.

Fig. 6
iScan 3

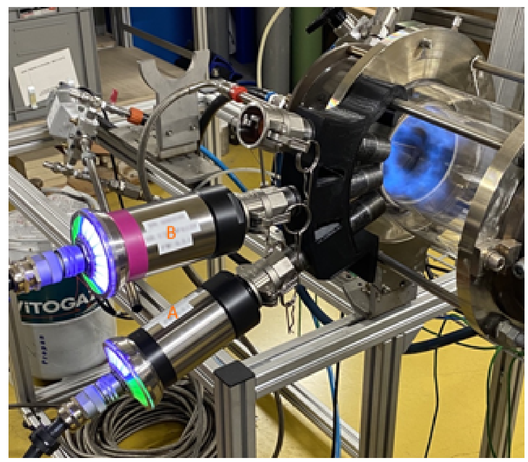

Fig. 7
Scanner A/Scanner B affixed to Laboratory burner test frame system

Data Collection

For each configuration tested, the burner was ignited, brought to the power level specified, and the test frame system acquired burner operating condition data. Once the burner was in steady operating condition and each iScan3 achieved positive flame detection, flame sensor data was recorded for 30 seconds at 0.5 second sampling intervals (2 Hz) for each test case. The Flame Strength values are derived from the flicker spectrum level at 26 Hz for SB model scanners. Data has been normalized to represent equivalent gain setting across the test cases.

Comparison Test: Hydrogen and Natural Gas Flame Detection

Table 1 presents iScan3 flame strength statistical data for Hydrogen and Natural Gas flames on burners each operating at 19kW (each row is a 30 second test case). Positive flame detection was maintained by the iScan3 throughout the test cases.

Fuel Type	Burner Flow Rate (m/s)	Flame Temp (K)	Scanner A Flame Strength (dB)			Scanner B Flame Strength (dB)		
			Min	Ave	Max	Min	Ave	Max
Hydrogen	43	1592	-23	-18	-15	-27	-22	-18
Natural Gas	23	646	-24	-20	-17	-28	-23	-17

Table 1
Hydrogen and Natural Gas flame strength statistics at 19kW burner operating power

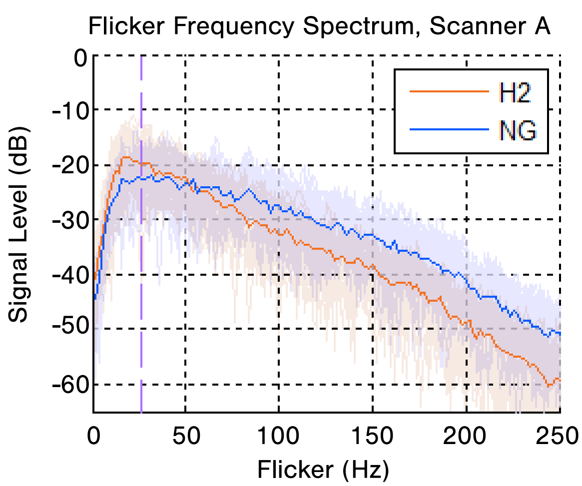

Fig. 8
Hydrogen (H2) and Natural Gas (NG) flicker spectrums, Scanner A

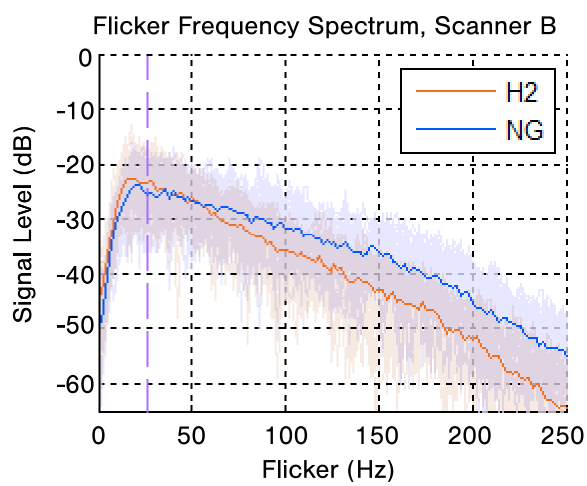

Fig. 9
Hydrogen (H2) and Natural Gas (NG) flicker spectrums, Scanner B

Viewpoint Test: iScan3 Viewpoint Positions Spanning Hydrogen Flame Length

Table 2 presents iScan3 flame viewpoint vs flame strength statistical data for a Hydrogen flame on a burner operating at 21kW (each row is a 30 second test case). Scanner position measurements are distanced relative to the burner's gas jet nozzle as shown in **Figure 10**. Positive flame detection was maintained by the iScan3 throughout the test cases.

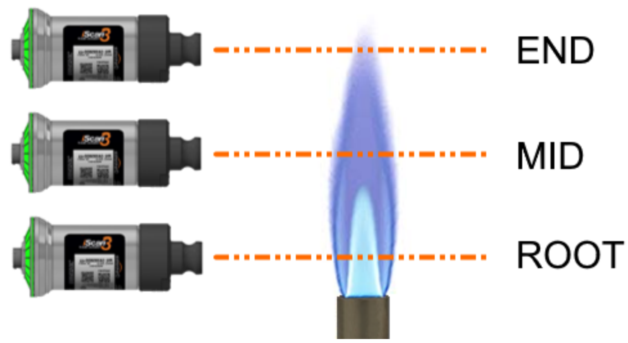

Fig. 10
Flame root, mid and end viewpoint positions.

Flame View point	Scanner Position (mm)	Burner Flow Rate (m/s)	Flame Temp (K)	Scanner A Flame Strength (dB)			Scanner B Flame Strength (dB)		
				Min	Ave	Max	Min	Ave	Max
Root	16	47	1760	-15	-11	-8	-15	-11	-8
Mid	43	49	1754	-23	-19	-16	-23	-18	-14
End	73	50	1752	-46	-39	-36	-49	-41	-37

Table 2
Scanner viewpoint position vs Hydrogen flame strength statistics at 21kW burner operating power

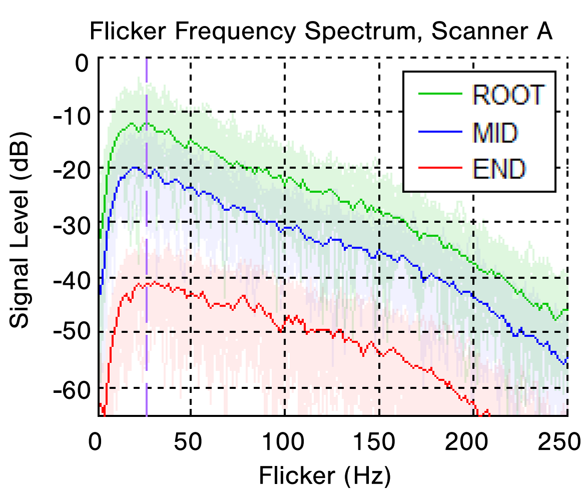

Fig. 11
Flicker spectrum for flame root, mid, and end viewpoints, Scanner A

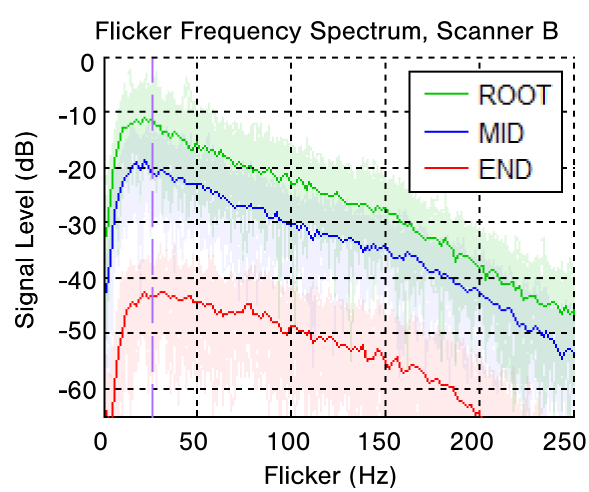

Fig. 12
Flicker spectrum for flame root, mid, and end viewpoints, Scanner A

Analysis

All flicker spectrum data acquired by the iScan3 demonstrates the expected characteristic pink noise flame profile. For Hydrogen fuel the iScan3 received 1-2 dB more signal strength on average than Natural Gas at flicker frequency targets below 50 Hz as shown in **Figures 8 and 9**. This increase is ideal for SB model scanners and MB model scanners operating with the commonly used target flicker frequency of 26 Hz, offering additional signal level for flame detection. As flicker frequency increases from 50 Hz to 250 Hz, the iScan3 received increasingly less signal strength for Hydrogen than for Natural Gas. However, in the 50-100 Hz target range, the iScan3 continued to receive signal level significantly above the -45 dB default threshold level desired for detection in all test cases where the iScan3 had good viewpoint of flame for both Hydrogen and Natural Gas.

The iScan3 provided excellent signal strength flame detection at a viewpoint directed towards the root of the Hydrogen flame. As viewpoint distance increases, moving towards the end of the flame and away from the root, signal strength quickly decreases as shown in **Figures 11 and 12**. This outcome is expected as UV intensity is highest toward the root of the flame and lowest toward the end of the flame. While each iScan3 continued to detect flame in the end viewpoint test cases, the signal was low and near the default detection threshold level. Such a configuration is likely to cause nuisance tripping of flame detection as the burner varies in performance, although MB model scanners could potentially be utilized by configuring a lower threshold setting.

Results Discussion

Results show that the Chentronics iScan3 has 100% detectability of Hydrogen flame over the operating conditions tested with equitable performance as compared to Natural Gas. Additionally, flame detection for Hydrogen is shown to be best achieved when the flame scanner is directed to include view of the root of the Hydrogen flame where the highest UV spectrum intensity is produced.

Availability

iScan3 Flame Scanners are manufactured in Norwich, NY by Chentronics, LLC, a division of Koch Engineered Solutions. For ordering information and product support, please visit www.Chentronics.com