METHODS OF FLAME DETECTION

February 2020

Combustion basics

States of combustion

Combustion can exist in one of three fundamental states:

- Perfect combustion

- Complete combustion

- Incomplete combustion

Carrier

Combustion basics

Chemistry of perfect combustion process

11 parts exhaust
1 part carbon dioxide
2 parts water vapor
8 parts nitrogen

1 part fuel
1 part carbon
4 parts hydrogen

10 parts air
2 parts oxygen
8 parts nitrogen

Image courtesy https://www.myodesie.com/wiki/index/returnEntry/id/3054
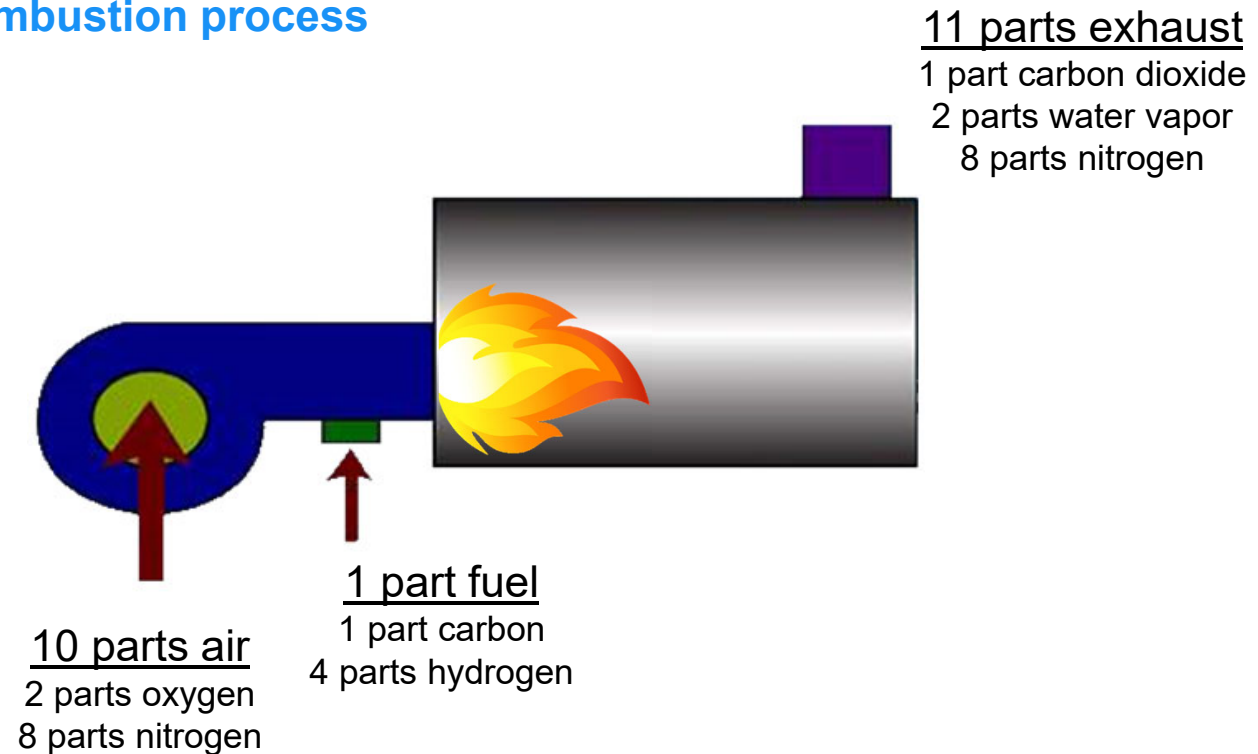
Combustion basics

Perfect combustion

Perfect combustion is the theoretical outcome of a combustion process.

- A mix of air and fuel where each is **100% consumed** in the process

- Also known as **Stoichiometric Combustion**

- No CO is produced

- The percentage of CO_2 in the exhaust peaks here

Combustion basics

Complete combustion

While perfect combustion is the theoretical outcome, complete combustion is the practical outcome of a combustion process. This allows for continued safe operation despite small changes in the ambient conditions.

- A mix of air and fuel where there is more than 100% of the oxygen required

- Also known as **Excess Air Combustion** or **Fuel-Lean Combustion**

- Acceptable amounts of CO produced

- The percentage of CO_2 in the exhaust lowers as the percentage of O_2 and excess air rises

- Safe side of stoichiometric mix as percentage of CO_2 in the exhaust decreases from the theoretical peak of perfect combustion
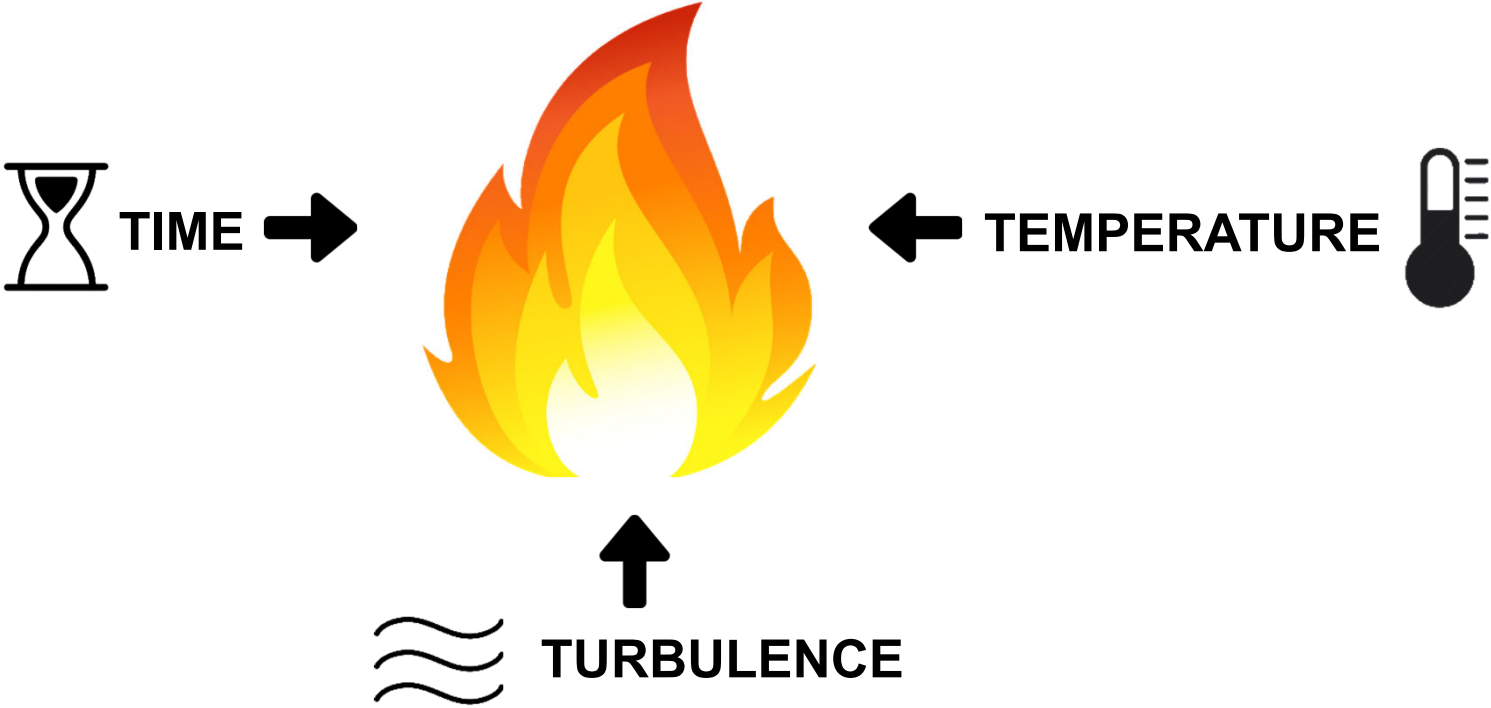
Combustion basics

Incomplete combustion

While perfect combustion is the theoretical outcome, complete combustion is the practical outcome of a combustion process. This allows for continued safe operation despite small changes in the ambient conditions.

- A mix of air and fuel where there is less than 100% of the oxygen required

- Also known as **Fuel-Rich Combustion**

- Rising amounts of CO (to potentially lethal levels) produced as oxygen deficiency increases

- The percentage of CO_2 in the exhaust lowers as the O_2 deficiency increases

- Dangerous side of stoichiometric mix as percentage of CO_2 in the exhaust decreases from the theoretical peak of perfect combustion

Combustion basics

Three T's of combustion

TIME ➡

TEMPERATURE ⬅

⬆ TURBULENCE

Combustion basics

Time

When a fuel is burned, sufficient time must be provided for the fuel to burn fully. If allowed to only partially burn there will be losses as unburnt fuel. If too much time is allowed the burner may not be able to achieve the desired power output.

Combustion basics

Temperature

If the temperature is not sufficiently high fuel will take longer to ignite. This may result in a change in the power output. Low NO_X burners may take advantage of this principal to lower the flame temperature by re-introducing exhaust gas into the combustion process (FGR). This lower temperature inhibits the chemical reaction between nitrogen and oxygen.

Combustion basics

Turbulence

Thorough mixing of the air and fuel is necessary to achieve proper combustion. If this is not done there may be partial combustion which can result in increased emissions or reduced power output.

Burner control

Divisions of burner control

Most types of burners used in process control will require by an applicable code that there is a flame safeguard and instrumentation system in place. Control can be further divided into two categories:

- Combustion Control System (CCS)
- Burner Management System (BMS)

Burner control

Combustion Control System

The combustion control system (CCS) regulates the furnace air and fuel inputs to maintain the air-fuel ratio. This ratio must be within the limits required for continuous combustion and flame stability throughout the modulating operating range, allowing the burner to safely adjust output from a minimum to a maximum in a linear manner. Servo motors are used to regulate dampers on the air and valves on the fuel to precisely control the input at all stages of combustion. This precision also provides repeatability whether the burner is increasing or decreasing output.

PID control is often used in conjunction with this modulating burner output to control a process variable to a defined setpoint.

Burner control

Burner Management System

The burner management system (BMS) is a system dedicated to burner safety. The BMS controls the safe starting and stopping of burners. A BMS can be programmed using an industrial PLC or a complete microprocessor-based BMS (also known as a **Flame Safeguard**) can be used. Regardless of type, a BMS has inputs and outputs to connect to all of the required parts of the burner. A BMS can be designed for a single- or multi-burner application.

Basic components of a BMS system are:

- Interlock monitoring
- Fuel monitoring
- Flame monitoring
- Ignition control
- Main burner control

Carrier

Burner control

Burner Management System

Fireye manufactures a variety of flame safeguards that satisfy the requirement for a Burner Management System:

- Flame Monitor

- BurnerLogix Y

- BurnerLogix Z

- BurnerPRO

- SB Series

- MicroM

- NXF4000 (with integrated Combustion Control System for air-fuel ratio control)

- NX6100 (with integrated Combustion Control System for air-fuel ratio control)

Burner control

Interlock monitoring

All required and any optional interlock inputs are connected either in series to a dedicated input, or to specific inputs where internal logic monitors the status of each individually. The status of these inputs can be annunciated as required via SCADA or HMI. The interlocks may individually or collectively require a manual reset upon a fault condition, depending upon the applicable code(s) or design.

Required interlock inputs are typically:

- Air pressure switches to monitor combustion air

- Low-water cutoff devices for pressure vessels such as boilers

- High temperature or pressure limit devices

- Emergency shutdown buttons

Burner control

Fuel monitoring

Incoming fuel pressure is monitored to ensure that there will be adequate fuel for combustion. There is typically an interlock for monitoring both a minimum and maximum allowable pressure for each fuel that is present. This monitoring can use an analog input or multiple digital inputs via adjustable switches. The switches and/or BMS may require a manual reset following a low or high fuel pressure incident depending upon the applicable code(s) or design.

Burner control

Flame monitoring

The flame monitoring system is designed to lockout the BMS whenever the actual state of detected flame does not match the desired state of flame. This can either mean that a flame is present when it should not be, or most commonly that a flame is not detected when it should be. A parameter known as flame failure response time (FFRT) dictates how long a lack of flame must be present before a flame failure is reported. This can vary from under a second to as long as four seconds depending upon the applicable code(s) and design.

There are three prevailing technologies used in flame detection:

- Ionization -- rectification via flame rod

- Radiation via infrared scanning

- Radiation via ultraviolet scanning

Burner control

Ignition control

The ignition system can vary depending upon the fuel used. In any event, the ignition system provides the energy required to begin the combustion process for the main fuel.

The BMS begins by running the combustion air blower and purging the firing vessel. This purge may occur with an open air damper for a fixed period of time (such as 30 seconds). Ignition will follow this purge period.

Burner control

Ignition control

One method of ignition is where the ignition source (such as a spark electrode) directly ignites the main fuel output. This is typically the case when the fuel source is an oil such as No. 2 (diesel). When this is the case, the ignition output precedes the main fuel trial for ignition (MTFI) period which is the amount of time that the main fuel has to prove a flame before a flame failure is registered (as long as 15 seconds).

Burner control

Ignition control

The other method of ignition is where the ignition source ignites a gas-based pilot (usually propane or natural gas). The ignition output precedes the pilot fuel trial for ignition (PTFI) period which is the amount of time that the pilot has to prove a flame before a flame failure is registered (up to 15 seconds, similar to the MTFI described above). After the PTFI, the main fuel valve is opened and the control enters the MTFI to prove the main flame.

Burner control

Main fuel control

Once the main fuel valve is opened and the flame is proven during the MTFI period, the burner is in the normal operating mode. This is the point where the CCS can take over the management of the air-fuel ratio and modulate the output. At any point during operation if the flame is not detected for the FFRT duration, the BMS will lockout the burner and a manual reset will be required to restart.

If the burner is shut down in a normal manner, the BMS will initiate a shut down sequence which may include a post purge of air by running the combustion air blower for a fixed duration, possibly with an open damper.

Burner control

Combustion Control System

Fireye manufactures several Combustion Control Systems:

- PPC4000 – interfaces with an external Burner Management System (flame safeguard)
- PPC6000 – interfaces with an external Burner Management System (flame safeguard)
- NXF4000 – integrated BMS/CCS
- NX6100 – integrated BMS/CCS

Flame detection

Flame ionization principle

Heat in the flame causes the molecules in and around the flame envelope to collide with one another. The force of the collision frees some of the outer (valence) electrons of the atoms forming the molecules. This creates free electrons and positive ions, allowing a current to be conducted through the flame. The whole process is called **Flame Ionization**. Within the flame there is very low conductivity and resistance can vary from 100,000 to 100,000,000 ohms. Current conducted through the flame (flame current) is low, generally in the range of 2-4 micro amps. The amount of current indicates the intensity of the flame.

If two electrodes were placed in a flame as shown to the right with a voltage applied, a current could be conducted between the two rods (**Flame Rods**).
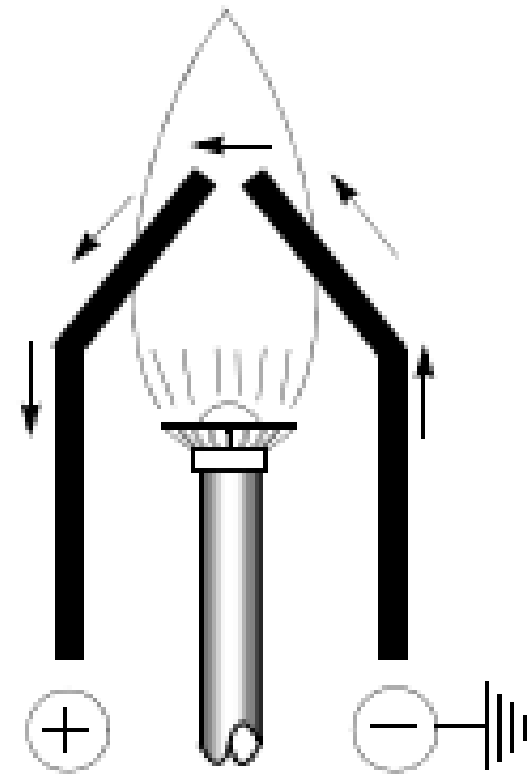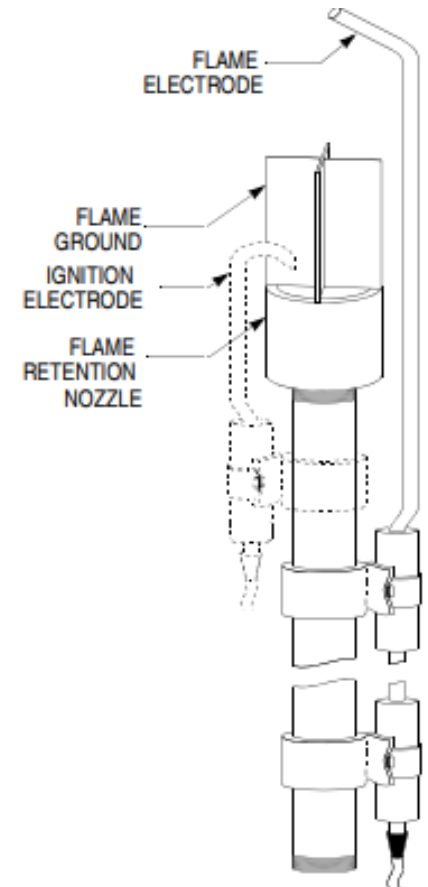
Flame detection

Flame rectification system

The issue with using two flame rods is that a high resistance short to ground would simulate a flame signal. This could be potentially hazardous. To avoid this, the flame current is rectified. Generally referred to as a **Flame Rectification System**, this is achieved by placing a grounding electrode in the flame which is several times (generally 4 times) larger than the flame rod or electrode. An AC supply voltage is applied across the electrodes. In the first half of the AC cycle, the flame rod is positive and the ground rod is negative. The positively charged ions will flow to the negatively charged grounding area.

Since the grounding area is larger, the flame current is significantly higher for one-half of a cycle than the other. If there is a short the current will be consistently high and the flame detection system or FSG will reject the signal.

FLAME ELECTRODE

FLAME GROUND

IGNITION ELECTRODE

FLAME RETENTION NOZZLE

Flame detection

Flame rod usage

Flame rods are small diameter metal rods supported by an insulator. The tip of the rod projects into the flame. They typically are made of a high temperature alloy or ceramic material.

Applications for flame rod or rectification flame detection are generally found in the supervision of gas-fired flames.

Requirements for successful applications include:

- Gas-fired burner

- Grounding area is at least four times greater than the flame rod area

- Stable flame with no physical movement from flame rod itself

- The flame rod is kept as short as possible for adequate coverage in the flame

- Proper rectifying flame current and associated circuitry

Flame detection

Flame rod operational diagram
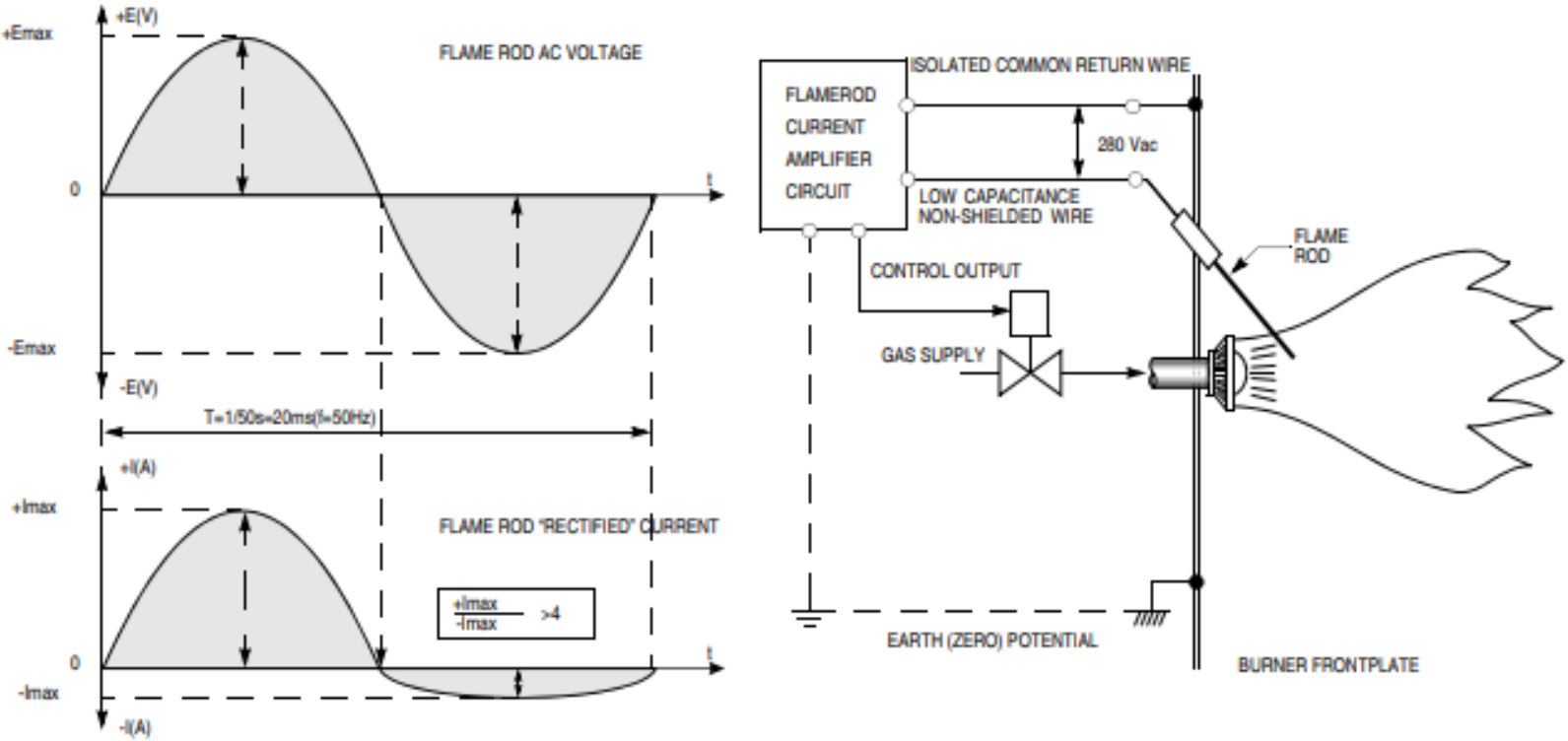
Flame detection

Fireye flame rods

Fireye products that support using flame rods include:

- Flame Monitor
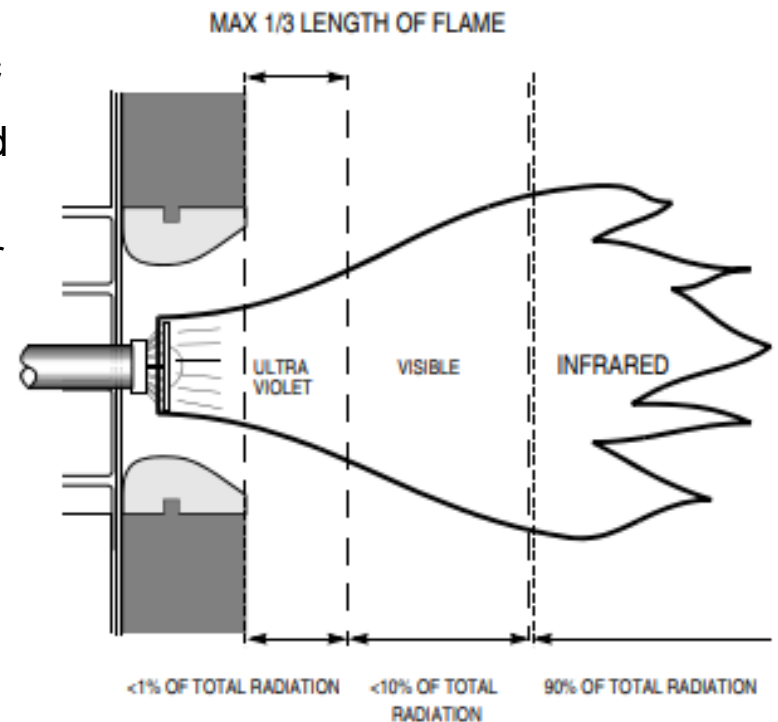- BurnerLogix Y
- BurnerPRO
- MicroM
- SB Series

Flame detection

Flame radiation properties

Flames emit radiation along a wide band of the electromagnetic spectrum called the flame spectrum. This spectrum consists of ultraviolet, visible, and infrared radiation. Ultraviolet and infrared radiation are at the opposite extremes of the flame spectrum and only wavelengths of 400 to 800 nanometers are visible to the human eye. It can appear as various colors such as blue for gas flames and bright yellow for oil flames. Flame detectors are selected to detect one of these types of radiation, each with their benefits and drawbacks.

Ultraviolet radiation makes up about 1% of the total flame spectrum. It is most abundant in the first third of a burner flame. More ultraviolet radiation is present as the flame temperature increases.

Infrared radiation makes up about 90% of the total flame spectrum. It is most abundant in the last two-thirds of a burner flame. Hot furnace parts (such as refractories) can emit infrared radiation when above 1000°F.

MAX 1/3 LENGTH OF FLAME

ULTRA VIOLET — VISIBLE — INFRARED

<1% OF TOTAL RADIATION   <10% OF TOTAL RADIATION   90% OF TOTAL RADIATION

Flame detection

Ultraviolet flame detection

Flame scanners operating in the ultraviolet wavelength use a detection tube. In this type of system the flame is considered present when ultraviolet radiation is detected. Differentiation between the targeted flame and neighboring flames is achieved by discriminatory scanner sighting. This focuses as much as possible on the targeted flame and then signal sensitivity adjustments and threshold settings help tune out unwanted signals at the controller.

Ultraviolet detection tubes should be sensitive only in the far wavelength range (200 to 300 nanometers) to be considered **solar blind**. Solar blindness is important to prevent stray light detection from sources other than the flame spectrum.

Carrier

Flame detection

Ultraviolet detection tubes

Ultraviolet detection tubes are made from quartz. The tube is then sealed and filled with gas, and contains two electrodes connected to a source of AC voltage.

Electrons are released and gas within the tube becomes conductive through ionization. An electric current flows from the cathode to the anode. If a high AC voltage is applied to the electrodes, an arc is produced when sufficient ultraviolet radiation is present. A quartz lens is used to focus the UV radiation through the optical shutter window directly on the detector tube electrodes.
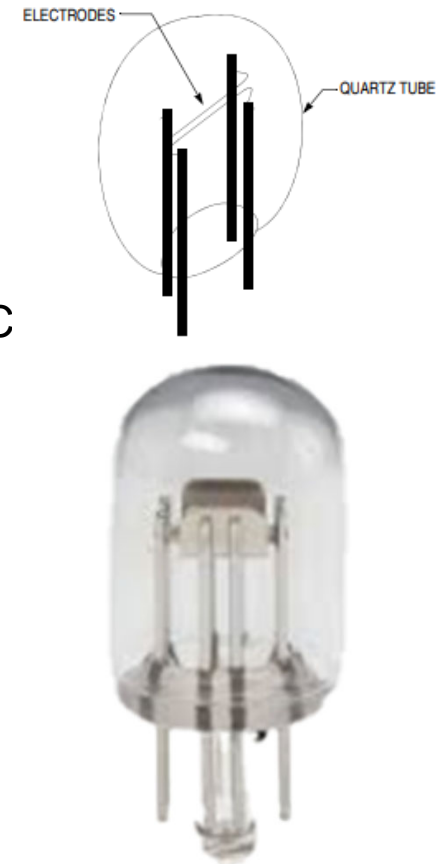

Image courtesy Hamamatsu Photonics

Flame detection

Ultraviolet flame count

Voltage across the electrodes will be zero for the first half-cycle of AC. This allows the tube to restore itself to a non-ionized or quenched state. On the second voltage half-cycle, current is re-established across the electrodes if sufficient ultraviolet radiation is present. The number of firings during each cycle is called the count. When a flame is present and ultraviolet radiation enters the tube, the system begins to count. When there is no ultraviolet radiation, counting stops. The **Flame Control Relay** electronically manages this count and when a preset flame-on threshold is reached, an output is set to indicate the presence of a flame. This output remains active as long as the threshold is satisfied. The count relates directly to the intensity of the ultraviolet radiation.
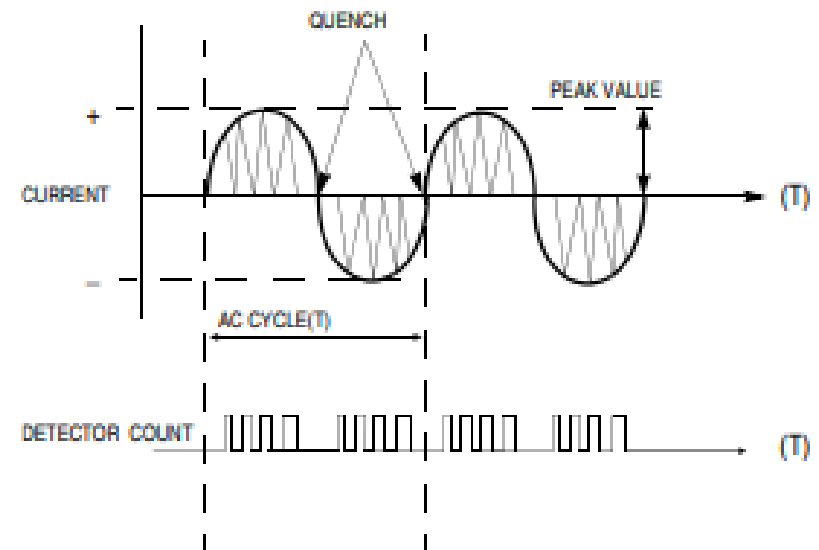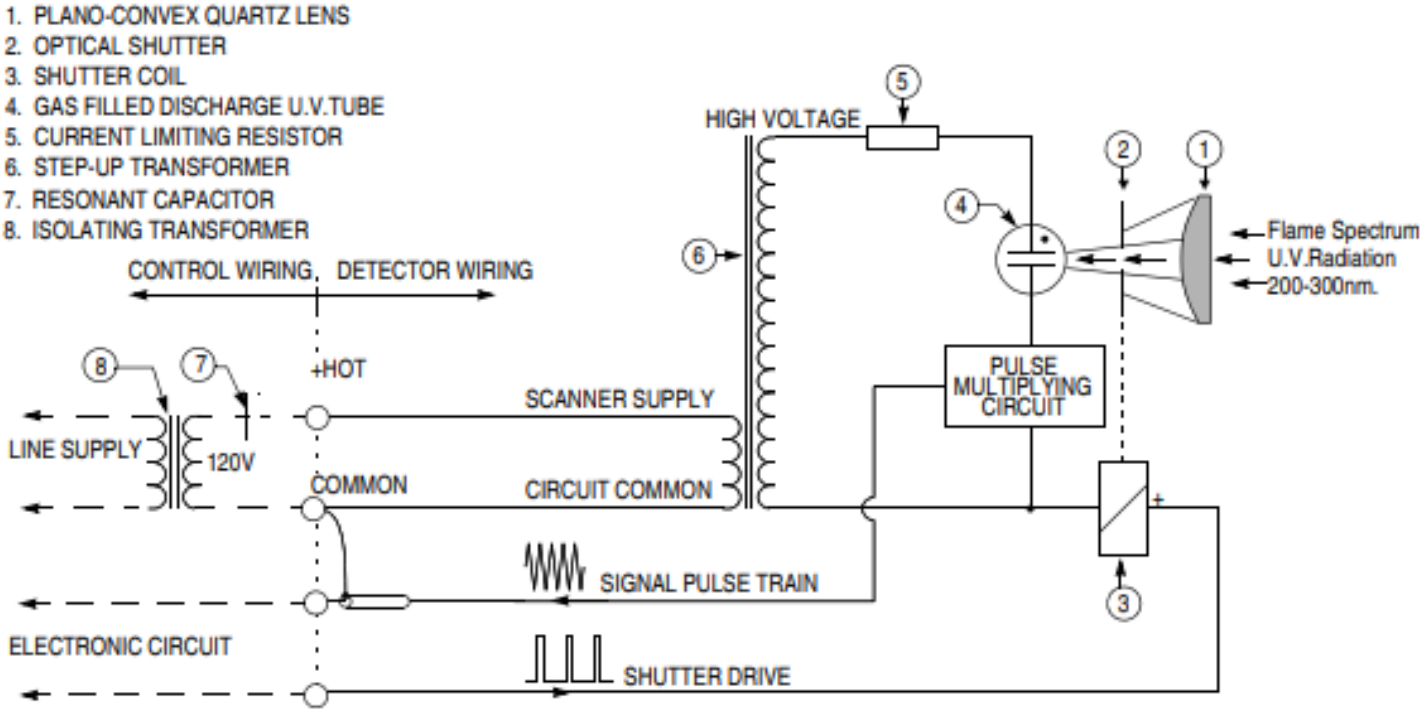
Flame detection

Ultraviolet considerations

Ultraviolet detection tubes can respond to sources other than the targeted flame, such as hot refractory (above 2000°F), spark ignition, welding arcs or halogen light. The gas inside the tube can eventually degenerate leading to random failure modes, where the count may occur even without a flame present (false flame indication). This can be detected by the flame safeguard or flame control since there will be a flame present when there should not be one. The issue is that the burner has to shut down and restart for this to happen.

A type of ultraviolet scanner called a **self-check** was developed for this situation when a burner does not cycle. Self-check may also be required by applicable code(s) when a burner does not cycle within a specified time period. The self-check contains a shutter that physically blocks the ultraviolet radiation from reaching the tube, and the flame safeguard or flame control is designed to expect this interruption to the count and to continue operation without issue. The duration of the self-check test must still be less than the FFRT or lockouts can occur.

Flame detection

Ultraviolet scanner schematic

1. PLANO-CONVEX QUARTZ LENS
2. OPTICAL SHUTTER
3. SHUTTER COIL
4. GAS FILLED DISCHARGE U.V.TUBE
5. CURRENT LIMITING RESISTOR
6. STEP-UP TRANSFORMER
7. RESONANT CAPACITOR
8. ISOLATING TRANSFORMER

CONTROL WIRING   DETECTOR WIRING

HIGH VOLTAGE

Flame Spectrum
U.V.Radiation
200-300nm.

PULSE MULTIPLYING CIRCUIT

LINE SUPPLY   120V

+HOT

SCANNER SUPPLY

COMMON   CIRCUIT COMMON

SIGNAL PULSE TRAIN

ELECTRONIC CIRCUIT

SHUTTER DRIVE

Carrier

Flame detection

Fireye UV scanners

All Fireye products offer a UV scanner option. Most are also available with straight or side viewing options.

Models that offer self-checking UV scanners:

- Flame Monitor (via 45UV5)
- BurnerLogix Y (via 45UV5 or 55UV5)
- BurnerLogix Z (via 45UV5 or 55UV5)
- MicroM (via 45UV5 or 55UV5)
- SB Series (via UV7A)

Straight viewing   Side viewing

45UV5   55UV5

Flame detection
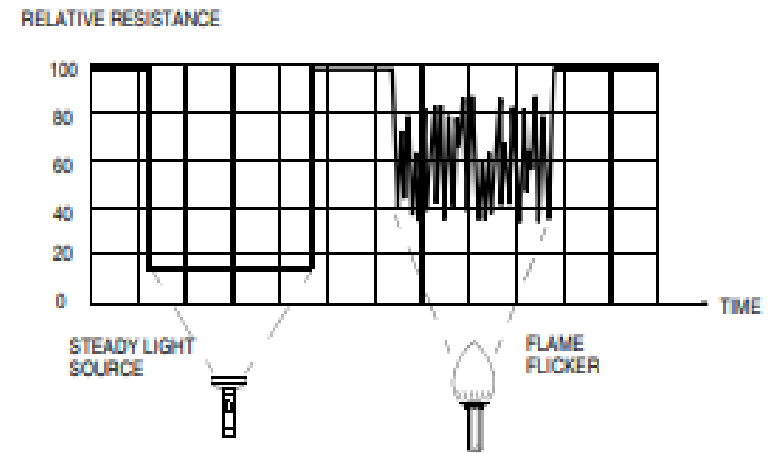
Infrared flame detection

Infrared and visible light (>400 nanometer wavelength) do not effectively detect the presence or absence of flame. Reliable detection of the targeted flame requires the infrared detector to distinguish between the modulating frequency of the radiation it receives. Infrared radiates from a flame in many frequencies – this is known as **flame flicker**. During the combustion process there are many small explosions, each emitting visible and infrared radiation.

Flame detection

Infrared photo-detector

Flame scanners operating in the visible and infrared spectrum use a lens, photo-detector and a solid-state frequency tuning circuit. The flame constantly moves, changing shape and brightness. The function of the photo-detector is to monitor flame flicker to distinguish between the targeted flame and other sources of radiation. The photo-detector most commonly used is the PbS (lead sulfide) photo resistor. The PbS cell lowers its electrical resistance relative to amplitude of radiation. Flame flicker frequency is noted in Hertz. Flicker frequencies can be as low as 5Hz or upwards of 200Hz.
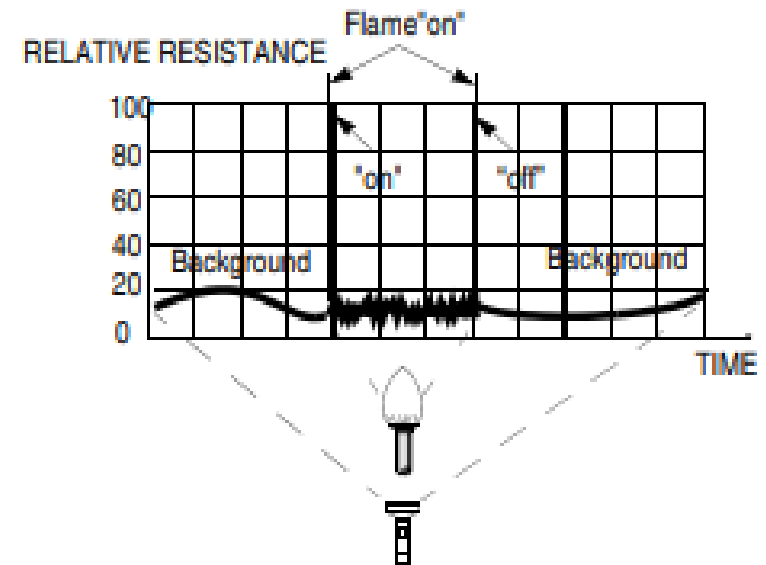
Flame detection

Infrared considerations

The ability of the photo-detector to detect flame flicker frequency can be adversely affected by low-frequency radiation from furnace background light or other sources of heat.
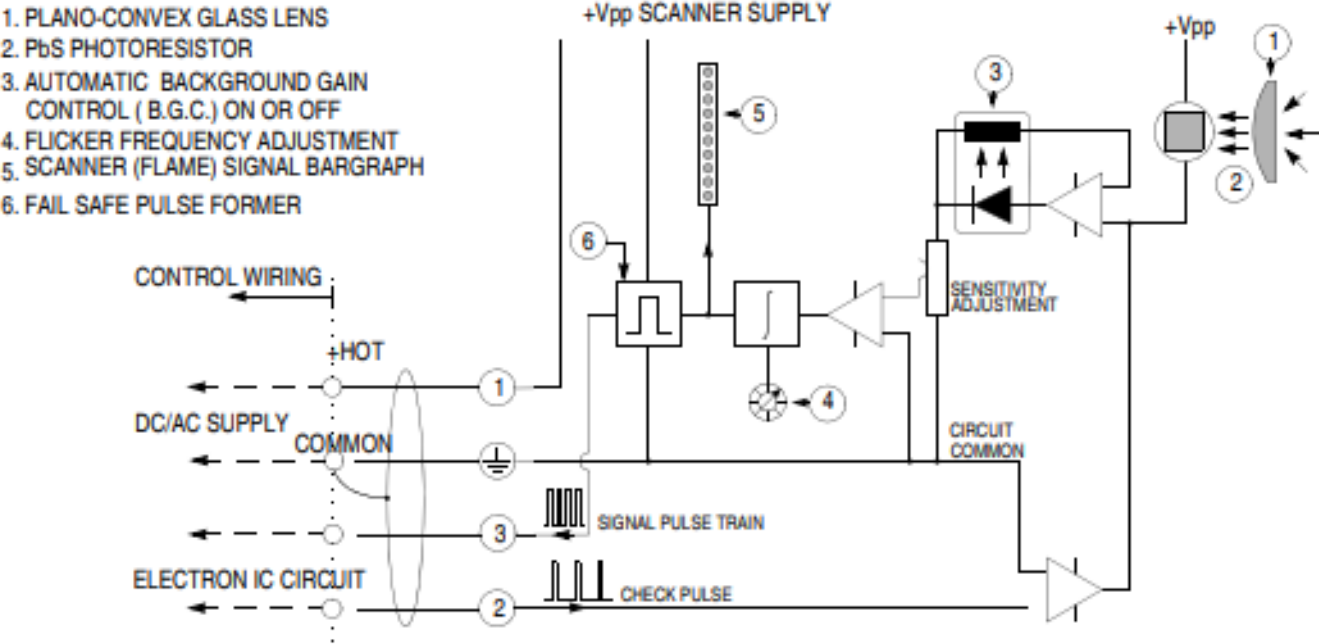
Strong sources of this low frequency radiation will have a saturation effect. Also called washout, saturation inhibits the ability of the cell to maintain a high enough electrical resistance value. This renders it unable to monitor flame flicker properly.

To minimize this saturation effect, sight the detector so that radiation from the ignition zone is maximized and radiation from furnace background is minimized. Infrared scanners also may offer background gain control or sensitivity adjustments to tune out background signals.

Flame detection

Infrared scanner schematic

1. PLANO-CONVEX GLASS LENS
2. PbS PHOTORESISTOR
3. AUTOMATIC BACKGROUND GAIN CONTROL (B.G.C.) ON OR OFF
4. FLICKER FREQUENCY ADJUSTMENT
5. SCANNER (FLAME) SIGNAL BARGRAPH
6. FAIL SAFE PULSE FORMER

+Vpp SCANNER SUPPLY

+Vpp

CONTROL WIRING

+HOT

DC/AC SUPPLY

COMMON

SENSITIVITY ADJUSTMENT

CIRCUIT COMMON

ELECTRON IC CIRCUIT

SIGNAL PULSE TRAIN

CHECK PULSE

Flame detection

Fireye IR scanners

Many Fireye products offer an IR scanner option:

- Flame Monitor
- BurnerLogix Y
- BurnerLogix Z
- MicroM
- NXF4000
- NX6100

Flame detection

Method selection

For each fuel, there is a method that works best based on the radiant energy present with the associated flame. Other considerations are the distance to the flame and response time. UV detection is the fastest but performance degrades as the distance increases. UV also doesn't work as well where the environment around the flame is smoky. IR detection can work well with a moderate response time at longer distances from the flame.

The table below shows the radiant energy for each fuel:

| Fuel	Infrared	Visible	Ultraviolet
Oil – air atomized	High	High	Medium
Oil – steam atomized	High	High	Low
Gas – air premix	Low	Low	High
Gas – no premix	Medium	Medium	Medium

Carrier

Instrumentation

Integrated flame scanners

Integrated flame scanners are available that can be mounted to sight the flame and provide a flame relay output to a BMS or SCADA system. They can also provide a fault output when there is a flame failure and some may provide an analog output to indicate the strength of the flame.
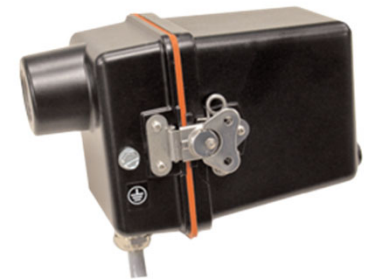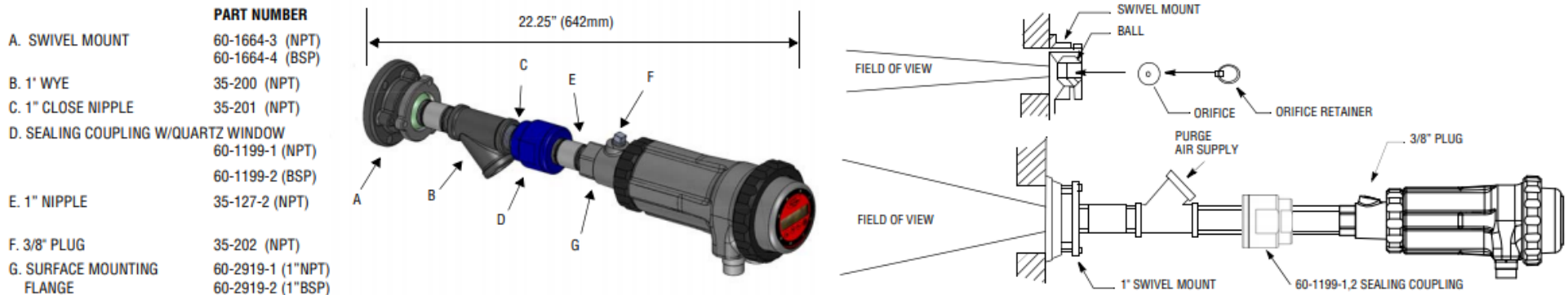
Instrumentation

Integrated flame scanner line of sight and electrical connection

SINGLE BURNER SCANNER SIGHTING
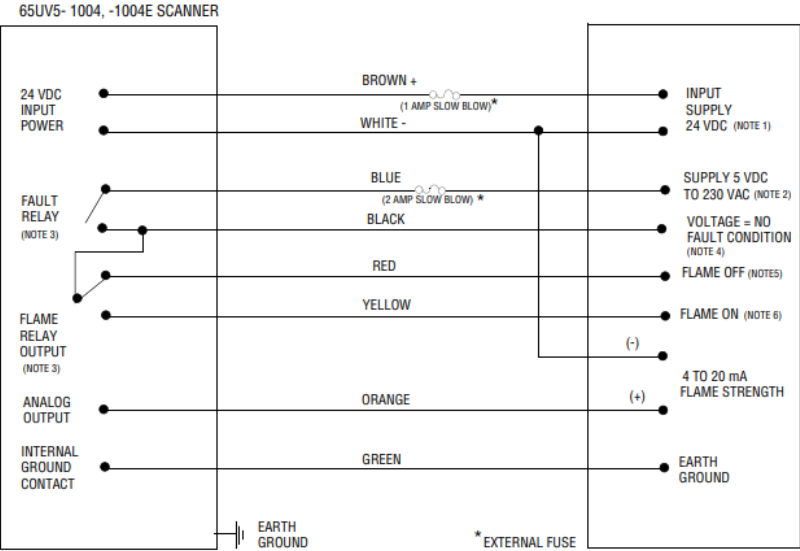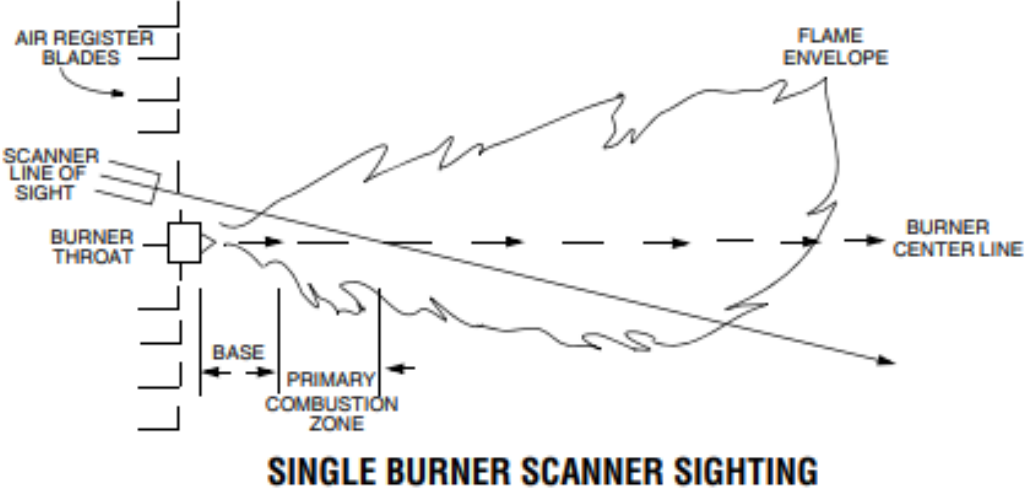
Instrumentation

## Integrated flame scanner rigid mounting

Integrated flame scanners typically mount to the burner using threaded connections or flanges for easy removal when servicing is required. Orifices are also available that can narrow the field of view to help direct the scanner to the targeted flame.

	PART NUMBER
A. SWIVEL MOUNT	60-1664-3 (NPT)
	60-1664-4 (BSP)
B. 1' WYE	35-200 (NPT)
C. 1" CLOSE NIPPLE	35-201 (NPT)
D. SEALING COUPLING W/QUARTZ WINDOW	
	60-1199-1 (NPT)
	60-1199-2 (BSP)
E. 1" NIPPLE	35-127-2 (NPT)
F. 3/8" PLUG	35-202 (NPT)
G. SURFACE MOUNTING FLANGE	60-2919-1 (1"NPT)
	60-2919-2 (1"BSP)

Instrumentation

Integrated flame scanner flexible mounting

Integrated flame scanners can also mount remotely and connect to the burner using a fiber-optic connection. This allows a connection into tighter spaces or when access requires it.
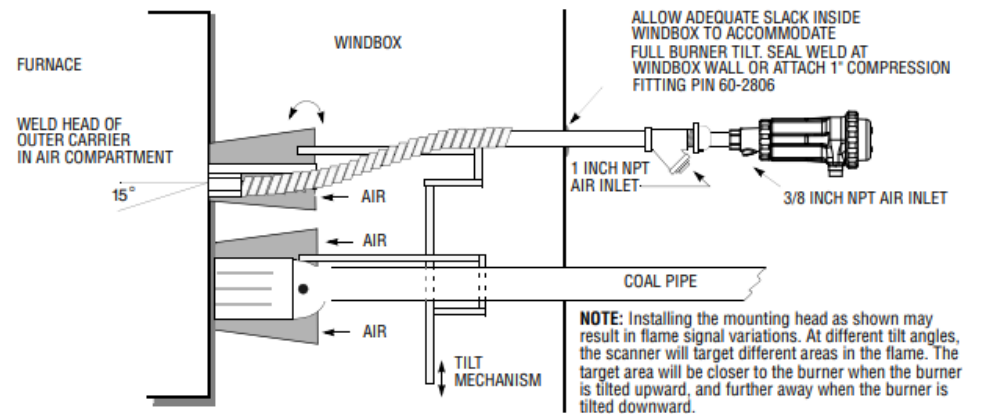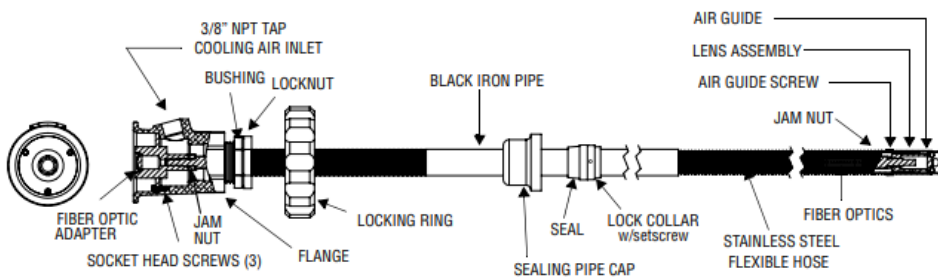
Instrumentation

Integrated flame scanner intelligence

Integrated flame scanners are available that contain both ultraviolet and infrared sensors, and can be programmed specifically to one targeted flame in a multiple burner environment. Since each flame has unique amplitudes of modulation (flame flicker) the flame scanner can be programmed to learn the specific details of the proper flame. Some have multiple relay outputs for connection to the BMS that can be individually programmed, providing either redundancy or outputs to multiple locations.

A programmable interface on the flame scanner or in some cases a PC connection tool may be used to program the specific settings and adjustments required.

Simplicity 65UV5

Overview

The Simplicity 65UV5 is a fully integrated scanner that does not require programming, making it an easy-to-use scanner.

- 8-pin quick disconnect (QD) connector

- 24VDC powered

- Voltage-free flame relay (fault relay internally wired in series) with additional voltage-free fault relay

- 4-20mA analog output for flame signal

- Two-color LED for status annunciation

- Class I, Div 2 (groups A, B, C, D) and ATEX hazardous area classification
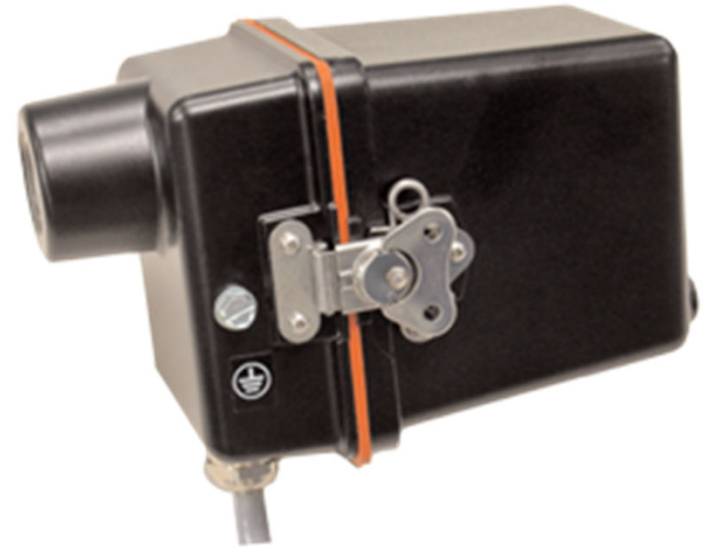
Phoenix 85 series (85UVF, 85IRF)

Overview

The Phoenix 85 series offer self-check models for detecting either ultraviolet or infrared radiation. Flame profiles can be programmed, including background flame.

- 8-pin quick disconnect (QD) connector
- 24VDC powered
- Voltage-free flame relay (fault relay internally wired in series) with additional voltage-free fault relay
- 4-20mA analog output for flame signal
- Keypad setup with LEDs for flame indication
- Class I, Div 2 (groups A, B, C, D) and ATEX hazardous area classification

InSight (95UV, 95IR, 95DS)

Overview

The InSight scanners offer self-check models available for detecting either ultraviolet radiation, infrared radiation or both in one unit. Flame profiles can be programmed, including background flame.

- 12-pin quick disconnect (QD) connector
- 24VDC powered
- Voltage-free flame relay (fault relay internally wired in series) with additional voltage-free fault relay
- 4-20mA analog output for flame signal
- Keypad with display for monitoring and programming
- Inputs to select file (profile) to use – four available
- Modbus communication
- Class I, Div 2 (groups A, B, C, D) hazardous area classification
- ATEX hazardous area classification with proper housing

InSight series 4 (95UVS4, 95IRS4)

Overview

The InSight series 4 scanners offer self-check models available for detecting either ultraviolet or infrared radiation. Flame profiles can be programmed, including background flame.

- 12-pin quick disconnect (QD) connector
- 24VDC powered
- Voltage-free flame relay (fault relay internally wired in series) with additional voltage-free fault relay
- 4-20mA analog output for flame signal
- Keypad with display for monitoring and programming
- Inputs to select file (profile) to use – four available
- Modbus communication
- Class I, Div 2 (groups A, B, C, D) hazardous area classification
- ATEX hazardous area classification with proper housing

InSight II 95DSS3

Overview

The Insight II 95DSS3 scanner can detect both ultraviolet and infrared radiation in one unit. Flame profiles can be programmed, including background flame. There are additional connectivity options for displays and remote viewing and data collection.

- 8-pin and 12-pin quick disconnect (QD) connectors
- 24VDC powered
- Two voltage-free flame relays (fault relay internally wired in series) with additional voltage-free fault relay
- Two 4-20mA analog outputs for flame signal and flame quality
- Inputs to select file (profile) to use – four available
- Modbus communication
- Class I, Div 2 (groups A, B, C, D) hazardous area classification
- ATEX hazardous area classification with proper housing

InSight II 95DSS3

Display

The 95DISP-1 display is available for programming parameters and monitoring operation. This display mounts directly on the scanner.

InSight II 95DSS3

Wireless transmitter

The 95WIDISP-2 display is available for programming parameters and monitoring operation. The transmitter mounts directly on the scanner and the receiver is handheld and uses batteries. Infrared technology is used for the 95WISP-2.

Hazardous areas

Hazardous area housings

All models are approved for use in Class I,
Division 2 groups A, B, C and D. Simplicity and
Phoenix models are also ATEX approved and
all InSight models offer ATEX housings.

Fireye Explorer (FEX)

Software for remote communication

Fireye Explorer software is available for connecting a PC to multiple Modbus compatible InSight or InSight II scanners on a network. Each scanner can be monitored or controlled remotely using this software. There are additional features such as trending to help with troubleshooting any issues with the flame.

Flame detection

Fireye integrated scanners with Fireye flame safeguards

Fireye integrated scanners can be used with many Fireye flame safeguards. Check the specific product bulletin for exact models that may be used.

Compatible models:

- BurnerLogix Y (Phoenix 85 series and InSight 95 series)
- MicroM (Phoenix 85 series and InSight 95 series)
- NXF4000 (Phoenix 85 series and InSight 95 series)
- NX6100 (Phoenix 85 series)

THANK YOU