Optical flame detection

Fire detection is based on fire's various properties (rise in temperature, smoke emission, and optical radiation emission). Optical flame detection is among the most reliable and fastest methods of detection for outdoor environments or in large spaces. This type of detection is based on radiation emitted by the flames in ultraviolet (UV), visible (Vis) or infrared (IR).

What is a flame?

The combustion of a hydrocarbon flame (oxidation reaction) generates, in particular, carbon dioxide (CO_2) and water (H_2O), in an excited state (*):

$2\ C_6H_{14} + 19\ O_2 + \text{Energy} \Rightarrow 12\ CO_2^* + 14\ H_2O^*$

The return to the fundamental state of these molecules occurs through the emission of photons at specific wavelengths:

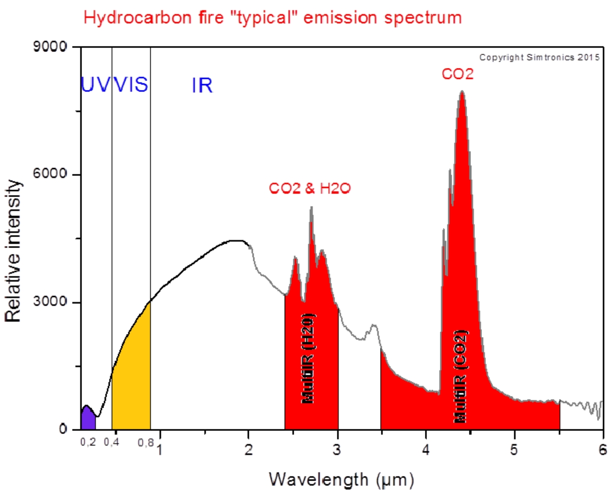
$CO_2^* \Rightarrow CO_2 + h\nu$ (2.9 µm - 4.3 µm)

$H_2O^* \Rightarrow H_2O + h\nu$ (2.8 µm)

In the emission spectrum of flames, there are also some bands characteristic of their signature:

A "bump" in the ultraviolet radiation around 200 nanometers;

A visible and near infrared part between 0.4 microns and 3 microns, more or less intense, depending on the nature of the fuel.



The second signature used to distinguish a flame from a background radiation (industrial or environmental) is of a temporal nature.

When a flame is burned naturally (with surrounding air), it flickers randomly, as opposed to an artificially combusted flame that does not flicker as with a Bunsen burner, for example. Its radiation is then typically modulated in the band from 1 to 20 Hz which can enable efficient pre-filtering of the signal received by the detectors.

Different types of detectors

Optical flame detectors are designed with one or more optical radiation sensors and can be configured on ultraviolet (UV), infrared (IR), a combination of ultraviolet and infrared (UV/IR), or multiple infrared bands (Multi IR).

Flame detection is made difficult by false radiation from a wide range of industrial or environmental sources that interfere with the fire spectrum. The device must not be disturbed by this environment, while having a good sensitivity to fire.

Ultraviolet (UV) detectors

Ultraviolet detectors (UV) only react to UV radiation having a wavelength of less than 300 nanometers (a solar blind region).

The sensor is a photo-tube, including a cathode and an anode placed in a large potential difference (about 300 volts). They are sealed in a quartz tube filled with inert gas. Illuminated by ultraviolet radiation, the photons striking the cathode release electrons which are drawn toward the anode. The electrons - energy carriers - ionize the gas molecules contained in the bulb, creating a chain reaction. The detector then generates an output signal as voltage pulses sequence.

This type of detector is sometimes used for flammable liquid fires (such as hydrocarbon fires) but not only. It is one of the few to enable detection of hydrogen, ammonia and metal fires. This type of detector can reach a sensitivity up to pico watt / cm² and offer a very fast response time, hundreds of milliseconds or less. However, its detection capacity is attenuated in the presence of smoke. Thus, in case of fuel fire in a closed environment, the UV sensor may not detect fire if it does not "see" the flames relatively early. Likewise, the ultraviolet radiation is absorbed by the oily films potentially deposited on the detector window, or by certain organic compounds present in the environment, thus limiting the detection sensitivity. Finally, it is sensitive to electric arcs, X-rays and lightning storm, which can generate false alarms.

Infrared (IR) detectors

This is generally a pyroelectric sensor that detects thermal radiation and which is sensitive to variations of the received light signal.

A lithium/tantalum crystal is associated with a field effect transistor or an OP amp. An optical filter (a spectral gate) selects a wavelength or specific spectral band (2.9µm, 4.3µm, 4 to 5µm…).

Random flickering emitted by the flame in the infrared band are perceived by the crystal that generates a signal processed by a low frequency band pass filter (1-20 Hz), before being interpreted by a microprocessor.

Current components have good signal to noise ratios which allows significant amplification factors, and therefore very good sensitivity to radiation from the flame.

Efficient on bad burn rate fires (gasoil for example) and in smoky environments, the infrared detector is however sensitive to aqueous environments (fog, frost ...) as well as many interfering infrared sources present in the environment which may overlap the signals which need to be detected.

To guard against this strong sensitivity and avoid false alarms, it is now common to use several sensors in one device (Multi IR). Cheaper and generally more reliable than ultraviolet detector, it has, moreover, a meantime before failure (MTBF) longer due to less severe constraints on components.

UV / IR combined detectors

By combining the two technologies (gate AND between "UV channel" and "IR channel"), this type of detector provides excellent rejection of false alarms while providing good detection distance.

However, they suffer from the combined limitations of infrared and ultraviolet detectors.

UV / IR² combined detectors

The combined UVIR detector using a performant UV sensor is limited, in terms of detection range (distance of detection), by the infrared part. Indeed the IR sensor is curbed to maintain a “reasonable” activation of the IR chain by the surrounding thermal background.

By the use of an additional information in IR band, through a second sensor, this allows to increases the gain of detector’s amplification chains, and therefore increases the detection range, while maintaining a very good immunity to false alarms.

Multi-IR detectors

Today, the market is clearly oriented towards multi IR detectors. The principle is to remove the UV and multiplying information in the IR domain.

Most of devices rely on the CO_2 IR band at 4.4 microns. Some, however, use the H_2O IR band (2.9 microns) so as to detect hydrogen fires or ammonia one.

Multi IR detectors usually have longer detection range while maintaining a very low rate of false alarms. They are also insensitive to attenuations related to fumes and oil vapors as well as interference sources like lightning, welding arcs...

Again, the idea is to increase the gain of the amplification chain and choose the wavelength and appropriate signal treatments. It is common to use three infrared detectors in three different spectral bands, and reaching detection ranges from 40 to 80 meters on standard heptane standardized fires, even when the environment is full of interfering infrared sources.

Detection by Imaging

This technique is also used for flame detection. It is based on image processing issued from CCD matrices. Limited to the visible range for a long time, some models now operate infrared matrices with a spectral filter similar to the one used on traditional multi-IR detector in order to improve the sensitivity to fire.

Although generally more limited in terms of detection range, one of the major advantages is its good treatment of "friendly fire" which enables to eliminate flare reflection on metallic elements which can be found in many industrial sites for instance.

Its limitations are intrinsic to the visible method (reduction of efficiency in case of smoky fires or of very little emissive fires (hydrogen, methanol...), or in the infrared range (range reduction due to the presence of water-related compound, detection of hydrocarbon fires only ...).

Several technological development areas are possible for the future devices:

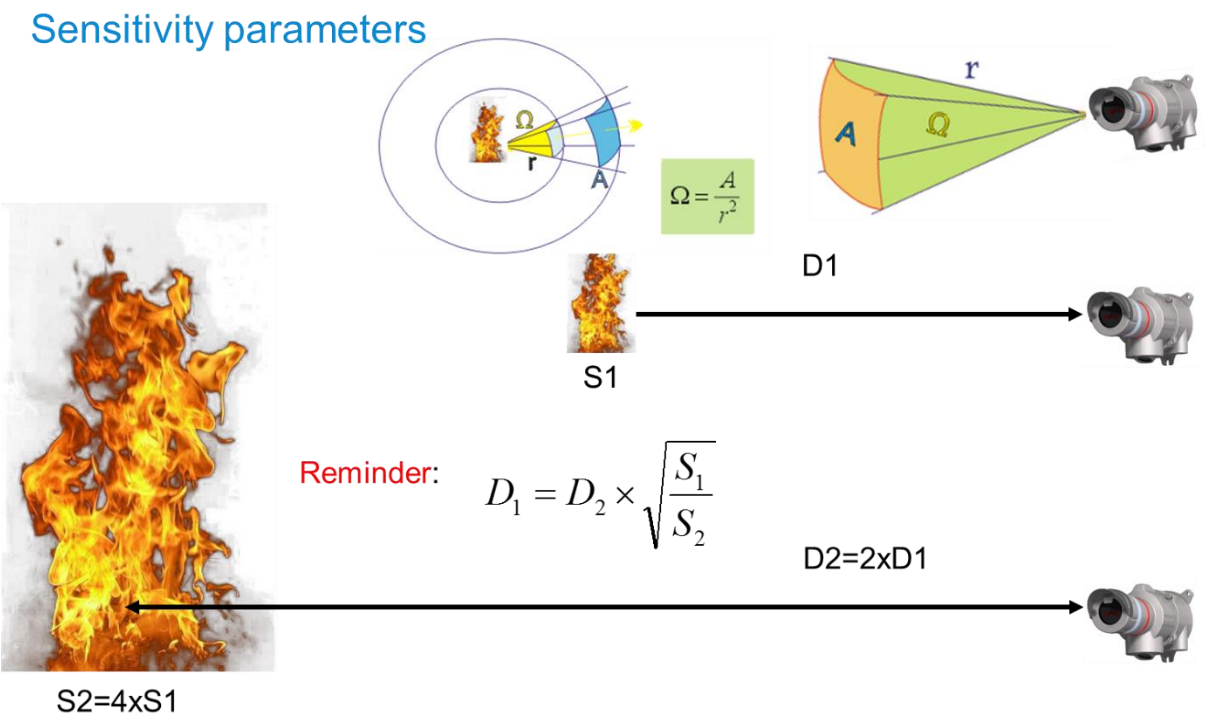
- Implementation of more sophisticated signal processing algorithms, based on Multi IR technologies with 3, 4 or 5 sensors.
- Multi-spectral infrared imaging. The cameras which are now able to reach the infrared range in the appropriate spectral bands, are still very expensive, but these are likely to take over from the "classic" cameras limited to the visible.
- Implementation of semiconductor components in the UV range by replacement of discharge tubes. Today there is no adequate component on the market to achieve this function in this application framework, but many laboratories are working on this type of components.

Metrological characteristics

The market is mainly oriented towards use in explosive atmosphere applications, therefore almost all of the devices are available with adequate protection modes under regulatory requirements (ATEX / IEC / FM / UL / CSA…) and classic information outputs signal (4-20 mA / relay / ModBus / ...).

From a strictly metrological point of view, optical flame detectors have certain particular features. The concept of **sensitivity**, in particular, is more difficult to grasp than for a gas sensor, and it is necessary to clearly identify the factors that affect it.

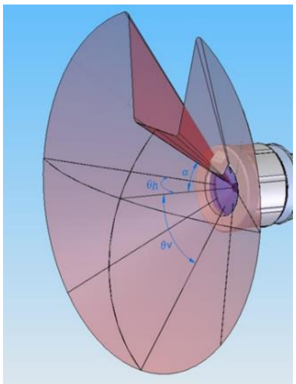
- First the fuel: all the combustions do not generate the same amount of CO_2 or H_2O molecules.
  A fire of methanol ($CH_3OH + 2\ O_2 \Rightarrow \underline{\mathbf{1}}\ CO_2^* + 2\ H_2O^*$) is, for example, less emissive than a heptane fire ($C_7H_{16} + 11\ O_2 \Rightarrow \underline{\mathbf{7}}\ CO_2^* + 8\ H_2O^*$).
- Secondly the size of the fire: Geometrically speacking, the amount of signal received by the detector from the fire decreases as the square of the distance between them.
  To obtain a signal equivalent to the one obtained at a distance **D** of fire surface **S**, with twice the distance (2x**D**), one have to multiply the fire surface by x4.



- Finally, if the fuel is gaseous, the nozzle diameter is not enough, this must be completed by information related to flow or flame height.

Other parameters are more difficult to master whereas they can also interfere, such as reabsorption of CO_2 radiation in the optical path, the attenuation by smoke, rain, fog, wind speed on the fire, the presence of interfering sources, etc.

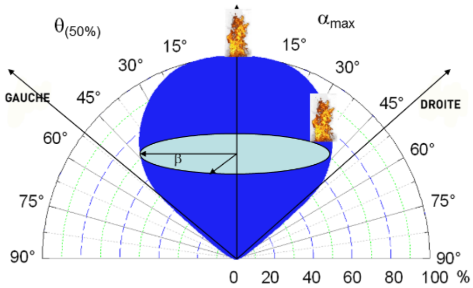
The **response time**. It is often associated with a particular fire because it usually decreases with the distance between the fire and the device. It varies significantly from one technology to another (UV detectors are generally faster than IR detectors) and can varies from less than one second to thirty seconds depending on fires, technologies and manufacturers.



The **cone of vision** is one of the delicate features, whereas it is crucial in terms of positioning of devices.

Manufacturers give values between 90° and 120° on the horizontal axis, sometimes less on the vertical axis due to the optical elements necessary for self-test.

One must keep in mind that the sensitivity to a fire is not constant over the entire extent of the cone of vision. The detection range is reduced when it moves away from the optical axis, and there is even a very rapid fall on the edge of the cone. Generally, vision angles are given for half distance sensitivity limit versus the one obtained on the optical axis. It is therefore appropriate to take this value into account in the definition of the installation.



The **false alarm immunity**. This is a very important parameter because the financial consequences can be significant in case of accidental activation of the extinguishing system. The devices offered by the major leaders have generally very good immunity with regard to false alarms and provide a list of evaluated sources, including: the type of source tested (halogen lamp, tungsten, welding arc ...), the test parameters (power, distance...), if the source is modulated or not, and if the device triggers an alarm in these conditions or not.

During installation, one still have to keep in mind that the presence of a parasitic source (modulated infrared source, such as sunlight through vapors or an open sky turbine) in the device field of view (multi-IR), even if cannot trigger alarm, it nevertheless constitutes an important background radiation which can reduce the sensitivity of the device.

<u>Choice of technology</u>

Choosing the most suitable technology for an application can be made thanks to the below criteria:

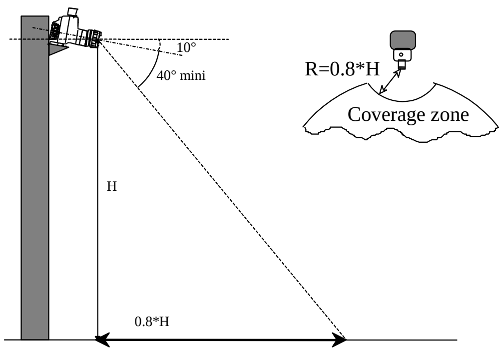
- The Fuel does not contain hydrocarbon molecules: The most suitable device would be a detector configured on UV or H_2O emission based infrared. The detection range is generally lower than for multi-IR versions for hydrocarbon fuels.
- The risk source (potential fire) is at a very long distance and/or is small. One shall then chose multi-IR versions that achieve the best sensitivity.
- The working area is a closed environment in which smoke will quickly accumulate or in which there may be some vapors, such as ammonia, hydrogen sulphide, ethyl or methyl acrylate, methyl methacrylate, aromatic compounds such as benzene, toluene, xylene, styrene, hydroxybenzene, some nitrogenous compounds such as nitrobenzene, nitro propane, nitromethane, nitromethane, some chlorinated compounds such as chlorobenzene, tetrachloroethylene, dichlorobenzene, vinyl chloride, chloro-nitro-propane, chloroprene and finally, some derivative from butane or ethane such as acetaldehyde, acetone or ethanol, butyl amine, butanone and butadiene.

  In that case, one should avoid using versions implementing UV because this band is highly attenuated by these particles or vapors.
- The working area is outdoor. It is therefore risky to use a single UV technology because of its sensitivity to a number of relatively intense UV sources and the fact that UV can be reflected on all types of surfaces, especially metallic.

- The coverage area contains hot equipment with opportunities for strong air convection and possible CO_2 presences. It is preferable to use the UV technology (UV, UVIR, UVIR²) to improve resistance to false alarms.
- The alarm triggering must be very short (<1 sec). We first need to cover the risk on a short distance, and then encourage UV technologies that are potentially faster.
- “Friendly” fires such as a flare is in the device field of view, live or by reflection, and the signal is strong enough to activate a traditional detector. If the decrease in sensitivity (see below) does not remove the activation, the use of devices based on image analysis can isolate this type of fire.

<u>Installation and Setup</u>

As it has already been pointed out, the installation must take into account the device cone of vision to cover the area to be monitored, preferably with recoveries between detectors.



Furthermore, devices are usually installed in a high place and it is important to note the presence of a “shadowed” area at the bottom of the detector.

It is much better not to install the detectors using the IR bands on pipes which can wobble with a strong wind, for example, so as not to generate a background signal which could interfere the detection.

The major part of the optical flame detectors allow the user to adjust the sensitivity and also the time delay before outputting an alarm, according to the type of risk to monitor to and the environment.

Sensitivity adjusts the maximum distance at which a given fire generates an alarm. The temporization is the time (in seconds) during which the unit must receive a continuous fire signal before giving an alarm.

<u>Normative Framework</u>

Beyond the hazardous areas equipment standards, there is a normative framework for other aspects of the device:

EN 54-10 - *Detection and Fire alarm systems - Flame detectors - Point detectors*. This standard has been attached to the BPD (Building Products Directive) through its amendment A1 (in March 2006). This standard provides, among others, the frame of the regulatory requirements with regards to performance, marking, functionality, EMC, vibration, shock resistance, software design, light signaling, documentation, or manufacturing control of the equipment. For example, detectors are evaluated on their sensitivity to fire in the following classes: Class 1, Class 2, Class 3. Class 1 being the highest level of sensitivity, class 3 being the lowest.

On the American market, the repository is according to FM3260 standard. The approach is a little different from the EN 54-10, but overall, the standard aims to check roughly the same type of features.

Functional safety

Although not mandatory, the evaluation devices according to IEC 61508 standard is more and more often required by users. Beyond defining reliability parameters (SFF, PFD, MTBF, MTTR ...), certification also covers the software, both in its structure and its development process.

The certification determines a SIL number (Safety Integrity Level) for the safety function provided by the device. This level is graduated from 1 to 4, with 4 being highest. A number of devices are certified SIL2, the best manage to achieve SIL3 certification.

Conclusion

Choosing the right flame detector is therefore based on a good identification of the need.

First, what type of fire we want to detect (flammable liquid fires, metal fire ...), what is the type of the working environment (indoor, outdoor, environmental interference sources, industrial ...), what is the response time expected and what are the distances that we need to cover.

Secondly, it is essential to properly configure the installation: devices location, control panel voting function, adjust the sensitivity and time delay settings, functional tests.

Finally, maintenance mainly consists of cleaning the device window, either preventively or when the optical self-tests indicate fault.