WHITE PAPER

Hydrogen and fire safety:

Detecting the most flammable element on earth

By itself, hydrogen is colorless, odorless, tasteless and nontoxic. But when even small amounts of this seemingly harmless substance mix with air, it morphs into a major fire hazard. Therefore, industries that use hydrogen require leading-edge flame and gas-leak detection technologies to ensure a safe environment for people and processes.

Hydrogen, the first element in the periodic table, is the most abundant chemical substance in the universe. On earth, it is normally found in combination with other elements (in water molecules, for example) but rarely in its pure form.

In addition, it takes only a small amount of energy to ignite hydrogen. In fact, it can actually self-ignite, even without an external energy source, in cases where it is leaking from a pipe at a sufficiently high pressure.

In addition to its importance in the natural world, hydrogen plays a major role in many industrial processes. These include refining and food processing, as well as the production of fertilizer, plastics, pharmaceuticals, silicon chips and glass sheets.

What makes hydrogen dangerous?

Industrial users of hydrogen must deal with the highly reactive and explosive properties of this gas. In NFPA 704, the labeling system used to identify hazardous materials, the National Fire Protection Association gives hydrogen its highest rating of 4 on the flammability scale because it is flammable when mixed even in small amounts with ordinary air. (See Figure 1.)

Flammability Hazard Ratings per NFPA® 704

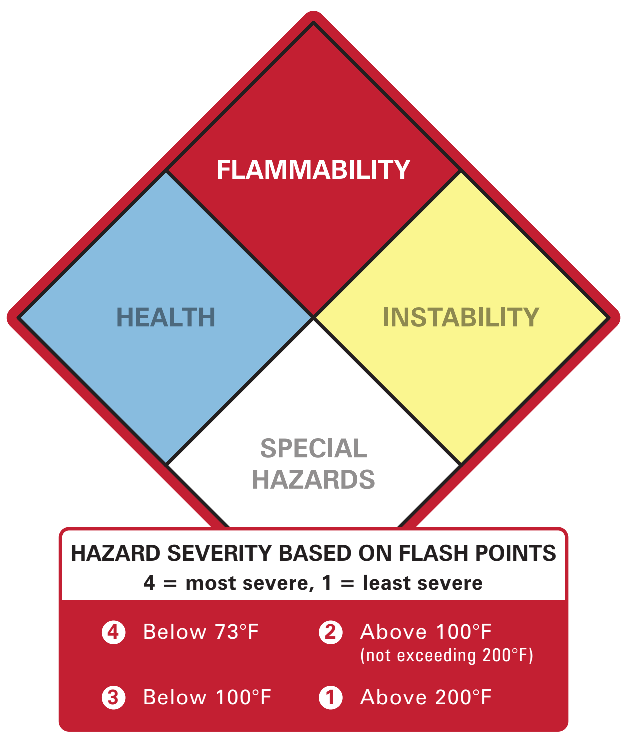

Figure 1: Materials rated a "4" in terms of flammability in NFPA® 704 are those that will readily burn at room temperature, including acetylene, propane and hydrogen gas.

Making hydrogen even more dangerous is the fact that, unlike a hydrocarbon flame, human senses cannot easily detect a hydrogen flame. People who come upon a hydrogen flame will not see it, even up close. (See Figure 2.) Instead, they may see an area ahead of them shimmering, as if it were a mirage. They may also see sparkles, which are dust particles burning briefly in the flame.

In addition, people approaching the flame will not feel intense heat. This is because hydrogen flames emit very little of the infrared (IR) radiation that causes humans to sense heat when standing next to a flame. With nothing to see and little radiant heat emitted to the environment, human senses won't warn people to stop as they approach a hydrogen flame. As a result, they could unknowingly walk right into it.

Gas detectors: The first line of defense

Fortunately for industrial firms that use hydrogen, gas detectors and flame detectors can work as a team to quickly identify a gas leak or a resulting flame. Since people cannot see, smell or taste hydrogen gas in average conditions, a gas detection system should be deployed to alert plant personnel of a leak before it ignites. Such systems can be considered the first line of defense in the case of a hydrogen release. If there is a release, fast detection makes it possible to stop the leak before it causes a fire or explosion.

Two common technologies for detecting combustible gas are IR and catalytic bead (pellistor) detectors. An IR gas detector responds to gases that absorb IR radiation, such as hydrocarbon-based methane and propane. But since hydrogen cannot absorb IR radiation, IR gas detectors will not detect hydrogen and therefore are not recommended.

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This makes catalytic bead-type detectors the right choice for detecting hydrogen at lower flammable limit (LFL) levels. A catalytic bead sensor detects any combustible gas that combines with oxygen to produce heat. If the gas can burn in the air, this sensor will detect it.

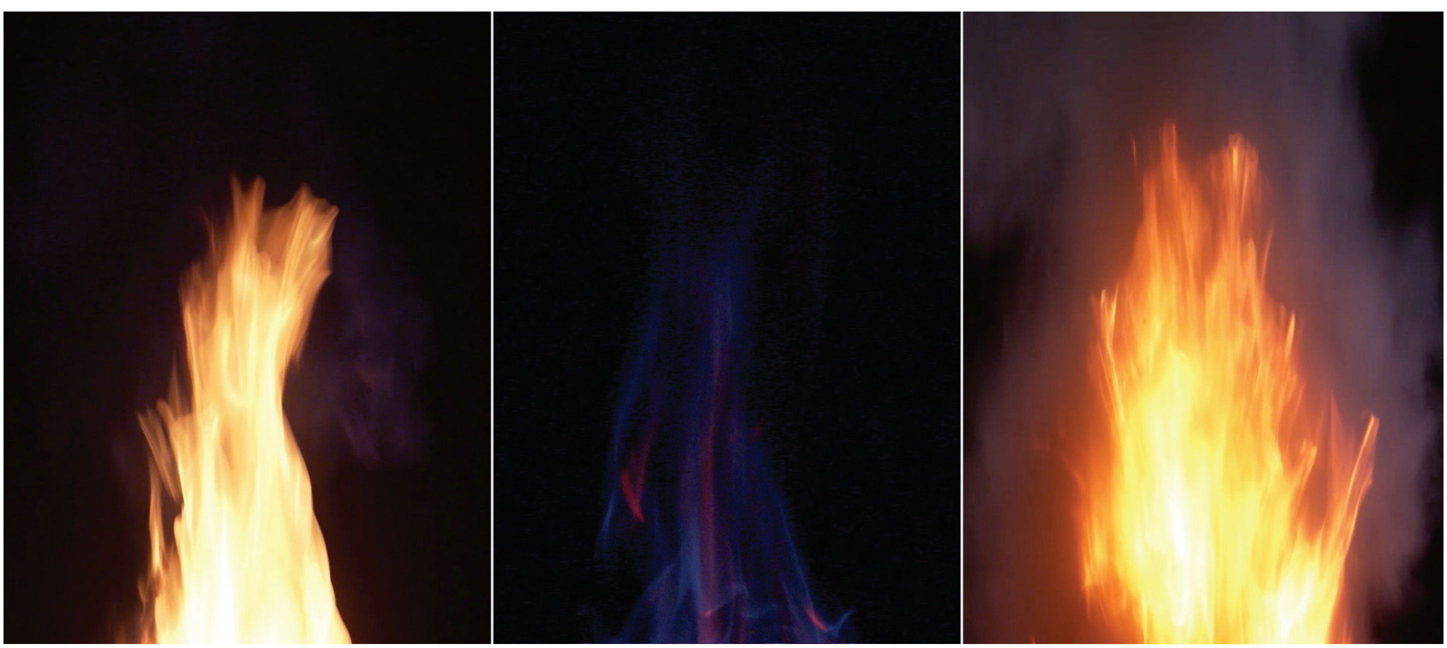

Figure 2: Every combustible gas burns differently, producing a signature flame. Compared to hydrocarbon flames depicted on the right and left above, a hydrogen flame (center) emits little visible light and IR radiant heat and therefore is more difficult for people and equipment to detect.

The catalytic gas sensor usually consists of a matched pair of platinum wire-wound resistors, one of which is encased in a ceramic bead. The active catalytic bead is coated with a catalyst; the reference catalytic bead remains untreated. This matched pair is then enclosed behind a flameproof sinter, or porous filter.

In operation, the beads are resistively heated. When a combustible gas comes in contact with the catalytic bead surface, it is oxidized and heat is released, causing the resistance of the wire to change. The reference (or passive) bead maintains the same electrical resistance in clean air as the active bead, but does not catalyze the combustible gas. The sensor detects gas by comparing the currents. If they are different, the detector can alarm. If there is no gas cloud, both beads will have the same current and no alarm will occur.

Hydrocarbon vs. hydrogen flame detection

Optical flame detection technology must match the type of fuel it is expected to see. To verify that a flame exists, a flame detector must see one or all of the flame components. In a flame fueled by a hydrocarbon source, the components are carbon dioxide (CO_2), carbon, water and heat (IR). But not all fires are the same. A hydrogen fire emits no CO_2.

Flame detection technologies that are widely used today are based on ultraviolet (UV) and infrared (IR) sensors. Since hydrocarbon-based fires are strong emitters in the IR spectrum, single- and dual-IR detectors are suitable for their detection. Combination UVIR detectors have also been popular choices for sensing hydrocarbon-based fires because they reduce false alarms.

Unlike hydrocarbon flames, hydrogen flames radiate energy primarily in the UV and water bands. Therefore, UV flame detectors are a logical choice for sensing hydrogen flames.

In fact, UV flame detectors provide good response to both hydrocarbon and non-hydrocarbon fires. But for sensing of both kinds of fires, UV, UVIR and single- and dual-IR detectors are being displaced by multispectrum IR (MIR), or triple IR, detection systems. MIR technology offers better performance, fewer false alarms and, often, a lower cost of coverage than its conventional detection counterparts in many applications.

Catalytic bead detectors do have shortcomings. For one, they may not signal when they fail. They are also susceptible to poisoning, which can cause them to fail from exposure to silicones and other chemicals that are common in industrial environments. In these cases, the porous filter gets clogged, resulting in the active bead behaving in the same manner as the reference bead, which may affect the system's accuracy or possibly prevent the detector from sensing gas.

If the active bead in a catalytic detector cannot sense gas, the operator in the control room will have no way of knowing it. Therefore, periodic bump or proof testing with calibration gas is required to ensure proper sensor operation.

When placing these gas detectors, users should keep in mind that hydrogen, the lightest gas, quickly floats upward and disperses. Because of this, installers should make sure the gas detector is located close to and above a spot where a leak might occur or hydrogen gas might accumulate — just above a valve stem, for example.

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Hydrogen flame detection comes in several forms

In addition to gas detectors, an optimal hydrogen safety team includes detectors that can sense a hydrogen flame quickly and accurately if a leak does ignite. One option for detecting hydrogen flames is a thermal heat detector. Detectors of this type will not alarm until the temperature of the area being monitored exceeds the detector's trip point, so it is logical to position them directly above the possible site of a hydrogen flame. However, the source of a hydrogen leak may create a flame that is directed away from the detector.

Further complicating matters, a hydrogen flame's low IR radiation may not be enough to send a thermal heat detector into alarm. While thermal heat detectors are helpful, proper positioning is the biggest challenge.

Another alternative is to use an optical flame detector that can detect a hydrogen flame. Compared to hydrocarbon flames, hydrogen flames emit little visible light. Technologies are available that detect hydrogen flames and include those that sense non-visible IR and ultraviolet (UV) radiation.

UV flame detectors use anode/cathode Geiger-Mueller-type vacuum tubes, a technology dating back to the early 20th century, to sense UV radiation emitted by a flame. UV radiation enters the vacuum tube through a quartz window and strikes the cathode. The energy from the UV photon releases a photo electron and creates an electrical impulse as it travels to the anode.

Since hydrogen flames radiate energy mainly in the UV band, UV flame detectors excel at fast detection of hydrogen flames.

On the other hand, UV flame detectors are sensitive to arcs, sparks, welding, lightning and other UV-rich non-flame sources. These UV emitters can cause UV flame detectors to set off false alarms, which can have expensive consequences and reduce people's sensitivity to real potential hazards.

Therefore, UV flame detectors are best suited for locations isolated from sources of false alarms, such as enclosed rooms. Even here, however, the problem probably won't be entirely eliminated since most enclosed rooms have ventilation ducts that can reflect UV from lightning and welding, thereby causing a UV flame detector to alarm.

Detectors exist that utilize both ultraviolet and infrared (UVIR) technologies. These detectors require both UV and IR signals to be present for an alarm to occur. This offers better false alarm rejection capability compared to just UV detection alone. However, UVIR detectors are still susceptible to combinations of false alarm sources.

MIR flame detectors emerge as the favorite

The false alarm challenges faced by UV and UVIR flame detectors are one reason multispectrum infrared (MIR) flame detection has become the preferred choice for detecting hydrogen flames in most indoor and outdoor settings. These flame detectors use a combination of IR sensor filters and software analysis to both see flames and reduce false alarms. (See Figure 3.)

Some MIR flame detectors have been designed specifically to detect the low-level radiation from hydrogen flames using a unique set of IR filters. These special devices offer very good detection range; equipped with the optimum IR filter set, some MIR flame detectors can detect hydrogen fires at about double the range of a UV flame detector. MIR flame detectors also offer a good response time, but do not set off false alarms when exposed to arcs, sparks, welding and lightning. In addition, they provide solar resistance and are insensitive to artificial lights and most blackbody radiation, things that may adversely affect other detection technologies.

On the downside, the range of MIR flame detectors is reduced by the presence of water or ice on the lens. To mitigate this problem, some detectors are equipped with lens heaters that melt ice and accelerate evaporation of water.

Figure 3: **To "see" hydrogen flames, today's best technology is multispectrum infrared flame detection as used in the new Det-Tronics X3302 MIR flame detector shown.**

In summary

Hydrogen is a valuable commodity with a growing list of uses. But it is also a highly combustible substance that poses special threats to people and property. These threats can be minimized by plant managers and personnel who understand the unique characteristics of hydrogen and then deploy detectors designed to meet the challenges of quickly and accurately detecting hydrogen gas leaks and flames.

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Resource

"NFPA® 704: Standard System for the Identification of the Hazards of Materials for Emergency Response," 2017; www.nfpa.org

About Det-Tronics

Det-Tronics is a global leader in fire and gas safety systems, providing premium flame and gas detection and hazard mitigation systems for high-risk processes and industrial operations. The company designs, builds, tests and commissions SIL 2 Capable flame and gas safety products ranging from conventional panels to fault-tolerant, addressable systems that are globally certified. Det-Tronics is a part of Carrier, a leading global provider of innovative HVAC, refrigeration, fire, security and building automation technologies.

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