TECHNICAL NOTE

Understanding Filter Methods for Uncooled Optical Gas Imaging

Optical Gas Imaging Cameras are a critical tool for detecting gas leaks. It is important to understand the capabilities of a cooled camera vs. an uncooled camera to ensure customers are making the right investment for their operations.

Infrared (IR) cameras have long been a valuable tool for detecting gas leaks at facilities such as natural gas power plants and many locations across the natural gas supply chain, using a technique known as optical gas imaging (OGI). By capturing the contrast between background energy and energy that's been absorbed or transmitted by gas, such cameras make it easy to identify leaking components. Cooled cameras available today are built using complex manufacturing processes and provide users with sophisticated capabilities and actionable insights, these cameras may have been out of reach for some due to the price points.

Now, with the advancements of a newer technology that relies on uncooled detectors and spectral filters, it expands the available OGI offerings to include a much more cost effective option.

Filtered, uncooled IR cameras are not as sensitive as their cooled cousins. For example, the uncooled cameras may not have enough sensitivity to meet the Environmental Protection Agency's (EPA) standard to comply with the OOOOa rule, which requires natural gas well pads and compressor stations to check for gas leaks. (Fig. 1) Fortunately, for

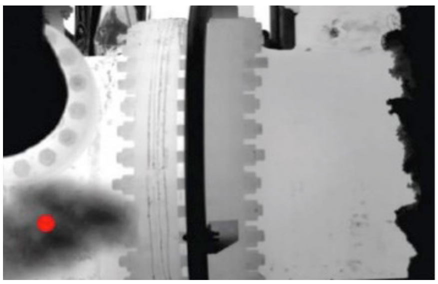

Figure 1: A leak in a natural gas compressor is easily visible using optical gas imaging.

Figure 2: OGI allows users to spot the source of leaks, such as in this valve.

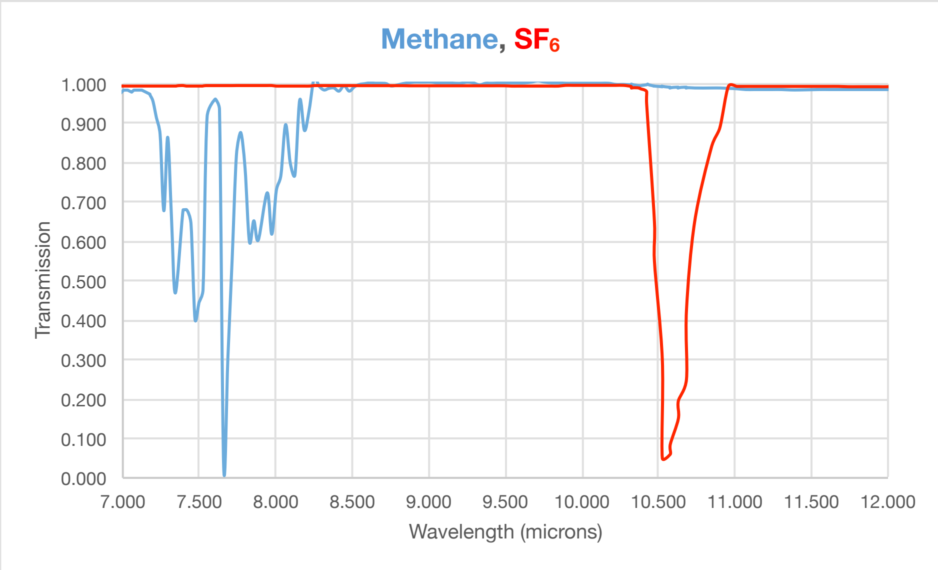

Figure 3: Methane has an absorption spectrum between 7 and 8.5 μm while sulfur hexafluoride's is between 10.5 and 11 μm. (Source: NIST Mass Spec Data Center)

companies that don't have to meet those requirements, the substantially lower price of an uncooled camera opens up new options. For instance, companies that liquefy natural gas for shipping across the ocean, then return it to its gaseous state after unloading it, could benefit by being able to detect methane leaks. Even though they're not bound by the same EPA regulations, using OGI for leak detection and repair would improve their safety and reduce the amount of product lost to the atmosphere, increasing their profits.

Looking for Contrasts

The idea behind OGI is straightforward. When energy passes through a plume of gas, the gas both absorbs and emits energy at particular wavelengths, depending upon the type of gas. If the temperature of the gas and the background differ, the strength of this absorption and emission will also differ, creating a contrast in the image. On a detector optimized for the correct wavelengths, the gas will appear as a smoke-like cloud against a bright background. While other technologies, such as electrochemical "sniffers," can also detect gas leaks, they only register the presence of the gas. An IR camera makes it easy to see not only the size of the gas plume but also where it's coming from. (Fig. 2)

But to achieve the sensitivity to pick out the contrast between background and gas, IR cameras have traditionally been cooled to cryogenic temperatures of 70 Kelvin, or minus 203 degrees Celsius. That helps cut out stray energy and thermal noise from the camera equipment itself and makes the gas easier to spot. Such cameras have relatively complex designs, including the cooling system and a spectral filter inside the dewar, where it too can be cooled to prevent it from causing thermal noise. These systems require sophisticated manufacturing processes and the coolers include moving parts built to tight tolerances, which inherently wear out over time. Other characteristics to consider, the helium gas used to cool the system may slowly leak and the coolers, due to regular use need to be rebuilt after approximately 30,000 hours in the field. For optimum use, these cameras require operators to wait approximately seven minutes for the system to cool to the correct temperature.

To provide customers with an option other than a cooled system, we are introducing a new type of detector that can capture IR radiation—a bolometer. Bolometers are made of materials such as vanadium oxide or amorphous silicon—which respond in the 7 to 14 μm range—and they work differently than the cooled IR cameras. While cooled detectors count the number of IR photons striking them, bolometers instead heat up when the IR radiation hits them, causing a change in their electrical resistance, which can be measured. Because they don't require cooling, bolometer-based cameras are simpler to design and build and therefore are more affordable then its big brother, the cooled camera. Another difference is the uncooled camera does not require any start-up time putting more time in the operators day.

Uncooled cameras, though, are not as sensitive as their cooled counterparts. In recent years, their performance has improved through such upgrades as a better pixel pitch, which increases the area of the detector and, therefore, the sensitivity.

Adding a Filter

Another performance improvement with the uncooled optical gas imaging cameras is the addition of spectral filters to cut out energy that's not relevant to detection. Methane, for instance, absorbs energy at around 7 to 8.5 μm. Another gas of interest, sulfur hexafluoride, is visible between 10.5 and 11 μm. (Fig 3) Filtering out other wavelengths reduces the energy that might tend to drown out the gas's signal and makes it easier to see. The narrower the wavelength range of the filter, the higher the contrast between the radiation from the gas and the background energy.

The trick is to design the filter correctly. While a narrower bandpass increases the contrast, it also means less energy gets through to the detector overall, so the signal-to-noise ratio changes for the worse. Much of the noise comes from the detector itself, so it remains constant even as the filter reduces the amount of signal.

There are systems that do not use filters. Some cameras are essentially wide open, picking up energy over the entire wavelength range of the detector. Operators need to use software to perform image subtraction, taking out the parts of the image they don't need in the hopes of seeing any gas leaks more clearly. While such software can improve the visualization of the gas image, they do not work as well as filters.

Measuring Noise

The quality of the signal is often characterized in noise equivalent temperature difference (NETD). NETD, measured in millikelvins, represents the temperature difference that would produce a signal in the image equal to the noise from the camera. In other words, it provides the minimum temperature difference a camera can resolve.

For example, a camera with no filter would collect energy across the entire range of 7 to 14 µm. The NETD in such a system would be low, perhaps 20, so the signal-to-noise ratio would be good. On the other hand, the contrast between the gas and the background would also be low, so the image would be harder to see. Adding a filter that transmits between about 9 and 12 µm improves the contrast, but the NETD more than doubles, making the noise worse and degrading the image. A filter that operates between 10.5 and 11 µm, the wavelength range of sulfur hexafluoride, provides a very high contrast image, but the NETD becomes roughly 10 times worse, nearly drowning out the signal from the gas.

Essentially, then, the contrast and the noise move in opposite directions. The key to get the best image is to pick a filter narrow enough to provide good contrast, but not so narrow that the signal vanishes in the noise.

The quality of the image is also affected by the volume of gas that energy is passing through, which is described in terms of concentration length. The quality of the signal, therefore, can also be characterized in terms of noise equivalent concentration length (NECL), a parameter similar to NETD. A camera with lower NECL has greater sensitivity. Concentration length is the average amount of gas in the air over a given distance, measured in parts per million per meter (ppm x m). If you had a 1-m-long tube filled with 100 percent methane, the concentration length would be 1 million ppm x m. If the gas were diluted to 50 percent, the concentration length would be 500,000 ppm x m. The greater the concentration length, the more energy is absorbed or transmitted, leading to a higher-contrast image. Larger gas plumes, in other words, are easier to see whether the filter is wide or narrow, so the choice of filters also plays a role in how big a leak is detectable.

Temperature Changes

IR cameras are not only useful for OGI, of course. Owners of natural gas processing facilities also use them to inspect equipment for temperature anomalies. For instance, if a connector in a gas line is a lot hotter than it should be, that could be a sign of imminent failure. Many facilities use IR cameras for such dual-purpose imaging and require accurate temperature readings. (Fig. 4) If that's the case, an uncooled camera might not be an appropriate choice without the appropriate lens for accurate temperature measurements.

The same change in NETD from a filter that degrades signal-to-noise and makes the image worse also reduces the accuracy of temperature measurements. For applications where it's important to both perform leak detection and gather precise temperature measurements with a single lens, a cooled IR camera might still be the best choice.

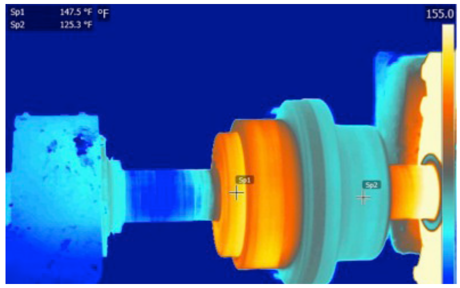

Figure 4: IR imaging can spot temperature differences that indicate equipment failure.

A Range of Options

The introduction of uncooled cameras equipped with spectral filters has opened up new options for the people who handle gas and need to perform leak detection and repair. Cooled cameras are still the best choice for companies that need to comply with OOOOa regulations or gather accurate temperature measurements along with finding gas plumes. However, uncooled bolometers could be ideal for companies that don't have such stringent requirements but would still like to turn to OGI to improve their safety profile and reduce losses. The less expensive uncooled IR cameras, when fitted with the correct spectrally filtered lens, can prove a valuable tool for detecting leaks.

For more information about thermal imaging cameras or about this application, please visit www.flir.com/ogi

The images displayed may not be representative of the actual resolution of the camera shown. Images for illustrative purposes only.