Detection of Volatile Organic Compounds (VOC's) with a Spectrally Filtered Cooled Mid-Wave Infrared Camera

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ABSTRACT

The world's petrochemical industry is constantly seeking methods for the detection of Volatile Organic Compounds (VOC's) such as benzene, propane and methane. Leaks of such materials all too often lead to catastrophic equipment damage and loss of life. EPA regulations require reduction of such emissions with statistics showing that 84% of the leaks are coming from only 0.13% of the equipment.

Current technology consists of hand held toxic vapor analyzers (TVA's), or "sniffers" which are accurate but labor intensive in that inspections must conducted as point-to-point surveys in close proximity with pipes, valves and other VOC carrying components. It is also easy to miss a leak as the devices give only an indication of a leak, but no image.

This paper will describe new infrared imaging technology that uses a special infrared imager employing a sensitive detector and a cold filter to observe active leaks. The paper will discuss a range of applications from small scans in local gas stations to extensive scans in petrochemical refineries.

INTRODUCTION

The long and arduous search for a viable technology for locating fugitive emissions of VOC's is over. After years of research, development, field application and experimentation, the new GasFindIR IR camera promises to find VOC leaks faster, more comprehensively and less expensively than current TVA technology. This is great news for both the environment and the petrochemical industry. The planet will be better off with less pollution caused by fugitive VOC emissions, and the petrochemical industry will suffer fewer losses of product and enhance their process stream, resulting in improved efficiency and profitability.

This breakthrough started with a small company in Texas that wanted to improve natural gas pipeline leak surveys. David Furry and his crew consulted for the City of Brady, Texas, which operates oil and gas wells and a gas transmission line for distribution to the city. The 45 mile long gas transmission line system was built in 1918, and it had 40% line loss, and check meters every 10 miles. Once a leak was isolated between check meters, the crew used an FID (flame ionization detector) sniffer to find the leak(s) by walking the line. David believed that there had to be a better way.

In 1990-91 he began his research and started thinking about using infrared technology. Early attempts with a Radiance PM IR camera were unsuccessful. During this time, he began learning about IR filters and realized they could be the key to a solution. He found a company that built a variable spectral lens for the military called IMSS which could spectrally scan through the 3 to 5 micrometer waveband in 0.01 micrometer steps. The IMSS was used by the military for rocket exhaust signature analysis.

David installed one on the front of a Radiance PM camera. Though the image was severely out of focus, he was able to find the absorption waveband for propane gas by putting a bottle of propane in front yard and scanning through the spectrum until he saw an image of the gas. David contacted the manufacturer and tried to get them to build a camera with a cold filter, but the $300,000 to $500,000 cost was prohibitive. The IMSS lens company received funding to build a camera with improved IMSS lens for VOC detection using a warm filter, but never finished the job.

Meanwhile, David continued to work with Amber Engineering on IR camera development which continued intermittently for several years until about 2002. By then, Amber had become Indigo Systems, the company that built the popular Merlin camera with a warm filter operating at a center wavelength of 3.38 micrometers, where propane has a strong absorption line. It had limited success as it didn't work well on cloudy days when the thermal contrast was low.

David learned about cold filtering, and with the technical acumen of Austin Richards and the Indigo team, a liquid-nitrogen filled Merlin Lab camera with a removable cold filter was built in February of 2003. They tested it in the Indigo parking lot with a bottle of propane. David rented a camera with a cold filter, and with successful test marketing, he ordered the first Merlin camera with a built-in cold filter (not removable) in May 2003. He modified the shoulder mount (for portability) built for the Merlin Lab camera, and continued pushing to sell to the natural gas market. Figure 1 shows this camera and mount in use.

In February of 2004, the EPA called and requested that he attend a VOC detection trial with other optical imagers. There were four different cameras: two were active systems that use laser beams, one used the spectrally variable IMSS lens and the fourth was the Merlin. The Merlin, with a special cold filter, found more leaks overall, detected smaller leaks, and found them more quickly than any of the other cameras. This test opened many doors in the VOC world, and as a result, David bought two more Merlins with cold filtering.

Other important milestones include: lab testing for sensitivity to highly reactive VOC's of ethylene, propylene, butene and 1,3 butadiene at an independent testing lab in Naperville, Illinois; the purchase of a helicopter in June of 2004; DOT approval to fly regulated natural gas lines in early 2005; and optical imaging as part of a consent decree to offset a $420 Million fine at a large oil company.

Another significant milestone in optical imaging of VOC emissions was the purchase of Indigo Systems by FLIR Systems in 2004. FLIR Systems has continued to evolve the VOC optical imaging detection technology by incorporating cold filtering into one of its robust, hand-held, battery-powered mid-wave infrared 3 to 5 infrared cameras. The result is the ThermaCAM GasFindIR infrared camera shown in Figure 1B. It is smaller, lighter and more rugged than the previous Merlin cameras.

Figure 1A. Man portable Merlin "Hawk" in use.

Figure 1B. The FLIR GasFindIR camera.

IR images of some Leaks

Figure 2A shows a Merlin Hawk image of two valves side by side, both of which are leaking gas. This one is difficult with a TVA, as it would be easy to call this one leak instead of two. Another Merlin Hawk image in figure 2B shows why we now have vapor recovery systems on gasoline pumps. There are significant amounts of gasoline fumes leaking from this pump with no recovery system. The live image seen by the operator (and recorded) gives a much clearer picture of these leaks due to the motion of the gas plume relative to a stationary background. We have taken the liberty of pointing to the darker areas to indicate where the gas plumes are in the images.

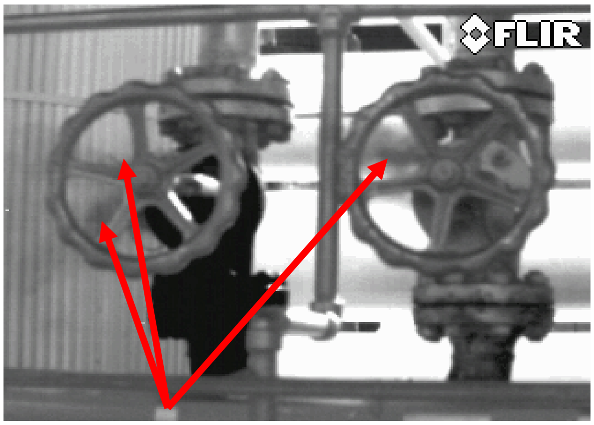

Figure 2A. Gas leaking from two valves. Arrows indicate gas plumes.

Figure 2B. Gasoline vapors wafting from the nozzle of a non-vapor recovery hose.

In addition to gas plume motion, thermal contrast between the absorbing gas and the background is a key element for detection. Figure 2A illustrates this as the plume from the right hand valve is much easier to see than that from the left hand valve due to higher thermal contrast. The video shows it was also a denser plume which is another key to detection.

Some sample GasFindIR images of leaks from a methane nozzle, melting naphthalene and butane lighter are given in Figures 3A, 3B and 3C. Again, motion is the key to detection of small amounts of gas, so we have indicated the plumes using arrows. Though not quantified, these are very small amounts of vapor. All of these were done in an exhausting fume hood, so the plumes were rapidly dissipated upward.

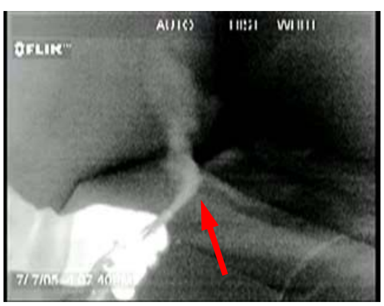

Figure 3A. Small amount of methane from nozzle.

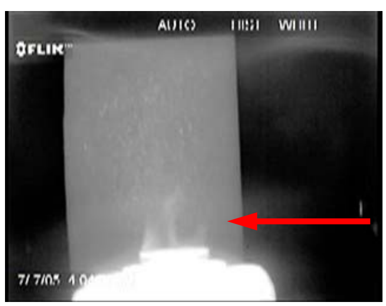

Figure 3B. Small amount of naphthalene evaporating from heated dish.

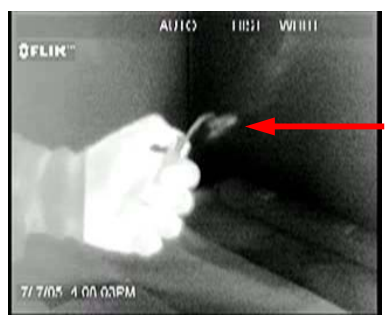

Figure 3C. Small amount of butane from lighter.

Figures 4A, 4B and 4C show sequential GasFindIR images of gasoline fumes accumulating close to the pavement. This cloud rapidly dissipated as shown in Figure 4C due to a gusty breeze. In the full video, one can see the fumes being blown into the operator's face, and he steps back momentarily.

Note that in figure 3 all the gas plumes have a lighter tone than the background, denoting a higher apparent temperature. In all the other figures the gas plumes are darker than the background denoting a lower apparent temperature. In all these cases the GasFindIR image polarity was set to "WHITE" indicating higher apparent temperatures appear as lighter tones.

Figures 4A, 4B, 4C. Gasoline fumes seen by the GasFindIR accumulating near the pavement, then dissipated by a breeze.

Testing and Applications

The GasFindIR camera technology opens the door to an entirely new infrared market; finding VOC's in the environment. With the capability of detecting such gases as methane, propane and butane, GasFindIR applications will evolve as did those in the commercial/industrial thermography market for radiometric IR cameras. Table 1 gives a list of gases the GasFindIR has detected in lab tests. This list is by no means complete, but it is a good start. The GasFindIR will not detect, nor was intended to detect, air, hydrogen or sulfur hexafluoride (SF_6), the latter two gases being of strong interest to the electric power generation industry. The compounds listed in Table I are liquids at room temperature, requiring heating to form gas plumes. This testing was done under a variety of conditions which provided useful data to our engineering and training staff.

Gas	Compound
Butane	Benzene
Ethane	Ethylbenzene
Ethylene	Heptane
Methane	Hexane
Propane	Isoprene
Propylene	Methanol
	MEK
	MIBK
	Octane
	Pentane
	1-Pentene
	Toluene
	Xylene

Table 1. Gases and compounds detected by GasFindIR in laboratory testing.

The petrochemical industry was one of the first, if not the first, to embrace IR cameras for finding "hot spots" and thermal anomalies in electrical, mechanical, refractory and other refinery applications. They will be among the first to use the GasFindIR camera as well. The natural gas producers and transporters (pipeline and otherwise), will also be early adopters. The Environmental Protection Agency and local air quality regulatory agencies are taking a strong interest and working on new regulations that incorporate infrared imaging technology as discussed in greater detail below.

Figures 5a, 5b and 5c give examples from a refinery survey. Figures 5a and 5b show leaking LPG compressor flanges. In the live image and in the video one can see in addition to the obvious leak on the left flange as shown in figure 5a, a much smaller leak from the right hand flange, shown in 5b. Figure 5c shows a larger leak from an LPG pumping station transfer line connection.

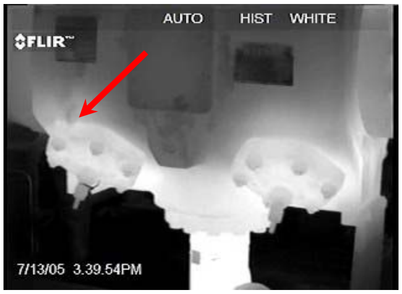

Figure 5a. Leak from LPG compressor left flange.

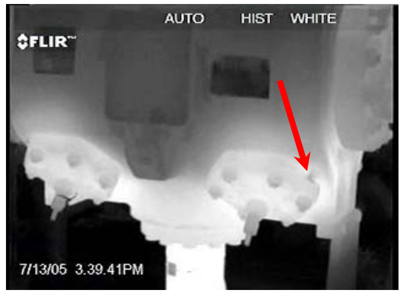

Figure 5b. Leak from LPG compressor right flange.

Figure 5c. Leak from LPG pumping station transfer line.

As applications evolve and the technology improves, we see the GasFindIR technology finding its way downstream from producers, refiners and shippers to distributors and distribution systems. There are applications beyond the standard petrochemical industry where detecting VOC's will improve production and enhance safety that no one has even thought of yet. This is a truly exciting time for the infrared industry.

LDAR and Smart LDAR

LDAR is Leak Detection and Repair. It is the current regulated technology used by the petrochemical industry to find, document and repair VOC leaks. EPA Method 21 provides the procedure for finding the leaks. Gas TVA technology is used and is a slow process requiring the operator to "sniff" for leaks at numerous tagged locations. As an example, a medium to large refinery can have 600,000 such points including connections, valve packing, pressure relief valves and so on. The EPA believes it is difficult for one operator to monitor more than an average of 500 valves in an eight hour shift on a routine basis. TVA's can be accurate in determining the concentration in ppm (parts per million). But leak concentration can be misleading. Even if taken at the leak location, a small pinhole leak can exhibit a high concentration where a large crack can be leaking orders of magnitude more gas but have a lower measured concentration.

A big difficulty with the TVA's is putting the probe where the leak is. Optical imaging solves this problem when used properly. The GasFindIR technology finds leaks where no one thinks to look, and in areas that may be difficult to reach with contact measurement tools. It also finds leaks that TVA's miss due to wind or other factors. The GasFindIR can be used to find leaks over significant distances depending on the size of the leak. One can often find small leaks at a 30 foot standoff range with standard optics, and GasFindIR cameras with longer focal length lenses have been used successfully from helicopters to spot leaks from barges, storage tanks and gas pipelines.

The GasFindIR infrared camera is able to survey over 3000 points an hour, and the EPA is currently developing a Smart LDAR program that uses infrared imaging as a new method of VOC leak detection, and they are currently working on detection limits and survey procedures as well.

SUMMARY

GasFindIR infrared imaging technology is a strategic inflection point due to a paradigm shift (Andrew Grove, Only the Paranoid Survive) for the petrochemical and regulatory industries. The applications in the petrochemical industry alone are numerous with at least 19 gases detectable by the GasFindIR at less than 1 gram per hour for several gases. GasFindIR technology evolved from a lot of hard work and persistence of small companies and a few individuals over a period of almost 15 years.

Significant work still needs to be done, especially on the regulatory and reporting sides. The ongoing Smart LDAR project is addressing that. We in the infrared industry are developing guidelines and training for the effective use of the GasFindIR camera to ensure the maximum benefit to both the environment, and to industry as a whole.

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