Gas leak detection in the oil and gas industry using infrared optical imaging

J. F. TEGSTAM, FLIR Systems AB, Danderyd, Sweden
R. DANJOUX, ITC Eurasia, Danderyd, Sweden

Abstract. Many industrial gases and chemical compounds are invisible to the naked eye. Yet companies transport, measure and transform these ingredients every day. They use a range of instruments to monitor these assets from the loading dock, throughout the refinery and chemical processing plant and back to the storage tanks, pipes and railcars.
The FLIR Systems ThermaCAM® GasFindIR™ enables its users to scan thousands of components per shift and spot small gas leaks from a safe distance. For the first time, an infrared (IR) camera – ThermaCAM® GasFindIR™ – allows you to spot methane and other volatile organic compound (VOC) gas leaks quickly and easily. Capable of rapidly scanning large areas and even kilometers of pipeline, this highly specialized infrared camera delivers real-time thermal images of gas leaks.
The ThermaCAM® GasFindIR™ is lab-tested to detect:
Benzene, Butane, Ethane, Ethanol, Ethylbenzene, Ethylene, Heptane, Hexane, Isoprene, MEK, Methane, Methanol, MIBK, Octane, Pentane, 1-Pentane, Propane, Propylene, Toluene, Xylene
Optical imaging using infrared cameras, such as ThermaCAM® GasFindIR™, offer a number of benefits that are becoming known in the industry as 'Smart Leak Detection and Repair' because it can scan a broader area, more rapidly and in areas that are difficult to reach with contact measurement instruments. Infrared displays a leak as a plume of vapor in the infrared image. Using infrared imaging to spot leaks, damaged pipes, breached seals or valves and other emissions makes business sense and common sense. The results are powerful, immediate and yield bottom-line results.

Introduction

New technologies have been a mainstay of oil and gas industries and their affiliated companies. For decades, the petrochemical industry has been among the first to embrace new ways of working better, faster and smarter. Operations that rely so heavily on engineers and science quickly recognize the benefits of problem-solving tools. Measurement and inspection is critical and knowledge is prized because acting on incomplete information can cost millions of dollars and non-productive down time.
Yet people have spent years working with some of the most explosive and toxic substances by relying on vague, subjective measures of sight, smell and hearing. Complex maintenance work in the petrochemical industries used leak detection, equipment monitoring, environmental controls and regulatory compliance that hinged on human experience – not that different from miners who used canaries for generations to warn of dangerous carbon monoxide levels.
Infrared imaging now allows workers to "see" volatile organic compounds that are invisible to the human eye. The first commercial camera to record these images now makes clear the presence of often odorless and lighter-than-air compounds that may be toxic, flammable or strictly regulated. By looking for the right wavelength of infrared "heat" the camera sees what people cannot.

Using infrared imaging to spot leaks, damaged pipes, breached seals or valves and other emissions makes business sense and common sense. The results are powerful, immediate and yield bottom-line results.

1 Benefits with infrared in the oil & gas industry

Many industrial gases and chemical compounds are invisible to the naked eye. Yet companies transport, measure and transform these ingredients every day. They use a range of tools to monitor, identify and contain these assets from the loading dock, throughout the refinery and chemical processing plant and back to the tanks, pipes, railcars and barges.

1.1 Gain a competitive edge and boost productivity

Armed with the latest technology, you'll do more in less time. Video records let you see clearly where leaks, repairs, damage or other conditions change over time. That knowledge is power when other companies are guessing at compliance, output and other metrics.

1.2 Increase workplace safety

Optical imaging provides more thorough and wide-ranging sweep areas, yielding definitive information before people enter potentially hazardous areas. Scanning from a safe distance means more area can be checked than using current methods. Fires and exposure hazards can be reduced dramatically when you see more than a single component or tagged site.

1.3 Ensure capacity and operating standards

Spotting leaks quickly and easily means rapid repairs and fewer loss-points where valuable products can escape. Some facilities have recovered millions of dollars in natural resources and sped up state or federal inspection requirements by using superior tools.

1.4 Improve air quality and cut greenhouse gas emissions

Emission reporting relies on imprecise measures and estimates. Optical imaging lets you prove the results of environmental or leak-detection programs. Know for certain what the impact of your facility is on neighboring properties and achieve new levels of community relations.

1.5 Cut maintenance time and costs

Instead of just spot-checking required sites – an estimated 98 percent of which have no flaws -- you can complete a broader, more complete program far more quickly. You'll see through varying weather conditions and other limitations.

2 ThermaCAM® GasFindIR™

The ThermaCAM® GasFindIR™ camera from FLIR Systems enables the quick, reliable location of those invisible chemicals and compounds. Inspections using infrared imaging can mean a recovery of time, product and manufacturing capacity.
The ThermaCAM® GasFindIR™, see figure 1 and table 1, is an infrared spectral imager designed to visualize the absorptive and emissive properties of gases/vapors allowing the user

the ability to discern the gas/vapor from its host environment. To wit, the imager “sees” the gas. The camera employs a spectral filter designed to transmit in a region of the IR spectrum that is coincident in wavelength with vibrational/rotational energy transitions of VOC molecular bonds. These transitions are typically strongly coupled to the field via dipole moment changes in the molecule, and are common to many types of gases and vapors. With this in mind, the camera’s detection sensitivity to a wide variety of gases and vapors is extremely small. Thermally, the camera’s sensitivity is <80mK when FLIR’s adaptive temporal filter is engaged. FLIR Systems has developed and fielded a passive IR imager capable of standoff leak detection of Volatile Organic Compounds (VOCs) in quantities beneficial to both industry and regulatory agencies.
The camera has been successfully deployed in a wide array of operating environments and settings. The technology has shown itself to be both cutting edge as well as user friendly. Pilot programs in natural gas transmission delivery service companies have documented over $2M savings in annual gas leaks with as few as five finds with the ThermaCAM® GasFindIR™.

Figure 1. ThermaCAM® GasFindIR™

Table 1. Camera Specifications

F-Number	2.3
Thermal Sensitivity	<80mK @ 30C
FPA	InSb 320x240 pixels
Spectral Range	3-5µm
Integration Time	16.6ms and selectable
Power consumption	<6W
Weight & Size	2 kg or less, 254x132x145 mm
Field of view (FOV)	25mm (22º), 50mm (11º), 100mm (5.5º)
Controls	Push Buttons on Camera and RS232
Outputs	S-Video, NTSC/RS-170, C-Video, PAL
Inputs	RS232

Table 2. Gases that ThermaCAM® GasFindIR™ can detect

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

The gases in table 2 are the ones that have been tested by independent laboratory. The ThermaCAM® GasFindIR™ can detect other VOC gases and FLIR is still doing tests on these.

3 Testing and verification

FLIR Systems has tested the ThermaCAM® GasFindIR™ camera system at the BP Naperville facility[1]. The testing was sponsored by FLIR, hosted by BP, and conducted by IES[2] under test methodologies developed by IES for the API. A summary of compounds tested and minimum detectable leak rates, (MDLR), are shown in table 3, note wind speed was varied from 0 to 5 MPH. The methodology employed was developed by IES and is reported in their submission to this conference. In brief, a leaking valve was imaged at a fixed distance with a known flow rate of gas being expelled. The flow rate at which minimum detection was achieved was recorded and images were saved. See figure 2 for a generic test image, note this image is not the MDLR for the gas shown. Some gases were also imaged with and without a nitrogen mix, see table 4.

Figure 2. Leaking Valve with Methane Plume

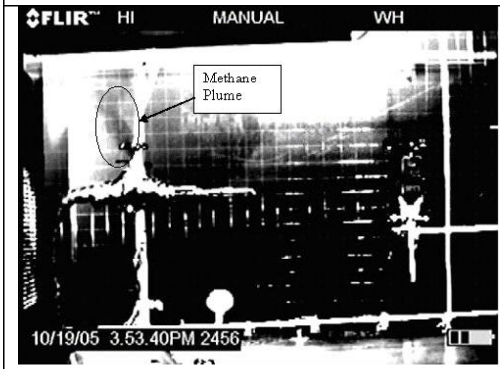


Table 3. Minimum Detectable Leak Rates for Compounds

MDLR's in Grams/Hr	Wind Speed in MPH		
Compound	0	2	5
Benzene	3.5	17.5	38.6
Ethanol	0.7	3.5	14
Ethylbenzene	1.5	7.6	17.5
Heptane	1.8	4.8	8.4
Hexane	1.7	3.5	8.7
Isoprene	8.1	14.3	38.8
Methanol	3.8	7.3	24.3
MEK	3.5	17.7	31.8
MIBK	2.1	4.9	13.3
Octane	1.2	3.4	8.7
Pentane	3.0	6.1	17.7
1- Pentene	5.6	19.7	43.8
Toluene	3.8	5.3	14.3
Xylene	1.9	9.1	18.9

Table 4. Minimum Detectable Leak Rates for Gases

MDLR's In Grams/HR	Wind Speed MPH					
Gases, Pure &	0		2		5	
†N2 Mixture	P	N2	P	N2	P	N2
Butane	0.4	6.5	1.5	7.3	4.2	13
Ethane	0.6	4.8	1.9	6.3	3.5	10
Methane	0.8	3.4	2.0	6.4	6.0	11
Propane	0.4	3.3	1.3	7.1	1.3	9.3
Ethylene	4.4	31	7.3	52	14	84
Propylene	2.9	14	8.9	30	16	35

†N2 mixture flow rates were typically3liters/minute.

The ThermaCAM® GasFindIR™ has a standard F/2.3 lens with a fixed focal length of 25mm. This generates a 21.74° horizontal FOV. Additional lenses with fixed focal distances of 50mm and 100mm were also tested. Horizontal FOVs for these lenses are 10.97° and 5.50° respectively. These lenses are offered by FLIR as optical accessories. The MDLR as a function

[1] British Petroleum, Naperville Illinois. Hosted by Dave Fashimpaur, Environmental & Loss Control Specialist.
[2] IES is Innovative Environmental Solutions, Inc., P.O. Box 177, Cary, IL 60013-0177.

of FOV for standoff distances of 3 to 12 meters is shown in table 5. For the 3 meter standoff distance images of each FOV are displayed in figure 3. The gas delivery system employed for the test was challenged by the ThermaCAM® GasFindIR™ with 100mm telescope at 3 meters distance. Unfortunately the delivery system could not deliver gas at small enough rates to accurately determine the MDLR. The camera began seeing "puffs" of gas, which was taken as an indication the system was at its lower limit.

Figure 3. MDLR vs. optical FOV at 3 meters.

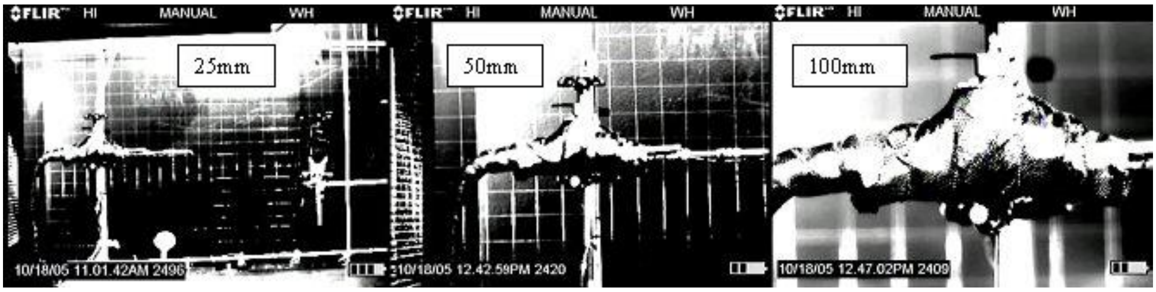


Table 5. MDLR vs. Optical FOV for methane

†MDLR in g/hr	Lens Back Focal Distance in mm								
	25			50			100		
Standoff distance (m)	3	6	12	3	6	12	3	6	12
Methane MDLR	0.8	1.4	4.0	0.4	0.8	1.6	‡0.3	0.5	0.8

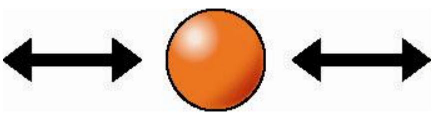
†MDLR was measured at 0 wind speed with no N2 mixing.
‡Lower limit of delivery system.

The data in table 5 indicate a nearly linear relationship between optical FOV and MDLR. The leaking valve under constant magnification was consistently found to have a near constant MDLR. For instance, the 3 meter standoff 25mm lens data shows a MDLR of 0.8g/hr. Both the 50mm at 6 meters and the 100mm at 12 meters show the exact same 0.8g/hr MDLR. These 3 points of course all have the same scene magnification.

4 Why do some gases absorb infrared radiation?

On a mechanical point of view, molecules in a gas could be compared to weights (the balls in the drawings below), connected together via springs. Depending on the number of atoms, their respective size and mass, the elastic constant of the springs, molecules may move in given directions, vibrate along an axis, rotate, twist, stretch, rock, wag, etc.
The simplest gas molecules are single atoms, like Helium, Neon or Krypton. They have no way to vibrate or rotate, so they can only move by translation in one direction at a time.

Figure 4. Singel atom



The next most complex category of molecules is diatomic, made of two atoms such as Hydrogen H2, Nitrogen N2 and Oxygen O2. They have the ability to tumble around their axes in addition to translational motion.

Then, there are complex polyatomic molecules, such as carbon dioxide CO2, methane CH4 sulfur hexafluoride SF6, or styrene C6H5CH=CH2 (these are just a few examples).

Figure 5. Two atoms

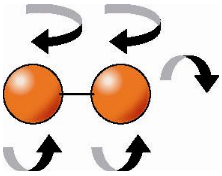


Figure 6. Carbon dioxide 3 atoms per molecule

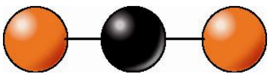
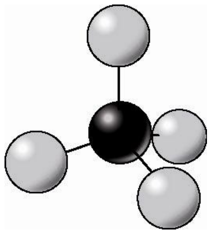


Figure 7. Methane 5 atoms per molecule



This assumption is valid for multi-atomic molecules.

Figure 8. SF_6 7 atoms per molecule

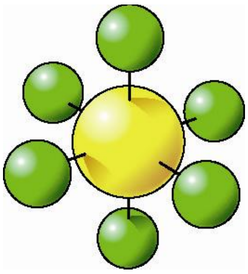
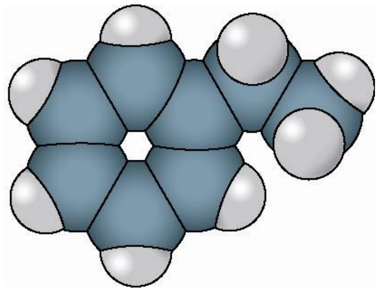


Figure 9. Styrene 16 atoms per molecule



Their increased degrees of mechanical freedom allow multiple rotational and vibrational modes. Because they are built from multiple atoms, they can store heat more effectively than simple molecules.
Depending on their frequency, some of transition modes fall into energy ranges that are located in the infrared region.

Table 6. MDLR vs. Optical FOV for methane

Transition type	*Frequency*	*Spectral range*
Rotation of heavy molecules	10^9 to 10^{11} Hz	Microwaves, above 3 mm
Rotation of light molecules & vibration of heavy molecules	10^{11} to 10^{13} Hz	Far infrared, between 30 µm and 3 mm
Vibration of light molecules. Rotation and vibration of the structure	10^{13} to 10^{14} Hz	Infrared, between 3 µm and 30 µm
Electronic transitions	10^{14} to 10^{16} Hz	UV - Visible

On order for a molecule to absorb a photon via a transition from one state to another, the molecule must have a dipole moment capable of briefly oscillating at the same frequency as the incident photon. This quantum mechanical interaction allows the electromagnetic field energy of the photon to be “transferred” or absorbed by the molecule.

ThermaCAM® GasFindIR™ cameras take advantage of the absorbing nature of certain molecules, to visualize them in their native environments.

ThermaCAM® GasFindIR™ focal plane arrays and optical systems are specifically tuned to very narrow spectral ranges, in the order of hundreds of nanometers, and are therefore ultra selective. Only gases absorbent in the infrared region that is delimited by a narrow band pass filter can be detected.

Since the energy from the gases is very weak, all camera components are optimized to emit as less energy as possible. This is the only solution to provide a sufficient signal-to-noise ratio. Hence, the filter itself is maintained at a cryogenic temperature: down to 60 K in the case of the new ThermaCAM® GasFindIR™ LW that is now under development.

Below are two transmittance spectra of gases:

Benzene C_6H_6 – absorbent in the MW region, Sulfur Hexafluoride SF_6 – absorbent in the LW region.

Figure 10. Benzene C6H6 – absorbent in the MW region

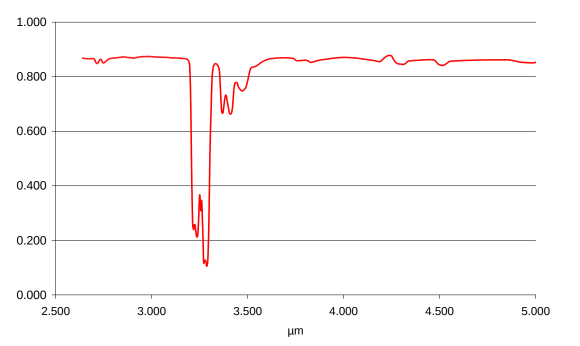
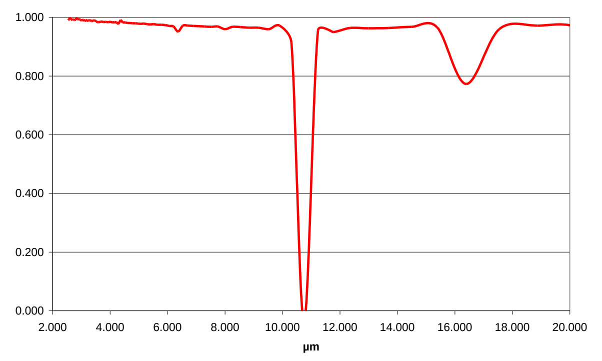


Figure 11. Sulfur Hexafluoride SF_6 – absorbent in the LW region. Strong absorption around 10.6 µm



5 Applications for infrared in the oil & gas industry

5.1 Delivery

Using infrared imaging, engineers can inspect transport systems, ensuring that containers, pipes and valves are secure. Leak detection is a critical part of operations for pipeline companies, sellers and buyers of oil, natural gas and other related products.

5.2 Production

Intense heat and the around-the-clock operations of chemical facilities produce mechanical stress on the equipment that creates petroleum, plastics, feedstocks and chemicals. Surface imaging using infrared can spot equipment that is operating outside its normal temperature range – providing predictive maintenance that can be fixed before a catastrophic failure or a major shutdown. Unplanned shutdowns can mean costs of thousands of dollars every minute, plus lost production and sales.

5.3 Safety

In hazardous working conditions, infrared imaging enables the rapid scan of a wide area before humans are exposed to heat, chemical, electrical or mechanical dangers. Unlike the current "point" solutions that check only a single site for hazards, the IR camera provide more complete information, more quickly.

5.4 Compliance

Regulations in many countries require oil & gas companies to document both the inspection methods and the findings to ensure worker safety, limit emissions of gases and chemicals to protect the environment and provide a record of the chemicals, products and combinations that are controlled by law. Companies need to monitor operations to protect air quality, water quality and comply with pollution control standards. By knowing more precisely where leaks are occurring, they can be detected, repaired and managed.

Pilot programs in the natural gas transmission industry have found failed rupture disks, crankcase vent leaks and numerous vent stack leaks. Vent stacks are difficult, if not impossible, to find with TVA's due to their inaccessibility. Leak volumes were documented using the bagging technique. See figures 12 and 13.

Figure 12. Compressor crankcase vent leak.

Quantified annual leakrate of $150K

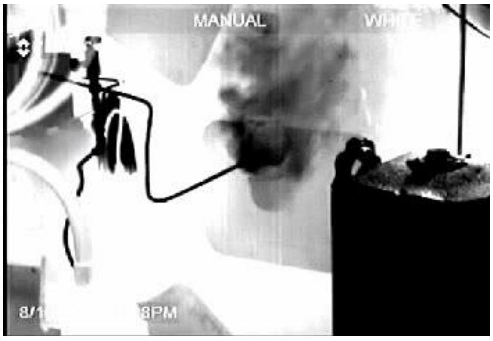
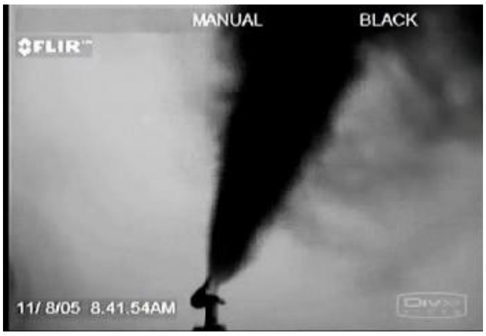


Figure 13. Failed rupture disk.

Quantified annual leak rate of $1M.



Petrochemical facilities such as refineries offer a target rich environment for VOC leaks. The remote imaging capabilities of IR cameras such as the ThermaCAM® GasFindIR™ dramatically reduce the task of finding leaks. Even when gases have a low contrast with their surroundings, the movement of the gas in a static environment makes finding small leaks, or larger leaks at greater distances feasible. Figures 14 and 15 show some examples of refinery applications.

Figure 14. LPG pumping station transfer leak, darker area just off arrow tip.

Figure 15. LPG compressor flange dark line leak, cloud just above arrow.

Figure 16. Gasoline fumes cascading from fill spout onto pavement.

Refined product leaks can also be found. Figure 16 shows vapors released during pumping gasoline into a vehicle. In all these examples viewing live video makes it much easier to spot the leaks than the still images in this publication. In the gasoline pump video, the operator is seen leaning back when the wind blows the fumes toward his face. The video is compelling imagery of why we should have vapor recapture devices and why we shouldn't smoke or have open flames while filling our tanks.

Applications of passive IR imaging continue to be developed. Moreover, we believe these applications truly start at the well head, continue through the entire transmission distribution system, and end only after the VOC has been used and it's by-products examined. This even includes gas meter and vapor recovery inspections at your local gas station. IR is a powerful tool. ThermaCAM® GasFindIR™ adds an all together new level of inspective capability to any technicians tool bag. Whether inspection technicians use a TVA to try and measure concentration levels or use the ThermaCAM® GasFindIR™ to "see" the source and magnitude of the VOC leaks, tools are essential to detect, locate, diagnose, repair, and report the hazardous conditions.

6. Future paths

The use of passive infrared technology has many benefits that require exploration. Although ThermaCAM® GasFindIR™ is a "new" technology for many inspection technicians, IR imaging itself has proven to be a mandatory diagnostic tool across a multitude of disciplines. From predictive maintenance (PdM), medical diagnoses, R&D applications and even climate control, hundreds of new applications continue to be found for IR imaging everyday. Based on FLIR's extensive history in IR, we are highly confident that VOC leak detection will mature at a rapid rate and join the many other industries that enjoy the full potential that IR imaging brings to bear. The ability to quantify leaks appears to be the next technological hurdle to overcome. Perhaps speciation will soon be a standard feature in passive IR systems. This type of technologic growth in the IR industry has historically followed the needs of the consumer, and therefore doesn't beg the question if it will happen but rather when. In addition to detecting VOC's that spectrally fall within the current ThermaCAM® GasFindIR's 3-5µm waveband, there are many other chemicals and gases of significant importance that fall outside this band. Many applications can be served by passive IR systems that utilize different IR bands to detect other VOC's or greenhouse gases, such as SF_6. FLIR is now developing the new ThermaCAM® GasFindIR™ LW that will be able to visualize gases like SF_6.

7 Reference

Standoff Passive Optical Leak Detection of Volatile Organic Compounds using a Cooled InSb Based Infrared Imager, Robert Benson, Robert Madding, Ron Lucier, James Lyons, Paul Czerepuszko

8 Illustrations

Jakob Robertsson, Typoform AB