IDENTIFYING NATURAL GAS LEAKS TO THE ATMOSPHERE WITH OPTICAL IMAGING

Robinson, D.R., ICF Consulting, In.
Luke-Boone, R.E., ICF Consulting, Inc.

ABSTRACT

Methane is one of the most significant anthropogenic greenhouse gases, whose global warming potential and sources are well documented. The natural gas industry is a major source of methane emissions. In 2001, unintended (fugitive) leaks from valves, piping connectors, open-ended lines, and pump and compressor seals totaled 3.9 Tg (58% of total U.S. emissions from the natural gas industry). In the U.S. hydrocarbon industry, less than 1 percent (%) of the thousands of potentially leaking sources contribute over 90% of fugitive emissions. Finding these few large leakers in a cost-effective way is a challenge for the industry. The current practice in the U.S. and other countries is to visit each and every potentially leaking component, and "sniff" it with a hand-held gas detector. This is time consuming, labor intensive, costly and limited to components within the reach of the gas detector user.

Optical imaging (OI) is a new technology that allows the user to "see" a live image of fugitive gas leaks into the atmosphere. Several different types of OI technologies -sensitive to fugitive leaks - are being developed, and one is now commercially available. These devices allow a user to scan hundreds of components in minutes, identify those few that are leaking, and video record the leakers for verification and documentation.

This paper describes different OI leak detection technologies, how they are more cost effective than currently used hand-held gas detectors, what may be possible in methane emission reductions, and future outlook for OI. The presentation will show an actual video of gas leaks detected with an optical imager.

1.0 INTRODUCTION

Fugitive leaks can be a major source of methane emissions from natural gas facilities. Left uncontrolled, fugitive methane emissions can, at the least, add up to significant economic loss, or can, at worst, pose safety hazards. In the United States, companies rely on initiatives such as Directed Inspection and Maintenance (DI&M) Programs to identify and repair leaks. Current DI&M techniques and technologies for detecting gas leaks e.g. soap bubble screening, acoustic detectors, Toxic Vapor Analyzers (TVAs) and Organic Vapor Analyzers (OVAs), require an operator to visit and screen every component by placing the screening instrument in the immediate vicinity of the potential leak. This approach is time consuming, inefficient, and costly, when operators must screen hundreds or thousands of components at each site.

Emerging optical imaging (OI) technologies may enable industry to reduce the time, labor and costs required to find and repair fugitive leaks. Remote sensing with OI technologies allows an operator to scan areas containing tens to hundreds of potential leaks, thus eliminating the need to visit and manually measure all potential leak sites. Leaks are identified immediately, allowing quicker repair, and ensuring efficient use of resources. Two emerging OI technologies have sufficient sensitivity for methane fugitive leak screening:

- An infrared laser camera based on Backscatter Absorption Gas Imaging (BAGI) techniques, and
- An infrared camera based on Image Multi-Spectral Sensor (IMSS) technology.

2.0 BAGI CAMERA

The BAGI camera developed by Sandia National Laboratory is suitable for detecting methane. It was developed to detect fugitive emissions of most organic compounds in the petroleum and natural gas industries. The current prototype camera weighs approximately 30 lbs and is about the size of a network television camera. It consists of two systems: a camera and a power/control unit (Figure 1). The camera is powered from a backpack borne power/control (Figure 2) that is connected to either a 28V lithium-ion battery or a 110-volt, 60 cps AC power chord through the unit's 28-volt DC converter. In the current prototype, battery lifetime while operational is between 1 and 1½ hours; batteries recharge in twelve hours. Batteries can be changed without shutting down the camera or greatly interrupting operations.

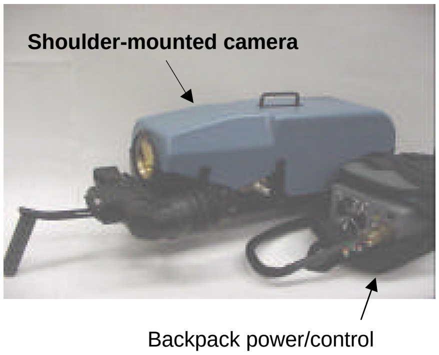


Fig. 1. BAGI Camera

The imager can be operated in a shoulder-mounted or a tripod-mounted position. A zoom lens allows the operator to adjust the focal distance to obtain a better view. The operator can switch between the infrared view and visible light, and can record video of the image seen in the viewfinder in both views. The camera has simple start-up procedures requiring 10 – 15 minutes after the power is switched on.

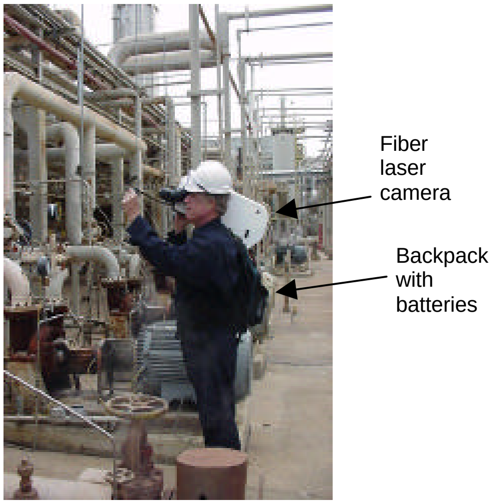
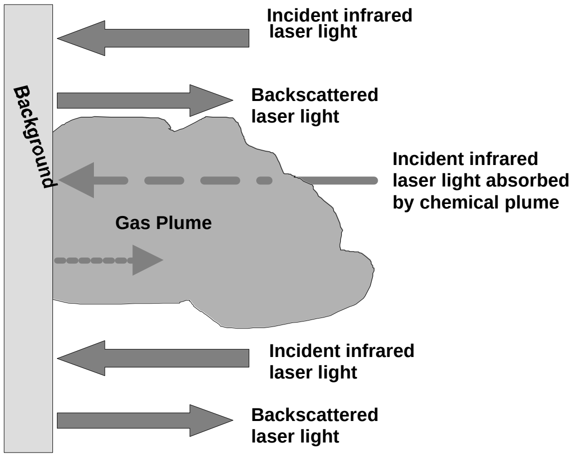


Fig. 2. Screening with the BAGI Camera

2.1 BACKSCATTER ABSORPTION GAS IMAGING (BAGI)

Backscatter Absorption Gas Imaging (BAGI) produces a live video image by illuminating the view area with laser light in the infrared frequency range. The reflected (backscattered) laser light is detected with a camera sensitive to that light. When the chosen laser wavelength is strongly absorbed by the gas of interest, a cloud of that gas does not provide much backscattered light compared to its surroundings. Because of its IR light absorption, the gas is revealed as a dark image on the camera. Figure 3 shows how BAGI works.



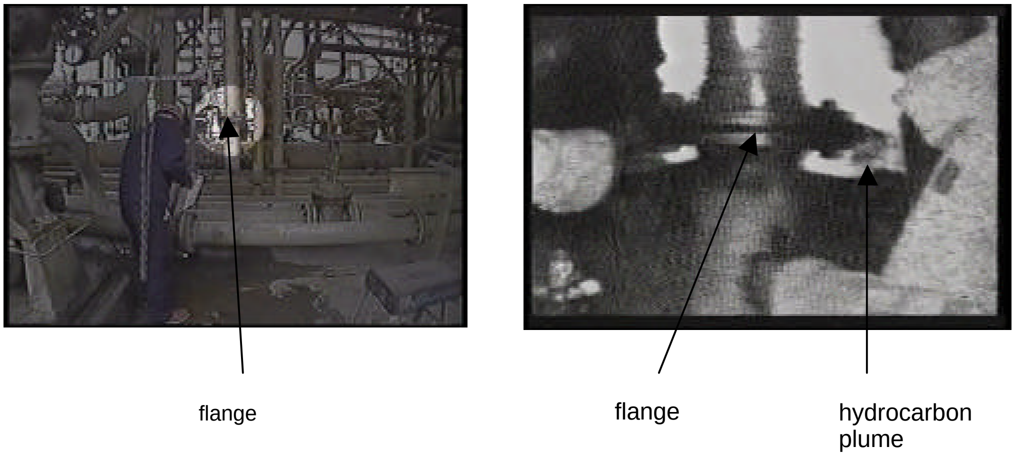
Source: As Adapted from McRae, Tom, *GasVue: A Rapid Leak Location Technology for Large VOC Fugitive Emissions*. (Presentation at the CSI Petroleum Refining Sector Equipment Leaks Group, Washington, DC, Sept. 9, 1997). U.S. Patent # 4,555,627

Note: Although gas is shown in contact with the background material, it is not a requirement. The gas plume need only be between the background and the infrared camera.

Fig. 3. BAGI Principle

A video camera-type scanner both sends out the laser beam and picks up the backscattered infrared light. The camera converts this backscattered infrared light to an electronic signal, which is displayed in real-time as a black and white image on the viewfinder (the camera has an auxiliary output to a video monitor). The same image will be seen whether the scanning is done in daylight or at night because the scanner is only sensitive to illumination coming from the infrared light source, not the sun. The visible-light view is an important attribute for the operator to identify the leaking component and differentiate between steam plumes and gas plumes (see discussion of Atmospheric Window below).

Figure 4 shows a leaking flange detected by the BAGI camera at a refinery in Texas, shown in visible and infrared light. In the current state of development,


Visible light view of leaking flange

Infrared view of leaking flange

Fig. 4. Visible and Infrared Views of Leaking Flange

the technology makes visible the size of a vapor cloud of hydrocarbons that are invisible to the naked eye, but does not quantify the mass emissions rate of the leak cloud. A detailed technical description of BAGI technology is available in [1].

2.2 BAGI PERFORMANCE PARAMETERS

Three main parameters influence the performance of the BAGI technology: background, laser wavelength, and atmospheric window.

BACKGROUND. For the technology to image a leak, there must be a reflective, or backscattering surface close behind the leak. It is not possible to visualize a gas plume against the sky or a distant background with BAGI. It is, however, possible in many circumstances to image a leak against the component itself, with a distant or sky background appearing dark. The operator knows that the imager is beyond detection range when the camera no longer produces a bright image of the components under inspection: the more distant the component or background, the darker the image. The operator would also visually check the equipment under inspection to determine whether there is an adequate background surface behind the potentially leaking components.

LASER WAVELENGTH. Gas leak detection sensitivity by OI depends most strongly on the match between the laser wavelength and the wavelength of strongest absorption by the gas of interest. To produce a dark image of a gas cloud, the hydrocarbon must be capable of absorbing the laser light at the tuned wavelength.

ATMOSPHERIC WINDOW. An “atmospheric window” is defined as a region of the spectrum where there is minimal or no light absorption by oxygen, nitrogen, carbon dioxide, and water vapor that are normally present in air. The major atmospheric windows in the infrared region are found in the 3 to 4.2 micron and in the 8 to 13 micron wavelength regions. A laser beam propagating through the atmosphere at wavelengths within these atmospheric windows will experience minimal attenuation.

However, laser light within these IR wavelength windows may still be attenuated by particulates in the air, including water droplets as in fog and steam. Consequently, plumes of these particulates will appear as dark clouds in the BAGI image as do the fugitive gases that absorb the laser light. Since these particulate plumes are also visible to the naked eye (while the fugitive gases are not), BAGI operators can easily distinguish between the two types of cloud images.

OTHER PERFORMANCE PARAMETERS. Wind speed, gas plume motion and viewing angle affect the fugitive gas cloud, and thereby, the detection sensitivity. The higher the wind speed, the more quickly the gas is dispersed as it leaves the leak source, and the less visible it becomes to the optical imager. However, some motion is beneficial for detecting a leak, as the human eye is particularly sensitive to movement. A stationary gas cloud is very difficult to distinguish against a non-uniform background.

Viewing angle and optical resolution also influences detection. While the best (most sensitive) viewing angle is when the gas comes directly towards the BAGI camera, this is not important if the camera has sufficient optical resolution to image the gas as it exits the leaking component. Consequently, the most favorable leak detection conditions are to view the leak source as close as possible, under low (but not stagnant) wind speed conditions, and with sufficient image resolution to see the escaping gas coming directly out of the leaking component. Under these conditions, and with a fairly uniform background surface, the BAGI technology is capable of visualizing smaller leaks.

3.0 The IMSS Camera.

Pacific Advanced Technology (PAT) developed an infrared camera based on Image Multi-spectral Sensor (IMSS) technology. The camera, originally developed for leak detection at refineries and chemical plants, can be adapted to methane detection at natural gas facilities. The current prototype of the IMSS camera (Figure 5) weighs 12 lb (including battery) and is 12 (L) x 6 (W) x 8 (H) inches in size and is battery operated. The camera, which holds a patented IMSS lens, contains the battery power source and a microprocessor to acquire and process the hyperspectral images.

Fig. 5. The IMSS Camera

Like the BAGI technology, the IMSS camera does not quantify leaks. However, unlike BAGI, it can identify chemical species within a leak. It can be used in unmanned aerial vehicles and controlled from remote locations. It can also detect chemical species from great distances, provided there is sufficient quantity of the chemical and a significant difference in IR radiance between the plume and background. In one test, the camera was able to screen a flare on an offshore oil platform 10 miles away and provide a spectrum showing the composition of the hot combustion gases. Figure 6 shows the IMSS camera in use at an oil refinery.

Fig. 6. IMSS Camera in Oil Refinery

3.1 THE IMSS PRINCIPLE

Image Multi-spectral Sensing is based on the principal of diffractive optics. It is a combination of a diffractive imaging spectrometer and an adaptive tunable filter. The basic concept is shown in Figure 7.

A basic monochrometer has an entrance and exit slit combined with a light-dispersing medium such as a prism. In order to obtain high resolution, the entrance and exit slits must be very narrow, thus reducing the optical throughput of the system. The light is dispersed perpendicular to the axis of the exit slit and is spectrally scanned across the slit.

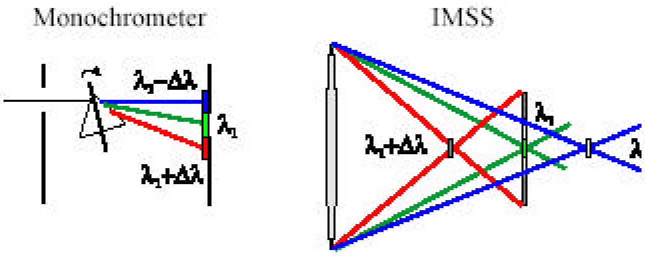


Fig. 7. IMSS Principle

In the IMSS approach, a diffractive element is used to perform both imaging and dispersion of light. The diffractive optical element disperses the light along the optical axis and the detector array/lens focal length is scanned to produce images of different IR “colors.” The advantage of this approach is that the entire input aperture collects the light as opposed to the narrow entrance slit and thus the throughput is greater. The detector element acts as the exit slit and must be matched with the blur diameter of the diffractive lens. The disadvantage of this approach is that micro processing must be done in order to sharpen the image of equipment and the chemical leak spectrum. A detailed description of the process is available in reference 2.

Figure 8 shows an image of a valve leaking methane at 0.1 standard cubic feet per min (scfm). The test setup is shown on the left. Gas temperature was 63.2 ^{o}F, air temperature 63.7 ^{o}F. Wind was 5 to 9 mph, gusting from the left [2].

Fig. 8. IMSS Images of Valve Leaking Methane

4.0 FUGITIVE METHANE REDUCTION OPPORTUNITY

Recent studies in the U.S. have shown that there are significant opportunities to reduce fugitive emissions at natural gas facilities. A recent study, co-sponsored by U.S. EPA's Natural Gas STAR Program, showed that the methane reduction potential using DI&M at 13 U.S. transmission stations averages 70% based on a payback period of 1 year [3]. The total value of gas saved by implementing these repairs was estimated at $765K/yr (gas valued $2/Mcf).

Another study at gas processing facilities found the fugitive methane emissions reduction potential at four plants about 79% based on a payback period of up to 4 years for all components [4]. If gas processing plant emission reduction opportunities with payout periods between 0.5 to 4 years are considered, the study estimated percent of total methane savings shown in Table 1.

Table 1. Payback Period For DI&M Program

	Payback Period			
	< 6 months	< 1 year	< 2 years	< 4 years
Methane Emission Reduction	71.9%	78.1%	79.2%	79.5%

The study of gas processing plants achieved an average $20 in gross savings ($13 in net savings after repair costs) per component for leak repairs with less than 1-year payback based on $4.50/ Mscf gas price.

OI offers significant savings in labor costs compared with conventional methods of leak screening. Table 2 compares screening a gas processing facility with 25,000 components using the current practice (TVA or OVA hand-held gas detector) and alternatively using optical imaging.

Table 2. Comparison of Screening Gas Plant with TVA/OVA or Optical Imaging

	Current TVA/OVA Leak Detector	Optical Imaging
Average Screening Rate	700 components/day	35 components/min
Time Required to Screen Plant	35 days	12 hr
Total Labor Cost (DI&M - $0.50/component) (1 OI Technician at $25/hr)	$12,250	$300
Note: time and cost to tag and repair leaking components is the same regardless of screening method and are excluded from these estimates. Cost of purchasing an OI camera or TVA is also excluded.		

5.0 FUTURE OF OPTICAL IMAGING

OI is currently used in the U.S. to identify SF_6 at power facilities and has shown great promise for fugitive emissions control at refineries and chemical plants. Several laboratory and field tests have been completed and negotiations are currently underway to begin long-term testing of the BAGI technology at hydrocarbon facilities. The technology offers a means to overcome cost and efficiency issues at facilities where hundreds or thousands of components are to be monitored. An important next-step in research is a means to quantify the mass rate of detected leaks. The future of optical imaging appears promising. As with other video technologies, more usage and time will lead to more efficient and less expensive methane leak detection and repair.

REFERENCES

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