ISBN: 978-92-990075-2-5

6th EnvImeko - IMEKO TC19
Symposium on Environmental Instrumentation and Measurements
June 24-25, 2016, Reggio Calabria, Italy

# PASSIVE THERMOGRAPHY FOR MONITORING POLLUTING PROCESSES

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**Abstract:** In this paper, passive thermography is proposed as a non-contact method to detect leakages or production of harmful and polluting gases. This technique can be used for a wide range of applications concerning the environmental monitoring. Infrared imaging allows to detect in real-time harmful and invisible gases such as methane, sulphur hexafluoride, ethylene, ammonia, carbon monoxide so to prevent hazards or explosions. By a spectral analysis of the heat radiation of the target into the infrared spectrum range, it is possible to characterize the presence of specific gasses or volatile compounds. In detail, spectral filters allow thermal infrared cameras to detect gas molecules radiating or absorbing radiation in a narrow infrared range. According to the spectral range of the gas, it is possible to build an appropriate selecting filter.

**Keywords:** passive thermography; spectral analysis; gas pollution; gas leak detection.

## 1. INTRODUCTION

Gases and volatile compounds are typically used in industrial and chemical plants during production processes. Such compounds can be the result of a combustion or chemical reaction. These waste products are invisible to the naked eye and can be harmful for the environment and for the exposed people. In specific cases, such gases can be toxic and flammable. Industries must trace and control any leak of volatile gaseous compounds during production process. Air quality can be monitored by using different technologies and methodologies. Each technology has its weakness and strength points. So, for example, probes and sniffer transducers must be used in proximity to the leak point, [1]. However, this methodology is time consuming and allows to get only local information. In addition, gas detection is strictly correlated to environmental conditions such as wind and weather. Therefore, the accuracy of measurement may be affected.

This paper discusses about the use of thermal infrared imaging as a valuable tool to detect gases and volatile compounds. By using specific filters, spectral thermography can allow an infrared camera to make visible such compounds. The measurement process does not require any contact or proximity to the gas leak. As a consequence, this technique can be used to monitor at a safe distance dangerous gasses or locations which are hard to reach, see Figure 1 for reference.

Fig. 1. Refinery gas leak, [FLIR].

In the above thermal picture, it is possible to watch clearly the gas leak. It appears as a smoke cloud, so the gas emission can be monitored in real-time, [2]. Depending on the leak size, even wide areas can be observed all at once.

The main applications of the present technique may be the control of gas emission in industrial processes, electrical distribution or supply chain. During a production process, flanges, valves, pumps, sealing parts or bursting discs can be subjected to faults and damages. As a consequence, gas leaks can occur. Governmental regulations and laws impose plants to be periodically inspected for leaks detection so to minimize emission of polluting volatile compounds into atmosphere.

Several volatile organic compounds can be detected by using passive thermography. For instance, Sulphur Hexafluoride ($SF_6$), CO, $CO_2$, Benzene, Butane, Ethane, Ethylene, Ethylbenzene, Heptane, Hexane, Isoprene, Methane, Methanol, Propane, Anhydrous Ammonia, Xylene, Ethyl Cyanoacrylate, Chlorine Dioxide, Acetic Acid, Freon, Methyl Vinyl Ketone, Vinyl Chloride, are only some produced waste products or compounds used in industrial or delivery processes which can be identified by means of a thermal camera mounting on board an appropriate spectral filter.

Sometimes, the inspections are made particularly complex when the plant to be checked is geographically distributed along a wide area. For example, if a complex petrochemical facility is considered, there are several kilometers of pipes and joints which may be leaking. A careful inspection requires that each node or junction of the distribution/production network must be checked. Such a kind of monitoring activity cannot be easily performed by using probes or sensors, or proximity probes, [3], [4].

ISBN: 978-92-990075-2-5

Differently, in these cases thermography allows user to inspect simultaneously many potential leak sources by means of a single snapshot of the area, [5].

In the following Sections, the basic principle of the Spectral Thermography, the measurement methodology and its possible applications are described.

## 2. SPECTRAL THERMOGRAPHY

In this Section, the main features of passive thermography are described. In detail, the spectral infrared imaging is here proposed for environmental monitoring applications to detect gas leaks. The basic principle of this technique is based on the analysis of the spectral properties of any object which is able to absorb or emit thermal energy in Infrared (IR) range.

The IR band is part of the electromagnetic spectrum near to the visible light, see Figure 2 for reference. The wavelength of IR spectral range is within the interval 0.78 µm – 1 mm.

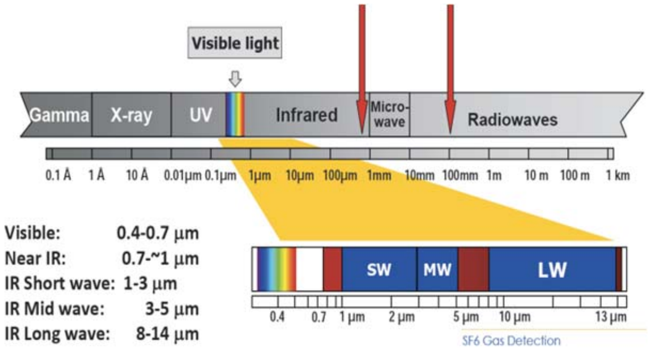


Fig.2. Electromagnetic spectrum and IR band, [8].

The previous figure shows in detail the classification of the different infrared sub-bands: near IR, IR short wave, IR mid wave and IR long wave. Energy of IR waves can be in specific percentages absorbed, reflected, refracted or emitted by an object. The value of each energy component depends on the characteristics of the object. For this reason, thermographic measurements require an accurate knowledge of spectral characteristics of the investigated object. The spectral thermography is a particular branch of infrared thermal imaging technique which allows to select specific wavelength ranges of infrared radiation, [6], [7]. In detail, accurate measurements of emissivity or transmissivity of an object can be obtained in specific ranges of IR band. Since, each gas emits or absorbs infrared energy only in a restricted IR sub-range, see Figure 3. The Figures 3 shows, for example, the absorption band of Sulphur Hexafluor ($SF_6$) in the long-wave band, [2]. This property can be used in order to characterize the thermal contribution of a specific gas so to detect its presence. An infrared thermographic camera is able to measure the irradiance of any object. The use of appropriate filters allows the camera to restrict its measurement range. Specific algorithms convert radiance into temperature values by using camera calibration data.

The emissivity of any object changes with the wavelength of radiation, [8]. According to its emissivity, the object is characterized by a specific spectral response.

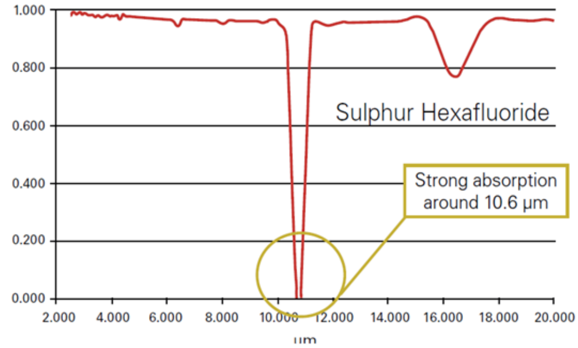


Fig. 3. $SF_6$ absorption band, [2].

In detail, the distribution of the spectral power is regulated by Planck's Radiation Law. The radiance per unit of wavelength can be evaluated by the following relation:

$$W(\lambda, T) = \frac{2\pi hc^2}{\lambda^5}\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1} \quad (1)$$

where $\lambda$ is the wavelength, $T$ is the thermodynamic temperature, $h$ is the Planck constant, $c$ is the velocity of light in vacuum, $k$ is the Boltzmann constant.

Since the radiance depends on the wavelength, a target of interest can be selected by means of a thermal camera if the camera spectral response is adapted to the wavelengths of the target. For this aim, spectral filters are designed and built. Figure 4 reports, for example, the transmission spectrum of a filter used for detecting $CO_2$.

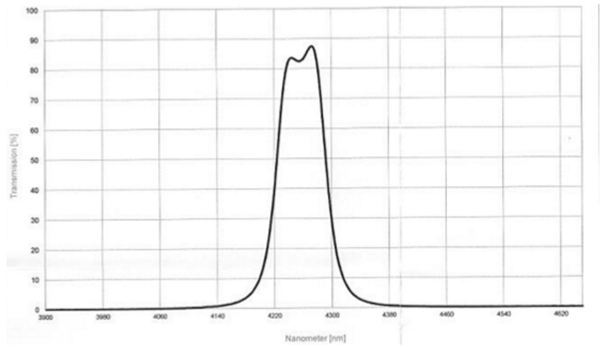

Fig. 4. Transmission spectrum of a $CO_2$ FLIR filter.

The previous filter allows only $CO_2$ radiation in a narrow band to pass. In this way, the range of the detected wavelengths is restricted so performing a spectral adaptation of the thermal camera. In presence of a $CO_2$ leak invisible to naked eye, the spectral thermal image will show a smoke cloud as in Figure 5.

Fig. 5. Smokestack gas leak, [8].

ISBN: 978-92-990075-2-5

By considering the most common polluting gasses used or produced in industrial and chemical plants, Table I reports the peak wavelength of each filter.

Table I. Peak wavelength of filter transmittance.

| Gas Molecule | Peak Wavelength [μm] |
|---|---|
| $H_2O$ (water) | 2.7 |
| $CH_4$ (Methane and Hydrocarbons) | 3.3-3.5 |
| $CO_2$ (Carbon Dioxide) | 4.26 |
| CO (Carbon Monoxide) | 4.67 |
| $N_2O$ (Nitrous Oxide) | 7.73 |
| $O_3$ (Ozone) | 9.0 |
| $NO_x$ (Nitrogen Oxides) | ~5.3 |

The development of any filter must consider the spectral absorption band of the gas to be monitored. According to the specific gas, filters can be band-pass, narrow band-pass, shortwave-pass or longwave-pass. In detail, the transmittance curve of the filter must be a negative copy of the absorption band of the gas, [8]. The absorption spectrum of a gas can be obtained by analysing at different wavelengths a sample into an IR spectrometer.

## 3. DETECTION OF POLLUTING GAS LEAKS

The spectral thermography is here proposed in order to detect leaks of harmful and polluting gases. The possibility to detect a specific gas is relevant for several applications concerning industrial/chemical plants and electrical distributions systems. In other cases, the presence of a gas is index of a combustion or deterioration process of food ($CH_4$, $CO_2$ and CO) or index of quality of air in particular workplaces ($NO_x$ e $CO_2$). Hydrocarbons, for example, may waste gas in chemical plants. They have a high power of absorption in the infrared spectrum, therefore such gases can be detected even in small concentration.

The gas concentration can be estimated by using the Lambert-Beer law:

$$I=I_0e^{kP} \quad (2)$$

where $I$ is the intensity of the captured radiation, $I_0$ is the reference intensity (no gas detected), $k$ is the absorption constant coefficient, and $P$ is the gas concentration.

In order to understand the detection principle the gas molecules have to be considered from a thermodynamical point of view. Molecules may move in specific directions and vibrate, rotate, twist along an axis. The motion depends on the number, size, mass of atoms. Gas with single atoms can only translate in one direction at a time. With the increase of atoms number, multiple rotational and vibrational transitions become possible due to an increase of the degrees of mechanical freedom. This mechanical interaction allows the infrared energy to be transferred to or absorbed by the gas molecule, [8]. If the gas temperature increases, a greater amount of thermal energy is emitted due to an increase of the mobility of the molecules by means of vibration and rotation motions.

When a real body is irradiated by an external source, it absorbs a part of the radiation, while a part is reflected and the remaining part is transmitted through the body. Differently, a black body absorbs all incident radiation. A thermal camera is able to detect the object radiance and convert it into temperature values, Figure 6.


Fig. 6. Infrared thermal imaging camera, FLIR X8400sc.

In order to allow the conversion to be carried out, the emissivity value $\varepsilon_\lambda$ of the object must be known. This parameter quantifies the amount of radiated energy in relation to incident radiation energy. Its value can be evaluated by the following equation:

$$\varepsilon_\lambda = 1 - \tau_\lambda - \rho_\lambda \quad (3)$$

where $\tau_\lambda$ is the transmittance and $\rho_\lambda$ is the reflectance of the object. A real (grey) body has a value of emissivity less than 1, whereas a black body has emissivity equal to 1.

Since the thermal radiation is affected by the atmosphere transmission and by the background radiation, the filter must reject all background interferences so to fit the detection with the radiance of the gas to be monitored. In this way, it is possible even to restrict the sensing spectral band of the camera to reject the influence of undesired objects. For example, inflammable gases emitted by an industrial smokestack can be altered by the intense radiation of the flames. Specific filters can avoid the influence on measurement of the medium through which the camera is looking (atmosphere, flame, etc.). So during a combustion, the radiation of the flames can be made invisible so to detect objects through the flames. Filters with an appropriate spectral window can even allow the camera to select a mixture of combustion gases inside a gas-fired furnace.

For these reasons, passive spectral thermography can be used as an efficient technique for real time detection of gas or vapour leaks in several application cases. Gases and volatile compounds are the waste products or basic medium of a large number of manufacturing and production industries. Leaks in components and mechanical parts can be cause of undesirable gas emission. That happens in industrial plants (refineries), gas distribution plants (flanges, valves, pipes), energy distribution plants. $CO_2$, technical gases (propylene, ethylene) and other volatile substances can be emitted into atmosphere. Therefore leaks may be cause of disastrous environmental pollution with potential harms to the exposed population. Leaks detection is a mandatory activity to prevent hazards which is economically onerous for industries. Due to their small size, leaks are often hard to locate especially if the plant has a large size. However, the exact position of the leaking spots must be detected with precision to repair the damage.

The gas leaks are a topic of scientific literature, nevertheless the state of the art shows few research works dealing with such issue. It can be due to the difficulty of industries to change their usual measurement methods. Several alternative methodologies are today used to detect leaks. Chemical sensors/transducers and gas detectors are widely used by operators to check plants, [9]-[11]. According to the complexity of the plant, such methods can be ineffective or unfeasible. It occurs if the damage concerns a distribution net geographically dislocated along a wide area or if the area is difficult to be reached due to security or access rights. Moreover small leaks are harder to be detected by instrumentation performing spot measurements.

A thermal camera overcomes the limits of the common technologies. The thermal energy is converted in a thermal image so to get an accurate temperature measurement without contact. Several application cases can be considered to prove the relevance of the proposed technique, [12]-[18]. Oil refining plants, petrochemical plants, smokestack, chemical plants, natural gas production plants, storage tank of volatile compounds, power generation and distribution nets, are just the most common applications of thermal imaging technique. Leaks of harmful and exhaust gases can be easily detected into pipelines, smokestack, plants or facilities. A large area can be scanned with one snapshot to detect gases from a safe distance.

## 4. CONCLUSIONS

The use of spectral thermography for detecting harmful gas leaks has been proposed in this paper. Detection of polluting gases has a wide range of possible applications in industrial and petrochemical plants, high voltage electrical distribution, natural gas production. Governmental regulations and laws force industries to perform regular inspections of plants in order to reduce the occurrence of polluting gas leaks. The use of specific filters allows a thermal camera to select the thermal energy emitted into a restricted range of wavelengths. In this way, qualitative and quantitative information can be got on the exact location of the leak so to assure people protection and environmental preservation.

IR thermography represents an alternative and effective method which has time, safety and cost benefits over the conventional measurement techniques based on sensors and probes. Wide areas can be simultaneously monitored in real-time at safe distance preserving operator from harms and risks.

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