UNIVERSITY OF NOVI SAD
Technical faculty "Mihajlo Pupin"
Zrenjanin, Republic of Serbia

In cooperation with partners

Industrial Engineering and Environmental Protection
IIZS conference

PROCEEDINGS

V International Conference – Industrial Engineering And Environmental Protection (IIZS 2015)

Zrenjanin, 15-16th October 2015.

University of Novi Sad
Technical faculty “Mihajlo Pupin”
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INTRODUCTION

Departments of Mechanical engineering at Technical Faculty "Mihajlo Pupin", Zrenjanin, organized four international conferences:
1. »PTEP 2011 - Process Technology and Environmental Protection»,
2. «IIZS 2012 - Industrial Engineering and Environmental Protection»,
3. «IIZS 2013 - Industrial Engineering and Environmental Protection»,
4. «IIZS 2014 - Industrial Engineering and Environmental Protection».

Industrial engineering is a field of technique, which includes the processes and procedures, plants, machinery and equipment used in manufacturing final products in different industries. The task of industrial engineers is that on the basis of theoretical and practical knowledge, solve specific problems in engineering practice, and the development of technology in the field of industrial production process.

The theme of scientific conference «IIZS 2015», covers the fields of industrial engineering, which are defined in the program of the conference, such as: Process technology and Energy efficiency, Engineering environmental protection and safety at work, Manufacturing technology and materials, Maintenance, Design and maintenance of process plants, Basic operations, machinery and processes, Oil and gas industry, Computer technologies and engineering education, Biotechnology, Reengineering and project management, Process management.

The main goals of the conference can be indentified here: innovation and expansion of knowledge engineers in industry and environmental protection; support to researchers in presenting the actual results of research projects, establishing new contacts with leading national and international institutions and universities; popularization of the faculty and its leading role in our society and the immediate environment, in order to attract quality young population for studing at our faculty, cooperation with other organizations, public companies and industry; initiative for collecting ideas in solving specific practical problems; interconnection and business contacts; introducing professional and business organizations with results of scientific and technical research; presentation of scientific knowledge and exchange of experiences in the field of industrial engineering.

We express gratitude to:

- The pratners of the conference – University of agriculture, Faculty of agricultural engineering, Krakow, Poland; Technical university-Sofia, Plovdiv branch, Faculty of mechanical engineering, Plovdiv, Bulgaria; University «St. Kliment Ohridski«, Technical faculty, Bitola, Macedonia; University Politehnica Timisoara, Faculty of engineering, Hunedoara, Romania; University of East Sarajevo, Faculty of mechanical engineering East Sarajevo, B&H, Republic of Srpska; „Aurel Vlaicu" University of Arad, Faculty of engineering, Arad, Romania; University of Niš, Faculty of mechanical engineering, Niš, Serbia,
- Zrenjanin Town Hall,
- Regional Chamber of Commerce,
- The management of Technical Faculty «Mihajlo Pupin», University of Novi Sad,

for supporting the organization of the conference «IIZS 2015». We are also grateful to all the authors who have contributed with their works to the organization of the scientific meeting «IIZS 2015».

We would like our Conference to become a traditional meeting of researchers, every year. We are open and thankful for all useful suggestions which could contribute that the next, International Conference - Industrial Engineering and Environmental Protection, become better in organizational and program sense.

President of the Organizing Committee
Prof. Ph.D Dragiša Tolmač

Zrenjanin, 15 - 16th October 2015.

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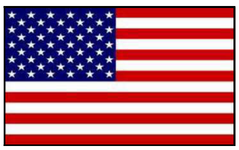

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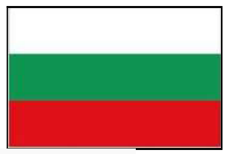

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GAS DETECTION THERMOGRAPHY

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Abstract: Infrared thermography is present in civil use since the end of fifties of the last century. Despite technical advances and development of thermography, until today statutory regulation and technical standardization in the field of thermography has fallen behind compare to the fast technical progress of equipment. First thermographic cameras hardly detected gases. Development of camera equipment, primarily sensors, filters, speed and signal processing, made detecting of gases with infrared camera (in the past decade) the simplest non-destructive testing method. There are two technical solutions for gas leaks. First, solution is a camera that analyses very narrow spectral band. Those cameras detects leaking of known gases. Second solution is a camera with changeable filters that analyze radiation (in real time) in a very narrow band and detect different (particular) type of gases. This paper gives basic review of gas detection thermography.
Key words: thermography, gas detection

INTRODUCTION

Infrared thermography is a method for determining the temperature distribution on the surface of the object by measuring the intensity of radiation of the electromagnetic spectrum in the infrared region. Thermography is classified as one of non-destructive testing methods (NDT). There are no unique standards in the field of thermal imaging. Education in the field of non-destructive testing is defined by the ISO 9712:2012 Non-destructive testing - Qualification and certification of NDT personnel. ISO 9712:2012 defines three levels of education in the field of NDT, [1]. The necessary knowledge in the field of thermal imaging is described in BS ISO 18436-7:2014 "'Condition monitoring and diagnostics of machines - Requirements for qualification and assessment of personnel Part 7: Thermography", [2]. Infrared cameras for gas detection can help in decrease of environmental damage. For example gas detection cameras can detect many gases as: Methane, CO, CO_2, Benzene, Sulphur Hexafluoride, and so on. Gas used widely in electric distribution, SF6, thanks to its properties provides technical solutions for small size high voltage equipment which saves space in urban areas it is often used and few thousand times more problematic than CO_2. Methane is the second most prevalent greenhouse gas emitted by human activities.

THE INFRARED BANDS IN THE ELECTROMAGNETIC SPECTRUM

The infrared bands in the electromagnetic spectrum can be divided: Near-infrared (NIR): 0.75-1 µm, Short-wave infrared (SWIR): 1-2.7 µm, Mid-wave infrared (MWIR): 3-5 µm, Long-wave infrared (LWIR): 8-14 µm, Ultralong-wave infrared (ULWIR): 14-30 µm, as shown in Fig. 1.

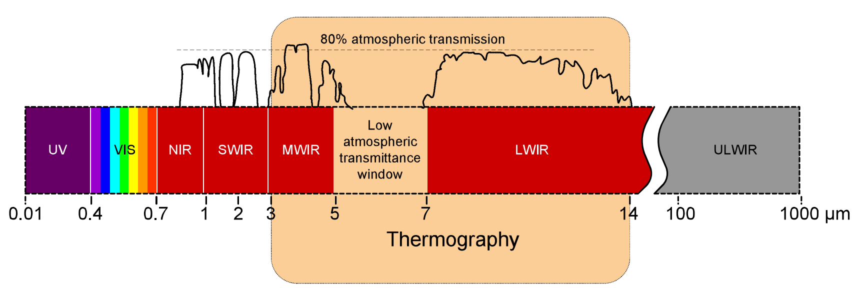

Figure 1. The infrared bands in the electromagnetic spectrum

Majority of thermal cameras register the radiation in two parts of the spectrum, MWIR and LWIR, [3]. The mid wave gas detection cameras have a detector response of 3-5 µm which is further spectrally adapted to approximately 3.3 µm by use of a cooled filter. This makes this particular model of camera most responsive to the gases commonly found in the petrochemical industries. Flir gas camera can detect many gases [4] but it has been laboratory tested against 19 which are: Benzene, Butane, Ethane, Ethylbenzene, Ethylene, Heptane, Hexane, Isoprene, MEK, Methane, Methanol, MIBK, Octane, Pentane, 1-Pentane, Propane, Propylene, Toluene and Xylene. The long wave gas detection camera has a detector response of 10-11 µm which is further spectrally adapted to approximately 10.5 µm by use of a cooled filter. This makes camera most responsive to Sulphur Hexafluoride (SF6) as well as Anhydrous Ammonia, Ethyl Cyanoacrylate ('Superglue'), Chlorine Dioxide, Acetic Acid, FREON-12, Ethylene and Methyl Ethyl Ketone (MEK), Acetyl Chloride , Allyl Bromide, Allyl Chloride, Allyl Fluoride, Bromomethane, FREON-11, Furan, Hydrazine, Methylsilane, Methyl Vinyl Ketone, Propenal, Propene, Tetrahydrofuran, Trichloroethylene, Uranyl Fluoride, Vinyl Chloride, Vinyl Cyanide, Vinyl Ether. Thermal resolution of infrared camera defines its quality in detection. Thermal resolution consist of four areas: Spectral resolution, Spatial resolution, Radiometric resolution and Temporal Resolution, [5]. For example spectral resolution of cameras used for building thermography most often detect long wavelength infrared radiation (8–14 µm). This is so because this band is less subject to solar reflectance problems. Radiant flux emitted by a surface at ambient temperatures is greater in the 8–14 µm band than it is in the 3–5 µm band, but the change in radiant flux for a small change in the temperature of a surface is greater in the 3–5 µm band [6], as can be seen in table 1.

Table 1. Radiance and contrast for different thermal wavelength bands, for a surface at ambient temperature

Wavelengt Band (µm)	**Radiance (watts/m2/steradian)**	**Contrast (% Change in Radiance for 1 °C delta T)**
3-5 µm	4.06	37.7
8-12 µm	93.4	16.9
8-14 µm	133.2	15.7

Spatial resolution refers to the smallest detectable target that can be measured. Radiometric resolution 'thermal sensitivity' refers to the smallest temperature differential, which can be perceived by the cameras pixels. Temporal resolution relates to the image refresh frequency of the camera.

GAS DETECTION THERMAL CAMERA

Thermographic camera has similar construction as digital video camera, except lens is opaque to visible light, detector and software are more complex. Detectors used in Gas Detection cameras are known as quantum detectors that require cooling to temperatures around -203°C. The MW camera uses an InSb detector and the LW camera uses a QWIP detector. Gas detection camera mainly differs from measurement cameras. The main difference is that sensor is cooled and there is a filter mounted on the front of the detector. The detector cools the filter to prevent any radiation exchange between the filter and the detector. The filter restricts the wavelengths of radiation allowed to pass through to the detector to a very narrow band called the band pass. This technique is called spectral adaptation. The filter band passes through wavelengths for different gas detection cameras. One of the largest infrared camera producers for civilian use is FLIR. At the moment FLIR produces these gas detection infrared cameras:

3.2 – 3.4 µm **GF300/320**, minimum detected leak rate (MDLR): 1-Pentene - 5.6g/hr, Benzene - 3.5g/hr, Butane -0.4g/hr, Ethane - 0.6g/hr, Ethanol - 0.7g/hr, Ethylbenzene - 1.5g/hr, Ethylene - 4.4g/hr, Heptane - 1.8g/hr, Hexane - 1.7g/hr, Isoprene - 8.1g/hr, MEK - 3.5g/hr, Methane - 0.8g/hr, Methanol - 3.8g/hr, MIBK - 2.1g/hr, Octane - 1.2g/hr, Pentane - 3.0g/hr, Propane - 0.4g/hr, Propylene - 2.9g/hr, Toluene - 3.8g/hr, Xylene - 1.9g/hr

3.8 – 4.05 µm **GF309** Furnace and Electrical Inspections

4.2 – 4.4 µm **GF343 CO_2 Leak Detection**,

4.52 – 4.67 µm **GF346 CO** Detection and Electrical Inspections Carbon Monoxide (CO), Nitrous Oxide (N_2O), Ketene, Ethenone (C_2H_2O), Butyl Isocyanide, Hexyl Isocyanide,

	Cyanogen Bromide (CNBr), Acetonitrile (C_2H_3N), Acetyl Cyanide, Chlorine Isocyanate (CClNO), Bromine Isocyanate (CBrNO), Methyl Thiocyanate (C_2H_3NS), Ethyl Thiocyanate, Chlorodimethylsilane ($(Ch_3)_2SiHCl$), Dichloromethylsilane, Silane (H_4Si), Germane (GeH_4), Arsine (AsH_3)
8.0 – 8.6 µm	**GF304 Refrigerant Leak Detection**, R404A, R407C, R410A, R134A, R417A, R422A, R507A, R143A, R125, R245fa
10.3 – 10.7 µm	**GF306 SF6**, SF6 (Sulfur Hexafluoride) - 0.026g/hr, Acetic Acid ($C_2H_4O_2$), Anhydrous Ammonia (NH_3), Chlorine Dioxide (ClO_2), Dichlorodifluoromethane "FREON-12" (CCl_2F_2), Ethyl Cyanoacrylate "Superglue" ($C_6H_7NO_2$), Ethylene (C_2H_4)

Gas detection technique with infrared camera is shown in figure 2. Infrared camera registers background radiation which passes through gas. Some IR wavelengths are transparent some opaque due to absorption so the gas can be seen on camera as darken region on bright background. The emission of gas and the emission of atmosphere are very small comparison to emission of background, so total infrared radiance at given wavelength can be expressed as:

$$E_{SUM}\left(\lambda\right)=\tau_{SUM}\left\lfloor \tau_a\tau_g E_b\left(\lambda,T_b\right)\right\rfloor \tag{1}$$

where: $E_{SUM}\left(\lambda\right)$ is the total infrared radiance at given wavelength,
τ_{SUM} is spectral transmission of objective and spectral filters,
τ_g is spectral transmission of gas,
τ_a is spectral transmission of atmosphere,
$E_b\left(\lambda,T_b\right)$ is infrared radiance of background at given wavelength and temperature.

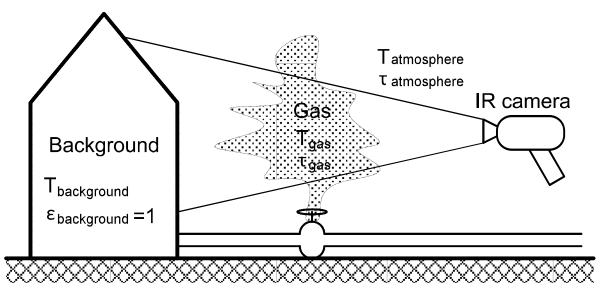

Figure 2. Measuring process for gas analysis in atmosphere

Transmission of the gas according to [7] can be defined as:

$$\tau_g\left(\lambda\right)=e^{-\sum k_i(\lambda)C_i d} \tag{2}$$

where k_i is absorption coefficient, C_i is average concentration of the chemical compound.

Depending of camera filter and gas characteristics identification of gases can be done. Infrared absorption spectra for water and carbon dioxide is shone on figure 3.

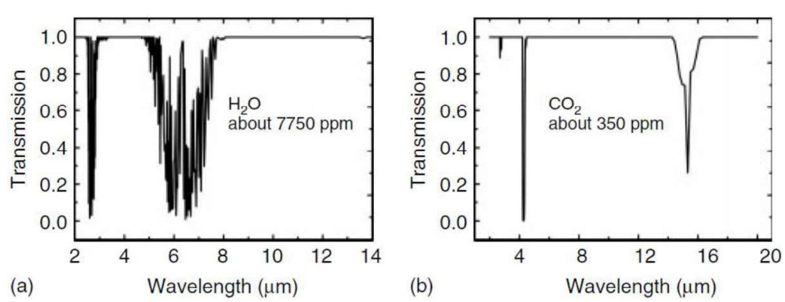

Figure 3. Transmission of H_2O and CO_2 as a function of wavelength, source [8]

Degree of transparency of gases varies with wavelength or ability to absorb infrared radiation. There are some IR wavelengths where gases are opaque due to absorption.

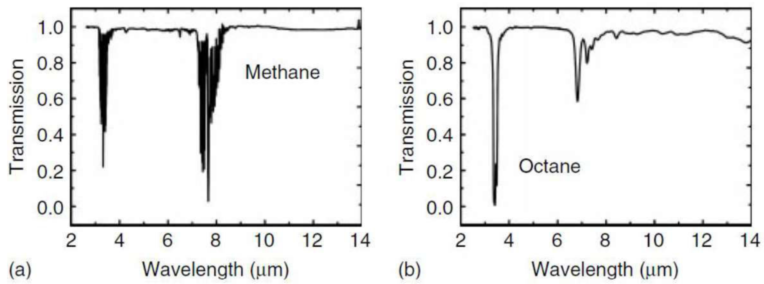

Figure 4. Transmission of CH_4 and C_8H_{18} as a function of wavelength, source [8]

On figure 4 a) it can be seen that methane can be easily detected in region from 7 - 8 μm but if we take into account that region 7 μm has low atmospheric transmittance and greater contrast in lover wavelength 3.2 – 3.4 μm region is used even methane transmission in that region is smaller. Figure 4 b) presents Octane transmission for different wavelengths. At a first look, it is obvious, that 3.2 – 3.4 μm camera will be used for detection of Octane.

Thermal image of gas can be seen on figure 5. which presents leakage of natural gas from reservoir in two pallets. On average natural gas processing plants lose between 0.05 to 0.5% of their total production to fugitive emissions. Up to 95% of these emissions can be prevented by identification and repair. Most equipment doesn't leak, almost 84% of all emission comes from 0.13% equipment, [9].

Figure 5. Detection of leakage of natural gas from reservoir, source [10]

Telops Inc. from Quebec City is a leading supplier of hyperspectral imaging systems [11] and high performance infrared cameras for the defense, industrial, environmental and research industries. They adopted little different approach to gas detection. Telops infrared camera shown on figure 6 is high performance cooled multispectral infrared camera which cover the complete mid-infrared spectral range or as shown in picture 7 very longwave.

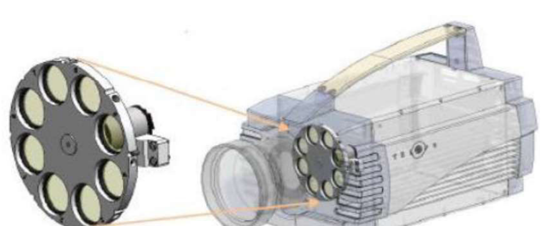

Figure 6. Telops MS-IR infrared camera

Telops Inc. integrated motorized filter wheel in camera which during of time of about 130 ms completes 4 full revolutions. Example of usage on methanol detection can be seen in Figure 7, absorption/emission of LWIR radiation mostly occurs in the 9.1-10.2 μm spectral range due to a spectral feature associated with the C-OH stretch vibration mode of methanol. Consequently, the greatest thermal contrast is obtained through filters #5 and #6.

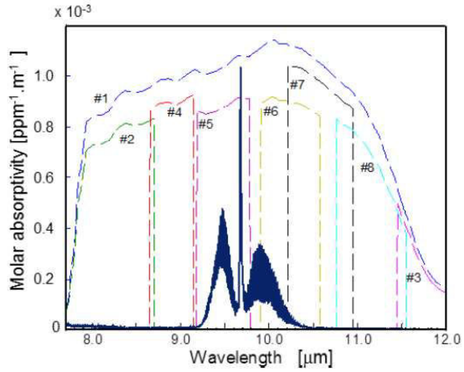

Figure 7. Telops MS-IR infrared camera filters detection area and absorption spectrum of methanol presented by dark blue curve

CONCLUSION

The ability of gases to absorb infrared radiation is base for gas detection with infrared camera. Degree of transparency of gases varies with concentration and wavelength, due to specified characteristic with usage of filters they can be identified. There are many technical solutions for infrared cameras that use the principle of absorption in a narrow spectral band. The main arguments for using infrared cameras in detecting gases is identifying gas leaking at an early stage and to avoid negative influence to environment. Considered that around 80% of all emission comes from 0.13% of equipment infrared thermography represents one of the most important methods in detecting gas leaking and conservation of technology systems.

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