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Infrared Sensor for Monitoring of LEL of Flammable Gases and Vapors of Flammable Liquids

A. Makeenkov[a]*, I. Lapitskiy[b], O. Kanischev[b], A. Somov[c]

[a]*MATI –Russian State Thechnological University, Moscow, 121552, Russian Federation*
[b]*FSUE SPA «ANALITPRIBOR»-Federal State Unitary Enterprise Smolensk Production Association «ANALITPRIBOR», Smolensk, 214031, Russian Federation*
[c]*CREATE-NET, Trento, 38123, Italy*

Abstract

We present an optical absorption infrared sensor for monitoring of lower explosive limit of gases and vapors containing flammable hydrocarbon compounds, and description of sensor design and characteristics. The sensor is capable of monitoring up to 30 components and can be interfaced with an external device using MODBUS RTU Protocol. Our design opens up wide opportunities for the indoor and outdoor gas monitoring applications at the petrochemical and oil processing industries and hazardous industrial facilities.

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Keywords: lower explosive limit (LEL); pre-explosive concentrations; optical absorption infrared sensor; sensitivity evaluation; sensor output characteristics

1. Introduction

The problem of monitoring of Lower Explosive Limit (LEL) of flammable gases and vapors of flammable liquids is a task of top priority in gas-and-oil industry, e.g. transportation and storage of gas and oil products. Explosion hazardous zones located near boiler facilities and processing stations are the subjects of heightened level of

* Corresponding author. Tel.: 7-4812-31-06-02.
E-mail address: amak2004@list.ru

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monitoring awareness which requires the reliable and high-precision measuring instruments with time-stable technical characteristics.

Catalytic [1], semiconductor [2] and optical [3] sensors are used extensively for monitoring of LEL of flammable gases and vapors of flammable liquids. An essential fault of these sensors is the ambiguity of the value of relative sensitivity coefficient between a calibration component, e.g. methane, and measured component (flammable gases and vapors of flammable liquids) within the full measuring range. The disadvantage of the approach is that this value is defined during the sensor adjustment in a single point of the sensor output characteristic. Limitation of maximum permissible intrinsic and complementary errors using calibration component does not provide the end user with the sufficient information on combined error of measuring instrument during detection of measured component.

We note that the optical sensors based on Non-Dispersive Infrared (NDIR) technology [4] have a number of advantages over catalytic and semiconductor sensors in terms of high zero stability, sensitivity, selectivity, high speed of response, resistance to corrosive atmospheres and to elevated concentrations of monitored and assist gases, and ability to operate in anoxic environment.

This paper presents the experimental results of research and development of parameters of optical absorption infrared sensor for detection of LEL of flammable gases and vapors of flammable liquids in gas-and-oil industries. The goal of this the work is to design the based on NDIR sensor node capable of monitoring up to 30 components (the catalytic or semiconductor sensor nodes typically monitor one or two hazardous gases at a time [5]) and having individual limitation of maximum permissible intrinsic error for each measured component and limitation of maximum permissible complementary error for measured components under actual operating conditions (operating temperature, pressure, humidity).

2. Optical Sensor Design

The operating principle of optical absorption sensor is based on the registration of changes in intensity of radiation interacting with a gaseous medium under test at the wavelengths characteristic of this medium. The identification of wavelength operating range in broadband spectrum of emitter is performed by the means of interference filters. During the development of the sensor node capable of monitoring up to 30 components the conventional structure of primary measuring transducer is complicated by the requirement for detection of such a wide range of substances with the essentially different spectral characteristics. It is necessary, therefore, to solve the problem of combined optimization of spectral characteristic parameters of interference filters and selective reflector (λ,τ) [6,7] of optical system, and the element construction of optical channel of the sensor (L) [8].

The block diagram and the sensor prototype are shown in Fig. 1. The architecture of IR sensor node includes the following main blocks: emitting source, radiation receiver, selective reflector and processing and communication unit. The optical circuit of the sensor is based on a two-channel measurement circuit with the use of operating (measuring) and reference (comparative) channels.

Emitting source is a mini infrared lamp with a wide spectral range of radiation. The feature of the lamp operating mode is a modulation of luminous flux with a frequency formed by the processing and communication unit.

Radiation receiver is a high-sensitivity two-channel pyroelectric detector with the integrated interference filters that have specific spectral characteristics. Construction and technical characteristics of the detector allow its exploitation in a temperature range from -60 ^{o}C to +85 ^{o}C. The application of temperature compensated crystal helps to exclude a signal ripple and provides the stable output signals of pyroelectric detector at a high rate of change in ambient temperature. As a radiation receiver we used a Pyroelectric Detector (PYS) by Perkin Elmer.

Selective reflector, which is, in fact, an interference filter applied to a spherical quartz substrate, performs the adjustment of spectral range of probe radiation coming from the emitting source. Therefore, the selective reflector is a regulating element, to some extent.

Processing and communication unit performs the function of processing input signals from the pyroelectric detector, measuring temperature, controlling emitter, saving sensor parameters, and also forming signals of interface channel. The unit is built the microcontroller Aduc7061.

A probe radiation I_0 passes through the gas cell with the analyzed component with length *L*, reflects from the selective reflector, and comes to the two-channel pyroelectric detector. Signals from operating (*U*) and reference channels (U_0) of pyroelectric detector are digitized by means of Analog-to Digital Converter (ADC) in the microcontroller.

Then digital band-pass filters select the signals on modulation frequency from the pyroelectric detector signals without noise. These signals are rectified by a phase-independent rectifier, and a signal constant component is selected by a digital low-pass filter.

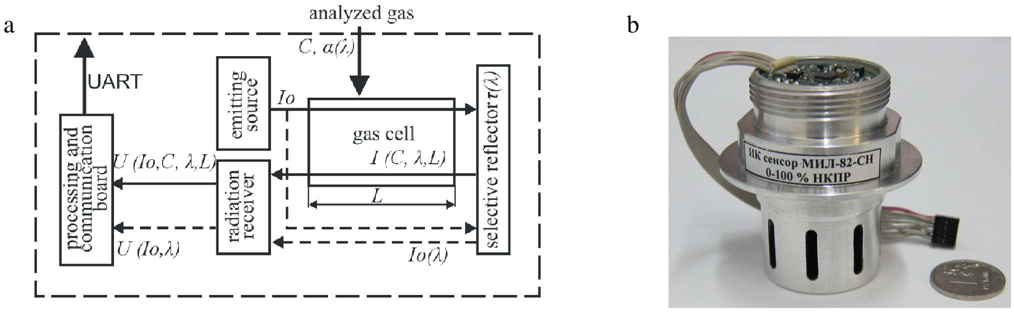

Fig. 1. (a) Sensor node block diagram, (b) sensor node prototype.

The obtained signal difference between operating and reference channels is a measure of component content in the analyzed sample. In order to provide the required metrological characteristics under higher and lower temperatures, the corrections are applied. After that the sensor conversion characteristic is linearized, and the value of measured concentration of detected component in the analyzed gas is obtained. The value of measured concentration is converted into a signal of UART interface which makes it possible to form a communication channel between the sensor node and a PC or other external devices by MODBUS RTU Protocol.

The sensor sensitivity evaluation, determination of metrological characteristics, rating of sensor parameters for monitoring of pre-explosive concentrations of flammable gases and vapors of flammable liquids can be conducted with the use of various types of metrological support. For monitoring of gaseous component concentrations we used the metrological support called “state standard sample – test gas mixture” (SSS-TGM). The liquid substances estimation and rating of sensor parameters requires the use of special test facilities, e.g. a calibration chamber, for preparation of certified air-vapor mixtures.

Data on output characteristics and correction coefficients for measured components obtained using the calibration chamber, or in case of monitoring of concentrations of gaseous components, SSS-TGM are saved in the nonvolatile memory of the sensor. Thereafter the type of measured component for monitoring of its pre-explosive concentrations is selected by a user with the help of the service software installed on PC. However, it should be emphasized that rating of metrological characteristics of the sensor for the measured component must be performed exactly with the use of actually selected measured component but not with the calibration component, as it is often the case.

3. Results

Eventually this approach makes the work easier for the end user by relieving him a labor-intensive activity of sensor adjustment in accordance with the measured components under the actual operating conditions, and provides the user with a complete and accurate information on the results of measurement of pre-explosive concentrations of flammable gases and vapors of flammable liquids. List of flammable substances monitored by the developed sensor is given in Table 1. Fig. 2 shows the sensor output characteristic of the sensor at feeding of test gas mixtures CH_4 – N_2 TGM No. 1 (96.1 % LEL), TGM No. 2 (52.2 % LEL) and TGM No. 3 (23.4 % LEL) are fed.

Among the basic characteristics of the developed sensor the following can be singled out: measuring range, setting time and limits of intrinsic error – 0—100 % LEL, 20 s and ≤±(2.5+0.05·Cin) % LEL, respectively. Sensor complies with the requirements of long-term stability according to GOST R 52350.29.1 –2010. Operating time without readings adjustment is 12 months. The sensor service life is at least 5 years.

Table 1. List of flammable substances monitored by the developed sensor

Component name	LEL, % vol.	Component name	LEL, % vol.	Component name	LEL, % vol.	Component name	LEL, % vol.
methane	4.4	ethanol	3.1	ethylene	2.3	hexane	1.0
ethane	2.5	octane	0.8	natural gas	5.0	propanol	2.1
propane	1.7	acetone	2.5	liquefied gas	1.5	kerosene KT-1	0.7
n-butane	1.4	benzol	1.2	methanol	5.5	butanol	2.6
i-butane	1.3	toluol	1.1	Dieselfuel (summer, winter)	0.5	fuel for rocket engines	1.5
pentane	1.4	benzine	1	oil "Urals"	1.2	white spirit	1.4

The development of optical absorption infrared sensor for measurement of LEL of flammable gases and vapors of flammable liquids was described in this article. Sensor capable of monitoring up to 30 components and can be used as a part of gas analyzers for monitoring of air in working areas of indoor and outdoor spaces in chemical,

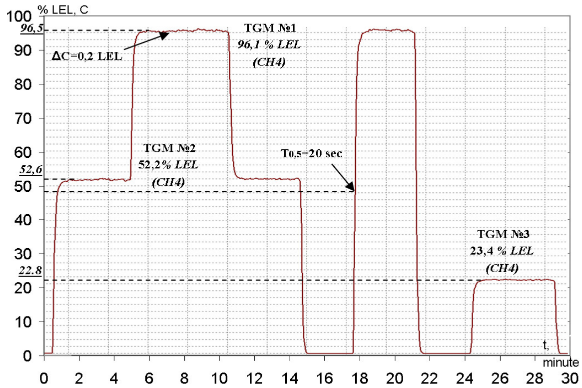

Fig. 2. Output characteristic of the sensor tested with gas mixtures CH_4 – N_2.

petrochemical and oil processing industries, where there is a risk of high concentrations of explosive substances, and also as a part of atmosphere control systems at hazardous industrial facilities [9].

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