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INFRARED TWO-WAVE GAS CONCENTRATION CONTROL SENSOR

The paper considers the mathematical model of the two-wave gas concentration control. There had been presented its optical, operating mode and simulation results.

Key words: *infrared two-wave gas concentration control sensor, concentration, control, bath, measurement, gas, impurities.*

Introduction

Many of the gas physical parameters control methods are used nowadays in various fields of science and engineering. They enable measuring gas density, gas concentration and quantity of impurities. One of the most important parameters for controlling is the gas concentration. The gas analyzers, produced by the enterprises: «ECOTEST» (Kharkiv, Ukraine), «Analitprylad» (Kyiv, Ukraine), «Orion» (Kharkiv, Ukraine), «Antex» (Severodonetsk, Ukraine) are purposed mainly for operating in the plants, since they don't ensure the sufficient level of sensitivity and accuracy in measurement. The "OXY" gas analyzer, for example allows to control the concentration of nitrogen oxide within of submilligram per 1 cubic metre of air, with BAC_{NO} = 40 μg/m^3 for living buildings. The relative error in measuring of some gas analyzers is about 25 % [1 – 3].

In many cases the main drawback of gas analyzing sensor, which measures the concentration of nitrogen, methane, ethane etc., is low accuracy of measurement, caused by no possibility to compensate for destabilizing factors and characteristsics, which characterize the adiabatic process.

The above requires to improve the accuracy in measuring control of gas analyzing sensor by the consideration of adiabatic process.

The main part

Sensor operates using the absorptive spectrometry method. The absorptive spectrometry method is based on light absorption of the gas molecules and registering the part of the light absorbed. Each gas has its own using absorbing spectrum and the maximum of that absorption corresponds to the specific wave length for different gas. Using the light emissions of the specific wave's length allows to determine the concentration of the corresponding component with high accuracy due to the use of the phenomenon of the selective absorption of high by multi atom molecules during its passing through the environment. The selective absorption may be explained by its occurrence on the waves, the frequency of which is a resonance for the specific molecules [4].

If the light beam (with intensity of $I_0(\nu)$) passes through the gas under analysis, the part of it shall be absorbed. In the common case the absorption occurs according to the Buger-Lambert-Ber law [5]

$$I(\nu) = I_0(\nu) e^{-K(\nu)Cd}, \qquad (1)$$

where $K(\nu)$ – absorption index, which is the function of frequency ν and depends on the gas nature; C – the molar gas concentration; d – width of gas layer.

Density of the gas mixture $\rho_{Г.С.}$ in common case is defined as the sum of the density of the pure, that is , the known gas $\rho_{Г.}$ and its impurities $\rho_{Д.}$ with their partial pressure and temperature

$$\rho_{Г.С.} = \rho_{Г.} + \rho_{Д.}.$$

Since the emission absorption is caused due to both, the influence of the pure, that is, the known gas, as well as due to its impurities which is of different concentration, the model of light emission transfer in such an environment may be presented as in [4]. Taking into account that molar concentration of substance is directly proportional to its density $C = \rho / \mu$, the Buger-Lambert-Ber law is:

$$I_{\text{Г.С.}}(v) = I_0(v) e^{-d\left(K^{\text{Г.}}(v)\frac{\rho_{\text{Г.}}}{\mu_{\text{Г.}}} + K^{\text{Д.}}(v)\frac{\rho_{\text{Д.}}}{\mu_{\text{Д.}}} \right)}, \quad (2)$$

where $K^{\text{Д.}}(\nu)$ and $K^{\text{Г.}}(\nu)$ – molar specific indexes absorption of the impurities as well known the known gas on the frequency - ν, correspondingly; $\mu_{\text{Д.}}$ and $\mu_{\text{Г.}}$ – molar mass of the impurities and that of the known gas correspondingly.

Since gas impurities concentration is determined as by the correlation $c = \frac{\rho_{\text{Д.}}}{\rho_{\text{Г.}} + \rho_{\text{Д.}}}$, the gas impurities density under operating conditions may be determined as $\rho_{\text{Д.}} = \frac{c\rho_{\text{Г.}}}{1-c}$.

Gas properties under the pressure of 10^5 Pa and with law densities are well studied and are close to those of the ideal gas, so they may be described by Medellev-Klapeyron equation:

where *p*, *V*, *m*, μ, *T* – pressure, volume, mass, molar mass and gas temperature correspondingly; *R* – universal gas constant.

Gas density under operation conditions shall be determined when $P = P_{(c)}$ and temperature $T = T_{(c)}$ in accordance with the equation:

$$\rho_{\text{Г.}} = \frac{P \cdot \rho_{(c)} \cdot T_{(c)}}{T \cdot P_{(c)}}, \quad (3)$$

where $\rho_{(c)}$ – density of pure gas in the ideal gas state.

Then the gas impurities density under the operating conditions may be described as follows:

$$\rho_{\text{Д.}} = \frac{c \cdot P \cdot \rho_{(c)} \cdot T_{(c)}}{(1-c)T \cdot P_{(c)}}. \quad (4)$$

Using the expressions (3) and (4), the Buger-Lambert-Ber law for the gas under the operating conditions shall be written as follows:

$$I_{\text{Г.С.}}(v_1) = I_0(v_1) e^{-d\left(K^{\text{Г.}}(v_1)\frac{P \cdot \rho_{(c)} \cdot T_{(c)}}{\mu_{\text{Г.}} \cdot T \cdot P_{(c)}} + K^{\text{Д.}}(v_2)\frac{c \cdot P \cdot \rho_{(c)} \cdot T_{(c)}}{\mu_{\text{Д.}}(1-c)T \cdot P_{(c)}} \right)}. \quad (5)$$

The drawback of such a model is the presence of gas molar mass, since in this particular case it is a variable, which depends on gas composition. To overcome this drawback, the paper suggests the two-wave model which allows to neglect the molar mass and to compensate for the adiabat indexes. The light waves are set in a way: that the first one has the most expressive absorptions properties in relation to the gas impurities, and the second– the lowest absorption level in relation to these gas impurities.

The Buger-Lambert-Ber law for the second wave length then may be described:

$$I_{Г.С.}(v_2) = I_0(v_2) e^{-dK^{Г\cdot}(v_2)\frac{P\cdot\rho_{(c)}\cdot T_{(c)}}{\mu_{Г.}\cdot T\cdot P_{(c)}}}. \quad (6)$$

Using the equatitons (5) and (6) we receive the gas impurities concentration:

$$c = \frac{\ln\frac{I_{Г.С.}(v_1)}{I_0(v_1)} - \frac{K^{Г\cdot}(v_1)}{K^{Г\cdot}(v_2)}\cdot\ln\frac{I_{Г.}(v_2)}{I_0(v_2)}}{\ln\frac{I_{Г.С.}(v_1)}{I_0(v_1)} - \frac{K^{Г\cdot}(v_1)}{K^{Г\cdot}(v_2)}\cdot\ln\frac{I_{Г.}(v_2)}{I_0(v_2)} - K^{Д\cdot}(v_1)\cdot\frac{d\cdot T_{(c)}\cdot\rho_{(c)}}{\mu_{Д.}\cdot T\cdot P_{(c)}}}. \quad (7)$$

Fig. 1 presents the gas impurities density function graph (7) of light intensity under the operating conditions, corresponding to standard, is made using the Mathcad system. The gas absorbtion coefficients $K^{Д\cdot}(v)$ and $K^{Г\cdot}(v)$ are taken from [4]. The graph shows that the dependence of gas impurities concentration on intensity is of exponential character. The influence of the known gas, though the insignificant is being executed.

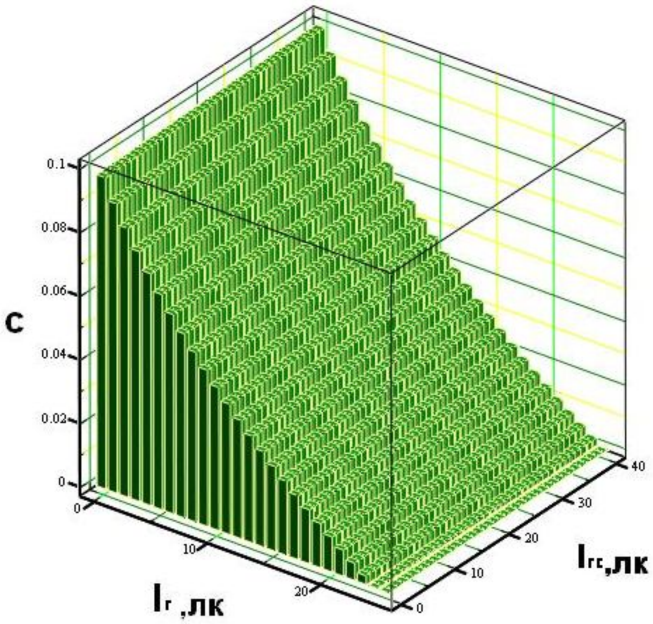

Fig. 1. The graph of dependence of gas impurities concentration on emission intensity

Fig. 2 presents the diagram of the two-wave optical gas concentration sensor, which consists of two-bathes ---the operational 1, which contains the gas mixture, and the control 2 which contains the unknown gas.

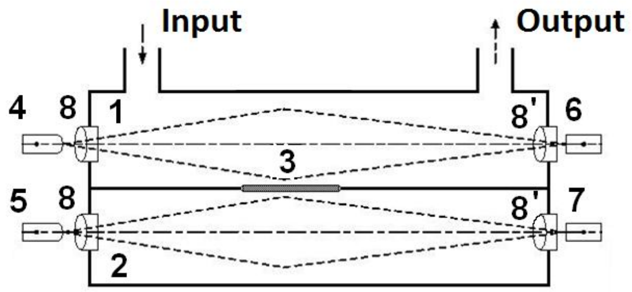

Fig. 2. The diagram of the optic gas concentration sensor :
1 – operating bath; 2 – controlling bath; 3 – diaphragm; 4, 5 – light emission sources of measuring channel and controlling channel correspondingly; 6, 7 – outputs of the light sensors of measuring channel and controlling channel correspondingly; 8 і 8′ – optical systems.

The gas to be analyzed is pumped through the input branch of the operating bath 1. Infrared light beams of the operating 4 and controlling 5 channels form light sources, which first pass through the input optical systems 8 for dispersion of light beams, and then through the gas, under analysis which presses the diaphragm 3 of the controlling bath 2, in the operating bath 1 and the gas in the controlling bath 2 correspondingly, and enter the output of optical systems 8' for collecting the light beams, and then the infrared light sensor of the measuring channel 6 and the controlling channel 7 [6, 7].

The suggested sensor and its diagram are simulated in the ORCAD system (Fig. 3).

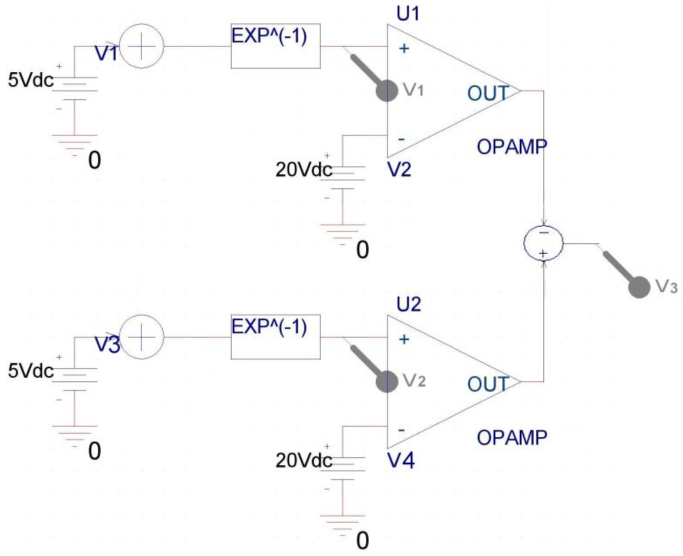

Fig. 3. Simulation sensor diagram

The simulation sensor diagram is presented as a two-channel device, which signals are compared in the output.

Fig. 4 presents the simulation results.

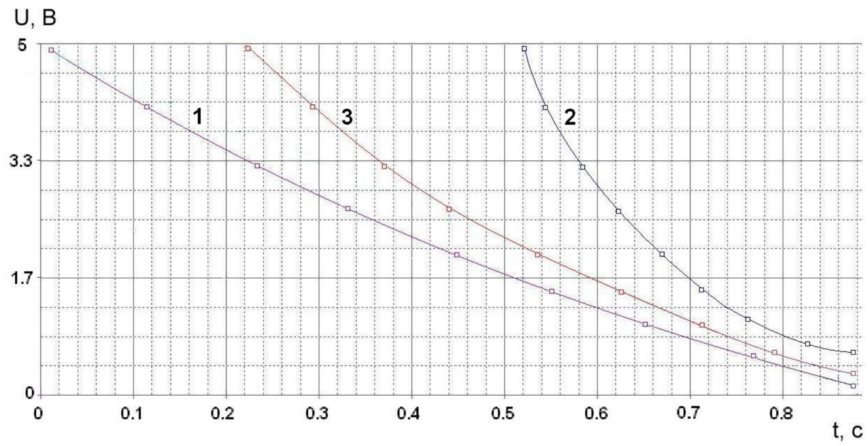

Fig. 4. Output sensor characteristics: 1 – in the first channel exponentiator; 2 – in the second channel exponentiator; 3 – in the output of the system

As is seen from the graph, all the dependences are of exponential character, that corresponds to the theoretical research. The output characteristic, which presents the difference between signals in the first and the second channels is also an exponential one, but more linear. So the results of the mathematical expressions, which describe the dependence of gas impurities concentration on intensity of high which passé through the gas mixture, had been proved experimentally.

Conclusions

There had been suggested the infra- red two-wave gas concentration sensor with special diagram, which allows to increase the accuracy of measurements due to the compensation for the adiabat indexes influence as well as influence of destabilization factors. The simulation helped prove experimentally the exponential dependence of gas impurities concentration on intensity of light which passes through the gas mixture.

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