Optoelectronic Method for Determining the Physicochemical Composition of Liquids

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Abstract: Currently, optoelectronic sensors which are based on anomalous photo-voltage (APV) curtains derived from semiconductor compounds are attracting the attention of many experts. The use of APV receivers to determine the physicochemical composition of liquids, especially in the optoelectronic method, is considered to be one of the promising methods. If APV receiver is used as the first converter in optoelectronic systems, it allows to increase the efficiency of a number of parameters of the system, such as energy saving, reliability, speed, accuracy.

Keywords: APV receiver, Lambert-Behr, optoelectronics, diode.

Introduction

In optoelectronic devices which are based on a light source and a receiver, the APV receiver is used as the primary element that converts optical signals into electrical signals. The resulting electrical signal is registered in the form of voltage or enters the electronic circuit, separates and processes the specified parameters and transmits information about the measured quantity to the computer. Thus, the changed signal falls on the computing device, which is graded by the measured quantities [1-4].

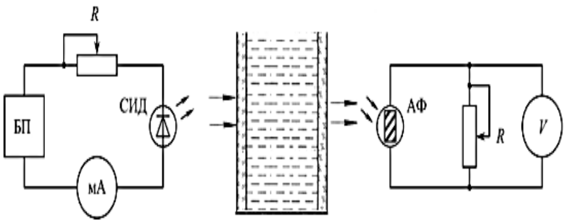

Fig. 1. Physicochemical analysis of liquids using APV-receiver content determination method

To check the colour of the liquids, the object being examined is irradiated with a light flux of two wavelengths λ_1 (green) and λ_2 (red).

According to Lambert-Behr's law, the luminous flux of wavelengths λ_1 and λ_2 passing through the layer of liquid under test is as follows:

$$\Phi_{\lambda_1} = \Phi_{0\,\lambda_1} e^{-k_1 d}; \qquad (1)$$

$$\Phi_{\lambda_2} = \Phi_{0\,\lambda_2} e^{-(k_1+k_2)d} = \Phi_{0\,\lambda_2} e^{-k_1 d} + \Phi_{0\,\lambda_2} e^{-k_2 d} \qquad (2)$$

$\Phi_{0\lambda_1}$, $\Phi_{0\lambda_2}$ - the flux of light coming from the emitting diodes, k_1 - absorption coefficient; k_2 - colour absorption coefficient; d – the thickness of the liquid layer that is being tested. Equalizing the initial light fluxes $\Phi_{0\lambda_1} = \Phi_{0\lambda_2}$, we create:

$$\frac{\Phi_{\lambda_1}}{\Phi_{\lambda_2}} = \frac{\Phi_{0\lambda_1} \cdot e^{-k_1 d}}{\Phi_{0\lambda_1} \cdot e^{-k_1 d} \cdot e^{-k_2 d}} = e^{k_2 d} \qquad (3)$$

It can be seen from this expression that when d - constant, the given light fluxes λ_1 and λ_2 are proportional to the colour of the controlled substance. Using the developed compositional scheme, the device automatically controls ambient colour of the liquid.

The role of optoelectronic devices in production is related to a number of requirements for them in providing information about the physicochemical parameters of products and technological processes: wireless control, high sensitivity and accuracy, speed, small volume, simplicity and reliability.

The essence of optoelectronic control is that any substance emits, absorbs or reflects light. Therefore, the physicochemical composition of a substance and the quantitative ratio of its constituent elements depend on changes in illumination, light absorption, angle of rotation, and other properties of light interaction with matter [3].

1. Mathematical calculation APV

If we look at the mathematical model of the APV receiver, it is a multi-variable function, and this function is expressed in terms of light flux Φ, spectral composition of optical radiation L, temperature T and humidity B:

$$U_\Phi = f(\Phi, T, L, B). \qquad (4)$$

Coefficient of variation in optical radiation of light sources (emitting diode, laser diode) of APV receivers:

$$K = \frac{\int_0^\infty \varphi_{e.\lambda}(\lambda) S_{\text{отн}}(\lambda) d\lambda}{\int_0^\infty \varphi_{e.\lambda}(\lambda) d\lambda}. \qquad (5)$$

Here $\varphi_{e.\lambda}(\lambda)$ is the relative scattering spectrum of the light flux emanating from the source; $S_{\text{отн}}(\lambda)$ is the relative spectral characteristic of the APV receiver sensitivity.

Spectral relationship of light flux with the integral sensitivity of the APV receiver:

$$S_{интФе} = S_{\lambda.Фе.max}\ K. \qquad (6)$$

Here $S_{\lambda.Фе.max}$ – the maximum spectral sensitivity of the APV receiver to light flux

Relative spectral sensitivity of APV receiver:

$$S_{\lambda.отн} = S_{\lambda.абс} / S_{\lambda.max}\ , \qquad (7)$$

$S_{\lambda.абс}$ - absolute spectral sensitivity of the APV receiver; $S_{\lambda.max}$ - maximum spectral sensitivity of the APV receiver.

Sensitivity of the APV receiver to the initial frequency:

$$\Phi_n = \frac{S_{отн}(\lambda)}{S_{\frac{I}{инт}}} = \frac{U_ш}{U_{u.инт}}, \qquad (8)$$

Here $U_ш$ – noise voltage; $S_{I.инт}$, $S_{u.инт}$ – current and voltage integral sensitivity of APV receiver.

Initial comparative sensitivity of the APV receiver:

$$\Phi_n^* = \Phi_n\sqrt{A\Delta f} = \Phi_{n.I}\sqrt{A}. \qquad (9)$$

Here $\Phi_{n.I.}$ – APV receiver's initial unit frequency bandwidth sensitivity; A – surface of the APV receiver; Δf – the frequency bandwidth of the amplified field.

The proposed frequency bandwidth for the measured area in the APV photoreceptor certification:

$$\Delta f = 0{,}2\ f_м\ . \qquad (10)$$

Here $f_м$ – frequency modulation in certification.

The comparative detection capability of the APV receiver:

$$D^* = \frac{1}{\Phi_n^*}, \qquad (11)$$

Here Φ_n^* – initial comparative specific sensitivity of the APV receiver.

Recalculation of the spectral sensitivity of the APV receiver to the light flux to the spectral sensitivity to the radiation flux:

$$S_{\lambda.Фе} = S_{\lambda.Фv}\ K_{max}\ V(\lambda), \qquad (12)$$

Here $S_{\lambda.Фе}$, $S_{\lambda.Фv}$ – spectral sensitivity to radiation flux and light flux; ; K_{max} – spectral maximum efficiency of monochromatic radiation; V(λ) – spectral relative light efficiency of monochromatic radiation for daylight (*Table* 1).

Recalculation of the parameters of the APV receiver in the given light PMD (photometric dimension), in the energy PMD parameters:

$$S_{инт.Фе} = S_{инт.Фv}\ K_{max}\ k_г; \qquad (13)$$

$$\Phi_{n.e} = \frac{\Phi_{n.v}}{K_{max}k_г},\quad Вт, \qquad (14)$$

Here $S_{инт.Фе}$, $S_{инт.Фv}$ – integral sensitivity of APV receiver to light flux and radiation flux; $k_г$ – the coefficient of radiation used by vision; $\Phi_{n.e}$, $\Phi_{n.v}$ – The initial sensitivity of the APV receiver to energy and light PMD at a given line frequency [2].

Table 1

Spectral relative light efficiency for day vision of monochromatic radiation

λ, nm	300	400	500	600	700
0 10 20 30 40 50 60 70 80 90	- - - - - - - - 0.00003 9 0.00012	0.00 4 0012 0040 0116 023 038 060 091 139 208	0.32 3 503 710 862 954 995 995 952 870 757	0.63 1 503 381 265 175 107 061 032 017 0082	0.0041 0021 00105 00052 00025 00012 00006 00003 00001 0 -

Recalculation of the parameters of the APV receiver given in energy PMDs for one source of radiation to the parameters in energy PMDs for another source of radiation:

$$S''_{инт.Фе} = \frac{S'_{инт.Фv}K''}{k'}; \qquad (15)$$

$$\Phi''_{n.Фе} = \frac{\Phi'_{n.Фv}K''}{k''}, \qquad (16)$$

Here $S'_{инт.Фv}$, $S''_{инт.Фе}$ – integral sensitivity of the APV receiver to the radiation flux for the first and second source radiation; $\Phi'_{n.Фv}$, $\Phi''_{n.Фе}$ – initial sensitivity of the PMD receiver to the frequency bandwidth at the given energy PMD for the first and second source.

Correlation of APV receiver sensitivity to voltage and current:

$$S_U \approx S_1 R_н\ , \qquad (17)$$

Here $R_н$ – load resistance.

$$U_Ф \approx S_1\ \Phi\ , \qquad (18)$$

Here S_1 - APV receiver sensitivity.

Voltage photo signal of APV receiver:

$$U_c = S_U\ \Phi\ , \quad (19)$$

Here S_U - voltage sensitivity of the APV receiver [2-5].

Conclusion

In summary, APV receivers for optoelectronic systems can be used to measure the parameters of non-electrical quantities in control-measurement techniques, such as density, thickness, humidity, coordinate of a moving object, colour, concentration, surface level, and so on. The use of APV receivers in optoelectronic systems as autonomous optical light receivers is promising in the areas of the field.

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The paper has been received on 12.04.2020