A photointegrator of the molecular condensation nuclei detector

Vladimir D. Kuptsov, Vladimir P. Valyukhov*

Peter the Great St. Petersburg Polytechnic University, 29 Politekhnicheskaya St., St. Petersburg, 195251, Russian Federation

Abstract

The problem of calculating the threshold sensitivity of an integrating photoreceiver (photocurrent integrator) is investigated. A noise model of a photointegrator is used to develop equivalent noise circuits and to calculate the RMS value of the voltage across the output of the photoreceiver. Among all the models of the real photointegrator it is conceivable that the approximation by an ideal photointegrator may be used. The threshold sensitivity of a photointegrator is defined as the power at the input of a photointegrator at which the root mean squared (RMS) voltage across its output is equal to the RMS voltage of total noise i.e. the signal-to-noise ratio is equal to one. A photomultiplier tube (PMT) can be used to increase the sensitivity. Formulas for calculating the sensitivity of a PMT-based photointegrator are given. The increase in sensitivity due to the use of PMT can be up to 18–30 times.

An experimental study of a photometer of a molecular condensation nuclei (MCN) detector that forms a base of highly sensitive MCN gas analyzers was conducted. The measured sensitivity differed from the calculated by 10%. However, at femtowatt power levels it is very difficult to get rid of parasitic optical signals that are responsible for a small decrease in sensitivity compared to the theoretical prediction. In many practical applications, for example, for the X-ray absorption method of mineral extraction using position-sensitive photodiode X-ray receivers, an approximation of a real photointegrator must be used.

Keywords: Photocurrent integrator; Photointegrator threshold sensitivity; Photometer; Molecular condensation nuclei detector.

1. Introduction

The photocurrent integrators are the basis of optical photometers that allows to accurately measure extremely small light intensities. Photocurrent integrators are used in scientific instruments to achieve high sensitivity of an optical measurement system in case of relatively slow physical processes. The photometers are applied to various fields of human activity: from medicine (for example, in systems for measuring optical densities of solutions and aerosols) to the mining and mineral processing technologies (x-ray scintillation detectors, etc.). The important problem in creating highly sensitive photometers is lowering the threshold optical power that can be registered by photoreceiving devices. The paper presents the results of developing a modern molecular condensation nuclei (MCN) detector.

The goal of this study is to analyze the threshold sensitivity of the as-developed detector to optical signals and to enhance the device as much as possible.

1.1. The photometer of a molecular condensation nuclei detector

The photometer is one of the main parts of highly sensitive gas analyzers based on the MCN method.
The molecular condensation nuclei method is based on the application of various physico-chemical processes to the flow of a gas containing impurities that need to be detected \[1,2\]. As a result of these physico-chemical processes monodisperse aerosol with a particle size of 0.23–0.25 μm is formed on the molecules of the detected substance \[3\]. The scattering by one aerosol particle has a non-monotonic interference nature \[4\]. At the final stage the light scattering by the obtained aerosol is measured by the nephelometric method. The signal of the photometer’s photoreceiver is proportional to the concentration of the detected impurities at the entrance of the detector. As a result of aerosol formation on the molecules of detected substances the particle size of the resulting aerosol is approximately 1000 times larger than the original molecule. The ability of the aerosol particle to scatter incident light also increases ∼10^{14−16} times compared with the original molecule and the aerosol particle with the molecule of the impurity in the center is easily detected by the light it scatters \[5\].

The mechanism of condensation of supersaturated vapor on MCNs is investigated in Refs. \[6,7\]. The problem of creation energy and equilibrium concentration of clusters was investigated in \[6\]. The equation connecting the energy required to transfer MCN from the gas phase into a homogeneous cluster with the energy required to break individual bonds was derived. A simulation of nucleation of supersaturated Di(2-ethylhexyl)sebacate (DEHS) vapor on FeO molecules using simplified structural models of clusters was done in \[7\]. It was established that the interaction between the electrical charges of a FeO molecule and the ether groups of a DEHS molecule played an important part in the process of nucleation. Also it was discovered that the strength of bonding between MCN and the first molecule of the condensate is very important. The strength of bonding influences the coefficient of conversion of MCN into aerosol particles and the dependence of this coefficient on the spontaneous condensation rate.

As mentioned above, the measurement of light scattering by the obtained aerosol is made by the nephelometric method. In this method the inner cavity of an aerosol photometer is illuminated through a hole by a lamp or laser and the scattered optical signal is measured at some angle to the incident light. The photocurrent of the photoreceiving device of an aerosol photometer is the current that changes proportionally to the concentration of detected substances the particle size of the obtained aerosol is approximately 1000 times larger than the original molecule and the aerosol particle with the molecule of the impurity in the center is easily detected by the light it scatters \[5\].

The aerosol particles in the photometric volume have the radii of about 0.25 μm with minor variations in size around this value \[8\]. Therefore, the Mie theory of light scattering by spherical particles with the size close to the wavelength of incident light can be applied \[5,9\]. It was established \[5\] that the intensity of light scattered by an aerosol particle at the optimal observation angle is about three times larger than scattering by the volume of air in the aerosol chamber of a nephelometer and is approximately 10^{15} times larger than scattering by a molecule of the detected impurity. The powers scattered by aerosol particles and air inside the chamber of a compact aerosol photometer measured in an experiment were only 8–10% larger than predicted by theory which is an acceptable
Fig. 2. A simplified schematic diagram of a photointegrator (I) with a photometer controller (II): IA – photoreceiver (photodiode or photomultiplier tube); REF – reference level, ADC – analog-to-digital converter, MC – microcontroller, To CPU – to central processing unit.

result. The optimization of the aerosol photometer design in general and of its optical-electronic part in particular allowed to reduce the detection limit for the gas analyzer target component to the level where it is determined by the background level of spontaneous condensation and not by the sensitivity of the MCN detector’s photoreceiver. The use of a PMT and current integrator in the photoreceiver of the photometer of MCN detector’s allows to calibrate the gas analyzer by the air scattering in the photometer’s chamber.

Scattering by air inside the photometer’s chamber produces the parasitic background illumination that masks the light scattering by aerosol particles. Calculation of light scattering by air is based on the Rayleigh’s theory [9].

A small size aerosol photometer and a microprocessor-based control, data acquisition and processing unit were developed [10]. This in turn allowed the development of highly sensitive MCN gas analyzers for the detection of various pollutants [2]. They include mass-produced poisonous gas detectors “Kaskad-G” and “Kaskad-5” [10], experimental detectors of metal carbonyls and explosives, medical breath analyzers [11], leakage detector for heat exchangers of nuclear reactors, gas mask testers [1].

To ensure high photocurrent sensitivity the photoreceiver uses a current integrator (Texas Instruments IVC102 chip) [10]. A simplified schematic diagram of the photointegrator and controller is shown in Fig. 2 and the corresponding time diagrams are shown in Fig. 3.

The input voltage of a photointegrator is given by

\[ U_{OUT} = -\frac{1}{C_{INT}} \int I_{INT}(t) \, dt, \]

where \( I_{INT} \) is the input current and \( C_{INT} \) is the photointegrator capacity.

For the case of a slow varying photocurrent this formula can be simplified to

\[ U_{OUT} = -\frac{I_{INT} \cdot T_{INT}}{C_{INT}}, \]

where \( T_{INT} \) – is the integration time.

The ATmega88 chip-based controller produces control signals for the \( S_1 \) and \( S_2 \) switches, reads the digital output of the ADC and transfers it via an SPI bus to the central processor.

If the concentration of the detected substance (Fig. 3a) and the corresponding level of scattered optical power inside a nephelometer are low, then during the measurement time \( T_{INT} = 1 \) s the output signal of the photointegrator changes from 0 to \( \pm U_{OUT(MAX)} \). The sampling
frequency of the ADC is 100 kHz, and therefore $10^5$ samples are digitized during a 1 s period. When the value of a sample reaches $\pm U_{OUT(MAX)}$ the controller resets the integrator to zero. For high concentrations (Fig. 3b) and the corresponding high levels of scattered light power the output level $\pm U_{OUT(MAX)}$ is reached during the time that is much shorter than 1 s.

The strongest possible photocurrent corresponds to the minimal measurement time of $T_{INT} = 100 \mu s$. During this time the ADC captures only 5–6 samples but the number of integration cycles (resets to zero) reaches $10^4$ in 1 s. The central processor calculates the tangent of the current vs. time curve and the photocurrent using the formula

$$I_{IN} = -\frac{\Delta U_{OUT}}{\Delta T_d} \cdot C_{INT},$$

where $\Delta T_d$ is the sampling interval which is 10 $\mu s$, $\Delta U_{OUT}$ is the increment of the output voltage during one sampling interval.

The application of the least squares method to all samples allows to achieve a significant increase in measurement accuracy. The mean squared error of the measured value of the photocurrent decreases as $1/\sqrt{N}$ where $N$ is the number of measurements.

As $10^4$ measurements are taken in a 1 s integration period, the mean squared error of the measured photocurrent decreases 100-fold. The maximum measurable photocurrent corresponds to the increase of the output voltage from zero to $U_{OUT_MAX}$ during 100 $\mu s$ and is

$$I_{IN_MAX} = -\frac{10 V}{100 \mu s} \cdot 100 pF = -10 \mu A.$$

The minimum measurable photocurrent corresponds to the increase in the output voltage equal to one quantization step of the ADC during 1 s and is

$$I_{IN_MIN} = -\frac{10 V}{2^{N-1} \cdot 1 s} \cdot 100 pF,$$

where $N$ is the number of bits in the ADC.

If a 14-bit ADC is used, then $I_{IN_MIN} = -60 fA$ and the dynamic range of the photointegrator is

$$D = \frac{I_{IN_MAX}}{I_{IN_MIN}} \approx 160 \cdot 10^6 \approx 160 dB.$$
If a 20-bit ADC is used then the minimum measurable photocurrent is $I_{IN,MIN} = -1.9 fA$ but the low boundary of the dynamic range is determined not by the quantization error of an ADC but by thermal and shot noise of a photointegrator.

### 1.2. Noise model of photointegrator

The equivalent noise model of the photointegrator is shown in Fig. 4.

The parameters of the operational amplifier are: the time constant $T_0$, transfer coefficient $A = A_0/(1 + pT_0)$, unit gain frequency $\sigma_1 = A_0/T_0$. The input impedance of the operational amplifier is moved out of the 4-pole circuit $A$.

The equivalent noise current and noise voltage generators describe random processes with spectral noise densities [12]: $I_{N1}$ is shot noise current of the photodiode, $S_{N1} = 2qI_S A^2/Hz$; $I_{N2}$ is the shot noise current of the operational amplifier, $S_{N2} = 2qA_{OA} A^2/Hz$; $I_{N3}$ is the thermal noise of the dynamic resistance of the photodiode, $S_{N3} = 4kT/R_{Dj} A^2/Hz$; $I_{N4}$ is the thermal noise of the input resistance of the operational amplifier, $S_{N4} = 4kT/R_{OA} A^2/Hz$; $I_{N5}$ is the thermal noise of the resistance of the input switch; $S_{N5} = 4kT R_{n} A^2/Hz$; $E_n$ is the thermal noise of the operational amplifier, $S_E = 4kT R_n V^2/Hz$.

The equivalent noise generators in the equivalent circuit can be considered noncorrelated and their power spectral density across the working frequency band is constant (white noise). The total power spectral density of noise current sources can be found by simple summation:

$$S_{N_{Σ,J}} = S_{N1} + S_{N2} + S_{N3} + S_{N4} + S_{N5}.$$

After substituting the appropriate power spectral densities we get

$$S_{N_{Σ,J}} = 2q \left( I_S + I_{OA} + 2\varphi T \left( \frac{1}{R_{OA}} + \frac{1}{R_D} + \frac{1}{R_I} \right) \right),$$

where $q$ is the charge of the electron, $\varphi T = kT/q$ is the thermal potential.

The mean squared noise current at the operational amplifier’s input is

$$\overline{I_{N_{Σ,J}}^2} = \int_0^\infty S_{N_{Σ,J}}(f) df = S_{N_{Σ,J}} \int_0^\infty df = S_{N_{Σ,J}} \cdot \Delta f$$

To find the root mean squared value of the noise voltage created by the noise currents across the output of the photoreceiver it is necessary to find the dispersion of the random process at the output of a linear circuit assuming that starting at time $t = 0$ it is excited by stationary random white noise with power spectral density $S_{N_{Σ,J}}$ [13]:

$$\overline{U_{N,J}^2} = \int_0^\infty \overline{h^2(τ_1)dt_1}$$

where $h(τ_1)$ is the impulse response of the linear circuit.

Three possible approximations are studied in [14]:

(a) noncorrelated noise generators (with white noise), which corresponds to the equivalent circuit shown in Fig. 4;

(b) an approximation with $R_I \rightarrow \infty$, which corresponds to the ideal integrating capacitor and reset switch;

(c) approximations with $R_I \rightarrow \infty, R_D \rightarrow \infty, R_{OA} \rightarrow \infty, C_{OA} \rightarrow 0$, which corresponds to an ideal photointegrator.
The formulas for approximations (a) and (b) are rather bulky and can be found in [14]; only approximation (c) is discussed in this paper.

The impulse response of the photointegrator’s current sources can be found by applying the inverse Laplace transform to the frequency response giving

$$U_{N,I}^2 = \frac{I_{E,N}^2}{C} \cdot \int_0^{T_{INT}} h_I^2(\tau) d\tau$$

$$= \frac{I_{E,N}^2}{C} \cdot \int_0^{T_{INT}} \frac{1}{C} d\tau = \frac{I_{E,N}^2}{C} \cdot \frac{T_{INT}}{C}$$  \hspace{1cm} (4)

The equivalent noise model of the photointegrator used in the calculation of the influence of the noise voltage on the root mean squared output noise voltage is shown in Fig. 5.

The frequency response of the integrator in operator form is

$$H_e(p) = \frac{\sigma_1}{\sigma_1 + p}.$$  

The impulse response is found by applying the inverse Laplace transform to the frequency response \(h_e(t) = \sigma_1 \cdot e^{-\sigma_1 t}\).

$$U_{N,E}^2 = \frac{\sigma_1}{\sigma_1} \cdot \int_0^{T_{INT}} h_N^2(\tau) d\tau = \frac{\sigma_1}{2} [1 - e^{-2\sigma_1 T_{INT}}].$$

Using the ideal photointegrator approximation results in a significant underestimation of the influence of the noise voltage source on the root mean squared output voltage.

1.3. Threshold sensitivity of a photodiode-based photointegrator

The threshold sensitivity of a photointegrator \(P_0 = I_0/S\) is defined as the power at the input of a photointegrator at which the root mean squared (RMS) voltage across its output is equal to the RMS voltage of total noise [15]. Mathematically, it is expressed as the equation

$$U_{OUT,S}^2 = U_{N,E}^2 + U_{N,I}^2,$$

that has to be solved to find the threshold input current \(I_0; S\) is the photodetector or photodiode light sensitivity.

To get the equation \(U_{OUT,S}^2 = U_{N,E}^2\) it is necessary to equate the square of the transfer function to the total RMS noise voltage across the output.

The photointegrator’s output signal for the input jump of the photocurrent \(I_0\) is determined by the following step function:

$$U_{OUT}(T_{INT}) = \int_0^{T_{INT}} I_0(T_{INT} - t) \cdot h_I(t) dt$$

$$= I_0 \cdot \int_0^{T_{INT}} h_I(t) dt = I_0 \cdot \frac{1}{C} \cdot T_{INT} \hspace{1cm} (5)$$

Now let us determine the photointegrator’s threshold current at which the root mean squared (RMS) voltage across its output is equal to the RMS voltage of total noise. The threshold current for short integration times is calculated in [3, 14] using approximations (a) and (b). The resulting complex equations are not repeated here.

If the condition

$$T_{INT} \gg \frac{C}{R_D + \frac{1}{R_{OA}} + \sigma_1 C_I}$$

is satisfied then the threshold current is given by

$$I_0 \approx \frac{1}{T_{INT}} \sqrt{\frac{T_{INT}^2}{C} \cdot \frac{\sigma_1^2 C_I (C_I + C_D)}{2}} \hspace{1cm} (6)$$

The relative influence of noise currents increases with the integration time. If the integration time is longer than

$$\frac{\sigma_1^2 C_I (C_I + C_D)}{2},$$

the effect of the noise voltage sources can be ignored.

Substitution of the spectral density of the noise current sources into (20) gives

$$I_0 = \frac{1}{T_{INT}} \left[ \frac{2g}{\frac{1}{R_D} + \frac{1}{R_{OA} + \frac{1}{R_D}} + \frac{1}{R_{OA}}} \right] T_{INT} + \frac{\sigma_1 C_I (C_I + C_D)}{2} \hspace{1cm} (7)$$

Shot noise current \(2qI_S\) is usually important in photosensitive devices with internal amplification, e.g. avalanche photodiodes and PMTs.

It is often convenient to use equivalent input spectral density of the noise current source \(\sqrt{N_{OA}}, \frac{N}{\sqrt{Hz}}\) and of
Table 1
The main parameters of a photointegrator based on the IVC102 Texas Instruments microchip.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrating capacitance</td>
<td>$C_I$</td>
<td>pF</td>
<td>100</td>
</tr>
<tr>
<td>OA input current</td>
<td>$I_{OA}$</td>
<td>A</td>
<td>$\pm 1 \cdot 10^{-13}$</td>
</tr>
<tr>
<td>OA input capacitance</td>
<td>$C_{OA}$</td>
<td>pF</td>
<td>50</td>
</tr>
<tr>
<td>OA noise voltage spectral density</td>
<td>$S_{U, OA}$</td>
<td>nV Hz$^{-1/2}$</td>
<td>10</td>
</tr>
<tr>
<td>OA unit gain frequency</td>
<td>$f_1$</td>
<td>MHz</td>
<td>2</td>
</tr>
<tr>
<td>Photodiode integrated current</td>
<td>$S$</td>
<td>A/V</td>
<td>0.5</td>
</tr>
<tr>
<td>Photodiode dark current</td>
<td>$I_D$</td>
<td>A</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td>Photodiode capacitance</td>
<td>$C_D$</td>
<td>pF</td>
<td>600</td>
</tr>
<tr>
<td>Photodiode resistivity</td>
<td>$R_D$</td>
<td>GΩ</td>
<td>1</td>
</tr>
<tr>
<td>Open reset switch resistivity</td>
<td>$R_I$</td>
<td>GΩ</td>
<td>1</td>
</tr>
<tr>
<td>Photointegrator dynamic range</td>
<td>$D$</td>
<td>dB</td>
<td>186</td>
</tr>
</tbody>
</table>

Noise voltage source $\sqrt{2S_{U, OA}} \ V/\sqrt{Hz}$ at the input of the operational amplifier because these parameters are given in the amplifier manufacturer’s technical specifications. In this case the input shot noise current and thermal noise of the operational amplifier’s input impedance are included in the total noise current spectral density and the equation for the threshold current takes the form

$$I_t = \frac{1}{T_{INT}} \left( 2q \left( I_s + \frac{2g_F}{R_D} + \frac{2g_p}{R_I} \right) + \sqrt{2S_{U, OA}} \sigma(C_I + C_D) \right) \mu$$

(8)

Sometimes a concept of the noise equivalent power (NEP) is introduced. NEP is defined as the power of the input signal at which the signal-to-noise ratio at the output is equal to one for the bandwidth of 1 Hz. NEP is equivalent to the spectral density of the noise current source at the amplifier’s input (measured in A/$\sqrt{Hz}$) divided by the steepness of the transformation $S$ (A/W). Therefore, NEP is measured in W/$\sqrt{Hz}$. The threshold sensitivity of a photointegrator $P_0$ is given by NEP integrated over the entire frequency band of a photoreceiver.

A photointegrator using a precision low noise operational amplifier with field effect transistors (FET) at the input, an integrating capacitor and a low loss FET switch (all integrated in an IVC102 chip) and a silicon $p$-$i$-$n$ photodiode has the parameters listed in Table 1.

The threshold sensitivity of a photoreceiver with a silicon $p$-$i$-$n$ photodiode and an integrator was $P_{0, FD} = 0.9 \cdot 10^{-14}$ W for the integration time of 1 s. The dynamic range of the photointegrator is

$$D = \frac{I_{IN, MAX}}{I_{IN, MAX}} \approx 2.2 \cdot 10^9 \approx 186 \text{ dB}.$$  

An analog-to-digital converter (ADC) must have more than 20 bit to cover this dynamic range completely.

1.4. Threshold sensitivity of photomultiplier tube (PMT)-based photointegrator

A PMT can be used as a photosensitive element to increase the sensitivity of a photointegrator. A PMT has a high coefficient of transformation of light power into an electric current $S_A$ (up to $10^6$ A/W compared to 0.5 A/W for a photodiode) but it is expensive and has a short lifetime and needs a high-voltage power supply.

In a PMT two sources of shot noise (shot noise of the signal current $I_S$ and the dark anode current noise $I_{DA}$) must be added to the above-mentioned noise sources.

The spectral density of the shot noise of thermal emission cathode current $I_{CATH}$ is calculated by the Shottky formula

$$S_{CATH} = 2qI_{CATH},$$

and the mean squared thermal emission noise current is

$$\overline{i_{FE}^2} = 2qI_{CATH} \Delta f.$$

The spectral density of the mean squared shot noise of the signal and dark anode currents of a PMT is given by

$$S_N = 2q(I_A + I_{DA}) \mu$$

(9)

The total mean squared noise voltage across the output of a PMT’s photointegrator is given by

$$\overline{U_{N, \Sigma}^2} = 2q \left( (I_A + I_{DA}) \mu + I_{OA} \right)$$

$$+ \frac{kT}{q} \left( \frac{1}{R_{OA}} + \frac{1}{R_{FMP}} \right) \frac{T_{INT}}{C_1^2} + \frac{q^2 \sigma_1(C_1 + C_{FMP})}{2C_1} - \frac{C_1^2}{C_1^2}$$

(10)

where $R_{FMP}$ and $C_{FMP}$ are PMT input resistance and capacitance respectively.

Because of a PMT’s high internal amplification the output voltage can be determined using the step response function of an ideal integrator

$$\overline{U_{OUT}^2} = \overline{I_A^2} \cdot \frac{T_{INT}}{C_1^2}.$$  

The threshold sensitivity of a PMT-based photointegrator is calculated in [14], and the following formula is obtained:

$$P_0 = \frac{1}{S_A} \sqrt{\frac{2qI_{DA} \mu}{T_{INT}}}$$

(11)
Shot noise of a PMT must be taken into account if the integration time is less than several tenths of a second.

The threshold sensitivity of a PMT-based photointegrator depends on the PMT’s anode voltage. To calculate the threshold sensitivity for various PMT anode voltages the corresponding values of $S_A$, $\mu$ and $I_{DA}$ from the technical specifications of a PMT must be substituted into (11). Calculations made for the threshold sensitivity of a photointegrator with an H6780 PMT (manufactured by Hamamatsu, Japan) and a 1 s integration time gave the best sensitivity of $P_{0,FMP} = 0.48 \cdot 10^{-15}$ W at the anode voltage of 700 V. Therefore, the gain in sensitivity achieved by using a PMT instead of a photodiode was 18–30 times.

1.5. Threshold sensitivity of MCN detector

The measured threshold sensitivity was $P_{0,\text{exp}} = 0.66 \cdot 10^{-15}$ W at the anode voltage of 600 V, while the theoretically calculated sensitivity was $P_{0,\text{teor}} = 0.59 \cdot 10^{-15}$ W. The 10% difference between experiment and theory can be attributed to parasitic light scattering inside the detector that is hard to get rid of for the powders on the order of fractions of a fW, and that increased the threshold sensitivity above the theoretically predicted value.

Equations for the calculation of the threshold sensitivity were significantly simplified because of the long integration time (about 1 s) and the use of a highly sensitive photomultiplier tube with a low noise preamplifier. However, in many practical situations where position-sensitive optical detectors are required and measurement time is only a fraction of a millisecond or less, photodiode-based photodetectors must be used. In this case approximations (a) and (b) must be used.

An example of such a detector is a position-sensitive X-ray detector used in a sensor for the X-ray absorption method of mineral enrichment [16]. In this sensor a linear array of photodiodes, each with its own preamplifier, is covered with a scintillating medium. The integration time is determined by the speed of a conveyor belt carrying minerals and is a fraction of a millisecond.

2. Conclusions

The threshold sensitivity of integrating photoreceivers (photointegrators) can be determined using their equivalent noise circuits and integrating the impulse response of a photodetector.

A photocurrent integrator based on measuring the photocurrent increase with time followed by the average aging of the tangent of this increase can detect photocurrents induced by the aerosol scattered light power in the fA range.

In an MCN detector such a low detected power allowed:

- to reach the sensitivity to the target substance that is lower than its dangerous concentrations;
- to calibrate the gas analyzer by measuring air scattering in the photometer’s chamber;
- to reach the target substance detection level close to the level of spontaneous condensation and not limited by the sensitivity of the optical-electronic system of a sensor.

References


