*Available online www.jsaer.com*

***Journal of Scientific and Engineering Research*, 2017, 4(4):53-61**

**Research Article**

**ISSN: 2394-2630**
**CODEN(USA): JSERBR**

# Metrological Providing of Infrared Spectral Radiometric Measurement of the Atmosfere's Ecological Parameters and Thermal Sources

**R.S. Asatryan[1]*, H.S. Karayan[1], N.R. Khachatryan[2]**

[1]*National Institute of Metrology, Komitas ave. 49/4, 0051, Yerevan, Armenia

[2]Yerevan State University, str. A. Manoogyan 1, 0025, Yerevan, Armenia

**Abstract** The creation of optoelectronic devices and systems with the best metrological parameters that enable the operational analysis of basic physical and environmental parameters, and distant monitoring of the atmosphere and air infrared environmental control of vast forest spaces (for detection of fires in the early stages of their development) and pipelines of natural gas is a very important task. The present work is devoted to presenting the results of research and development work on the development of metrological providing methods and manufacturing of optical-electronic instruments for environmental purposes to explore the basic physical and ecological parameters of the atmosphere, as well as monitoring atmospheric $CO_2$ and $H_2O$ vapor on the horizontal path, infrared (IR) spectral analysis of hot gas ejections from industrial plants in the spectral range from 2.5 to 5.5µm, at a distance of 3000m, and forest spaces and main gas pipelines.

**Keywords** Infrared Radiometer, Forest Fire, Natural Gas Pipelines, $CO_2$ and $H_2O$ vapor on the horizontal path , Infrared spectral analysis; hot gas ejection in atmosphere.

## Introduction

Currently sharply increased interest in environmental issues, which is primarily due to the ever-increasing contamination of the environment.

According to the latest data on the study of atmospheric pollution in industrial developed countries [1-4] the main sources of pollution are industrial and energy facilities and transport, which accounted for over 80% of the total amount of pollution. The major components of air pollution are gaseous compounds of carbon, nitrogen and sulfur, as well as solid and liquid aerosol formation, which are of particular concern for the normal functioning of humans and other biological objects [5-6].

Significant contamination of air space and its devastating effects on human health, climate and vegetation is also due to macroscopic leaks (or sometimes emissions) of natural gas pipelines and extensive fires, particularly forest areas.

In ecological researches of a terrestrial atmosphere rather great value measurements of quantity water vapor and carbonic gas in an environment have. On the basis of the experimental data received on measurements of a spectral transparency of atmosphere in the wave lengths from 2.5 up to 5.5µm where there are strong band of absorption water vapor (on 2.7µm) and carbonic gas (on 4.3 µm), and with the help of existing empirical dependences between a spectral transparency and quantity of absorbing molecules it is possible to determine concentration $H_2O$ vapor and CO2 on a site of measurements.

The study of gaseous components in the atmosphere plays a significant role in the sphere of ecological researches. One of main tasks of environmental control is the spectral study of chemical composition of atmosphere pollution, as well as analysis of gaseous outbursts of either industrial processes or ground transport.

Important value has also distant measurements of radiation temperatures of point and extended sources of thermal radiation in an industry and in atmosphere.

Therefore, the creation of optoelectronic devices and systems with the best metrological parameters that enable the operational analysis of basic physical and environmental parameters, and distant monitoring of the atmosphere and air infrared environmental control of vast forest spaces (for detection of fires in the early stages of their development) and pipelines of natural gas is a very important task.

The present work is devoted to presenting the results of research and development work on the development and manufacturing of optical-electronic instruments for environmental purposes to explore the basic physical and ecological parameters of the atmosphere, as well as monitoring forest spaces and main gas pipelines, to representation of results and discussion of the given measurements infrared spectral transparency of the atmosphere. In the wave lengths region from 2.5 up to 5.5 µm carried out with the help developed by us universal IR Spectral Radiometer "Sipan-A", and the results of IR spectral analysis of hot gas ejections from industrial plants in the spectral range from 2.5 to 5.5 µm, at a distance of 3000 m. The obtained with a hydrocarbon gas group, $SO_2$, $N_2O$, CO and $CO_2$ gases, as well as $H_2O$ vapor. Relative content of ejected gases (to CO-$CO_2$ group) per unit time was evaluated by means of an integral intensity ratio for each gas. Distant IR Spectral analysis of hot gas ejections (both industrial firms, and various vehicles) have huge value, in particular at ecological monitoring of an environment.

**Universal Infrared Spectral Radiometer "USR-A"**

For the purpose of spectral and radiometric studies of atmospheric and thermal objects parameters in the wavelength range from 0.4 to 14 microns, we have developed and manufactured a universal spectral radiometer "USR-A", a detailed description and principle of operation is presented in [7-8].

"USR-A" is designed to measure the spectral density of the brightness and radiation temperature (or drops) of point and extended sources of infrared radiation in the laboratory and field conditions, as well as for remote spectral analysis of hot gas facilities.

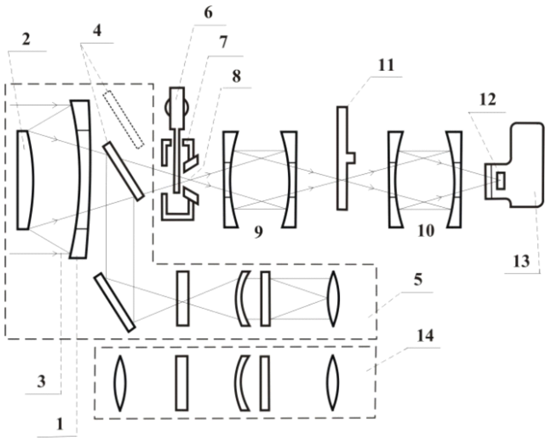


*Figure 1*: *OMB Optical Scheme:1-Primary mirror lens; 2-secondary mirror lens; 3-radiation from the object; 4-retractable flat mirror; 5-sight; 6-modulator; 7-bearing cavity; 8-field stop; 9,10-projection lens; 11-disk interference filters; 12-sensitive area of the photo detector; 13-dewar of liquid nitrogen; 14-visual tube.*

Structurally spectroradiometer made up of two parts: optical-mechanical (OMU) and the electronic control unit (ECU). The electrical connection between the units is by means of cables. Full spectral range of the instrument is covered by three sets of interchangeable filters and photo detectors sub bands: from 0.4 to 1.1 microns from 2.5 to 5.5 microns and from 8 to 14 microns. Optical scheme OMU is shown in Figure 1.

An Electronic Control Unit Constructively Desktop Performance: all organs and display controls are located on the front of the ECU. We note some of the benefits we developed IR spectroradiometer "USR-A" as compared to the existing close analogues (see for example [9]). To extend the functionality of spectral studies of thermal objects, except for the broadband interference filters for spectral regions from 0.4 to 1.1, from 2.5 to 5.5 and from 8 to 14 mm, the device is also provided with the ring tunable optical filters [10].

In order to eliminate chromatic aberrations in the optical system of the device includes two pairs (Figure 2) Mirror projection lenses, in the focus of which are installed filters and photo detectors tipple.

At the end of this section, we note that after some design improvements in the optical system spectroradiometer "USR-A" (adding the input deflecting mirror) in [11] described in detail the method of air environmental control of forest spaces and gas main pipelines.

**The Metrological Characteristics of a Universal Spectroradiometer "USR-A"**

Metrological certification was conducted in accordance with the universal spectroradiometer specially designed program of metrological certification (AEL2.807.007PMA, [12]). In metrological evaluation determined device characteristics shown in Table 1. In carrying out metrological certification spectroradiometer “USR-A” to apply the necessary instrumentation and equipment referred to in [12]. In the same paper the conditions and procedure for certification are presented. Measurements to determine the difference between the radiation temperature equivalents to noise $\Delta T_{eq.N}$, performed with the setup diagram of which is shown in [12]. Value of noise equivalent temperature difference $\Delta T_{eq.N}$ determined by the formula: $\Delta T_{eq.N} = \frac{U_N}{K_{\Delta T}}$, was found to be 0.05 within ± 10%.

To determine the basic error of measurement of radiation temperature difference Spectroradiometer, on the installation of certification established blackbody temperature in the range of 288 to 298 and in increments of $1^0$ K, five times the output signals of the device checked.

The standard deviation of the measurements was determined by the formula: $S_{U_{sr}} = \sqrt{\frac{\sum_{i=1}^{n}(U_{sri} - U_{sr})}{n(n-1)}}$.

Reduced error in the measurement of the difference between the spectroradiometer radiation temperatures was within ± 15%.

**Table 1**: Metrological Parameters of the Equipment “USR-A”

| The Name of the Metrological Characteristics and Units of Measuring | Nom. Values | Permissible Declinations | Comment |
|---|---|---|---|
| Working spectral ranges, $\mu m$: | | | |
| I channel | 0.40-1.1 | ± 10% | |
| II channel | 2.50-5.50 | ± 10% | Provided with filters |
| III channel | 7.90-13.5 | ± 10% | |
| Field of view, mrad, no more than: | | | |
| I channel | 3 | ± 10% | |
| II channel | 3 | ± 10% | |
| III channel | 3 | ± 10% | |
| The difference in noise-equivalent radiation temperatures, $\Delta T_{eq.N}$, K, no more than: | | | |
| II channel | 0.05 | ± 10% | |
| III channel | 0.05 | ± 10% | |
| Summary reduced measurement error of the temperature difference between the radiation range of 0.5 to $20^0$ at the lever 293 ± $5^0$ K, no more than: | | | |
| II channel | | ± 15% | |
| III channel | | ± 15% | |

**IR Monitoring Environmental $CO_2$ and $H_2O$ Vapors**

We have carried out experiments in the middle latitudes of the European part of Russian, in summer. 1500m long horizontal path was selected. The measuring equipment included a standard black-body source (at a temperature 1270K), a chopper positioned in front of the source and IR Spectral Radiometer "Sipan-A" [13]. Structural diagram of experiment and measuring equipment is shown in Figure 2.

In this experiment, the internal reference source of "Sipan-A" system was not used, due to existence of the external source with chopper.

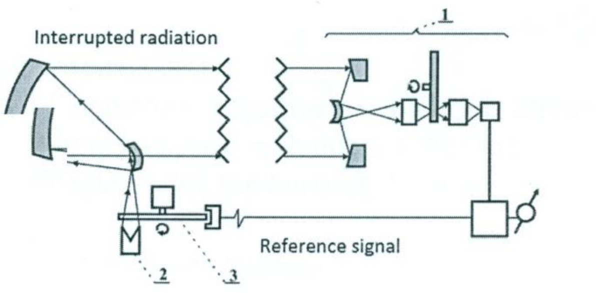


*Figure 2: Structural diagram of the measurement equipment*

The system was synchronized by a radio signal transmitted from the source position and repeating the modulation half-periods. As results, the synchronous detector output was equal to a difference of signals "source + background" and "background". The same spectral measurements were repeated for a short path (200m). Using the brightness spectrum relations (1) for a point IR source we have obtained the spectral transparency of atmosphere $\tau(\lambda)$ at a distance 1500m. Averaged results over 30 spectral measurements are shown in Figure 3. Solid curves in Figure 2. correspond to calculated value [14-15], while crosses show the results of our measurements. Simultaneously, meteorological parameter values were measured at the receiver site (humidity, pressure and temperature).

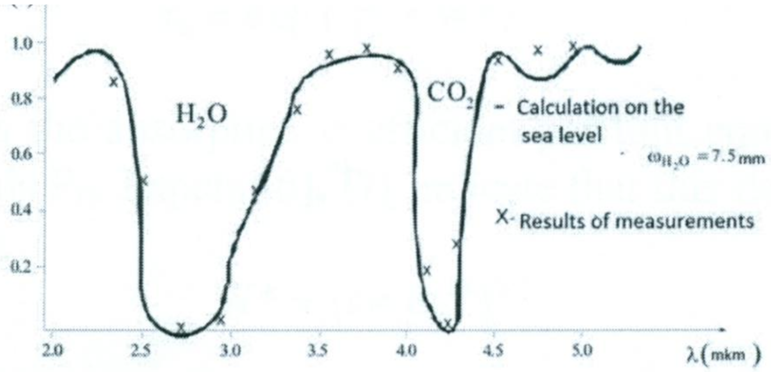


*Figure 3: Spectral transparency of the atmosphere on a horizontal track length L=1500m*

As a result of numerous experiments, Elder & Strong [14] have suggested the following empirical relation for water vapor absorption in narrow wavebands $\tau(\lambda)$, valid for horizontal paths at altitudes up to 3000m: $\tau(\lambda)=t_0 \bullet k \bullet \lg\omega_{H20}$ (2)

Here $\omega_{H20}$ is the thickness of condensed vapor layer (cm), $t_0$ and k, are empirical constants for the considered $\lambda$ [14]. Using the relation (2), with constants given in [14], as well as the results of our measurements, we have found the condensed layer thickness $\omega_{H20}$= 4.5 and 9.5mm respectively in the 1.9- 2.71 µm and 2.7-4.3µm wavebands. Thus the average value of $\omega_{H20}$ for a distance 1500m makes 7.0mm, which is close to the value 7.5mm obtained from in-situ measurement of meteorological parameters. The solid curve $\tau(\lambda)$ in Figure 2. was drawn for that very value (7.5mm). Multi-year theoretical and experimental researches by the group of authors

[16-17] has shown that atmospheric transparency in general is a function of the absorbent mass (condensed layer), effective pressure and wave number: τ= τ(ω, $P_E$,u). The effective pressure $P_E = P_N + B \cdot Pa$, where $P_N$ is the line-broadening nitrogen pressure, B is self-broadening coefficient of the absorbing gas having pressure Pa (B=6 or 2 respectively for $H_20$ and $C0_2$). The same authors have shown that spectral transparency is well described by the relation: $\tau_u = \exp(-\beta_0 \cdot W^*)$ (3).

Where is the absorption coefficient per unit equivalent mass W*, which depends $P_E$. Papers [16-17] indicate that this dependence may be taken in form

$$W^* = (\omega \cdot P_E{}^{2k})^{1/2} \quad (4)$$

Where k and 1 are parameters depending on ω• $P_E$ and u, the values of which are given in [18]. For computation using the results of our experiments (in the 4.3 μm waveband of $CO_2$) it was convenient to introduce the equivalent masses separately for the center and peripheral parts of the waveband:

$$W_1^* = (\omega CO_2 \cdot P_E{}^{0,96}) \text{ (center)} \qquad W_2^* = (\omega CO_2 \cdot P_E{}^{0,7})^{0,64} \text{ (periphery)} \quad (5)$$

$W_1^*$- was used in (2) when W* ≤0.7 and $W_2^*$ otherwise

$$\tau_u = \exp(-\beta_{1u} \cdot W_1{}^*) \text{ (center)} \qquad \tau_u = \exp(-\beta_2 u \cdot W_2{}^*) \text{ (periphery)} \quad (6)$$

The values of coefficients -$\beta_1$u and -$\beta_2$u are given in [18]. Effective pressure $P_E$ in the relations (3)-(6) were expressed in atmospheres (~latm. at a see level), while min centimeters. $CO_2$ content in the 1500m long path was found from the relations (5) and (6) for the $t_0$ values measured in the 4.3μm waveband. The averaged value of $CO_2$ content was equal $\omega_{H20}$ = 4.2cm. Numerous researches dealt with $C0_2$ content in atmosphere, the results being given in the monograph [15]. Although there is a 6-fold difference between the minimum and maximum concentration of $CO_2$, one may assume it constant and equal to 0.03% in volume while calculating its IR absorption (large deviations from this value are extremely rare). Note that our calculated value of $CO_2$ volume concentration, equal to 0.028% stays in good agreement with the value obtained from multi- year investigations.

**Distant IR Spectral Analysis of Industrial Hot Gas Ejection in Atmosphere**

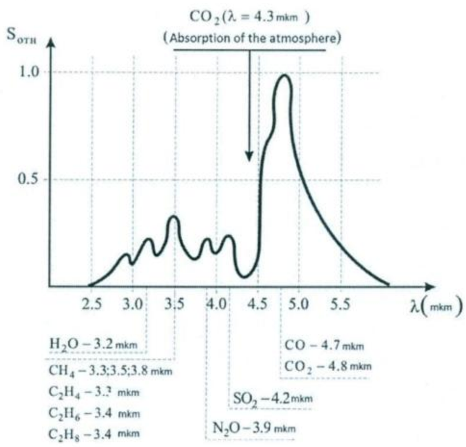


*Figure 4: IR spectrogram of hot gas of industrial emissions into the atmosphere.*

Note that, due to low spectral resolution (≈3% ), hydrocarbon line group's lines merge into a single band, however their integral intensity may be still compared with that for CO and $CO_2$, gases, which is important for qualitative analysis in ecology. An intensive $CO_2$, absorption band of the atmosphere is distinctly visible in Figure 4 at a wavelength 4.3 μm [15]. CO and $CO_2$, gases are known to be the major combustion component, which is reflected in our spectrogram in form of high intensity emission band at 4.7 - 4.8μm wavelength.

We have selected the 3-5μm waveband for measurements because (1) it is one of the main "Transparency windows" in the atmosphere, and (2) because low-concentration gas pollutants, such as hydrocarbons, $N_2O$, $SO_2$ etc., possess more or less intensive oscillatory (rotation) spectra in this very range [15]. One may easily identify some groups of these molecules by their emission bands. Most distinctly visible is the hydrocarbon group, with maximum at 3.5µm, which is explained by the fact that natural gas was present in the fuel of the plant.

At a flame temperature above 2000K, the emission bands of $H_2O$, CO and $CO_2$, gases are broadened to an extent when their spectrum in the range 3 - 5µm becomes continuous [20]. However, at temperatures below 2000K the bands may be resolved, which was indeed observed in our experiment. Comparison of the maximum intensity wavelength in the obtained spectrum with that for the black body radiation, we have found that the effective temperature of gas ejection was in the interval 500 - 600k. Relative content of ejected gases (to CO –$CO_2$, group) per unit time was evaluated by means of an integral intensity ratio for each gas. One may see that hydrocarbons content is respectively 2 and 3 times higher than $SO_2$ and $N_2O$ content, and on the other hand it is 4 times less then CO-$CO_2$, group. The obtained results on IR spectrometry of hot gas ejections provide important information about the extent of atmospheric pollution. Our proposed method and used equipment make possible fast determination of content for various hot-gas ejections, by passive spectral measurements in 3 - 5µm and 8-14µm wavebands.

**Infrared Monitoring of Large Forest Space and Gas Main Pipelines**

The IR radiometer is mounted in the helicopter [21] and, with the help of a deflecting plane mirror, by its field of vision scans (through the bottom hatch, along the helicopter motion routing) terrestrial surface of large forests, see Figure 5.

*Figure 5: Helicopter IR scanning of large forests.*

In the presence of fire hearths the radiation temperature in this region (within the wavelength range of 2.5 to 5.5 µm) considerably increases that is registered by the electronic control unit.

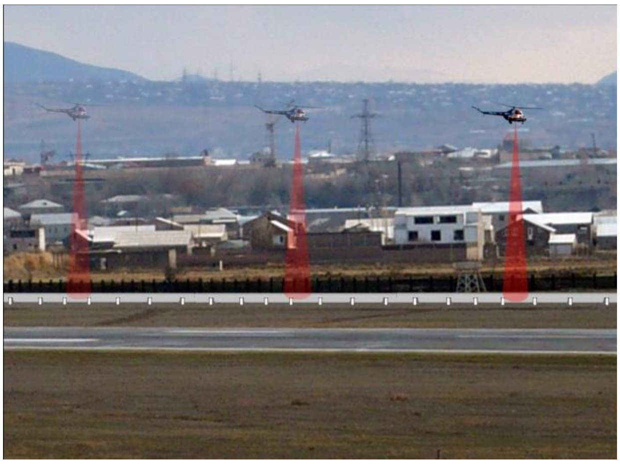

*Figure 5: Helicopter IR scanning of GMPs*

At the helicopter flight altitudes of 200, 500 and 700 m the radiometer covers, with its field of vision, surface areas of about 120, 750 and 1500 sq.m, correspondingly.

The IR radiometer scans the Earth's surface along the GMPs routes within its field of view through the bottom hatch. If there are macroscopic gas leaks in this region, the radiation temperature (in the wavelength region 8–14 μm) drops significantly [22] and is recorded by the ECU.

At helicopter flight altitudes of 200 and 150 m, the radiometer fields of view on the ground encompass surfaces with radius of ~6 and ~2.5 m, respectively, see figure 5.

With the helicopter speed of 150-200 km/hr the time of one measurement cycle is 0.1 sec.

**Measurement Technique of IR Flows From Extended and Point Thermal Sources:**

Before carrying out quantitative measurements of IR radiation emitted by an unknown source, it is necessary to fulfill energetic calibration of the spectroradiometer, the aim of which is the measurement of the device response to the known standard source (usually a black body with known temperature). By definition, the device calibration means obtaining an electrical signal at the output, which corresponds to a radiation flow unit incident into the radiometer inlet. The calibration is expressed by some function k(λ) called spectral calibration characteristic of the device, which includes combined effect of optical elements and electronic amplification of the whole system. k(λ) is expressed in V/radiation unit, with standard level of amplification degree. An output signal of the device is proportional to the difference between the IR radiation flows coming to the photodetector from an external source and from the internal modulated reference black body. In calibrating the radiation from the calibration black body (with known temperature) entirely fills the device field of vision. An output signal S(λ) is expressed by the following ratio:

$$S(\lambda)=k(\lambda)\cdot\{r(\lambda,T)\cdot\tau(\lambda,l)-r(\lambda,T_0)+r(\lambda,T_B)[1-\tau(\lambda,l)]\} \quad (7)$$

where $r(\lambda,T)$ is Plunk function at the temperature $T$ and the wavelength $\lambda$;

$T$ – temperature of the calibration black body;

$\tau(\lambda,l)$ – atmospheric transparency over the path $l$ between the calibration source and device;

$T_0$ – temperature of the internal reference black body;

$T_B$ – temperature of the air during the experiment.

In the windows of the atmosphere transparency (e.g. for the wavelength range of 2.5 to 5.5 $\mu$m), where the transmission is high, $\tau(\lambda,l)$ may be taken as 1, if the calibration is carried out from the distance "$l$" equal to several meters. Therefore in this approximation for $S(\lambda)$ we can write:

$$S(\lambda)=k(\lambda)\cdot[r(\lambda,T)-r(\lambda,T_0)] \quad (8)$$

with the amplification coefficient equal to 1. And in measuring with the amplification coefficient different from 1 the $S(\lambda)$ value decreases by the same factor. The Plunk function value is calculated according to the ratio:

$$r(\lambda,T)=\frac{c_1}{\lambda^5}[\exp(c_2/\lambda T)-1]^{-1}$$

where

$c_1=3{,}74-10^4$ W $\mu$m$^4$/cm$^2$

$c_2=1{,}438\cdot10^4$ $\mu$m deg

The objects studied the radiation flow of which completely fills the device field of vision are extent in these measurements. In this case radiance spectral density (W$(\lambda,T)$W/cm$^2$ $\mu$m) of the object is measured. The ratio (1) may be rewrite as:

$$S(\lambda)=k(\lambda)\{W(\lambda,T)\cdot\tau(\lambda,l)-r(\lambda,T_0)+r(\lambda,T_B)[1-\tau(\lambda,l)]\}\cdot\beta \quad (9)$$

where $W(\lambda,T)$ is the radiance spectral density of the object studied, $\beta$ is an amplification coefficient of the whole system , and the rest symbols remain previous. The atmosphere transparency $\tau(\lambda,l)$ is either measured simultaneously, or calculated with the help of data from literature [23-24]. From the ratio (9) we can get for $W(\lambda,T)$:

$$W(\lambda,T)=\frac{S(\lambda)/k(\lambda)\beta+r(\lambda,T_0)-r(\lambda,T_B)\cdot[1-\tau(\lambda,l)]}{r(\lambda,l)} \quad (10)$$

Usually the radiation of point sources does not fill the visual field of the device. If the area A of a radiating object is known we can measure its spectral radiance according to the above-stated technique, that is

$$W_p(\lambda,T)=W(\lambda,T)\cdot\omega\cdot\frac{l^2}{A} \quad (11)$$

Where ω is a solid angle of the spectroradiometer visual field, W(λ,T) is a total spectral radiance measured according to (10); $l$ is the distance from the object under test to the spectroradiometer. While measuring point sources spectral contrast of a radiation source is also of interest, when the background radiance is comparable to the object radiation. In this case it is necessary to separate the background signal $S_\Phi(\lambda)$ from the signal "source+background" S(λ). For the spectral radiation contrast of the source we can get the ratio:

$$W(\lambda)=\frac{\Delta S(\lambda)\cdot\omega\cdot l^2}{\beta\cdot k(\lambda)\cdot\tau(\lambda,l)A} \quad (12)$$

Where $\Delta S(\lambda)=S(\lambda)-S_\Phi(\lambda)$

If A is unknown we may define the contrast of the spectral luminous intensity of the source (in W/strad.μm):

$$I(\lambda)=W(\lambda)\cdot A=\frac{\Delta S(\lambda)}{\beta\cdot k(\lambda)\cdot\tau(\lambda,l)}\cdot\omega\cdot l^2 \quad (13)$$

Calculation of the radiation temperatures of the objects under test is carried out in accordance with specially developed algorithms and programs.

**Conclusion**

The developed optical-electronic systems offer the possibility of remote sensing of physical and environmental parameters of the atmosphere and IR sources. The experimental results of the metrological characteristics developed devices confirm the high accuracy of the measurements.

The developed method of infrared air monitoring can be widely used for remote environmental monitoring forest spaces and natural gas main pipelines.

Mobile version of the complex created instruments can be used successfully for the rapid assessment of physical and ecological state of the atmosphere, as well as for the distant researches of thermal objects.

Received results of IR spectrometric measurements of atmospheric $CO_2$ and $H_2O$ vapor can provide the significant information on structure of atmospheric gas pollution. The measurement methodology developed by us and the applied equipment represent an opportunity of carrying out of an operative estimation of the contents of different gases with the help passive spectrometry in the wavebands from 3 up to 5μm and from 8 up to 14μm**.**

Distant IR Spectral analysis of hot gas ejections (both industrial firms, and various vehicles) have huge value, in particular at ecological monitoring of an environment.

Application of the given method of remote ecological monitoring of vast forest spaces and extended gas pipelines will undoubtedly bring to the considerable technical-economical effectiveness and will also have a great importance in the problem of preventing the fire occurrences, especially of large-scale ones, and also will be imported in solving the problem of monitoring atmospheric pollution from natural - gas emissions.

**References**

[1]. S.M. Musaelyan, (1985) The Problems of Clean Air. - Yerevan: Armenia, 225 p.

[2]. A.G. Bannikov, A.K. Rustamov, (1985) The Nature Conservancy. 2nd ed., Rev. and add. - M. Agropromizdat, 287 p.
[3]. O.S. Owen, (1977), Protection of Natural Resources / Transl. from English. - Moscow: Kolos, 416 p.
[4]. Y.T. Feldman, (1975), Hygienic Evaluation of Motor Vehicles as a Source of Air Pollution. , M., 187 p.
[5]. Laser Monitoring of Air Pollution: $SO_2$, $NO_2$, Ozone, Benzene, Toluene and Aerosols. (2000) ELIGHT, Laser systems, GmbH, Berlin.
[6]. A.A. Popov, S.V. Kachin, (1994), Computerized Analytical Systems for Environmental Monitoring.- Devices and control systems. № 9, p. 15-17.
[7]. R.S. Asatryan, R.A. Epremian, H.G. Gevorkyan and others, (2003), Universal Infrared Spectral Radiometer. - Intern. Journal of IR and MM Waves. V.24, № 6–p. 1035-1046.
[8]. R.S. Asatryan, Yu,A. Abrahamyan, H.G. Gevorkyan and others, (2004) ,IR Spectral Method of Monitoring the Industrial Gas Ejections in Atmospere. - Dubai Intern. Confer. on Atmospheric Pollution: 21-24 febr. 2004 - Dubai, UAE.-Proceed. p. 134-139.
[9]. Dual Channel Radiometer- Patent, 1998, Internationally U. S. Pat. 3476914.
[10]. Ring Price filter for Tunable Optical Spectral Range from 1.8 to 5.6 Microns, (1984), OST-5683- 84.
[11]. Ruben S. Asatryan, Hamlet S. Karayan, Norayr R. Khachatryan. Air Infrared Radiometer, (2016), Journal of Scientific and Engineering Research, 3(2), 187-192.
[12]. [12] R.S. Asatryan, Development and Manufacturing of Infrared Spectroradiometer "Wedge". (1987) – Report R & D (final) p/ya- A-1376: № 4115-DSP, Erevan. 143 p.
[13]. R.S. Asatryan, N.R. Khachatryan, H.S.Karayan, (2015), On the Infrared Method of Monitoring Environmental $Co_2$ and $H_2o$ Vapors, Inter. Jour. Of Research Studies in Science, Engineering and Technology, Vol.2, Iss. 10, pp 38-41.
[14]. Elder, T. & Strong, J. (1989), Journal Franklin Institute, 255, 189.
[15]. V. Zuev, (1966), Atmosphere Transparency .for Visible and Infrared Beams, Sov. Radio Publ. Moscow (In Russian).
[16]. N. Moskalenko, & S. Mirumyants, (1970), Izvestia AN SSSR, .ser. Physics of Atmosphere and Ocean, 6, 1110.
[17]. A.V. Pavlov, (1974), Oplical/Electronic Instruments Energy PubL, Moscow (In Russian).
[18]. N. Moskalenko, (1969), Izvestia AN SSSR, ser. Physics of Atmosphere and Ocean, 5, (In Russian) , 962.
[19]. R.S. Asatryan, N.R. Khachatryan, H.S. Karayan, (2015), DISTANT INFRARED SPECTRAL ANALYSIS OF INDUSTRIAL HOT GAS EJECTION IN ATMOSPHERE, INTERNATIONAL JOURNAL OF RESEARCH –GRANTHAALAYAH, ., Vol.3(Iss.7):July.
[20]. A. Kadishevich, (1954), Simplest methods of Flame Emission Capacity Measurement. Moscow, Oborongiz. (In Russian) .
[21]. R.S. Asatryan, N.R. Khachatryan, H.S. Karayan, (2015), “On the Method of Distant Infrared Monitoring of Forest Spaces and Gas Main Pipelines, American Research Journal of Agriculture, Vol.1 Issue 2, April :Page, 1-6.
[22]. Shilin, B.V. and Molodchinin, I.A.,(1992) Kontrol’ sostoyaniya okruzhayushchei sredy teplovoi aeros” emkoi (Monitoring of Environment by IR Aerial Survey), Moscow: Nedra, Pages 186, (in Russian).
[23]. L. Macgloulin ,P. Maccvistan , (1964) Bases of Infrared Technique, M. Voenizdat, USSR DD, 464pages, (in Russian).
[24]. A.V. Pavlov, (1974) ,Optoelectronic Devices, M. Energia, 360pages (in Russian).