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OVERVIEW OF MATERIALS AND COATINGS EMISSION COEFFICIENT CONTROL METHODS

Abstract. *The emissivity of a coating and materials determines the intensity of radiation heat exchange on the surface of the object under study. Therefore experimental determination is important to ensure the necessary thermal protection characteristics of structures. The article considers methods of emissivity control, which are currently regulated by the main standards ASTM E408-13, ISO 9050:2003, C835–06, C1371–15. The methods of experimental determination of the emissivity can be divided into two large groups: optical and thermal. Spectrometric is the most widespread optical method. The technique of spectrometric research in determining the curve of specular reflection, measured in a wide range of wavelengths at an angle of incidence of the radiation close to normal. Based on the obtained results, the average value of the normal and hemispherical emissivity of the surface is calculated. Among the thermal methods of experimental determination of the emissivity the following have become widespread: radiation, calorimetric, regular mode method, and the method of continuous heating at a constant rate. The stationary systems with a wide range of research temperatures and portable express devices for control at temperatures close to room temperature are used to measure the emissivity. In stationary systems for measuring the emissivity, which apply thermal methods, heat fluxes between the object under investigation and some emitter, as well as the temperature of the structure elements, are usually determined. But these methods cannot be used in the control of products. Therefore, it is promising to develop a method for measuring the emissivity which will non-destructive and in same do not require additional standard samples for comparations.*

Keywords: express control; emissivity; emissometers; spectrophotometers; reflectometers.

1. Introduction

The issue of measuring the emissivity is relevant for many spheres of the national economy. It is known that about 40% of all extracted organic fuel is spent on heating residential and industrial buildings [1]. At the same time, more than 60% of thermal energy losses occur through the enclosing structures, which are determined by the conditions of heat exchange with the surrounding environment. The emissivity of a coating or material largely determines the intensity of radiation heat exchange on the surface of the object under study, therefore its experimental determination is important to ensure the necessary thermal protection characteristics of structures. The problem of creating advanced heat-saving technologies and materials with a given emission coefficient and means of measuring this parameter is relevant all over the world.

When creating modern energy-efficient windows and double-glazed windows low-emission glass is used. Which ensures a decrease in the radiation component of heat exchange and accordingly an increase in heat transfer resistance compared to ordinary translucent structures. For space vehicles on the contrary the shell should contribute to the dispersion in space of the heat released in the on-board equipment, but have a low coefficient of absorption of solar radiation. When implementing technology for the production of energy-efficient glass and shells for space vehicles, as well as for determining the characteristics of products surfaces it is relevant to carry out express control of the emissivity [2–6].

Known modern methods of determining the emissivity use either complex and expensive spectrometric equipment, or calorimetric methods which in order to reduce the convective component of heat exchange involve vacuuming the chamber with the samples under study. For the most part devices for express control have a relatively narrow spectral range and a limited directional pattern.

Therefore, the purpose of the work is to determine, on the basis of the conducted analysis ways of developing the method of measuring the emission coefficient which would allow conducting research of structures and materials in a non-destructive way without the use of additional control samples.

2. Methods and devices for controlling the emissivity of materials and coatings

2.1. Classification of the methods

The radiation of gray bodies corresponds to the Stefan-Boltzmann law [7, 8], which establishes the dependence of the density of integral hemispherical radiation on temperature:

$$q = \varepsilon\,\sigma\,T^4 (\mathrm{W/m^2}), \qquad (1)$$

where: q – density of integrated hemispherical radiation; $s = 5.67 \times 10^{-8}$ ($\mathrm{W/m^2 \cdot K^4}$) Stefan-Boltzmann constant; ε – emissivity.

For real bodies, the emissivity is a complex function that depends on the nature of the emitting body, its temperature, the state of the surface, and for metals – on the degree of oxidation of this surface. For pure metals with a polished surface, the emissivity has low values. At temperatures up to 100 °C, the value of the emission coefficient of the polished metal surface does not exceed 0.1. With the appearance of oxide films on the surface of the metal, the emissivity increases sharply and can take values greater than 0.5.

Several methods of experimental determination of the emissivity are known. They can be divided into two large groups: optical and thermal.

Among the optical methods, the most widespread is the spectrometric. The technique of spectrometric research in determining the spectral curve of specular reflection, measured in a wide range of wavelengths at an angle of incidence of the radiation beam close to normal. Based on the obtained results, the average value of the normal and hemispherical emissivity of the surface is calculated. To implement the spectrometric method of measurements, rather complex and expensive equipment is required, and the result is obtained by calculations using empirical correction factors. Thus, this method of measurement is indirect.

Among the thermal methods of experimental determination of the emissivity, the following have become widespread: radiation, calorimetric, regular mode method, and the method of continuous heating at a constant rate. In all methods, heat transfer due to convection and thermal conductivity of the air should be very small compared to radiation.

The radiation method is a relative method [7]. It is based on a comparison of the radiation of the investigated body with the radiation of a completely black or other reference body with a known radiation coefficient. For example, a receiving device is used, in which a differential thermocouple is placed. One of the junctions of the thermocouple receives radiation from the test body, and the other - from the surface of the reference body. Based on the measurement result of the thermocouple U-signal, the emissivity is determined.

The calorimetric method is based on the direct measurement of the radiation flow from the body under study [7]. This method is absolute. The emissivity is determined based on the Stefan-Boltzmann law.

The method of the regular thermal regime is based on the laws of the regular thermal regime for a body whose heat exchange is only radiative [7]. For such a case, the emissivity is proportional to the cooling rate, which is determined by the usual method for the regular regime.

In the method of heating at a constant rate [7], a sample of the studied material of a simple geometric shape (for example, a cylinder) is placed inside a massive cylindrical block, which serves to create a uniform temperature field around the sample. Heat exchange between the sample and the block is carried out only due to thermal radiation. The massive block is heated so that the heating rate of the sample is constant. The emission coefficient is found from the heat balance equation for the sample, based on the value of the sample's heating rate, its heat capacity, and the emissivity of the massive block.

2.2 Standards in the field of determining the emissivity

The ASTM E408-13 standard [9] defines methods for measuring the total normal emissivity of surfaces using control and measuring devices.

The standard gives the definition: Total normal radiation (ε_N) is defined as the ratio of the normal radiation of the sample to the radiation of the black body at the same temperature. The equation relating ε_N to wavelength and spectrally dependent normal radiation [$\varepsilon_N(\lambda)$] is:

$$\varepsilon_N = \int_0^\infty L_b(\lambda,T)\,\varepsilon_N(\lambda)\,d\lambda \Big/ \int_0^\infty L_b(\lambda,T)\,d\lambda, \qquad (2)$$

where: $L_b(\lambda,T) = c_1 \cdot \lambda^{-5} (e^{c_2/\lambda T} - 1)^{-1}$ – Planck's blackbody radiation function; $c_1 = 3.7415 \times 10^{-16}$ W · m²; $c_2 = 1.4388 \times 10^{-2}$ m · K; T – absolute temperature; λ – wavelength; $\int_0^\infty L_b(\lambda,T)\,d\lambda = \sigma T^4$.

The E408-13 standard considers in general terms three different methods of making these measurements. The first method measures the radiant energy reflected from the sample (test method A), the second method measures the radiant energy emitted from the surface of the sample (test method B), and the third method measures the near-normal spectral reflectance (that is, the energy of radiation reflected from the sample as a function of wavelength) and converts this to a total near-normal emission factor (test method C).

Test method A is best described as a reflection method. When the surface is irradiated, the flux is either reflected, transmitted, or absorbed. The expression $\rho + \tau + \alpha = 1$ is valid, where ρ is the reflectivity, τ is the transmission coefficient, and α is the absorption. For opaque surfaces, the transmission coefficient is zero ($\tau = 0$), and the expression reduces to $\rho + \alpha = 1$. Kirchhoff's law states that for the same angles and spectral ranges, $\alpha = \varepsilon$. This allows you to determine from the value of the normal reflectivity the value of the normal emission coefficient for a given temperature, or $\varepsilon_N = 1 - \rho_N$. At the same time, the spectral range should be the blackbody range at this temperature.

The use of test method A imposes two important requirements on the instruments. The first – the optical system must measure the reflection coefficient in the full hemisphere. The second is that the spectral characteristic of the device should match well with the blackbody radiation at this temperature, which is usually 300 K, but in principle other temperatures are possible. The standard provides general requirements for instrumentation of measurements, and one example of such measurements is discussed in detail in [10].

Method B [9, 11] assumes that the surface under investigation is placed opposite the hole on the portable sensitive element. Radiant energy emitted and reflected from the sample passes through the appropriate transmission vacuum window and illuminates the thermal battery. The output signal of the thermal battery is amplified and fed to the appropriate measuring device. The indicators of the device are relative and it must be calibrated using standard samples with a known emission factor.

Method C is based on Fourier transform spectroscopy (FTIR).

Fourier-transform spectroscopy – a set of methods of measuring spectra of various nature, in which the spectrum is calculated not by signal intensity, as, for example, in prism spectroscopes, but by response in the time) or spatial domain (for optical spectroscopy).

Measurements according to method C can be carried out using emissometers/reflectometers based on FTIR, which determine the reflection spectrum with high resolution ($\rho_N(\lambda)$) or ($\varepsilon_N(\lambda)$), in a short period of time. For opaque samples, the total near-normal emissivity can be expressed as:

$$\varepsilon_N = 1 - \frac{\int_0^\infty L_b(\lambda,T)\rho_N(\lambda)d\lambda}{\int_0^\infty L_b(\lambda,T)d\lambda} = 1 - \rho_N. \quad (3)$$

There are many FTIR tools for determining $\rho_N(\lambda)$ and $\varepsilon_N(\lambda)$ for a large number of wavelength values of λ. Accordingly, there are various methods for approximating the above integrals. The most important feature of any instrument is the ability to collect reflectance or radiance in the entire hemisphere above the sample. Some means and methods of their application are considered in [12–14].

The standard considers the procedure for implementing each of the methods, the limitations that exist during measurements, and the main information that must be indicated in the report.

ISO 9050:2003 [15] standard is used for testing window and low-emission glass. The measurement method corresponds to method A of the standard considered above [9].

The essence of the method is to determine the specular reflection curve measured in the wavelength range of 5 μm – 50 μm at an angle of incidence of the radiation beam close to normal, and to calculate the normal emissivity of the surface ε_n.

Tests are carried out on glass samples of the accepted batch that do not have defects in appearance. Glass samples for testing are made in accordance with the requirements of the operating instructions for the measuring equipment.

For measurements, a spectrophotometer with a wavelength range of 5 μ – 50 μm and with an attachment for measuring specular reflection at an angle of incidence of light ≤ 20°, with an error of no more than 1% is used.

The test is carried out in accordance with the instructions for use of the spectrophotometer, measuring at room temperature (20 ± 5)°C the light reflection coefficient R_i from the side of the sample with a low-emission soft coating.

The normal reflection R_n is determined by calculating the mathematical average of 30 values of the reflection coefficient R_i according to the formula:

$$R_n = \frac{\sum_{i=1}^{30} R_i(\lambda_i)}{30}, \quad (4)$$

where R_i – coefficient of light reflection; λ_i – wavelength.

If the used spectrophotometer has a wavelength range of up to 25 μm, then the value obtained at a wavelength of 25 μm is equated to the values of the spectral reflectance coefficient at a wavelength of more than 25 μm. At the same time, the approximation must be specified in the test report.

The normal emissivity ε_n is determined by the formula:

$$\varepsilon_n = 1 - R_n, \quad (5)$$

where R_n is the normal reflection.

The emission coefficient ε is determined by multiplying the normal emissivity ε_n by the coefficient A specified in Table 1.

Table 1. Indicators for determining the emissivity

Normal emissivity ε_n	Coefficient A
0.01	1.30
0.02	1.26
0.03	1.22
0.05	1.18
0.1	1.14
0.2	1.10
0.3	1.06
0.4	1.03
0.5	1.00
0.6	0.98
0.7	0.96
0.8	0.95
0.89	0.94

Intermediate values of coefficient A are obtained by linear interpolation.

It is allowed to use other measuring devices that ensure the determination of the emission coefficient within the limits of the values, with a measurement error of no more than 2%, certified and verified in the prescribed manner.

As follows from the given spectrometric method of measurements, its implementation requires rather complex and expensive equipment, and the result is obtained by calculations using empirical correction factors. Thus, this method of measurement is indirect.

Standard C835-06 [16] defines a test method for determining the full hemispherical emissivity of surfaces up to 1400 °C. The specified calorimetric test method covers the determination of the total hemispherical emission of metal and graphite surfaces and coated metal surfaces up to approximately 1400 °C. The upper temperature of use is limited only by the characteristics of the sample and the design limits of the test equipment. The measurements described in this test method are performed in a vacuum environment.

In general, the device should consist of the following equipment: bell jar, power supply and multimeter for voltage and current measurement, thermocouples and voltmeter or other indicators, vacuum system and sample holders. The test scheme is shown in Fig. 1. Means for electrically heating the sample shall be provided and instruments necessary to measure the input electrical power applied to the sample and the temperatures of the sample and the surrounding surface. The bell jar should have a black coating to absorb sample radiation, and the area of its inner surface should be significantly larger than the surface area of the sample.

During the tests, the bell jar is vacuumed, an electric current is passed through the sample, heating it to a given temperature. After establishing a stationary thermal regime, determine the power dissipated from the surface of the sample and the temperature of the sample and the bell jar.

Based on the assumption that the test sample is a small emitting body that is surrounded by a large absorbing surface, the total hemispherical

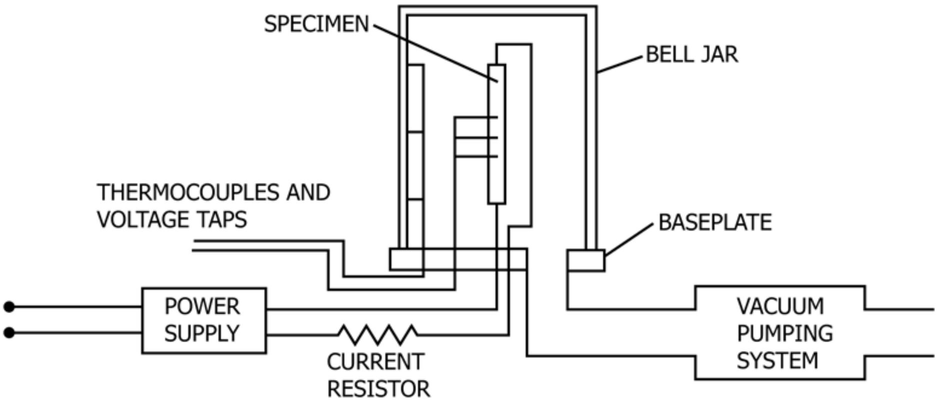


Fig. 1. Test scheme for C835 [16]

emission coefficient of the sample can be calculated as follows:

$$\varepsilon = \frac{Q}{\sigma A_1 \left(T_1^4 - T_2^4\right)}, \tag{6}$$

where Q – the heat generated in the sample; A_1 – surface area of the sample; T_1 and T_2 – temperature of the surfaces of the sample and the bell jar.

The standard also specifies the requirements for the equipment, the sample, the test conditions, and the content of the report, the factors that can affect the accuracy of the measurements, and the uncertainty assessment method are specified.

The standard contains references to the original studies on which this document is based and reference literature on heat transfer [17–25].

Standard C1371-15 [26] contains a test method for determining the emissivity of materials using portable emissometers at near room temperature. The test method covers the method of determining the radiation of opaque and highly thermally conductive materials using a portable differential thermoelectric emissometer.

The test method given in C1371-15 [26] uses a differential thermocouple emissometer to measure total hemispherical emission. The thermal batteries of the detector are heated to ensure the necessary temperature difference between the detector and the examined surface. The differential thermal battery consists of one thermal battery covered with a black coating and a second battery covered with a reflective coating. The device is calibrated using two standard samples, one with a high emissivity and the other with a low emissivity, placed on the flat surface of the radiator (heat sink), as shown in Fig. 2.

The diameter of the measuring head of the emissometer is about 50 mm, and the detector elements are buried about 3 mm into the measuring head.

A sample of the material under examination is placed on a radiator, and its emissivity is determined quantitatively by comparison with standard samples. Calibrations should be performed repeatedly during the test.

The manufacturer of the emissometer must supply two sets of standards, each set consisting of a polished stainless steel (emissivity of about 0.06) and a black standard (emissivity of about 0.9). The characteristics of the reference samples shall be traceable to measurements made using an absolute test method (eg test method C835). It is recommended that one set be used as working standards and the other set be used for periodic checks of the emission factor of the working standards.

The sample of the surface to be tested shall be carefully selected in such a way as to preserve the condition of the surface in situ. A sample slightly larger than the external dimensions of the measuring head of the emissometer is carefully cut out of the sample. The thermal resistance of the sample should not exceed 0.00091 m^2 · K/W.

During measurements, the device is turned on and the head is heated to a temperature 40–60 K high-

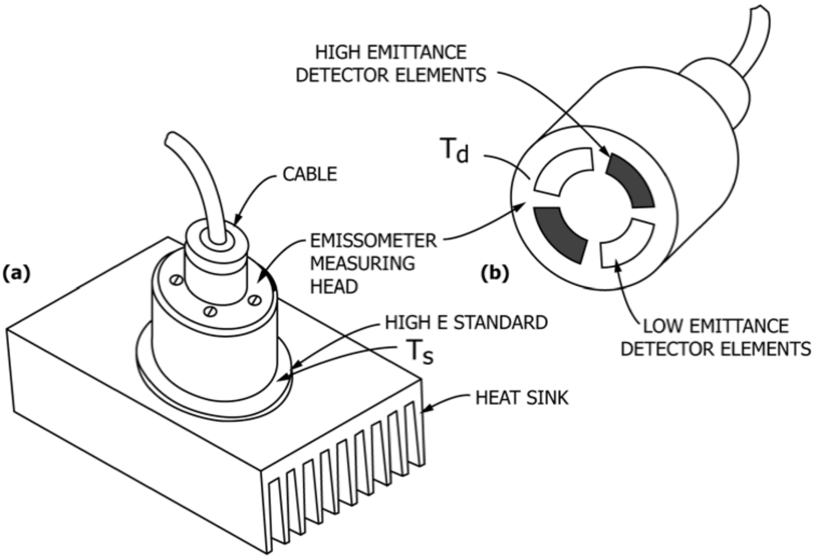


Fig. 2. Schematic representation of the thermal part of the emissometer [26] (a) – the measuring head of the emissometer on the standard with a high emissivity during calibration, the radiator and the cable of the reading device are also shown; (b) is a bottom view of the measuring head of the emissometer, showing the elements of the coated thermocouples having high and low emissivity

er than the ambient temperature. The head is placed over the «black» sample mounted on the heatsink, and after 90 seconds the output signal voltage V_{hi} is measured. The head is then placed over the «light» sample mounted on the heatsink, and after 90 seconds the output voltage V_{low} is measured. The relationship between the measured values is valid:

$$V_{low} = \varepsilon_{low} \times \varepsilon_{hi} / V_{hi}. \quad (7)$$

The head is placed over the tested sample and after the signal stabilizes, the V_{spec} value is measured. The emissivity of the tested sample is determined by formula (8):

$$\varepsilon_{spec} = V_{spec} \times \varepsilon_{hi} / V_{hi}. \quad (8)$$

The standard specifies the requirements for the equipment, the sample, the test conditions and the content of the report, as well as the factors that can affect the accuracy of the measurements. It is indicated that the measurement error is usually ±0.02.

In the appendix to the standard, the question of the influence of factors affecting the accuracy of determining the hemispherical measurement coefficient is considered. It was noted that the angle of exposure of thermal batteries is about 168–169° (approximately ±84° from the normal), that is, less than a full hemisphere. On the other hand, different materials have significantly different radiation patterns.

2.2 Portable control devices

Portable devices are used, as a rule, to control characteristics at the temperature of the surrounding environment, that is, close to room temperature.

In Fig. 3–5 presents the appearance of some portable devices, as well as their main technical characteristics and advantages are given (according to the manufacturers).

Devices & Services Co. model AE1 emissometer is a specialized device for determining the emission coefficient [27]. The device complies with the C1371-15 standard discussed above.

The main characteristics and advantages of the AE1 model emissometer:

- reproducibility (+/– 0.01 emissivity unit);
- it is easy to measure: (detector part of the device is heated electrically so that the sample does not need to be heated. No need to measure the temperature);
- fast measurements (after an initial warm-up period of approximately 30 minutes, emissivity readings can be taken every half minute);
- low cost (devices for comparative measurements cost much more);
- additional adapters (these make measurements in small areas available and special adapters for samples with irregular surface geometries).

Portable electronic emissometer/reflectometer TESA 2000 from AZ Technology (USA) [28] is compact, light, durable and ergonomic, designed to facilitate use in the field or in the laboratory to determine the integral emission coefficient at ambient temperatures. The device can be used in autonomous mode using battery power. The main technical characteristics of the device are listed in Table 2.

The principle of operation of the device is based on the measurement of the radiation falling on the test sample and reflected by the surface of the test sample. The radiation reflected from the test sample is collected by a mirror ellipsoid and directed to the radiation receiver. At the same time, the surface under investigation is irradiated by a source of thermal radiation with an emissivity close to the emissivity of a black body at a temperature of 340 K. The angle of incidence of radiation on the sample under investigation is 12° to its normal.

Fig. 3. Emissometer model AE1 of the firm Devices & Services Co. (D&S) [27]

Fig. 4. Portable electronic emissometer/reflectometer TESA 2000

Table 2. Main technical characteristics of the TESA 2000.

Wavelength	from <3µm to >35µm
Accuracy of measurements (for specular and diffuse samples)	± 1% of full scale for gray samples ± 3% of the full scale for non-gray samples
Reproducibility	± 0.5% of full scale or better
Sample temperature	environment temperature
Measured quantity	- infrared reflection - normal emissivity (300 K) - hemispherical emissivity (300 K)
Measuring range (reflection)	0.00 to 1.00

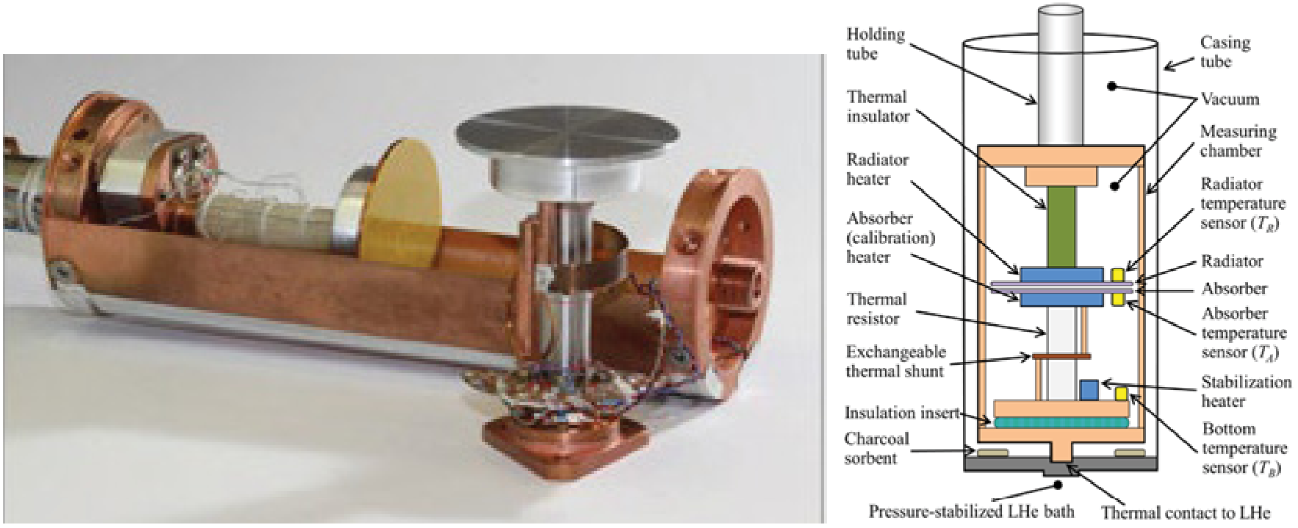
Fig. 5. Manual emissometer/reflectometer ET-100 [29]

Manual emissometer/reflectometer ET-100 of Surface Optics Corporation (USA) [29] measures the directional reflectivity in six bands in the thermal infrared spectrum at two sectors of incidence angles – 20° and 60°. Based on these values, the directional and integral hemispherical emissivity is calculated.

The features of the device are the implementation of reflection measurement in the infrared spectral range and the calculation of the directional emissivity. The measurement is carried out in two sectors of incidence angles: a sector of 20° near the normal to the surface and a sector close to 60°, the measurement time is approximately 10 seconds.

2.3 Stationary control systems

Stationary laboratory systems, as a rule, provide measurements in a wide temperature range while evacuating the working chamber to reduce the conductive-convective component of heat exchange. An example of such an installation, intended for measuring thermoradiation characteristics, is given in [30]. A photo of the working chamber of the installation is shown in Fig. 6.



a) b)

Fig. 6. Measuring chamber of the emissometer [30]: a) open chamber with the absorber part removed; b) diagram of the installation used to measure the emissivity

A cryogenic method for measuring integral hemispherical emission and absorption coefficients of various materials at temperatures from 320 K to 20 K is presented. When measuring the absorption, the temperature of the test sample is approximately 5 K–35 K. Using a thermal resistance (thermometer), the radiation heat flow between two flat parallel surfaces in the form of discs with a diameter of 40 mm, which are placed in a vacuum, is determined. The test sample and a reference disc with a surface having known characteristics are immersed in a bath cooled by liquid helium (LHe). The heat flow is measured by the substitution method, using the thermal power from an electric heater to calibrate the sensor.

Much attention is paid to the assessment of the uncertainty of measurements that occurs when using this method. The capabilities of the device are demonstrated by measuring the absorption and emission coefficients of a sample of pure aluminum. Fig. 7 shows reference samples and their characteristics.

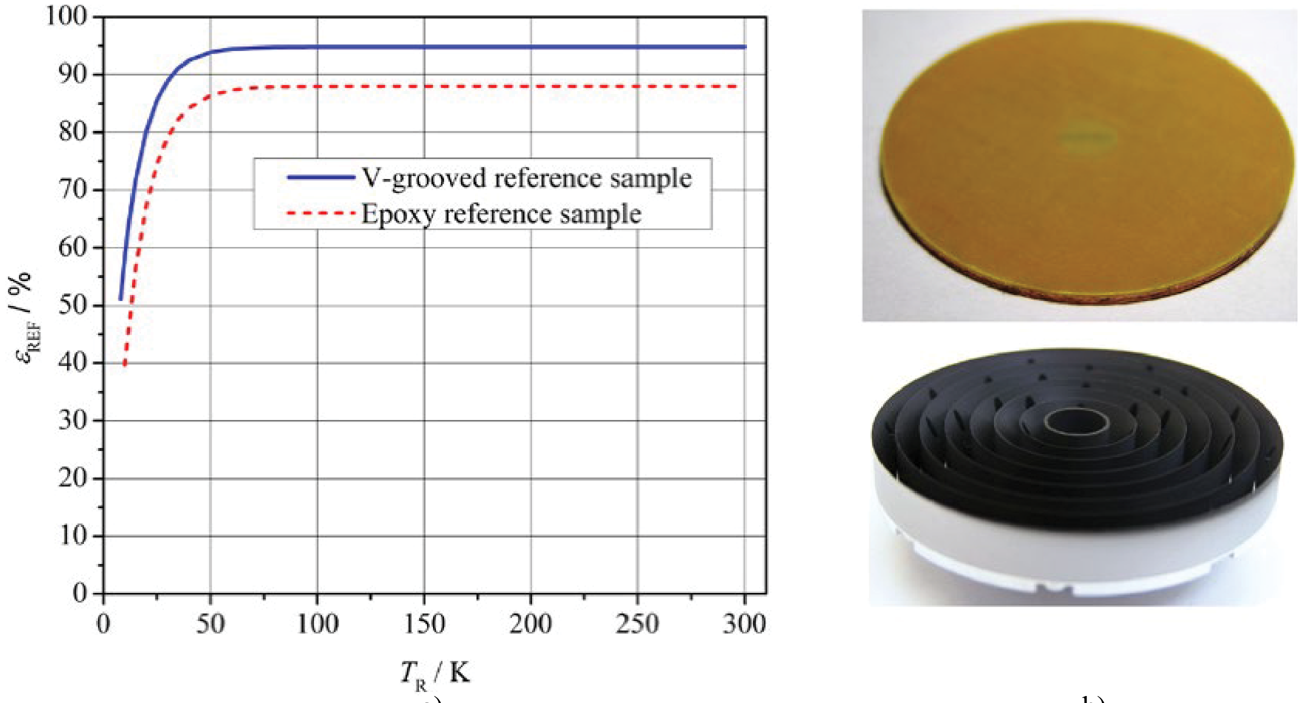
The expanded uncertainty (k = 2) of the emissivity measurement $\varepsilon = 0.0041$ measured at ≈30 K for pure aluminum is less than 11%, and for values of the emissivity $\varepsilon > 0.0053$ measured at temperatures above 60 K, the uncertainty is lower 7%. The method was developed primarily for the study of materials with a low value of the emissivity coefficient, such as pure metals, but the high emissivity of the reference sample also allows the study of non-metallic materials with reasonable accuracy.

The Sun LabTek company (India) proposed a computerized device for measuring the emissivity [31]. The appearance of the device is shown in Fig. 8. The experimental unit is based on a metal sample heated by a concentrated light beam. The light beam is generated by a continuously adjustable halogen lamp and a parabolic reflector. The reflector concentrates the radiation to a focal point. The sample is placed on a thermocouple located at the focal point. The thermal radiation emitted by the sample is measured by a thermocouple. In order to be able to measure radiation at different distances, the thermal battery is installed on a movable carriage.

Microprocessor devices are located in a protected housing. The device is equipped with software to operate the system and to collect data and training software. With explanatory texts and illustrations, the educational software greatly helps to understand the theoretical principles.

3. Conclusions

Determination of the emissivity is relevant for all cases of research, calculation and modeling of radiative heat exchange, in particular when determining the properties of energy-efficient glass and



a) b)

Fig. 7. Reference samples. Temperature dependence of their emission coefficient (a) and photograph (b) of the epoxy sample (upper picture) and the corrugated sample with V-shaped grooves [30]

Fig. 8. Computerized device for measuring the emissivity «LabTek», India [31]

windows, covering elements of space technology, when conducting pyrometric and thermal imaging measurements. Both stationary installations with a wide range of research temperatures and portable express devices for control at temperatures close to room temperature are used to measure the emission coefficient.

In stationary systems for measuring the emissivity, which apply thermal methods, heat fluxes between the object under investigation and some emitter, as well as the temperature of the structure elements, are usually determined. But these methods cannot be used in the control of finished products.

Portable devices are used for control, but a significant disadvantage is the limited temperature range in which the measurement is performed and the need to have two standard samples, one with a high and the other with a low radiation coefficient. A sample of the material under study is placed on a surface, and its radiation is quantified by comparing it with the radiation of standards. For reflectometers the main disadvantage is the indirect measurements which required the calculations of the emissivity from the reflection coefficient.

Therefore, it is promising to develop a method for measuring the emissivity which will non-destructive and in same do not require additional standard samples for comparations.

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ОГЛЯД МЕТОДІВ КОНТРОЛЮ КОЕФІЦІЄНТА ЕМІСІЇ МАТЕРІАЛІВ ТА ПОКРИТТІВ

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Анотація. *Коефіцієнт емісії покриття чи матеріалу значною мірою визначає інтенсивність радіаційного теплообміну на поверхні досліджуваного об’єкта,* *тому його експериментальне визначення важливе для забезпечення необхідних теплозахисних характеристик конструкцій. У статті розглядаються методи контролю коефіцієнту емісії, які регламентуються основними стандартами ASTM E408-13, ISO 9050:2003, C835-06, C1371-15. Методи експериментального визначення коефіцієнту емісії можна розділити на дві великі групи: оптичні та теплові. Найбільш відомим та розповсюдженим оптичним методом є спектрометричний. Методика спектрометричного дослідження полягає у визначенні спектральної кривої дзеркального відбиття, виміряної у широкому діапазоні довжин хвиль при куті падіння випромінення, близькому до нормального. За отриманими результатами обчислюють середнє значення нормальної та напівсферичної випромінювальної здатності поверхні. Серед теплових методів експериментального визначення коефіцієнта емісії розповсюдження набули: радіаційний, калориметричний, метод регулярного режиму, метод неперервного нагріву зі сталою швидкістю. Для вимірювань коефіцієнту емісії застосовують як стаціонарні установки з широким діапазоном температури досліджень, так і переносні експрес-прилади для проведення контролю за температури, близької до кімнатної. У стаціонарних системах для вимірювання коефіцієнту емісії, які застосовують теплові методи, зазвичай визначають теплові потоки між досліджуваним об'єктом та деяким випромінювачем, а також температури елементів структури. Але ці методи не можуть бути використані при контролі готових виробів. Тому перспективним є розробка методу вимірювання коефіцієнта випромінювання, який буде неруйнівним і при цьому не потребуватиме додаткових стандартних зразків для порівнянь.*

Ключові слова: експрес-контроль, коефіцієнт емісії, емісометри, спектрофотометри, рефлектометри.

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