INVESTIGATION OF THE EMISSIVE CHARACTERISTICS OF TRANSLUCENT FABRICS AND FILMS

L. Ya. Paderin

UDC 536.3

The method, experimental setup, and results of investigation of the integral emissivity, transmissivity, and reflectivity of translucent fabrics and films have been presented.

Fabrics and flexible translucent (semitransparent) films are widely used in thermal-protection and thermal-regulation systems in various fields of technology, in particular, as multilayer and flexible heat insulation [1–4]. Information on the emissive characteristics of the optimum thermal-protection structures in which the above elements are used is necessary for adequate computational analysis, designing, and creation of such structures. The special properties of measurements of the emissive characteristics of translucent materials, including fabrics and films, are determined by the difficulties associated with separation of the intrinsic and foreign radiant fluxes through the specimen under study and with determination of the specimen’s temperature. The existing methods of measurement of the integral normal emissivity of translucent materials that are presented in the literature, in particular, in [5–9], are based on elimination of foreign radiant fluxes. Implementation of these methods requires that the experimental equipment be much more sophisticated than the analogs for investigation of opaque specimens. The specimen under study and the heater are in the chamber, whereas the radiation detector is outside the chamber. However the above methods and equipment ensure a low accuracy of measurement, which is still further reduced in investigations of fabrics and films because of the additional difficulties associated with determination of their temperature.

Below we present a method that is based on measurements and comparison of the effective emissivity of the specimens under study with two different opaque substrates of known differing emissive characteristics. Determination of the effective emissivity is carried out at the same temperatures by measuring the radiant fluxes of a rotating specimen with a substrate in the isothermal zone of heating with a controlled temperature. The method presented differs from the existing ones and enables one to determine both the normal and hemispherical emissivity, transmissivity, and reflectivity of the specimens under study in a wide temperature range. This is of particular importance for fabrics since their emissive characteristics are inconsistent with the Lambert law because of their specific physical structure, which makes it impossible to determine the hemispherical emissive characteristics on the basis of the known normal characteristics. Thus, the possibilities of investigating translucent materials, including fabrics and films, are extended.

The method of determination of the integral emissivity is based on the rotation of the specimen under study in the isothermal zone of heating with a controlled temperature and measurements of the specimen’s radiant flux by a radiation detector introduced into the heating zone.

Figure 1 gives a diagram of the experimental setup for determination of the integral hemispherical and normal emissivity, transmissivity, and reflectivity of translucent fabrics and films. The setup consists of vacuum chamber 1 on which a mechanism of rotation of a specimen is placed; the mechanism consists of an electric motor with a regulated rotational velocity and shaft 2 hermetically introduced into the chamber. The experimental specimen 3 of a round shape with a diameter \(d\) is fastened to an opaque substrate — a heat-insulated metallic disk 4 having the same diameter as the specimen. A coating with known emissivity and reflectivity is applied to the surface facing the specimen. The substrate is secured on a plane holder which is rigidly joined to the shaft. A layer of heat-insulating material ensuring heat insulation of the metallic substrate is placed between the holder and the substrate. The total thickness of the specimen, the substrate, and the heat-insulating material can attain 50 mm. The sample is heated with a plane radiation ohmic heater 5.

Between the heater and the specimen, there is a plane disk 6. The heater and the disk have coaxial holes at a distance \( r \) from the center of rotation of the specimen for the radiation detector 7; the radiation detector is placed inside a cooled copper tube 8, whereas its detecting surface is in the upper end plane of the tube. In such a manner, we ensure the possibility of measuring practically the hemispherical radiant flux and the emissive characteristics of the specimen. In the cases where it is necessary to measure the normal emissive characteristics of the specimen we move the detector to a corresponding depth inside the tube. Thermocouples 9 are installed on the circle with a radius \( r \) in the gap between the disk 6 and the specimen to determine the specimen’s temperature. To ensure isothermality in the zone of heating of the specimen a part of the heater, which is beyond the specimen, is also faced with heat insulation 10.

Before the measurements, we calibrate the radiation detector, the thermocouples, and the device for determination of the pressure in the chamber. Calibration of the radiation detector is carried out with the isothermal spherical model of a black body directly under operating conditions in the vacuum chamber (at a residual pressure of the gas in the chamber of less than 1 Pa). To calibrate the thermocouples by the comparison method we use a reference platinum-rhodium thermocouple. The device for measuring pressure is also calibrated by the comparison method with the use of reference devices. Furthermore, the emissive characteristics of the substrates 4 are checked, when the occasion requires, directly under operating conditions and in the corresponding temperature ranges before and after testing the specimens under study.

The temperature dependences of the integral hemispherical emissive characteristics of a specimen are determined in the course of two runs of tests with different metallic substrates in which the surfaces facing the specimen have differing values of emissivity and reflectivity. The test are carried out as follows. We produce a vacuum in the chamber and apply regulated electric power to the heater. Once the thermal regime of the heaters, the disk, and the rotating specimen has been stabilized, we measure the radiant flux and the specimen’s temperature and the pressure of the gas in the chamber. Within the framework of the two runs of experiments, the radiant fluxes are measured at the same temperatures. According to the results of the tests, we can write the following relations:

\[
E_1 = \varepsilon_s \sigma T_s^4 + \varepsilon_{d1} \sigma T_{d1}^4 \tau_s (1 + \rho_s \rho_{d1} + \rho_s^2 \rho_{d1}^2 + ... + \varepsilon_s \tau_s \rho_{d1}^2 \sigma T_s^4 (1 + \rho_s \rho_{d1} + \rho_s^2 \rho_{d1}^2 + ...)),
\]

\[
E_2 = \varepsilon_s \sigma T_s^4 + \varepsilon_{d2} \sigma T_{d2}^4 \tau_s (1 + \rho_s \rho_{d2} + \rho_s^2 \rho_{d2}^2 + ... + \varepsilon_s \tau_s \rho_{d2}^2 \sigma T_s^4 (1 + \rho_s \rho_{d2} + \rho_s^2 \rho_{d2}^2 + ...)).
\]

The expressions in the parentheses on the right-hand sides of (1) and (2) allow for the effects of rereflection between the specimen and the substrate and represent infinitely decreasing geometric progressions. In the case where the specimen is in close contact with the substrate (adhesion), allowance is made only for the first term of the progression. Owing to the heat insulation on the back side of the substrate and the lateral heat insulation, we can assume that \( T_s = T_d \). After the substitution of the sums of progressions and simple transformations, Eqs. (1) and (2) are reduced to the form

Fig. 1. Diagram of the experimental setup for measurements of the integral emissive characteristics of translucent specimens.

Before the measurements, we calibrate the radiation detector, the thermocouples, and the device for determination of the pressure in the chamber. Calibration of the radiation detector is carried out with the isothermal spherical model of a black body directly under operating conditions in the vacuum chamber (at a residual pressure of the gas in the chamber of less than 1 Pa). To calibrate the thermocouples by the comparison method we use a reference platinum-rhodium thermocouple. The device for measuring pressure is also calibrated by the comparison method with the use of reference devices. Furthermore, the emissive characteristics of the substrates 4 are checked, when the occasion requires, directly under operating conditions and in the corresponding temperature ranges before and after testing the specimens under study.