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STUDY OF THE OPTICAL PROPERTIES OF MATERIALS TREATED BY THERMAL RADIATION

A. S. Ginzburg, V. V. Krasnikov, and N. G. Selyukov

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The article presents the basic results of an experimental study of the spectral optical properties of certain materials and products in the 0.3-5 μ range. The results indicate that the scattering of light by the materials is quite considerable and that the optical properties in the unfrared region have considerable spectral selectivity.

The optical properties of greatest practical and theoretical importance for the treatment of materials by thermal radiation are the transmissivity, reflectivity, and absorptivity of the material.

In most experimental studies of the optical properties of materials the property measured was one of the total properties: total emissivity, total transmissivity, or total reflectivity. Several investigators [1-7] have shown that the transmissivity of many moisture-containing materials increases with increasing emitter temperature, i.e., with decreasing emitter wavelength λ_{max}*.

The variation of the total transmissivity of materials with emitter temperature indicates that most materials have selective optical properties. Therefore methods based on the direct determination of one of the total properties cannot satisfy the requirements of thermal-radiation technology.

The shortcomings of methods based on the determination of the total optical properties have been pointed out by Rabinovich [9]. Here we would like to add that in the case of direct measurement of total properties the intrinsic characteristics of the optical properties become obscured, and it is not clear which particular range of wavelengths is transmitted (reflected, absorbed) by the material.

Thus, if one finds that a given material transmits, say, 25% of the radiative energy emitted by an emitter with $\lambda_{max} = 4\ \mu$, this does not necessarily mean that the material transmits radiation with wavelength $\lambda = 4\ \mu$. This can be illustrated by the properties of glass. It has been found [1] that the total transmissivity of glass for a light beam emitted by an emitter with $\lambda_{max} = 3.76\ \mu$ is 25%. Yet it is well known that crown and flint glass of a thickness of 3 mm or more do not transmit any radiation with a wavelength of more than 3.5 μ [8].

Furthermore, during the determination of transmissivity as reported in [1-7], no account was taken of the possible scattering of light by the materials.

In the course of the measurement of the spectral transmissivity of paper, cloth, potatoes, bread, apples, pears, and other materials we found considerable scattering of light by these materials in the infrared range. Therefore the values of the transmissivity which are obtained by means of instruments which do not account for scattered light can be one order of magnitude smaller than the true values. Thus, the values of transmissivity of the above materials, obtained by means of the SF-4, IKS-12 instruments with layers of 1 mm thickness (in the case of paper and cloth – 1 layer) in the 0.3-5.0 μ range of the spectrum, did not exceed 2-3%. Measurements of transmissivity carried out with a special attachment to the monochromator gave, for the same materials, values up to 60% (Fig. 1). This indicates that the SF-4 and IKS-12 spectrophotometers cannot be used for the determination of the true transmissivities of light-scattering materials. Instruments which would measure the true transmissivity of a material, taking into account scattering, as well as instruments for the measurement of the total reflectivity (taking into account scattering) in the infrared range of the spectrum ($\lambda > 1.1\ \mu$), are not manufactured commercially at the present time [10, 11].

In order to measure the spectral transmissivity and reflectivity of materials, taking into account light scattering, there have been developed at the spectrophotometric laboratory of the Moscow Institute of Food Technology special attachments to the SF-4 and IKS-12 spectrophotometers. All measurements were carried out in the 0.3-5.0 μ range.

During measurements of the transmissivity of materials the monochromatic beam was aimed at the specimen, and the transmitted hemispherical radiation was collected by a receiver. In order to eliminate the natural emission of the specimen, caused by the radiative heating, a LiF filter was placed in front of the receiver. The transmissivity of the

*This is the basis of the widely held view that during the drying of moist materials of considerable thickness it is advisable to use "bright" emitters with a temperature of ~ 2500°K and wavelength $\lambda_{max} = 1.1-1.2\ \mu$.

filter was measured and was less than 4% for $\lambda > 8\ \mu$.

During measurements of the reflectivity of the materials the receiver collected the hemispherical monochromatic reflected radiation from the specimen.

The analysis of the results obtained for the materials mentioned above shows:

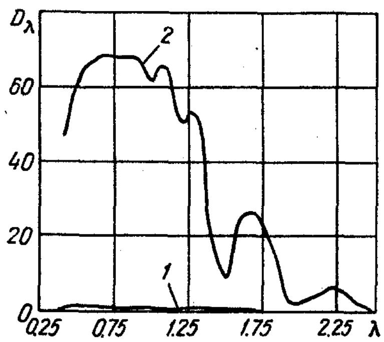

Fig. 1. The effect of the scattering of light on the observed values of the transmissivity D_λ of raw potatoes of 1 mm thickness with 71.8% moisture content at t = 20°C. 1) Values obtained by the usual method; 2) values obtained using an attachment to the SF-4 and IKS-12 instruments (taking into account scattering.

1. The materials have considerable scattering ability in the infrared range of the spectrum, both for transmission and for reflection. Therefore in order to determine the true transmissivity and reflectivity of these materials one must use instruments which take account of the scattering.

2. The optical properties of these materials are markedly selective (Fig. 1-4), which shows that these properties must be measured by spectrophotometric methods.

3. The reflectivity of the investigated materials increases with increasing thickness of the layer (Fig. 2). This effect can be explained by the scattering ability of the materials and indicates that one cannot use the usual method of calculating the absorptivity from two values of monochromatic transmissivity, which is based on Buguer's law (without taking into account scattering), as in these calculations one assumes that the reflectivity is the same in both cases.

4. The optical properties of these materials are strongly affected by the presence of water, as indicated by the minima of transmissivity and reflectivity at the wavelengths 0.75, 1, 1.2, 1.5 and 2.0 μ.

5. The transmissivity of these materials for a given range of wavelengths can be quite high. Thus, for all raw fruits and vegetables investigated by us the transmissivity in the 0.6-1.1 μ range of a 1 mm layer of normal moisture content was 60-70%. For a 10 mm layer it was 8-18%, and for a 30 mm layer it was of the order of 0.5% (Fig. 3). Similar values of transmissivity were obtained for dough and for bread [12]. The transmissivity of wet flannel (1 layer) in the same range is up to 50%.

One can assume that for many moisture-containing materials the highest spectral transmissivities occur in the 0.6-1.1 μ range of the spectrum.

However, this range of the spectrum corresponds to the maximum reflectivity which is approximately the same for all the materials which were mentioned above and reaches 70-80% for a 40 mm layer for which the transmissivity is

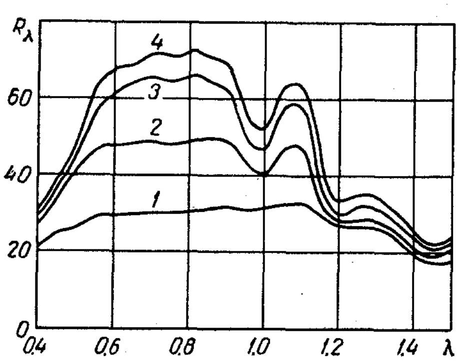

Fig. 2. Increase of reflectivity of raw potato (t = 20°C, moisture content 71.8%) with increasing thickness of the layer: 1) h = 1 mm; 2) 3; 3) 10; 4) 40.

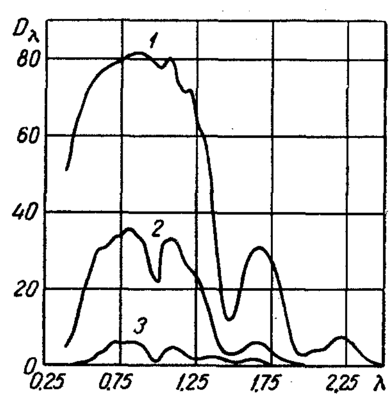

Fig. 3. Transmissivity of pear (t = = 20°C moisture content 86.3%): 1) h = 1 mm; 2) 3; 3) 10.

practically zero (Fig. 2, 4). This indicates that the transmission and reflection by these moisture-containing materials in this range of the spectrum are determined mainly by the scattering properties, as the absorption of energy for all layer thicknesses was quite low. Thus it is clear that the range of short wavelengths (up to 1.2 μ) is not suitable for thermal radiation treatment (drying, baking, etc.) of these materials.

This property of these materials indicates that in choosing the most suitable range of the spectrum for thermal-radiation treatment it is not always sufficient to take into account the total transmissivity only.

6. Besides the near infrared, transmission of radiation by moisture-containing vegetables, fruits, dough, and bread can be observed in the range up to 2.4 μ for 1 mm layers and in the range up to 1.75 μ for 3 mm layers. In this region transmission can be observed for layers of up to 10 mm thickness (Fig. 3).

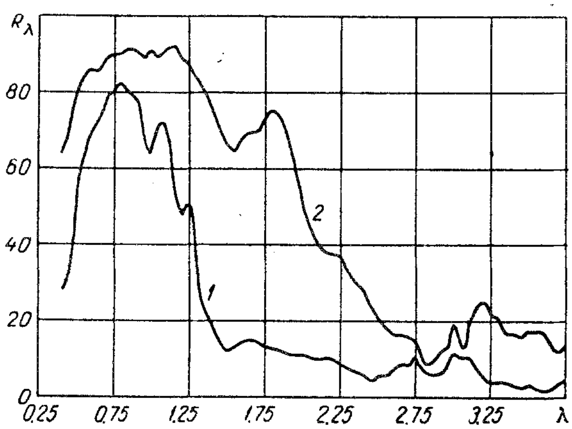

Fig. 4. Reflectivity of 1) pear pulp (h = 40 mm, moisture content 86.3%), and 2) of gelled pastila (a kind of candy made of fruit) (h = 20 mm, moisture content 30%).

In the region of 2.4-5 μ all materials investigated here are opaque to radiation for layers of 1 mm thickness.

The reflectivity of the materials investigated, in the moist state, in a layer of 40 mm thickness falls from about 40% at 1.2 μ wavelength to about 20% at λ = 1.4 μ, in the 1.4-1.8 μ range it has values of the order of 20%, and in the range 1.8-5 μ its values are of the order of 10% (Fig. 4).

These results indicate that the optimum range of wavelengths for the drying of vegetables and fruits and for the baking of bread is the range 1.2-2.4 μ, and the optimum temperature of a "gray" emitter is of the order of 1800°K (λ_{max} = 1.6 μ). In this case about 7% of the energy of the emitter will be in the range λ ≤ 1.2 μ, and about 50% will be in the range 1.2-2.4 μ.

In the case of "bright" emitters, with λ_{max} = 1.1-1.2 μ, the range 1.2-2.4 μ will again include about 50% of the energy, but about 25-27% of the energy of the emitter will be lost in the λ ≤ 1.2 μ range.

7. Our conclusions regarding the optimum range of wavelengths for the drying of fruit and vegetables and for the baking of bread cannot be extended to other moisture-containing materials, as the optical properties of moisture-containing materials are determined not only by their moisture content, but also by the properties of the material and by the nature of the bond between the water and the material.

Thus, the reflectivity of gelled pastila, containing 30% moisture, is 70-90% in the range 0.4-2.0 μ and 50-30% in the range 2.0-2.4 μ (Fig. 4). Therefore the region of short wavelengths below 2.4 μ cannot be used in drying of pastila. Consequently, in the drying of pastila λ_{max} of the emitter should be above 2.4 μ. This example shows that the optical properties are characteristic of each specific material, and must be studied in detail before one can choose the optimum range of the spectrum for the thermal-radiation treatment of the material.

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Institute of Food Technoloty,
Moscow