DETERMINATION OF THE IR REFRACTIVE INDEX
AND ABSORPTION COEFFICIENT OF SOLID FUELS

A. G. Blokh and L. D. Burak

Measured optical constants are presented for anthracite over the infrared range from 0.8 to 5.5 μm. The spectral absorption and scattering coefficients have been calculated by computer.

The emission from a flame formed by combustion of coal dust is determined by two basic emitters, the triatomic molecules H₂O and CO₂, together with the suspended solid particles of fuel, ash, and partly burned material.

To calculate the radiation energy transport in such a system, one needs to know first of all the radiation properties of the particles, together with the absorption coefficient kₐ, abs and the scattering coefficient kₐ, scat, together with the scattering indicatrix γₐ(β).

Available solutions [1-3] show that γₐ(β), kₐ, abs and kₐ, scat are functions of two basic dimensionless parameters: the complex refractive index m and the relative particle size ρ = πx/λ; the first m = n−iκ relates the electro-magnetic and optical properties of the particles; this m is itself dependent on the wavelength.

To calculate the emission from a coal-dust flame, one needs to determine n and κ for the solid particles of fuel, ash, and coke, together with the dispersion in the infrared region. Unfortunately, no such data have yet been published, and for this reason it has not been possible to produce a physically sound method of calculating the emission of such flames. An important step in solving this problem is to examine the optical constants of the condensed solid phase in the flame.

There is no great difficulty in determining n and κ for the absorbing materials; there are various methods, such as prisms, critical angle, interference, and immersion that enable one to determine the refractive index n [4]. In the case of strongly absorbing materials, such as particles of coal and coke, the methods of [4] are unsuitable, because the light interacts with material in very thin layers. One has to use thicknesses comparable with the wavelength of the incident radiation, and the physical properties of such films are very much dependent on methods of preparation, the material of the substrate, and other factors.

Also, n and κ for strongly absorbing materials are very difficult to measure; while n for a transparent or weakly absorbing medium can be measured to 0.1%, one has to accept errors of several per cent for strongly absorbing conditions. Under these conditions, the sole radiation characteristic accessible to measurement [5] is the reflection spectrum. In turn, reflection methods for measuring optical constants of absorbing materials are very varied and a detailed survey has been made in [5].

All solid fuels are strongly absorbing substances, so n and κ are determined by reflection. One measures the reflection at the boundary with an external medium with two different refractive indices n₁ and n₂ for that medium. As one of the media one uses air, while as the other one uses CCl₄. The measurements are made at nearly normal incidence.

In that case, the reflection coefficients R₁ and R₂ may be put in the form

\[ R_1 = \frac{(n - n_1)^2 + \kappa^2}{(n + n_1)^2 + \kappa^2}, \]


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Fig. 1. a) Optical system; b) liquid cell for specimen and standard.

\[ R = \frac{(n - n_\infty)^2 + \kappa^2}{(n + n_\infty)^2 + \kappa^2} \quad (2) \]

From (1) and (2) we determine the refractive index as

\[ n = \frac{1}{2} \frac{(1 - R_1)(1 - R_2)(1 - n_\infty)(1 + n_\infty)}{(1 - n_\infty)(1 - R_1R_2) - (1 + n_\infty)(R_2 - R_1)} \quad (3) \]

and the absorption parameter as

\[ \kappa = \sqrt{\frac{R_1(n + 1)^2 - (n - 1)^2}{1 - R_1}} \quad (4) \]

This method was first used by Orsel [6]; Kravets [7] used it to determine the optical constants of some absorbing materials by depositing them as films on various types of glass. Further improvements in the method have also been reported [8-11]. The optical constants of germanium have been published [11]. The measurements were made by immersing the specimens in a liquid with a known refractive index. The same method has been used [12, 13] for the optical constants of Co, Ni, Cu, Ag, and Al together with certain ore minerals. In all these studies, the values of \( n \) and \( \kappa \) were obtained only for the range from 0.3 to 0.8 \( \mu \text{m} \).

In the present study, the above method was applied to determine the optical constants of coals in the infrared region. The reflection spectra were measured with an LOMO attachment to an IKS-14A spectrophotometer. Figure 1a shows the equipment used, which consisted of the illuminator 1, the IKS-14A infrared spectrometer, and the two attachments 2 and 3, which were placed respectively in the working channel and in the reference channel. The light source was imaged by the plane and spherical mirrors 4 and 5 near the specimen 6 and standard 6' with a magnification of 0.5. Further, the image was transferred to the plane of the IKS-14A photometric wedge by means of mirrors 7 and 8.

Figure 1b shows the liquid cell for holding the specimen and standard; the body 1 is attached to the holder 2 by means of the flat spring 3 and the screws 4. The fluorite window 5 is set at 20° to the axis of the cell. This setting for the window enables one to eliminate reflections from the fluorite—air and fluorite—liquid boundaries. Device 6 is used to adjust the cell. Specimen 7 is pressed by screw 8 on to the carefully polished surface of the cell body. The cavity in the cell is filled with the immersion liquid 9.

In measuring the reflection coefficient at the boundary between the material and the liquid, particular attention was given to obtaining good optical contact between the liquid and the surfaces.

As the standard we used a polished germanium crystal, whose reflection coefficient was fairly close to that of the polished coal surface. One therefore obtains roughly equal energy fluxes in the two channels, which somewhat improve the error of measurement, especially since the optical constants of germanium are known accurately.