# RADIATIVE HEAT TRANSPORT AND OPTICAL DENSITY IN LOOSELY PACKED FIBERS

N. V. Komarovskaya

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Results are given on the effective thermal conductivity of loosely packed fibrous material in relation to optical density in the case of radiative heat transport.

This study is a continuation of experiments on radiative heat transfer in optically thin layers; results have been given [1] on radiative heat transport under conditions close to equilibrium for small heat fluxes. Here we present results performed over a wide temperature range using loosely packed fiber at temperatures up to 1000°C. The measurements were done at pressures of $10^{-4}$-$10^{-5}$ mm Hg, which rendered negligible all causes of heat transport apart from radiation, while providing radiative equilibrium. The silica fiber was of diameter 8-10$\mu$. The optical density was measured by varying the amount of material in the instrument.

The measurements were made by the classical sheet method under stationary heat-flux conditions. The effective thermal conductivity was measured with two equipments: with an electrical calorimeter [1] (range 300-500°K) and with a water one (range 500-800°K).

The effective thermal conductivity was calculated from

$$\Lambda_{\Delta T}=\frac{QL}{F\Delta T}. \tag{1}$$

The reduced degree of blackness was calculated from the relationships for unbounded plates using the heat fluxes determined in the absence of the specimen:

$$\varepsilon_{\text{re}}=\frac{Q}{F\sigma(T_1^4-T_2^4)}. \tag{2}$$

The maximum error in determining the effective thermal conductivity with the water calorimeter was 10%.

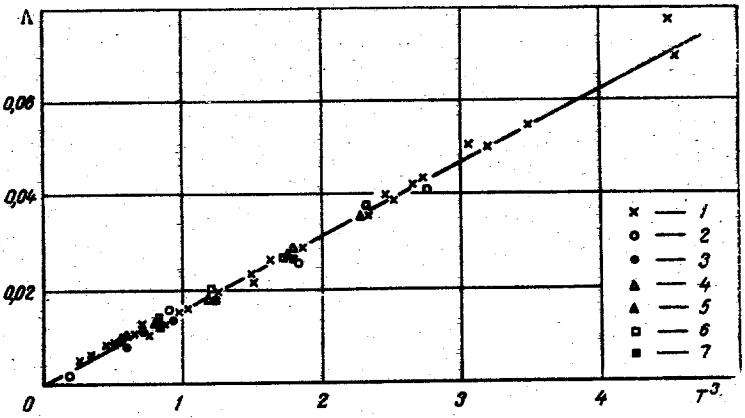

Fig. 1. Effective thermal conductivity of an optically dense layer of silica fiber of bulk density $\gamma$ = 80 kg/m$^3$ as a function of $T^3$: 1) three specimens with optical densities > 100; 2) $\tau$ = 6.75; 3) 9.43; 4) 18.3; 5) 25.9; 6) 42.9; 7) 73.4 [2–7 derived from (5)].

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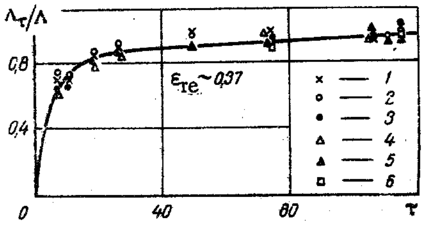

Fig. 2. Ratio of thermal conductivities for optically thin and optically dense layers of silica fiber of bulk density $\gamma = 80\ \mathrm{kg/m^3}$ as a function of optical density of layer. The curve has been calculated from (5); 1) $T_{av} = 430$°K; 2) 500°K; 3) 550°K; 4) 600°K; 5) 700°K; 6) 800°K. $\varepsilon_{re} \approx 0.37$.

The average value was $\varepsilon_{re} \sim 0.37$ within the limits of error of experiment within the above temperature ranges.

We measured the radiative heat transfer for an optically dense layer and used the following formula [1, 2]:

$$\Lambda = \frac{16}{3}\sigma T^3 l, \tag{3}$$

to examine the photon mean free path as a function of temperature. We found that this was independent of temperature and was $0.53\ \mu$.

Figure 1 shows the effective thermal conductivity of an optically dense layer as a function of the cube of the temperature. It also gives the calculated results for an optically dense layer based on the experimental data for the thermal conductivity of a layer of low optical density. The figures have been calculated via a formula applicable to radiative heat transfer in a gray medium with diffusing boundary surfaces under conditions of local thermodynamic equilibrium and radiative equilibrium [1]:

$$\Lambda = \frac{1}{\dfrac{1}{\Lambda_\tau} - \dfrac{1}{4\varepsilon_{re}\sigma T^3 L}}. \tag{4}$$

Figure 2 shows $\Lambda_\tau/\Lambda = f(\tau)$, which indicates that the ratio of the thermal conductivities of optically thin and optically thick layers is independent of temperature over the range used. This relationship is universal for a variety of materials [1]. The experimental results show that the effective thermal conductivity of an optically thin layer is directly proportional to the cube of the mean temperature in °K.

The values given in the figures were calculated with correction for the temperature gradient in the layer:

$$\Lambda = \frac{\Lambda_{\Delta T}}{\varphi(\Delta T)}. \tag{5}$$

The correction was introduced because the difference in temperature between the hot and cold surfaces rose to 1000°C in the high temperature tests. The correction was calculated from the following formula [3]:

$$\varphi(\Delta T) = 1 + \left(\frac{\Delta T}{2T}\right)^2. \tag{6}$$

These experimental results show that the gray diffusely radiating and reflecting surfaces around a thin layer of fibrous material can be incorporated as regards their effect on the transfer via (4) for a wide range of temperatures, and one can use the correction of (6) even though the radiative heat transport rate is high.

## NOTATION

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| $Q$ | is the heat power, W; |
| $\Lambda$, $\Lambda_T$, $\Lambda_{\Delta T}$ | are the radiative thermal conductivity of optically dense layer, effective thermal conductivity of optically thin layer, and measured effective thermal conductivity, W/m · deg; |
| $L$ | is the geometrical thickness of fiber layer, m; |
| $F$ | is the working surface area of instrument, $\mathrm{m^2}$; |
| $T_1$, $T_2$, $T$, $\Delta T$ | are the temperatures of boundary surfaces, mean temperature of layer, temperature drop in specimen, °K; |
| $\varepsilon_{re}$ | is the reduced emissivity of instrument; |
| $\sigma$ | is the Stefan's bulk constant, $\mathrm{W/m^2 \cdot deg^4}$; |

$\bar{l}$ is the photon mean free path, m;

$\tau = L/\bar{l}$ is the optical density;

$\gamma$ is the volume density of samples, kg/m$^3$;

$\varphi(\Delta T)$ is the correction for temperature drop in layer.

## LITERATURE CITED

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2. J. M. Sparrow and R. D. Sess, Radiative Heat Transfer [Russian translation] (1971).
3. V. M. Kostylev, Thesis (1961).