TABLE 4. Experimental Data on C_2D_6 Thermal Conductivity

T, °K	Q, W	$T_f - T_w$, °K	δT_q, °K	Δ_g, °K	$\lambda \cdot 10^4$, W/m·°K
315,32	0,1840	25,21	0,05	24,96	266
329,12	0,3283	41,82	0,09	41,53	284
381,69	0,3331	31,84	0,09	31,45	388
402,21	0,6487	57,69	0,17	57,22	418
440,67	0,3391	25,99	0,09	26,1	478
531,34	0,3427	19,27	0,08	19,59	663
551,68	0,3436	18,15	0,08	18,37	709
555,13	0,4476	23,47	0,08	23,69	716

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THERMAL CONDUCTIVITY OF CARBON BLACK

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Experimental data are presented on the effective thermal conductivity of carbon black in particle sizes from 0.1 to 0.5 mm in an air medium over the temperature range 350-475°K under pressures of 0.04 to 0.42 MPa.

Various branches of industry make wide use of technical-grade carbon black as a technological ingredient, thermal insulator, thermostable material, etc. The carbon black used in the tire industry is in the form of polydispersed granules 0.2-3.0 mm in size, which are formed in granulators from amorphous carbon black by the addition of a binder solution of molasses in water using 3% molasses by weight. The granules are then dried at temperatures on the order of 350-500°K. In this and certain other processes, in calculating heat-transfer processes it is necessary to know the effective thermal conductivity coefficient of such carbon black particles. In [1-3] some information is provided on the thermal conductivity of lamp black, but these data refer to other brands of carbon black and were obtained in different gaseous media.

The present study made use of the stationary comparative method of determining thermal properties of materials in an inorganic plane layer, described in [4, 5], for determination of the thermal conductivity of type PM-15 carbon black.

Using this method, the carbon black to be studied was first milled into a powderlike state and pressed into the form of a relatively thin circular plate, with thickness less than 0.1 mm diameter. The plates were produced between two reference specimens by pouring carbon black on the top of the lower specimen, which was bounded by a cork ring slipped over its upper part. The poured powder was leveled by light taps on the reference specimen and a second reference specimen placed on top of it within the cork ring. Slight pressure with simultaneous twisting of the reference specimens together provided a final equalization of the carbon black layer height. The transfer parameters of the cork ring are approximately the same as those of the carbon black studied, so that the ring was maintained in place for all experiments as mechanical protection and an aid in eliminating thermal flux loss through the lateral surface into the surrounding medium. The height of the reference specimens together with the carbon black layer was measured by a micrometer to an accuracy of ±0.01 mm. The bar-type experimental apparatus with beam landing system used in the present studies was described in detail in [6].

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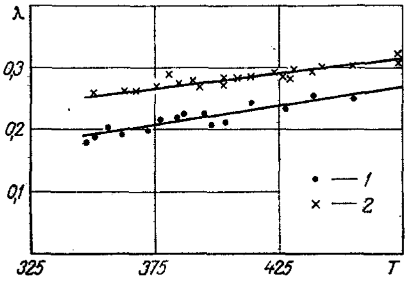

Fig. 1

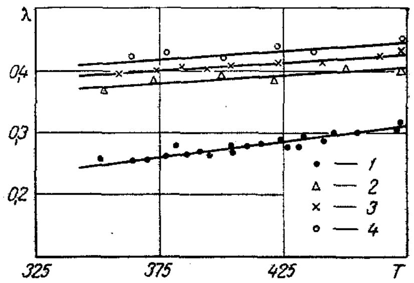

Fig. 2

Fig. 1. Effective thermal conductivity of carbon black versus temperature, particle size, and bulk density: 1) d_m = 0.1 mm, ρ = 295 kg/m³; 2) 0.5, 310. λ, W/m·deg K; T, °K.

Fig. 2. Effective thermal conductivity of carbon black with 0.5-mm particle size and bulk density of 310 kg/m³ versus compressive loading: 1) 0.04 MPa; 2) 0.18; 3) 0.30; 4) 0.42.

The effective thermal conductivity of the carbon black was determined in 1-mm-thick layers. It was found in the course of the experiments that layers of greater thickness had a significant thermal resistance which strongly reduced the directed thermal flux through the material tested, and thus increased systemic error to unacceptable levels. It is for this reason that in [1] the thermal conductivity of lamp black was determined by the tube method at temperatures of 450-1100°K only for an intertube layer thickness of the order of 2 mm. The maximum relative error in our experiments reached 17.5%.

In the heat-transfer theory [7] by thermal conductivity we understand molecular transfer of heat in a continuous medium, produced by a temperature gradient, without consideration of heat transfer by diffusion of material. The thermal conductivity coefficient of porous and dispersed materials depends to a significant degree on their volume density and the thermophysical properties of the media which fill their cavities and pores. Such a dependence is partially explained by the fact that the thermal conductivity of the filling media differs significantly from the thermal conductivity of the solid component of a given material [8].

PM-15 carbon black is a dispersed and porous material. Considering this fact, by the effective thermal conductivity of the carbon black we must understand a value equal to the thermal conductivity of some homogeneous body, through which, given identical dimensions and temperatures on the boundaries, there passes the same quantity of heat as passes through the given carbon black.

The results of the experiments performed are shown in Figs. 1 and 2. The filling medium was air at normal atmospheric pressure. Curves 1 and 2 (Fig. 1) show the dependence of thermal conductivity on temperature, particle size, and bulk density for a loading of 0.04 MPa. As is evident from these curves, the effective thermal conductivity increases with increase in temperature, particle size, and bulk density. We will consider each of these factors in more detail.

The increase in conductivity with increasing temperature occurs mainly because of an increase in the thermal conductivity of the air filling the pores and cavities. It is known from [9] that with an increase in air temperature from 100°K to the range 350-450°K, the effective thermal conductivity increases by 24%. The effective thermal conductivity of the carbon black studied increased over this temperature range by an average of 22%. The increased thermal conductivity over this temperature range is also due to a growth in size of the interparticle contact spots and an increase in the radiant component. However, according to the data of [1], the contribution of the radiant component at temperatures below 750°K is insignificant.

As is well known, the effective thermal conductivity of dispersed and porous materials depends to a certain degree on the size and form of the pores and cavities [8, 10]. A fraction of the pores and cavities may be closed volumes, while the other portion may interconnect, forming open channels. Heat transfer in such materials is produced by a number of phenomena. Within the particles and at points of direct contact transfer occurs by conductivity. In the air medium of the pores and cavities, transfer occurs because of both conductivity and radiation. With increase in pore and cavity size the contribution of radiant heat transfer increases [8]. The cavities between particles increase in size with increase in the size of the particles themselves, and with coarser particles the direct contact area between particles is larger than with fine particles.

This eventually leads to a reduction in contact thermal resistance, and thus, an increase in effective thermal conductivity.

Direct determination of the bulk density of the carbon black revealed that with an increase in mean particle size from 0.1 to 0.5 mm the density increased from 295 to 310 kg/m^3. From this it can be concluded that the cause of the increase in effective thermal conductivity of the PM-15 carbon black with increase in bulk density is the same as the reason for increase with increase in particle size (curve 2, Fig. 1).

In [10] a graph was presented of the correlation between mean particle size of a dispersed material and porosity in the freely poured state. The carbon black studied with particle sizes of 0.1 and 0.5 mm had a porosity of 0.6 and 0.5, respectively. It should be noted that the experimental values of carbon black porosity fit satisfactorily within the scattering zone of the graph referred to, confirming its reliability and universality.

Figure 2 presents experimental curves of the variation of thermal conductivity with loading. After pouring on the reference specimen face the carbon black was packed by percussion of a metallic rod on the specimen. A single blow did not always ensure a repeatable stable packing of all the powder particles. Only a slight additional loading of some 0.04 MPa produced a stable configuration.

It is evident from Fig. 2 that subsequent increase in loading by stages by a total factor of more than 10 times (from 0.04 to 0.42 MPa) led to an increase in effective thermal conductivity by 70% on the average. The degree to which conductivity depends on temperature decreases somewhat at heavy loading (curves 2-4) because of a decrease in the volume of pores and cavities. It is characteristic that a relatively significant increase in effective thermal conductivity occurs only in the initial range of pressure increase from 0.04 to 0.18 MPa (curves 1 and 2). Evidently within this range the particle packing reaches a certain stable value, after which, with loading increase up to 0.42 MPa the thermal conductivity increases only insignificantly. Repeated measurement of the carbon black density after pressing showed an insignificant increase in this parameter. Thus, the density of the material with 0.5-mm particle size increased from 310 to 380 kg/m^3.

Thus, the effective coefficient of thermal conductivity of dispersed carbon black with particle dimensions from 0.1 to 0.5 mm in the temperature range from 350 to 475°K at a loading of 0.04 MPa lies within the range 0.2-0.3 W/m · deg K. With increase in temperature from 350 to 475°K the conductivity increases by ≈22%, while with increase in particle size by a factor of five (from 0.1 to 0.5 mm) with other conditions maintained the same, it increases by 25%. Increase in compressive loading from 0.04 to 0.18 MPa increases the effective thermal conductivity coefficient by 40-70%. Further increase in loading up to 0.42 MPa produces a relatively insignificant increase in conductivity. With increase in compressive loading the temperature dependence of the thermal conductivity becomes weaker.

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