V. N. Adrianov

FUNDAMENTALS OF RADIATIVE AND COMPOUND HEAT TRANSFER*

Reviewed by A. G. Blokh

The monograph deals with processes of radiative and compound heat transfer, which play an important role in conventional and modern engineering. It systemizes and generalizes the vast scientific material on the subject available in both the Soviet and foreign literature. The author has also made wide use of his own theoretical and experimental research work concerning this problem.

Outstanding features of this monograph are its highly scientific content, a general and rigorous treatment of radiative and compound heat transfer theory, and an exhaustive unbiased discussion of the state of the art. The monograph is made up of three parts with a total of sixteen chapters.

The first part covers the physical principles of interaction between radiation and matter, the basic concepts in the theory of radiative heat transfer, and a derivation of the classical laws which govern radiation under thermodynamic equilibrium. This part concludes with a discussion concerning the validity of the hypothesis of local thermodynamic equilibrium, which is important in principle and on which the modern phenomenological theory of radiative heat transfer is based.

The second part of the monograph deals with radiative heat transfer. On the basis of the mathematical description of processes dealt with in the first part, a system of equations is formulated to define radiative heat transfer in the most general terms, with the anisotropy of volume and surface scattering taken into account as well as the selective radiation from the medium and from the surface under arbitrary boundary conditions. On the basis of such a formulation, then, it has been possible to generalize and to refine the theoretical methods of calculating the radiative heat transfer. From this standpoint, the author analyzes thoroughly various differential methods of measuring and calculating the radiative heat transfer: the Schuster–Schwarzschild approximation, the diffusion and the tensor approximations, the Milne–Eddington approximation, and the approximation based on radiative thermal conductivity. It is to be noted that the author, jointly with G. L. Polyak, had been the first to propose the tensor approximation. A special chapter in the second part of the monograph is devoted to integral equations of radiative heat transfer and various methods of solving them. Interesting is the author's attempt to generalize the integral equations which pertain to selectively radiating systems with anisotropic volume and surface scattering. He thoroughly analyzes the methods of algebraic approximation and, especially, his universal zonal method for obtaining the most accurate and general results. This theoretical analysis of methods used for measuring and calculating the radiative heat transfer is illustrated by the solution of several specific problems of scientific and practical significance.

In the last few chapters on the second part we find a thorough analysis of radiative heat transfer processes and their simulation: thermal, electrical, and optical. These chapters should be of special interest to experts engaged in experimental research concerning the radiative heat transfer and, in addition to a more complete and rigorous treatment of the state of the art, a few new and original ideas developed by the author are also shown here. The latter include, for instance, new methods of optical simulation which render this technique applicable to many more problems.

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The third part deals with compound (combined) heat transfer. The basic principles of this kind of heat transfer are outlined here and its various particular modes are analyzed: radiative heat transfer in a moving medium, radiative–conductive heat transfer, and radiative–convective heat transfer. Processes of compound heat transfer are widely encountered in various branches of engineering and, consequently, this part of the monograph is very important. In its physical and mathematical aspects, compound heat transfer differs from purely radiative heat transfer by a greater complexity due to the simultaneous occurrence of several processes.

The author has set up a system of equations describing the compound heat transfer in the general case, with all the earlier mentioned features of radiative heat transfer taken into account. This system of equations is then reduced to dimensionless form, which has made it feasible to more rigorously formulate the similarity criteria for simulating the processes of compound heat transfer.

When analyzing the radiative heat transfer in a moving medium, the author of the monograph has thoroughly reviewed the state of the art and has solved several specific problems typifying this mode of heat transfer. Moreover, a very characteristic extremal effect of the optical density of the medium on heat transfer characteristics of the stream has also been revealed in the study. Of considerable interest are also the chapters dealing with radiative–conductive and radiative–convective heat transfer, where the author not only reviews the state of the art but also presents his own analysis with results which are unusually innovative.

The last chapter of the third part deals with experimental studies of radiative heat transfer in a chemically reacting or in a homogeneous medium, such studies having been made by the author himself. He discusses here also certain methodological problems of interest to researchers concerned with compound heat transfer. The method of combining analysis with experiment in a study of compound heat transfer must be recognized as an advance.

On the whole, the author had set himself an important and difficult task: to systematize, to generalize, and to present from a unified viewpoint the now available material on radiative and compound heat transfer based on both theory and experiment. Since there is an abundance of such material, this could have been done in a single book only in a concise manner and by covering merely the most salient features. In the forthcoming editions, therefore, the author would be well advised to pay more attention to a more thorough analysis of theoretical problems and to treat the experimental part in a separate book.

Problems of radiative and compound heat transfer are becoming nowadays ever more important, attracting the attention of a wide range of experts. For this reason, the publication of this monograph is very timely and useful. The material has been treated here with exceptional clarity, precision, and in logical sequence. It has been organized very thoughtfully. All this should help the readers in grasping the problems at hand.

The book was intended for a diverse group of readers. It will be of foremost interest to engineers and scientists specializing in thermophysics and heat technology. It will certainly be useful to graduating students and to teachers at the academic level, perhaps also to students who are taking advanced courses and specialize in thermophysics, heat power, and heat technology.

V. A. Grishin

THERMAL MEASUREMENTS BY THE METHOD OF INSTANTANEOUS COMPENSATION*

Reviewed by O. A. Gerashchenko, T. G. Grishchenko and V. G. Karpenko

According to the fundamental law of heat conduction, the thermal flux density is directly proportional to the intensity of the temperature field:

$$q = \lambda E = -\lambda \operatorname{grad} t.$$

It has already been considered that the thermal conductivity of many substances is a function of such fundamental variables as the temperature, the pressure, the moisture content, and others. It has also been often suggested that the thermal conductivity depends on the derivatives of these variables as well, namely, on their derivatives with respect to time and space coordinates. For example, in birefringent crystals along certain axes one assumes substantially different values of thermal conductivity in opposite directions [2-4], which in basic terms can be related to the semiconductor effect. The theory of heat conduction does not exclude the possibility of such relations, but a convincing proof can only be provided by the results of reliable experiments.

Thorough research on birefringent crystals has revealed that the said effect is either nonexistent or so small as to be undetectable by measurements with a large enough error. This was ascertained many times within the past century.

During the last eleven years there appeared in print many articles and the monograph by Grishin [1] summarizes their contents. The monograph [1] deals basically with the thermal conductivity as a function of the temperature gradient. The effect of this relation is particularly strong when the temperature gradient approaches zero, according to Grishin, and this makes sense. Heat conduction ceases then, as a physical phenomenon, and thermal conductivity looses its meaning at the limit. Thus, the authentication of a new phenomenon depends entirely on the physical correctness of the appropriate experiments and on the reliability of the error evaluation.

The instrument described in [5] and used for many years allows for the temperature and the temperature gradient to be varied independently. In earlier measurements the problem of varying the temperature gradient was never considered. For this reason, only a few researchers were able to pick out more than ten pertinent data from among a thousand or so data collected. The specimens were made of varnished cloth in combination with impregnated and unimpregnated interlayers of paper or cotton-paper cloth. According to [1], it was in such specimens that the said effect had been observed. Our earlier measurements, however, have not revealed a dependence of the thermal conductivity on the temperature gradient.

In view of this, we have performed special measurements on specimens exactly corresponding to those described by Grishin. Specimens of various thicknesses were prepared by alternating layers of filter paper with layers of grade LSK varnished cloth. The temperature gradient was varied from grad t = 10^4 °K/m, at which no Grishin effect was observed, down toward small values. In our tests we decreased the temperature gradient to grad t = 200 °K/m, i.e., to a level one order of magnitude below the minimum temperature gradient in Grishin's experiment. The results of our measurements are shown in

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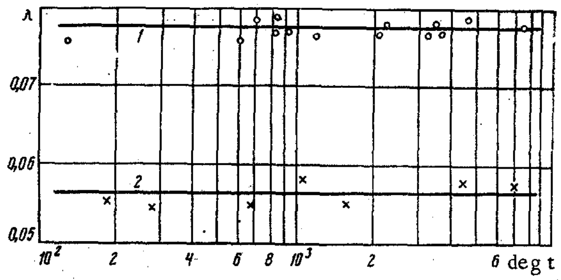

Fig. 1. Thermal conductivity (W/m · °K) as a function of the temperature gradient (°K/m) in multilayer composites: 1) filter paper with varnished cloth; 2) filter paper with aluminum foil.

Fig. 1 (curve 1). Obviously, neither do these results yield any positive evidence concerning the new phenomenon.

Considering that Grishin had observed the effect predominantly in multilayer composites with contrasting properties, we performed additional tests on specimens of filter paper with 0.02 mm thick aluminum foil interlayers, i.e., on specimens of even more contrasting pairs of materials. The results of these tests are shown in Fig. 1 (curve 2). They also do not reveal any dependence of the thermal conductivity on the temperature gradient. Thus, our results do not confirm those obtained by Grishin.

The thesis of the book "Thermal Measurements by the Method of Instantaneous Compensation" is entirely based on the said effect. Since the existence of such an effect has not been proved, any discussion of the remaining contents of this book seems premature.

It is to be noted, in conclusion, that some probability of the thermophysical properties depending on the derivatives of state variables must not be ruled out. It has been suggested in [6], for instance, that the equation of heat conduction may be expected to become nonlinear at high temperature gradients – just as in the case of Ohm's law within the range of high field intensities. For this reason, one should continue searching for convincing evidence of such relations.

Dependence on the derivatives with respect to time can, in the final analysis, result in thermal hysteresis. Dependence on the derivatives with respect to space coordinates, on the other hand, would be related to the existence of the thermal semiconductor effect. Both are very important in the physics of heat conduction and have for a long time often intrigued researchers; in our opinion, they deserve undiminished attention. The new phenomenon can only become "legitimate," however, after it has been reliably verified by experiment.

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