# FOREWORD

Processes of heat and mass transfer with phase transitions take an important place in such modern technologies as thermal treatment and drying of materials, welding of details, vacuum techniques, metallurgy, heat protection, laser and electron-beam treatment of materials, etc. Correct description of such processes, especially of high-rate ones and of the ones proceeding in non-equilibrium conditions, requires the use of the methods of physical kinetics. In certain cases here it is necessary to use a kinetic approach for describing transfer processes on the whole, whereas in other cases it should be used only for the formulation of the corresponding boundary conditions for phenomenological transfer equations. The kinetic examination refers, mainly, to mass transfer processes in a gaseous phase. At the same time, the issues, related to the kinetics proper of physicochemical transitions on surfaces (for instance, step mechanism of crystal bodies evaporation, the appearance and the growth of crystals, etc.), go beyond the framework of this book and are not examined here.

The problems of heat transfer with phase transitions for solid bodies in a heated gas flow (as well as during the injection and the suction of substance through a porous surface) should be regarded as conjugated [1], i.e. transfer equations in two media, for instance, an equation for a boundary layer in gas and a heat conduction equation for a solid body should be solved simultaneously. The most complicated issue during the mathematical formulation of such problems is a correct formulation of boundary conditions on a phase transition boundary.

A moving phase boundary is a discontinuity surface on which conjugation conditions, obtained from mass, momentum and energy conservation laws [2–4], should be set. However, to find a unique solution of this problem, additional conditions, the form of which depends on gas rarefaction degree and on non-equilibrium degree of phase transitions, should be formulated on this boundary. It turns out here, that such conditions are not always evident even in the case of a dense gas (for example, ordinary sticking conditions [5] can become unfeasible). To obtain similar additional conditions on gas-body interface the methods of kinetic theory of gases should be used.

Chapter 1 examines the problems of boundary conditions on a permeable phase boundary surface and their use during the examination of weakly non-equilibrium processes, for the description of which ordinary equations of viscous and heat conductive gas movement (the Navier-Stokes approximation) are used, while kinetic effects, appearing only in a thin layer near a gas-body surface, are taken into consideration in boundary conditions.

It should be noted, that in markedly non-equilibrium conditions the problem of studying heat and mass transfer during phase transitions becomes much more complicated. For these conditions transfer processes in a gaseous phase should be examined on the basis of the Boltzmann kinetic equation. Such an approach is used, for instance, in [6] to describe the evaporation of solid bodies into vacuum in a one-dimensional case, whereas paragraph 2.6 displays the examination results of high intensity gas escape into vacuum from an axiasymmetric hole during material evaporation from an inner surface.

An interesting situation appears during the description of mass transfer in porous bodies. The matter is, that the radii of pores (capillaries) can often be compared to a mean free path of molecules, so to examine evaporation (condensation) processes in pores even at a normal outer pressure, strictly speaking, it is also necessary to solve a kinetic equation with corresponding boundary conditions.

Real porous bodies have an extremely complicated structure, which makes mathematical description of heat and mass transfer processes in them very difficult. Various models of porous bodies are therefore widely used. Here we will use only two of them, i.e. a "dusty gas" globular model and a capillary model, since these are the models which are adjusted best of all to the use of the methods of kinetic theory of gases. In the first of the above models a highly porous body is simulated by a homogeneous system of stationary and chaotically located spheres of the same radius. Chapter 3 "Transfer Processes In High-Porous Media At Different Knudsen Numbers" provides a review of kinetic theories of transfer processes in dispersed and porous bodies. On the basis of the already mentioned "dusty gas" model a new approach to describe mass transfer during gas evaporation and filtration through a layer of a finite thickness has been suggested. In a one-component case simple expressions have been found for evaporation and filtration velocities, permeability coefficient and density jumps on a gas-porous medium boundary which depend on the Knudsen number and comparison has been made with the experimental results on the permeability of porous catalysts.

A capillary model (a system of parallel cylindrical capillaries) is the simplest one and it is widely used for describing heat and mass transfer during the drying of capillary-porous bodies, for heterogeneous catalysis and in thermal protection. Various asymptotic relations, for example, the Fick law and the Knudsen law for diffusion and the Poiseuille formula for hydrodynamic gas flow regime are widely used for calculating mass transfer in technological processes. One of the aims of solving the above-mentioned internal boundary problems of the kinetic theory of gases is to find the limits of the application of such relations. Besides, in many cases, to describe transfer processes in porous media (catalysis, separation of gas mixtures and drying) it is necessary to know the detailed structure of a gas flow in individual pores, i.e. internal boundary problems of the kinetic theory of gases acquire an independent significance. In the case of a free molecular flow, however, when a major role is played by collisions of molecules with walls, mass transfer in channels is examined taking into consideration adsorption and the presence of mobile adsorbed layers on the surface. A kinetic analysis here makes it possible to reject an assumption on the equilibrium between gas and adsorbed phases in each cross-section whereas such an assumption is characteristic for channels of infinite length. The calculation of mass transfer taking into consideration phase transitions on the walls of a non-isothermal channel shows, that the value and the sign of the temperature drop influence considerably the character of mass transfer since there may take place either a transition from evaporation to condensation or, on the contrary, a transition from condensation to evaporation. All these issues are examined in Chapters 2 and 4.

The knowledge of the kinetics of transfer processes inside pores is also required for the correct statement of the problems of heat and mass transfer with phase transitions in porous and capillary-porous bodies. During the thermal treatment of such media the phase transition boundary is moving into the depth of the material with a velocity depending on the nature of a vapor flow in a "dry" zone of a porous body. Differently speaking, the kinetics of mass transfer in pores determines the boundary conditions on the phase transition surface which is inside the body. In Chapter 5 "Problems of Heat and Mass Transfer with Phase Transitions in Porous Media" at first the known methods of describing heat and mass transfer during phase transitions in porous media are analyzed and then certain problems of the Stefan type with a mobile phase transition boundary inside a model porous body are examined. The expressions, obtained on the basis of the analysis of mass transfer kinetics during evaporation in a channel are used here for the movement velocity of the above boundary.

During the examination of the influence of high-concentration radiation (laser beam, electron beam) on materials it is necessary, in certain cases, to study the kinetics of photon and electron absorption in a substance, which makes it possible to define the form of a heat source. In particular, the analysis of the heat source form with the use of the numerically obtained spatial distribution of electron energy losses shows, that with an increase of the electron beam diameter the energy release maximum shifts from the surface to the depth of the material. This result, which cannot be obtained with the help of the known approximate models for the distribution of electron energy losses, gives an additional opportunity to explain the experimental fact, that a transition from a continuous mass removal to explosive boiling up is observed only at beam diameters, exceeding electron mean free path. The peculiarities of transfer processes during melting, surface and volume vapor formation in metals, related to the structure of the heat source, being formed in a sample, are examined in Chapter 6.

There are some additions and changes, introduced into this publication in comparison with the book in Russian. A greater number of works has been reviewed in Chapter 2 due to new research of intensive evaporation and condensation processes and a new paragraph has been added on high intensity gas escape from a hole during evaporation from an inner surface. Chapter 3 is new (with the exception of the part of para 3.2). A new paragraph has been added to Chapter 4 on a new phenomenon, i.e. on a lightinduced drift of molecules as applied to porous bodies. Certain changes have been introduced into the statement of the Stefan problem in porous bodies (Chapter 5). New paragraphs have been added to Chapter 6 about the influence of a high-current electron beam's proper magnetic field on electron absorption kinetics and about a possibility to strengthen the subsurface layer of a metal by an electron beam. Certain explanations and additions have also been introduced into some paragraphs of the book for a better understanding of the issues considered there. At the same time, certain materials, illustrating the use of the obtained boundary conditions, have been taken away from Chapter 1.

The bibliography has been considerably enlarged at the expense of new works on the problems under examination.

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