INTRODUCTION

The rapid advances in modern science and engineering depend directly on the availability of reliable information on the properties of various individual substances and their mixtures, that participate in given processes. It can be definitely stated that not a single scientific or engineering calculation is possible without data on properties of substances and materials. For this reason the increasingly rising needs of science and technology widen the gap between the need for reliable data and the feasibility of actually obtaining them.

The primary source of information is reliable experimentation, however, the experimental determination of handbook data over a wide range of parameters of state and compositions is very difficult, and in a number of cases simply impossible. It should be added that the formulation and conduct of experiments is highly work consuming and expensive, whereas the data that are obtained are to one or another degree fragmentary. This situation has simulated the development of analytic methods of correlation of data on properties of substances and materials and prediction of these properties. In the case when the experimental and numerical results are equivalent with acceptable accuracy, the latter become more preferable for use in various engineering calculations and also in systems of computer design and control of industrial processes.

The absence of a comprehensive theory, which would allow predicting properties of substances from elementary principles with sufficient accuracy gave birth to a large number of empirical methods for investigating properties of substances. Such methods are of definite practical importance, but are "blind" by nature and, as a rule, cannot be used for extrapolating properties past the limits of parameters in which the input data were presented. A more fruitful path consists in efficiently combining the pragmatic advantages of empirical methods with the underlying theoretical results. When doing this, it becomes possible to quite consistently systematize and correlate experimental

results and to obtain reliable correlations even in the case of very limited body of such results. The effectiveness of the method increases when it is extended to a certain group of substances with typical characteristic attributes.

Moist gases may be regarded as belonging to such a group. All of them consist of binary systems with water vapor serving as one of the constituents. Under certain conditions the vapor may fully or partially condense, becoming liquid or crystalline. The limiting content of water vapor in the mixture is characterized by the equilibrium fraction content, which depends uniquely on the specified temperature and pressure of the mixture. It should be noted in conjunction with this that dry gases do not exist in nature. All the substances surrounding us are in the state of phase equilibrium on tend to it.

The thermodynamic state of moist gases is defined by any three independent parameters, for example, temperature, pressure and composition of the mixture. The last parameter is one of the characteristics of the moisture content. In addition to it, one frequently makes use of concepts such as the absolute moisture content, relative moisture content and degree of saturation. Precise definition of these characteristics of moist gases allows establishing unique relationships between them.

The field of practical application of moist gases is rather wide. They participate in drying and air conditioning, in the manufacture and processing of various materials, in solving specific problems in metrology, biology, medicine, meteorology, agriculture, in the food, chemical and other industries. Data on thermodynamic properties are utilized in: designing economic, highly efficient and safe processes in cryogenic engineering, developing technologies for the transportation and storage of agricultural products, optimizing chemical technology processes and equipment.

In spite of this, no specialized handbook is available in Russia or in the West which would collect, systematize and correlate data on thermodynamic processes of moist gases over the entire range of independent parameters of practical importance. The only exception is moist air, for which tables of thermodynamic properties are available, but only at atmospheric pressures and above zero temperatures.

The present book comes to fill this void. Its structure becomes obvious from it content. It starts by briefly presenting information from the thermodynamics of solutions.

The main purpose of the first chapter is to prove that the equation of state of moist gas and the equation of solubility of water and ice in a gas have the same form. This chapter also examines and analyzes all the possible phase equilibria in the binary system over the selected range of parameters of state.

In general moisture may be present in moist gases in three states: as a vapor, liquid and crystal. In the second chapter equations of state which transmit, with accuracy of modern experimentation, these properties up to the corresponding phase equilibrium curves are obtained for each of these states. Special attention is paid to these curves, since they control to a large measure the accuracy of calculation of the equilibrium fractional content of water vapor in the mixture. These equations serve for calculating the thermodynamic properties of water vapor at 200 to 400 K and pressures from zero to the corresponding values along the phase equilibrium (sublimation and saturation curves).

The third chapter is central to the book and is concerned with application of the above methods for determining the virial coefficients of the equations of state for the

twelve moist gases. The description of general approaches to solution of this problem is the content of the first twelve sections (3.1–3.12) of this chapter. This treatment implements a principle combining simultaneous utilization of original experimental data with the underlying results of the molecular-kinetic theory of gases and liquids.

The structure of all the sections of this chapter is the same. Each section shows by way of examples the implementation of the previously obtained methods of correlation of input data and obtaining final analytic equations incorporating specifics of each of the moist gases under study. This is done in most detail for moist air (Section 3.1). The material for other moist gases is given in more compact form, but not as compact as to infringe upon the independence of each subsequent section, which contains virtually the entire information that is needed on the given question.

The fourth chapter presents equations for calculating the principal thermodynamic properties of moist gases, an overall schematic diagram of such a calculation and equations for estimating the uncertainty of the final results. This was done on the assumption that the results of measurements or calculations as such are not valuable without a metrologically validated estimation of their accuracy. For this reason this problem was afforded all the necessary attention, with the result that all the predicted thermodynamic quantities have a confidence interval of uncertainty that follows from all the preceding estimations of the latter obtained at each preliminary stage of calculations.

Tables of the equilibrium mass fraction of water vapor and of its thermodynamic properties (specific volume, enthalpy, entropy, specific heat at constant pressure, partial pressure of the water vapor, mass- and absolute moisture content) in a form convenient for practical use were calculated for twelve moist gases (air, nitrogen, oxygen, methane, hydrogen, helium, neon, argon, krypton, xenon, carbon dioxide and ethane) at 200 to 400 K and relative moisture content form 0 to 1 at pressures to 10 MPa.

Every effort was exerted to make the book as convenient as possible to the readers. For this reason each chapter and section were made, as far as possible, independent of one another. A bibliography is provided at the end of each chapter. A reference can be repeated, if necessary, from one chapter to another. Although the symbols used are standard in thermophysics, we deemed it necessary to list, in the beginning of the book, the designators of all the symbols and their definitions, to make it easier for nonspecialists to use the book.

The book is intended for use in engineering practice, particularly in working out processes and equipment of the chemical technology, cryogenic engineering and other industries. It can also be useful to a wide circle of scientists, higher-degree candidates and students of energetics and chemical technology institutions of higher learning, since it content is closely related to the molecular-kinetic theory of gases and liquids and to results of utilization of this theory.

In preparing this book the authors had to overcome great difficulties, consisting in developing programs and algorithms for calculating the thermodynamic properties of moist gases and estimating the uncertainty of the predicted values. We were greatly assisted in this work by M. D. Rogovin, senior staff member of the All-Russian Research Institute of Materials and Substances, to whom we are very thankful. Thanks are also extended to candidates of engineering sciences P. V. Popov and A. V. Semenov, staff

members of this Center, who constantly extended assistance in preparing the manuscript for publication.

The assumed structure of the book followed from our desire to find, within the intended scope, an optimum compromise between the traditional forms of scientific monographs and handbooks. For this reason we limited ourself, for each gas, to the most necessary input information, which would allow, after processing, obtaining sufficiently reliable analytic expressions and to calculate the tables. The simplifications which became necessary from time to time under this approach did not seriously infringe upon the rigour and accuracy of the final equations of state for the moist gases. Still, the authors are left with a feeling that not everything came out the way it was intended. Most likely, some shortcomings will be noticed by the intended readership and we will be grateful to those who would communicate these to us and share with us their opinions and concerns.

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