

# **THERMODYNAMIC PROPERTIES OF FLUIDS AND FLUID MIXTURES**

---



# **THERMODYNAMIC PROPERTIES OF FLUIDS AND FLUID MIXTURES**

---

**I. M. Abdulagatov**

Institute of Problems in Geothermy  
Makhachkala, Russia

**V. A. Rabinovich**

Russian Metrological Academy  
Moscow, Russia

**V. I. Dvoryanchikov**

Institute of Problems in Geothermy  
Makhachkala, Russia

Translated by:

**Stanislav N. Gorin**

**BEGELL HOUSE INC. PUBLISHERS**  
New York

Copyright © 1999 by begell house, inc., publishers. All rights reserved

Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

**Library of Congress Cataloging-in-Publication Data**

Abdulagatov, I. M.

Thermodynamic properties of fluids and fluid mixtures / I.M.

Abdulagatov, V.A. Rabinovich, V.I. Dvoryanchikov : translated by Stanislav N. Gorin

p. cm.

Includes bibliographical references.

ISBN 1-56700-130-0 (hardcover)

1. Thermodynamics. 2. Fluids—Thermal properties.

I. Rabinovich, V. A. (Victor Abramovich) II. Dvoryanchikov, V. I. (Vasilli I.) III. Title.

00504.A23 1999

536'.63—DC21

99-17215

CIP

Il'mutdin M. Abdulagatov, Dr. Sci. (Eng.), Prof., Head of the Department of Thermophysical Investigations at the Institute of Problems in Geothermy, Dagestan Division, Russian Academy of Sciences, Makhachkala, Dagestan, Russia. Specialist in the field of experimental investigation and theoretical computation of thermophysical and thermodynamic properties of liquids, gases, and their mixtures near the critical point. Winner of the Dagestan Republic Prize in science and technology.

Viktor A. Rabinovich, Dr. Sci. (Eng.), Prof., Corresponding Member, Russian Metrological Academy, Principal Researcher at the All-Russian Research Center for Standardization, Information, and Characterization of Raw Materials, Products, and Individual Substances, Russian Bureau of Standards (VNIITs SMV, GOSSTANDARD), Moscow, Russia. Specialist in the field of experimental investigation and theoretical computation of thermophysical and thermodynamic properties of substances. Winner of the USSR Council of Ministers' Prize (1987) and Russian Federation State Prize (1996) in Science and Technology.

Vasilii I. Dvoryanchikov, Cand. Sci. (Eng.), Senior Researcher at the Department of Thermophysical Investigations, Institute of Problems in Geothermy, Dagestan Division, Russian Academy of Sciences, Makhachkala, Dagestan, Russia. Specialist in the field of experimental investigation of thermodynamic properties of substances.



# Contents

---

Annotation	ix
Preface	x
<b>1 Methods of Studying <math>(p, V, T, x)</math> Properties of Fluids and Fluid Mixtures: Experimental Results</b>	1
1.1 Method of Hydrostatic Weighing	1
1.2 Method of Variable-Volume Piezometer	9
1.3 Method of Constant-Volume Piezometer	18
<b>2 Methods of Studying Constant-Volume Heat Capacity of Fluids and Fluid Mixtures: Experimental Results</b>	89
2.1 Classical Method of Adiabatic Calorimetry	90
2.2 Method of High-Temperature High-Pressure Integrating Adiabatic Calorimeter	129
2.2.1 Main Principles Underlying the Method	129
2.2.2 Construction of the Calorimeter	131
2.2.3 Heat Capacity of Empty Calorimeter	133
2.2.4 Measurement of the Working Volume of the Calorimeter	133
2.2.5 Preparation of the Calorimeter and the Technique of Measurements	135
2.2.6 Errors in Measuring $C_V$	137
2.2.7 Measurements of Isochoric Heat Capacity $C_V$ near the Coexistence Curve	201
<b>3 Compensation-Relaxation Method for Simultaneously Measuring Isochoric Heat Capacity <math>C_V</math> and <math>(p, V, T)</math> Properties of Liquids and Gases</b>	220
3.1 General Description of the Apparatus and the Main Principles of its Operation	221
3.2 Construction of Piezocalorimeter Vessel	224
3.3 Construction of the Isothermal Shield	227
3.4 System of Measuring Pressure and Mass	229

3.5 Power-Supply and Control Unit (PSCU)	231
3.6 Some Specific Features of the Calorimeter Functioning in the Relaxation-Compensation Regime	231
3.7 Quantitative Estimation of Disturbing Factors	232
3.7.1 Thermal Expansion of the Calorimeter Vessel	232
3.7.2 Pressure Effects on the Calorimeter-Vessel Volume	233
3.7.3 Error of Measuring Heat Capacity of Empty Calorimeter	234
3.7.4 Corrections for Nonideal Isochoricity of the Process	234
3.8 Equations for Calculating $C_c$ , $C_v$ , and $C_p$	236
3.9 Equations for Calculating Pressure, Density, and the Derivatives $(\partial p/\partial T)_V$ and $(\partial p/\partial V)_T$	237
3.10 Calibration of the Experimental Apparatus	240
3.11 Measuring Heat Capacity of the Calorimetric System	245
3.12 Estimation of Corrections and Measurement Accuracy	246
3.13 Experimental Results	248
3.13.1 Measuring $(p, \rho, T)$ Properties of Propanol	248
3.13.2 Measuring Heat Capacities $C_v$ and $C_p$	248
3.13.3 Measuring Temperature Coefficient of Pressure	248
<b>4 Equations of State for Pure Fluids and Fluid Mixtures</b>	<b>253</b>
4.1 Potential Functions of Intermolecular Interactions and Virial Coefficients	253
4.1.1 Hard-Sphere Equation of State [299]	282
4.1.2 PHCT Model of the Equation of State	283
4.1.3 SPHCT Model of the Equation of State	284
4.1.4 Hole Quasichemical Model	285
4.2 Classical Equations of State	288
4.2.1 Van der Waals-Type Equations of State	288
4.2.2 Cubic Equations of State	293
4.2.3 Virial Equations of State	294
4.2.4 Calculation of Mixture Properties	296
4.3 Non-Classical Equations of State. Crossover Models	311
<b>References</b>	<b>337</b>

## **Annotation**

---

Experimental methods of determining thermodynamic properties of pure substances and binary mixtures in wide parameters' ranges including near-critical regions are considered. A brief survey of apparatus designed in various laboratories of the former USSR is given; the main units of the apparatuses, their characteristic features, and the experimental procedures are described. Primary experimental data obtained using these apparatuses are given; the main uncertainties are estimated.

Equations of state are analyzed to show which of them are best to describe the thermodynamic behavior of real gases and liquids and their binary mixtures. Special attention is paid to problems of the critical state and to the verification (using experimental data available) of the results of the modern theory of critical and crossover phenomena in pure substances and binary mixtures. New equations of state are obtained based on the theoretically substantiated model of hard chains (SPHCT) for some mixtures of water and hydrocarbons under supercritical conditions. The computation results are compared, where possible, with experimental data.

This book is addressed to specialists, both theorists and experimentalists, working in the fields of molecular physics, chemical technology, and power engineering, as well as for researchers, lecturers, postgraduates, and students of the appropriate specialities in technical colleges and universities.

The book contains 114 tables, 110 figures, and 517 references.

## Preface

---

Because of the rapid development of various branches of engineering, an ever growing interest in obtaining information on the thermodynamic properties of numerous pure substances and mixtures with which researchers and practical engineers deal when solving various scientific and application problems has been observed in the last years. No one of the science or engineering projects can be implemented without data on the properties of materials involved in particular processes. Modern physics only rarely makes it possible to calculate substances' properties. Therefore, it is experiment that is the principal source of information for the great majority of properties of most common substances and materials.

For many years, a vast amount of experimental data on the thermodynamic properties of gases, liquids, and their mixtures has been obtained in various research laboratories over the world. In this sea of data, the results of the authors of this country hold a firm place. Unfortunately, they are frequently represented in foreign editions insufficiently, because significant part of these data has been published in sources that are difficult to reach for foreign readers.

This book corrects the situation to a certain degree. The book considers various methods of experimental study of thermal and caloric properties of pure substances and binary mixtures in wide ranges of the variation of independent variables, including the near-critical region. Primary experimental  $(p, V, T)$ ,  $(C_V, V, T)$ , and  $(p_s, T_s)$  results for pure substances and  $(p, V, T, x)$ ,  $(C_V, V, T, x)$ , and  $(p_s, T_s, x)$  results for binary systems obtained in a number of laboratories of the former USSR are presented and evaluated.

It is well known that to develop new methods and improve the existing techniques of theoretical computation of determining thermodynamic properties of substances, reliable experimental data are required; it is due to the existence of such data that practical methods of the use of equations of state have been developed extensively in the last two decades. Here, the formal theory that relates the macroscopic nature of the virial coefficients and the microscopic nature of molecular forces is most relevant. The equations of state considered in this book are, on the one hand, a kind of instrument for obtaining information on the

intermolecular forces and, on the other hand, are a basis for calculating thermodynamic properties of pure substances and binary mixtures.

With approaching to the critical point, the classical equations of state lack their efficiency, because they cannot ensure universality in describing the behavior of substances in the critical region. In this region, the details of interparticle interaction become insignificant and the behavior of the system is determined by anomalous fluctuations that involve a large number of molecules. The behavior of fluctuations has for years been described phenomenologically in terms of the modern theory of critical and crossover phenomena for pure substances and binary mixtures. These problems are dealt with in numerous publications; so, we here only give a brief analysis of the last achievements in this field. The problems of crossover description of the behavior of thermodynamic functions of binary systems near the critical line are considered in more detail.

We hope that the results represented in this book will be useful to a wide circle of researchers and practitioners working in various fields of science and technology.

In conclusion, we note that we were possible to perform the work, including the experimental investigations of the last several years, due to a financial support of the Russian Foundation for Basic Research (projects no. 93-05-8627 and no. 96-02-16005).

Moscow–Makhachkala  
*I. Abdulagatov*  
*V. Rabinovich*  
*V. Dvoryanchikov*



# 1

## Methods of Studying $(p, V, T, x)$ Properties of Fluids and Fluid Mixtures: Experimental Results

---

In this chapter, we describe in detail modern techniques used for the experimental investigation of  $(p, V, T, x)$  properties of pure substances and their mixtures. We give the main results obtained in research laboratories of the former USSR.

All existing methods for measuring  $(p, V, T, x)$  properties of liquids and gases can arbitrarily be separated into three main groups: (1) the methods of hydrostatic weighing; (2) the methods of constant-volume piezometer; and (3) the methods of variable-volume piezometer.

### 1.1 Method of Hydrostatic Weighing

---

The method of hydrostatic weighing is based on the Archimedean principle. The density of a fluid under study is determined by the difference in the weights of a load of known volume located in the liquid to be studied and in a liquid of known density. The method is, usually, applied at low pressures and temperatures, with air or distilled water used as the standard substances. However, in some cases this method is used for liquids at high pressures and gases at high pressures and temperatures [1]. In apparatuses of this type, a high-sensitive balance is placed into a high-pressure vessel. A load made of sapphire is suspended in the hot zone using a thin wire. The balance is calibrated under the conditions at which the experiment should be performed; the specific volume of the gas to be studied is determined by the loss of the load's weight in comparison with that in a standard substance. The advantages of this method are the absence of a dead volume and no need in determining the volume of the piezometer and its thermal and pressure-induced expansion.

## 2 THERMODYNAMIC PROPERTIES OF FLUIDS AND FLUID MIXTURES

The most suitable and most widely used version of the apparatus for hydrostatic weighing was developed by Golubev [2–4]. Setups of this type were used by many researchers in Russia and in the former USSR for measuring  $(p, V, T)$  properties of various substances in wide ranges of pressures and temperatures [5]. The apparatus consists of a thermostatically controlled high-pressure vessel with a narrow tube in which a ferromagnetic rod connected by a thin wire with a quartz float is mounted. The ferromagnetic rod and the solenoid connected with the pan of an analytical balance form a magnetic suspension. The solenoid is fed from an electronic circuit that is controlled by the signal from a high-frequency coil-a sensor that traces the position of the ferromagnetic rod. Thus, the system of a float and a ferromagnetic rod located in the vessel is rigidly connected with the balance pan. The density of the sample is determined from the formula

$$\rho = \frac{G - (G_2 - G_1) - \rho_r(V_r + 0.5V_w)}{V_f + \Delta V_T + \Delta V_p + 0.5V_w}$$

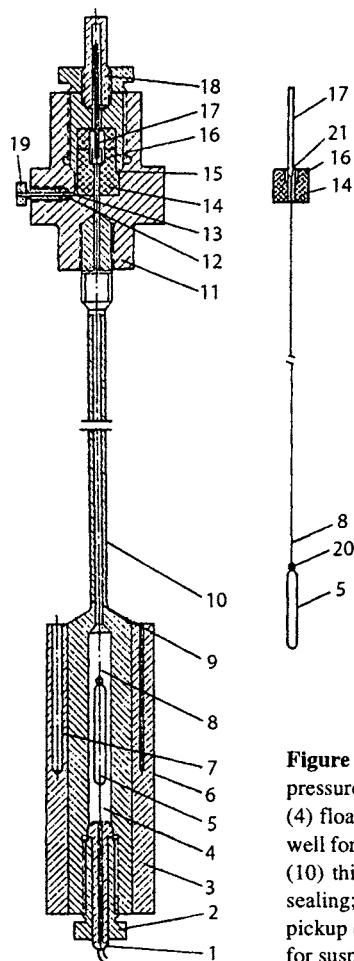
where  $G$  is the weight of the "float + rod + wire" system in a vacuum;  $G_1$  is the weight of the solenoid;  $G_2$  is the weight of the solenoid plus the weight of the "float + rod + wire" system;  $\rho_r$  is the density of the substance under study in the zone of the rod;  $V_r$  is the volume of the rod;  $V_w$  is the volume of the wire;  $V_f$  is the volume of the float under the conditions maintained during the calibration procedure; and  $\Delta V_T$  and  $\Delta V_p$  are the volume changes due to temperature and pressure effects under the experimental conditions, respectively.

The maximum relative error of the density measurements by this method is  $\pm 0.1\%$ . According to [2, 5], the reproducibility and scatter of experimental data do not exceed  $\pm 0.01\%$  and  $\pm 0.05\%$ , respectively.

In the literature, there are many versions of the apparatus for hydrostatic weighing, which mainly differ in the construction of the weighing device [6–12]. Dix and Fareleira [13] developed a new version of the hydrostatic-weighing technique, in which resonance vibrations of a string carrying a float are used to determine density. Handel et al. [14] describe a "two-sinker" method, in which two loads of the same masses but sharply differing in volumes are used in order to eliminate the influence of other elements on the results of weighing the float.

In the setups described in [2, 5–13], the float system is affected by changes in the temperature and pressure, but corrections can be made, which improve the results to a certain degree. Handel et al. [14] were able, at the expense of some complications made in the apparatus, to compensate the effects of the experimental conditions.

Golubev et al. [15–18], using a modernized apparatus that differed from the previous versions [2–4] by an improved construction of the weighing device and an updated electronic servosystem, measured  $(p, V, T)$  properties of the *n*-propyl, *n*-butyl, and amyl alcohols and their isomers. The measurements were performed at temperatures of 290 to 620 K and pressures of up to 49.14 MPa. Pressure was created and measured with dead-weight piston manometers (of MP-600 and MP-60 types) with an accuracy of  $\pm 0.05\%$ . Temperature was measured with a platinum resistance thermometer and an R363-2 potentiometer to an accuracy of  $\pm 0.002$  K. During the experiments, the temperature was maintained constant using a VRT-2 high-precision temperature controller. The device is shown schematically in Fig. 1.



**Figure 1** Apparatus for determining densities of liquids and gases at high pressures (schematic) [2, 4]: (1) gas inlet; (2) lock-nut; (3) copper jacket; (4) float's chamber; (5) quartz hollow float; (6) well for thermocouple; (7) well for resistance thermometer; (8) suspension filament; (9) bored 6.5 mm; (10) thick-walled high-pressure tube; (11) head of the device; (12) teflon sealing; (13) pressing bushing; (14) teflon liner; (15) screwed cover; (16) pickup coil; (17) core (Armco iron); (18) cap; (19) pressing nut; (20) eyelet for suspension filament; and (21) pin.

During the measurements, the effect of the current-direction reversal in the power coil on the measurement results was taken into account. The values of these corrections were not more than  $\pm 1 \text{ kg}\cdot\text{m}^{-3}$ . With allowance for various corrections inherent in this method and for the scatter of the experimental points upon repeated measurements, the total accuracy was about  $\pm 0.1\%$ . At high temperatures and pressures, at which sharp changes in density occur (critical region), the errors of measurements reach  $\pm 0.2\%$ .

Table 1 shows experimental ( $p$ ,  $\rho$ ,  $T$ ) data for the *n*-propyl and isopropyl alcohols [15].

The most elaborate version of the method of hydrostatic weighing is represented by the apparatus developed in [14, 19–23]. The apparatus and the measurement technique developed in these works were used for measuring ( $p$ ,  $V$ ,  $T$ ) properties of methane,  $\text{CO}_2$ , argon, and  $\text{SF}_6$  in wide ranges of temperatures and pressures, including the critical region. The accuracy that was achieved by the authors of these papers is  $1.5\cdot 10^{-4}$  to  $2\cdot 10^{-4}$  for densities and  $1\cdot 10^{-4}$  to  $2\cdot 10^{-4}$  for pressures.

Another version of the setup for hydrostatic weighing was suggested in [12]. The apparatus is displayed schematically in Fig. 2. The main element of the setup is piezometer 11 in which spherical quartz floats are located. The piezometer as a unit is placed into

4 THERMODYNAMIC PROPERTIES OF FLUIDS AND FLUID MIXTURES

**Table 1 Experimental ( $p$ ,  $\rho$ ,  $T$ ) data of *n*-propanol and isopropanol [15]**

<i>n</i> -Propanol								
$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>	$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>	$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>
531.08	5.010	423.6	543.48	7.461	434.3	585.65	5.500	55.00
531.10	5.108	428.8	543.45	9.913	477.6	585.72	5.990	59.90
531.17	5.304	437.7	543.39	14.82	522.0	585.72	6.480	64.80
531.20	5.500	444.4	543.33	19.72	547.8	585.71	7.461	74.61
531.25	5.990	458.1	543.29	29.53	582.9	585.73	8.442	84.42
531.33	7.461	484.9	543.33	39.33	608.0	585.78	8.932	89.32
531.36	9.913	511.7	543.33	49.14	627.4	585.85	9.913	99.13
531.40	14.82	544.9	542.94	5.990	354.1	585.87	11.38	113.8
531.42	19.72	567.3	542.90	5.304	155.8	585.87	12.36	123.6
531.44	24.62	584.2	542.58	5.010	134.3	585.94	14.82	148.2
531.46	29.53	598.6	558.25	5.304	116.4	585.94	19.72	197.2
531.47	39.33	621.3	558.17	5.550	124.9	585.94	24.62	246.2
531.49	49.14	639.0	558.17	5.990	154.4	586.00	29.53	295.3
531.33	7.461	484.5	558.17	6.480	198.5	586.06	39.33	393.3
531.32	5.500	443.8	558.39	6.971	264.1	586.06	49.14	491.4
531.33	5.010	421.0	558.47	6.461	322.3	585.60	5.990	59.90
531.37	4.912	414.0	558.52	7.953	342.1	619.57	5.500	55.00
531.39	4.814	403.9	558.61	8.932	400.6	619.69	6.480	64.80
542.95	5.304	156.3	558.68	9.913	426.2	619.74	7.461	74.61
543.12	5.402	168.2	558.75	12.36	464.2	619.80	9.913	99.13
543.28	5.500	184.7	558.84	14.82	489.3	619.84	12.36	123.6
543.38	5.696	241.0	558.95	19.72	521.8	620.00	14.82	148.2
543.44	5.794	286.1	559.01	24.62	544.9	620.40	17.27	172.7
543.28	5.843	313.1	559.03	29.53	563.1	620.35	19.72	197.2
543.25	5.892	329.1	559.08	39.33	590.8	620.41	24.62	246.2
543.33	5.990	349.3	559.13	49.14	491.4	620.46	29.53	295.3
543.36	6.480	396.1	558.99	9.913	99.13	620.46	39.33	393.3
543.42	6.971	417.4	558.95	7.461	74.61	620.52	49.14	491.4

**Table 1 Experimental ( $p$ ,  $\rho$ ,  $T$ ) data of *n*-propanol and isopropanol [15] (Continued)**

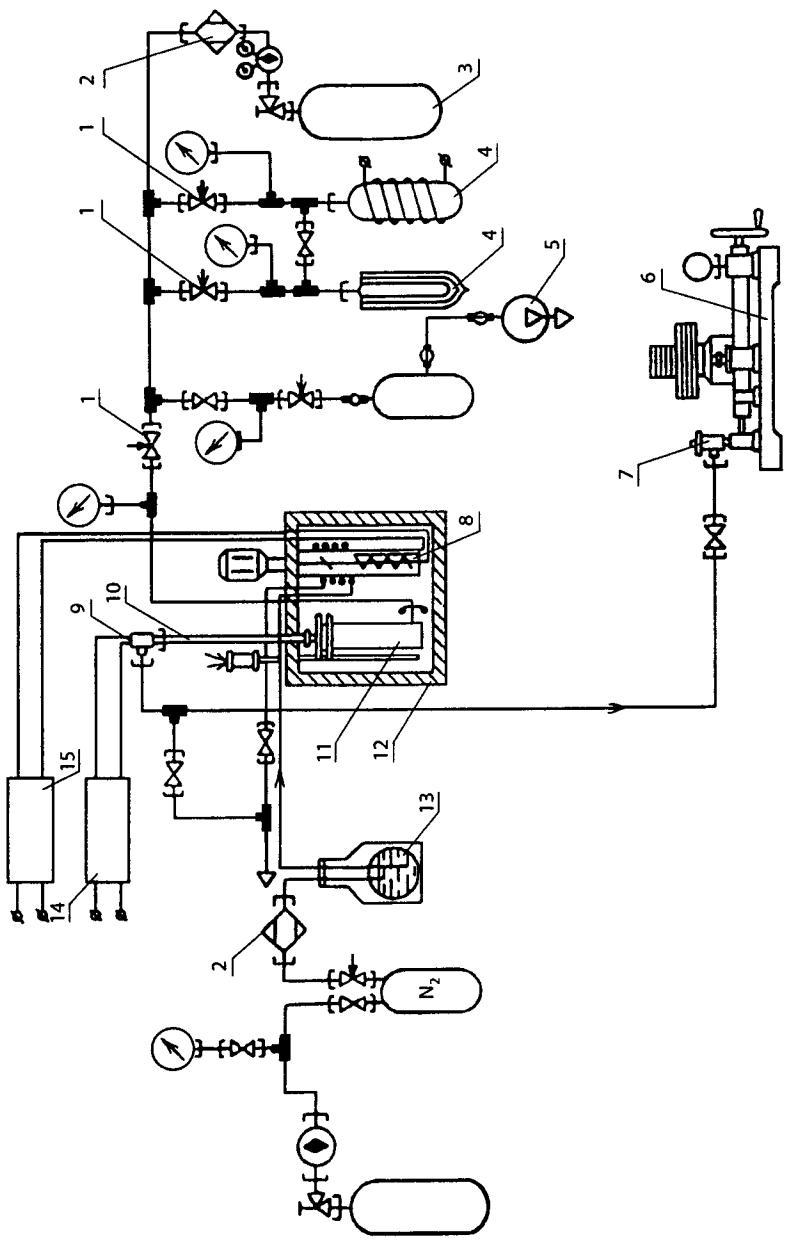
Isopropanol								
$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>	$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>	$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>
504.12	5.010	430.6	527.07	7.461	379.5	555.32	49.14	586.0
504.15	5.990	459.3	527.01	8.442	414.3	572.39	5.010	85.6
504.17	7.461	483.8	526.90	9.913	444.9	572.52	5.990	111.0
504.28	9.913	506.1	526.93	14.82	497.7	572.64	7.461	159.2
504.30	14.82	542.3	527.04	19.72	527.9	572.72	8.442	198.3
504.28	19.72	564.6	537.81	4.715	97.8	572.64	9.913	262.0
504.29	24.62	581.8	538.60	5.500	129.5	572.61	10.89	300.0

**Table 1** Experimental ( $p$ ,  $\rho$ ,  $T$ ) data of *n*-propanol and isopropanol [15] (Continued)

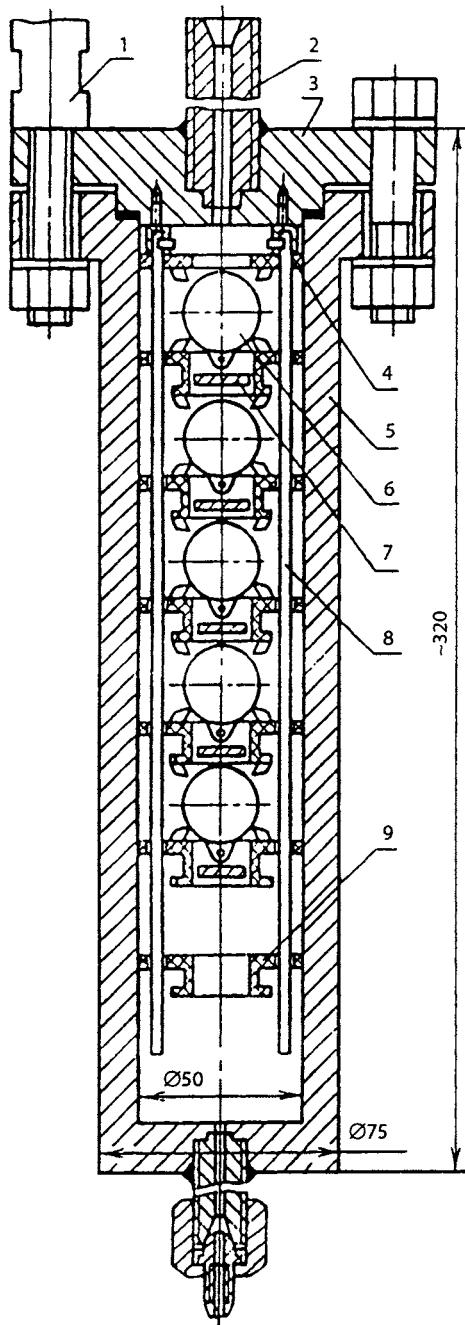
Isopropanol								
$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>	$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>	$T$ , K	$p$ , MPa	$\rho$ , kg·m <sup>-3</sup>
504.28	29.53	596.0	538.90	6.480	192.7	572.69	12.36	342.9
504.30	39.33	619.0	538.90	7.461	286.3	572.80	14.82	391.2
504.25	49.14	636.8	539.01	8.442	349.8	572.88	17.27	423.3
512.60	4.715	146.3	539.01	9.913	400.2	572.90	19.72	447.0
512.76	4.764	150.3	539.01	12.36	444.3	572.88	24.62	481.2
513.01	5.010	197.8	539.01	14.82	471.6	572.99	29.53	506.4
513.15	5.206	309.1	539.18	19.72	507.1	572.94	39.33	542.7
513.26	5.108	234.6	539.23	24.62	531.7	572.66	49.14	569.0
513.52	5.304	331.6	539.18	29.53	550.7	593.05	5.010	77.8
513.55	5.500	367.6	539.18	39.33	580.0	593.38	5.990	98.3
513.55	5.990	404.3	539.13	49.14	601.9	595.38	7.461	134.5
513.63	7.461	449.2	554.76	5.010	94.9	593.44	8.442	161.9
513.74	9.913	485.1	554.73	5.500	109.9	595.60	9.913	208.0
513.80	14.82	524.3	554.73	6.480	148.2	593.66	10.89	238.9
513.86	19.72	549.4	554.95	7.461	199.3	593.60	12.36	282.3
513.92	24.62	568.4	555.15	8.442	258.6	593.60	14.82	338.8
513.95	29.53	583.6	555.27	9.913	331.4	593.77	17.27	378.4
513.95	39.33	608.1	555.32	10.89	364.5	593.79	19.72	407.5
513.90	49.14	627.2	555.49	12.36	394.9	593.87	24.62	448.9
526.50	4.715	110.7	555.50	14.82	435.0	595.77	29.53	478.3
526.00	5.010	126.8	555.50	19.72	479.8	593.84	39.33	518.9
526.32	5.500	163.8	555.15	24.62	508.4	593.87	49.14	548.0
526.54	5.990	224.8	555.15	29.53	529.9			
526.88	6.480	302.1	555.25	39.33	562.0			

thermostat 12 with a liquid heat-transmitting medium (petroleum ether, ethyl alcohol, or silicone oils); the thermostat makes it possible to perform measurements in a temperature range of 100 to 300°C.

The temperature in the experiments is measured using a standard potentiometric circuit with a PTS-10 platinum resistance thermometer 10 in combination with an R384 potentiometer to an accuracy of  $\pm 0.01$  K. The pressure is measured with dead-weight piston manometers of types MP-600 (accuracy class 0.05) and MP-60 (accuracy class 0.02). To separate the substance to be studied from the oil system of the piston manometer, a membrane separator 7 is used, whose sensitivity was estimated to be  $\pm 0.001$  MPa. To fill the manometers with the liquid to be studied and to create a pressure, two thermocompressors 4 are used in the system. Filter 2 serves to absorb water vapors and eliminate possible mechanical impurities. To provide enhanced temperatures, a nichrome heater located inside the thermostat is used. To ensure uniform distribution of the desired temperature



**Figure 2** Experimental apparatus for measuring  $(P, V, T)$  properties by the hydrostatic-weighing method (schematic) [12]: (1) high-precision needle valves; (2) filter; (3) balloon with the substance to be studied; (4) thermocompressors; (5) VN-461M vacuum fore pump; (6) dead-weight piston manometer; (7) separator; (8) stirrer; (9) high-pressure-tight electric lead; (10) resistance thermometer; (11) piezometer; (12) resistance thermometer; (13) Dewar flask with liquid nitrogen; (14) device for measuring density; and (15) temperature controller.



**Figure 3** High-pressure piezometer (schematic) [12]. (1) stands; (2) fitting pipe with a pressure-tight electric lead; (3) head; (4) case of the measuring cell; (5) high-pressure chamber of the piezometer; (6) quartz float; (7) additional load; (8) stands of the stack; and (9) induction coil.

throughout the thermostat, a mechanical stirrer 8 is employed. To monitor temperature, a thyratron temperature controller was used.

Figure 3 shows the construction of a high-pressure piezometer. The high-pressure chamber (5) of the piezometer was made of steel Kh18N9T. Inside the chamber, measuring cells (inductance transducers) are located. The construction contains five measuring cells 4

## 8 THERMODYNAMIC PROPERTIES OF FLUIDS AND FLUID MIXTURES

consisting of inductance coils 9 and quartz floats 6 carrying additional loads (sinkers) 7 that serve as metallic cores. The loads are made of covar (an alloy with a small thermal expansion coefficient); the coil casings and the stands of the stack are made of radio ceramics. The quartz floats (26±1 mm in diameter, with walls of at least 0.5 mm in thickness) can move in the cell within 4 mm from the upper to the lower point contacts. The upper fitting pipe 2 is connected with a pressure-tight electric lead-in. The piezometer unit is suspended on a load-carrying plate made of textolite (a fabric-based laminate) and mounted on a special rack.

In order to decrease heat transfer and maintain a stable temperature field in the zone of the piezometer, the stands 1 are insulated from the piezometer by textolite washers. A special measuring device is used to detect the state of indifferent equilibrium of the quartz floats (having a standard density). The detection is performed by the inductive method which is based on the property of induction coils to change their inductance when a metallic object is introduced into the field of a coil. The change is due to eddy currents induced in the conductor by the primary field of the coil. These currents create a magnetic flux opposing the primary field of the coil and weaken it. The inductance coil is connected in the circuit of an *LC* generator; changes in the inductance of the coil change the frequency of the generator. Displacements of the metallic load attached to a quartz float change the inductance of the coil and, correspondingly, the generation frequency; the frequency changes are detected by a digital frequency meter.

The accuracy of density measurements of a liquid to be studied is completely determined by changes in the density of the quartz floats under the effect of pressure and temperature. The density of the quartz floats was preliminarily calibrated using distilled water as the working liquid; the water density was determined at a given temperature from the international skeleton tables. The density of a float was determined from the formula

$$\rho_f = \frac{m_s - m_l}{V_s - V_l}$$

where  $m_s$  is the mass of the "float + load" system;  $V_s$  is the volume of this system;  $m_l$  and  $V_l$  are the mass and the volume of the load attached to the quartz float in order to increase the accuracy when weighing samples in distilled water. The accuracy of determining the density of the floats was ±0.01%.

To take into account possible changes in the temperature and pressure during measurements, corrections allowing for the effect of these parameters on the equivalent density of the floats must be introduced. Calculations show that the volume of a quartz float changes by 0.005% as the temperature changes from -100°C to 300°C. Application of corrections for changes in the equivalent density of floats depending on pressure is a more difficult problem. Calculations show that, depending on the diameter of the float and the thickness of their walls, this correction may reach ~2% at the highest pressure of 60 MPa used in the experiments. In order to more accurately determine corrections for the change of the equivalent density of floats depending on pressure, special calibration runs were carried out using distilled water. This correction was found to be a linear function of pressure for all of the ten floats studied.

Prior to measurements, the inner volumes of the piezometer and thermocompressors, as well as the connecting pipes, are evacuated to a residual pressure of  $10^{-2}$  Torr and

flushed with the substance to be studied. Then, the liquid to be investigated is supplied from cylinder 3 (Fig. 2) with the help of thermocompressors 4 into the internal space of piezometer 11 and a desired pressure is established. Thermostat 12 specifies a desired temperature, which is maintained with an electronic temperature controller to an accuracy of  $\pm 0.005$  K. In order to control the temperature gradient along the piezometer, a copper-constantan differential thermocouple is used. The run starts when the differential thermocouple shows that the temperature difference is less than 0.005 K. With the help of thermo-compressor 4 (see Fig. 2), the pressure of the liquid is increased via valve 1 until the lower float, which has the smallest equivalent density, begins floating up. The position corresponding to the state of indifferent equilibrium of this float is achieved at the expense of a minimum change of pressure with the help of valves 1 (Fig. 2). The state of the indifferent equilibrium of the float is kept for 10–15 min, after which the pressure in the piezometer is increased until the next float (with a greater density) begins floating up, etc. Thus, using this device, five values of the liquid's density can be determined for each isotherm. The number of experimental points may be increased by varying load masses. It was established experimentally that the dead range for the breaking of a float away from a lower contact is  $\pm 0.01$  MPa.

## 1.2 Method of Variable-Volume Piezometer

---

The method of the piezometer of a variable volume implies measurements of volume changes for a known amount of a substance upon its compression or expansion. As a result of measurements, a relationship between the volume and the pressure at a known temperature is obtained. In this method, one of the main elements of the apparatus is a separator, which is located in the working volume of the piezometer; very high requirements are imposed on this element. The separator must be high-sensitive, corrosion-resistant, and ensure a pressure-tight connection between the working volume and the transmitting medium. Usually, constructions with mercury, bellows, or pistons are used as separators. At low temperatures, mercury is usually employed, because this is an ideal inert separator with a zero friction under these conditions (its vapor pressure may be neglected at low temperatures). The main source of errors in this method is the way of determining the volume of the gas to be studied. For this purpose, visual readings through special windows or various electrical contacts located at certain positions (preliminarily calibrated with respect to volume) are used, as well as resistive or inductive displacement gages.

Modern displacement transducers make it possible to determine longitudinal displacements of a separator to a high accuracy (0.001–0.002 mm). Nevertheless, the determination of the volume of the piezometer at high pressures and temperatures is a very complex problem. Factors that must be taken into account are the thermal and pressure-induced expansion of the piezometer, the compressibility of the pressure-transmitting liquid, the effect of nonisothermal volumes (which is difficult to calculate exactly), etc. The method of the piezometer of variable volume with a variable amount of the substance to be studied was suggested by Barnett [24]. In this method, two piezometers of different volumes separated by a valve are placed into a thermostat. The gas to be studied is supplied into one of the piezometers until a certain pressure is reached at a given temperature. The second piezometer is evacuated. After this, the valve connecting the piezometers is opened and the

## References

---

1. Basset, I., Basset, I. I., *Phys. et al. rad., Suppl. A*, 1954, Vol. 15, p. 47.
2. Golubev, I. F., *Trudy GIAP*, GIAP [Gos. Inst. Azotn. Promyshl.], Moscow, 1957, No. 7, p. 47.
3. Golubev, I. F., Vagina, E. N., *Trudy GIAP*, GIAP [Gos. Inst. Azotn. Promyshl.], Moscow, 1963, No. 60, p. 39.
4. Golubev, I. F., Dobrovolskii, O. A., *Trudy GIAP*, GIAP [Gos. Inst. Azotn. Promyshl.], Moscow, 1964, No. 5, p. 43.
5. Abas-Zade, A. K., Kerimov, A. M., *Teplofizicheskie svoistva zhidkostei* (Thermophysical Properties of Liquids), Nauka, Moscow, 1970, p. 34.
6. Pavlovich, N. V., Timrot, D. L., *Teploenergetika*, 1958, No. 4, p. 69.
7. Voityuk, B. V., Moseichuk, L. V., Dalakyan, Zh. A., *Izmeritel'naya tekhnika*, 1974, No. 1, p. 38.
8. Haynes, W. M., *Rev. Sci. Instrum.*, 1977, Vol. 48, No. 1, p. 39.
9. Beams, I. W., *Rev. Sci. Instrum.*, 1969, Vol. 40, No. 1, p. 167.
10. Haynes, W. M., Hiza, M. I., *Rev. Sci. Instrum.*, 1976, Vol. 47, No. 10, p. 1237.
11. Slabskii, L. N., *Metody i pribory eksperimental'noi fiziki predel'nykh izmerenii* (Methods and Devices of the Experimental Physics of Fine Measurements), Nauka, Moscow, 1973, p. 330.
12. Voityuk, B. V., Rabinovich, V. A., Moseichuk, L. V., Denisenko, A. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1975, No. 8, p. 246.
13. Dix, M., Fareleira, I. M., *Int. J. Thermophysics*, 1991, Vol. 12, No. 2, p. 357.
14. Handel, G., Kleinrahm, R., Wagner, W., *J. Chem. Thermodynamics*, 1992, Vol. 24, p. 685.
15. Golubev, I. F., Vasil'kovskaya, T. N., Zolin, V. S., *Trudy GIAP*, 1979, No. 54, p. 5.
16. Zolin, V. S., Golubev, I. F., Vasil'kovskaya, T. N., *Trudy GIAP*, 1979, No. 54, p. 26.
17. Vasil'kovskaya, T. N., Golubev, I. F., Zolin, V. S., *Trudy GIAP*, 1979, No. 54, p. 15.
18. Zolin, V. S., Vasil'kovskaya, T. N., Golubev, I. F., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1983, No. 18, p. 20.
19. Gilden, R., Kleinrahm, R., Wagner, W., *J. Chem. Thermodynamics*, 1994, Vol. 26, p. 399.
20. Gilden, R., Kleinrahm, R., Wagner, W., *J. Chem. Thermodynamics*, 1994, Vol. 26, p. 383.
21. Duschek, W., Kleinrahm, R., Wagner, W., *J. Chem. Thermodynamics*, 1990, Vol. 22, p. 841.
22. Duschek, W., Kleinrahm, R., Wagner, W., *J. Chem. Thermodynamics*, 1990, Vol. 22, p. 827.
23. Kleinrahm, R., Wagner, W., *J. Chem. Thermodynamics*, 1986, Vol. 18, p. 739.
24. Burnett, E. S., *J. Appl. Mechanics. A*, 1936, No. 19, p. 136.
25. Tsiklis, D. S., Linshits, L. R., Rodkina, I. B., *Zh. Fiz. Khim.*, 1966, Vol. 40, No. 11, p. 2823.

**338 REFERENCES**

26. Kuskova, N. V., Martynets, V. G., Matizen, E. V., Sartakov, A. G., *Zh. Fiz. Khim.*, 1983, Vol. 57, No. 12, p. 2971.
27. Kuskova, N. V., Kukarin, V. E., Martynets, V. G., Matizen, E. V., *J. Chem. Thermodynamics*, 1991, Vol. 23, p. 523.
28. Martynets, V. G., Matizen, E. V., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1979, No. 13, p. 13.
29. Kuskova, N. V., Martynets, V. G., Matizen, E. V., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1989, No. 27, p. 82.
30. Greenwood, H. J., *Amer. J. Science*, 1969, Vol. 267 A, p. 191.
31. Michels, A., Michels, C., Wonters, H. H., *Proc. Roy. Soc. London A*, 1935, Vol. 153, p. 214.
32. Michels, A., Wijker, H., Wijker, H. K., *Physica*, 1979, Vol. 15, p. 627.
33. Keyes, F. G., Smith, L. B., Gerry, H. T., *Proc. Amer. Acad. Arts and Sci.*, 1936, Vol. 70, p. 319.
34. Bilevich, A. V., Vereshchagin, L. F., Kalashnikov, Ya. A., *Prib. Tekh. Eksp.*, 1961, No. 3, p. 146.
35. Zakirov, I. V., *Ocherki fizicheskoi khimii petrologii* (Issues on the Physical Chemistry of Petrology), Nauka, Moscow, 1977, No. 7, p. 28.
36. Zakirov, I. V., *Problema eksperimenta v tverdofazovoi i gidrotermal'noi apparature vysokogo давления* (The Problem of Experiments Using High-Pressure Hydrothermal Apparatuses), Nauka, Moscow, 1982, p. 206.
37. Shmulovich, K. M., Shmonov, V. M., Zakirov, I. V., *Metody eksperimental'nogo issledovaniya hidrotermal'nykh ravnovesii* (Methods of Experimental Studies of Hydrothermal Equilibria), Nauka, Novosibirsk, 1979, p. 82.
38. Tsiklis, D. S., Polyakov, E. V., *Dokl. Akad Nauk SSSR*, 1967, Vol. 176, p. 308.
39. Shmonov, V. M., Shmulovich, K. M., *Tablitsy termodinamicheskikh svoistv gazov i zhidkostei. Dvuokis' ugleroda* (Tables of Thermodynamic Properties of Gases and Liquids: Carbon Dioxide), Izd. Standartov, Moscow, 1978, No. 3, p. 1807.
40. Vukalovich, M. P., Altunin, V. V., *Teploenergetika*, 1969, No. 11.
41. Vukalovich, M. P., Altunin, V. V., Timoshchenko, N. I., *Teploenergetika*, 1963, No. 1, p. 85.
42. Rivkin, S. L., Akhundov, T. S., *Teploenergetika*, 1962, No. 5, p. 62.
43. Rivkin, S. L., Akhundov, T. S., *Teploenergetika*, 1962, No. 3, p. 57.
44. Rivkin, S. L., Akhundov, T. S., *Teploenergetika*, 1963, No. 9, p. 219.
45. Rivkin, S. L., Troyanovskaya, G. V., *Teploenergetika*, 1964, No. 10, p. 72.
46. Rivkin, S. L., Troyanovskaya, G. V., Akhundov, T. S., *Teplofiz. Vys. Temp.*, 1964, Vol. 2, No. 2, p. 219.
47. Rivkin, S. L., Akhundov, T. S., Kremenevskaya, E. A., Asadullaev, N. N., *Teploenergetika*, 1966, No. 4, p. 59.
48. Akhundov, T. S., Asadullaev, N. N., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1968, No. 6, p. 83.
49. Akhundov, T. S., Abdullaev, F. G., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1974, No. 1, p. 62.
50. Akhundov, T. S., Imanov, Sh. Yu., *Teplofizicheskie svoistva zhidkosteii*, Nauka, Moscow, 1970, p. 48.
51. Akhundov, T. S., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1973, No. 11, p. 20.
52. Kurumov, D. S., Grigor'ev, B. A., *Zhur. Fiz. Khimii*, 1982, Vol. 56, p. 551.
53. Grigor'ev, B. A., Kurumov, D. S., Abdulagatov, I. M., Vasil'ev, Yu. L., *Teplofiz. Vys. Temp.*, 1986, Vol. 24, p. 1096.
54. Kurumov, D. S., Topchiev, S. A., *Fazovye perekhody i teplofizicheskie svoistva mnogokomponentnykh sistem* (Phase Transitions and Thermophysical Properties of Multicomponent Systems), Dagestan. Filial Akad. Nauk SSSR, Makhachkala, 1990, p. 180.
55. Kurumov, D. S., Grigor'ev, B. A., Vasil'ev, Yu. L., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1989, No. 27, p. 101.
56. Kurumov, D. S., *Doctoral (Eng. Sci.) Dissertation*, Inst. for Power Engineering, Moscow, 1991, p. 40.
57. Kurumov, D. S., Olchowy, G. A., Sengers, J. V., *Int. J. Thermophysics*, 1988, Vol. 9, p. 73.
58. Zubarev, V. N., *Teploenergetika*, 1973, No. 8, p. 19.
59. Zubarev, V. N., *Teploenergetika*, 1962, No. 7, p. 64.
60. Vukalovich, M. P., Zubarev, V. N., Aleksandrov, A. A., *Teploenergetika*, 1961, No. 10, p. 79.
61. Zubarev, V. N., Prusakov, P. G., Barkovskii, V. V., *Pribory i tekhnika eksperimenta*, 1974, No. 4, p. 180.
62. Zubarev, V. N., *Teploenergetika*, 1965, No. 10, p. 88.
63. Zubarev, V. N., *Teploenergetika*, 1965, No. 9, p. 67.

64. Zubarev, V. N., *Teploenergetika*, 1963, No. 10, p. 74.
65. Zubarev, V. N., *Teploenergetika*, 1966, No. 3, p. 77.
66. Dobrokhотов, А. В., Устюзhanin, Е. Е., Dudenkov, V. N., Miloslavskii, D. S., *Trudy MEI*, 1982, No. 575, p. 103.
67. Dobrokhотов, А. В., Устюзhanin, Е. Е., *Trudy MEI*, 1986, No. 114, p. 90.
68. Dobrokhотов, А. В., *Cand. Sci. (Eng.) Dissertation*, Moscow, MEI, 1989, p. 16.
69. Bronstein, I. K., Zakirov, I. V., Lunicheva, I. I., Mishchenchuk, O. A., Sokurenko, Yu. V., *Metody i sredstva tenzometrii i ikh ispol'zovanie v narodnom khozyaistve* (Methods and Devices of Tensimetry and their Application in Economy), IMAShONTI, Moscow, 1976, p. 31.
70. Sokurenko, Yu. V., Zakirov, I. V., Mishchenchuk, O. A., *Metody i sredstva tenzometrii i ikh ispol'zovanie v narodnom khozyaistve* (Methods and Devices of Tensimetry and their Application in Economy), IMAShONTI, Moscow, 1976.
71. Zakirov, I. V., *Geokhimiya*, 1984, No. 6, p. 805.
72. Zakirov, I. V., *Termodinamika i geologiya* (Thermodynamics and Geology), Chernogolovka, 1985, Vol. 1, p. 163.
73. Zakirov, I. V., *Cand. Sci. (Geol.-Mineralog.) Dissertation*, Chernogolovka, IEM, 1987.
74. Abdulagatov, I. M., Bazaev, A. R., Ramazanova, A. E., *Int. J. Thermophysics*, 1993, Vol. 14, p. 231.
75. Abdulagatov, I. M., Bazaev, A. R., Ramazanova, A. E., *J. Chem. Thermodynamics*, 1993, Vol. 25, p. 249.
76. Abdulagatov, I. M., Bazaev, A. R., Ramazanova, A. E., *Ber. Bunsenges. Phys. Chem.*, 1994, Vol. 98, p. 1596.
77. Abdulagatov, I. M., Bazaev, A. R., Gasanov, R. K., Ramazanova, A. E., Physical Chemistry of Aqueous Systems, *Proc. 12th Int. Conference on the Properties of Water and Steam*, H. J. White, J. V. Sengers, D. B. Neumann, and J. C. Bellows, Eds., Begell House, New York, 1995, p. 558.
78. Abdulagatov, I. M., Bazaev, A. R., Gasanov, R. K., Ramazanova, A. E., *J. Chem. Thermodynamics*, 1996, Vol. 28, p. 1037.
79. Abdulagatov, I. M., Bazaev, A. R., Gasanov, R. K., Ramazanova, A. E., *Proc. 4th Asian Thermo-physical Properties Conference*, Tokyo, 1995, Vol. 3, p. 809.
80. Bazaev, A. R., *J. Heat Transfer*, 1988, No. 1, p. 113.
81. Abdulagatov, I. M., Bazaev, A. R., Gasanov, R. K., Bazaev, E. A., Ramazanova, A. E., *J. Supercritical Fluids*, 1997 (in press).
82. Abdulagatov, I. M., Bazaev, A. R., Gasanov, R. K., Bazaev, E. A., Ramazanova, A. E., *High Temperatures – High Pressures*, 1997.
83. Haar, L., Gallagher, J. S., Kell, G. S., *NBS/NRC Steam Tables*, Hemisphere Publ. Co, Washington, DC, 1984.
84. Sychev, V. V., Aleksandrov, A. A., Ershova, Z., *Svoistva materialov i veshchestv. Voda i vodyanoi par* (Properties of Materials and Substances: Water and Steam), Izd. Standartov, Moscow, 1990, No. 1, p. 49.
85. Beattie, J. A., Key, W. C., *J. Amer. Chem. Soc.*, 1937, Vol. 59, p. 1585.
86. Kurumov, D. S., Grigor'ev, B. A., Vasil'ev, Yu. L., *Zhur. Fiz. Khimii*, 1986, Vol. 60, p. 14.
87. Grigor'ev, B. A., Rastorguev, Yu. L., Kurumov, D. S., Gerasimov, A. A., *Termodynamicheskie svoistva n-geksana v zhidkoi i parovoi fazakh pri temperaturakh 180–620 K i davleniyakh 0.1–60 MPa* (Thermodynamic Properties of n-Hexane in the Liquid and Vapor Phases at Temperatures of 180–620 K and Pressures of 0.1–60 MPa), GNI, Groznyi, 1981, p. 47.
88. Mamedov, A. M., Akhundov, T. S., *Tablitsy termodinamicheskikh svoistv gazov i zhidkosteii. Uglevodorody aromaticheskogo ryada* (Tables of Thermodynamic Properties of Gases and Liquids: Aromatic Hydrocarbons), Izd. Standartov, Moscow, 1975, No. 5.
89. Golovskii, E. A., Tsymarnyi, V. A., *Teploenergetika*, 1969, No. 1, p. 67.
90. Golovskii, E. A., Tsymarnyi, V. A., *Teplofizicheskie svoistva veshchestv. Trudy Vsesoyuznoi Nauchno-tehnicheskoi konferentsii po termodinamike* (Thermophysical Properties of Substances. Proc. All-Union Symposium on Thermodynamics), LTIKhP, Leningrad, 1969, p. 257.
91. Golovskii, E. A., *Cand. Sci. (Eng.) Dissertation*, Odessa Inst., Odessa, 1969.
92. Golovskii, E. A., Mitsevich, E. P., Tsymarnyi, V. A., *Izmerenie plotnosti etana v intervale 90.23–270.21 K do davlenii 604.09 bar* (Measuring Ethane Density at Temperatures of 90.23–270.21 K and Pressures up to 604.09 Bar), Available from All-Union Research Inst. (VNII Gazprom), 1978, No. 39M.

93. Golovskii, E. A., Elema, V. A., Zagoruchenko, V. A., Tsymarnyi, V. A., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1969, No. 1, p. 85.
94. Golovskii, E. A., Zagoruchenko, V. A., Tsymarnyi, V. A., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1973, No. 9, p. 73.
95. Zozulya, V. N., Blagoi, Yu. P., *Fiz. Nizk. Temp.*, 1975, Vol. 1, p. 1171.
96. Blagoi, Yu. P., Zozulya, V. N., Teplofizicheskie svoistva veshchestv, *Trudy Vsesoyuznoi Nauchno-tehnicheskoi konferentsii po termodinamike* (Thermophysical Properties of Substances, Proc. All-Union Symposium on Thermodynamics), LTIKhP, Leningrad, 1969, p. 199.
97. Hollis-Hallet, A. C., *Proc. Roy. Soc. A*, 1951, Vol. 210, p. 404.
98. Dash, J. G., Taylor, R. D., *Phys. Rev. A*, 1957, Vol. 105, p. 7.
99. Rabinovich, V. A., Tokina, L. A., Berezin, V. M., *Tepl. Vys. Temperatur*, 1970, Vol. 8, p. 789.
100. Rabinovich, V. A., Tokina, L. A., Berezin, V. M., *Tepl. Vys. Temperatur*, 1973, Vol. 11, p. 64.
101. Mikhailov-Mikheev, P. B., *Metall gazovykh turbin* (Metal for Gas Turbines), Mashgiz, Moscow, 1958.
102. Ermakov, G. V., Skripov, V. P., *Tepl. Vys. Temperatur*, 1968, Vol. 6, p. 89.
103. Ermakov, G. V., Baidakov, V. G., Skripov, V. P., *Zhur. Fiz. Khimii*, 1973, Vol. 47, p. 1026.
104. Chukanov, V. N., Skripov, V. P., *Tepl. Vys. Temperatur*, 1971, Vol. 9, p. 739.
105. Evstafeev, V. N., Chukanov, V. N., Skripov, V. P., *Tepl. Vys. Temperatur*, 1977, Vol. 15, p. 659.
106. Evstafeev, V. N., Chukanov, V. N., Skripov, V. P., *Teploenergetika*, 1977, No. 9, p. 66.
107. Skripov, V. P., Chukanov, V. N., Baidakov, V. G., Bulanov, N. V., *Teplofizicheskie svoistva zhidkostei* (Thermophysical Properties of Liquids), Nauka, Moscow, 1976, p. 121.
108. Chukanov, V. N., Shtokolov, E. A., *Teplofizicheskie svoistva zhidkostei i vzryvnoe vskipanie* (Thermophysical Properties of Liquids and Burst Boiling), UNTs Akad. Nauk SSSR, Sverdlovsk, 1976, p. 48.
109. Baidakov, V. G., Skripov, V. P., Kaverin, A. M., *Zh. Eksp. Teor. Fiz.*, 1974, Vol. 67, No. 2(8), p. 676.
110. *Teplofizicheskie svoistva zhidkostei v metastabil'nom sostoyanii*. Spravochnik (A Handbook on the Thermodynamic Properties of Liquids in a Metastable State), Skripov, V. P., Sinitsyn, E. N., Pavlov, P. P., Ermakov, G. V., Muratov, G. N., Bulanov, N. V., Baidakov, V. G., Atomizdat, Moscow, 1980, p. 208.
111. Strelkov, P. G., Itskevich, E. S., Kostryukov, V. N., *Zhurn. Fiz. Khimii*, 1954, Vol. 28, p. 459.
112. Voronel', A. V., Strelkov, P. G., *Prib Tekh. Izmerenii*, 1960, No. 6, p. 111.
113. Chashkin, Yu. R., Smirnov, V. A., Voronel', A. V., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1970, No. 2, p. 139.
114. Voronel', A. V., *Phase Transitions and Critical Phenomena*, Domb, C., Green, M. S., Eds., Academic Press, London, 1976, Vol. 5A, Chap. 5.
115. Voronel', A. V., Gorbunova, V. G., Chashkin, Yu. R., Shchekochikhina, V. V., *Zhur. Eksp. Teor. Fiziki*, 1966, Vol. 50, p. 897.
116. Shavandrin, A. M., Potapova, N. M., Chashkin, Yu. R., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1976, No. 9, p. 141.
117. Chashkin, Yu. R., Voronel', A. V., Smirnov, V. A., Gorbunova, V. G., *Zhur. Eksp. Teor. Fiziki*, 1967, Vol. 52, p. 112.
118. Goodwin, R. D., *J. Res. Nat. Bur. Stand. (U.S.)*, Sect. C, 1961, Vol. 65, p. 231.
119. Gladun, G., *Cryogenics*, 1966, Vol. 6, No. 1, p. 27.
120. Goodwin, R. D., Weber L. A., *J. Res. Nat. Bur. Stand. (U.S.)*, Sect. A, 1969, Vol. 73A, p. 1.
121. Goodwin, R. D., Weber L. A., *J. Res. Nat. Bur. Stand. (U.S.)*, Sect. A, 1969, Vol. 73A, p. 15.
122. Magee, J. W., Ely, J. F., *Int. J. Thermophysics*, 1986, Vol. 7, No. 6, p. 1163.
123. Mayrath, J. E., Magee J. W., *J. Chem. Thermodynamics*, 1989, Vol. 21, p. 499.
124. Weber, L. A., *J. Chem. Thermodynamics*, 1981, Vol. 13, p. 389.
125. Weber, L. A., *J. Chem. Eng. Data*, 1982, Vol. 27, p. 203.
126. Goodwin, R. D., Prydz, R., *J. Res. Nat. Bur. Stand. (U. S.)*, Sect. A, 1970, Vol. 74A, p. 499.
127. Prydz, R., Goodwin, R. D., *J. Res. Nat. Bur. Stand. (U. S.)*, Sect. A, 1970, Vol. 74A, p. 661.
128. Roder, H. M., *J. Res. Nat. Bur. Stand. (U. S.)*, Sect. A, 1976, Vol. 80A, p. 739.
129. Younglove, B. A., Diller, D. E., *Cryogenics*, 1962, Vol. 2, No. 5, p. 283.
130. Younglove, B. A., Diller, D. E., *Cryogenics*, 1962, Vol. 2, No. 5, p. 348.
131. Younglove, B. A., *J. Res. Nat. Bur. Stand. (U. S.)*, Sect. C, 1974, Vol. 78A, No. 3, p. 401.

132. Buckingham, M. J., Edwards, C., Lipa, J. A., *Rev. Sci. Instrum.*, 1973, Vol. 44, p. 1167.
133. Lipa, J. A., Edwards, C., Buckingham, M., *J. Phys. Rev. A*, 1977, Vol. 15, p. 778.
134. Lipa, J. A., Edwards, C., Buckingham, M., *J. Phys. Rev. Lett.*, 1970, Vol. 25, p. 1086.
135. Wuzz, V., Grubic, M., *J. Phys. E., Sci. Instrum.*, 1980, Vol. 13, p. 525.
136. Kruger, K., *Fortschritt-Berichte VDI-Zeitschrift*, Reihe, 1964, Vol. 6, p. 1.
137. Michels, A., Strijland, I. C., *Physica*, 1952, Vol. 18, p. 613.
138. Eucken, A., *Berl. Bericht*, 1912, p. 141.
139. Trautz, M., Trautz, O., *Ann. Phys.*, 1929, Vol. 2, p. 737.
140. Bennewitz, K., Solittgerber, Zs., *J. Phys. Chem.*, 1926, Vol. 124, p. 49.
141. Sage, B. H., Lacey, W. N., *Ind. Eng. Chem.*, 1935, Vol. 27, p. 1484.
142. Maass, O., Geddis, A. Z., *Trans. Roy. Soc. London A*, 1937, Vol. 236, p. 303.
143. Pall, O. B., Broughton, I. W., Maass, O., *Can. J. Res. B*, 1938, Vol. 16, p. 230.
144. Bruant, M. O., Jones, G. O., *Proc. Phys. Soc. Ser. B*, 1953, Vol. 66, p. 421.
145. Hoge, H. J., *J. Res. Nat. Bur. Stand. (U. S.)*, 1950, Vol. 44, p. 321.
146. Anisimov, M. A., Koval'chuk, B. A., Rabinovich, V. A., Smirnov, V. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1975, No. 8, p. 237.
147. Anisimov, M. A., Beketov, V. G., Voronov, V. P., Nagaev, V. B., Smirnov, V. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1982, No. 16, p. 48.
148. Anisimov, M. A., Beketov, V. G., Voronov, V. P., Nagaev, V. B., Smirnov, V. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1982, No. 16, p. 124.
149. Anisimov, M. A., Beketov, V. G., Voronov, V. P., Smirnov, V. A., *Tepl. Vys. Temperatur*, 1982, No. 2, p. 382.
150. Adamov, Sh. P., Anisimov, M. A., Smirnov, V. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1983, No. 18, p. 13.
151. Kiselev, S. B., Khalidov, S.-E., Yudin, A. V., *Inzh. Fiz. Zhurnal*, 1988, Vol. 54, No. 5, p. 797.
152. Nagaev, V. B., Smirnov, V. A., Khalidov, S.-E., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1989, No. 27, p. 20.
153. Adamov, Sh. P., Smirnov, V. A., *Issledovaniya v oblasti nizkotemperaturnoi termometrii i teplofiziki* (Studies in Low-Temperature Thermometry and Thermal Physics), Izd. VNIFTRI, Moscow, 1981, p. 47.
154. Adamov, Sh. P., Anisimov, M. A., Smirnov, V. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1983, No. 18, p. 7.
155. Shmakov, N. G., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1973, No. 7, p. 155.
156. Anisimov, M. A., Koval'chuk, B. A., Rabinovich, V. A., Smirnov, V. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1978, No. 12, p. 86.
157. Karpukhin, G. V., Rykov, V. A., Sarmina, M. D., *Metrologicheskoe obespechenie teplofizicheskikh izmerenii pri nizkikh temperaturakh* (Metrological Devices and Methods for Thermophysical Measurements at Low Temperatures), Dal'standart, Khabarovsk, 1988, Part 2, p. 47.
158. Mikhailov, Yu. P., Ryabushova, T. I., Lysenkov, V. F., *Protsessy i apparaty kriogennoi tekhniki i konditionirovaniya* (Processes and Apparatuses of Cryogenics and Conditioning), LTI im. Lensoveta, Leningrad, 1985, p. 97.
159. Godvinskaya, N. V., Lysenkov, V. F., *Inzh.-Fiz. Zh.*, 1991, Vol. 60, No. 6, p. 1037.
160. Guigo, E. I., Ershova, N. S., Margolin, M. F., *Kholodil'n. Tekh.*, 1978, No. 11, p. 29.
161. Rabusheva, T. I., Ershova, N. S., *Eksperimental'nye znacheniya teploemnosti C<sub>V</sub> propana* (Experimental Values of the Heat Capacity C<sub>V</sub> of Propane), Available from Leningrad. TsNIII, 1979, No. 1111-79.
162. Shmakov, N. G., Gorbunova, V. G., *Issledovaniya v oblasti nizkotemperaturnoi termometrii i teplofiziki* (Studies in Low-Temperature Thermometry and Thermal Physics), Izd. VNIFTRI, Moscow, 1981, p. 89.

163. Shmakov, N. G., Gorbunova, V. G., Chernova, G. N., *Izokhurnaya teploemkost' propana v dvukhfaznom sostoyanii pri temperaturakh ot 90 K do 350 K. Tablitsy standartnykh dannykh* (Tables of Standard data on the Isochoric Heat Capacity of Propane in the Two-Phase State at Temperatures of 90–350 K), Izd. Standartov, Moscow, 1983, No. 38-82.
164. Ryabushcheva, T. N., Guigo, E. I., Petrunina, E. B., *Kholodil'n. Promyshl.*, 1978, No. 11, p. 30.
165. Adamov, Sh. P., Smirnov, V. A., *Teplofizicheskie svoistva chistykh veshchestv i vodnykh rastvorov elektrolitov* (Thermophysical Properties of Pure Substances and Aqueous Solutions of Electrolytes), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1987, p. 61.
166. Adamov, Sh. P., Anisimov, M. A., Kiselev, S. B., Rabinovich, V. A., Smirnov, V. A., *Tepl. Vys. Temperatur*, Available from VINITI, 1980, No. 2618-80
167. Bektov, V. G., *Cand. Sci. (Eng.) Dissertation*, Azizbekov Azerbaijan Inst., 1981.
168. Amirkhanov, Kh. I., Adiabatic Calorimeter, USSR Inventor's Sertificate No. 77653, MKL G No. 25/20, 1948.
169. Amirkhanov, Kh. I., *Doctoral Dissertation*, Leningrad, 1943.
170. Amirkhanov, Kh. I., Stepanov, G. V., Alibekov, B. G., *Izokhurnaya teploemkost' vody i vodyanogo para* (Isochoric Heat Capacity of Water and Steam), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1969, p. 216.
171. Amirkhanov, Kh. I., Stepanov, G. V., Abdulagatov, I. M., Bui, O. A., *Izokhurnaya teploemkost' propilovogo i izopropilovogo spirtov* (Isochoric Heat Capacity of Propyl and Isopropyl alcohols), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1989, p. 195.
172. Amirkhanov, Kh. I., Alibekov, B. G., Vikhrov, D. I., Mirskaya, V. A., *Izokhurnaya teploemkost' i drugie kaloricheskie svoistva uglevodorodov metanovogo ryda* (Isochoric Heat Capacity and Other Caloric Properties of Hydrocarbons of the Methane Series), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1981, p. 254.
173. Vargaftik, N. B., *Teplofizicheskie svoistva zhidkostei and Gases* (Thermophysical Properties of Liquids and Gases), Nauka, Moscow, 1976, p. 720.
174. Defoe, C. G., Furukawa, G. T., *J. Amer. Chem. Soc.*, 1953, Vol. 75, p. 522.
175. Abdulagatov, I. M., Levina, L. N., Zakaryaev, Z. R., Mamchenkova O. N., *J. Chem. Thermodynamics*, 1995, Vol. 27, p. 1385.
176. Abdulagatov, I. M., Kiselev, S. B., Levina, L. N., Zakaryaev, Z. R., Mamchenkova, O. N., *Int. J. Thermophysics*, 1996, Vol. 17, No. 2, p. 423.
177. Abdulagatov, I. M., Levina, L. N., Zakaryaev, Z. R., Mamchenkova, O. N., *Proc. Fourth Asian Thermophysical Properties Conference*, Tokyo, 1995, p. 635.
178. Abdulagatov, I. M., Levina, L. N., Zakaryaev, Z. R., Mamchenkova, O. N., *Fluid Phase Equilibria*, 1996, Vol. 26.
179. Zakar'yaev, Z. R., *O termicheskikh i baricheskikh deformatsiyakh sosudov vysokogo davleniya* (On the Temperature and Pressure Induced Deformations of High-Pressure Vessels), Ruk. dep. v VINITI, No. 559, 1979, No. 11, p. 87.
180. Bochkov, M. M., *Cand. Sci. (Eng.) Dissertation*, Inst. High Pressures, Akad. Nauk SSSR, Moscow, 1985.
181. Amirkhanov, Kh. I., Alibekov, B. G., Polikchronidi, N. G., Batyrova, R. G., *Teplofizicheskie svoistva zhidkostei i gazov* (Thermophysical Properties of Liquids and Gases), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1979, p. 15.
182. Abdulagatov, I. M., Polikchronidi, N. G., Batirova, R. G., *J. Chem. Thermodynamics*, 1994, Vol. 26, p. 1031.
183. Abdulagatov, I. M., Polikchronidi, N. G., Batirova, R. G., *Ber. Bunsenger. Phys. and Chem.*, 1994, Vol. 98, p. 1018.
184. Abdulagatov, I. M., Stepanov, G. V., Bou, O. A., *J. Chem. Thermodynamics*, 1991, Vol. 23, p. 617.
185. Amirkhanov, Kh. I., Abdulagatov, I. M., Alibekov, B. G., Stepanov, G. V., Bou, O. A., *J. Chem. Thermodynamics*, 1988, Vol. 20, p. 513.
186. Abdulagatov, I. M., Vikhrov, D. I., Mirskaya, V. A., *Termodynamicheskie svoistva n-pentana* (Thermodynamic Properties of *n*-Pentane), Izd. Standartov, Moscow, 1990, p. 71.
187. Amirkhanov, Kh. I., Kerimov, A. M., *Teploenergetika*, 1957, No. 9, p. 68.
188. Kerimov, A. M., *Teploenergetika*, 1968, No. 1, p. 60.
189. Amirkhanov, Kh. I., Kerimov, A. M., *Teploenergetika*, 1963, No. 9, p. 61.

190. Amirkhanov, Kh. I., Kerimov, A. M., *Teploenergetika*, 1963, No. 8, p. 64.
191. Abdulagatov, I. M., Mursalov, B. A., Gamzatov, N. M., Physical Chemistry of Aqueous Systems, *Proc. 12th Int. Conference on the Properties of Water and Steam*, H. J. White, J. V. Sengers, D. B. Neumann, and J. C. Bellows, Eds., Begell House, New York, 1995, p. 94.
192. Stepanov, G. V., Bui, O. A., Shakhbanov, K. M., *Zhur. Fiz. Khimii*, 1989, Vol. 63, No. 9, p. 2524.
193. Abdulagatov, I. M., Dvoryanchikov, V. I., Abdurakhmanov, I. M., *Proc. of the 11th Int. Conference on the Properties of Water and Steam*, Pichal, M., Shifner, O., Eds., Hemisphere Pub. Cor., New York, 1989, p. 203.
194. Abdulagatov, I. M., Dvoryanchikov, V. I., *Teploenergetika*, 1990, No. 8, p. 69.
195. Abdulagatov, I. M., Dvoryanchikov, V. I., *J. Chem. Thermodynamics*, 1993, Vol. 25, p. 823.
196. Mursalov, B. A., Bochkov, M. M., *Teplofizicheskie svoistva individual'nykh veshchestv i smesei* (Thermophysical Properties of Pure Substances and Mixtures), 1989, p. 5.
197. Abdulagatov, I. M., Bochkov, M. M., Mursalov, B. A., *Teploenergetika*, 1988, No. 1, p. 67.
198. Amirkhanov, Kh. I., Vikhrov, D. I., Mirskaya, V. A., *Teplofizicheskie svoistva chistykh veshchestv i vodnykh rastvorov elektrolitov* (Thermophysical Properties of Pure Substances and Aqueous Solutions of Electrolytes), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1987, p. 32.
199. Amirkhanov, Kh. I., Polikhronidi, N. G., Alibekov, B. G., Batyrova, R. G., *Teplofizicheskie svoistva veshchestv v kondensirovannom sostoyanii* (Thermophysical Properties of Substances in the Condensed State), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1982, p. 3.
200. Abdulagatov, I. M., Dvoryanchikov, V. I., Mursalov, B. A., *Fluid Phase Equilibria*, 1997 (in press).
201. Abdulagatov, I. M., Bochkov, M. M., Mursalov, B. A., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1989, Vol. 27, p. 95.
202. Kerimov, A. M., Alieva, M. K., *Teplofizicheskie svoistva zhidkostei* (Thermophysical Properties of Liquids), Nauka, Moscow, 1970, p. 172.
203. Kerimov, A. M., Kafarov, T. E., Gamidov, Sh. G., Suleimanov, Ya. M., *Teplofizicheskie svoistva zhidkostei* (Thermophysical Properties of Liquids), Nauka, Moscow 1970, p. 176.
204. Kerimov, A. M., Alieva, M. K., Muradov, A. A., *Teplofizicheskie svoistva zhidkostei* (Thermophysical Properties of Liquids), Nauka, Moscow 1970, p. 179.
205. Amirkhanov, Kh. I., Alibekov, B. G., Polikhronidi, N. G., Batyrova, R. G., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1982, Vol. 16, p. 17.
206. Abdulagatov, I. M., Levina, L. N., Zakar'yaev, Z. R., Mamchenkova, O. N., *Zh. Prikl. Khim.*, 1996, Vol. 69, Vol. 10, p. 1625.
207. Abdulagatov, I. M., Levina, L. N., Zakar'yaev, Z. R., Mamchenkova, O. N., *Dokl. Ross. Akad. Nauk*, 1994, Vol. 339, p. 764.
208. Stepanov, G. V., Shakhbanov, K. A., Bui, O. A., *Teplofizicheskie svoistva individual'nykh veshchestv i smesei* (Thermophysical Properties of Pure Substances and Mixtures), Dagestan. Nauch. Tsentr, Ross. Akad. Nauk, Makhachkala, 1991, p. 58.
209. Stepanov, G. V., Shakhbanov, K. A., Bui, O. A., *Termodinamika fazovykh prevrashchenii i kriticheskikh yavlenii* (Thermodynamics of Phase Transformations and Critical Phenomena), Dagestan. Nauchn. Tsentr, Russian Akad. Nauk, Makhachkala, 1991, p. 8.
210. Oleinik, B. N., *Tochnaya kalorimetriya* (Precise Calorimetry), Izd. Standartov, Moscow, 1973, p. 208.
211. Vasil'ev, Ya. V., Matskevich, N. I., *Teplovoy ekvivalent lineinykh kalorimetricheskikh sistem. Kalorimetriya v adsorbsii i katalize* (Thermal Equivalent of Linear Calorimetric Systems. Calorimetry in Adsorption and Catalysis), A Collection of Research Works, Novosibirsk, 1984, p. 90.
212. Kondrat'ev, G. M., *Teplovye izmereniya* (Thermal Measurements), Mashizdat, Moscow-Leningrad, 1957, p. 244.
213. Hsieh, C. K., Wang, X. A., *Rev. Sci. Instrum.*, 1982, Vol. 53, No. 5, p. 684.
214. Zaka'yaev, Z.R., *Cand. Sci. (Eng.) Dissertation*, Inst. of Problems in Geothermy, Dagestan Division, Russian Academy of Sciences, Makhachkala, Dagestan, Russia, 1994.
215. Gebhardt, E., Becker, M., *Ztschr. Metallk*, 1951, Bd. 42, No. 4, S. 111.
216. Belyaev, N. M., *Soprotivlenie materialov* (Strength of Materials), Gos. Izd. Tekhniko-Teoreticheskoi Literatury, Moscow, 1956, p. 856.

217. Malkov, M. P., Danilov, I. B., *Spravochnik po fiziko-tehnicheskim osnovam glubokogo okhlazdeniya* (A Handbook on the Physicotechnical Fundamentals of Deep Cooling), Moscow-Leningrad, GEI, 1963, p. 416.
218. Kein, V. M., *Konstruirovaniye termoregulyatorov* (Constructing Temperature Regulators), Moscow, 1971, p. 152.
219. Zakar'yaev, Z. R., *Prib. Tekh. Eksp.*, 1986, No. 5, p. 210.
220. *Experimental Thermodynamics*, Butterworths, London, 1968, Vol. 1, p. 295.
221. Zakar'yaev, Z. R., *Teplofizicheskie svoistva chistikh veshchestv i vodnykh rasvorov elektrolitov* (Thermophysical Properties of Pure Substances and Aqueous Solutions of Electrolytes), Dagestan. Filial, Akad. Nauk SSSR, Makhachkala, 1987, p. 68.
222. Amirkhanov, Kh. I., Stepanov, G. V., Zakar'yaev, Z. R., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1982, No. 16, p. 43.
223. Zakar'yaev, Z. R., *Inzh.-Fiz. Zh.*, 1982, Vol. 53, No. 5, p. 796.
224. Bilevich, A. V., Vereshchagin, L. F., Kalashnikov, Ya. A., *Prib. Tekh. Eksp.*, 1961, No. 3, p. 146.
225. Porkhun, A. I., Tsaturyants, A. B., Porkhun, L. D., *Prib. Tekh. Eksp.*, 1976, No. 5, p. 253.
226. Zakar'yaev, Z. R., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials) Dagestan. Filial Akad. Nauk SSSR, Makhachkala, 1979, p. 52.
227. Zakar'yaev, Z. R., *Termicheskie i baricheskie deformatsiih sosudov vysokogo davleniya* (Temperature and Pressure Induced Deformations of High-Pressure Vessels), Available from VINITI, No. 559, Moscow, 1979, p. 7.
228. Zhokhovskii, M. K., *Teoriya i raschet priborov s neuplotnennym porshnem* (Theory and Calculations for Devices with a Nontightened Piston), Moscow, 1960, p. 108.
229. Dul'nev, G. N., *Izv. Akad. Nauk SSSR*, Otd. Tekh. Nauk, 1956, Vol. 7, p. 122.
230. Dul'nev, G. N., Kondrat'ev, G. M., *Izv. Akad. Nauk SSSR*, Otd. Tekh. Nauk, 1955, Vol. 7, p. 201.
231. Gladun, G., *Cryogenics*, 1966, Vol. 6, No. 1, p. 27.
232. Gritsenko, A. N., Buleiko, V. M., Nagaev, V. B., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1984, No. 5, p. 55.
233. Kaye, G. W. C., Laby, T. H., *Tables of Physical and Chemical Constants and some Mathematical Functions*, Longmans, London, 1959, p. 248.
234. Hirshfelder, J. O., Curtiss, C. F., Bird, R. B., *Molecular Theory of Gases and Liquids*, Chap. 3, Wiley, N.Y., 1954.
235. Buckingham, A. D., *Intermolecular Interaction from Diatomic to Biopolymer*, B. Pullmann., Ed., Wiley, Chichester, 1978, Vol. 2, p. 1.
236. Das, G., Wagner, A. F., Wahl, A. C., *J. Chem. Phys.*, 1978, Vol. 68, No. 11, p. 4917.
237. Ree, F. H., Winter, N. W., *J. Chem. Phys.*, 1980, Vol. 71, p. 322.
238. Pritchard, D. E., *J. Chem. Phys.*, 1972, Vol. 56, No. 8, p. 4206.
239. Leonas, V. B., Samuilov, E. V., *Teplofiz. Vys. Temp.*, 1966, Vol. 4, p. 710.
240. Gough, D. W., Maitland, G. C., Smith, E. B., *Mol. Phys.*, 1972, Vol. 24, No. 1, p. 151.
241. Maitland, G. C., Mason, E. A., Vichland, L. A., Wakeham, W. A., *Mol. Phys.*, 1978, Vol. 36, No. 3, p. 797.
242. Abdulagatov, I. M., Alibekov, B. G., *Zh. Fiz. Khim.*, 1982, Vol. 56, No. 2, p. 1162.
243. Abdulagatov, I. M., Akhundov, R. T., Ishkhanov, Yu. B., *Izv. Vyssh. Uchebn. Zaved., Neft' i Gaz*, 1985, No. 6, p. 51.
244. Sokolova, I. A., *Obzory po teplofizicheskim svoistvam veshchestv*, Inst. Vysokikh Temperatur, Akad. Nauk SSSR, Moscow, 1990, No. 6 (86), p. 138.
245. o'Connell, J. P., *Supercritical Fluids, Fundamentals for Applications*, E. Kiran and J. M. N. Levelt Sengers, Eds., NATO ASI Series, London, 1993, Vol. 273, p. 191.
246. Mchugh, M. A., Krukonis, V. J., *Supercritical Fluid Extraction*, Butterworths, Boston, 1986.
247. *Supercritical Science and Technology*, Johnston, K. P., Penninger, J. M. L., Eds., ACS Symposium Series, 406, ACS, Washington, DC, 1989.
248. Penninger, J., M. L., Rados, Z. M., Mchugh, M. A., Krukonis, V. J., *Supercritical Fluid Technology*, Elsevier, N. Y., 1985.
249. Kihara, T., *Rev. Modern Phys.*, 1953, Vol. 25, No. 4, p. 831.
250. Mason, E. A., Spurling, T. N., *The Virial Equation of State*, Pergamon Press, London, 1969.

251. *Physics of Simple Liquids*, Temperley, H. N. Y., Rowlinson, J. S., Rushbrooke, G. S., Eds., North-Holland Pub. Company, Amsterdam, 1968.
252. Japas, M. L., Franck, E. U., *Ber. Bunsenges. Phys. Chem.*, 1985, Vol. 89, p. 793.
253. Boyes, S. J., Weber, L. A., *Int. J. Thermophys.*, 1994, Vol. 15, p. 443.
254. Christoforakos, M., Franck, E. U., *Ber. Bunsenges. Phys. Chem.*, 1986, Vol. 90, p. 780.
255. Heiling, M., Franck, E. U., *Ber. Bunsenges. Phys. Chem.*, 1989, Vol. 93, p. 898.
256. Heiling, M., Franck, E. U., *Ber. Bunsenges. Phys. Chem.*, 1990, Vol. 94, p. 27.
257. Rowlinson, J. S., *Mol. Phys.*, 1963, Vol. 6, p. 75.
258. Kihara, T., *Prog. Theory Phys. Suppl.*, 1967, Vol. 40, p. 177.
259. Kihara, T., *Adv. Chem. Phys.*, 1963, Vol. 5, p. 147.
260. Kihara, T., *Intermolecular Forces*, Wiley, New York, 1976.
261. Wischel, W., *Int. J. Thermophys.*, 1990, Vol. 11, p. 1075.
262. Koide, A., Kihara, T., *J. Chem. Phys.*, 1974, Vol. 5, p. 34.
263. Hoover, A. E., Nagata, I., Leland, T. W., Kobayashi, R., *J. Chem. Phys.*, 1968, Vol. 48, p. 2633.
264. Edalat, M., Lan, S. S., Pany, F., Mansoori, G. A., *Int. J. Thermophys.*, 1980, Vol. 1, p. 177.
265. Sherwood, A. E., Prausnitz, J. M., *J. Chem. Phys.*, 1964, Vol. 41, No. 2, p. 413.
266. Pompe, A., Spurling, T. H., *Virial Coefficients for Mixtures of Gaseous Hydrocarbons*, CSIRO, Australia. Div. Appl. Organic Chem. Tech. Pap. No. 3. 1976.
267. Dymond, J. H., Smith, E. B., *The Virial Coefficients of Pure Gases and Mixtures. A Critical Compilation*, Clarendon Press, Oxford, 1980.
268. Marjorie de Reuck, K., *High Temperatures-High Pressures*, 1985, Vol. 17, p. 201.
269. Wagner, W., Ewers, J., Schmidt, R., *Cryogenics*, 1984, No. 1, p. 37.
270. Kell, G. S., McLaurin, G. E., Whally, E., *Proc. of the 11 th Int. Conference on the Properties of Water and Steam*, Pichal M. and Sifner, O., Eds., Hemisphere Publ. Corp., New York, 1990, p. 99.
271. Keyes, F. G., Smith, L. B., Gerry, H. T., *Proc. Am. Acad. Arts*, 1936, Vol. 70, p. 319.
272. Kell, G. S., McLaurin, G. E., Whally E., *J. Chem. Phys.*, 1968, Vol. 48, p. 3805.
273. Keyes, F. G., *Int. J. Heat Mass Transfer*, 1962, Vol. 5, p. 137.
274. Keenan, J. H., Keyes, F. G., Hill, P. G., Moore, J. G., *Steam Tables*, New York, Wiley, 1969, p. 148.
275. Keyes, F. G., *J. Chem. Phys.*, 1949, Vol. 17, p. 923.
276. LeFevre, E. J., Nightingate, M. R., Rose, J. W., *J. Mech. End. Sci.*, 1975, Vol. 17, p. 243.
277. O'Connell, J. P., Prausnitz, J. M., *Ind. Eng. Chem. Fundam.*, 1970, Vol. 9, p. 579.
278. Michels, A., van Straaten, W., Dawson, *Physica*, 1954, Vol. 20, p. 17.
279. Ayber, R., *Wasserstoff-hemischen Vol-Forch*, 1965, No. 511, p. 1.
280. Sytchev, V. V., Vasserman, A. A., Zagoruchenko, V. A., Kozlov, A. D., Spiridonov, G. A., Zymarnyi, V. A., *Termodynamicheskie svoistva metana* (Thermodynamic Properties of Methane), Izd. Standartov, Moscow, 1979.
281. Griskey, R. G., Canjar, L. N., *AICHE*, 1959, Vol. 5, p. 29.
282. Griskey, R. G., Canjar, L. N., *J. Chem. Eng. Data*, 1963, Vol. 8, p. 341.
283. Pompe, B. A., Spurling, T. H., *Virial Coefficients for Gaseous Hydrocarbons*, CSIRO, Australia. Div. Appl. Organic Chem. Tech. Pap. No. 1, Melbourne, 1974, p. 103.
284. Starling, K. E., *Fluid Thermodynamics Properties for Light Petroleum Systems*, Cult Publishing, Houston, TX, 1973.
285. Kurumov, D. S., Grigor'ev, B. A., Rastorguev, Ya. L., *Automatizatsiya i elektrofikaziya obiektov neftyanoi promyshlennosti*, Grozny, 1978, p. 49.
286. Bich, E., Lober, T., Milat, J., *Fluid Phase Equilibria*, 1992, Vol. 75, p. 149.
287. McGlashan, M. L., Potter, D. J. B., *Proc. Royal Soc. London. A*, 1962, Vol. 267, p. 478.
288. Collings, A. F., Laughlin, I. L., *J. Chem. Phys.*, 1980, Vol. 73, No. 7, p. 3390.
289. Lambert, J. D., Roberts, G., A. H., Rowlinson, J. S., Wilkinson, V., *J. Proc. Royal Soc.*, 1952, Vol. 196, p. 113.
290. Lee, B., Edmister, W. C., *Ind. Eng. Chem. Fundam.*, 1971, Vol. 10, p. 32.
291. Dymond, J. H., *Fluid Phase Equilibria*, 1986, Vol. 27, p. 1.
292. Rettich, T. R., Battino, R., Wilhelm, E., *J. Solution Chem.*, 1984, Vol. 13, p. 335.
293. Rigby, M., Prausnitz, J. M., *J. Phys. Chem.*, 1968, Vol. 72, p. 330.
294. Richards, P., Wormald, C. J., Yerlett, T. K., *J. Chem. Thermodynamics*, 1981, Vol. 13, p. 623.

346 REFERENCES

295. Aoyagi, K., Song, K. Y., Sloan, D., Dharmawardhana, P. B., Kobayashi, R., *Proc. 5th Annual Conventional Gas Proces. Assoc.*, Tulsa, Oklahoma, 1979.
296. Wormald, C. J., Lancaster, N. M., *J. Chem. Soc. Faraday Trans. I*, 1988, Vol. 84, p. 3141.
297. Smith, G. R., Sellars, A., Yerltt, T. K., Wormald, C. J., *J. Chem. Thermodynamics*, 1983, Vol. 15, p. 29.
298. Smith, G. R., Fahy, M. J., Wormald, C. J., *J. Chem. Thermodynamics*, 1984, Vol. 16, p. 825.
299. Wang, W., Khoshbarchi, M. K., Vera J. H., *Fluid Phase Equilibria*, 1989, Vol. 21, p. 25.
300. Barboy, B., Gelbort, W. M., *J. Chem. Phys.*, 1979, Vol. 71, p. 3053.
301. Gibbons, R. M., *Mol. Phys.*, 1970, Vol. 18, p. 809.
302. Kaul, B. K., Donohue, M. P., Prausnitz, J. M., *Fluid Phase Equilibria*, 1980, Vol. 4, p. 171.
303. Donohue, M. O., Prausnitz, J. M., *AIChEJ*, 1978, Vol. 24, p. 849.
304. Morachevskii, A. G., Smirnova, N. A., Piotrovskaya, E. N., et al., Ed. Morachevskii, A. G., *Termodinamika ravnovesiya zhidkost'-par* (Thermodynamics of Liquid-Vapor Equilibria), Khimiya, Leningrad, 1989.
305. Tsonopoulos, C., Dymond, J. H., Szafranski, A. M., *Pure and Appl. Chem.*, 1989, Vol. 61, No. 8, p. 1387.
306. Eubank, P. T., Joffrion, L. L., Patel, M. R., Warawhy, W., *J. Chem. Thermodynamics*, 1988, Vol. 20, p. 1009.
307. Wong, D., S. H., Sandler, S. I., *AIChEJ*, 1992, Vol. 38, p. 671.
308. Orbey, H., Sandler, S. I., *Int. J. Thermophysics*, 1995, Vol. 16, p. 695.
309. Hayden, J. G., O'Connell, J. P., *Ind. Eng. Chem. Proc. Des. Devel.*, 1975, Vol. 14, No. 3, p. 209.
310. Millat, J., Hendl, H., Bich, E., *Int. J. Thermophysics*, 1994, Vol. 15, p. 903.
311. Grigor'ev, B. A., Kurumov, D. S., Vasil'ev, Yu. L., *Zh. Fiz. Khim.*, 1986, Vol. 60, p. 14.
312. Hajjav, R. F., Kay, W. B., Leverett, G. F., *J. Chem. End. Data*, 1969, Vol. 14, p. 377.
313. Smith, L. B., Beattie, J. A., and Kay W. C., *J. Am. Chem. Soc.*, 1937, Vol. 59, p. 1587.
314. Van Pelt, A., Peters, C. J., de Swaan, J. A., *J. Chem. Phys.*, 1993, Vol. 99, p. 9920.
315. Van Pelt, A., Peters, C. J., de Swaan, J. A., *Fluid Phase Equilibria*, 1993, Vol. 84, p. 23.
316. Peters, C. J., de Roo, J. L., de Swaan, J. A., *Fluid Phase Equilibria*, 1992, Vol. 72, p. 251.
317. Gasem, K., A. M., Robinson, R. L., *Fluid Phase Equilibria*, 1990, Vol. 58, p. 13.
318. Ponce-Ramirez, L., Lira-Galeuna, C., Tapia-Medina., *Fluid Phase Equilibria*, 1992, Vol. 70, p. 1.
319. Kim, C. H., Vimalchand, P., Donohue, M. D., Sandler, S. I., *AIChE J.*, 1986, Vol. 32, p. 1726.
320. Anderko, A., *Fluid Phase Equilibria*, 1990, Vol. 61, p. 145.
321. van Pelt, A., *Ph. D. Thesis*, Delft University of Technology, 1992.
322. Sandler, S. I., Supercritical Fluids: Fundamentals for Application, E. Kiran and J. M. H. Levelt Sengers, Eds., *NATO ASI Series*, Boston, 1994, Vol. 273, p. 147.
323. Vukalovich, M. P., Novikov, I. I., *Uravnenie sostoyaniya real'nykh gazov* (Equation of State of Real Gases), Gosenergoizdat, Moscow, 1948.
324. Abdulagatov, I. M., Doctoral Dissertation (Chem.), Moskovskii gosudarstvennyi energeticheskii institut, Moscow, 1991.
325. Batalin, O. Yu., Brusilovskii, A. N., Zakharov, M. Yu., *Fazovye ravnovesiya v sistemakh prirodnykh uglevodorodov* (Phase Equilibria in Systems of Natural Hydrocarbons), Nedra, Moscow, 1992, p. 272.
326. Wang, W., Kroshkarchi, M. K., Vera, J. H., *Fluid Phase Equilibria*, 1996, Vol. 115, p. 25.
327. Labes, P., Daridon, J. L., Lagourette, B., Saint-Guirons, H., *Int. J. Thermophys.*, 1994, Vol. 15, No. 5, p. 803.
328. Rabinovich, V.A., Sheludyak, Yu. E., *Teplofiz. Vys. Temp.*, 1996, Vol. 34, No. 5, p. 796.
329. Van der Waals, J. D., Kohnstamm, P., *Lehrbuch der Thermodynamik*, Vol. 1, Maass and Van Suchten, Amsterdam, 1908, Vol. 2, Barth, Leipzig, 1912.
330. Redlich, O., Kwong, J. N. S., *Chem. Rev.*, 1949, Vol. 44, p. 233.
331. Soave, G., *Chem. Eng. Sci.*, 1972, Vol. 27, p. 1197.
332. Peng, D. Y., Robinson, D. B., *Ind. Eng. Chem. Fundam.*, 1976, Vol. 15, p. 59.
333. Fuller, G. G., *Ind. Eng. Chem. Fundam.*, 1976, Vol. 15, p. 254.
334. Schmidt, G., Wenzel, H., *Chem. Eng. Science*, 1980, Vol. 35, p. 1503.
335. Harmens, A., Knapp, H., *Ind. Eng. Chem. Fund.*, 1980, Vol. 19, p. 291.
336. Patel, N. C., Teja, A. S., *J. Chem. Eng. Sci.*, 1982, Vol. 37, p. 463.
337. Mansoori, G. A., Ely, J. F., *J. Chem. Phys.*, 1985, Vol. 82, p. 406.

338. Guggenheim, E. A., *Mol. Phys.*, 1965, Vol. 9, p. 199.
339. Sadus, R. J., *High Pressure Phase Behavior of Multicomponent Fluid Mixtures*, Elsevier, Amstrdam, 1992.
340. Sadus, R. J., *AIChEJ*, 1994, Vol. 40, p. 1376.
341. Sadus, R. J., Young, C. L., *Chem. Eng. Sci.*, 1988, Vol. 43, p. 883.
342. Park, S. J., Kwak, T. Y., Mansoori, G. A., *Int. J. Thermophysics*, 1987, Vol. 8, p. 449.
343. Lielmezs J., Merrian L. H. *Thermochim. Acta*. 1986, Vol. 105, p. 131.
344. Cheok, N.-T., Atwal, V. S., Lielmezs, J. *Thermochim. Acta*. 1986, Vol. 106, p. 201.
345. Lielmezs, J., Beatson, G. A., *Chem. Eng. Sci.*, 1989, Vol. 40, p. 1994.
346. Abbott, M. M., *Adv. Chem. Ser.*, 1979, Vol. 182, p. 47.
347. Patel, N. C., *Int. J. Thermophysics*, 1996, Vol. 17, No. 8. C. 673.
348. Gibbons, R. M., Laughton, A. P., *J. Chem. Soc. Faraday Trans. II*, 1984, Vol. 80, p. 1019.
349. Melhem, G. A., Saini R., Goodwin, B. M., *Fluid Phase Equilibria*, 1989, Vol. 47, p. 189.
350. Twu, C. H., Bluck, D., Cunningham, J. R., Coon, J. E., *Fluid Phase Equilibria*, 1991, Vol. 69, p. 33.
351. Peneloux, A., Rauzy, E., Freze, R., *Fluid Phase Equilibria*, 1982, Vol. 8, p. 7.
352. Anisimov, M. A., *Critical Phenomena in Liquids and Liquid Crystals*, Gordon and Breach, Philadelphia, 1991.
353. Sengers, J. V., Levelt Sengers, J. M. H., *Progress in Liquid Physics*, ed. by C. A. Croxton, Wiley, New York, 1978, p. 103.
354. Rabinovich, V. A., Shcheludyak, Yu., *Inzh.-Fiz. Zh.*, 1993, Vol. 64, No. 3, p. 341.
355. Albright, P. C., Sengers, J. V., Nicoll, J. F., Ley-Koo, M. A., *Int. J. Thermophysics*, 1986, Vol. 7, p. 75.
356. Jin, G.-X., Tang, S., Sengers, J. V., *Phys. Rev. E*, 1993, Vol. 47, No. 1, p. 388.
357. Albright, P. C., Chen, Z. Y., Sengers, J. V., *Phys. Rev. B*, 1987, Vol. 36, p. 847.
358. Beattie, J. A., Bridgeman, O. C., *Proc. Am. Acad Arts. Sci.*, 1928, Vol. 63, p. 229.
359. Benedict, M., Webb, G. B., Rubin, L. C., *J. Chem. Phys.*, 1940, Vol. 8, p. 334.
360. Strobridge, T. R., *Thermodynamic Properties of Nitrogen from 64 to 300 K between 0.1 and 200 atm*, NBS Technical Note (U. S.), No. 129. 1962.
361. Bender, E., *5th Symp. on Thermophysical Property ASME*, No. 4. 1970.
362. Starling, K. E., *Hydrocarbon Process*, 1971, Vol. 50, p. 101.
363. Jacobsen, R. T., Stewart, R. B., *J. Phys. Chem.*, Ref. Data, 1973, Vol. 2, p. 767.
364. Schmidt, R., Wagner, W. A., *Fluid Phase Equilibria*, 1985, Vol. 19, p. 175.
365. Prüß, A., Wagner, W., Physical Chemistry of Aqueous Systems, *Proc. of the 12th Int. Conference on the Property of Water and Steam*, H. J. White, J. V. Sengers, D. B. Neumann, and J. C. Bellows, Eds., Begell House, New York, 1995, p. 66.
366. Sychev, V. V., Vasserman, A. A., Zagoruchenko, V. A., Kozlov, A. D., Spiridonov, G. A., Tsymarnyi, V. A., *Termodinamicheskie svoistva metana* (Thermodynamic Properties of Methane), Izd. Standartov, Moscow, 1982, p. 303.
367. Goodwin, R. D., *Adv. Cryogenic Eng.*, 1978, Vol. 23, p. 611.
368. Benedict, M., Webb, G. B., Rubin, L. C., *J. Chem. Phys.*, 1942, Vol. 10, p. 747.
369. Lee, B. I., Kesler, M. G., *AIChEJ*, 1975, Vol. 21, p. 510.
370. Reid, R. S., Prausnitz, J. M., Poling, B. E., *The Properties of Gases and Liquids*, McGraw Hill, No. 4, 1986.
371. Georgeton, G. K., Teja, A. S., *Chem. Eng. Sci.*, 1989, Vol. 44, p. 2703.
372. Prikhod'ko, I. V., Viktorov, A. I., Smironova, N. A., *Zh. Prikl. Khim.*, 1989, Vol. 62, No. 12, p. 2734.
373. Prikhod'ko, I. V., Shmel'tser, Yu., Viktorov, A. I., Smironova, N. A., *Zh. Prikl. Khim.*, 1989, Vol. 62, No. 12, p. 2738.
374. Viktorov, A. I., Kudryavtseva, L., Kuus, M., *Izv. Akad. Nauk. Estonii, Khim.*, 1989, Vol. 38, No. 3, p. 178.
375. Prikhod'ko, I. V., de Loos Th. W., Victorov, A. I., *Int. J. Thermophys.*, 1995, Vol. 16, No. 5, p. 1278.
376. Smirnova, N. A., Viktorov, A. I., *Zhur. Prikl. Khimii*, 1989, Vol. 60, No. 5, p. 1091.
377. Smirnova, N. A., Victorov A. I., *Fluid Phase Equilibria*, 1993, Vol. 82, p. 333.
378. Smirnova, N. A., Victorov A. I., *Fluid Phase Equilibria*, 1987, Vol. 34, p. 235.
379. Prikhod'ko, I. V., Doctoral Dissertation, St.-Petersburg State University, St.-Petersburg, 1992.
380. Johnston, J. K., Gubbins K. E. *Mol. Phys.* 1992, Vol. 77, p. 1033.

**348 REFERENCES**

381. Landau, L. D., Lifshitz, E. M., *Statistical Physics*, Parts 1 and 2, 3rd ed., Pergamon Press, Oxford, 1980.
382. Findenegy, G. H., *Statistische Thermodynamik*, Dr. Dietrich Steinokopff Verlay, Darmstadt, Germany, 1985.
383. Sandler, S. I., *Fluid Phase Equilibria*, 1985, Vol. 19, p. 233.
384. Carnahan, N. F., Starling, K. E., *AIChEJ*, 1972, Vol. 18, p. 1184.
385. Viktorov, A. I., Kuranov, G. L., Morachevskii, A. G., Smirnova, N. A., *Zhur. Prikl. Khimii*, 1991, Vol. 64, No. 5, p. 961.
386. Weeks, J. D., Chandler, D., Andersen, H. C., *J. Chem. Phys.*, 1971, Vol. 54, p. 5237.
387. Carnahan, N. F., Starling, K. E., *J. Chem. Phys.*, 1970, Vol. 53, p. 600.
388. Monsori, G. A., Carnahan, N. F., Starling, K. E., Leland, T. W., *J. Chem. Phys.*, 1971, Vol. 54, p. 1523.
389. Boublík, T., *J. Chem. Phys.*, 1975, Vol. 63, p. 4084.
390. Chen, C. H., Greenkorn, R. H., Chao, K. C., *AIChEJ*, 1983, Vol. 29, p. 560.
391. Alder, B. J., Young, D. A., Mark, M. A., *J. Chem. Phys.*, 1972, Vol. 56, p. 3013.
392. Tildesley, D. J., Streett, W. D., *Mol. Phys.*, 1980, Vol. 41, p. 85.
393. Honnell, K. G., Hall, C. K., *J. Chem. Phys.*, 1989, Vol. 90, p. 1841.
394. Beret, S., Prausnitz, J. M., *AIChE J.*, 1975, Vol. 21, p. 1123.
395. Beret, S., Prausnitz, J. M., *Macromolecules*, 1975, Vol. 8, p. 878.
396. Donohue, M. P., Prausnitz, J. M., *Statistical Thermodynamics of Solutions in Natural Gas and Petroleum Refining*, Report RR-26, Gas Processors Assn., 1977.
397. Donohue, M. P., Vimalchand, P., *Fluid Phase Equilibria*, 1988, Vol. 40, p. 185.
398. Liu, D. D., Prausnitz, J. M., *Ind. Eng. Chem. Prod. Des. Dev.*, 1980, Vol. 19, p. 205.
399. Liu, D. P., Prausnitz, J. M., *J. Appl. Polymer Sci.*, 1979, Vol. 24, p. 725.
400. Gmehling, J., Liu, D. D., Prausnitz, J. M., *Chem. Eng. Sci.*, 1979, Vol. 34, p. 951.
401. Lee, K. H., Lombardo M., Sandler S. I., *Fluid Phase Equilibria*, 1985, Vol. 21, p. 177.
402. Vimalchand, P., Thomas, A., Ecovomou, I. G., Donohue, M. D., *Fluid Phase Equilibria*, 1992, Vol. 73, p. 39.
403. Sandler, S. I., *Fluid Phase Equilibria*, 1985, Vol. 19, p. 233.
404. Prigogine, I., *The Molecular Theory of Solutions*, North-Holland, Amsterdam, 1957.
405. Lin, H. M., Kim, H., Guo, T. M., Chao, K. S., *Fluid Phase Equilibria*, 1983, Vol. 13, p. 143.
406. Kim, H., Lin, H. M., Chao, K. C., *Ind. Eng. Chem. Fund.*, 1986, Vol. 25, p. 75.
407. Chen, C. H., Kreglewski, A., *Phys. Chem.*, 1977, Vol. 81, p. 1048.
408. Cotterman, R. L., Schwarta, B. J., Prausnitz, J. M., *AIChEJ*, 1986, Vol. 32, p. 1787.
409. Cotterman, R. L., Prausnitz, J. M., *AIChEJ*, 1986, Vol. 32, p. 1799.
410. Dimitrelis, D., Prausnitz, J. M., *Chem. Eng. Sci.*, 1990, Vol. 45, p. 1503.
411. Chapman, W. G., Gubbins, K. E., Jackson, G., Radosz, M., *Ind. Eng. Chem. Res.*, 1990, Vol. 29, p. 1709.
412. Huang, S. H., Radosz, M., *Ind. Eng. Chem. Res.*, 1990, Vol. 29, p. 2284.
413. Chapman, W. G., *J. Phys. Chem.*, 1990, Vol. 93, p. 4299.
414. Wertheim, M. S., *J. Stat. Phys.*, 1984, Vol. 35, p. 19.
415. Wertheim, M. S., *J. Stat. Phys.*, 1986, Vol. 42, p. 477.
416. Wertheim, M. S., *J. Chem. Phys.*, 1986, Vol. 85, p. 2929.
417. Fisher, M. E., *Critical Phenomena*, Lecture Notes in Physics, 1982, Vol. 186, p. 1.
418. *Phase Transitions: Cargese 1980*, Ed. by M. Levy, J. C. Le Guillou, and J. Zinn-Justin, Plenum, New York, 1981.
419. Anisimov, M. A., Rabinovich, V. A., Sychev, V. V., *Termodinamika kriticheskogo sostoyaniya individual'nykh veshchestv* (Thermodynamics of the Critical State of Individual Substances), Energoatomizdat, Moscow, 1990, p. 190.
420. Sengers, J. V., Critical Phenomena, *Proc. of the Int. School "Enrico Fermi"*, Course L. M. S. Green, Ed. AP. New York, 1971, p. 445.
421. Kiselev, S. B., *Obzory po teplofizicheskim svoistvam veshchestv*, Inst. Vysokikh Temperatur, Akad. Nauk SSSR, Moscow, 1989, No. 2 (76), p. 148.

422. Anisimov, M. A., Kiselev, S. B., Thermophysical properties of liquid and liquid solutions in critical region, *Sov. Tech. Rev. Ser. B. Term. Phys.*, Harwood Academic Publisher, New York. 1987, Vol. 1, p. 337.
423. Alibekov, B. G., Abdulagatov, I. M., *Obzory po teplofizicheskim svoistvam veshchestv*, Inst. Vysokikh Temperatur, Akad. Nauk SSSR, Moscow, 1988, No. 2 (70), p. 109.
424. Anisimov, M. A., Kiselev, S. B., Sengers, J. V., Tang, S., *Physica A.*, 1992, Vol. 188, p. 487.
425. Sengers, J. V., *Supercritical Fluids: Fundamentals for Application*, Ed. by E. Kiran and J. M. H. Levelt-Sengers, Dordrecht, Kluwer, 1994, Vol. 273, p. 231.
426. Kadanoff, L. P., *Physica*, 1966, Vol. 2, p. 263.
427. Potashinskii, A. Z., Pokrovskii, V. L., *Zh. Eksp. Teor. Fiz.*, 1966, Vol. 50, No. 2, p. 439.
428. Migdal, A. A., *Zh. Eksp. Teor. Fiz.*, 1968, Vol. 55, No. 5, p. 1964.
429. Polyakov, A. M., *Zh. Eksp. Teor. Fiz.*, 1986, Vol. 55, No. 3, p. 1026.
430. Wilson, K. G., *Phys. Rev.*, 1971, Vol. 4, No. 9, p. 3174.
431. Wilson, K., Kogut, J., *The Renormalization Group and the  $\epsilon$ -Expansion*, Wiley, New York, 1974.
432. Ma, S., *Modern Theory of Critical Phenomena*, Reading, Benjamin, Mass., 1976.
433. Potashinskii, A. Z., Pokrovskii, V. L., *Fluktuatsionnaya teoriya fazovykh perekhodov* (Fluctuational Theory of Phase Transitions), Nauka, Moscow, 1982, p. 381.
434. Fisher, M. E., *The Nature of Critical Points*, Boulder, University of Colorado Press, Colo., 1965.
435. Anisimov, M. A., Voronel', A. V., Gorodetskii, E. E., *Zh. Eksp. Teor. Fiz.*, 1971, Vol. 60, No. 3, p. 1117.
436. Anisimov, M. A., Berestov, A. T., Kiselev, S. B., *Zh. Eksp. Teor. Fiz.*, 1982, Vol. 82, No. 4, p. 1147.
437. Potashinskii, A. Z., Pokrovskii, V. L., Khokhlachev, S. B., *Zh. Eksp. Teor. Fiz.*, 1972, Vol. 63, No. 4, p. 1521.
438. Povodyrev, A. A., *Ph. Dr. Thesis*, Inst. of High Temperatures, Moscow, 1995.
439. Fisher, M. E., *Phys. Rev.*, 1968, Vol. 176, No. 1, p. 257.
440. Kiselev, S. B., *Ph. Dr. Thesis*, Inst. of High Temperatures, Moscow, 1989.
441. Fakhretdinov, I. A., Chalyi, A. V., *Izv. Vyssh. Uchebn. Zaved., Fiz.*, 1976, No. 1, p. 35.
442. Barantsev, V. G., Kuz'min, V. D., *Fizika zhidkogo sostoyaniya* (Physics of Liquid State), Vysshaya Shkola, Kiev, KGU, 1977, p. 32.
443. Thompson, C. J., *J. Math. Phys.*, 1966, Vol. 7, No. 3, p. 531.
444. Mikulinskii, M. A., *Usp. Fiz. Nauk*, 1973, Vol. 110, No. 2, p. 213.
445. Gorodetskii, E. E., Mikulinskii, M. A., *Zh. Eksp. Teor. Fiz.*, 1974, Vol. 66, No. 3, p. 986.
446. Leung, S. S., Griffiths, R. S., *Phys. Rev. A*, 1973, Vol. 8, No. 5, p. 2670.
447. Moldover, M. R., Gallagher, J. S., *AIChEJ*, 1978, Vol. 24, No. 2, p. 267.
448. Levelt-Sengers, J. M. H., *Pure and Appl. Chem.*, 1983, Vol. 55, No. 3, p. 437.
449. Levelt-Sengers, J. M. H., Morrison, G., Chang, R. F., *Fluid Phase Equilibria*, 1983, Vol. 14, p. 19.
450. Chang, R. F., Levelt-Sengers, J. M. H., *J. Phys. Chem.*, 1986, Vol. 21, p. 5421.
451. Sengers, J. V., Levelt-Sengers, J. M. H., *Ann. Rev. Chem.*, 1986, Vol. 37, p. 189.
452. Onuki, A. J., *Low Temp. Phys.*, 1985, Vol. 61, No. 1/2, p. 101.
453. Rainwater, J. C., Willumsson, F. R., *Int. J. Thermophysics*, 1986, Vol. 7, No. 1, p. 65.
454. D'Arrigo, G., Mistura, L., Tartaglia, P., *Phys. Rev. A*, 1975, Vol. 12, No. 6, p. 2587.
455. Chang, R. F., Doiron, T., *Int. J. Thermophysics*, 1983, Vol. 4, No. 4, p. 337.
456. Chang, R. F., Levelt-Sengers, J. M. H., Doiron, T., Jones, J., *J. Chem. Phys.*, 1983, Vol. 79, No. 6, p. 3058.
457. Kukarin, V. F., Kuskova, N. V., Martynets, V. G., Matizen, E. V., *Inzh.-Fiz. Zh.*, 1986, Vol. 50, No. 1, p. 71.
458. Kiselev, S. B., Povodyrev, A. A., *Teplofiz. Vys. Temp.*, 1997 (in press).
459. Povodyrev, A. A., Kiselev, S. B., Anisimov, M. A., *Int. J. Thermophys.*, 1993, Vol. 14, No. 6, p. 1187.
460. Matsche, D. E., Thodos, J., *J. Chem. Eng. Data*, 1962, Vol. 7, p. 232.
461. Bagnuls, C., Bervilier, C., *J. de Phys. Lett.*, 1984, Vol. 45, No. 3, p. 95.
462. Bagnuls, C., Bervilier, C., *Phys. Rev. B*, 1985, Vol. 31, No. 11, p. 7209.
463. Bagnuls, C., Bervilier, C., Neiron, D. I., Nickel, B. G., *Phys. Rev. B*, 1987, Vol. 35, No. 7, p. 3585.
464. Bagnuls, C., Bervilier, C., Garrabos, Y., *J. de Phys. Lett.*, 1984, Vol. 45, No. 3, p. 127.
465. Kiselev, S. B., *Teplofiz. Vys. Temp.*, 1989, Vol. 29, No. 1, p. 187.
466. Kiselev, S. B., Kostukova, I. G., Povodyrev, A. A., *Int. J. Thermophysics*, 1991, Vol. 12, No. 5, p. 877.
467. Kiselev, S. B., Sengers, J. V., *Int. J. Thermophys.*, 1993, Vol. 14, No. 1, p. 1.
468. Nicoll, J. F., Albright, P. C., *Phys. Rev. B*, 1985, Vol. 31, No. 7, p. 4576.

## 350 REFERENCES

469. Wegner, F. J., *Phys. Rev. B*, 1972, Vol. 5, No. 12, p. 4529.
470. Anisimov, M. A., Kiselev, S. B., Kostukova, I. G., *Int. J. Thermophys.*, 1985, Vol. 6, No. 5, p. 465.
471. Anisimov, M. A., Kiselev, S. B., Kostyukova, I. G., *Teplofiz. Vys. Temp.*, 1987, Vol. 25, No. 1, p. 31.
472. Anisimov, M. A., Kiselev, S. B., Kostyukova, I. G., *Teplofizicheskie svoistva veshchestv i materialov* (Thermophysical Properties of Substances and Materials), Izd. Standartov, Moscow, 1989, Vol. 27, p. 6.
473. Nicoll, J. F., *Phys. Rev. A*, 1981, Vol. 24, No. 4, p. 2203.
474. Nicoll, J. F., Bhattacharjee, J. K., *Phys. Rev. B*, 1981, Vol. 23, No. 4, p. 389.
475. Bruce, A. D., Wallace, D. J., *J. Phys. A*, 1976, Vol. 9, No. 7, p. 1117.
476. Nelson, D. R., *Phys. Rev. B*, 1975, Vol. 11, p. 3504.
477. Nelson, D. R., Domany, E., *Phys. Rev. B*, 1976, Vol. 13, p. 236.
478. Chen, Z. Y., Albright, P. C., Sengers, J. V., *Phys. Rev. A*, 1990, Vol. 41, p. 3161.
479. Chen, Z. Y., Abbaci, A., Tang, S., Sengers, J. V., *Phys. Rev. A*, 1990, Vol. 42, p. 4470.
480. Tang, S., Sengers, J. V., Chen, Z. Y., *Phys. A*, 1991, Vol. 179, p. 344.
481. Ley-Koo, M., Green, M. S., *Phys. Rev. A*, 1981, Vol. 23, No. 5, p. 2650.
482. Neuwman, K. E., Riedel, E. K., *Phys. Rev. B*, 1984, Vol. 30, p. 6615.
483. Luettmer-Strathmann, J., Tang, S., Sengers, J. V., *Fluid Phase Equilibria*, 1992, Vol. 75, p. 39.
484. Abdulagatov, I. M., Polikchronidi, N. G., Batyrova, R. G., Dokl. Ross. Akad. Nauk, 1994, Vol. 336, No. 2, p. 202.
485. Liu, A. J., Fisher, M. E., *Physica A*, 1989, Vol. 156, p. 35.
486. Levelt-Sengers, J. M. H., Kamgar-Parsi, B., Balfour, F. W., Sengers, J. V., *J. Phys. Chem., Ref. Data*, 1983, Vol. 12, p. 1.
487. van Pelt, A., Sengers, J. V., *J. of Supercritical Fluids*, 1995, Vol. 8, p. 81.
488. Tang, S., Jin, G. X., Sengers, J. V., *Int. J. Thermophys.*, 1991, Vol. 12, No. 3, p. 515.
489. Tang, S., Sengers, J. V., *J. of Supercritical Fluids*, 1991, Vol. 4, p. 209.
490. Luettmer-Strathmann, J., Tang, S., Sengers, J. V., *J. Chem. Phys.*, 1992, Vol. 97, p. 2705.
491. Bischoff, J. L., Rosenbauer, R. J., *Geochimica et Cosmochimica Acta*, 1988, Vol. 52, p. 2121.
492. Marshall, W. L., Jones, E. V., *J. Inorg. Nucl. Chem.*, 1974, Vol. 36, p. 2313.
493. Sourirajan, S., Kennedy, G. C., *Amer. J. of Science*, 1962, Vol. 260, p. 115.
494. öLander, A., Liander, H., *Acta. Chem. Scand.*, 1950, Vol. 4, p. 1437.
495. Scröer, E. Z., *Phys. Chem.*, 1927, Vol. 129, p. 79.
496. Rosenbauer, R. J., Bischoff, J. L., *Geochimica et Cosmochimica Acta*, 1987, Vol. 51, p. 2349.
497. Khaibullin, K. H., Borisov, N. M., *Teplofiz. Vys. Temp.*, 1966, Vol. 4, p. 518.
498. Khaibullin, K. H., *Tables of Thermodynamic Relationships of Gas and Vapours. Liquid-Vapour Solutions of the NaCl+H<sub>2</sub>O System*, Standards Press, Moscow, 1980, p. 80.
499. Urusova, M. A., *Russian J. Inorg. Chem.*, 1975, Vol. 20, p. 1717.
500. Urusova, M. A., *Russian J. Inorg. Chem.*, 1974, Vol. 19, p. 450.
501. Bischoff, J. L., Rosenbauer, R. J., *Geochimica et Cosmochimica Acta*, 1986, Vol. 50, p. 1437.
502. Tkachenko, S. J., *5th Symp. on Solubility Phenomena*, Inst. Inorg. Chem. of the RAN, Moscow, 1992, p. 52.
503. Tkachenko, S. I., Shmulovich, K. I., *Dokl. Ross. Akad. Nauk*, 1992, Vol. 326, No. 6, p. 1055.
504. Oakes, C. S., Bodnar, R. J., Simonson, J. M., Pitzer, K. S., *Int. J. Thermophys.*, 1995, Vol. 16, No. 2, p. 483.
505. Pitzer, K. S., Tanger, J. S., *Chem. Phys. Lett.*, 1989, Vol. 156, p. 418.
506. Pitzer, K. S., Bischoff, J. L., Rosenbauer, R., *J. Chem. Phys. Lett.*, 1981, Vol. 134, p. 60.
507. Pitzer, K. S., *Acc. Chem. Res.*, 1990, Vol. 23, p. 333.
508. Belyakov, M. Y., Kiselev, S. B., *Physica A*, 1992, Vol. 190, p. 75.
509. Wilson, K. G., Kogut, J., *Phys. Rev.*, 1974, Vol. 12, p. 75.
510. Brezin, E., Guillou Le, J. C., Zinn-Justin, J., *Phase Transitions and Critical Phenomena*, C. Domb and M. S. Green, Eds., New York, 1976, Vol. 6, p. 125.
511. Rudnic, J., Neslon, D. R., *Phys. Rev. B*, 1976, Vol. 13, p. 2208.
512. Bagnuls, C., Berviller, C., *Phys. Lett. A*, 1986, Vol. 115, p. 84.
513. Patel, M. R., Holste, J. C., Hall, K. R., Eubank, P. T., *Fluid Phase Equilibria*, 1987, Vol. 36, p. 279.
514. Vukalovich, M. P., Trakhtengert, M. S., Spiridonov, G. A., *Teploenergetika*, 1967, Vol. 14, p. 65.
515. Hill, P. G., MacMillan, R. O., *Ind. Eng. Chem. Res.*, 1988, Vol. 27, p. 874.
516. Douslin, D. R., Harrison, R. H., Moore, R. T., McCullough, J. P., *J. Chem. Eng. Data*, 1964, Vol. 9, p. 358.
517. Al-Bizreh, N., Wormald, C. J., *J. Chem. Thermodinamics*, 1978, Vol. 10, p. 231.