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STUDY OF THE DENSITY AND THERMAL COEFFICIENTS OF "PALCHIQ-OBA" THERMAL WATER IN KHACHMAZ DISTRICT OF AZERBAIJAN AT VARIOUS PRESSURES AND TEMPERATURES

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ABSTRACT

The presented study examines the temperature and pressure-dependent variations in the density of the geothermal water known as "Palchyg-oba," located in the Khachmaz district of Azerbaijan. The experiments were conducted using a high-pressure, high-temperature DMA HPM vibrating densimeter within the temperature range of T = (278.15÷373.15) K and the pressure interval of p = (0.1÷40) MPa.
The measuring unit of the device primarily comprises a magnetic measurement system, a DMA HPM Density Meter chamber equipped with a Hastelloy C-276 vibrating tube, an interferometer, and the high-pressure, high-temperature mPDS2000V3 control system (Anton Paar, Austria).
The obtained results are presented in graphical form. The DMA HPM Density Meter registers the oscillation period and temperature, transmitting these data to the IBM PC–based computing system, where the parameters can be monitored continuously. Simultaneously, the signals from the P-10 pressure gauge are transferred to the mPDS2000V3 control system and subsequently forwarded to the IBM PC computing unit. During the experiments, the temperature in the measuring cell was maintained with an accuracy of 0.01 K using an F32-ME thermostat (Julabo, Germany). Temperature measurements were performed using calibrated Pt100 platinum resistance thermometers (ITS-90) with an uncertainty of ±3 mK.

INTRODUCTION

The depletion of traditional energy sources, global climate change, and environmental pollution are among the main environmental problems of today. Various measures are being taken to address these problems, the most significant of which is the utilization of renewable and alternative energy sources. Taking these into account, environmentally friendly alternative energy sources (solar and wind energy, small hydroelectric power plants, thermal waters, biomass energy) are widely used in developed countries of the world.

Azerbaijan, due to its geographical location and climatic conditions, is among the countries with highly favorable potential for utilizing alternative energy sources. Across the territory of the

Republic of Azerbaijan, there are more than 200 underground thermal, mineral, and potable spring water resources enriched with various mineral substances, with a total daily productivity exceeding 100 million liters. These waters have more than 1,000 natural outlets [1]. According to their chemical composition, the mineral waters of Azerbaijan are classified into ten groups: hydrocarbonate, hydrocarbonate–chloride, hydrocarbonate–chloride–sulfate, chloride–hydrocarbonate, chloride, chloride–sulfate, sulfate–chloride, sulfate–hydrocarbonate, and bluestone.

Following the Decree of the President of the Republic of Azerbaijan dated October 21, 2004, on the approval of the "State Program on the Use of Alternative and Renewable Energy Sources in the Republic of Azerbaijan", large-scale initiatives have been implemented in this field across the country [2]. In the present study, the density of the "Palchig-oba" geothermal water, located in the northern part of Azerbaijan (Khachmaz region), was investigated under high temperature and pressure conditions. The primary objective of this research is to assess the potential of alternative energy resources in the northern regions of Azerbaijan. The waters in this area contain gaseous compounds such as H_2S and sulfate ions and are characterized by a high degree of mineralization. The geothermal waters discharge at surface temperatures that are relatively close to each other. The outlet temperature of the "Palchig-oba" geothermal water is T=317.15 K. These geothermal waters in the Khachmaz region are mainly utilized for therapeutic purposes and as a source of hot water [3].

The DMA HPM Density Meter measuring system determines the oscillation period and temperature and transmits these data to the IBM PC computer-based computing system, where the parameters are continuously monitored. Simultaneously, the signals from the P-10 pressure gauge are transmitted to the mPDS2000V3 control system and subsequently to the IBM PC computing unit. During the experiment, the temperature in the measuring chamber is maintained with an accuracy of 0.01 K using an F32-ME thermostat (Julabo, Germany). Temperature measurements are performed using calibrated Pt100 platinum thermometers, with an error of ±3 mK (ITS-90) [4].

The sample was collected directly from the source, filtered, and degassed, as the presence of air and gas bubbles in geothermal water negatively affects density measurements. First, a chemical analysis of the "Palchig-oba" geothermal water was performed using an IRIS II optical emission spectrometer with a dual argon plasma source [5]. Subsequently, the density was experimentally analyzed over a wide range of temperatures and pressures. The obtained results are presented in Table 1 and Figures 2–3.

Table 1. Experimental pressure p, density ρ, temperature T, isothermal compressibility k_T, isobaric thermal expansion coefficient α_p, and the difference between isobaric and isochoric heat capacities c_p-c_υ. of the "Palchig-oba" geothermal water.

$\frac{p}{MPa}$	$\frac{T}{K}$	$\frac{k_T \cdot 10^6}{MPa^{-1}}$	$\frac{\alpha_p \cdot 10^6}{K^{-1}}$	$\frac{c_p - c_\upsilon}{C \cdot кq^{-1} \cdot K^{-1}}$	$\frac{\gamma}{MPa \cdot K^{-1}}$	$\frac{p_{int}}{MPa}$
0.786	278.21	500.3	41.3	0.9	0.0825	22.2
5.073	278.22	489.6	57.8	1.9	0.1181	27.8
9.995	278.23	478.8	75.1	3.2	0.1568	33.6
15.101	278.22	467.0	94.3	5.2	0.2019	41.1
20.015	278.22	456.7	111.5	7.4	0.2441	47.9

25.229	278.22	446.4	129.2	10.2	0.2895	55.3
30.097	278.21	436.9	145.9	13.3	0.3338	62.8
34.985	278.21	428.1	161.8	16.6	0.3778	70.1
40.100	278.20	418.8	179.0	20.7	0.4273	78.8
0.958	288.24	470.2	169.9	17.6	0.3612	103.2
5.188	288.25	459.1	181.1	20.4	0.3944	108.5
10.057	288.24	448.9	191.5	23.3	0.4267	112.9
15.089	288.23	438.8	202.1	26.5	0.4606	117.7
19.951	288.21	429.5	212.0	29.7	0.4937	122.3
24.990	288.20	419.7	222.7	33.5	0.5306	127.9
30.037	288.18	410.5	233.0	37.4	0.5676	133.5
35.041	288.17	402.1	242.5	41.3	0.6031	138.8
40.010	288.15	393.6	252.4	45.6	0.6413	144.8
1.035	298.24	452.5	271.7	48.4	0.6005	178.0
5.147	298.24	442.9	277.0	51.4	0.6255	181.4
10.054	298.23	433.2	282.5	54.5	0.6520	184.4
14.991	298.23	423.3	288.3	57.9	0.6810	188.1
20.021	298.22	413.6	293.9	61.5	0.7105	191.9
25.061	298.21	404.9	299.1	64.9	0.7387	195.2
30.128	298.21	396.4	304.2	68.4	0.7673	198.7
35.104	298.20	388.2	309.2	72.1	0.7966	202.4
40.035	298.17	380.1	314.1	75.8	0.8263	206.3
0.845	313.15	442.5	397.6	111.9	0.8986	280.6
5.021	313.16	433.8	398.1	114.2	0.9177	282.4
10.002	313.14	423.9	398.3	116.8	0.9396	284.2
15.203	313.15	413.9	398.7	119.5	0.9631	286.4
19.996	313.15	405.3	398.9	122.0	0.9842	288.2
25.025	313.16	396.5	399.1	124.6	1.0064	290.1
29.994	313.14	388.3	399.0	126.9	1.0275	291.8
35.024	313.15	380.4	399.1	129.4	1.0493	293.6
39.995	313.15	372.9	399.0	131.7	1.0702	295.1
0.870	327.11	446.4	500.3	184.6	1.1207	365.7
5.123	327.12	437.5	497.7	186.1	1.1377	367.1
10.042	327.13	428.2	494.9	187.7	1.1560	368.1
15.187	327.14	418.3	491.8	189.2	1.1755	369.4
19.978	327.15	410.2	489.0	190.5	1.1922	370.0
25.227	327.16	401.0	485.7	191.8	1.2111	371.0
30.096	327.16	392.8	482.5	192.8	1.2282	371.7
35.090	327.17	385.1	479.4	193.8	1.2449	372.2
40.068	327.18	378.1	476.4	194.6	1.2600	372.2
0.924	343.14	459.8	602.4	275.1	1.3102	448.7
5.001	343.15	451.5	598.5	276.0	1.3256	449.9
10.005	343.16	441.9	593.7	276.9	1.3435	451.0
15.203	343.15	432.4	588.4	277.4	1.3610	451.8
19.997	343.15	424.0	583.6	277.7	1.3765	452.4
25.004	343.15	415.6	578.5	277.8	1.3920	452.7
29.989	343.16	407.6	573.4	277.7	1.4066	452.7
35.207	343.15	399.7	568.0	277.2	1.4209	452.4
39.992	343.15	392.8	563.0	276.7	1.4333	451.9
1.012	358.15	473.2	672.1	350.7	1.4206	507.8
5.065	358.16	465.4	668.7	352.2	1.4369	509.6
10.025	358.15	456.4	664.3	353.7	1.4556	511.3

15.047	358.14	447.5	659.6	354.7	1.4738	512.8
20.035	358.15	439.1	654.7	355.4	1.4909	513.9
25.621	358.15	430.2	649.1	355.7	1.5089	514.8
30.058	358.16	423.3	644.4	355.7	1.5225	515.2
35.106	358.15	415.8	639.0	355.2	1.5367	515.2
39.985	358.15	408.9	633.6	354.4	1.5496	515.0
1.326	373.12	481.7	701.4	394.8	1.4561	542.0
5.108	373.12	474.7	700.1	398.4	1.4750	545.2
10.166	373.15	466.5	698.3	402.4	1.4968	548.4
15.004	373.18	459.0	696.2	405.6	1.5167	551.0
20.071	373.18	451.3	693.6	408.5	1.5368	553.4
25.167	373.18	443.8	690.6	411.0	1.5560	555.5
30.106	373.16	436.7	687.4	412.7	1.5738	557.2
35.011	373.17	430.3	684.1	414.0	1.5896	558.2
40.022	373.16	423.8	680.2	414.8	1.6052	559.0

The obtained results were analyzed using the equation of state [6]:

$$p = A(T)\,\rho^2 + B(T)\,\rho^8 + C(T)\,\rho^{12}, \tag{1}$$

here: the coefficients *A(T), B(T)* and *C(T)* of equation (1) depend on temperature:

$$A(T) = \sum_{i=1}^{3} a_i T^i,\ B(T) = \sum_{i=0}^{2} b_i T^i,\ C(T) = \sum_{i=0}^{2} c_i T^i, \tag{2}$$

The values of the coefficients *ai, bi* and *ci* are presented in Table 2.

Table 2: Coefficients *ai, bi* and *ci* of the equation of state of the "Palchig-oba" geothermal water.

ai	***bi***	***ci***
a1= -5.96906137647	b0= 7660.5225241	c0= -5397.473667514
a2= 0.03060188658	b1= -49.491673	c1= 35.409651677
a3= -0.4800227471·10-4	b2= 0.0829263	c2= -0.0575229913

Equation of state (1) allows the experimental density values to be expressed with an average relative error of $\Delta\rho/\rho = 0.010$ %, and this error for each experimental value is shown in Figure 3.

Using the equation of state, various thermodynamic parameters were determined: the isothermal compressibility, k_T/MPa^{-1} which describes the relative volume change under a pressure change at constant temperature, is computed as follows:

$$k_T = (1/\rho)(\partial p/\partial \rho)_T^{-1}, \tag{3}$$

Equation of state (1) can be expressed in the following form using Equation (3):

$$k_T = 1/(2A\rho^2 + 8B\rho^8 + 12C\rho^{12}). \tag{4}$$

The calculated values of the isothermal compressibility, k_T/MPa^{-1} are presented in Table 1 and illustrated in Figure 4.

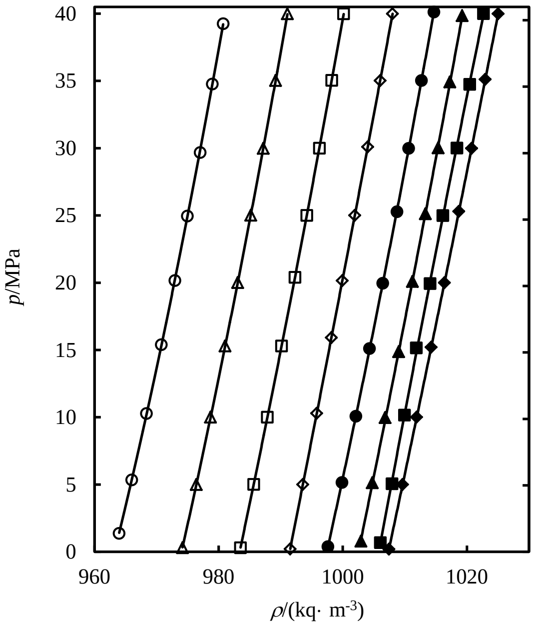

Figure 1. Dependence of the pressure ρ of the "Palchig-oba"geothermal water on density ρ : ◆, 278.15 K; ■, 288.12 K; ▲, 298.15 K; ●, 312.95 K; ◇, 328.15 K; □, 343.16 K; Δ, 358.15 K; ○, 373.09 K; ___ result calculated using the equation of state.

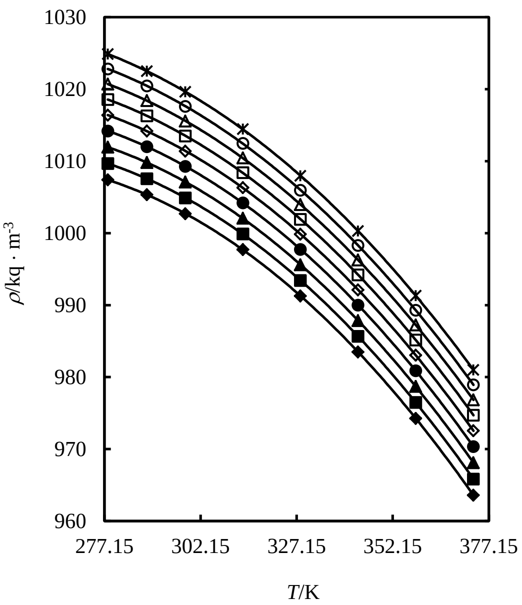

Figure 2. Dependence of the density ρ of the "Palchig-oba"geothermal water on temperature *(T)* : ◆, 0.101 MPa; ■, 5 MPa; ▲, 10 MPa; ●, 15 MPa; ◇, 20 MPa; □, 25 MPa; Δ, 30 MPa; ○, 35 MPa; *, 40 MPa.

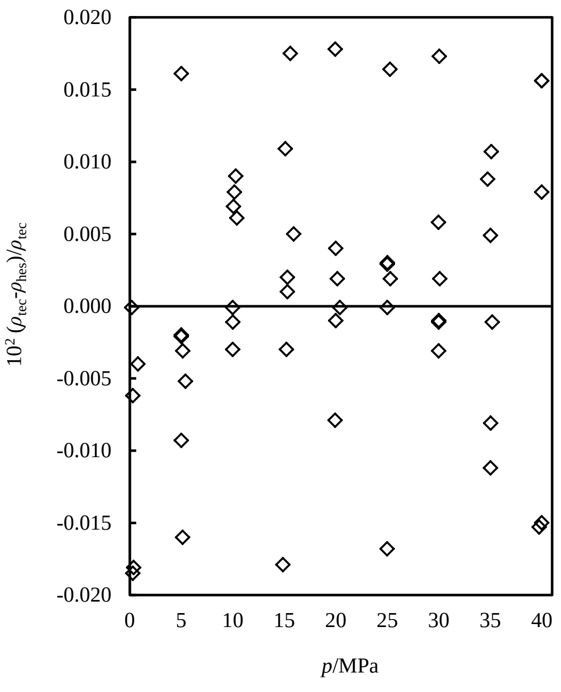

Figure 3. Percent difference between the experimental density (ϱ_exp) and the density calculated using the equation of state (ϱ_calc).

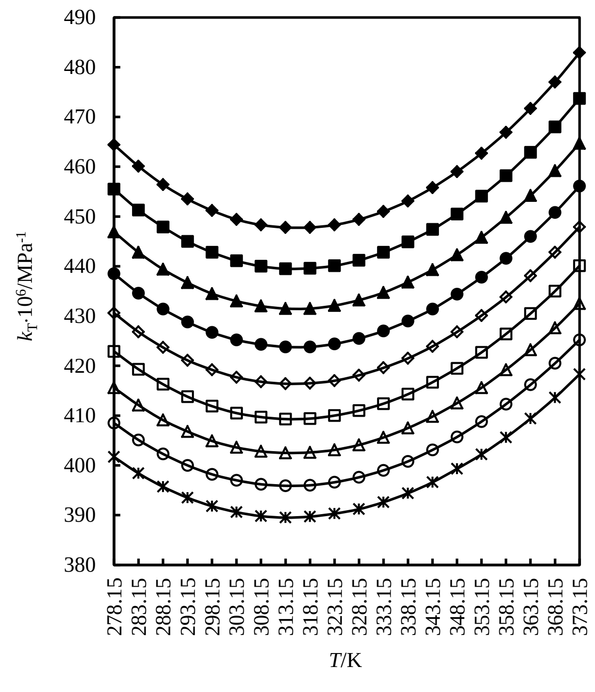

Figure 4. Dependence of the isothermal compressibility $k_T \cdot 10^6/MPa^{-1}$ of the "Palchig-oba" geotermal water on temperature T ◆, 0.101 MPa; ■, 5 MPa; ▲, 10 MPa; •, 15 MPa; ◇, 20 MPa; □, 25 MPa; Δ, 30 MPa; ○, 35 MPa; *, 40 MPa.

The isobaric thermal expansion coefficient α_P/K^{-1} for the "Palchig-oba" geothermal water was determined using the following relation.

(5)

$$\alpha_p = [A'(T) + B'(T)\rho^6 + C'(T)\rho^{10}]/[2A(T) + 8B(T)\rho^6 + 12C(T)\rho^{10}], \quad (6)$$

here: *A'(T), B'(T),* and *C'(T)* denote the temperature derivatives of the coefficients *A(T), B(T),* and *C(T),* respectively, and are determined as follows:

$$A'(T) = \sum_{i=1}^{3} ia_i T^{i-1},\ B'(T) = \sum_{i=1}^{2} ib_i T^{i-1},\ C'(T) = \sum_{i=1}^{2} ic_i T^{i-1}\ . \quad (7)$$

Calculated values of the isobaric thermal expansion coefficient α_P/K^{-1} are given in Table 1.

The difference in specific heat capacities at constant pressure and constant volume (c_P-c_V) / Jkq^{-1}K^{-1} is calculated as follows:

$$c_p = c_v + T\frac{(\partial p/\partial T)_\rho^2}{\rho^2(\partial p/\partial \rho)_T}, \quad (8)$$

here: c_p and c_v are the specific heat capacities at constant pressure and constant volume. Using equations (3) and (5), the following dependence can be obtained:

$$c_p - c_v = \frac{\alpha_p^2 T}{\rho k_T}, \quad (9)$$

Calculated values of (c_P-c_V)/Jkq^{-1}K^{-1} the difference in specific heat capacities at constant pressure and volume, are presented in Table 1.

As a result of the experimental analysis, anomalies were observed in the dependence of density and the calculated thermal properties of the "Palchig-oba" geothermal water. Specifically, the isothermal compressibility initially decreases with increasing temperature, as is typical for water, but begins to increase again at approximately *T* = (313.15–318.15) K. These anomalies are primarily attributed to the high water content of the geothermal fluid, which constitutes (96–97%) of its composition. Thus, at low temperatures, the molecular network of water adopts an expanded, open structure, which facilitates higher compressibility. As the temperature increases, the molecular structure becomes more compact, resulting in reduced compressibility.

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