THERMAL-PHYSICAL CHARACTERISTICS OF GALA-ALTI GEOTHERMAL WATER OF SHABRAN DISTRICT OF AZERBAIJAN AT HIGH PRESSURE AND TEMPERATURES

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Abstract

The article presents the experimental data obtained using high-precision experimental devices on the density of the Gala-alti geothermal water of the Shabran region of Azerbaijan at high pressure and temperature.

Geothermal energy is a part of alternative energy and is widely used for various purposes all over the world. In recent years, due to the increase in the cost of traditional energy sources and their possible shortage in the future, technologies using thermal waters are being actively developed. In order to use geothermal waters in various power plants, it is necessary to know their thermophysical properties. Geothermal waters in Azerbaijan were studied in the 20th century [1-5]. Most of these studies are related to geological analysis and chemical structure analysis of geothermal waters. In order to study the methods of using geothermal waters and obtaining energy from them, it is necessary to study their thermal-physical properties. This article presents experimental data about the "Gala-alti" geothermal water in the Shabran region of Azerbaijan.

In order to measure the density of the "Gala-alti" geothermal water of Shabran region at high pressure and temperature, a high-precision experimental device using the vibration-tube densimeter method was used [6]. This method for modern experimental thermal physics is characterized by high measurement accuracy, simplicity, insignificant time and economic costs, as well as the possibility of automation of the measurement process. The working principle of the experimental device is given in [7-9]. The main element of the Anton-Paar DMA HPM vibrating tube densimeter unit is a measuring cell consisting of a Hastelloy C-276 vibrating tube made of nickel-based stainless steel alloys with high corrosion resistance. The measuring element is designed to measure temperature in the range T=263.15-473.15 K and pressure p=0.1-140 MPa. The temperature in the measuring chamber containing the U-shaped tube is maintained using an external thermostat F32-ME (Julabo, Germany) with an error of 0.01 K. Temperature is measured using a platinum resistance thermometer (ITS-90).) Pt100 (Type 2141) with an error of ±15 mK. The pressure is generated using a HIP pump (No. 37-6-30, USA) and pressure sensors (WIKA Alexander Wiegand GmbH & Co., Germany) using P-10 accuracy class 0.1% and HP-1 accuracy class 0.5% is measured by The signals from the pressure gauges are also transmitted to the computer control system. In these conditions, the error in density measurement was $\Delta\rho/\rho$ = ±(0.01 - 0.03)%. (p, ρ,T) dependences were measured using isotherms from the minimum possible pressure for a given temperature and then increasing it in increments of about 10 MPa. Researches were carried out in the range T=(274.15 - 413.15) K and pressures up to p=100 MPa. Densities obtained at atmospheric pressure were compared with those measured on the DSA 5000M. The data obtained by different methods are in good agreement with each other within $\Delta p/\rho$ = ±0.02%. The obtained results of density of "Gala-alti" geothermal water of Shabran region are shown in Table 1.

For the measurement of the thermal physical properties of the Gala-alti geothermal water of the Shabran region of Azerbaijan, the methodologies that allow for very accurate measurements in

the liquid phase at high state parameters have been selected and substantiated. An experimental device was assembled and adjusted for measuring density at different temperatures and pressures using the vibrating tube densimeter method. In order to check the working capacity of the experimental unit, the densities of aqueous solutions of water, toluene, methanol, and NaCl as reference substances were studied in a wide range of state parameters.
Since the thermal-physical properties of the Gala-alti geothermal water of the Shabran region of Azerbaijan were studied for the first time, it is impossible to compare them with the literature data. The obtained data were compared with the thermal-physical properties of pure water and it was determined that similar anomalies of water in the behavior of the studied properties are known.

Keywords: geothermal water, density, experimental studies, thermal-physical properties, energy

I. Introduction

Geothermal energy is a part of alternative energy and is widely used for various purposes all over the world. In recent years, due to the increase in the cost of traditional energy sources and their possible shortage in the future, technologies using thermal waters are being actively developed. In order to use geothermal waters in various power plants, it is necessary to know their thermophysical properties. Geothermal waters in Azerbaijan were studied in the 20th century [1-5]. Most of these studies are related to geological analysis and chemical structure analysis of geothermal waters. In order to study the methods of using geothermal waters and obtaining energy from them, it is necessary to study their thermal-physical properties. This article presents experimental data about the "Gala-alti" geothermal water in the Shabran region of Azerbaijan.

II. Methods

In order to measure the density of the "Gala-alti" geothermal water of Shabran region at high pressure and temperature, a high-precision experimental device using the vibration-tube densimeter method was used [6]. This method for modern experimental thermal physics is characterized by high measurement accuracy, simplicity, insignificant time and economic costs, as well as the possibility of automation of the measurement process. The working principle of the experimental device is given in. The main element of the Anton-Paar DMA HPM vibrating tube densimeter unit is a measuring cell consisting of a Hastelloy C-276 vibrating tube made of nickel-based stainless steel alloys with high corrosion resistance. The measuring element is designed to measure temperature in the range T=263.15-473.15 K and pressure p=0.1-140 MPa. The temperature in the measuring chamber containing the U-shaped tube is maintained using an external thermostat F32-ME (Julabo, Germany) with an error of 0.01 K. Temperature is measured using a platinum resistance thermometer (ITS-90).) Pt100 (Type 2141) with an error of ±15 mK. The pressure is generated using a HIP pump (No. 37-6-30, USA) and pressure sensors (WIKA Alexander Wiegand GmbH & Co., Germany) using P-10 accuracy class 0.1% and HP-1 accuracy class 0.5% is measured by The signals from the pressure gauges are also transmitted to the computer control system. In these conditions, the error in density measurement was $\Delta\varrho/\varrho$ = ±(0.01 - 0.03)%. (p, ρ,T) dependences were measured using isotherms from the minimum possible pressure for a given temperature and then increasing it in increments of about 10 MPa. Researches were carried out in the range T=(274.15 - 413.15) K and pressures up to p=100 MPa. Densities obtained at atmospheric pressure were compared with those measured on the DSA 5000M. The data obtained by different methods are in good agreement with each other within $\Delta p/\rho$ = ±0.02%. The obtained results of density of "Gala-alti" geothermal water of Shabran region are shown in Table 1.

Table 1: *Experimental values of pressure p, density ρ, temperature T of "Gala-alti" geothermal water of Shabran region*

p/MPa	*ρ*/kg·m³	*T*/K	*p*/ MPa	*ρ*/ kg·m³	*T*/K
0.101	1000.75	274.15	20.169	1007.69	293.18
1.023	1001.21	274.15	30.215	1011.95	293.18
5.023	1003.18	274.15	40.220	1016.13	293.18
10.005	1005.62	274.15	50.160	1020.23	293.18
19.968	1010.41	274.15	59.912	1024.18	293.18
29.934	1015.10	274.15	69.940	1028.18	293.19
40.005	1019.73	274.15	79.925	1032.10	293.18
49.936	1024.19	274.15	90.002	1035.98	293.15
59.998	1028.60	274.15	99.985	1039.77	293.14
70.005	1032.88	274.15	0.101	997.92	298.15
80.065	1037.07	274.15	0.784	998.22	298.15
89.935	1041.08	274.15	5.021	1000.07	298.16
99.964	1045.05	274.15	10.002	1002.23	298.15
0.101	1000.82	278.12	20.003	1006.52	298.14
0.613	1001.09	278.10	30.014	1010.74	298.15
5.134	1003.19	278.11	39.985	1014.88	298.13
10.124	1005.54	278.11	49.952	1018.95	298.15
20.102	1010.17	278.11	59.924	1022.95	298.16
30.043	1014.68	278.12	70.024	1026.94	298.15
40.042	1019.18	278.12	79.934	1030.79	298.14
50.115	1023.62	278.12	89.968	1034.62	298.15
60.112	1027.95	278.12	99.235	1038.10	298.14
69.967	1032.21	278.10	0.101	993.06	313.15
80.007	1036.26	278.13	0.954	993.43	313.15
90.021	1040.41	278.15	5.143	995.21	313.15
99.845	1044.36	278.14	10.014	997.28	313.15
0.101	1000.71	283.21	19.986	1001.45	313.15
1.377	1001.21	283.23	29.935	1005.54	313.15
5.259	1003.04	283.22	39.947	1009.59	313.15
10.092	1005.28	283.21	50.004	1013.59	313.15
20.173	1009.81	283.21	59.924	1017.46	313.15
29.794	1014.08	283.21	70.024	1021.34	313.15
40.468	1018.73	283.21	80.045	1025.11	313.15
50.065	1022.68	283.25	89.924	1028.76	313.15
59.969	1026.78	283.27	99.935	1032.39	313.15
70.048	1031.24	283.21	0.101	983.66	333.15
79.948	1035.33	283.20	0.750	983.94	333.14
0.101	998.97	293.18	20.093	992.20	333.13
0.774	999.27	293.18	30.074	996.33	333.15
5.023	1001.14	293.18	40.067	1000.39	333.14
10.019	1003.31	293.18	50.067	1004.37	333.15
0.101	1000.75	274.15	59.999	1008.24	333.17
1.023	1001.21	274.15	70.137	1012.10	333.15
5.023	1003.18	274.15	79.997	1015.78	333.16
10.005	1005.62	274.15	89.985	1019.42	333.15
19.968	1010.41	274.15	99.947	1022.96	333.14
29.934	1015.10	274.15	0.101	971.50	353.15
40.005	1019.73	274.15	20.169	1007.69	293.18
49.936	1024.19	274.15	30.215	1011.95	293.18

The experimental data were generalized using the equation of state:

$$p = A \cdot \rho^2 + B \cdot \rho^8 + C \cdot \rho^{12} \tag{1}$$

Here the coefficients A(T), B(T) and C(T) in equation (1) are functions of temperature.

$$A(T) = \sum_{i=1}^{4} a_i T^i$$

$$B(T) = \sum_{i=0}^{3} b_i T^i \tag{2}$$

$$C(T) = \sum_{i=0}^{3} c_i T^i$$

The obtained coefficients ai, bi and ci in equation (2) are given in Table 2. Equations (1) - (2) describe well the experimental data on density of "Gala-alti" geothermal water in Shabran region.

Table 2: *Values of the coefficients a_i, b_i and c_i in equation (2)*

a_i	b_i	c_i
a_1 = -3.77278411	b_0 = 8820.374609	c_0 = -6716.43133642012
a_2 = 0.0103724374	b_1 = -72.493837104	c_1 = 57.00035877163
a_3 = $-0.1779354 \cdot 10^{-4}$	b_2 = 0.2129181614	c_2 = -0.16486118
a_4 = $0.2274616251 \cdot 10^{-7}$	b_3 = $-0.20544052 \cdot 10^{-3}$	c_3 = $0.15801767 \cdot 10^{-3}$

The errors are calculated using the following equations and are presented in Table 3.

Standard error:

$$STD = \sqrt{\frac{\sum(\rho_{exp} - \rho_{calc})^2}{n(n-1)}} \tag{3}$$

Absolute error:

$$ABD = \frac{1}{n}\sum|\rho_{exp} - \rho_{calc}| \tag{4}$$

Average percentage error:

$$APD = \frac{100}{n}\sum\left|\frac{\rho_{exp} - \rho_{calc}}{\rho_{exp}}\right| \tag{5}$$

where ρ_{exp} – experimental density values; ρ_{calc} –– density values calculated using the equation of state; n – number of experimental data.

Table 3: *Error values of equation (1)*

Average percentage error	Standard error	Absolute error
0.0097	0.142	0.12

The density of the geothermal water "Gala-Alti" of the Shabran district at atmospheric pressure was also measured using the DSA 5000M installation, which allows measurements to be taken at atmospheric pressure and temperatures up to 363.15 K with an accuracy of 0.01% (more accurate measurements than at high pressures).

Based on the equation of state, the following thermophysical properties were calculated:

- isothermal compressibility coefficient

$$\kappa_T = 1/[2A(T)\rho^2 + 8B(T)\rho^8 + 12C(T)\rho^{12}] \tag{6}$$

- isobaric coefficient of thermal expansion

$$\alpha_p = (1/\rho)(\partial p/\partial T)_\rho (\partial p/\partial \rho)_T^{-1} \tag{7}$$

$$\alpha_p = \frac{A'(T) + B'(T)\rho^6 + C'(T)\rho^{10}}{2A(T) + 8B(T)\rho^6 + 12C(T)\rho^{10}} \tag{8}$$

where A', B' and C' derivatives of coefficients A, B and C of the equation of state defined by the following formula:

$$A(T)=\sum_{i=1}^{3}a_iT^i,\ B(T)=\sum_{i=0}^{2}b_iT^i,\ C(T)=\sum_{i=0}^{2}c_iT^i. \tag{9}$$

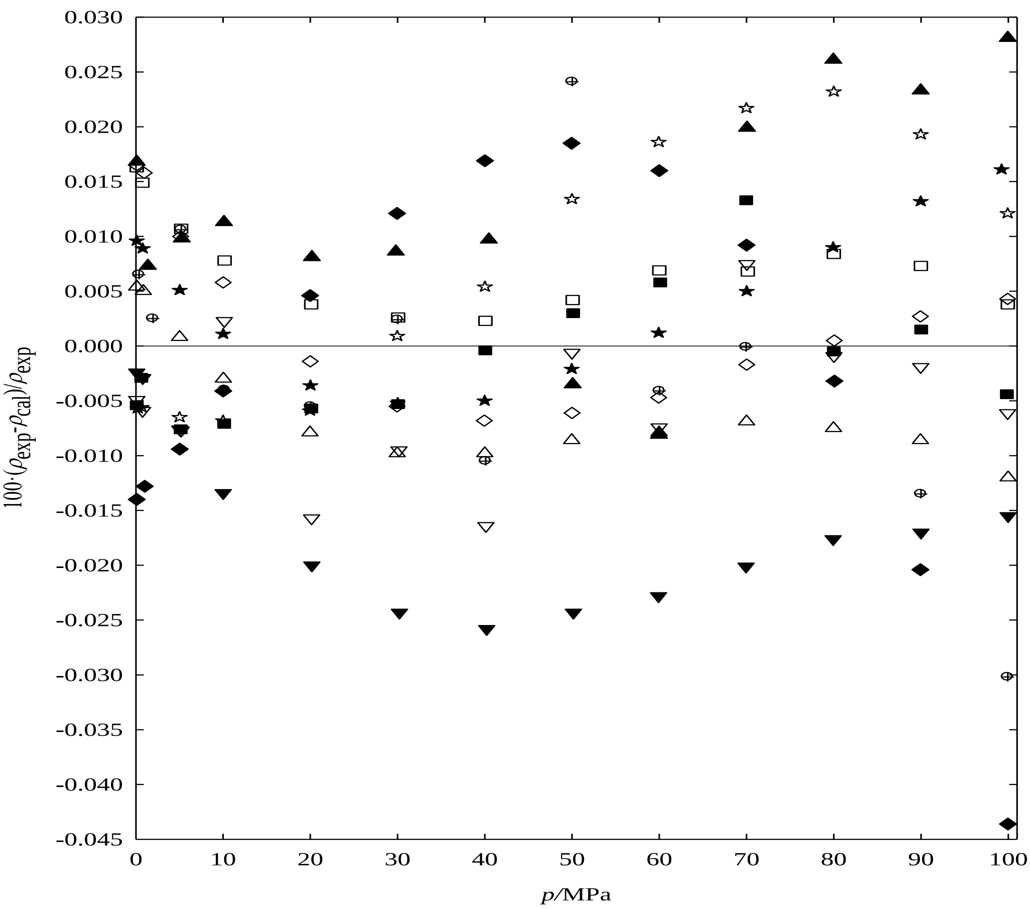

Figure 1: *Dependence of the pressure p on the pressure p of the density of the experimentally measured density of the Gala-alti thermal water of the Shabran region of Azerbaijan and the density ρ_{cal} calculated with the help of the equation of state $\rho_{exp.}$ ◆, 274.15 K; ■, 278.12 K; ▲, 283.21 K; ▼, 293.18 K; ★, 298.15 K; ◇, 313.15 K; □, 333.15 K; △, 353.15 K; ▽, 373.16 K; ☆, 393.15 K; ⊕, 413.15 K.*

III. Results

For the measurement of the thermal physical properties of the Gala-alti geothermal water of the Shabran region of Azerbaijan, the methodologies that allow for very accurate measurements in the liquid phase at high state parameters have been selected and substantiated. An experimental device was assembled and adjusted for measuring density at different temperatures and pressures using the vibrating tube densimeter method. In order to check the working capacity of the experimental unit, the densities of aqueous solutions of water, toluene, methanol, and NaCl as reference substances were studied in a wide range of state parameters.

IV. Discussion

Since the thermal-physical properties of the Gala-alti geothermal water of the Shabran region of Azerbaijan were studied for the first time, it is impossible to compare them with the literature data. The obtained data were compared with the thermal-physical properties of pure water and it was determined that similar anomalies of water in the behavior of the studied properties are known.

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