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UTILIZING THERMAL WATER FOR ENERGY: A STUDY OF THE PROPERTIES (P, Ρ, T) OF THE "KHACHMAZ" THERMAL WATER IN AZERBAIJAN

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ABSTRACT

This study investigates the potential of using thermal waters for energy production and presents a table showing the role of thermal power plants in global electricity generation. Additionally, an experimental study was conducted on the properties (pressure, density, temperature) of the "Khachmaz" thermal water from Azerbaijan. To evaluate the performance and accuracy of the experimental apparatus, the measured properties (p, ρ, T) of water, toluene, and an aqueous NaCl solution ($m = 2.96661$ mol·kg^{-1}) were compared with reference data from various literature sources. The results obtained are displayed in graphical form.

I. INTRODUCTION

Thermal waters, which naturally emerge from the ground, are utilized for various purposes, including the generation of environmentally friendly and cost-effective electricity, the treatment of various diseases, heating of buildings, greenhouses, and small agricultural enterprises, as well as providing heat for facilities operating with natural steam. Additionally, these waters, containing high concentrations of diverse salts, are used for the extraction of mineral substances and therapeutic applications. This, in turn, fosters the development of various industries such as hotels, motels, campsites, catering services, communication networks, and infrastructure in regions with abundant thermal water resources. As a result, the country's state budget receives a large amount of funds, creating conditions for a positive solution to the unemployment problem [1].

In accordance with the State Program on the Use of Alternative and Renewable Energy Sources, the Ministry of Energy was tasked with implementing a special program, as specified in the Decree of the Republic of Azerbaijan dated October 21, 2004 [1]. In the State Program, the use of wind energy is emphasized, along with energy sources that are suitable for our republic. These include solar energy, geothermal water, hydropower from mountain rivers and canals, and biomass energy. There are significant possibilities for utilizing the heat from the Earth's depths. Depending on its temperature, water or a water-steam mixture can be used for hot water supply, heating, electricity generation or for all of these purposes simultaneously. It is more suitable to utilize the high-temperature heat from volcanic regions and dry mountain rocks for electricity generation and heat supply. The total operational capacity of geothermal power plants worldwide remains behind that of most other renewable energy sources. However, in specific populated geographic regions where fuel and mineral resources are either nonexistent or relatively expensive, the high energy density, in conjunction with government policies, is driving the advancement of this sector.

The temperature of mineral waters in Azerbaijan ranges from 4 to 65°C. This refers only to natural water sources. Additionally, waters with temperatures reaching 95°C are extracted by drilling deep into the earth.

II.Description of the Processing System

Thermal waters are commonly used worldwide for electricity generation through thermal power plants (TPPs) [2]. This type of power plant has the advantage of requiring less time and fewer financial resources for construction compared to other types of power plants. Electricity from geothermal power plants is 70-80% cheaper than that from thermal power plants relying on oil, gas, or coal. Such power plants have a negligible environmental impact, with the electricity they generate being notably cleaner from an ecological perspective compared to that produced by other types of power stations. The CO2 emissions associated with the generation of 1 kW of electricity from high-temperature thermal sources vary between 13 and 380 grams, with an average of 65 grams per kilowatt-hour. When using different fuels, this index measures 453 grams for natural gas, 906 grams for oil, and 1042 grams for coal. The chemical compounds generated by thermal flow are carefully contained and not allowed to escape into the atmosphere. Instead, they are efficiently redirected back into the earth's depths using advanced specialized devices [3-4].

The primary requirement for developing Thermal Power Plants is the presence of high-temperature thermal waters that emerge from the ground, with an efficiency exceeding 90%. Therefore, given the advantages of thermal power stations (TPP) over other types of power plants and the low cost of energy procurement, regions such as Latin America, Northern Europe, and Northern Africa—which are endowed with abundant hydropower resources—place significant emphasis on the development of thermal stations. This is regarded as one of the most promising sectors for these countries. The global electricity generation from thermal power plants has experienced significant growth, increasing from 5,000 MW in 1990 to approximately 11,000 MW in 2010. In the same year, thermal power plants contributed to 30% and 27% of the total electricity generated in Iceland and the Philippines, respectively, while accounting for 14% each in El Salvador and Costa Rica [5-6].

In general, for the first time in the world, heat was obtained from thermal waters in Italy in 1904, and similar power plants were built in New Zealand, Japan, the Philippines and the United States in the following years.

Russia has significant geothermal resources distributed across various regions, including Kamchatka, Chukotka, Primorsky Krai, Western Siberia, the North Caucasus, Krasnodar and Stavropol Territories, as well as the Kaliningrad Oblast. In these regions, thermal waters emerge from multiple hot sources ranging from 50 to 90°C. More than 100 natural thermal water outlets are known in Kamchatka. The sources are distinguished not only by their high temperature (170-200^0 C) but also by their relatively low mineral content. Significant reserves of highly thermal waters (temperature over 100°C, depth 1500 m) are located in the artesian basins of Moscow and Western Siberia.

Table 1 clearly demonstrates the significant share of thermal power plants in total electricity production for the years 2007 and 2010 across the 12 most developed countries operating thermal power plants in the world [5,6].

The United States stands as the global leader in electricity production from thermal power plants. In 2007, the country generated an impressive 2,687 MW of electricity from thermal energy, further increasing to 3,086 MW in 2010. Notably, in 1999, the utilization of thermal energy saved an astonishing 60,000 barrels of oil. During that same year, the production from thermal sources reached 2,200 MW, equivalent to the output of four nuclear power plants. This demonstrates the significant role thermal energy plays in the nation's energy landscape [7].

III.Performance Improvement

Iceland leads the world in utilizing geothermal resources, employing thermal waters for heating the capital city Reykjavík, as well as for residential needs, public utilities, greenhouse operations, and the production of environmentally sustainable electricity.

Despite having abundant thermal water resources, Azerbaijan utilizes only a small fraction of them. Based on usability, geostructural, and hydro-geothermal conditions, the hydrothermal regions include Greater Caucasus, Absheron Peninsula, Caspian-Guba, Kur-Araz Lowland, Lesser Caucasus, Talysh-Lankaran, Jalilabad-Zar, Shamakhi-Gobustan, Ajinohur-Kur Interfluve, and Nakhchivan. The thermal regions of Azerbaijan have reserves totaling 249 thousand m^3/day; however, a significant portion of these reserves is utilized for treatment purposes [8].

TABLE I. THE CONTRIBUTION OF THERMAL POWER PLANTS TO GLOBAL ELECTRICITY PRODUCTION WAS ANALYZED FOR THE YEARS 2007 AND 2010

№	Countries utilizing thermal power plants	Capacity of thermal power plants, MW		The proportion of electricity generated by TPP in the overall electricity output of the country, expressed as a percentage
		In 2007 [5]	In 2010 [6]	
1.	USA	2687	3086	0,3
2.	Philippines	1969,7	1904	27
3.	Indonesia	992	1197	3,7
4.	Mexico	953	958	3,0
5.	Italy	810,5	843	-
6.	New Zealand	471,6	628	10,0
7.	Iceland	421,2	575	30,0
8.	Japan	535,2	536	0,1
9.	Salvador	204,2	204	14,0
10.	Kenya	128,8	167	11,2
11.	Costa Rica	162,5	166	14,0
12.	Nicaragua	87,4	88	10,0
	Total	9423,1	10352	

The thermal waters in Absheron are primarily used for restoring the health of the population and treating various diseases. If the Surakhani thermal water, which has significant potential, is utilized effectively, it could generate substantial revenue for the republic's budget. For comparison, it is worth noting that thermal water with a temperature of 71°C emerges in the center of Budapest, the capital of Hungary. This water is cooled to 30-35°C and is utilized daily by 4-5 thousand people at the Széchenyi Thermal Baths, a complex of indoor and outdoor pools located in the Széchenyi area of the city. Each person's daily access fee for using this thermal water facility is 12 euros. The daily revenue from this operation amounts to 54,000 euros, while the annual revenue reaches 19.5 million euros.

Considering the numerous thermal water resources with a temperature of 30-35°C in the Gabala, Gakh, Oghuz, and Guba administrative regions, we consider it appropriate to create closed and open-type beaches in these areas. The presence of rich oil and gas reserves in the territory of the economic-geographic region, the continuation of tectonic events and orogeny processes, and the fact that it is surrounded by the Caspian Sea in a large area are the main factors for the existence of a large number of thermal and mineral waters here (Fig. 1) [9]. This region lags behind only Absheron and Lankaran-Astara economic-geographic regions in terms of the use of thermal and mineral waters for the restoration of human health, as well as the use of beaches.

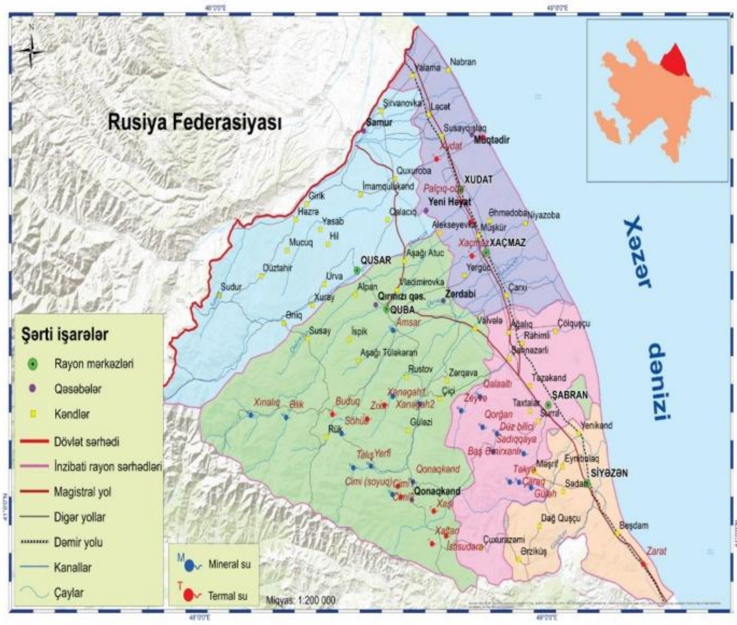
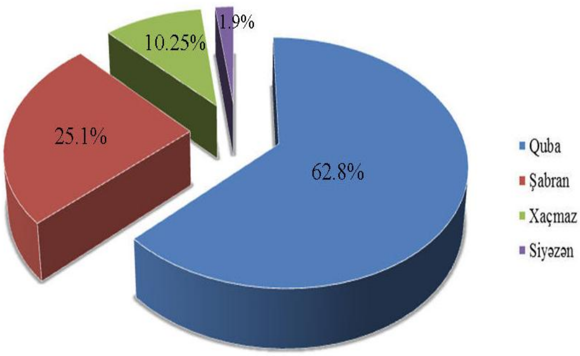


Fig. 1. Map illustrating the thermal and mineral water resources of the Guba-Khachmaz economic-geographical region

Azerbaijan has many favorable opportunities for developing thermal power stations, but none have been built yet. Although Azerbaijan possesses abundant oil and gas resources, these are classified as non-renewable assets. Therefore, leveraging the historically established experience of utilizing thermal waters worldwide should be considered one of the most critical priority areas for Azerbaijan. Considering the substantial reserves of high-temperature thermal waters in various administrative regions of the Republic of Azerbaijan, and their immense potential for the cost-effective and environmentally friendly generation of electricity, strategic emphasis should be placed on advancing this sector, particularly in regions of the republic that face deficiencies in fuel supply, energy infrastructure, and hydroelectric capacity. The percentage of thermal and mineral waters in the Guba-Khachmaz economic-geographic region, categorized by administrative district, is presented in Fig. 2 [9].



Considering the above, we can draw the following conclusion:

1. The initiatives undertaken in Azerbaijan to harness electricity from thermal waters, an inexhaustible natural resource, have thus far proven insufficient.
2. The lack of detailed information regarding the exact number of high-temperature thermal water sources in Azerbaijan, along with their flow rates and potential applications, poses a significant obstacle to the development of thermal power plants within the republic.

3. Given the favorable conditions for constructing power plants using high-temperature thermal waters in Azerbaijan, it would be beneficial to develop such facilities. This approach could help meet the growing electricity demand in the country's regions, utilizing best practices from around the world to harness this inexhaustible resource effectively.
4. Foreign investors in Azerbaijan are allocating significant financial resources to develop various economic sectors. By encouraging both foreign and local entrepreneurs to participate in the construction of thermal power plants, which require relatively low financial investment, the utilization of thermal waters in the power industry can be effectively advanced. Geothermal technologies, at various stages of development worldwide, are widely utilized in central heating systems, greenhouses, and other applications. The technology for generating electricity from naturally high-permeability hydrothermal reservoirs is considered reliable. Most of the geothermal power plants currently operating worldwide utilize dry steam turbines or "flash" units (including single, double, and triple flash systems) and rely on hot water sources that exceed 180°C. Additionally, new technologies such as "Enhanced Geothermal Systems (EGS)" are under development and moving towards implementation.

Another type of geothermal power plant utilizes natural geothermal resources, which consist of water heated to high temperatures through natural processes. However, the availability of such resources is limited. For instance, in Russia, regions like Kamchatka and the Caucasus are known for their mineral water sources. In this system, heated water is drawn from the ground and enters a heat exchanger. In another case, water rises freely through a specially drilled well due to high geological pressure. This general operating principle is applicable to nearly all types of geothermal power plants.

The thermal waters under investigation were directly collected from their surface discharge zones and processed using various chemical treatment methods for experimental purposes. These locations are rich in both thermal and cold mineral springs, which contain nitrogen and hydrogen sulfide. In the "Khachmaz" geothermal energy resource of the Khachmaz region in Azerbaijan, sodium (Na) is the predominant chemical element. It constitutes approximately 72.41–90.12% of all chemical substances found in the composition of the "Khachmaz" geothermal energy resource in Azerbaijan's Khachmaz region. [10,11].

Prior to conducting the main experiments, the functionality of the experimental apparatus was evaluated through verification experiments using substances with well-documented experiment-tal data. Given that the vibrating tube method requires calibration with at least three substances, water, toluene, and NaCl aqueous solutions were chosen as the primary calibrators for this purpose. The calibration process was subsequently analyzed in detail. Following the calibration of the device, repeated measurements were conducted using the selected calibrating substances to ensure the reliability and precision of the calibration process. In some cases, experiments were conducted 4-5 times at the same temperatures, and the device's performance was evaluated at different times, regardless of variations in its filling and experimental conditions. The laboratory in which the experiments were conducted was maintained at a constant temperature of $T = 293.15$ K under climate-controlled conditions. A comparative analysis of the results obtained for aqueous solutions of water, toluene, and NaCl ($m = 2.96661$ mol·kg^{-1}) with the corresponding values reported in the literature is presented in Figures 1, 2, and 3.

As illustrated in the figures below, the discrepancy between the newly obtained density data and the values reported in the literature does not exceed the estimated measurement errors associated with this device. Double-distilled water was obtained from different laboratory facilities. NaCl, toluene, and other chemicals were sourced from Merck (Germany). Consistently, the results obtained were in close agreement with minimal error. All of this demonstrates the high accuracy of the constructed experimental device.

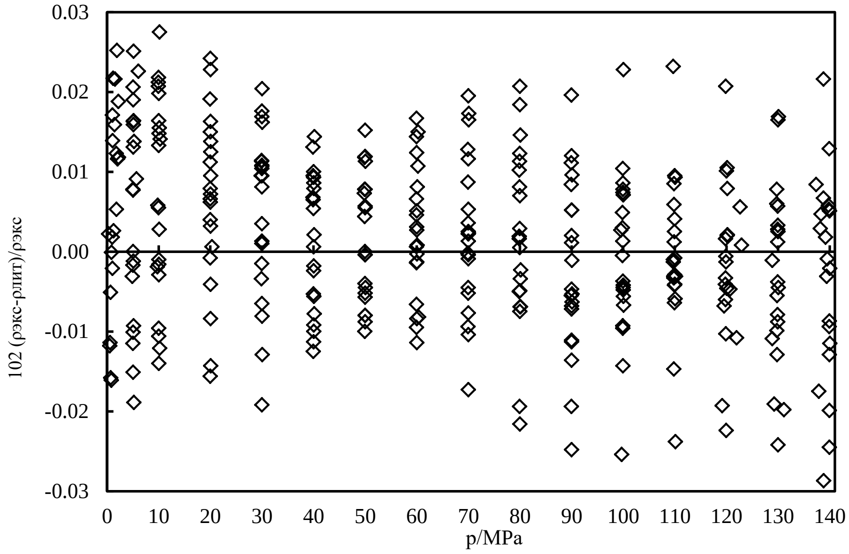


Fig. 1. The pressure dependence of the measured density of water at temperatures T=(278.15–468.15) K and its deviation from the IAPWS 95 data reported in the literature.

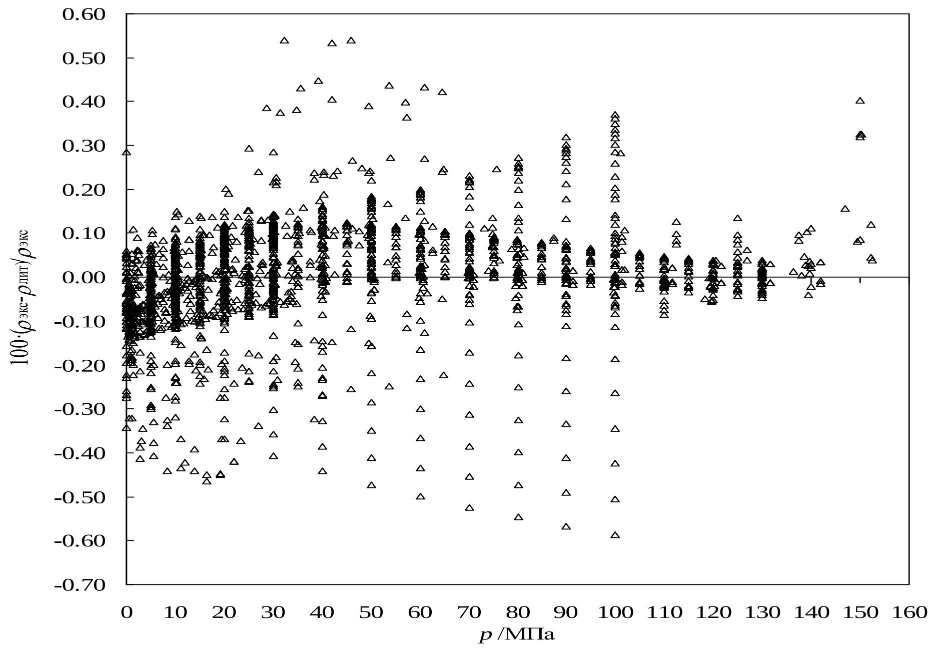


Fig. 2. The pressure dependence of the measured density of toluene at temperature T=(278.15-468.15) K and along with comparisons to data found in various literature sources up to the year 2000.

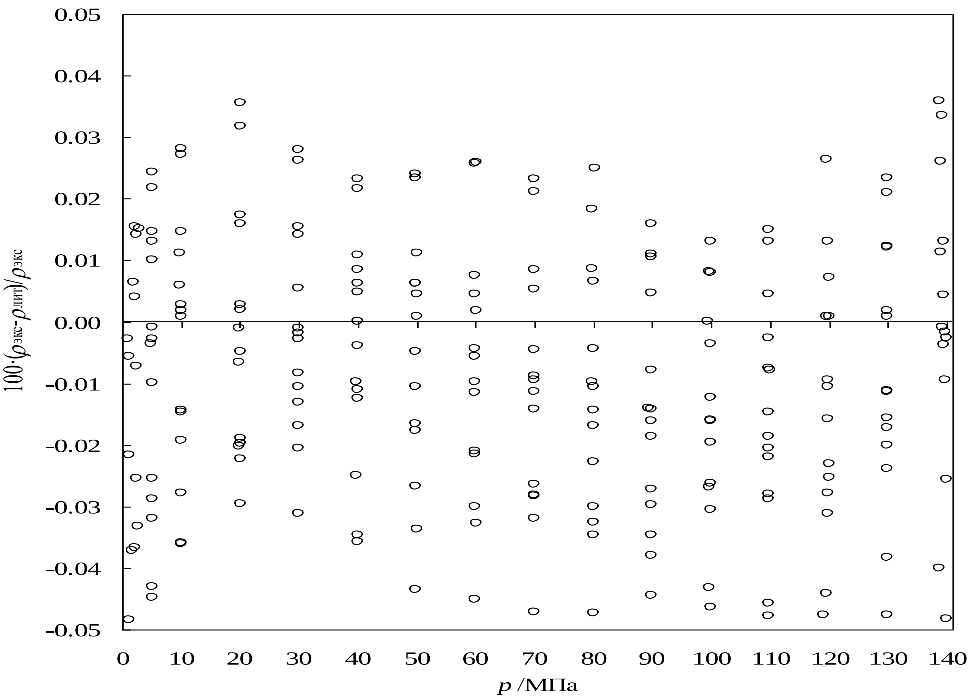


Fig. 3. The pressure dependence of the measured density of an aqueous solution of NaCl (m=2,96661 mol·kq[1]) at temperature T=(278.15-468.15) K and along with comparisons to data found in various literature sources up to the year 2000.

After performing verification experiments on water, NaCl, and toluene (p, ϱ, T), the pressure, density, and temperature dependencies of Azerbaijan's 'Khachmaz' thermal water were systematically measured at elevated pressures and varying temperatures using the vibrating tube method in the experimental setup.

During the measurement of the (p, ϱ, T) dependencies at each equilibrium state, efforts were made to achieve the lowest possible pressure values. This approach was intended to obtain highly accurate density values through graphical extrapolation to atmospheric pressure and extrapolated density values were subsequently compared with measurements obtained using the DMA 4500 device. The data obtained from these methods are in good agreement, with a variation of ±0.02%. Experiments were conducted at pressure intervals of approximately 5 MPa for each isotherm. For all studied subjects, the research was performed at temperatures ranging from T = (278.15 K ÷373.15 K), and pressures up to p = 40 MPa. The experimental values of pressure (p), density (ϱ), and temperature (T) are presented in Table 2.

TABLE II. THE EXPERIMENTAL EVALUATION OF THE DENSITY OF "KHACHMAZ" THERMAL WATER FROM AZERBAIJAN'S KHACHMAZ REGION AT VARYING PRESSURES AND TEMPERATURES

$\frac{p}{MPa}$	$\frac{\rho}{kq/m^3}$	$\frac{T}{K}$	$\frac{p}{MPa}$	$\frac{\rho}{kq/m^3}$	$\frac{T}{K}$
0.624	1004.04	278.15	1.160	989.32	328.02
5.004	1006.21	278.15	5.024	990.99	328.04
10.023	1008.65	278.16	10.079	993.00	328.17
15.012	1011.05	278.15	15.576	995.38	328.18
20.035	1013.43	278.14	19.985	997.22	328.19
25.036	1015.76	278.15	25.527	999.61	328.17
30.054	1018.07	278.15	30.023	1001.50	328.14
35.124	1020.37	278.14	35.513	1003.58	328.12
40.021	1022.56	278.15	39.978	1005.37	328.06
0.539	1002.59	288.14	0.846	981.22	343.15
5.006	1004.66	288.16	5.097	983.06	343.16
9.855	1006.87	288.17	9.967	985.17	343.14
15.151	1009.25	288.17	15.525	987.55	343.15
20.064	1011.43	288.17	20.000	989.45	343.15
25.121	1013.64	288.16	25.586	991.82	343.14
30.103	1015.79	288.16	30.045	993.68	343.16
35.111	1017.92	288.16	35.514	995.98	343.15
40.145	1020.04	288.15	40.050	997.87	343.15
1.025	1000.15	298.27	0.846	974.29	354.24
5.079	1002.02	298.22	5.097	976.23	354.25
9.818	1004.22	298.22	9.967	978.33	354.27
15.593	1006.61	298.17	15.525	980.63	354.27
20.018	1008.46	298.13	20.000	982.58	354.27
25.104	1010.69	298.13	25.586	984.92	354.27
30.155	1012.85	298.12	30.045	986.83	354.28
35.089	1014.82	298.13	35.514	989.17	354.27
40.040	1016.88	298.13	40.050	991.07	354.27
0.898	995.52	313.08	1.626	962.02	372.90
4.995	997.25	313.10	5.059	963.59	372.90
9.972	999.20	313.15	10.042	965.73	372.96
15.563	1001.65	313.17	15.525	968.08	372.97
20.008	1003.42	313.20	20.014	970.00	372.99
25.534	1005.80	313.18	25.596	972.31	373.00
30.057	1007.65	313.19	30.001	974.44	372.90
35.586	1009.82	313.17	35.576	976.79	372.91
39.970	1011.52	313.15	40.013	978.53	372.92

Isotherms were constructed in the pressure-density (p-ϱ) coordinates for pressure values ranging from 0.1 to 40 MPa, as illustrated in Figure 4.

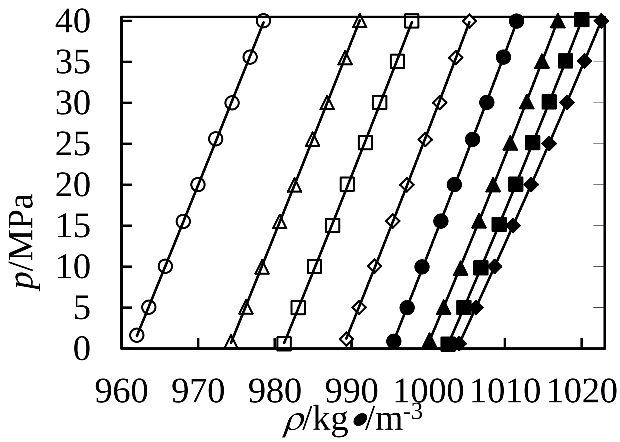


Fig. 4. The relationship between pressure (p) and density (ϱ) of the "Khachmaz" thermal water in the Khachmaz region of Azerbaijan was calculated using formulas 1 and 2.

♦, 278,15 K; ■, 288,16 K; ▲, 298,17 K; •, 313,18 K; ◊, 328,18 K;□, 343,15 K; Δ, 354,27 K; ○, 372,96 K.

IV.Conclusion

The measured density of "Khachmaz" thermal water of Khachmaz region of Azerbaijan was also measured at atmospheric pressure with an accuracy of 0.01% (more accurate than at high pressures) on a DMA 5000M device. This device enables precise measurements at temperatures up to T=363,15 K. The results obtained are expressed using the following equation of state:

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

Adding a third term to the Akhundov-Imanov equation has been shown to reduce the error in describing experimental data to Δϱ/ϱ=±(0.001 to 0.003)%. The coefficients A(T), B(T), and C(T) are functions of temperature and can be expressed in polynomial form:

The values of the coefficients a_{ij}, b_{ij}, and c_{ij} in the equation $A(T) = \sum_{i=1}^{3} a_i T^i$, $B(T) = \sum_{i=0}^{2} b_i T^i$,

$$C(T) = \sum_{i=0}^{2} c_i T^i$$

are given in Table 3.

TABLE III.

a_1= -3.9508587	b_0= 8322.6444921	c_0= -6583.286607275
a_2= 0.019210690563	b_1= -56.828468335	c_1= 45.23492762848
a_3= -0. 3685081337·10^{-4}	b_2= 0.103286734291	c_2= -0.07893862924

Equation (1), considering the values of the coefficients A(T), B(T), and C(T), allows for the empirical determination of the dependency of the "Khachmaz" thermal water on (p, ϱ, T) with an average error of 0.007%.

REFERENCES

[1] The State Program on Use of Alternative and Renewable Energy Sources in Azerbaijan Republic (approved by the order of the President of the Azerbaijan Republic, no. 462 dated October 21, 2004)

[2] "Methods for measuring the thermal-physical properties of geothermal energy sources in the Khachmaz region, Republic of Azerbaijan", Baku – "Science" – 2013

[3] Namazova A.M. Thermal waters of the Greater Caucasus and their rational use // Bulletin of modern science. Scientific-theoretical journal, Volgograd: 2015, No. 4, pp. 178-181

[4] Namazova A.M. "Utilization of thermal waters in electric energy industry in the world and in Azerbaijan" Proceedings of the Azerbaijan Geographical Society. Geography and natural resources, 2015, No. 2, pp. 119-121

[5] Online resources: www.eco.gov.az; www.az.wikipedia.org; https://www.renewable.com/; http://topnews.az/news/439714/_www.//ru/wikipedia/org/wiki/геотермальная_энергетика

[6] Bertani, Ruggero (September 2007) "Wordl Geothermal Generation in 2007", Geo-Heat Centre Quarterly Bulletin (Klamath Falls, Oregon: Oregon Institute of Technology). T.28 (3): s.8-19, ISSN 0276-1084

[7] Holm, Alison (May 2010), "Geothermal Energy: International Market Update", Geothermal Energy Association, cc. 7

[8] Namazova A.M. Economic significance of mineral and thermal waters of the Sheki-Zagatala economic-geographical region // Baku University News. Natural Sciences Series, 2015, No. 3, pp. 152-159.

[9] Namazova A.M. Thermal and mineral water of Guba-Khachmaz economic region,their rational use opportunities // Proceedings of young scientists. 2016, No 13, p.61-68

[10] N.D.Nabiev, M.M.Bashirov, J.T.Safarov, A.N.Shahverdiyev, E.P.Hassel "Thermodynamic properties of geothermal energy resources (Khachmaz Sabir-Oba) of Azerbaijan" Journal of Chemical and Engineering data, Vol. 54,No.6, 2009.

[11] N.D.Nabiev "Study of thermal-physical properties of geothermal energy resources of the Khachmaz region of Azerbaijan." Dissertation submitted for the degree of Doctor of Philosophy in Engineering, Baku, 2011, 177 pages.

[12] Akhundov T.S., Imanov Sh.Y. Equation of State for Ortho- and Paraxylene // Proceedings of Higher Educational Institutions, Oil and Gas, 1969, No. 12, p. 24.