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GENERALIZATION OF EXPERIMENTAL DATA ON THE VISCOSITY AND DENSITY OF THE “KHACHMAZ” THERMAL WATER OF THE KHACHMAZ REGION OF AZERBAIJAN

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ABSTRACT

The main objective of the research is to analytically generalize the experimental results of the dynamic and kinematic viscosity, as well as the density, of the "Khachmaz" thermal water from the Khachmaz region of Azerbaijan at various temperatures. As a result of the scientific studies conducted by us, the data obtained from the “Stabinger SVM 3000” viscometer for dynamic viscosity (η) and kinematic viscosity (ν), and from the experimental setup operating on the vibrating-tube densimeter method for the density (ρ) of the thermal water, were used in this work.

Then, based on the experimental results of the “Khachmaz” thermal water obtained under the same temperature conditions in the η–ρ and ν–ρ coordinate systems determined using polynomial equations, the dependencies η = f(ρ) and ν = f(ρ) were proposed in the article. The polynomial coefficients were calculated from the experimental data using the least squares method and are presented in a table. Considering the proposed equations and polynomial coefficients, it is possible to calculate the values of the dynamic viscosity (η) and kinematic viscosity (ν) of the “Khachmaz” thermal water from the Khachmaz region of Azerbaijan at different temperatures within the experimental error range.

1. INTRODUCTION

As a result of various geological and volcanic processes, thermal waters that reach the Earth’s surface at high temperature and pressure by utilizing the planet’s natural heat are widely used as alternative energy sources. The extraction of heat from geothermal sources was first implemented in Italy in 1904. Later, various facilities were constructed in New Zealand, Japan, the Philippines, and the United States for the production of geothermal energy. For instance, about 95% of the heating system in Reykjavik, Iceland, is supplied by geothermal energy.

There are various geothermal technologies with different levels of development that are widely used in central heating plants, heating systems, and other application areas. The technology of generating electric power from naturally permeable hydrothermal reservoirs is also considered reliable. At present, most of the geothermal power plants operating worldwide are based on dry steam turbines or “flash” systems (single, double, or triple flash) and are used for hot water sources with temperatures above 180°C. In addition, new technologies such as “Enhanced Geothermal Systems (EGS)” which are in the development stage are also being advanced [1].

According to data from the UN Commission on Global Warming, the Earth’s surface temperature has risen by 3°C over the past 170 years. The continuation of this process poses a global warming threat to the planet. Currently, the accelerated melting of Alpine glaciers, the annual rise of ocean (sea) levels by 1÷2 mm-amounting to 10÷20 cm over the past 100 years and the 0.3°C increase in the temperature of tropical seas since 1994 all serve as evidence of this phenomenon [1–3].

At present, geothermal energy is one of the least utilized alternative energy sources in the world. However, as the quantity of conventional energy resources decreases and their prices continue to rise, the demand for alternative energy sources is increasing, which will lead to a wider use of geothermal energy. Currently, in many developed countries, geothermal energy is primarily used for power generation (by driving turbines with geothermal steam) and for domestic heating systems as a source of hot water.

In order to utilize thermal waters as alternative energy sources, it is essential to study their properties. One of the primary requirements is the chemical analysis of the waters and the investigation of the geological structures of the areas where these waters emerge. In addition, the study of key thermophysical parameters such as dynamic and kinematic viscosity, as well as density that determine the thermal properties of these waters is also of great importance. Significant scientific research has been carried out worldwide by scholars in this field.

By making extensive and efficient use of thermal and mineral waters, it is possible to establish many new sectors in our country, such as mineral water bottling plants, chemical and energy industries, medical and health facilities, as well as tourism and recreational centers. This would have a positive impact on the employment of the workforce in the country. As a result, the problem of unemployment could be partially alleviated, catering establishments would expand, and agricultural sectors would develop to meet the food demands of tourists.

In Azerbaijan, significant work has been carried out in this direction over the past 21 years. The Republic of Azerbaijan confirmed its target regarding alternative and renewable energy sources as early as 2004 [2]. Among these renewable energy sources are geothermal energy resources, which are derived directly or indirectly from chemical substances, hot water, and steam generated by heat accumulated at various depths of the Earth. Geothermal energy can also be used for heating and cooling purposes or for the production of clean electricity. The role of thermal waters as underground heat energy accumulators, as well as their high thermal energy capacity, highlights their special importance among renewable energy sources.

Although the Republic of Azerbaijan is rich in thermal water resources, only a very small portion is currently utilized. Depending on usability, as well as geostructural and hydrogeothermal conditions, the country's thermal resources are concentrated in the following regions: Greater Caucasus, Absheron Peninsula, Caspian-Quba, Kura-Araz Lowland, Lesser Caucasus, Talysh-Lankaran, Jalilabad-Zar, Shamakhi-Gobustan, Aghinokhur-Kur interfluve, and Nakhchivan hydrothermal zones. Although the total reserve of these thermal regions amounts to 249,000 m^3/day, the majority of these resources are used for therapeutic purposes [3–5]. The temperature of Azerbaijan's mineral waters ranges from 4°C to 65°C, which applies only to natural water sources. In addition, geothermal waters with temperatures reaching up to 95°C have been extracted through deep drilling in the country.

In Azerbaijan, there are more than 200 underground, thermal, mineral, and drinking water resources enriched with various minerals, with a total capacity exceeding 100 million liters per day. Significant scientific research in this field has also been conducted in Azerbaijan over a long period [1–8]. The country's thermal water sources, including their chemical composition and related characteristics, have been studied to a considerable extent. Nevertheless, the thermophysical properties of these thermal waters remain relatively under-researched [6–8].

2. RESEARCH METHODOLOGY

The Khachmaz district of Azerbaijan is rich in valuable thermal energy resources, encompassing all types of waters, including carbon dioxide–carbonate, carbon dioxide–chloride, and hydrogen sulfide–sulfate waters. The diverse chemical composition of the district's thermal waters, their high therapeutic properties, and the favorable geographical location of the area provide a solid foundation for the use of these thermal waters for medical treatments as well as for various sectors of the national economy.

The main objective of this study is the analytical generalization of the experimental results of the dynamic viscosity (η), kinematic viscosity (ν), and density (ϱ) of the "Khachmaz" thermal water from the Khachmaz district of Azerbaijan at various temperatures.

The dynamic and kinematic viscosities of the "Khachmaz" thermal water from the Khachmaz district have been studied experimentally. The main objective of these investigations is to reveal the potential of alternative energy resources in the northern regions of Azerbaijan.

The experiments were conducted using the Stabinger SVM 3000 viscometer (Figure 1). The device features a very compact design, ease of use, and high accuracy (0.1÷0.35%). Its main operating principle is based on the constant rotation of a tube inside the device. The substance under investigation is filled into the tube, which is equipped with a coaxial rotor. The friction between the tube and the sample inside forces both the sample and the rotor to rotate.

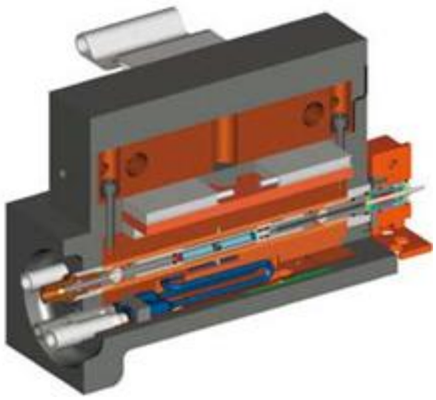

***Figure 1.** Internal structure of the Stabinger SVM 3000 viscometer.*

When there is no resistance, all three components rotate at the same speed. It should also be noted that a magnet inside the rotor acts as a brake. The magnetic field generated around the magnet creates eddy currents. These currents extract energy from the rotor, causing it to experience a braking effect. As a result, a difference arises between the speeds of the tube and the internal rotor, which is characterized as viscosity [7].

During the experiments, the dynamic and kinematic viscosities of the "Khachmaz" thermal water were measured. The thermal waters were collected directly from their source areas and prepared for testing through various chemical purification procedures. To ensure measurements were performed under conditions as close as possible to those at the Earth's surface, all dissolved gases and air in the thermal water were removed, and natural samples were also used.

The experiments were carried out in the temperature range of T = 278.15÷343.15 K and at atmospheric pressure. Since the Stabinger SVM 3000 viscometer allows simultaneous measurement of dynamic viscosity and density, the device automatically calculates the kinematic viscosity ν (m^2/s) using the following relation for viscosity:

$$\nu = \frac{\eta}{\rho} \qquad (1)$$

Here, η is the dynamic viscosity (Pa·s) and ϱ is the density (kg/m^3).

The density of the "Khachmaz" thermal water was measured at atmospheric pressure (p = 0.101 MPa) within the temperature range of T = 278.15÷343.15 K.

3. RESULTS AND DISCUSSION

The experimental values of the dynamic viscosity (η), kinematic viscosity (ν), and density (ϱ) of the "Khachmaz" thermal water from Azerbaijan are presented in Tables 1 and 2:

Table 1. *Experimental values of dynamic viscosity η (Pa·s) and kinematic viscosity ν (m^2/s) of the "Khachmaz" thermal water from Azerbaijan at various temperatures under atmospheric pressure.*

T/K	η	ν
278,147	1537,60	1,53195
288,147	11780,0	1,17484
298,150	937,70	0,93778
313,152	713,16	0,71619
328,153	559,22	0,56528
343,152	421,66	0,42977

Table 2. *Experimental values of the density ρ (kg/m^3) of the "Khachmaz" thermal water from Azerbaijan at various temperatures under atmospheric pressure.*

T/K	ρ/ kq/m^3
278,15	1003,80
288,15	1002,80
298,15	1000,54
313,15	995,80
328,14	989,10
343,16	981,20

The temperature dependence of the dynamic viscosity, kinematic viscosity, and density of the "Khachmaz" thermal water from Azerbaijan is shown in Figures 2–4. As seen from Figures 2–4, the dynamic and kinematic viscosities, as well as the density of the "Khachmaz" thermal water, exhibit the same trend as the temperature dependence of the dynamic and kinematic viscosities of pure water, decreasing significantly with increasing temperature.

The figures also show that the experimental values of the dynamic viscosity (η), kinematic viscosity (ν), and density (ϱ) of the investigated thermal water are higher than those of pure water, which constitutes the main component of thermal waters [9,10]. Based on the analysis of the chemical composition of the "Khachmaz" thermal water, it can be concluded that these differences are due to the presence of numerous chemical elements in the sample [4]. Therefore, dissolved chemical substances, gases, and air influence the dynamic viscosity and density of the thermal water, resulting in higher viscosity and density compared to pure water.

The dynamic and kinematic viscosities of the "Khachmaz" thermal water from Azerbaijan have been described as polynomial functions of temperature as follows:

$$\eta = \sum_{i=0}^{3} a_i T^i \quad (2)$$

$$\nu = \sum_{i=0}^{3} b_i T^i \quad (3)$$

Here, a_i and b_i are the coefficients of the polynomials. The values of these coefficients, calculated using the least squares method, are presented for the investigated thermal water in Table 3.

Table 3. *The coefficients a_i and b_i in equations (2) and (3) representing the polynomial temperature dependence of the dynamic and kinematic viscosities of the "Khachmaz" thermal water from Azerbaijan.*

a_i	b_i
a_0= 527.256774	b_0= 530.37865
a_1= - 6.208266	b_1= - 6.249937
a_2= 0.027522	b_2= 0.027726
a_3= - 0.543113·10^{-4}	b_3= - 0.547516·10^{-4}
a_4= 0.402·10^{-7}	b_4= 0.405·10^{-7}

Considering equations (2) and (3) and the polynomial coefficients (Table 3), it is possible to calculate the dynamic (η) and kinematic (ν) viscosities of the "Khachmaz" thermal water at various temperatures within the experimental error range. These equations also allow for the interpolation and extrapolation of dynamic (η) and kinematic (ν) viscosity values beyond the measured experimental data.

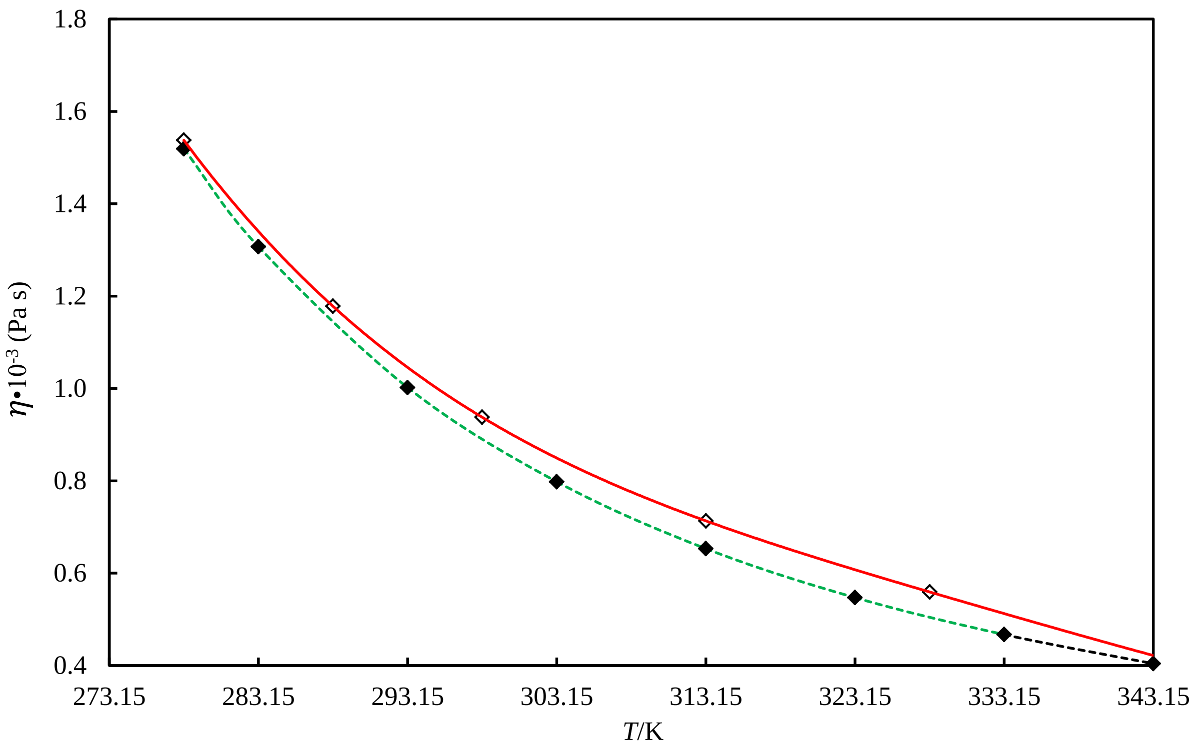

Figure 2. *Temperature dependence of the dynamic viscosity η (Pa·s) of the geothermal waters from the Khachmaz district of Azerbaijan: (◊, "Khachmaz"; --♦--, Water [9]).*

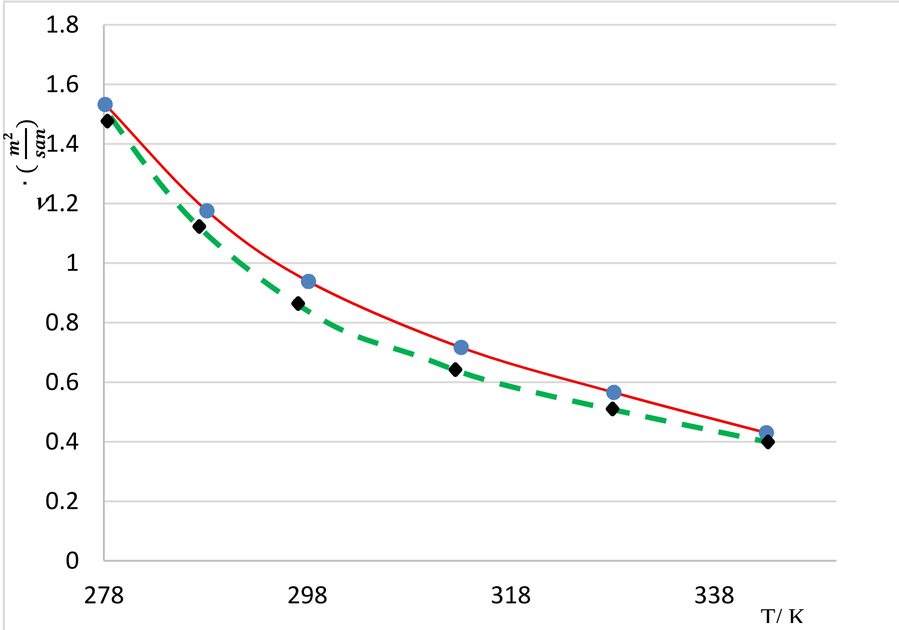

Figure 3. *Temperature dependence of the kinematic viscosity ν (m²/s) of the geothermal waters from the Khachmaz district of Azerbaijan: (●, "Khachmaz"; --♦--, Water [9]).*

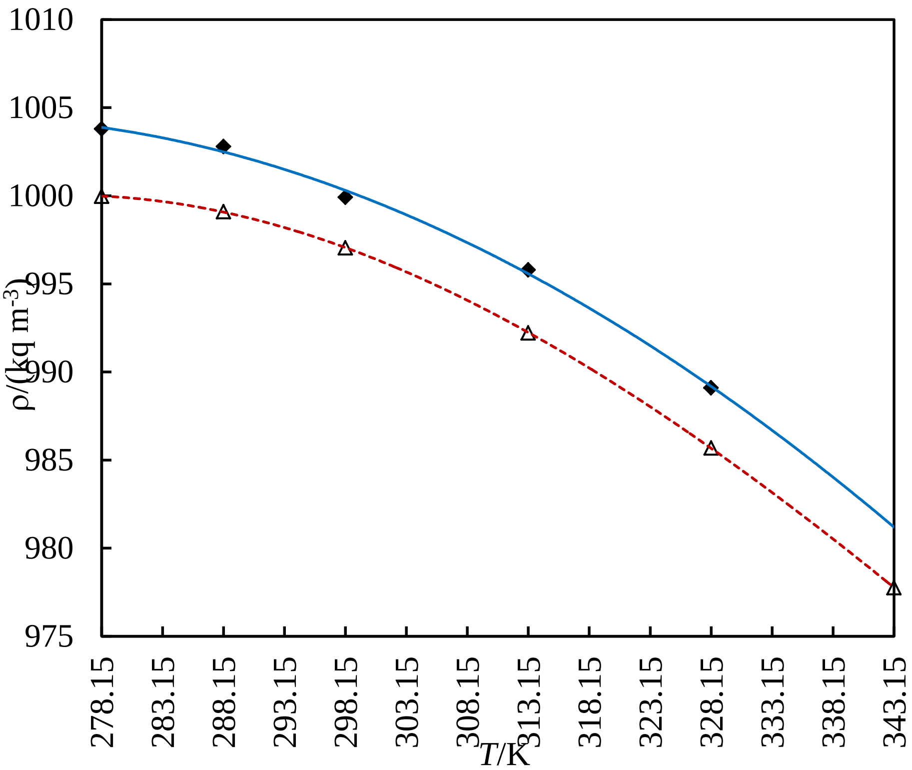

Figure 4. *Temperature dependence of the density (ρ) of the "Khachmaz" thermal water from the Khachmaz district of Azerbaijan: (♦, "Khachmaz"; --Δ--, Water [10]).*

Based on the experimental results (Tables 1 and 2) and using the data of the "Khachmaz" thermal water obtained under the same temperature conditions in the η–ϱ and ν–ϱ coordinate systems, the following polynomial equations were proposed in the article to describe the dependencies η = f(ϱ) and ν = f(ϱ):

$$\eta = \sum_{i=0}^{4} a_i \cdot \rho^i \qquad (4)$$

$$\nu = \sum_{j=0}^{4} b_j \cdot \rho^j \qquad (5)$$

Here, $a_i$and $b_j$are the polynomial coefficients calculated from the experimental data using the least squares method and are presented in Table 3.

Table 4*. Values of the coefficients $a_i$and $b_j$for the "Khachmaz" thermal water from Azerbaijan, obtained from equations (4) and (5).*

a_i		b_j	
a_0	$-0.224957 \cdot 10^9$	b_0	$-0.223394 \cdot 10^6$
a_1	$0.597108 \cdot 10^{+6}$	b_1	$0.592956 \cdot 10^{+3}$
a_2	$-0.431975 \cdot 10^{+3}$	b_2	-0.428976
a_3	-0.027641	b_3	$-0.274363 \cdot 10^{-4}$
a_4	$0.874658 \cdot 10^{-4}$	b_4	$0.868507 \cdot 10^{-7}$

Considering equations (4) and (5) and the polynomial coefficients (Table 4), it is possible to calculate the dynamic (η) and kinematic (ν) viscosities of the "Khachmaz" thermal water at various temperatures within the experimental error range. These equations also allow for the interpolation and extrapolation of dynamic (η) and kinematic (ν) viscosity values beyond the measured experimental data.

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