JOURNAL OF BAKU ENGINEERING UNIVERSITY - PHYSICS
2024. Volume 8, Number 2 *Pages 91-96*

UOT 536.77:547.442

DOI: https://doi.org/10.30546/09081.2024.102.7084

SUMMARY OF EXPERIMENTAL DATA ON THE DENSITY AND VISCOSITY OF "ILISU SANGAR" AND "ILISU BESHBULAG" THERMAL WATERS IN THE GAKH DISTRICT OF AZERBAIJAN

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ARTICLE INFO

Article history:
Received: 2025-02-07
Received in revised form: 2025-02-20
Accepted: 2025-02-25
Available online

Keywords:
thermal waters,
renewable energy sources,
dynamic viscosity,
kinematic viscosity,
density.

ABSTRACT

This study presents a comprehensive analysis of experimental data on the density, dynamic viscosity, and kinematic viscosity of the thermal waters of "Ilisu Sangar" and "Ilisu Beshbulag," located in the northern region of the Gakh district in the Republic of Azerbaijan. The experiments on the density, dynamic viscosity, and kinematic viscosity of the thermal waters were conducted using advanced instrumentation manufactured in Germany. The densities of the "Ilisu Sangar" and "Ilisu Beshbulag" thermal waters were precisely quantified using the "Anton-Paar SVM-300 Stabinger" viscometer, while their dynamic viscosities were determined with high precision utilizing the DMA 5000 M apparatus. Using the experimental data of p=f (u) p and p=f (v) p at selected temperatures, analytical dependences of thermal waters were derived. The obtained values are described by polynomial equations. Polynomial equations enable the calculation of the experimental density values of the "Ilisu Sangar" and "Ilisu Beshbulag" thermal waters in the Gakh district at various temperatures, with a maximum error margin of ±0.25%.

1. Introduction

Adoption of alternative energy sources has become increasingly prevalent in both developed and developing nations. This transition is primarily driven by the imperative for environmental sustainability and the objective to minimize the harmful waste emissions into the ecosystem. Furthermore, there is an escalating demand for alternative energy sources as substitutes for conventional ones. Although the economic costs associated with renewable energy sources are generally higher than those of non-renewable sources, efforts are being made to enhance their economic viability. In pursuit of this, the United Nations and various international organizations have implemented a range of policies aimed at promoting the utilization of renewable energy. Consequently, Azerbaijan has fostered considerable opportunities for the advancement and utilization of alternative energy sources.

Azerbaijan has a favorable geographical position for utilizing thermal waters. The country can harness the energy from 172 million m^3 of geothermal waters, with temperatures ranging from 40 to 100°C, year-round.

Solar energy is regarded as an economically viable solution for heating administrative and residential buildings, warming greenhouses, and processing agricultural products.

On a local scale, both biomass and geothermal energy are actively utilized. In an effort to enhance the deployment of alternative energy sources, drawing upon global best practices, the President signed Decree No. 4 on November 24, 2003. The preparation of the document on the use of these energy sources was entrusted to the Ministries of Ecology and Natural Resources, Economic Development, Fuel and Energy, as well as the Azerbaijan National Academy of Sciences (ANAS).

To gain from global experience, the Republic of Azerbaijan became a member of the International Renewable Energy Agency, which was established on June 10, 2009. This initiative will be carried out continuously, as outlined in Decree No. 182, signed by the President of the Republic of Azerbaijan in November 2009 [1].

The State Program advocates for the development and implementation of regulatory and legal frameworks to facilitate the utilization of alternative energy sources in the Republic of Azerbaijan. Engaging private investors in the preparation of projects is essential for the successful deployment of alternative and renewable energy sources. This involvement will ensure the efficient operation of these projects under optimal conditions and foster the integration of environmentally sustainable energy solutions into the energy market.

The action plan also encompasses public education on alternative and renewable energy sources, alongside the development and dissemination of educational materials in this field. Currently, various higher education institutions in Azerbaijan are effectively undertaking these initiatives.

To attract investors with international expertise, the Ministry of Energy and Industry has engaged specialists in consultations with international institutions, embassies, global organizations, and foreign enterprises. These efforts aim to acquire valuable insights for the effective implementation of this State program and to facilitate the invitation of foreign investors to participate in initiatives within Azerbaijan [1].

Azerbaijan is endowed with a substantial reserve of mineral waters, with more than 1,000 natural springs distributed across the country. These springs are predominantly located in the mountainous regions, which are characterized by a high concentration of natural water sources. The extraction of mineral waters is typically conducted through drilling. Azerbaijan has a highly diverse and complex relief structure from a physical and geographical perspective.

Approximately 90% of Azerbaijan's natural mineral water sources, totalling 905, are located in mountainous regions, while the remaining 10%, or 98 sources, are found in flat, plain areas. The composition of mineral water, determined by the concentration of various elements by weight, is chemically highly active. Unlike ordinary water, mineral waters contain dissolved gases, salts, and trace elements. The physical and chemical properties, as well as the quality of the mineral waters, vary depending on the types and concentrations of elements present.

The temperature of mineral waters in Azerbaijan varies between 4 and 65^{0}C. This applies only to natural water sources. In addition, waters reaching 95^{0}C are extracted by drilling deep into the earth in Azerbaijan.

In our republic, there are high-temperature mineral waters—Donuzutan (64^{0}C in Masalli) and Istisu (62^{0}C in Kalbajar). Waters with a temperature of 35-36^{0}C are more valuable due to their temperature characteristics. This temperature closely matches that of the human body, giving these waters significant therapeutic benefits.

This type of water can be found in Khaltan (in the Shabran district), Ilisu (in the Gakh district) (36^0-42^0C) etc.

Problem statement. Among geothermal energy resources, the Ilisu spring group, located within the Sheki-Zagatala economic-geographical region (figure 1), is particularly well-known. Situated in the northwestern part of Azerbaijan, the Gakh administrative district is distinguished not only by its other natural advantages but also by the abundance of its thermal and mineral waters. The Ilisu thermal water groups, known for their hydrosulfide and hydro carbonate properties, along with the mineral waters found on both banks of the Gurmukh River near the village of Alibeyli and in the Qaynama area, hold significant potential for resort and tourism development. However, these resources remain underutilized. The Ilisu mineral water group operates 10 outlets and consists of hydrosulfide waters containing sodium bicarbonate (NaHCO3). This mineral water has been used for therapeutic purposes by the local population since ancient times. The names of the two main springs—Oglan-Bulag (for men) and Qız-Bulag (for women), confirm this.

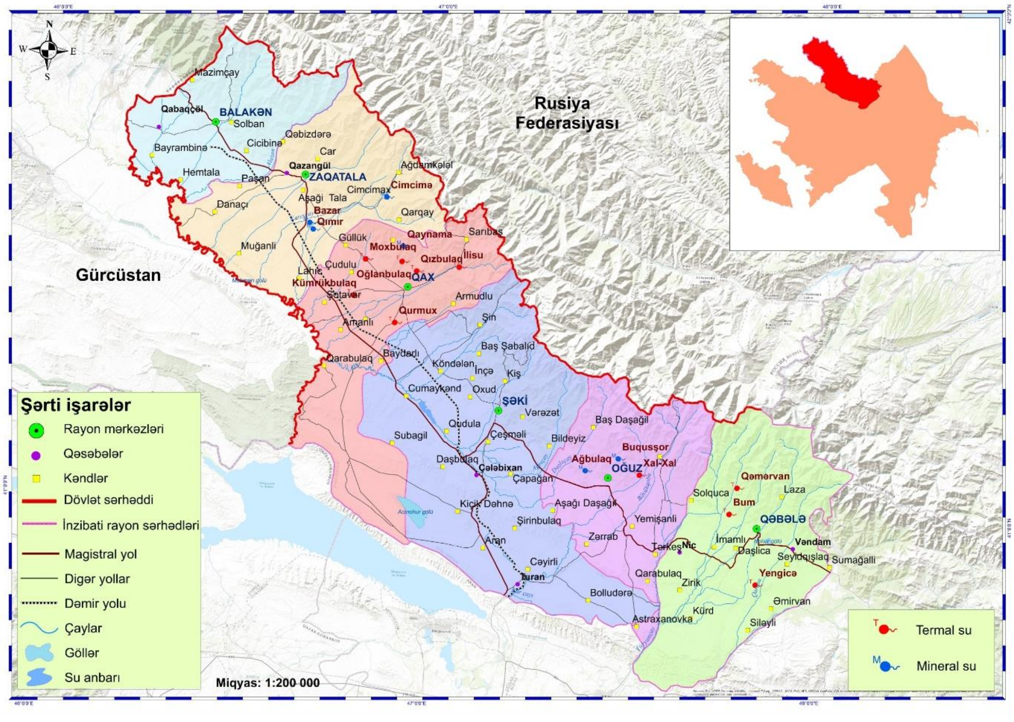

Fig.1. Map of the thermal and mineral water resources in the Sheki-Zagatala economic-geographical region.

The thermal energy resources of the Gakh administrative district, which is part of the studied Sheki-Zagatala economic-geographic region, are particularly valuable. As such, their diverse chemical composition, high healing properties, and favorable geographical location of the area create a good basis for their wide application for therapeutic purposes and in various sectors of the national economy [2]. The experimental study of the thermal properties of water, specifically its (viscosity and density), in this administrative region is highly relevant. The viscosity (internal friction) of liquids and gases is one of the most important transfer properties. To accurately calculate flow rate, velocity, and pressure drop, it is essential to know the dynamic viscosity coefficient. Additionally, viscosity plays a crucial role in determining heat exchange in both liquids and gases, as it influences both free and forced convection. The viscosity coefficient is a key component in several important criteria (modules), including Reynolds, Prandtl, Rayleigh, and Stanton numbers.

The coefficient of viscosity plays a significant role in the molecular-kinetic theory of liquids and real gases. It is well-established that the most accurate viscosity information is obtained through experimental methods. Various techniques have been proposed for measuring viscosity, and new viscometer designs have been developed. Additionally, existing viscometers have been modernized, and formulas for calculating viscosity have been refined.

The geographical coordinates of the "Ilisu Sangar" and "Ilisu Beshbulag" thermal springs in the Gakh administrative district, along with the temperatures of these waters at the point of emergence, are presented in Table 1.

Table 1. The geographical coordinates of the Gakh thermal springs and their temperatures at the point of emergence from the source.

The name of the source	Geographical coordinates	Temperature at the point of emergence
"Ilisu Sangar"	41°28'05" North 47°03'37" East	T=305,15 K
"Ilisu Beshbulag"	41°27'58" North 47°03'50" East	T=303,15 K

Purpose of the study. It consists of an analytical summary of the experimental results of the density, dynamic and kinematic viscosity of the thermal waters of the "Ilisu Sangar" and "Ilisu Beshbulag" thermal waters of the Gakh district of the Republic of Azerbaijan at different temperatures.

2. Problem-solving approach.

Extensive experimental studies have been carried out over several years to accurately examine the density, dynamic viscosity, and kinematic viscosity of the thermal waters in the Gakh administrative district of the Republic of Azerbaijan, specifically at "Ilisu Sangar" and "Ilisu Beshbulag." The results of these studies have been published in esteemed scientific journals both nationally and internationally [3-9].

The thermal waters under investigation were collected directly from their surface sources and processed for experimental analysis using various chemical methods. To measure density under atmospheric pressure, a high-precision DMA 5000 M instrument from the Anton Paar series was used [10]. The density measurements of the liquids were conducted at temperatures ranging from **T = 278.15 K to 343.15 K** and at a pressure of **p = 0.101 MPa.** To determine the dynamic viscosity, the **German-made SVM3000 Stabinger viscometer** was utilized. This instrument offers an exceptionally broad range of measurement capabilities in terms of viscosity and temperature.

The experiments were conducted at atmospheric pressure and temperature T= (278.142÷373.150) K and it is also possible to calculate the kinematic viscosity in $\left(\nu, \frac{m^2}{s}\right)$ by using the equation $\nu = \frac{\mu}{\rho}$ (1). Here, **μ** represents the dynamic viscosity (Pa·s), and **ϱ** denotes the density (kg/m^3).

The experimental values of density (ϱ), dynamic viscosity (μ), and kinematic viscosity (ν) of the "Ilisu Sangar" and "Ilisu Beshbulag" thermal waters in the Gakh administrative district of the Republic of Azerbaijan are presented in Tables 2 and 3.

Table 2. The experimental values of the density of the "Ilisu Sangar" and "Ilisu Beshbulag" thermal waters at various temperatures in the Gakh administrative district of the Republic of Azerbaijan.

"Ilisu Sangar"		"Ilisu Beshbulag"	
T/K	ρ/ kg/m³	T/K	ρ/ kg/m³
278.16	1000.40	278.15	1000.56
283.14	1000.12	283.14	1000.18
293.14	998.71	293.14	998.64
298.15	997.61	298.14	997.50
303.15	996.27	303.15	996.12
313.14	992.90	313.14	992.73
323.15	988.68	323.15	988.55
333.16	983.71	333.15	983.67
343.15	978.12	343.16	978.19

Table 3. The experimental values of dynamic viscosity μ (Pa·s) and kinematic viscosity $\nu\left(\frac{m^2}{s}\right)$ at various temperatures of "Ilisu Sangar" and "Ilisu Beshbulag" thermal waters in the Gakh administrative district of the Republic of Azerbaijan.

"Ilisu Sangar"			"Ilisu Beshbulag"		
T/K	$\mu\cdot10^6$	$\nu\cdot10^6$	T/K	$\mu\cdot10^6$	$\nu\cdot10^6$
278.147	1549.52	1.5489	278.148	1526.15	1.5253
283.148	1348.26	1.3481	283.148	1325.24	1.3250
293.151	1052.64	1.0540	293.154	1031.39	1.0328
298.155	943.93	0.9462	298.151	924.88	0.9272
313.151	697.01	0.7020	313.152	694.91	0.7000
333.151	502.68	0.5110	333.150	519.38	0.5280
343.151	435.26	0.4450	343.150	461.71	0.4720
353.150	382.96	0.3940	353.152	417.08	0.4290
363.150	339.81	0.3520	363.150	382.85	0.3964
373.150	305.74	0.3190	373.150	355.06	0.3702

Based on the experimental results for the thermal waters studied at the same temperature, the data were analyzed in the ***ρ-μ*** and ***ρ-ν*** coordinate systems using the polynomial equations presented in **equations (2) and (3).** The article highlights the derived relationships and key findings $\rho = f(\mu)$ $\rho = f(\nu)$ from this analysis.

$$\rho = \sum_{i=0}^{3} a_i \cdot \mu^i \quad (2)$$

$$\rho = \sum_{j=0}^{2} b_j \cdot \nu^j \quad (3)$$

Here, ***ai*** and ***bj*** represent the polynomial coefficients determined from the experimental data through the **least squares regression method** and are provided in **Table 4.**

Table 4. The values of coefficients ***ai*** and ***bi*** obtained from **equations (2) and (3)** for the thermal waters of "**Moksu,**" "**Ilisu Sangar,**" and "**Ilisu Beshbulag**" in the **Gakh district of the Republic of Azerbaijan.**

"Ilisu Sangar"	"Ilisu Beshbulag"
a_i	a_i
$0.926312506572\cdot 10^{3}$	$0.905605233673\cdot 10^{3}$
0.172757438379	0.241573032787
$-0.136742202183\cdot 10^{-3}$	$-0.206702661061\cdot 10^{-3}$
$0.362714422921\cdot 10^{-7}$	$-0.206702661061\cdot 10^{-3}$

“Ilisu Sangar”	“Ilisu Beshbulag”
b_j	b_j
$0.923496875591 \cdot 10^3$	$0.912248432340 \cdot 10^3$
$0.179754846953 \cdot 10^3$	$0.211873411334 \cdot 10^3$
$-0.142463926142 \cdot 10^3$	$-0.172041331853 \cdot 10^3$
$0.378093573540 \cdot 10^2$	$0.466817289082 \cdot 10^2$

3. Conclusion

Considering equations (2) and (3) along with the polynomial coefficients provided in Table 4, it is possible to calculate the density values of the thermal waters from the “Ilisu Sangar” and “Ilisu Beshbulag” thermal springs located in the Gakh district of the Republic of Azerbaijan at various temperatures. The maximum error in these calculations is ±0.25%. Furthermore, equations (2) and (3) enable us to derive both extrapolated and interpolated density values of the thermal waters from the “Ilisu Sangar” and “Ilisu Beshbulag” springs at different temperatures.

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