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Geological conditions for the development of geothermal energy in Azerbaijan

A.V. Islamzade, A.Sh.Mukhtarov, 2024

Institute of Geology and Geophysics of the Azerbaijan Academy of Sciences,
Baku, Azerbaijan
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The article considered the thermal waters existing in Azerbaijan, the prospects for their use, business opportunities and other issues. Forecast operational reserves of thermal waters in the Republic, renewable energy potential of Azerbaijan, including the share of renewable energy in Azerbaijan in 2020 are reflected here. Thus, there are a large number of closed and unused exploration wells that can be restored and used to generate geothermal energy with less investment. Now the main goal is to determine the optimal location for drilling wells with a higher geothermal potential and the problems of using this energy. Thermal waters with different chemical composition and mineralization in Azerbaijan are predominantly common in the fold regions of the Caucasus and Talysh Mountains and have significant reserves. As a result of research conducted on more than 1,000 thermal water sources in Azerbaijan, it was determined that the total reserve of thermal water is more than $245 \cdot 10^3$ m^3/day. The main discharge paths of these waters are tectonic faults of different directions and amplitudes. The gas content of the thermal water sources of the Greater Caucasus and Talysh mountains are methane, nitrogen, hydrogen-sulfur mixture, and the content of the Lesser Caucasus' are mainly carbon dioxide. Methane waters are usually high-pressure and high-flow, and high-temperature (64—95 °C). The number of sources containing methane is up to 200. Such sources include Masalli (Arkivan), Devechi (Ledzh), Salyan (Babazanan) and others. Sources of nitrogen are found in the southern part of the Greater Caucasus and in Talysh. These include both cold (14—180 °C) and hot (41—550 °C) springs. The highest nitrogen content among them is Alasha — 100 % (Astara), Meshesu 100 % (Lankaran), Ledzh — 37 %, Khaltan — 88 % (Devechi).

Besides (in addition), in the article the recent use of low-potential geothermal energy, the issues of application of new technologies in the development and management of geothermal resources also reviewed.

Key words: thermal waters, energy potential, low temperatures, chemical composition, Lumped modeling.

Introduction. Springs are sources of water, one of the indispensable elements of the living world. These waters can be classified according to different parameters. One of these parameters is temperature. Warm or hot water with an outlet temperature above 20 °C is called thermal water. Geological exploration for different types of groundwater (drinking and technical, mineral treatment and purification, heat and power, industrial) should be carried out in the required quantity and quality. The field operation conditions should meet geological, technical, technical-economic and socio-ecological requirements, including groundwater use planning, groundwater management, design and construction of new pumping stations, as well as reconstruction and expansion of existing

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pumping stations [Khutorskoy et al., 2021].

The subsoil study shall be conducted in the following phases:

– regional study of subsoil for estimation of predicted groundwater resources;

– geological study of subsoil of local sites, search and evaluation of deposits [Mamedova, 2008].

Due to its geological and geomorphological features, Azerbaijan has large reserves of thermo-mineral water resources. Thermal and thermomineral waters are widespread in the country, which, in addition to natural outlets (springs), were discovered through wells in the Kura basin, Samur-Devechi and Lankaran foothills in Meso-Cenozoic rocks. Natural outlets of thermal waters in mountainous areas (Greater and Lesser Caucasus) are mainly associated with tectonic faults. As a result of research in Azerbaijan, many thermal fields with a total reserve of more than 245000 m^3/day have been identified [Mammadova, 2016].

Zones of thermal water distribution on the territory of the republic. Thermal water resources in the country are mainly distributed in mountainous areas. The most popular thermal springs are Istisu and Bagyrsakh. The temperature in Bagyrsakh at a depth of 100 m is 80 °C; while in Istisu it is 62 °C at a depth of 70 m and 75 °C at a depth of 300—350 m. The water flow rate in Upper Istisu is 800—900 m^3/day and in Lower Istisu it is 25 m^3/day.

In addition, promising areas of thermal waters include Lenkoran, Astara and Masalli districts, Jarli, Sarysu and other areas in the Kurin lowland. For example, the water temperature at Donuzuten is 64 °C and the flow rate is more than 1.5 ml/day. On the left bank of the Kura River between the villages of Dzharly and Mollakend, a deep well Dzharly-3 was drilled, which produced a fountain of thermal water with an initial temperature of 96 °C. Current water temperature at the mouth (outlet) is 92 °C, mineralization is 50 g/L, water flow rate is more than 20000 m^3/day. These parameters were obtained during the last period, the initial capacity potential of the well is about 70 MW (if the thermal water temperature cools to 20 °C). In the same area, the thermal water flow rate in another well is 10000 m^3/day, the temperature at the wellhead is 82 °C, the potential of the well is 20.4 MW (if the thermal water is cooled to 40 °C) [Mukhtarov et al., 2015].

A more interesting area is the eastern part of the South Caucasus along the Talysh-Vandam gravity high, which reflects the buried part of the Mesozoic Island. Local volcanic eruptions have been studied here to the finest detail, as an oil field was discovered in the volcanic rocks at Muradkhanly in the 1970 s. This area is characterized by high fluid activity, high anomalous heat flow. The Jarli-3 well is still spouting and bringing water to the surface at high flow rates. At a depth of 2800—3000 m, the temperature of volcanic rocks in some places (e.g., in the Jarli area) reaches the boiling point of water [Aliyev et al., 1984].

Table 1 shows the predicted exploitable reserves of thermal waters in Azerbaijan, and these reserves should be indicated depending on the purpose of exploitation of the aquifers and the areas where they occur.

Thermal waters are natural renewable underground energy sources with high energy potential. Natural sources of thermal waters are found in all wrinkled zones of the Caucasus and Talysh. The main discharge pathways for these waters are tectonic faults of different direction and amplitude. The temperature of natural springs varies within 28—62 °C. The flow rates are 0.1—2 l/s, less often 5—8 l/s. Mineralisation is 0.4—5.8 g/l. The gas content of thermal water springs of the Greater Caucasus and Talysh is a mixture of methane, nitrogen, hydrogen sulphide, while thermal water springs of the Lesser Caucasus are mainly carbon dioxide.

Methane waters typically have high pressure and high flow rates and high temperatures (64—95 °C). The number of methane sources is up to 200. These include Masalli (Arkivan), Devechi (Lesh), Salyan (Babazanan) and others.

Nitrogen sources are located in the southern part of the Greater Caucasus and in Talysh. They include both cold (14—18 °C) and

Table 1. Forecast of operational reserves of thermal waters of the republic [Mamedova, 2003]

Hydrogeologicalregions	Water temperature, °C, denominator — at depth, numerator — at surface	Forecastreserves, m^3/day
Mountainous part of the Greater Caucasus	30–50 / n.i.	2000
Gusar Foothill Plain	30–67 / 39–97	21654
AbsheronPeninsula	20–90 / n.i.	20000
Mountainous part of the Lesser Caucasus (mineral waters)	30–74 / n.i.	4171
Territory of Nakhchivan Azerbaijan Republic	40–53 / n.i.	3000
Talyshmountainregion	31–43 / n.i.	14405
LenkoranPlain	44–64 / 42–50	7908
Kursklowland	22–71 / 26–95	172466
Total fortherepublic		245604

Note: n.i. — no information.

hot (41—55 °C) springs. The highest nitrogen content among them is Alasha — 100 % (Astara), Meshesu — 100 % (Lenkoran), Ledj — 37 %, Khaltan — 88 % (Devechi).

It is known that most of the mineral waters of Azerbaijan are thermal waters and have a temperature of 40—97 °C. The temperature of thermal waters fluctuates mainly within 20—160 °C depending on the depth. It should be noted that the age of rocks in aquifers does not play a determining role in the formation of thermal waters. The presence of water of the same temperature at different depths indicates their mixing [Israfilov, Israfilov, 2014].

Favorable geological conditions for the use of geothermal energy. Controllingthe concentration of carbon dioxide is an important issue in solving the global warming problem. Since carbon dioxide is the result of the combustion process of petrol, we must reduce the use of energy from standard fuels and seek a solution to this problem worldwide through the use of alternative energy sources. The issue of using alternative energy has become more active worldwide in recent years and it will be the only priority in the near future.

Azerbaijan has great potential in terms of alternative energy. Detailed study of this issue requires the development of modern prospecting methods (Table 2).

Table 2. Renewable energy potential of Azerbaijan (http://www.area.gov.az)

Type ofpotential	Capacity, MW
Solarenergy	>5000
Wind energy	>4500
Bioenergy	>1500
Geothermalenergy	>800
Small hydroelectricpowerplants	>350

It should be noted that geothermal energy in Azerbaijan is one of the most promising alternative energy sources. There are various forms of heat rising to the Earth's surface: volcanoes, geysers, mud volcanoes, thermal water wells, etc. There are no active volcanoes and geysers in the country, but there are enough exploration wells with thermal water temperatures of 100 °C and higher.

For many years there has been no need for alternative energy in Azerbaijan. This is explained by the fact that it is an oil country. Therefore, the possibilities of geothermal energy, with the exception of thermal water sources, have not been studied separately. Recently, low-potential geothermal energy technologies have been developed.

Lumped parametric modeling. Modelling plays an important role in geothermal reservoir engineering studies, and indirectly in the development and management of geothermal resources. Different modelling techniques range from key source estimation or simple analytical modelling of well tests to comprehensive numerical modelling of a geothermal system that is subject to structurally complex patterns of change due to long-term production. The purpose of geothermal modelling is primarily to obtain information about the nature and characteristics of the system and the conditions in the geothermal system. This helps in the proper assessment of its nature and the successful development of the source.

Second, the purpose of modelling is to predict the reservoir response to future production. From the predictions, the production potential of the system can be estimated. Model predictions also play a key role in the management of geothermal resources during long-term use, e.g. in evaluating the results of various management activities. There are many examples of the successful role of modelling in geothermal resource management [Axelsson, Gunnlaugsson, 2000; O'Sullivan et al., 2001].

Modelling methods can be divided into static modelling and dynamic modelling. Both methods involve the development of a kind of mathematical model that simulates some or most of the information available in the system. The volumetric method is the basic static method. This method is based on estimating the total heat stored in a given volume of rock and how efficiently this heat can be recovered. On the other hand, dynamic simulation methods are based on modelling the dynamic conditions and behavior (production response) of geothermal systems. The main dynamic modelling methods applied to geothermal systems have been analyzed by [Axelsson, 2013]. These include simple mathematical (analytical) modelling methods, concentrated parameter methods and complex numerical modelling [Axelsson, Egilson, 2013].

In models such as simple analytical models and centralized parametric models, the actual structure and spatially varying characteristics of the geothermal system have been greatly simplified to produce analytical mathematical equations describing the model's response to energy production. These models actually simulate only one side of the response of the geothermal system. On the other hand, detailed and sophisticated numerical models can accurately simulate most aspects of the structure, conditions and production response of a geothermal system. Simple modelling takes relatively little time and requires only limited information about the geothermal system and its response, whereas numerical modelling is time consuming and requires exhaustive information about powerful computers as well as the geothermal system. The complexity of the model should be determined by the purpose of the study, available data and relative cost. A centralized parameter model is a simple, cost-effective and time-saving alternative model. Validation of numerical modelling results can be used as part of a more comprehensive study when available funds are limited or when available data are limited.

A new centralized parametric model that accounts for non-isothermal flow has been introduced in many countries, including neighboring Turkey, which can be used to estimate the probability and estimate heat and fluid production in geothermal reservoirs of low-temperature single-phase fluids. The most important advantage of the new model presented here is that it accounts for the variation in mean reservoir pressure and temperature due to the effects of extraction, reinjection and natural supply compared to other models with centralized parameters available in the literature. As noted above, this model can be used to estimate model parameters and future pressure and temperature readings of a future geothermal reservoir by comparing downhole pressure (or dynamic well water level) measured in the field with a history of downhole temperature data. Centralized parametric models are widely used to predict the future performance of low-temperature geothermal systems.

In order to determine the possibility and direction of using geothermal energy in different spheres since the 60s of the last century, to study the distribution and other characteristics of underground thermal waters, which are the main carriers of geothermal energy in the foothills of Lankaran and the central part of the Kura basin in the early 80 s, the search and exploration of thermal waters in the Yalama-Khachmaz areas of the Caspian-Guba region and on the south-western flank of the Kura basin expanded, as a result of which the calculation of thermal water reserves on the p. of the Kura basin was made Thermal water reserves in the republic are registered in the amount of 25375 m^3/day. Containing trace elements J — 0.34—3.0 mg/l, Br — 3.09—21.8 mg/l, B_2O_3 — 8.79—16.4 mg/l, these thermal mineral water resources can be used for thermal energy and balneological purposes.

Despite the fact that there is complete information about the flow rate, temperature, chemical composition, etc. of the thermal waters existing in the Lankaran district and in Azerbaijan, there is very little information about the ways of utilization of these thermal springs. More than 100 years have passed since the initial data on thermal waters of Masalli district, despite this fact, researchers studying this problem still use this information.

Later, many sources widely review the issues and provide information on geology, hydrogeology of the area, flow rate, temperature, chemical composition, etc. of the characterized thermal waters. The studies conducted by foreign scientists and experts on thermal waters by Arkiwan and others at that time have not lost their relevance today. This does not mean that the chemical composition, temperature and flow rate of thermal waters remain unchanged for more than 100 years. All over the world, in countries where thermal water is widespread, its values are reviewed annually. In addition to measuring, thermal water users can increase or decrease the water temperature at will. When studying thermal and mineral waters of Azerbaijan, including Masalli district, in the monograph «Mineral springs of Azerbaijan» published in the 50 s of the last centuries, M.A. Kashkai comprehensively characterised the mineral water springs of Arkivan, Donuzuten, Gotursu, Misharchay [Kashkai, 1952]. A.G. Askerov's monograph «Mineral springs of Azerbaijan SSR» [1954] is one of the invaluable works on the study of thermal waters of Azerbaijan. On the territory of Masalli district there are only 2 outlets of thermal waters of Arkivan, which were used in the past and now. One of them is thermal water and the other is moderately hot water with a temperature of 18—20 °C. Arkiwan thermal water with a temperature of 50 °C and a flow rate of $627 \cdot 10^3$ l/day on the left bank of the Vilash River is currently the main source of use. There is a thermal water spring Donuzutan, which once had 20 outlets and a flow rate of $1.6 \cdot 10^6$ l/day, with a temperature of 63—64 °C, 500 m west of the Arkivan spring on the right bank of the Vilash River, 30 m apart, no information is currently available on the number of outlets of the spring. This spring is currently not properly utilised. 2.5 km west of Arkiwan, on the bank of the Vilesh River, on an area of 35 m is the Gotursu thermal spring with 17 outlets, a daily flow rate of $4 \cdot 10^6$ l/day, temperature of 60 °C, high methane content, low iodine and bromine content. The Misarchai thermal water, located 3 km southwest of the Arkiwan thermal waters, has a flow rate of $1.2 \cdot 10^5$ l/day, a temperature of 31—45 °C and historically had 7 outlets in an area of 100 m. Misarchai thermal water is rich in methane gas. Currently, this thermal water is not used.

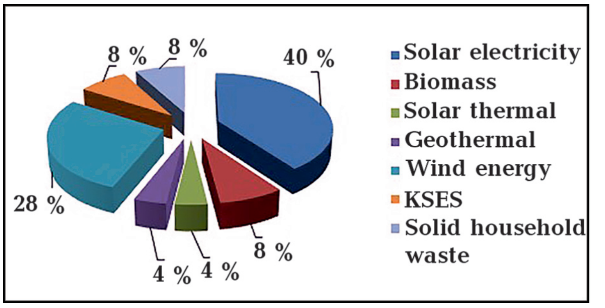
Business Opportunities. The Earth is known to have a significant concentration of thermal energy (geothermal energy) and this energy can be utilized under certain conditions. In some cases (volcanic eruptions, hot springs, pressure from thermal water wells, etc.) this energy naturally reaches the Earth's surface. On the other hand, despite the significant amount of geothermal energy per square metre deep in the earth, there are many challenges in harnessing it, including the transfer of geothermal energy from the depths to the surface. This, in turn, is one of the most important factors determining the cost-effectiveness and efficiency of geothermal energy.

Recently, the efficiency of thermal energy utilization has depended mainly on deep wells. However, Azerbaijan has a large number of abandoned and unused exploration wells that can be rehabilitated and utilised for geothermal energy production with less investment. The main objective now is to identify the optimal location for drilling wells with higher geothermal potential and the problems of utilising this energy. The main task of research and exploration specialists is to support the implementation of the proposed plans and to develop optimal proposals for efficient investments. The aim is to summarise and present basic information on geothermal sources in Azerbaijan (such as thermal springs, mud volcanoes, thermal wells, etc.) and to harmonise the results with current technology and business opportunities.

Groundwater, oil and gas, which are active fluids, are necessary for convective heat transfer in the Earth's crust. If we take into account that millions of tons of oil are extracted annually from the deep layers of the earth in Azerbaijan, and this oil transfers heat from the depth to the surface, we face an interesting problem related to the use of geothermal energy. Recently, after the problem of energy shortage became a subject of discussion, some researchers have started to pay attention to this problem [Mukhtarov, 2004; Sanyal et al., 2011].

Recently, the issue of finding and utilizing alternative energy sources has become an urgent issue due to energy shortages and global warming. Recently, the assessment of geothermal energy carried by oil production and the study of the prospects for utilizing this energy has come to the fore as an important issue of the day.

Unfortunately, the above-mentioned thermal waters, such as the Arkivan thermal water in Lankaran district with a temperature of 30—55 °C and a flow rate of $1.6 \cdot 10^6$ l/day, are not fully utilized today. If we pay attention to the plans of the State Agency for Alternative and Renewable Energy Sources of Azerbaijan for the development of alternative energy sources in Azerbaijan for 2020, the extent of utilization of geothermal energy becomes clear.



Share of renewable energy in 2020 (http://www.area.gov.az).

By utilizing the high temperature of the thermal water of Arkiwan, it is possible to heat its 170-seat complex, residential buildings, catering establishments and it would also make sense to install a greenhouse in the complex, given that the temperature of this thermal water has not changed in the last 20—30 years. In countries rich in thermal waters around the world, hotels and campsites are built in close proximity to thermal waters and outdoor and partially indoor swimming pools are built for year-round use.

Depending on the size and number of users, each such basin generates significant income for the country.

It should be noted once again that in a country with such large thermal water resources, their targeted utilisation can provide a significant boost to the country's energy sector.

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Геологічні умови розвитку геотермальної енергії в Азербайджані

А.В. Ісламзаде, А.Ш. Мухтаров, 2024

Інститут геології та геофізики Національна академія нацук Азербайджану, Баку, Азербайджан

У статті розглянуто поширення термальних вод в Азербайджані, перспективи їхнього використання як поновлюваних джерел енергії, а також можливості для бізнесу та інші геолого-геофізичні питання. Наведено прогноз ресурсів термальних вод, потенціал поновлюваних геотермальних джерел енергії, їхню частку в енергетиці країни у 2020 р. Отже, є велике число закритих і розвідувальних свердловин, що не використовуються; вони можуть бути відновлені з метою виробництва геотермальної енергії з меншими інвестиціями.

В Азербайджані термальні води з різним хімічним складом і мінералізацією переважно поширені у складчастих зонах Кавказу і Талиських гір та мають достатні запаси. За даними досліджень, проведених на джерелах термальних вод країни, визначено, що їхній загальний запас становить понад 245 000 м^3/добу. Основними шляхами розвантаження цих вод є тектонічні розломи різного напрямку та різної амплітуди. Газовий склад джерел термальних вод Великого Кавказу і Талиських гір є сумішшю метану, азоту, сірководню, а джерел Малого Кавказу — переважно вуглекислий газ. Метанові води зазвичай характеризуються високим тиском і великими запасами, а також високою температурою (64—95 °C). На цей час відомо до 200 джерел із вмістом метану — Масаллі (Арківан), Девечі (Ледж), Сальян (Бабазанан) та ін. Термальні джерела, що містять азот, розміщуються у південній частині Великого Кавказу і в Талиських горах як холодні (14—18 °C) і гарячі (41—55 °C) джерела. Найвищий вміст азоту виявлено в джерелах Алаша — 100 % (Астара), Мешесу — 100 % (Ленкорань), Ледж — 37 %, Халтан — 88 % (Девечі).

У статті обговорено використання низькопотенційної геотермальної енергії та застосування нових технологій у розробці та управлінні геотермальних ресурсів.

Ключові слова: термальні води, енергетичний потенціал, низькі температури, хімічний склад, Lumped моделювання.