GEOLOGICAL CONDITIONS AND BUSINESS OPPORTUNITIES FOR GEOTHERMAL ENERGY DEVELOPMENT IN AZERBAIJAN

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The territory of Azerbaijan is rich in thermal waters. Sources of thermal water can be found in the Greater and Lesser Caucasus, on the Absheron Peninsula and Talysh. Also in the vast territory of the Kur basin and the Precaspian-Guba area numerous wells drilled for oil and gas discovered aquifers with thermal water. The highest initial temperature of thermal water 96°C was registered in Jarly-3 well. Currently temperature of water is 92°C and mineralization is 50 g/l at the well head. Flow rate of the well exceeds 20000 m^3/day. According to estimates based on the set of parameters, currently the capacity of the well is approximately 70 MW if water is cooled down to 20°C. Another high-potential well is located in the Daridagh thermal area of Nakhchivan with the power potential about 10 MW.

Introduction. Geological and geothermal conditions

Recently control of carbon dioxide concentration in atmosphere is very important because of the global warming problem. As CO_2 is the result of the fuel burning processes, we should reduce usage of the energy of conventional fuels and look for solution of this problem in alternative energy sources globally. Alternative energy sources are actively used in the world recently and it will be one of the priorities in the near future.

Azerbaijan Republic does not stand idle in this area. The President of the country has repeatedly mentioned the importance of development and use of various forms of alternative energy in Azerbaijan. As Azerbaijan possesses vast potential of the alternative energy, this issue must be investigated in detail. Research and development should comply with the requirements of modern industry.

Geothermal energy is one of the most promising sources of alternative energy. There are different forms of outcrops of the Earth heat to the surface, e.g. volcanoes, geysers, mud volcanoes, thermal water wells, etc. There are no active volcanoes and geysers in Azerbaijan, however we have enough exploration wells where temperatures of thermal water in aquifers are higher than 100°C.

The most interesting area is western part of the South Caspian basin along the Talysh-Vandam maximum (Надиров, 1985). This gravitation maximum reflects buried fragment of Mesozoic island arc where local volcanic uplifts were explored in detail, as Muradkhanli oil field was discovered here in 70-s within the weathered and fractured volcanic rocks. The area is characterized by high fluid activity, which promotes formation of local abnormally high heat flows. Jarly-3 well is still flowing to the earth surface with high production rate. Temperature of volcanic rocks penetrated here at 2800-3000 m depth in some places is higher than 100°C (Алиев и др., 2002).

Sources of geothermal energy: Some results of research

Thermal waters

Thermal water resources in Azerbaijan are found mainly in the mountainous regions. In Lesser Caucasus, especially famous regions are Istisu and Bagirsag. Measurements in Bagirsag region have shown that water temperature there is 80°C at 100 m depth; in Istisu region temperature is 62°C at 70 m depth and 75°C at 300-350 m depth. Flow rate of water in Higher Istisu is 800-900 m^3/day, and in Lower Istisu it is 25 m^3/day.

As Azerbaijan is an oil country, there was no need in alternative energy in the past; geothermal energy potential was not studied separately, except researches targeted thermal waters. Another reason is that Azerbaijan has a lot of thermal water sources with relatively low temperatures (<80°C), while technologies using low potential geothermal energy were developed recently. At present, such technologies are developing rapidly following growing demand for alternative energy. The Global warming problem targets the humanity to the direction of low-carbon technologies. As examples of the most perspective objects in Azerbaijan we can list thermal water sources in Lyankaran, Astara and Masally regions, Jarly, Sarisu, etc. E.g. water temperature in Donuzuten spring is 64°C and flow rate up to 1.5 million l/day.

A number of thermal springs and thermal water wells are available in Azerbaijan. The highest temperature (initial temperature 96°C) of thermal water flowing to the surface is from Jarly-3 well, which was drilled between the villages Jarly and Mollakend on the left bank of the Kur River. Currently water temperature is 92°C, mineralization is 50 g/l at the well head (Fig.1). Flow rate from the well is more than 20000 m^3/day. According to the parameters obtained during the recent period, initial potential power of the well is approximately 70 MW (if 100% efficiency is achieved by cooling water down to 20°C).

Another well in the same region exposed thermal water with the flow rate 10000 m^3/day and temperature at the wellhead 82°C. Thermal capacity (on cooling to 40°C) is 20.4 MW.

In the Precaspian-Guba zone (Fig.2, south-eastern slope of the Greater Caucasus) eight wells specially drilled to aquifers with thermal water flowed with calcium-sodium bicarbonate type of water, mineralization 0.8-1.9 g/l and total production rate 20470 m^3/day (Aliyev et al., 2002) with temperature 50-84°C. Overall capacity (provided that water is cooled only by 20°C) is about 20 MW. In Khachmaz region one well exposed thermal water with the flow rate 1228 m^3/day and temperature 58°C. In Yalama one well exposed thermal water with the flow rate 500 m^3/day and temperature 95°C. Minimum thermal capacity of these wells is respectively 1.2 and 0.5 MW.

Total energy capacity of thermal waters for hydrogeological areas determined on the basis of their commercial reserves is presented in Table 1 (Мухтаров, Хаммедов, 2003; Тагиев и др., 2001).

Nakhchivan (Fig.2) is one of the less investigated regions of Azerbaijan from the geothermal point of view. Besides well-known sources of mineral water, such as Sirab, Badamli, Vaykhir, etc., there is also thermal spring Daridagh. Thermal spring Daridagh with its sodium bicarbonate type of water is one of the most important resources in Nakhchivan, because of its mineral content (up to 20% arsenic and antimony). Temperature of thermal spring reaches 26.5°C. Wells drilled to the 137-665 m depth produced water with temperature 41-53°C. The water is highly mineralized (14.3-21.3 g/l). Flow rate of some wells is 25-34 l/sec. Energy potential power of wells in this area is 10 MW. Table 2 shows energy potential of water flowing from those wells.

Figure 1. Jarly-3 thermal water well

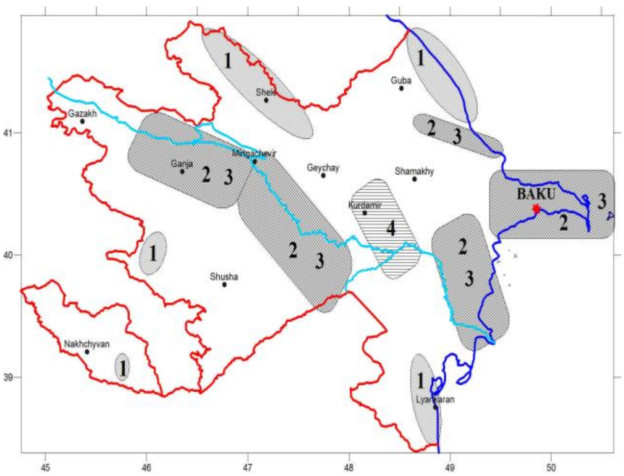


Figure 2. Schematic map of thermal fields of Azerbaijan
1 – Regions with thermal waters; 2 – Regions with mud volcanoes; 3 – Regions with oil and gas fields; 4 – Regions with petro-thermal systems

Table 1

Hydrogeological areas	Water T, °C	Water flow rate, m^3/day	Energy potential, MW
Absheron Peninsula	20-90	20000	up to 504
Kur depression	22-95	172466	up to $47 \cdot 10^3$
Greater Caucasus	30-50	2000	up to 168
Lesser Caucasus	30-74	4171	up to 771
Gusar foothill lowlands	30-97	21654	up to 609
Nakhchivan	40-53	3000	126-290
Talysh	31-64	14405	605-778
Lyankaran	42-84	7908	399-1129
Total		245604	Up to $51 \cdot 10^3$

Table 2

Well number	Minerali-zation, g/l	pH	T, ºC	Flow rate, l/sec	Energy potential, MW	
					ΔT=10ºC	ΔT=T-20°C
16	18.9		20	0.34	0.01	0
32	14.3		22	0.51	0.02	0
7/64	19.0		42	29.9	1.26	2.76
8/64	19.5	7	42	25.5	1.07	2.36
9/64	17.4	6.8	28	5.5	0.23	0.18
10/64	21.3		52	33.4	1.40	4.49
28	15.7		21	0.17	0	0
			Total	95.3	3.72	9.75

Mud volcanoes

Mud volcanism is one of the most interesting natural phenomena encountered in many countries of the world. A number of geological factors promoted development of mud volcanism in the South Caspian basin. The thickness of the sedimentary layer reaches 30 km, the upper 10 km being composed of the Pliocene-Quaternary predominantly clayey rocks deposited at extremely high sedimentation rates (up to 1300 m/my). Among the special features of the basin are low heat flow, abnormally high formation pressure, high degree of dislocation and seismicity, etc. In the South Caspian Basin, both onshore and offshore of Azerbaijan, there are over 300 mud diapirs and mud volcanoes. These mud structures are associated with the production of oil and gas field, because here production wells were drilled on the flanks of many onshore mud diapir structures.

For the first time temperatures of mud volcanoes in Azerbaijan were measured in 1904-1905. It was established that water temperature of mud volcanoes could be compared with the average annual temperature at this location.

Various anomalies of geothermal field were established in the area of mud volcanism development (Fig. 2). Against the overall low heat flow backgrounds across the basin, mud volcano sites stand out by comparatively high values of the parameter. Temperature gradients defined in the depth interval 0.3-1.5 m are very high and vary in the range of 0.02-21.25 K/m; it was established that temperature gradient declined with depth (Mukhtarov, 2003).

More extensive study of geothermal aspect regarding mud volcanoes was carried out in the course of oil and gas fields' development. As a result of these studies various anomalies of thermal field were identified, including decline of regional geothermal gradient with depth, and in the area of mud volcanism development (Мехтиев и др., 1971; Якубов, Атакишиев, 1973). Mud volcanoes are characterized by high values of heat flow density. At the same time in the areas of mud volcanism the regional values of heat flow density were below medium continental ones (Кашкай, Алиев, 1974; Алиев, 1988). Besides, Lower Kur depression is characterized by the lowest heat flows in the same region. However, in all these cases the abnormal heat flow exceeds the medium value across the structure approximately twice and reaches just about 100 mW/m^2 at mud volcanoes.

Geothermal studies and the results of experimental determinations of rocks' thermal conductivity also allow evaluating the magnitude of thermal flows in wells at a number of fields on the Absheron Peninsula. Thus, at the Lokbatan field, thermal flows at 23 sites, evenly arranged along the structure, have been determined. Geothermal investigations were undertaken near the neck of mud volcano at two wells.

Maximum values of thermal flow were registered on these wells at the Lokbatan mud volcano field, 2.6 and 1.96 HFU (Heat Flow Unit, 1HFU = 42 mW/m^2), which is quite credible provided that the roots of mud volcano are located within the Upper Cretaceous deposits at a large depth (>6-12km). Also, the eruptive process promotes intensive heat transmission from the root horizons along with observed rock fragments of the same age.

Heat flow density was determined using drilled well temperature gradients and thermal conductivity of core samples. The offshore heat flow density through the Caspian Sea bottom was determined with the marine thermal probe. (Алиев и др., 2002; Nadirov et al., 1997).

It is necessary to note that mud volcanoes are distributed in a zone of minimum of thermal field (the thickness of the sedimentary layer reaches 20 km).

It turned out, that mud volcanoes are known by the high values of heat flow density. At the same time in districts of mud volcanism development regional values of heat flow density occurred below medium continental ones.

Other interesting places are crater fields of continuously erupting mud volcanoes in Azerbaijan, where local abrupt anomalies of temperature gradients and heat flows exceed and three magnitudes higher than regional background values of respective parameters. E.g. this fact was confirmed by measurements of heat flow in the area of a Haakon Mosby mud volcano in the Barents Sea, reaching 1045 mW/m^2. Similar local anomalies of a heat flow (210-600 mW/m^2) were found in the Caspian Sea.

These data demonstrate disintegrated character of the crust and high fluid-dynamic activity in the boundaries of tectonically active areas. In the boundary zones processes of heat-transportation are described by the equations of heat-mass transportation in porous media. As a result, abnormally high heat flows can be formed locally.

The results can hardly be explained in the context of the theory of thermal conductivity. So the process of simultaneous transportation of substance and heat through the channels of mud volcanoes should be considered. This process can be simulated as a thermal jet or as pressure filtration of fluids. That is described by the system of differential equations. The solution of this system shows the dependence of temperature from the depth.

Taking into consideration thermal features of fluids and rocks, and the temperature along the channel gives us an opportunity to explain the high temperature gradients on the surface and decrease of gradient with depth. It is similar to temperature distribution on the contours of the area of mud volcano; zones of hydrocarbons' formation are accordingly displaced upwards.

Thus, within the neck of mud volcano, in its deeper parts there are high temperatures and low gradient. With approach to the surface the gradient is sharply increased, and temperature falls down. It is necessary to take into consideration these conditions for estimation of parameters for formation of hydrothermal minerals (temperature dependence of depth and age) along the neck of the volcano.

Estimation of heat flow density shows that during eruption heat flow via the neck of mud volcano might be very high (10^8-10^{10} W/m^2).

Oil-gas fields and geothermal wells

There are thermal water wells at the Absheron oil fields (Fig.2). The most interesting one was drilled in Shikh field. This well (depth 2400 m) produced mineralized water with temperature 68°C, and this mineral water is being used for the balneo-therapy. Potential power of the well reaches 1.3 MW.

At the Absheron Peninsular thermal water was discovered by drilled wells at various depths and as natural outcrops. At the Absheron Peninsular, to the east from Hovsan village temperature of mineralized water from drilled wells reaches 100-135°C. Overflowing thermal waters are found in various places of the Absheron Peninsula. At Bibi-Eibat, near Baku, wells flow with chloride-hydrocarbonate sodium water, with mineralization 16.5 g/l, temperature 71°C and flow rate more than 450 m^3/day. In Gyuzdek well flowed with water with temperature over 50-65°C. Hot water also flows from wells in Gara-Eibat, Chilov Island and other places. With depth temperature of thermal water increases and mineralization falls down.

It is interesting to note that in many countries of the world, potential energy of each unit of low potential geothermal energy sources varies between 1-4 MW. These types of sources are successfully used and this area is developing rapidly. Therefore, usage of this kind of geothermal energy sources has wide perspectives in Azerbaijan.

In exploration wells near Barda area within the depth interval 1500-1600 m thermal water was produced from Sarmatian deposits with the flow rate up to 1500 m^3/day and temperature 45°C. Thermal water with similar parameters also flowed from wells at Sorsor, Karajally, Beylagan, Sovetlar areas, etc (Fig.2).

It should be noted that at all Azerbaijan oil-gas fields numerous oil and gas exploration wells produced thermal water with temperature 100°C and above in relatively deep drilled intervals (Fig. 3).

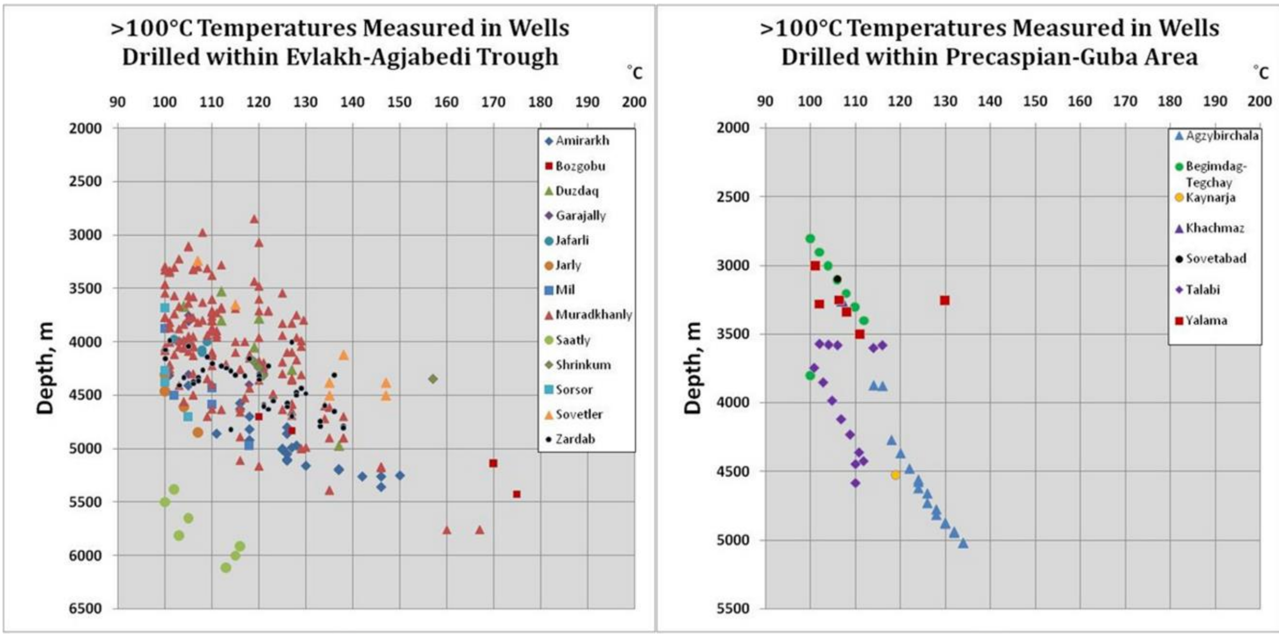
Petro-thermal energy systems

To assess full energy accumulated within the Earth, all geothermal energy, including petro-thermal energy accumulated within the solid rock and formation fluids must be evaluated (Fig.2). Various methods of the assessment of geothermal resources are available. In this work new methods developed in the countries of Western Europe were used. For the evaluation of density of geothermal resources they represent restorable part of geothermal energy that could be recovered and used. In the countries of Western Europe researchers use the model of volume content of heat in porous reservoirs.

Based on geothermal data of deep wells from various regions density of geothermal resources in Pliocene deposits in Azerbaijan per unit of area (1 m^2) was calculated, and map of distribution of geothermal resources in the Pliocene deposits has been plotted on the base of these data. It was found that density of geothermal resources in Pliocene deposits per unit of area varied within the range of 10-75 MW (Асадова, Мухтаров, 2013).

Business opportunities

It is known that in the Earth concentrated significant amount of thermal energy (geothermal energy) and within certain conditions it is possible to use this energy. In some cases (when the eruption of volcanoes, hot springs, pressure of thermal water wells, etc.), this energy is delivered to the surface of the Earth by natural ways, with increasing ways of geothermal energy using. In other cases, despite the presence in the bowels of the earth a significant amount of geothermal energy that falls on each square meter of surface, its use is accompanied by a host of problems, chief among which is the delivery of geothermal energy from the depths to the surface. This, in turn, is one of the important factors responsible for the profitability and efficiency of geothermal energy. From this point of view beneficial objects (except for the natural output of geothermal energy) are oil and gas fields, which from the earth



a *b*

Figure 3. Temperature vs Depth graphs based on data > 100°C from drilled wells in Evlakh-Agjabedi and Precaspian-Guba areas

to the surface derived substrates (water, oil, gas) - carriers of geothermal energy by technical ways. It should be noted that this issue is still not fully understood and its value is scientifically not justified. Therefore, in this project, the task of a comprehensive science-based study of the issue and assessment of geothermal energy resources that are brought to the surface in the oil fields, and a study of the prospects for its use.

Recently, efficiency of the use of thermal energy depended mainly on drilling deep wells. However there are many plugged and abandoned exploration wells in Azerbaijan and these wells could be restored and used for the production of geothermal energy with less investments. Main objective now is the identification of optimal locations of drilled wells with higher geothermal potential and use of this energy. Institute of Geology and Geophysics of the Azerbaijan National Academy of Sciences has vast database with the geothermal data. At present we analyse these data in order to identify optimal sites for the construction of geothermal stations, efficient heat pump unit and also sites for hybrid installations.

State plans envisage increasing several folds volumes of energy produced from alternative sources to 2020. The primary task of specialists involved in research and development is to support implementation of these plans and propose the best sites for effective investments. The purpose of this paper is to summarize and to present a key information about geothermal sources (such as hot springs, mud volcanoes, thermal wells, etc.) in Azerbaijan and adjust results with the opportunities of modern thermal technologies and business opportunities.

Underground water, oil, gases are an example of fluids, actively involved in the process of heat transfer in the Earth's crust convective means. If we consider that in Azerbaijan every year from the bowels of the earth are extracted millions of tons of oil, and this oil carries with it the heat from the interior to the surface, then we get up an interesting problem in connection with geothermal energy. This question has remained without a study and only recently, after the problem of shortage of energy in the world has become urgent, researchers began to pay attention to it (Muxtarov, 2004; Sanyal, 2011). Recently, in connection with the problem of energy shortage and global warming, how to search and use alternative forms of energy have become urgent. Therefore, the assessment of associated geothermal energy carried by the produced oil, and the study of the prospects of using this energy came to the fore as an important task of the day.

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