POLITECNICO DI TORINO

Master’s degree programme in Petroleum and Mining Engineering

EXPLOITATION OF GEOTHERMAL ENERGY RESOURCES FROM ABANDONED OIL&GAS WELLS LOCATED IN THE AZERBAIJAN TERRITORY

Supervisors

Prof. Lo Russo Stefano, Supervisor

Dott.ssa Taddia Glenda, Co-Supervisor

Dott.ssa Gizzi Martina, Co-Supervisor

Candidate

Ibrahim Hasanov (s250340)

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CHAPTER 1: INTRODUCTION

Alternative types of energy sources as solar, wind, hydro, geothermal and biomass energy sources are actively used in the world and their usage will represent one of the priorities in the near future. According to 2030 UN Agenda for Sustainable Development, every nation should reduce the amount of the energy produced by means of conventional fuels, looking for new sustainable solutions and alternative energy sources that are increasingly sustainable and distant from those based on fossil fuel, through technological development and environmental values [1].

1.1 Energy Sources

Energy sources in terms of exhaustibility can be subdivided into:

- Non-renewable energy sources
- Renewable energy sources

Non-renewable energy sources includes exhaustive natural resources that diminish as they are used. This kind of resources are natural reserves of substances and materials as nuclear fuel, coal, oil, gas etc. that can be used by people for energy production. Energy from non-renewable resources is found in nature in a bound state and is released with purposeful human actions.

Unlike non-renewable, renewable energy, sources are based on energy flows permanently existing or periodically occurring in the environment. In contrast to non-renewable energy, renewable energy is not a consequence of purposeful human activity, and this is its unique characteristic. Alternative (renewable) energy sources include flows of solar energy, wind energy, heat of the Earth (geothermal energy), biomass, seas and oceans, rivers, existing constantly or periodically in the environment that are practically inexhaustible.

1.2 Advantages and Limits of Renewable Energy Sources

In the complex of existing environmental problems, energy resources occupies one of the leading places. Renewable energy resources in comparison with traditional non-renewable resources have the following advantages:

- practically inexhaustible resources;
- extremely lower negative impact on the environment, including emissions of various pollutants, greenhouse gases, radioactive and thermal pollution, etc.;

The main limiting factors that have to be noted in use of renewable energy resources are the following:

- low energy flux density;
- significant unevenness of energy production over its use;
- high capital cost of used equipment and generated electricity;

1.3 Purposes of Geothermal Energy Researches

Thermal energy accumulated in the Earth subsurface represents geothermal energy resources, which can be extracted efficiently and competitively (in terms of expenses) with other types of energy [2].

Geothermal Energy resources is stable, environmentally friendly and especially weather-independent resource among different alternative energy resources and are accessible to be used for power generation and direct use as one of the significant future energy solutions.

The study of the geothermal heat regime of lithosphere is needed to solve a wide variety of scientific and practical problems in geology, geochemistry and geophysics. This include modeling of thermal evolution of the Earth and issues of energy and dynamics of geological processes – tectonic movements and seismicity, metamorphism and magmatism, hydrothermal activity, the origin and dynamics of thermal waters and origin and methodology of mineral deposit exploration. In addition, there are important tasks that include the practical use of the Earth's deep heat reserves for heating of industrial and agricultural facilities and generation of electricity, as well as the development and implementation of thermal methods for the exploitation of mineral deposits.

The reserves of geothermal energy are enormous and in a number of countries (Italy, Iceland, Hungary, Mexico, New Zealand, Russia, USA and Japan) are still widely used for heating purposes and electricity generation.

There are steam power plants that are functioning primarily on hydrothermal steam. These are the oldest geothermal power plants, the first of which was built in Larderello (Italy) in 1904, and it is still operating today.

Geothermal energy provides heating to Iceland's capital city Reykjavik. In 1943, 32 (nine of them are still operating) wells were drilled there to the 440 – 2400 m depth interval, through which thermal water rises to the surface with 60 – 30°C temperature [3].

1.4 Extraction of Geothermal Energy Resources in Oil and Gas Bearing Regions

Because of different reasons as water flooding or very low production rates, oil and gas wells are abandoned or dismissed in oilfields. Taking high depth of petroleum wells into account, they can be promising carrier of high temperature fluids and therefore adequate structures for harnessing deep geothermal energy resources. Unlike special geothermal fields, in oil and gas bearing zones, which are at late stage of development, there is usually an enough number of wells that are not used for hydrocarbon production due to mentioned above reasons.

Drilled oil-gas wells and partly water wells discovered many underground artesian basins of thermal waters. Generally, artesian basins located in plain areas and foreland basin contain water with a temperature of 100-150°C at a depth of 3-4 km [4].

Another advantage of geothermal energy resources extraction in oil and gas fields is existing production data and reservoir properties collected over long periods of production and exploration that could empower new potential geothermal projects by reducing capital costs, minimising risks and significant inconveniences.

In addition, by reusing abandoned wells in oilfields for geothermal energy production there is a possibility to compensate energy use required for various processes done on hydrocarbons, for instance increasing of mobility of heavy oil with help of thermal treatment.

1.5 Extraction of Geothermal Resources in Azerbaijan

Over the past, as Azerbaijan is an oil country, there was no real need in alternative energy; geothermal energy potential has not been studied separately, with the exception for some researches about resources associated to thermal waters.

However, ensuring of the dynamic and sustainable growth of the non-oil sector is a key focus in the Azerbaijan's development strategy: the extraction of geothermal energy resources available as associated to hydrocarbon wells in oil and gas field could contribute in achieving this goal.

Azerbaijan possesses vast potential of the alternative energy, such as thermal water resources associated to hydrocarbon wells. Considering long development period of several oil and gas fields in the territory of Azerbaijan and therefore, number of non-active wells, this issue needs to be investigated in detail.

Geological and hydrogeological observations in oil and gas bearing zones, conducted with the help of exploration and production wells, have indeed ascertained the presence of productive aquifers with associated thermal water resources.

Given the above, providing overview of the geothermal environment in oil and gas bearing regions located in the territory of Azerbaijan, the paper targets mainly to give information on geothermal energy resources associated to deep hydrocarbon wells in the territory and possibilities of use these resources for various purposes.

1.6 Thesis objectives

The paper aims to analyses, also from a geological and energetic point of view, and give information about the following main topics:

- Geothermal energy resources associated to deep hydrocarbon wells in oilfields
- Geothermal energy researches carried out in the territory of Azerbaijan
- Potentialities of geothermal energy resources associated to hydrocarbon wells in the Azerbaijan territory as future renewable source of energy

CHAPTER 2: GEOTHERMAL ENERGY RESOURCES

2.1 Origin of Geothermal Energy

Contemporary energy usage is mainly based on non-renewable energy sources, which have limited reserves and thus are exhaustible and cannot guarantee sustainable development of world energy consumption in long term. Their use is one of the main factors leading to global environmental degradation. Taking these issues into account geothermal energy as one of the promising alternative energy sources should be investigated widely.

The expression "geothermal energy" literally means the energy of the Earth's heat ("geo" - earth, "thermal" - heat). The main source of heat in the Earth's bowels is heat flow, the intensity of which for a very long geological time can remain constant.

Geothermal energy sources of the Earth can be divided (in terms of origin) into two different groups [5]:

-internal

-external

Internal sources include Earth's initial internal heat, change of the kinetic energy of Earth's rotation, radioactive decay and different chemical processes. The main source of external energy is solar radiation and it is an order of magnitude greater than the heat flow from the subsoil. However, about 40% of the energy is immediately reflected from the Earth's surface. The rest undergoes a number of transformations in the Earth's geospheres and goes on the destruction of native rocks. Part of this energy in another form is accumulated in the organic matter of sedimentary rocks, including in combustible minerals.

2.2 Parameters of Geothermal Fields

The main parameters characterizing the thermal field include a geothermal gradient, which is an increase in temperature with a depth of usually 100 m or 1 km and a geothermal step (distance in depth at which the temperature increases by 1°C). In practice, a geothermal gradient is more often used as °C/km. Due to the change in the intensity of solar radiation, thermal regime of 1.5 – 40 m of the earth's crust is characterized by daily and annual fluctuations.

Observations in boreholes related to the upper 2 - 3 km of the Earth's crust show that the temperature rises with depth by an average of 3°C for every 100 m. However, there are known cases when an increase in temperature by 1°C occurs with a deepening of 2-3 m [6].

2.3 Thermo-physical Properties of Rocks

Thermo-physical properties of rocks are characterized by such parameters as:

- thermal conductivity,
- heat capacity
- thermal diffusivity;
- heat flux density;

One of the most important parameters is thermal conductivity that is amount of heat passing per unit time, through a unit area with a temperature difference of 1°C per unit length. Thermal conductivity is generally measured in W/m*K.

According to [5], the following factors determines the thermal conductivity of rocks:

1. Rock density
2. Granulometric composition and material sorting
3. Saturation with fluids
4. Orientation with respect to flow (lamination direction)
5. Degree of rock crystallinity
6. Pressure

Heat capacity – the amount of heat dQ supplied to 1 kg of a body in any process and often expressed through the temperature increment dT of this body: dq = cdT. The factor c is specific heat capacity of the substance.

Thermal diffusivity (coefficient of thermal diffusivity) is a physical quantity that characterizes the change rate of the temperature (of substance) in non-equilibrium thermal processes. Numerically equal to the ratio of thermal conductivity to volumetric heat capacity at constant pressure and it is measured as m^2/s in SI [7]:

$$(1)\ \alpha = \frac{k}{\rho c_p}$$

Here, k – thermal conductivity, $\rho * c_p$ – volumetric heat capacity (c_p – specific heat capacity).

Another parameter characterizing the thermal field is the value (density) of the heat flux (q). It is expressed by the Fourier equation:

$$(2)\ q = \lambda \cdot grad\ T$$

where λ – thermal conductivity, grad T – thermal gradient. Unit of (q) is W/m^2.

2.4 Classification of Geothermal Fields

Geothermal energy fields in terms of resources can be subdivided into the following types [5]:

- hydrothermal systems – reservoirs of hot or warm water;
- steam hydrothermal systems – steam and steam-water mixture fields;
- petro-geothermal zones – heat of dry rocks;

Geothermal energy resources in terms of reservoir temperature (enthalpy) can be subdivided into the following types [8]:

- Lower enthalpy (I - <90°C, II - <125°C, III - 100°C, IV - ≤150°C)
- Medium enthalpy (I – 90-150°C, II – 125-225°C, III – 100-200°C)
- Higher enthalpy (I - >150°, II – 225°C, III - >200°C, IV - >150°C)

References to this classiffication: I – Muffler and Cataldi, 1978, II – Hochstein, 1990, III – Benderitter and Cormy, 1990, IV – Haenel 1988, Dickson, 1990

2.5 Thermal Water

In the Earth's crust, there is a mobile energy carrier with extremely high heat capacity that is water, which plays an important role in the heat balance of the upper geospheres. Thermal waters are capable to come out to the surface in the form of hot springs, if there is a possibility of flowing through fractures. Moreover, for the water to remain thermal, its rise to the surface must occur very quickly, for example, through wide cracks. Over a slow rise, hydrothermal fluids cool down, releasing the accumulated heat and energy to the host rocks. However, if there is a drilled well to a depth of 3000 – 4000 meters and it ensures a rapid rise in water, thermal water can be extracted with a temperature of up to 100°C [4].

In any point on the Earth's surface, at a certain depth, depending on the geothermal features of the area, there are layers of rocks, containing thermal waters. Areas of distribution of thermal water fields include the volcanic ring of the Pacific Ocean basin, the Alpine folded belt, continental rift valleys, mid-ocean ridges, platform dips and foreland basin.

2.6 Thermal Water Fields

Fields of thermal water can be subdivided in terms of thermal energy transfer way, into the following types:

- convectional origin
- conductive heating

The first type is located in the volcanic areas and characterized by high temperature of waters and steam discharging to the surface.

The second type of geothermal fields is concentrated in deep platform depressions and foreland basin. They are located in non-volcanic areas and are characterized by normal geothermal gradient as 30 – 33°C/km [3].

2.7 Generation of Electricity from Geothermal Resources

Systems of electricity generation from geothermal resources in terms of structure can be subdivided generally into the following types [9]:

- Direct Use
  -With Condenser
  -Without Condenser
- Binary Cycle

2.7.1 Direct Use (without condenser)

Natural steam from the well is fed directly into a turbine with subsequent release into the atmosphere or into a device, which collects valuable chemicals. Backpressure turbine can be supplied with secondary steam or steam from the separator. According to this scheme, the power plant operates without condensers, and there is no need for a compressor to remove non-condensable gases from the condensers. This setting is the most simple and operating costs are minimal (Fig. 1).

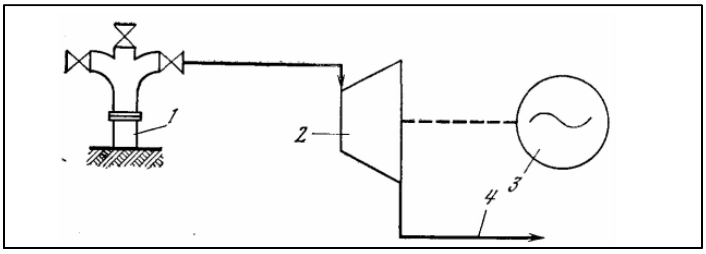

Fig. 1. Diagram of a geothermal power plant with direct use (without condenser) of natural steam: 1 - well; 2 - turbine; 3 - generator; 4 - outlet to the atmosphere or to a chemical plant [4]

2.7.2 Direct Use (with condenser)

Steam from the well is fed to a turbine and then, it enters into the mixing condenser. A mixture of cooling water and condensate of steam already exhausted in the turbine is discharged from the condenser into an underground tank. From the tank, it is taken by circulation pumps and sent to the cooling tower. From the cooling tower, the cooling water flows back into the condenser. (Fig.2)

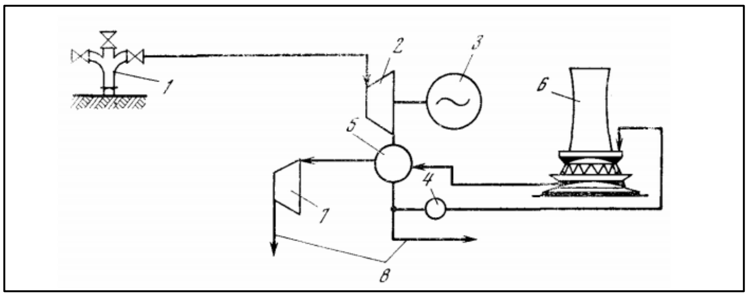

Fig. 2. Scheme of a geothermal power plant with a condensing turbine and direct use of natural steam: 1 – well; 2 – turbine; 3 – generator; 4 – pump; 5 – condenser; 6 – cooling tower; 7 – compressor; 8 – discharge [4]

2.7.3 Binary Cycle

In this kind of power plant, natural steam from the well enters the steam converter and gives up its heat to the secondary heat carrier. The pure secondary steam is sent to the condensation turbine and the processed steam goes to the condenser. The non-condensable gases contained in the steam are separated in a steam converter and either released into the atmosphere or sent to chemical plants. Compared to the power plants directly using natural steam, the specific steam consumption is 30% less. (Fig. 3)

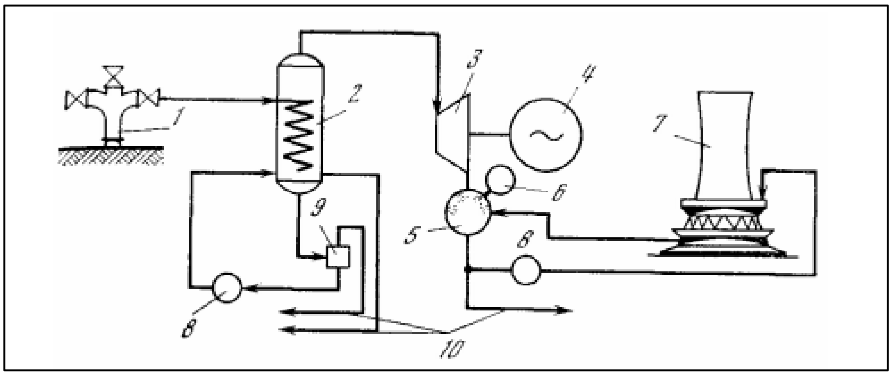

Fig. 3. Scheme of a geothermal power plant with a steam converter (binary cycle): 1 – well; 2 – steam converter; 3 – turbine; 4 – generator; 5 – condenser; 6 – vacuum pump; 7 – cooling tower; 8 – pump; 9 – degasser; 10 – discharge [4]

2.8 Using Geothermal Energy for Heating

For heating and hot water supply for residential and industrial buildings temperature of the used water, have to be at least 50 – 60°C [6]. The most rational use of thermal waters can be achieved with their consistent operation: initially in heating, and then in hot water supply. However, this presents some difficulties, since the demand for hot water is relatively constant over the season, while heating is seasonal. It depends on the climatic conditions of the area, outside temperature, time of year and day. Currently, various schemes have been developed for the use of thermal waters for heating and hot water supply of residential and industrial buildings.

2.8.1 Categories of Thermal Water Used for Heat Supply

Thermal Waters used for heat supply can be subdivided in terms of temperature and mineralization into the following categories [9]:

- extremely mineralized and high-temperature thermal water;
- weakly mineralized and low-temperature thermal water;

2.8.2 Heat Supply with Extremely Mineralized and High-Temperature Thermal Water

Thermal water has a temperature above 80°C, but it is highly mineralized. Under these conditions, there is a need for intermediate heat exchangers. A scheme of the system relevant for this kind of thermal water is shown in Fig. 4.

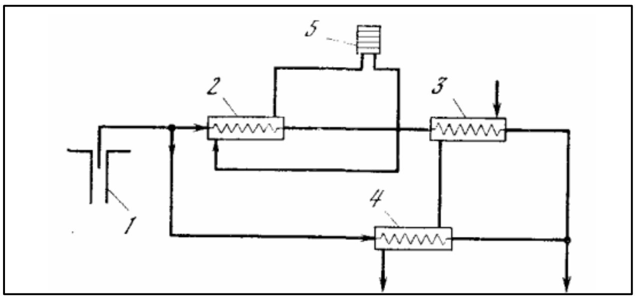

Fig. 4. Schematic diagram of geothermal heat supply with heat exchangers: 1 - well; 2 - heat exchanger of the heating system; 3, 4 - heat exchangers for hot water supply of the 1st stage and 2nd stages; 5 - heating system [4]

2.8.3 Heat Supply with Weakly Mineralized and Low-Temperature Thermal Water

Thermal water is weakly mineralized, but with a low thermal potential, thus, temperature is below 80°C. In this case, increase of the thermal water potential is needed and following systems can be applied:

- supply of thermal water in parallel for heating and hot water and peak reheating of heating water;
- drainless geothermal heating system;
- use of heat pumps;
- combined use of heat pumps and peak heating.

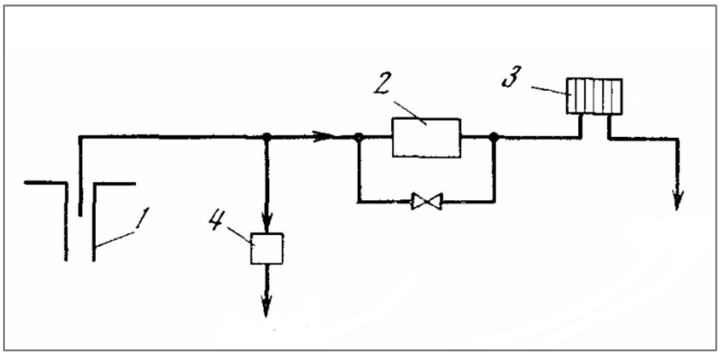

Fig. 5. Schematic diagram for supply of thermal water in parallel for heating and hot water with peak reheating: 1 - well; 2 - peak heater; 3 - heating system; 4 - storage tank [4]

According to the first type of scheme, thermal water from wells enters into system (hot water supply) and boiler. Here it gets warm to a temperature corresponding to meteorological conditions, and served in heating systems (Fig. 5). This scheme is especially suitable for areas with expensive drilling, since the peak boiler house allows reducing number of wells.

In the second type of scheme thermal water coming from wells is heated 160-200°C temperature. The third type of scheme provides heating with low-temperature thermal waters using a certain heat pump. Fourth type of scheme is integrated heat supply system with transformation of discharge water heat in combination with peak heating and high-quality regulation [9].

CHAPTER 3: OVERVIEW OF GEOLOGICAL STRUCTURE OF AZERBAIJAN AND INFORMATION ON OIL AND GAS BEARING REGIONS

3.1 Geological Structure of Azerbaijan

Sedimentary, volcanic, volcanic-sedimentary, intrusive, metamorphic deposits and continental rocks of the Mesozoic and Cenozoic, and partly of the Paleozoic age are widespread on the territory of the Azerbaijan Republic.

In terms of geological structure and geotectonic development, the territory of the Republic of Azerbaijan belongs to the alpine fold belt formed in the collision zone of the Eurasian and Africa-Arabian lithospheric plates. The composition of the main tectonic elements includes mega-structures of the Greater and Lesser Caucasus, Talish, the Kura depression located between them, in the northeast part of the Pre-Caucasian trough, in the east the Middle and South-Caspian depressions (Fig. 6) [10].

The complexity and diversity of the history of the geological and tectonic structure of the Eastern Caucasus, including the territory of Azerbaijan, is due to the repeated manifestation of tectonic-magmatic processes over a long period of its formation. Paleozoic-Mesozoic-Cenozoic periods were cycles reflecting the evolution of the Caucasus.

In terms of seismicity, the territory of the Republic of Azerbaijan is one of the most active regions of the Alpine orogeny (fold belt). According to historical information, strong and destructive earthquakes have repeatedly occurred here.

In terms of the number of mud volcanoes, their size, morphological features, vigorous activity and the variety of eruption products, Azerbaijan is on the top in the world. All types of mud volcanic manifestations as active, extinct, buried, underwater, island, abundantly oily are found in the territory. There are more than 300 mud volcanoes on the east land of Azerbaijan and the adjacent Caspian Sea. There are over 200 underwater mud volcanoes in the South Caspian and 8 islands in the Baku archipelago of mud volcanic origin. [11, 12]

Azerbaijan is rich in some ferrous, non-ferrous metals, as well as rare earth elements and minerals. Ore deposits of iron, aluminum, mercury, gold, copper, lead, zinc, cobalt etc. are known on its territory.

In the Azerbaijan Republic, iron ores create industrial fields and among them, the most important and largest in the Caucasus is the Dashkesan iron ore deposit. In addition, commercial deposits of cobalt ore have been identified in this region.

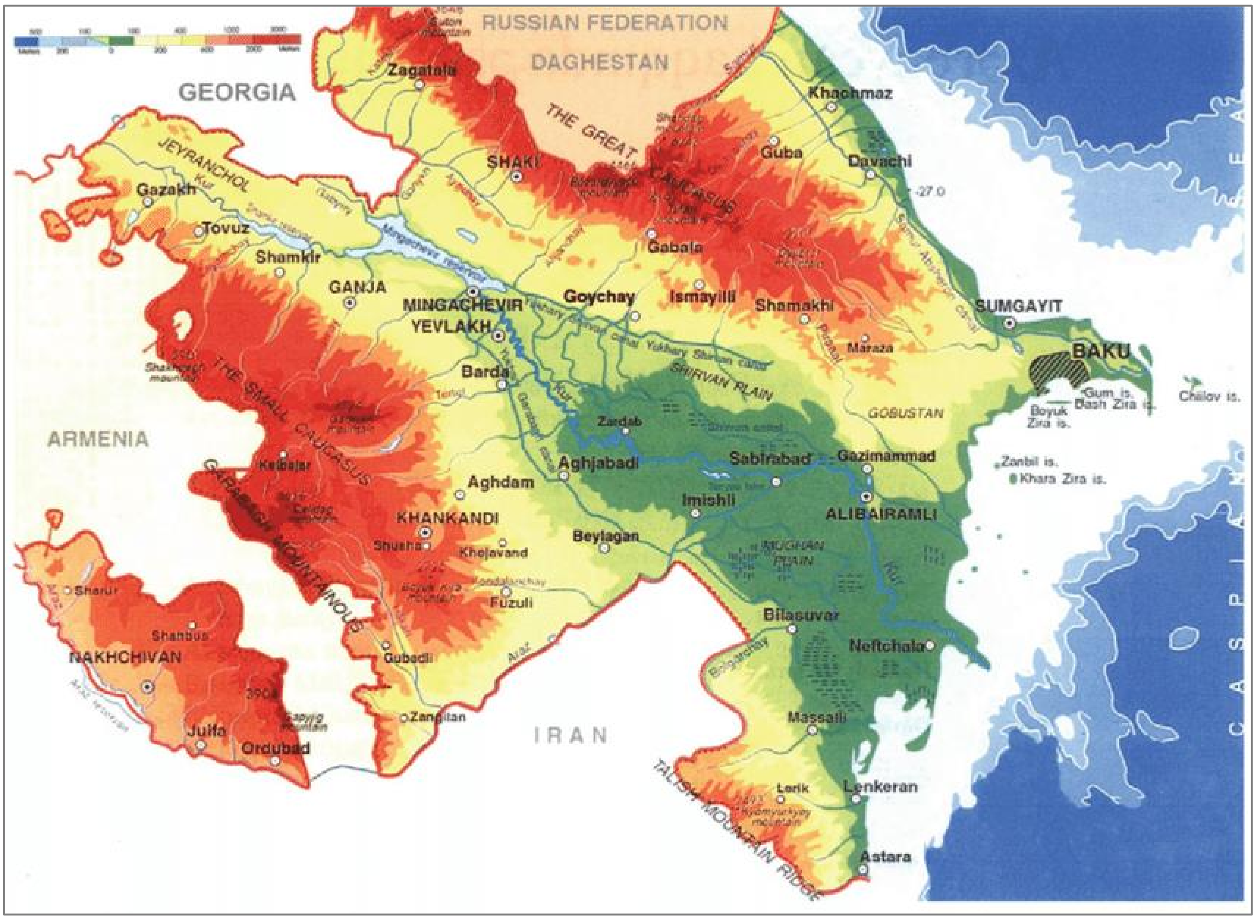

Fig. 6. Orographic Map of Azerbaijan [13]

3.2 History of Oil and Gas Industry in Azerbaijan

The territory of the Republic of Azerbaijan, especially the Absheron Peninsula, is one of the richest in term of hydrocarbons and most ancient oil-producing regions in the world. In Absheron, in 1594, the first oil well was drilled with a depth of 35 m. In 1847, the first well in the world was mechanically drilled in the Bibiheybat area (Absheron) [14]. Fig. 7 shows one of the oil well fountained in an ancient oil field Balakhani in Baku, Azerbaijan, in 1887.

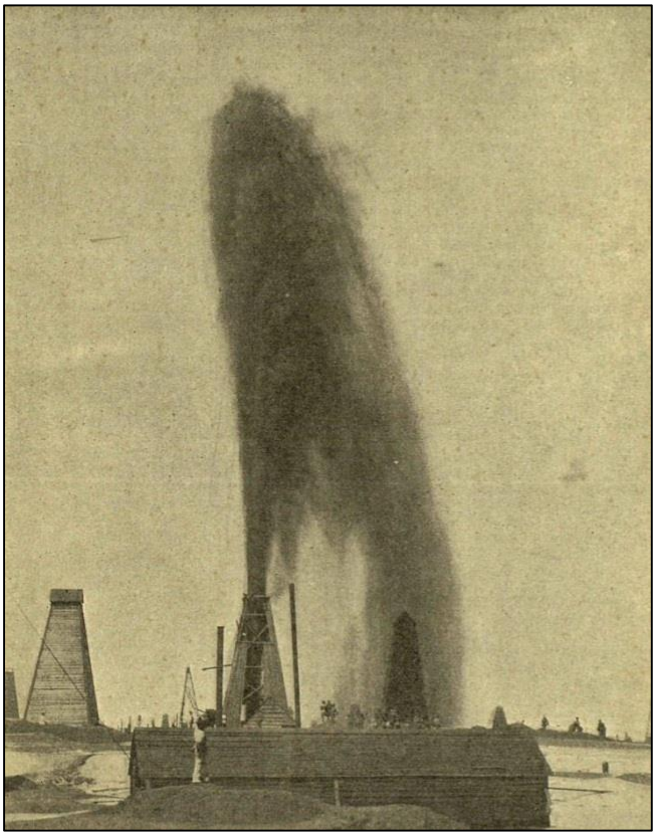

Fig. 7. Oil Fountain in Balakhani (Baku, Azerbijan, 1887)

The dynamics of oil production over 1882 – 1897 was form 832 thousand tons to 6921 thousand tons per year. The maximum production was reached in 1901 reached about 11000 thousand tons, which amounted to more than half of world production and Azerbaijan came out on top among countries producing oil [15].

3.3 Oil and Gas Bearing Regions in the Territory of Azerbaijan

Main oil and gas fields are concentrated in the deposits of the productive stratum (layer), the thickness of which is 1200-3000 m and in some areas reaches 4000 m. Presently, 90% of oil and gas production in Azerbaijan is carried out from the productive strata and 80-85% of oil production is carried out from offshore fields [16].

In the central part of the Absheron threshold of the South Caspian, oil and gas fields Gunashli, Azeri and Chirag have been discovered with large reserves, when in the Baku archipelago the Bakhar and Shah Deniz gas condensate fields opened.

List of the main oil and gas bearing regions (OGBR) in the territory of Azerbaijan is given below (Fig. 6) [16]:

- Absheron OGBR
- Baku archipelago OGBR
- Lower-Kura OGBR
- Shamakhi-Gobustan OGBR
- Precaspian-Guba OGBR
- Ganja OGBR

3.3.1 Absheron Oil and Gas Bearing Region

Absheron oil and gas bearing region. On the Absheron Peninsula in Balakhani-Sabunchi-Ramana, Bibiheybat, Surakhani, Gala, Lokbatan and other old oil fields, the entire section of the productive strata is oil and gas bearing. Onshore gas-condensate fields Garadagh and Zira are located in this region. Besides, there are several significant offshore fields related to this region in the Caspian Sea.

Balakhani – Sabunchu – Ramana field, located in the central part of the Absheron peninsula, is the largest field in terms of oil production and reserves, among the developed onshore fields. Reservoir properties of productive horizons as porosity and permeability are accordingly 23-27% and 90-600 mD [16]. Development regime is mainly the regime of the dissolved gas. Taking into account that this field has been operated since ancient times, it can be noted that the field is on the last stage of development also according to water cut percentages.

Average daily debit of one well was 0.6 tons/d of oil and 11.9 t/day of total liquid, water cut of produced fluid is about 95.3%.

The diversity in geological and physical properties influenced technological indicators. Development indicators in the formations of the upper section of the Productive Stratum relatively higher than in the lower one, which is associated with the characteristics of the collectors, energy feature, as well as the intensity of the operation process. From the total oil produced in the field since the beginning of development, 75.5% is related to the upper section, and 24.5% to the lower section.

Artificial stimulation methods applying on layers also affected to the development results. So that, in 2004 through 107 water injection wells, 2292 thousand m^3 of water was injected, due to which 54.4 thousand tons of oil received. Therefore, consumption per ton of oil production increase is 42 m^3 of water [16].

Neft Dashlari (Oil Rocks) is one of the large offshore fields in terms of production and reserves of oil and gas. This field entered to industrial development in 1950. The field is multi-layered and reservoir porosity changes averagely from 9.16 to 29%, permeability from 0.011 to 1.3 μm^2. The density of oil varies from 843 to 929 kg/m^3, and the viscosity from 1.3 to 13 MPa*s. Average flow rate of one well was 5.7 tons/day oil and 10.1 tons/d liquid, water cut of produced fluid is about 42.7%.

Gunashli oil field is located in the deep-water part of the Azerbaijan shelf of the Caspian Sea. Average values of porosity along the horizons range from 12 to 22% and permeability values vary widely from 0.001 to 0.15 μm2. Oil density in standard conditions varies from 845 to 863 kg/m^3. Industrial development of Gunashli field began in 1985. Average production rate of one well is 90.7 tons/d and 38.5 ton/day for oil and condensate correspondingly. The percentage of water cut is 12.8% for oil production and 25.8% for condensate [16].

3.3.2 Lower-Kura Oil and Gas Bearing Region

Oil and gas fields are associated with a productive stratum, in the section of which 20 oil-bearing horizons have been identified and about 10 deposits have been discovered here. Kurovdag, Kursangi, Mishovdag fields located in this region are large ones in terms of oil and gas reserves.

Kurovdag field is the largest oil field of developed Lower-Kura OGBR (oil and gas bearing region). The reservoir properties of productive horizons have porosity within 19.7-29.4%, permeability 25.0-388.10-3 μm2, oil density 850-918 kg/m^3 and viscosity 11.9-25.9 MPa*s.

Industrial development of the field began in 1955 and the maximum annual production of 2254 thousand tons was reached in 1966. Oil production rate of one well is averagely 2.1 tons, liquid 11.1 tons and water cut of the produced liquid is about 80.8%.

Water injection was started at the Kurovdag field in 1958 and in 2004, through 13 injection wells, 422.1 thousand m3 of water was injected and as a result, 15.6 thousand tons of oil produced additionally [16].

3.3.3 Baku Archipelago, Shamakhi-Gobustan, Precaspian-Guba OGBRs

In Baku Archipelago OGBR, the oil and gas content is associated with the upper section of the productive strata. Currently, the Sangachal-Deniz, Duvanny-Deniz, Khare-Zira Island (gas-condensate-oil), Khare-Zira-Deniz (gas-condensate), Alat-Deniz and Garasu Island are being exploited.

In Shamakhi-Gobustan oil and gas bearing region several promising areas have been identified. The oil-gas-condensate fields Duvanny, Dashgil, Kyanizadag are associated with the productive strata, the Umbaki oil field with Miocene deposits.

In Precaspian-Guba oil and gas bearing region, Chandagar-Zarat, Siyazan-Nardaran, Saadan, Amirkhanly, Zagly and Zeyva deposits are being developed along the Siyazan monocline.

3.3.4 Yevlakh-Agjabedi Oil and Gas Bearing Region

In this region, at the Muradkhanli field, for the first time in Azerbaijan, oil with industrial importance was found in the Upper Cretaceous volcanogenic deposits. The Muradkhanly field, which is part of the Middle-Kura oil and gas-bearing region, is the only field in the province where oil reservoir opened in volcanogenic deposits. The density of oil is 877 kg/m3, the oil is paraffinic. The average depth of occurrence of productive horizons varies within 2750-4050 m. This field is characterized by abnormally high reservoir pressure. The maximum oil production was in 1978 with volume of 446 thousand tons [16].

CHAPTER 4: GEOTHERMAL ENVIRONMENT IN OIL AND GAS BEARING REGIONS IN THE TERRITORY OF AZERBAIJAN

4.1 History of Geothermal Researches in Azerbaijan

Considering the purpose and nature of the works carried out in Azerbaijan, as well as current direction of geothermal researchs, the history of study of the territory can be distinguished into three periods [17]:

1st stage (1880-1920). The beginning of geothermal observations in the oil wells of the Absheron peninsula dates back to 1880, when L. Batsevich made temperature measurements in oil wells of Sabunchu area (village on the Absheron peninsula). Absheron peninsula is located on the western coast of the Caspian Sea, in Azerbaijan. Based on interval temperature measurements with maximum thermometer in three different wells he found the fact of temperature increase by rise in depth. According to M.V. Abramovich geothermal step for Ramana (village on the Absheron peninsula) area fluctuates from 21 to 35 m/°C and wells with abnormal temperatures caused by an influx of less mineralized deep water were also observed along with wells with normal temperatures.

2nd stage (1920-1968). Over this period, systematic geothermal researchs in Azerbaijan have been carried out mainly by academician S.F. Mekhtiyev and his associates. Based on measurement results made by S.F. Mekhtiyev and based on large actual field material geothermal step values were calculated for a number of fields in the Absheron area and patterns of temperature distribution in the subsoil due to tectonics revealed.

3rd stage (1968-currently). Geothermal properties (as thermal conductivity, heat capacity and thermal diffusivity) of rocks located in the territory of Azerbaijan, were studied widely over this period. Development of instruments for geothermal research and determination of density of heat flux through the bottom of the Caspian Sea began in 1970s. Full range of geothermal researches made over this stage includes thermal water studies, surface geothermal survey, studies of radiogenic heat generation in the Earth's subsoil, studies of the relationship between the thermal field and seismicity, studies of the thermal field of mud-volcanic regions, modeling of the thermal field of sedimentary basins in the territory of Azerbaijan.

Drilling of Superdeep SD-1 well in Saatli began in 1977 and for technical reasons was halted in 1982 reaching a well bottomhole depth of 8324 m. One of the main purposed of drilling was construction of a geophysical model of the Earth's crust within the intermountain depression. The planned depth was initially 15 km.

It was predicted that at a depth of 8 km the temperature will be 141°C, and at a depth of 15 km it is 250-260°C and as a result of drilling of SD-1 well at a depth of 8 km temperature appeared within 140-150°C. The maximum value of thermal conductivity belongs to the interval of 7000-7500 m and is 3.17 W/ m*K. In general density of heat flux increases with increasing of depth except for slight decrease in 3500 – 4000 m. In the upper parts of the sedimentary section, the heat flux density is too low, and average can be taken as 20 mW/m2 until 1500 m [17].

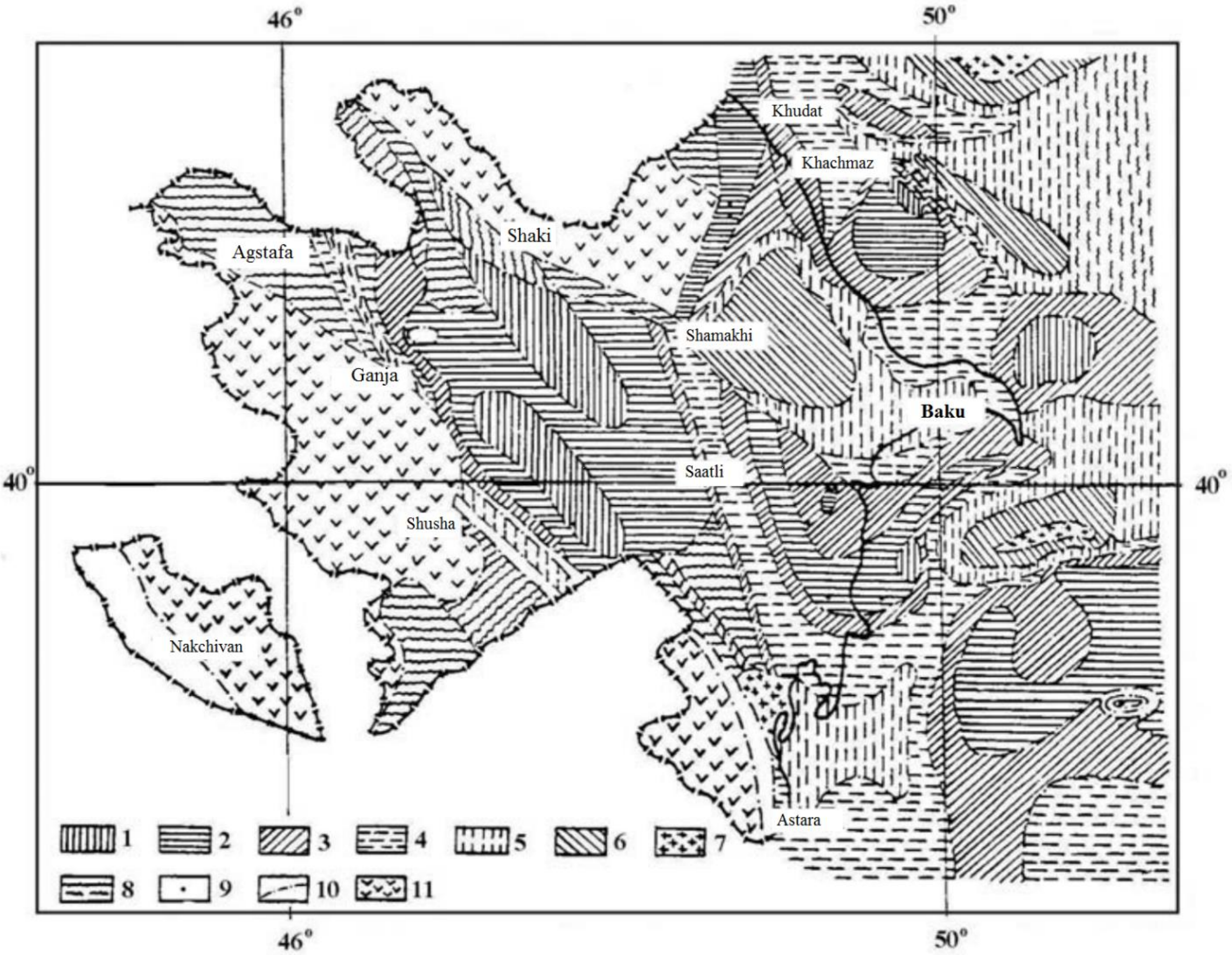

Fig. 8. Heat flux map of depression zones of Azerbaijan [17]

Heat flux value (mW/m^2): 1) 0 – 20; 2) 20 – 30; 3) 30 – 40; 4) 40 – 50; 5) 50 – 70; 6) 70 – 90; 7) 90 and more; 8) assumed values of heat fluxes; 9) points for measuring heat flows; 10) boundaries of zones; 11) areas of mountain structures.

4.2 Thermal Waters in Territory of Azerbaijan

For a hydrothermal deposit to form and exist, three following lithological parameters are required [5]:

1. large volume of sufficiently hot rocks (at a certain depth)
2. an aquifer or permeable formation above the these rocks
3. an impermeable layer above this aquifer preventing significant amount of heat carrier from reaching the surface.

The Republic of Azerbaijan is rich in thermal waters penetrated by numerous oil-gas and water wells, which are known in a number of regions of the Greater and Lesser Caucasus, Absheron Peninsula, Talysh, in the vast territory of the Kura depression and the Caspian-Guba regions.

Thermal waters in Masalli, Lankaran and Astara regions confined to the regional fault that crosses the entire mountain Talysh. In Masalli, wells drilled to 500 m deep revealed thermal waters with a temperature of 44-45°C at the outlet. Temperature of water in various springs varies from 50 to 64°C. Well flow rate is 10 – 15 l/sec, water is mineralized and with calcium chloride composition. In Lankaran, a number of wells drilled with a depth of 465 – 1000 m, which opened thermal water with temperature up to 50°C. Water temperature in the springs is 30 – 43°C, flow rate – 2260 m3/day. Water is mineralized with sodium chloride-calcium composition. The water temperature in the wells at the outlet is 23 – 39°C, the flow rate is up to 46 l/sec [17].

Geothermal conditions of the southern and northeastern slopes of the Greater Caucasus poorly studied, but there are indicators of the wide spread of thermal waters. These areas include thermal water fields in the Gakh region – Ilisu with a source temperature of up to 40°C and Kurmukh with temperatures up to 30.5°C. In Gabala region, there are springs with a temperature of 39.4°C, in Oguz region there are Khalkhal springs with a temperature of 32°C.

The thermal waters of the Precaspian-Guba region with hydrocarbonate-calcium-sodium composition wand salinity of 0.8 – 1.9 g/l possess total water flow rate as 20470 m3/day. Temperature of these thermal waters changes from 50 to 84°C.

The Kura depression is an artesian basin with a complex structure, temperature distribution and water composition. In 1969, in the Dzharly area, thermal water with a flow rate of 20,000 m3/day and temperature of 100°C was opened. There are several geothermal researches dedicated to the Dzharly well.

In the Kurdamir region, one well penetrated thermal waters with a flow rate of 10000 m3/day with 82°C temperature at the wellhead. In the Shirvanli area, thermal water with a flow rate of 3000 m3/day and temperature of 60°C was opened by a well.

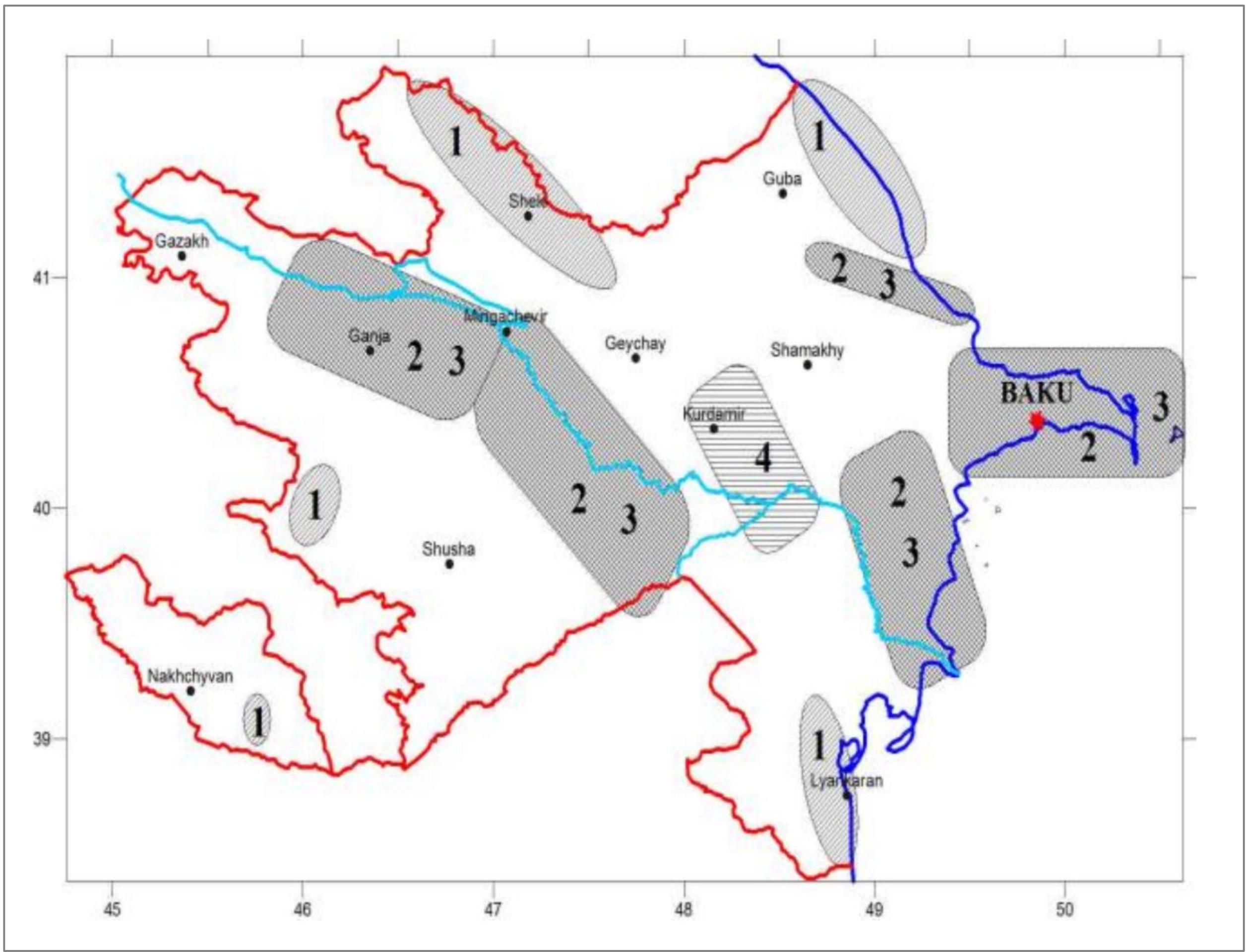

Fig. 9. Map of regions with thermal fields in the territory of Azerbaijan Republic [18]

1 – Only thermal waters; 2 – Mud volcanoes; 3 – Oil and gas fields; 4 – Petro-thermal systems

Hydrogeological studies of the thermal waters in the territory of Azerbaijan made it possible to identify vertical and horizontal hydro-geochemical zoning. By dipping of sediments from the foothills of the Lesser and Greater Caucasus, mineralization and hydro-chemical properties changes. Salty, bicarbonate-sodium and chloride-sodium waters gradually replace fresh, bicarbonate-calcium waters. Table 2. demonstrates energy potential of different hydrogeological areas in the territory of Azerbaijan [18].

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 Energy Potential of Various Hydrogeological Areas

4.3 Geothermal Conditions of OGBRs

Geothermal conditions of the following Oil and Gas Bearing Regions (OGBRs) given below:

- Absheron OGBR
- Baku archipelago OGBR
- Precaspian-Guba OGBR
- Lower-Kura OGBR
- Yevlakh-Agjabedi OGBR
- Ganja OGBR

In structures that do not contain oil and gas deposits, thermal activity much lower than in productive ones. Thermal activity of structures containing accumulations of gas and gas-condensate, significantly lower than that of structures saturated with oil, which is explained by cooling during adiabatic expansion of gas and limited flow at these structures of deep hyper-thermal waters [17].

There are certain features of temperature change by section and area. Zones of abnormally high reservoir temperatures and low values of geothermal stages, as a rule, are confined to areas complicated by mud volcanoes, diapirs, characterized by groundwater discharge [17].

In the sections of individual areas, the increase in temperature with depth slows down, and the values of geothermal steps increase averagely from 20 – 25 m/°C at depths of 0 – 500 m to 100 – 125 m/°C in the interval 4500 – 5000 m.

If all other geological and hydrogeological properties are same, geothermal step in the sections of fields are minimal in clay and maximum in sandy interval. This feature is associated with the thermal conductivity of rocks.

Almost all oil fields compared to surrounding areas is characterized by elevated temperatures. Within individual fields, areas of mud volcanoes and large disturbances are characterized by local positive thermal anomalies [19].

4.3.1 Absheron Oil and Gas Bearing Region

Background value of temperature field within the region sections 3000 and 4000 m is equal respectively to 74 and 88°C. Heat flux density values vary widely from 20 to 90 mW/m2. Wide information on geothermal conditions of Absheron region is given in the Chapter 5.

According to academician S.F Mekhtiyev, development of the field also affects local distribution temperatures in the earth's crust. One of the reasons influencing a decrease in the temperature of oil layers over time, apparently, is artificial flooding of reservoirs with cold water, as well as the duration of the operation processes and the associated drop in reservoir pressure.

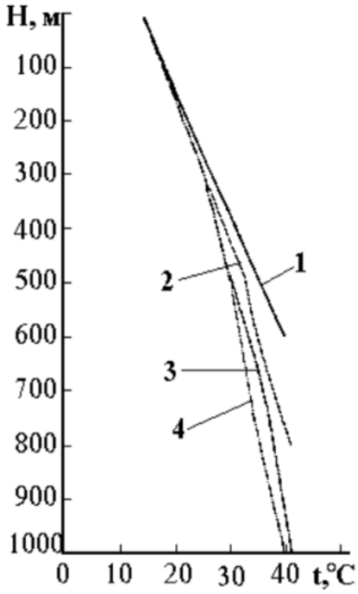

Fig. 10. Dependence of temperature on depth at Bibi-Eibat field (Absheron peninsula) measured in the following years: 1 – 1911, 2 – 1913, 3 – 1944, 4 – 1962 [17]

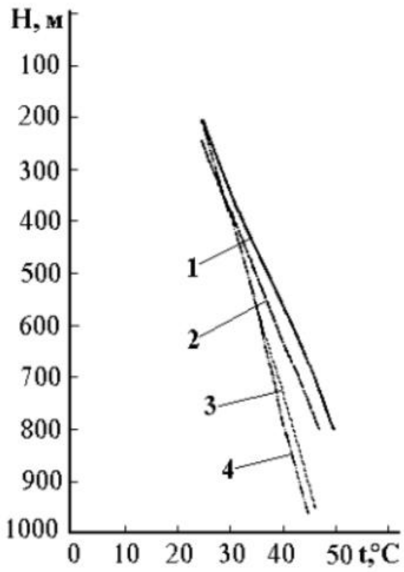

Fig. 11. Dependence of temperature on depth at Surakhany field (Absheron peninsula) measured in the following years: 1 – 1913, 2 – 1944, 3 – 1950, 4 – 1961 [17]

At the Surakhany and Bibi-Eibat fields (Absheron peninsula) at the same depth, the temperature decreases over time (years) by an average of 2-5°C and can be explained as a result of millions cubic meters of cold water injection into the layer during development (Fig. 10, Fig.11).

4.3.2 Baku Archipelago Oil and Gas Bearing Region

Background temperature within the archipelago, at depths of 3000 and 4000 m is equal to 62.6 and 75.4°C, accordingly. The average value of the heat flux density for the given region is 30-50 mW/m2.

4.3.3 Precaspian-Guba Oil and Gas Bearing Region

In the most part of this region, the values of the heat flux density are low. The indicators does not exceed 30 mW/m2. In the southeast part of the Siyazan monocline, the heat flux density reaches 50 mW/m^2.

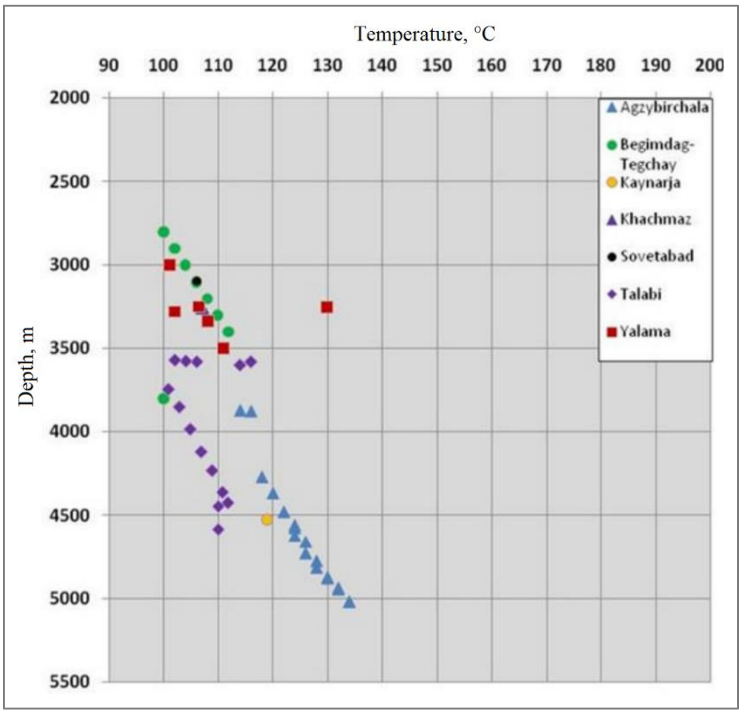

Fig. 12. Temperature dependence on depth for wells in Precaspian-Guba area with >100°C [18]

In this zone, with several wells thermal waters opened with 12360 m3/day total output and temperature 50 – 84°C. In Khachmaz district (Fig. 6) thermal waters with 1228 m3/day output and 58°C temperature opened by a certain well. The amount of heat carried by the thermal waters was $4.4*10^5$ Gcal. In addition, by a one well, thermal waters with 500 m3/day output and 95°C temperature opened in Yalama region. The amount of heat carried by the water was $3.5.10^5$ Gcal.

4.3.4 Lower-Kura Oil and Gas Bearing region

The region has a background temperature as 64.5 and 76.4°C for 3000 and 4000 m depths, respectively and is characterized by 20 – 50 mW/m^2 heat flux density. On the example of the Kyurovdag area of the Lower-Kura depression change of temperature by depth shown in the Fig. 13.

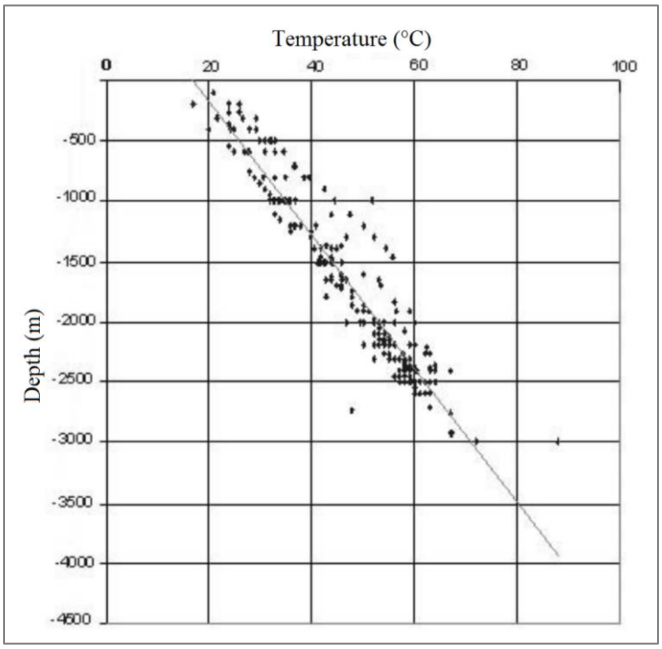

Fig. 13. Geothermal section of the Kyurovdag area [17]

4.3.5 Yevlakh-Agjabedi Oil and Gas Bearing Region

For depths of 3000 and 4000 m, background temperature values are respectively 75°C and 95°C. Two temperature zones are distinguished, in which, compared to the background, positive and negative local temperature anomalies are determined. In this region, the average value of heat flow density changes mainly from 20 to 50 mW/m^2.

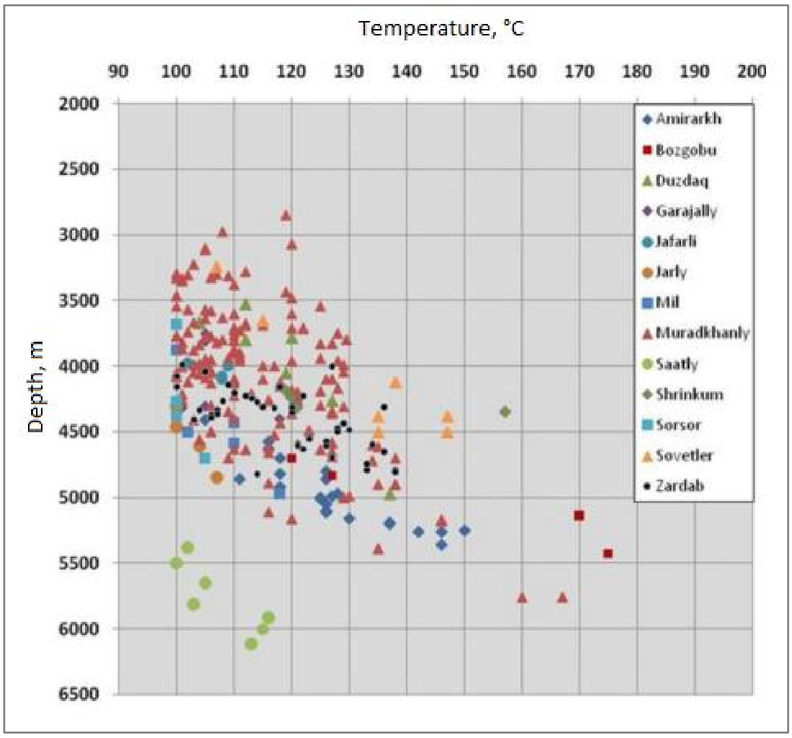

Fig. 14. Temperature dependence on depth for wells in Yevlakh-Agjabedi area with >100°C [18]

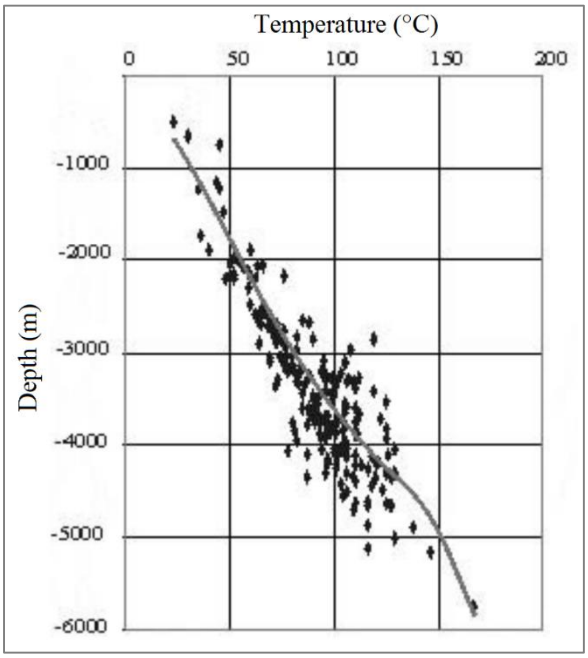

Fig. 15. Geothermal section of the Muradkhanly field [17]

4.3.6 Ganja Oil and Gas Bearing Region

Background temperature values at the depths of 3000 and 4000 m, respectively, are 99.5°C and 129°C. For this area, the heat flow density varies from 30 to 70 mW/m2. On the example of the Gazanbulag area of the Ganja OGBR, change of temperature by depth shown in the Fig. 16.

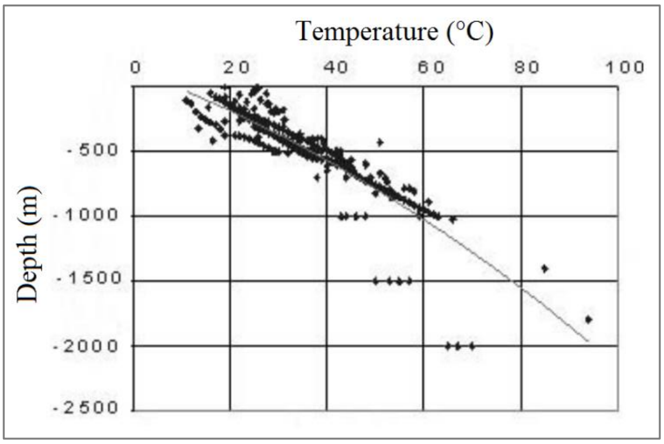

Fig. 16. Geothermal section of the Gazanbulag area [17]

CHAPTER 5: GEOTHERMAL RESEARCH DATA OF OIL AND GAS BEARING REGIONS IN THE ABSHERON PENINSULA

5.1 Geological Characteristics of the Absheron Peninsula

The region can be in terms of orography divided (by Fatmai – Balkhany – Surakhany – Zig anticline boundary) into the following parts [20]:

- Western part
- Eastern part

Eastern part is more plain type (flat) compared to western part of the peninsula, which possesses several mud volcanoes.

Geological structure of the Absheron peninsula contains the following types of deposits:

- Cretaceous
- Paleogene-neogene
- Quaternary

Cretaceous deposits widespread in northeastern part of the region and contains sandy limestone and gray clays in terms of lithology. Paleogene deposits come out to the surface in this part of the peninsula and contains clays, marl and sandstone. Neogene deposits consist of clays, volcanic ash and marl.

Productive stratum (oil-bearing) of the Absheron peninsula has a complex structure composed by alternating sand-clay deposits. Thickness of the stratum in southern part is 2000 m, however, in in eastern part is higher than 3000 m. Productive stratum is subdivided into the following sections:

- Upper (Surakhany, Sabunchu, Balkhany suites)
- Middle (Sandy section, 200 – 300 m)
- Lower (On-Girmaki, On-Girmaki-Sand, Girmaki suites)

5.2 Thermal Water Resources of Absheron Peninsula

At the oil fields of productive stratum in the territory of Absheron peninsula 18 water-bearing horizons being in complex communication with oil-bearing layers are determined.

Formation water of the upper part of productive stratum in Absheron peninsula are subdivided into the following zones:

- cold (< 20°C)
- thermal (20 – 40, 40 – 50, 50 – 75, 75 – 100°C)

Western and northwestern parts of the Asbheron peninsula are related to the cold zone. In this region, deposits of productive stratum comes to the surface or lies down in 110 – 200 m from the surface.

Depths from 110 – 180 m to 560 – 950 m is considering as a zone of formation waters with 20 – 40°C when depth from 560 – 980 to 830 – 1440 m related 40 – 50°C.

High-temperature water-bearing horizons are related southern oil fields of the Absheron peninsula, where temperature changes from 38 to 68°C. In northern and north-eastern fields of the peninsula temperature changes from 25 – 30 to 45 – 50°C.

Wells located in the upper part of productive stratum have water rate from 0.1 to 6 l/sec. These formation waters is highly mineralized and sodium-chloride type.

On the Absheron Peninsula, thermal waters are met by wells at a wide variety of depths and in natural outlets. In a peninsular part of Absheron, to the east of the village of Hovsan, temperature of the mineralized waters from the drilled depths reaches 100-135°C. Chloride-hydrocarbonate-sodium water fountain was observed with mineralization of 16.5 g/l with temperature of 71°C and flow rate of more than 18450 thousand-liters/day at Bibi-Eibat directly near Baku. Temperature of thermal waters increases, and mineralization decreases with increasing depth [17].

5.3 Geothermal Research on the Absheron Peninsula

During the 1944 – 1967 years at the oil fields of Absheron Peninsula, academicians S.F. Mekhtiyev A.K. Mirzadjanzade and S.A. Aliyev carried out geothermal observations, collected, systematized and processed valuable temperature measurement data from several non-active and operational wells. A part of the geothermal data is given below for the following oil fields:

- Lokbatan Field
- Balakhany – Sabunchu – Ramana Fields
- Surakhany Field
- Neft Dashlary (Oil Rocks) Field
- Zig – Hovsan Fields
- Bibi-Eibat Field
- Gum-Deniz Field

5.3.1 Lokbatan Field

Geothermal profiles of well №1469, 664, 1361, 1084, 439, 1043 demonstrate comparison of geothermal conditions through mud volcano and its surrounding (Fig. 17). Table 3 illustrates dependence between temperature and depth for several non-active wells in Lokbatan field. Chapter 6 gives results of analyses of the data reported in proposed chapters.

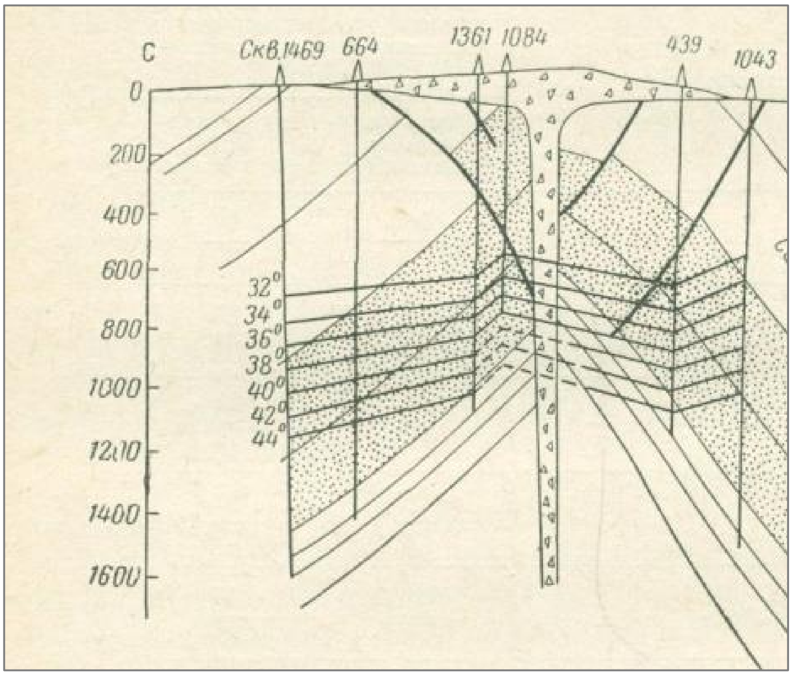

Fig. 17. Geothermal profiles of different wells in Lokbatan Field [20]

Well (№)	Duration of well non-activity (years)	Depth (m)	Temperature (°C)
423	1	684	37
		1368	54
192	1	361	35
		723	43
338	1,5	600	36
		1286	52
436	1	638	39
		1260	53
416	1	684	37
		1384	54
493	2	474	34
		949	54
1377	1,5	215	32
		415	33
		615	36
		815	40
219	1,5	203	30
		403	31
		603	34
		803	39
		1003	44
1348	1,5	974	44
		774	40
		574	35
		374	31
		174	30
1289	1,5	325	31
		525	35
		725	34
		925	40
		1125	43
1064	1,5	190	32
		390	32
		590	35
		790	39
		990	45
		1100	50

Table 3. Temperatue indicators of different wells in Lokbatan field [20]

5.3.2 Balakhani – Sabunchu – Ramana oil field

Temperature indicators at different depths of five non-active wells in Balakhani – Sabunchu – Ramana field are shown in the table 4. Temperature measurements were conducted in 1967 for well №1562, in 1961 for well №1524, in 1962 for well №2197 and for well №1512, in 1963 for well №1374 [20].

Depth (m)	Well (№)				
	1562	1524	2197	1512	1374
200	-	-	-	22,3	-
300	-	-	-	25,2	-
400	-	-	-	27,8	-
500	-	-	-	31	-
600	-	37,9	-	33,9	-
700	42,8	41,3	-	36,3	38
800	45,3	44,7	35,1	38,5	42
900	48	4,4	37,9	40,7	43,5
1000	52,7	49,7	39,5	42,2	45
1100	53,3	51,7	41,6	45,6	46
1200	54,5	53,3	44	47,1	48
1300	-	54,9	45,6	-	49
1400	56,1	56,8	47,6	-	50,5
1500	57,5	58,3	49	-	52,5
1600	58,5	59,5	50,4	-	53,5
1700	59,4	-	51,1	-	54
1800	60,6	-	52,3	-	54,5
1900	-	-	53,4	-	-
2000	-	-	54,5	-	-
2100	-	-	55,7	-	-

Table 4. Temperatue indicators (°C) of different wells in Balakhani – Sabunchu - Ramana field [20]

5.3.3 Surakhany Field

Table 5 shows dependence between temperature and depth at five different non-active wells in the Surakhani field of Absheron oil and gas bearing region. The measurements for well №1106 was conducted in 1959, for the other four wells in 1960 [20].

Depth (m)	Well №				
	1106	1598	1403	1697	1268
100	-	-	-	33	31
200	21,5	-	22	-	-
300	-	23	-	35	36
400	27	-	27,5	-	-
500	-	29	-	38	38
600	32	-	32	-	-
700	-	35	-	41	40,5
800	37	-	36	-	-
900	-	41	-	47	-
1000	41	-	40,5	-	-
1100	-	46,5	-	52	-
1200	46	-	45,5	-	-
1300	-	51	-	55	-
1400	50	-	50	-	-
1500	-	55	-	-	-
1600	54	-	54	-	-
1700	-	59	-	-	-
1800	57,5	-	58	-	-
1900	-	62	-	-	-
2000	60	-	62	-	-
2100	-	64,5	-	-	-
2200	64	-	65	-	-
2300	-	67	-	-	-
2400	67	-	67	-	-
2500	-	-	-	-	-
2600	70	-	-	-	-
2700	-	-	-	-	-
2800	73	-	-	-	-
2900	-	-	-	-	-
3000	76	-	-	-	-

Table 5. Temperatue indicators (°C) of different wells in Surakhany field [20]

5.3.4 Neft Dashlary (Oil Rocks) field

This field located in the Caspian Sea, on 110 km distance to the East direction from Baku. According to the 104 measurements conducted over 1952 – 1956 in 35 production wells, temperature changes from 39 to 59°C at the 457 – 964 m depth interval. Geothermal step value for the given depth interval changes from 21 to 22 m/°C [20].

5.3.5 Zig – Hovsan Fields

Temperature measurement results for the Zig and Hovsan fields are given in Table 6. In 1944, temperature measurements in this field were carried out in several non-active wells.

Depth (m)	Zig	Hovsan		
	Well №			
	18	1501	1507	1816
	Temperature (°C)			
200	30	25	-	20
400	35	31	33	24
600	42	37	39	29
800	46,5	42	42	33
1000	51	43	45	38
1200	56	52	47	-
1400	60	56	50	48
1600	64	60	53	54
1800	6	64	55	58
2000	70	68	58	62
2200	4	2	60	66
2400	7	75	64	68
2600	79	78	67	71
2800	-	81	70	74
3000	-	83	73	77
3200	-	85	76	80
3400	-	87	79	-
3600	-	89	81	-

Table 6. Temperatue indicators of different wells in Zig – Hovsan Fields [20]

5.3.6 Turkan – Zira Fields

In the table 7 given below, there are temperature measurement indicators related to well№1820 and well№1306 of Turkan field, and Well №22 of Zira Field [20].

Depth (m)	Turkan		Zira
	Well №		
	1820	1306	22
	Temperature (°C)		
400	-	25	-
500	26	-	-
900	34	36	-
1000	-	-	-
1100	39	-	-
1300	43,5	-	-
1500	49	-	-
1600	-	-	-
1700	52	56	-
1900	56	-	-
2000	-	-	-
2100	60	-	-
2300	62	65,2	-
2500	64	-	-
2600	-	-	-
200	69	-	-
3000	-	73	-
3100	76	-	-
3250	-	-	71
3500	-	-	74
4000	-	-	79,5
4500	-	-	86
4700	-	-	88

Table 7. Temperatue indicators of different wells in Turkan – Fields [20]

5.3.7 Bibi – Eibat Field

For Bibi-Eibat field over 1951-1962 years measurement data collected, systemized and processed from non-active (for a long period) and production wells. Results of the measurements in non active wells are given in the Table 8 [20].

Well №	Depth (m)	Temperature (°C)
2840	1010	54
	1210	67
	1812	80
2701	1160	55
	1460	67
	1760	75
2008	748	48
	848	51
	948	54
2940	1000	47
	1250	54
	1500	60
	1750	64
	1875	65
3282	1000	51
	1250	56
	1500	58
1286	1000	48
	1200	54
	1350	57

Table 8. Temperatue indicators of different wells in Bibi – Eibat field [20]

5.3.8 Gum-Deniz Field

Fig. 18 demonstrates geothermal profiles of wells №178, 154, 189 field in Gum-Deniz Field [16]. Description of this geothermal environment is reported in the Chapter 6. Table 9 shows dependence between average temperature and depth in Gum-Deniz Field related to various production wells.

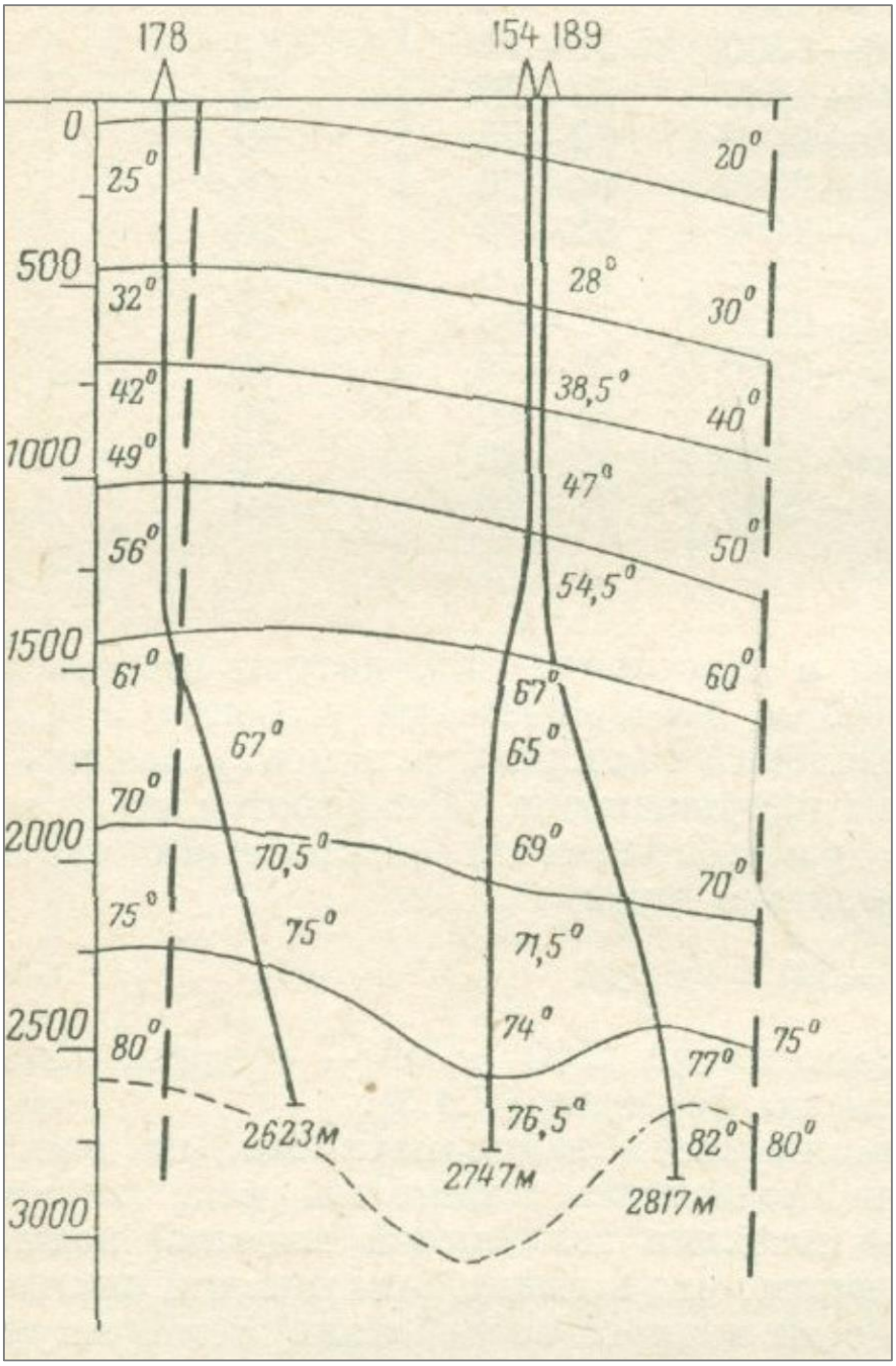

Fig.18. Geothermal profiles of different wells in Gum-Deniz field [20]

Formation (Suite)	Horizon	Depth (m)	Average temperature (°C)	Well №
Absheron	Lower	0-600	31	17
Akchagil		600-660	41	17
Surakhany	I	660-1580	50	17
Balakhany	II	1580-1800	63	16
	III	1800-1880	65	16
	IV	188-2100	68	17
	V	2100-2200	69	14
	VI	2200-2400	70	14
	VII	2400-2500	75	14
	VIII	2500-2600	76	13
	IX (middle)	2650-2700	78	12
	IX (lower)	2700-2780	79	5
	X (upper)	2780-2840	79	4
	X (lover)	2840-2900	80	3

Table 9. Temperature indicators of different wells in Gum-Deniz field [20]

CHAPTER 6: RESULTS AND CONCLUSION

Wells drilled in the bowels of oil fields of the Caucasus region bring to the surface significant amount of heat contained in thermal waters with a temperature from 40- 45 to 80-90°C (sometimes higher) and with a total flow rate of hundreds of millions of cubic meters per year.

Oil fields, in the last stage of their development, can be characterized by a high percentage of water cut and number of repair processes. In this kind of fields, due to low productivity of the wells, expenses and production costs for oil and gas extraction are more than their selling price. Several oil and gas fields developing more than 70-80 years in Absheron region and so with high possibility in possessing abandoned or non-active (for various reasons) wells are demonstrated in this paragraph.

6.1 Final Geothermal Indicators of Lokbatan Field

Abnormal high temperatures and geothermal gradients for a given area recorded in the well №1084 located in the area of the active mud volcano. Lokbatan field (Absheron) is located on the slopes of the mud volcano with the same name and, undoubtedly, it has considerable influence on such a deviation in the distribution of the temperature regime of the observed well (Fig. 17).

In addition, characteristics of lithology and tectonics also have effect on geothermal indicators of the given region. Layers within the productive strata are crushed until considerable depth and broken by tectonic faults. Thus, by increasing depth, geothermal step increases when geothermal gradient decreases. This kind of behavior of parameters can be explained by increase of rock density and decease of clayiness. The section of the Lokbatan field is more clay compared to the deposits of the eastern part of the Absheron Peninsula.

According to collected and processed 90 temperature measurements from 80 production wells, for 320 – 1765 m depth interval temperature changes from 30 to 64°C. Geothermal step changes from 29.8 to 41 m/°C for 500 – 5000 depth interval (Fig. 19), according to 37 measurements conducted in eleven non-active wells.

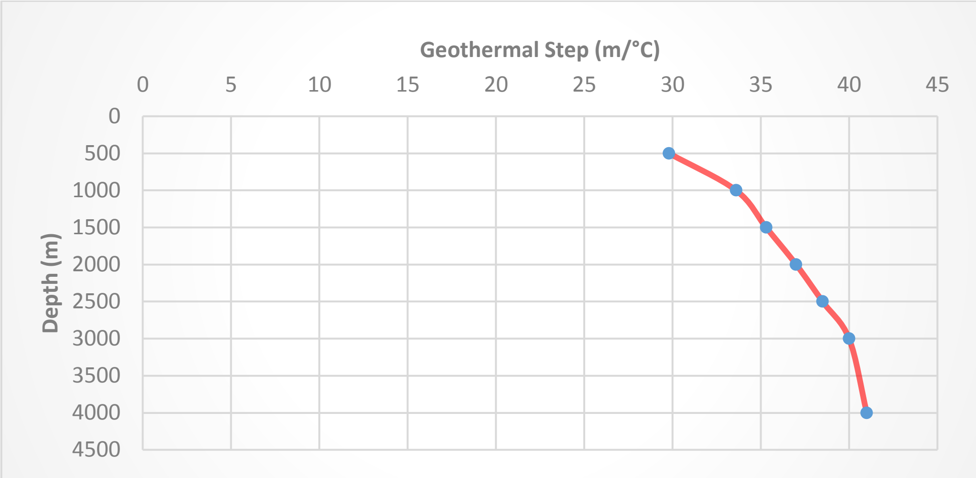

Fig. 19. Change of Geothermal Step in Lokbatan Field

Geothermal energy conditions of Lokbatan field (southwestern Absheron) depend significantly on hydrodynamic regime and high temperature of circulating formation waters, which enter into the layers through fractures from the bowels of the Earth. Thermal waters moving inside high permeable sandy layers warm up intensively surrounding rocks and create high temperature.

6.2 Final Geothermal Indicators of Hovsan Field

In the well №1501, temperature changes from 78 to 89 °C for 2600 – 3600 m depth interval. In the well №1507, temperature changes from 67 to 81 °C for 2600 – 3600 m depth interval. In the well №1816, temperature changes from 66 to 80°C for 2200 – 3200 m depth interval. (Fig. 20, 21, 22). In Absheron peninsula, nearby Hovsan district, with help of wells drilled in oil and gas region, existence of subsurface water with temperature of 100 – 135°C has been determined. Therefore, Hovsan Field can be considered one of the perspective fields as a source of geothermal energy.

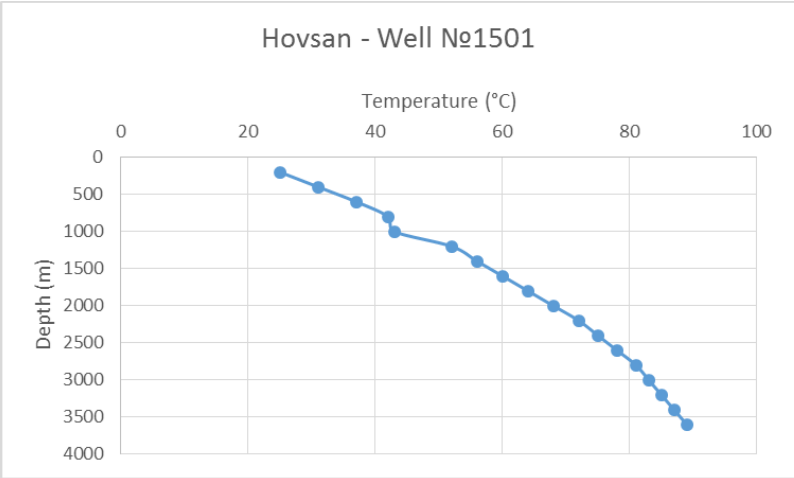

Fig. 20. Temperature change in well N1501 (Hovsan Field)

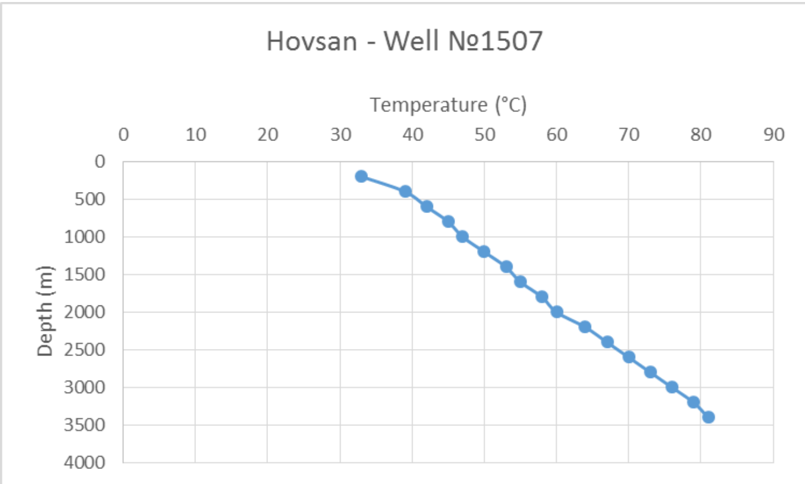

Fig. 21. Temperature change in well N1507 (Hovsan Field)

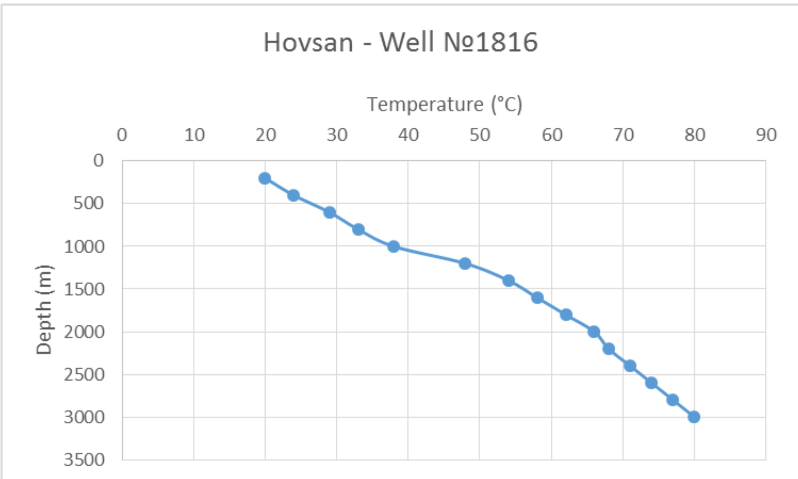

Fig. 22. Temperature change in well N1816 (Hovsan Field)

6.3 Final Geothermal Indicators of Bibi-Eibat Field

According to thirty temperature measurements conducted with help of 30 production wells, it is defined that temperature changes from 34 to 54°C in 500 – 1500 m depth interval. Geothermal step value changes from 27 to 41 m/°C in 500 – 5000 m depth range (Fig. 23).

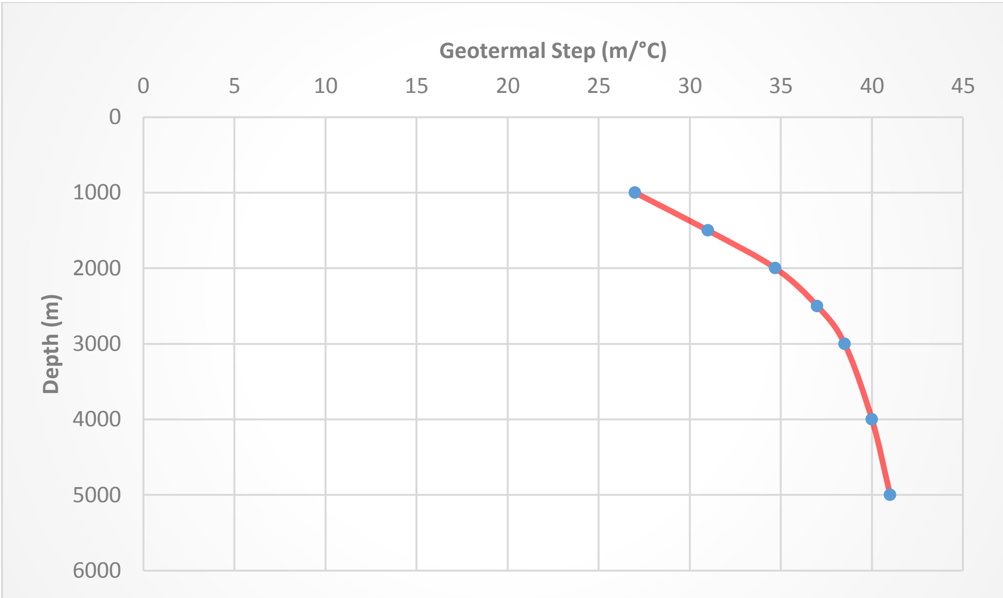

Fig. 23 Change of Geothermal Step in Bibi-Eibat Field

6.4 Final Geothermal Indicators of Gum-Deniz Field

To determine geothermal gradient and geothermal step values temperature measurement data received from 17 production wells is used. It is defined that temperature changes linearly and until 1400 – 1600 m defining with following equation:

$$(3)\ t=14+0.0323z$$

In this interval for each 1000 m, temperature increase is equal to 31°C and geothermal step is about 32 m/°C. From 1400 – 1600 m this pattern is violated, because geothermal gradient and step values change sharply. From 1600 to 3000 m, increase of temperature is observed, however intensity of rise decreases approximately two times obeying linearity. Considering these depths values, temperature growth for every 1000 m is 15°C, geothermal step is equal approximately to 66 m/°C.

To determine temperature from 1500 m in the central II block, where IX and X horizons are complicated by disorders, water flooding and developing intensively with deviated wells the following equation should be used:

$$(4)\ t=60+0.0149z$$

Where z – depth (from 1500 m); 60 – average temperature in 1500 m depth determined with the formula mentioned above.

According to geothermal profiles of wells №178, 154, 189 it can be seen that there is anomaly from 1500 m depth. From this point the second equation (4) given above is applied.

6.5 Final Geothermal Indicators of Balakahny – Sabunchu – Ramana Field

According to the data received from 61 production wells, temperature changes from 35 to 54.5°C for 409 – 1500 m depth interval. Geothermal step value changes from 35 to 45 m/°C for 518 – 1500 depth range.

Balakhany-Sabunchu-Ramana field (Absheron) is at a late stage of development which began more than 150 years ago. Exploitation in this field is carried out under conditions of low formation pressure, the average daily production rate is 0.3 tons, and the water cut of products varies within 80-98%.

One of the important factors impeding the increase in oil production with an increase in PI (productivity index) is the natural intensive increase of water cut of wells, which is characteristic for fields at a late stage of development.

In this case, the increase of water cut of wells practically nullifies the results of activities to affect the bottomhole zone of wells and increase PI. In this regard, the implementation of measures to limit water inflows along with the increase in PI is a very urgent problem for all long-term developing fields.

6.6 Final Geothermal Indicators of Surakhany Field

Totally, in Surakhani field 431 temperature measurements were held in 235 production wells in the depth interval of 608 – 2386 m, where temperature fluctuates from 35 to 78°C. Magnitude of geothermal step for this depth changes from 30 to 70 m/°C.

6.7 Final Geothermal Indicators of Neft Dashlary Field

According to the data from five non-active 35 production wells located in the Neft Dashlary (Oil Rocks) field temperature changes from 39 to 59°C in 457 – 964 m depth interval. Geothermal step value the given depth is about 21 – 22 m°C.

6.8 Conclusion

The territory of Azerbaijan turned out to be rich in thermal waters: sources of thermal water were 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 review work carried out on the proposed and described large quantity of material and data related to geothermal researches demonstrated a considerable variety of geothermal conditions of subsoil in the territory of Azerbaijan. In a number of regions of the Azerbaijan territory, available thermal waters resources can be used for practical purposes as a source of geothermal energy.

In the territory of Azerbaijan, thermal waters extracted from oil and gas wells with temperature from 40 – 45°C to 80 – 90°C and with total production rate 75 – 80 mln. m^3/year can take out about $3*10^9$ MJ of heat per year [16].

As a result of the study about geothermal environment of oil and gas bearing regions in the territory of Azerbaijan, Absheron oil and gas bearing region can be considered as one of the main promising zones with its thermal waters of which can have great practical importance.

In the territory of Absheron peninsula, thermal waters with 20 – 90°C were found to be associated to numerous oil wells in the depth of 300 – 5000 m. For instance, in Bibi-Eibat oil-gas bearing region a well with enough high production rate of thermal water demonstrated a temperature value of 71°C.

Hydrodynamic regime and high temperature of circulating waters penetrating into the layers through numerous fractures have considerable effect on geothermal conditions of southwest Absheron fields. Flowing through high-permeable sandy layers, thermal waters warm up intensively surrounding sediments creating high temperatures. Forecasted thermal water reserves in this region related to aquifers of productive layer constitute about 20000 m^3/d. A certain number of wells in oil-gas fields of this region has been abandoned due to water invasion and is not used for oil production. The presence of industrial facilities in the peninsula makes possible a future usage of available thermal waters as a source of heat for municipal, household and agriculture needs by means of direct use-geothermal technologies.

In addition, the existence of thermal waters with 100 – 135 °C temperature in Hovsan field (Absheron peninsula) was proved with the help of wells drilled for oil and gas. Taking into account that the recorded temperature values of the thermal waters were higher than 120°C, available geothermal resources could be efficiently used for electric power generation through indirect use-geothermal technologies. Zig – Hovsan fields can be considered as a promising region for future geothermal research.

Finally, taking high temperature indicators in the observed data into account, Yevlakh-Agjabedi and Precaspian-Guba region should be researched additionally in terms of defining promising thermal waters.

Long development period of the several hydrocarbon fields located in the territory of Azerbaijan could increase possibility of the existence of a number of abandoned wells, therefore making possible practical exploration and extraction activities of identified geothermal resources. Taking observed above data into consideration, it can be comprehended that extraction of geothermal energy from oil and gas bearing regions in this territory could be a perspective topic for discussions and further researches.

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