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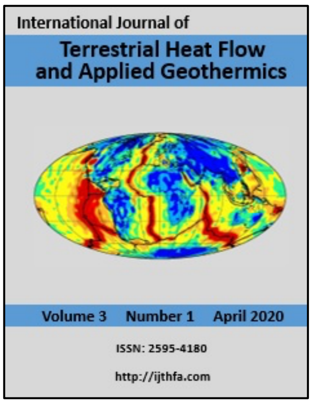


# Temperature Distribution and Heat Flow Density Estimation in Geothermal Areas of Absheron Peninsula

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## Abstract

Geothermal field of the Pliocene complex in the Absheron peninsula, Azerbaijan have been examined on the basis of temperature distributions in over 50 deep wells. Data analysis include variations in geothermal gradient and distribution of heat flow within complexes of Absheron formation of upper Pliocene in age. Geothermal gradients are in the range of 17 to 25ºC/km. The heat flow values are found to fall in the range of 50 to 80mW/m$^2$. Estimates have been made of geothermal energy resources up to depths of 6000 meters. The main productive strata are of middle Pliocene in age. The results have allowed identification of geothermal resources with temperature above the 20°C and at depths less than 110-180 meters. Assessments of in-situ and recoverable resources have been made for 21 sites. Model simulations point to perspectives for widespread utilization of geothermal energy in the Absheron peninsula.

## 1. Introduction

Non-traditional energy resources have several advantages in dealing with ecological problems. An example is the potential use of internal heat energy of Earth, in particular resources associated with geothermal waters. This option has been adopted by several West European countries over the last few decades. In the present work we examine characteristics of geothermal resources of the Absheron Peninsula, in Azerbaijan. This is one of the most perspective regions in the Azerbaijan territory for extracting geothermal energy. There are many unused oil-gas wells in the Absheron peninsula that provide highly advantageous conditions for relatively inexpensive extraction of geothermal energy resources (Aliev and Aliev, 1995; Rustamov, 2001).

In this context it is convenient to note that territory of Azerbaijan forms a constituent parts of the Alpine fold belt which is known to host significant sedimentary deposits. It embraces southwestern parts of the Major and Minor Caucasus, including the intermountain Kur River trough, as well as the Mid- and South Caspian basins. The crustal thickness varies from 38 to 55 km. The maximum is observed in the Minor Caucasus area, while minimum occurs along the Talysh foothills.

The Absheron peninsula is located on the western part of Azerbaijan, jetting into the Caspian Sea. Geological setting of the area consists of sedimentary, volcanic-sedimentary, volcanic and terrestrial deposits embracing almost entire stratigraphic range beginning from Pre-Cambrian through Holocene times (Babayev and Ibrahimova, 2004). 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 Pre-Caspian Guba area numerous wells drilled for oil and gas discovered aquifers with thermal water. The location of oil fields in the Absheron peninsula is indicated in the map of Figure 1.

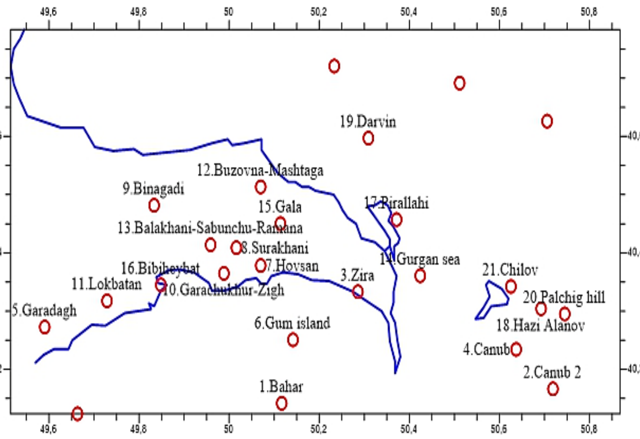

*Figure 1 - Locations of oil fields in the Absheron peninsula, Azerbaijan (number of structures consistent with Table 2).*

## 2. Temperatures of thermal water complexes

Analysis of temperature distribution of the Absheron peninsula is based on the database setup by the geothermic laboratory of the institute of Geology, ANAS. It provides information on location, drilling and mud circulation history of bottom-hole temperature measurements carried out in oil wells. This compilation also provides information on the lithological sequences encountered in the wells as well as geophysical well-logs (Mukhtarov, 2018).

In this peninsular region, sediments of the so-called Productive Strata occur at intermediate depths. The central parts of Productive strata are encountered at 1000 meters depth in the west, while it dips to about 3000 meters depth in the eastern parts. However, much larger thicknesses of about 6000-8000 meters are found along the boundaries of peninsula. The investigations of the present work are confined to depth levels of less than 6000 meters. According to lithological descriptions these sediments are mainly intercalated sequences of sand and clay rich layers. These are characterized by changes in the horizontal and vertical direction. Logs of lithologic sequences in oil wells also mention sand, sandstone, clay, siltstone, gravel, pebble and conglomerate. Conditionally, Productive strata has been divided into about 40 water saturated sediment layers in the different oil-field areas. These strata have considerable influence on oil layers.

Vertical distribution of temperatures measured in deep wells is illustrated in Figure 2. The blue colored diamond symbols in this figure indicate results of temperature measurements. Note that non-linear variations in temperatures of about 20-90°C occur at depths less than 4000 meters. The general temperature log is indicated in this figure by the curve in red color, which is a second-degree polynomial fit to the data set. Such non-linear variations in temperatures are induced by several mechanisms, as for example heat advection by up flow of interstitial fluids. Ascending flows are common in sedimentary strata either under the action of thermal convection or occurrence of overpressure conditions of interstitial fluids.

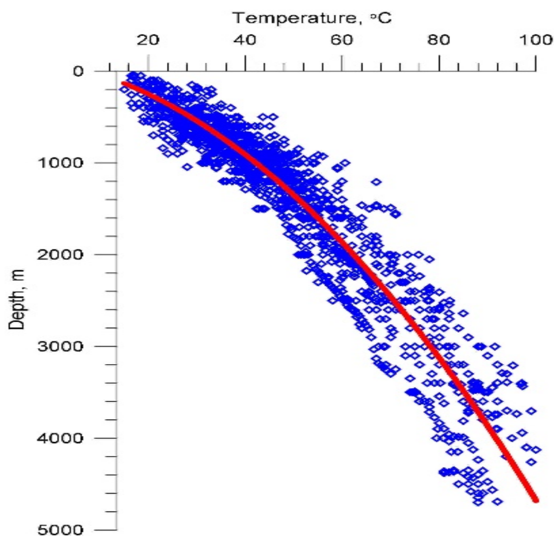

*Figure 2 - Temperature distribution in the thermal water complex of the Absheron peninsula.*

Non-linear variations may also arise as a result of systematic changes in thermal conductivity structure of subsurface layers. For example, systematic depth related changes in high thermal conductivity sand fraction relative to low thermal conductivity clay or silt could lead to curvatures in temperature profiles.

The data from many oil wells reveal temperatures of above 20°C occur at depths greater than 110-180 meters. Temperature of the waters gradually increase to 40°C until the depth level of 1000 meters. In the South and North of the peninsula sediments of Absheron formation submerge beneath the Caspian Sea. In some localities, temperatures reach values of 40-50°C at depths of 1000-1100 meters. At larger depths temperature of the waters reach up to 75°C, at the bottom of Absheron formation.

Sediments of Absheron formation are abundant especially in the Northern part of the peninsula (Alizadeh, 2008). Figure 3 illustrate vertical distribution of temperatures distribution at depths less than 1500m. The temperature (t) variation with depth (h) may be characterized by a linear regression equation of type:

$$t = 0.0247 \cdot h + 7.73 \quad (1)$$

for which correlation coefficient $R^2$ is equal to 0.78. The results have been considered as indicate of a geothermal gradient of 24.7ºC/km and intercept of 17.73ºC, for data at depths less than 1500m.

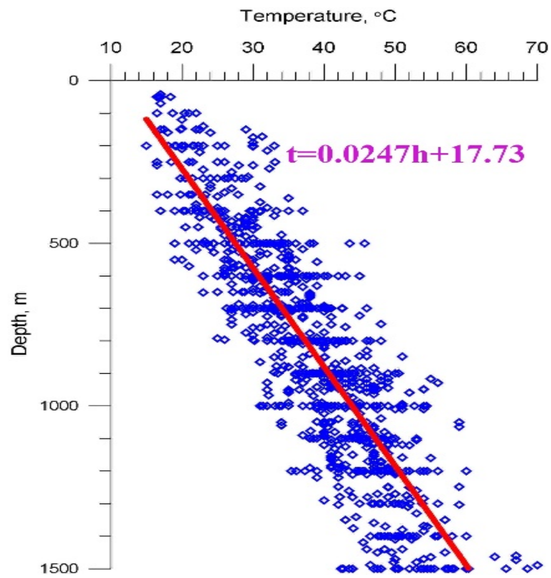

*Figure 3 - Temperature distribution for depths less than 1500 meters in the thermal water complex of the Absheron peninsula.*

Significant groundwater resources with relatively higher temperatures occur also in layers of Productive strata in the South (Qarachuxur, Zigh, Qala oil fields) and on continental shelf in the north (Buzovna-Mashtaga oil field) of the peninsula. Temperatures of these waters are higher than 40°C in many of the wells of these oil fields. Also, overpressure conditions occur in Productive strata. Artesian waters are also found in the South and South-West shore (Shikh) of the Absheron peninsula. Temperature of these waters change between 38 to 68°C and in some places have higher temperatures. Temperature of the waters change between 25 to 50°C in the North and North-East area of the peninsula.

Figure 4 illustrates distribution of temperatures for the depth interval of 1000 to 3500m. In this case the regression equation between temperature and depth for Productive strata is:

$$t = 0.0166 \cdot h + 27.19 \qquad (2)$$

It has been considered as indicative of a lower value for geothermal gradient of 16.6°C/km.

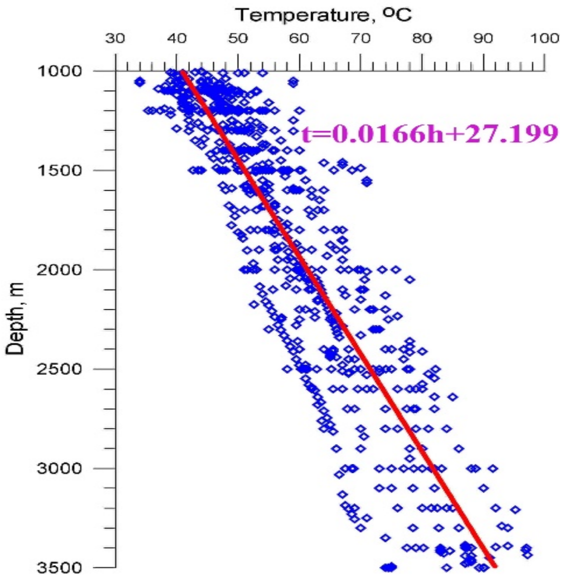


*Figure 4 - Temperature distribution for depths between 1000 to 3500 meters in the thermal water complex of the Absheron peninsula.*

The data sets have also been employed in deriving maps of the distribution of isotherms at the bottom of Productive strata. An example is illustrated in Figure 5. Note that subsurface layers in the central parts of Absheron peninsula are characterized by closely spaced isotherms, relative to those in the northern and southern parts. This is indication of a thermal anomaly along the central parts of the peninsula. In the south-west, near the Bibiheybet structure, the sediments of the Productive strata are closer to the temperature anomaly, compatible with the isohypse of the Productive strata sediments. It clearly seems to hold relations with the structure map of the peninsula (Mukhtarov, 2004). Sub horizontal motion fluid near the arch appears to be the cause of decrease of heat flow along the flanks of the productive strata. Another possible mechanism is the occurrence of mud volcanoes.

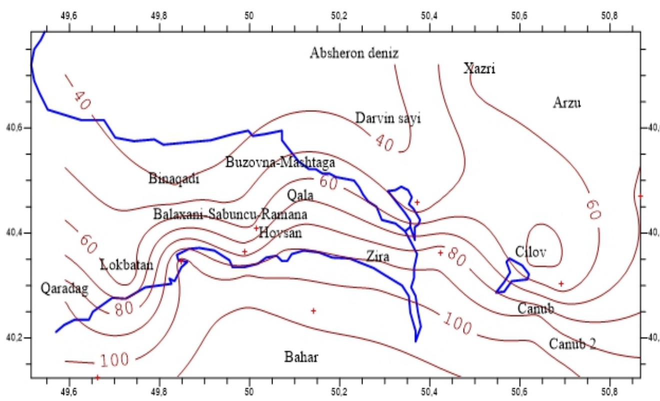


*Figure 5 - Isotherms at the bottom of the Productive Series.*

## 3. Estimation of heat flow density

In this paragraph was calculated heat flow density, as the main parameter that characterizes the heat energy which towards surface from within the earth. Heat flow was calculated as product of geothermal gradient (G) and thermal conductivity (λ):

$$q = \lambda \cdot G \qquad (3)$$

In using equation (3) use was made of the temperature gradient values discussed in the previous section as well as results of thermal conductivity values for the Absheron peninsula. The thermal conductivity values measured by the needle probe for unconsolidated sediments and flat plate lambda sensor for hard sediments. The representative thermal conductivity for lithologic units of the Absheron formation is 2.1 W/m/K. For lithologic units of the productive strata the value adopted is 1.9 W/m/K. The low thermal conductivity value for productive strata is a consequence of the presence of shale rich sedimentary complexes of Pliocene age.

On basis of above explanations, it is possible to determine the heat flow density. Heat flow calculated using representative values of thermal conductivity and temperature gradients discussed in Figures 2 and 3 are listed in Table 1.

*Table 1 - Heat flow values for the Absheron Peninsula.*

| Geologic Unit | G (°C/km) | λ (W/m/K) | q (mW/m²) |
|---|---|---|---|
| Absheron formation | 24.74 | 2.1 | 51 |
| Productive strata | 16.6 | 1.9 | 31 |

As per values in Table 1 heat flow in the Productive strata is less than that in the Absheron formation. In the lower Productive strata lateral fluid migration is believed to be more intense than that in the upper Absheron formation. Hence the difference in heat flow point to lateral transport of heat by fluid flows. The depth to bottom of Productive strata also seems to play an important role. In the south of the Absheron archipelago (in the Baku area) depth to bottom of Productive strata is larger and density of heat flow is relatively smaller. On the other hand, in the north-east part of the Absheron peninsula depth to bottom of Productive strata is shallower and density of heat flow larger.

## 4. Assessment of Geothermal Resources

The energy of thermal waters, which originate from inside of Earth and flow to the surface, may be estimated according to the flow rate. If we express flow rate ϕ as $m_w/t$, the flow of water which has mass $m_w$ could bring as much energy as the product of porosity (P) and heat capacity ($c_w$) of fluid parcel. In such cases, the amount of heat transported (Q) is the product $m_w c_w \Delta T$ or $m_w c_w (T_t - T_0)$, where $T_t$ the temperature of outflowing water at the top of the layer, $T_0$ temperature at the surface. Hence, the amount of heat carried by thermal waters with flow rate *m* per the unit time *t* is:

$$W = \frac{Q}{t} = \mathrm{P}\, c_w (T_t - T_0) \qquad (4)$$

Equation (4) allow us to calculate the thermal power (W) of outflow systems. An estimate of energy strength of the thermal water flows of the Absheron peninsula can be made on the basis of procedure proposed by Tagiyev et al. (2001).

The results indicate prognosis of thermal water flows of 20000 $m^3$/day and outflow temperatures of 25-90°C. Cooling condition of these waters have been considered for rejection temperatures of 25°C. Under these conditions the associated energy output is 504 MW. It reflects perspective of using the energy of the thermal waters in the Absheron peninsula. The energy of the thermal waters is a small part of the geothermal resource base in the subsurface strata. However, its role is important in transportation of underground heat and distribution of heat flow.

Two approaches have been adopted in investigating resources associated with heat conduction of local rock complexes. The first one considers heat content of porous media (Muffler and Cataldi, 1978; Hurter and Haenel, 2002; Zui, 2007) according to which geothermal resources $H_1$ are evaluated using the formula:

$$H_1 = H_0 \cdot R_0 \quad (5)$$

where $H_0$ is the heat content of the rock matrix and Ro the recovery factor. If heat content of water filling the porosities is included and outlet temperatures specified, the resource estimate becomes:

$$H_0 = [(1-P)\rho_m \cdot c_m + P\rho_w c_w] \cdot [T_t - T_0]A\Delta z \quad (6)$$

In equation (6) $\rho_m$, and $\rho_w$ are respectively the densities of rock matrix and water in kg/$m^3$, $c_m$ and $c_w$ the heat capacities of rock matrix and water in units of J/(kg/K), $P$ the effective porosity, $A$ the surface area and $\Delta z$ the effective thickness of water saturated layer. According to considerations of Muffler and Cataldi (1978) and Zui (2007) the heat recovery coefficient ($R_0$) may be defined as:

$$R_0 = \frac{0.33(T_t - T_r)}{(T_t - T_0)} \quad (7)$$

where $Tr$ is the injection temperature. In the present case, the value assigned for $Tr$ is 25°C. It means, that outflowing thermal water is cooled to 25°C. In some cases of single well systems $R_0$ is assigned a value of 0.1 (Yifan et al, 2017).

A summary of the proposed estimates for utilization geothermal resources of the Absheron peninsula is provided in Table 2. The locations of oil fields associated with the geothermal areas listed in column 2 are indicated in Figure 1. In these calculations, values of physical parameters of rock matrix ($\rho_m$, $c_m$) and fluids ($\rho_w$, $c_w$) were selected taking into consideration log data from wells close to the geological structure. The second column of this table provide depth values of inflow ($D_b$) and outflow ($D_t$). The difference between $D_b$ and $D_t$ provide the thickness of the caprock. The corresponding values of inlet and outlet temperatures are provided in column 3. Listed in column 4 of this table are estimated geothermal energy resources of $H_0$ and $H_1$ per unit area productive strata sediments. The value is expressed in units of GJ/$m^2$.

It is clear from the results of Table (2) that Absheron Peninsula is characterized by low enthalpy of geothermal resources. Such conditions favor installation of exploitation systems belonging to $P_1$ category, operating in the 70/20°C scheme for hot water supply and for 90/40°C scheme for heating system. Bahar is the best site indicated for extraction of geothermal resources. However, Janub, Zira, Garadagh and Gum Island are also sites with relatively high values of $H_1$. The heat flow values for depth intervals of the exploitation scheme fall in the interval of 50-60mW/$m^2$. Hence, medium to high enthalpy geothermal systems are expected for larger depths of greater than 5000m.

*Table 2 - Proposed schemes for utilization of geothermal resources in the Absheron peninsula. Db and Dt are depth values for inflow and outflow. H0 and H1 are values of geothermal resource. See figure 1 for locations of main oil fields associated with geothermal resources.*

| № | Field | Dt/Db (m/m) | Tl/Tt (°C) | $H_0$ (GJ/$m^2$) | $H_1$ (GJ /$m^2$) |
|---|---|---|---|---|---|
| 1 | *Bahar* | 1500/ 5700 | 11/50 | 5283 | 1118 |
| 2 | *Janub 2* | 1400/ 4500 | 12/41 | 3314 | 603 |
| 3 | *Zira* | 1400/ 4800 | 16/41 | 2848 | 601 |
| 4 | *Janub* | 1000/ 4200 | 12/43 | 2936 | 563 |
| 5 | *Garadagh* | 100/ 3600 | 16/22 | 911 | 501 |
| 6 | *Gum island* | 600/ 4600 | 12/31 | 3009 | 295 |
| 7 | *Hovsan* | 900/ 3700 | 17/34 | 1554 | 272 |
| 8 | *Surakhanı* | 230/ 1820 | 17/23 | 308 | 186 |
| 9 | *Binagadi* | 20/ 1240 | 17/ 20 | 212 | 186 |
| 10 | *Garachukhur-Zıgh* | 320/ 2290 | 17/31 | 900 | 127 |
| 11 | *Lokbatan* | 20/ 1400 | 16/20 | 181 | 119 |
| 12 | *Buzovna-Mashtagha* | 680/ 2040 | 16/33 | 703 | 109 |
| 13 | *BalakhanıSab unchu-* | 70/ 1270 | 17/20 | 116 | 102 |
| 14 | *Gurgan sea* | 20/ 3200 | 10/14 | 362 | 60 |
| 15 | *Gala* | 380/ 2115 | 16/28 | 612 | 50 |
| 16 | *Bibiheybət* | 340/ 3080 | 17/27 | 849 | 44 |
| 17 | *Pirallahı* | 20/ 800 | 12/16 | 104 | 34 |
| 18 | *Hazi Aslanov* | 50/ 1400 | 10/15 | 139 | 28 |
| 19 | *Darvin* | 20/ 700 | 10/14 | 102 | 17 |
| 20 | *Palchıq hill* | 30/ 1500 | 10/14 | 76 | 11 |
| 21 | *Chilov* | 100/ 1000 | 10/14 | 64 | 11 |

## 5. Perspectives for Utilization of Resources

The term assessment of geothermal resources is often employed in discussions of heat content in the rocks, for which exploitation is possible. Another approach (see for example Dyadkin et al., 1991) is to make use of resource categories classified as perspective (C) and prognosis (P), with numerical subscripts for convenient classification. In the present case, the categories are designated respectively by symbols $C_3$, $P_1$ and

$P_2$. The resources of $C_3$ category are considered as having economic efficiency for appropriation of geothermal energy. $P_1$ category refers to resources with possibility for appropriation of geothermal energy. $P_2$ category indicate possibility to form geothermal energy deposits.

Distribution of $P_1$, $P_2$ and $C_3$ categories of geothermal systems for Shikh thermal area (located on Bibiheybat oil field) is described below. $P_2$ category is based on the primary condition of rock massif cooling till ambient temperature is reached. This resource is evaluated based on the following relation:

$$q_{P_2} = kc_v(H_{pr} - h_{n.l})(T_e - t_{e.t}) \quad (5)$$

In equation (5) the coefficient k has a value of 0.036 GJ (Dyadkin et al, 1991). The value adopted for volumetric heat capacity ($c_v$) of limestone rocks in the Shikh thermal area is 887J/m$^3$/°C. The term $H_{pr}$ (which indicates the depth of prognosis) is assumed to have a value of 1000m, while the term $h_{n.l}$ which refers to the thickness of neutral layer is assumed to have a value of 20m. The values adopted for extraction and environmental temperatures $T_e$ and $t_{e.t}$ are respectively 68°C and 14°C. Calculations indicate that $P_2$ category resources for Shikh thermal area have value of about 0.0169 GJ.

Prognosis resources of $P_1$ category refer to potential heat contents of rock complexes. In estimating resources of this category, the depth boundary is taken as 6km. Temperature regime is determined taking into consideration effects of heat production. Such resources may be considered as falling into three types, namely hot water supply, heating system and production of electrical energy. For hot water supply systems, the top boundary temperature is set to value in the range of 60 to 65°C. The corresponding range for bottom boundary is 5 to15°C (in winter 5°C, in summer 15°C). For hot water supply systems, it is convenient to adopt the scheme of 70/20°C, considering eventual temperature losses in geothermal heat transfer.

For space heating systems the required temperatures are 80 to 90°C because of relatively larger heat loads. In this case, it is possible to consider reinjection temperatures of nearly 35 to 40°C. Thus, the scheme recommended temperature interval is 90/40°C. Even higher temperatures are needed for electric energy production. Exploitation schemes for electrical power require extraction of resources at depths 6km, implying systems with temperature interval of 210/70°C (Dyadkin et al, 1991).

Estimates have been made in the example for Shikh thermal area, where it is convenient to allow for resources of P1 category in the regime of 70/20°. Density of these resources is valued as following:

$$q_{P_1} = kk_e c_v(H_b - H_t)(T_m - t_0) \quad (6)$$

In equation (6) $k$ is the commodity norm of heat debit with value of 45.4 GJ (Dyadkin et al, 1991), $k_e$ the coefficient of extracted geothermal energy with value of 0.125 (Dyadkin et al, 1991), $c_v$ the volumetric heat capacity of rocks, $T_m$ mean extraction temperature, $t_0$ injection temperature (equal to the temperature of neutral layer), $H_b$ bottom boundary of the resource layer and $H_t$ top of the resource layer. Estimates for Shikh thermal area indicated that the value of $P_1$ category resources is 4326 GJ.

Density of perspective geothermal resources $C_3$ is valued as following:

$$q_{C_3} = kc_v \cdot \begin{bmatrix} 0{,}125(H_b - H_0)\cdot \\ \cdot\left(\frac{T(H_b)+T(H_0)}{2} - t_0\right) + \\ +k_e(H_0 - H_t)\cdot \\ \cdot\left(\frac{T(H_0)+T(H_t)}{2}\right) - t_0 \end{bmatrix} \quad (7)$$

Here, $H_0$ is depth of required temperature according to regime of heat production. Considering 70/20°C regime for Shikh thermal area the value of $H_0$ is accepted as 1500 m.

## 6. Conclusion

It is necessary to note that the scheme for assessment of heat content in porous strata, employed in countries of Western Europe, gives opportunities of more exact evaluation of geothermal resources. In the Absheron territory assessments of geothermal energy resources has been realized by this method for 21 structures (table 2, column 6). Results show that this district holds six areas with low enthalpy geothermal energy resources suitable for heating systems and agriculture.

There are different technological perspectives for using this energy of low potential geothermal resources. One of these is heat pumps, usage of which has been developed recently. Modern technologies allow possibility to get high pressure steam from geothermal resources by different heat exchange fluids. Such technologies give opportunity of production of electric energy from low potential geothermal resources. There is potential for applying such technologies for development of geothermal energy in Azerbaijan.

## 7. Acknowledgments

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