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HYDROCHEMICAL AND SEISMIC VARIABILITY OF THERMAL WATERS PARAMETERS IN CONDITION OF THE OPERATION AND MAINTENANCE PHASE OF GEOTHERMAL DEPOSITS IN REPUBLIC DAGHESTAN (RUSSIA)

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ABSTRACT

Perennial variability of chemical components (the mineralization, anions, cautions, acidity and acerbity) is explored in fluids in geothermal deposits of Dagestan in mode of the industrial development. Hydrohemical variability, as well as thermo bar and working thermal waters parameters, were studied by methods of correlation-regression and cluster analysis.
The studied types of hydrochemical variability move into functional dependencies at approximations multinomial 6-ouch degree. Correlation relationship is studied between hydrochemical, thermo bar and working parameter of fluids. The tightness of these correlations depends on variability of thermo bar and working parameter under development of deposits. The taxonomic hierarchy of the resemblance of variability is revealed for hydrochemical parameters. Cluster resemblances form the groups depending on relationship with determined structured element of deposits, depth to roofing's water-bearing stratum of the sort's formation temperature.
Seismic anomaly effects of the order 2-16^{0}C reveal itself in variability of the temperature on mouth of the bore holes. They are connected with series of the strong earthquakes. But analysis of multiple types of hydrochemical parameters variability in under development of geothermal deposits has not found hydrochemical anomalies during series of the strong earthquakes. Probably, increasing of intensities of geothermal fluids selection from bore holes practically completely avoids the manifestations of seismic effects of hydrochemical factors in mode of the industrial development.

INSTRUCTION

Variability of main chemical components of thermal water for the 10-years period (1974-1983) is studied on the material of the geological fund, got in the course of operation and maintenance phase of 50 operation and bore holes on the 4 geothermal deposits of Daghestan: "Makhatchkala", "Ternair", "Izberbash" and "Kizlyar" (Boykov, 2006). This is variability of mineralization, anions (CO^{-2}_3, HCO^{-3}, SO^{2-}_4, CL^-), kations ($Na^+ + K^+$, Ca^{2+} and Mg^{2+}, NH^+_4), acidity (pH), and acerbity of water (Ca^{2+} and Mg^{2+}).
The studied thermal waters were selected Chockrack sediments of Middle Miocene complex of the rocks. Underground water of these sediments belongs to sulphat – chloride – sodium, sulphat – hydrocarbon – chloride – sodium – vapor and chloride – sodium – vapor types). The range of mineralization of thermal water of the working bore holes on the contents of the dry remainder was rather broad: from weak salty to salty water (the dry remainder: 1.0-1.0 g/l). The range of water acerbity: 0.6-19.4 meg/l). The range of water acidity – from strong acid to weak (6.35-8.30 pH).

CHEMICAL COMPOSITION AND CORRELATION RELATIONSHIPS OFGEOTHERMAL FLUIDS

Variability of the temperature and pressure on mouth of the bore holes, working parameters (the average annual consumption and annual volume of of the mining) are also analyzed.
The idea about variability of the chemical composition of thermal water in the process of the industrial development of the geothermal deposits give the data from table 1 on the 4 bore holes of two geothermal deposits. Appreciable changes of thermal water chemical composition characteristics, what follows from table 1, have occurred for 5 years, as to the increase to decrease of the absolute values.
HCO^-_3, Cl^-, SO^{2-}_4, N^+ - mg/l, dry remainder, M – g/l, general hardness – meg/l.

Deposit "Makchatchkala", 1975/1980					
№ well	pH	HCO_3^-	Cl^-	SO_4^{2-}	Na^++K^+
24T	7.8 /7.6	610,0 /683.2	497/ 497	2062 /2046	1547.0 /1518.0
29T	7.95 /8.0	646.6 /640.5	143 /213	718.5 /728.3	661.84 /725.65
№ well	Ca^{2-}	Mg^{2+}	Dry remainder	M, г/л	General hardness
24T	27 /32	9.2 /7.4	4.42 /4.49	4.83 /4.80	2.1 /2.2
29T	10 /12	1.8 /0.6	1.82 /1.94	2.18 /2.34	0.7 /0.7
Deposit "Ternair", 1975/1980					
№ well	Ca^{2-}	Mg^{2+}	Dry remainder	M, г/л	General hardness
6	7.3 /7.5	738.1 /750.3	2031 /1721	1139 /1733	2026 /2135
7	8.0 /7.4	768.6 /786.9	338 /359	1169 /1166	401.4 /1039.4
№ well					
6	56 /38	24.3 /26.1	5.53 /5.98	5.97 /6.40	4.8 /4.1
7	24 /23	13.4 /11.6	2.89 /2.78	3.33 /3.39	-/ 2.1

Table 1. The chemical composition of geothermal fluids in the wells "Makchatchkala" and "Ternair" in 1975 and 1980 years. The conditional indications: M–mineralization. The units of measurement: CO^{2-}_3,

Type of regression	Variability factor of approximation (R^2)						
	pH	Cl^-	SO_4^{2-}	Na^+ +K^+	Ca^{2+}	M	T
Linear	0	0.76	0.77	0.23	0.23	0.87	0.47
Logarithmic	0.01	0.63	0.67	0.11	0.12	0.68	0.35
To some degree	0.01	0.64	0.66	0.09	0.08	0.67	0.35
Exponential	0	0.76	0.76	0.20	0.19	0.86	0.47
Polynomial of 3÷6 degree	1	1	1	1	1	1	0.73

Table 2. The types of approximation of perennial (1974-1983 y.y.) variability of informative parameters of geothermal fluid in the well 36 of the deposit "Makchatchkala" in mode of the operation and maintenance phase. Conditional indications are the same, T – temperature (^0C).

Perennial variability of the chemical composition of underground water in all wells for each of the 4 deposits was approximated with trends by means of the program Microsoft Excel. The separate types of this variability, as it was established can be approximated, with trends of elementary function with significant factors of approximation validity (R^2>0.6). The examples of approximation of perennial variability of chemical composition of geothermal fluid and temperature are given in Table 2. These are trends of linear, logarithmic, to some degree, exponential and polynomial of 3-6 degree.

Variability practically of any chemical component of geothermal fluids at deposit development, with follows from table 2, can be approximated with polynomial trends. These are 6-ouch degree multinomial, having value R^2=1. That is taken the type of functional dependencies. Variability of the chemical composition of fluids is formed in the course of operation and maintenance phase of deposits under action of several factors. But this approximation has a top degree of validity.

The approximation of the temperature on mouth of the well with polynomial trend of 6-degree, as can be seen from table 2, has unlike components of chemical composition although significant but smaller degree of validity (R^2=0.73). This approximation has a status of correlation relationship. The chemical composition of geothermal fluids as thence follows, is more stable to external influence in contrast with the temperature. That is shaping of the fluid temperature is defined in greater degree, the well (consumption and amounts of selection of fluid), structural-geological conditions, of occurrence of water bearing layer and thermodynamic particularity. The method of correlation-regressive analysis, as thence follows can be reasonable to use for formal analysis and understanding of the regularities of the shaping of varied and polyfactor types of variability of the chemical composition of thermal water in mode of the deposit development. The regularities of variability and tight nesses of correlation relationships of mineralization, thermo bare (the temperature and pressure on mouth of the wells), working (the average annual consumption and annual volume of mining) and structural-geological conditions of exploited water bearing layers are studied by correlation-regressive method. The analysis of the tightness of relationships was executed on bass of the

Factor of validity of approximations (R^2) of correlation relation shops with polynomial trends of the 6-th degree. The feature chosen for analysis wells of geothermal deposits and their parameter s are presented in table 3.

The approximation of correlation relationships of perennial variability of mineralization, thermo bar and working parameters of these wells are presented in table 4.

Some general correlations of the tightness of correlation relationships from tables 3-4 with intervals of working parameters and geological conditions for all 4 deposits of different structural types (anticline and monocline) are absent. But such correlations can exist and be rather close fitting within one deposit.

№ n/n	Well: № and deposit	ΔH, m	H_{roof}, m	ΔP, Atm	ΔQ, m^3/day
1	68- Izberbash (under overlap fault)	1200÷ 1242	1200	2.4÷4.5	812÷ 1500
2	150- Izberbash (monocline – overlap fault)	988÷ 992	988	0.8÷1.9	450÷ 600
3	15T- Izberbash (under overlap fault)	1380÷ 1390	1380	1.5÷3.9	480÷ 620
4	18T- Izberbash (under overlap fault)	1378÷ 1352	1352	2.0÷3.9	195÷ 1082
5	20- Ternair (monocline)	1085÷ 1110	1085	1.4÷4.6	600÷ 800
6	9- Ternair (monocline)	1260÷ 1290	1260	0.7÷2.5	100÷ 350
7	175- Makhatchkala (crown)	1200÷ 1390	1200	1.0÷1.8	20÷ 60
8	94- Makhatchkala (crown)	1200÷ 1248	1200	1.3÷3.2	50÷ 200
9	25T- Makhatchkala (limb)	1110÷ 1214	1110	2.4÷6.6	300÷ 700
10	36- Makhatchkala (crown)	1047÷ 1090	1047	1.2÷3.5	350÷ 570
11	3T- Kizlyar (monocline)	2902÷ 2872	2872	2.0÷23.0	850÷ 2100
12	5T- Kizlyar (monocline)	2846÷ 2832	2846	3.0÷23.0	850÷ 2300

Table 4 . The tishtness of correlation relationships of variability parameters of the deposits “Makchatchkala”, “Ternair”, “Izberbash” and “Kizlyar” in mode of the usages. The conditional indications: R^2 – a factor of validity of approximations of correlation relationship by equation of regression, expressed by multinomial of the 6-th degree; T – temperature on mouth of the well, ^0C; P – pressure on mouth, atm; Q – consumption, m^3/day; M – mineralization, g/l.

For instance, the most close-fitting is a sedate regression of the type $Y=0.0851X^{2.862}$ of mineralization and pressure. Here Y – is a value, characterizing degree of tightness of correlation relationship of mineralization and pressure, and X – an interval of pressures on mouth of the wells. The validity factor of approximation for this regression $R^2_{MP\text{-}\Delta P}=0.98$. This regression shows that tightness of correlation relationship of mineralization and pressure on mouth of the wells of the anticline deposit “Isberbash” grows in degree 2.862 with the increase of interval of pressure and consequently, pressure on mouth of the concrete well. However validity factor of approximation reaches the value $R^2MP\sim\Delta P=1$, if we express regression of the same correlation relationship by multinomial from 3-rd to the 6-th degree of the type: $Y=3.1282X^3+17.154X^2-29.346X+15.798$. That is correlative relationship moves over to functional dependence. But evident hydrogeological sense of correlation slips away herewith since dependence of the tightness of correlation relationship of mineralization with pressure from interval of pressures becomes tacit, not evident, expressed by complex graphic image. The similar correlations in practice more reasonable to express through regressions of the type of elementary function. Similarly dependence of the tightness of mineralization correlation and pressure to depth of the roofing of water bearing layer is expressed by regressions of elementary functions (linear, logarithmic, to some degree, exponential). The most close – fitting among them is a sedate regression of the type: $Y=4E\text{-}18X^{5.5172}$. The validity factor of approximation for this regression $R^2_{MP\sim H}=0.98$. Here Y – a value, characterizing degree of tightness of correlation relationship of mineralization and pressure, numerically expressed by value $R^2_{MP\sim H}$, and X – a depth of roofing of water bearing layer. This regression shows the growing in degree 5.5172 tightness of correlation relationship of mineralization and pressure on mouth of the wells of anticline deposit “Izberbash” due to increase of the depths of roofing’s of water bearing layer.

Characteristics of resemblance exist for variability values of these parameters. This is absolutely visual obvious from graphs of perennial variability of hydrochemical parameters of fluids of geothermal deposits which are shown here. The cluster analysis of variability of the main chemical components of thermal waters is made for the reason categorization, revealing of characteristics and consequence of resemblance. These thermal waters were selected from Chockrack sediments according to the data of the 4 deposits of Deghestan, mentioned above, for the 10-years period of usage.

The cluster analysis, geological interpretation of its results and taxonomic categorization, have shown, that variability of the main chemical components of thermal water forms the hierarchical systems of resemblance as within one deposit of determined structural type, so as between structural deposits of alike type (the anticline structures “Makhatchkala” and “Izberbash” or monocline structures “Ternair” and “Kizlyar”). The cluster groups, for instance, of the 1-st level of resemblance hierarchy (well 13T and 18T in the wing part of the structure “Izberbash”, as well as 150 and near grown 67) inside one deposit, but of an anticline type, are formed in deposit, but of an anticline type, are formed in another way, than for monocline “Ternair” and “Kizlyar”. In particular, the specified cluster resemblance groups are attached to the wells, where water inlets are within narrow swing of depths of structural surface of roofing of Middle Miocene complex of racks (100 m – in the first oven and 200 m – in the second). The general depths of occurrence of structural surface of roofing of Middle Miocene complex of rocks increase when turning to wells of the 2-nd level of resemblance hierarchy. The cluster group of the 2-nd level spreads already on the other element of structure. The number of structural elements for this group of clusters enlarges herewith. The hierarchical structures of resemblance are defined by attachment of each well to one or another element of anticline structures (code, wing, or per cline – in the deposits “Makhatchkala”, “Izberbash”) or to intervals of angles of falls (7-9^0) water bearing layers of monocline structures (“Ternair” and “Kizlyar”).

But tightness of correlation relation shops of temperature with hydrochemical parameters (Cl^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+}) are higher for monocline type of geothermal reservoir, than for anticline, except correlation with pH, where regularity of the tightness of relationships is inverse. Variability of the chemical composition of thermal water is group ending on complex combination of the influence of 3 main factors: a) belonging to a structural element of the deposit; b) formation temperatures of water bearing horizons; c) depths of roofing of water bearing complex of rocks of the Middle Miocene. In anticline structural deposit there exists quasi-wave (direct and inverse) displacement of level of hierarchy of cluster groups on wells toward code – wing – monocline background.

The temperatures on mouth of the wells are closest (the differences do not exceed 2-10^{0}C). for the deposits of thermal waters in code of anticline structures. Such fluids in anticline code differ as a rule, by close factors of viscosity (0.38-0.47 cP) and close factors of specific gravity. But these geothermal fluids sharply differ on their hydrogeological parameters – on 1-2 orders, as well as on power of containing water bearing layers – in times and on containing water bearing layers – in 3 times and on depth of occurrence of these layers – up to 320 m . The structural – tectonic conditions in the region are factors of paramount influence upon the temperature of fluids in mode of the operation and maintenance phase of geothermal reservoirs. In scientific press there are very few if any publications about the results of regime observations of variability of temperature and other parameters of geothermal fluids in condition of the industrial development of geothermal deposits in seismic active regions. The possibility of the influence of seismic activation of the depths on complex of parameters (in interrelation: thermo bar, hydrochemical and working) of geothermal fluids in mode of their operation and maintenance phase, probably, is not studied either, though the urgency of such study is obvious.

SEISMOGENOUS VARIABILITY OF GEOTHERMAL FLUIDS

Seismic variability of the temperature on mouth of the wells is fixed on the data of studies of informative parameters of fluids of geothermal deposits of Daghestan only in respect of strong earthquakes on territory of the region. Only strong enough deformations in layers, engulfed by area of the general increasing tension of depths when preparing the strong earthquakes and at the moments of their fulfillment, consequently, as it is installed, influence upon the shaping of warm-up anomaly. This illustrates, for instance, the graph of variability of fluid temperature, selected during 10 years from occurrences of Chockrack water bearing horizon, on mouth of the well 175, located on code of the geothermal deposit “Makhatchkala” (Fig.1). The data about earthquakes of the 13-th class and higher with maximum depth centre h=20 km, happened in the Caucasus since 1973 up to 1983 years, are registered on seismic stations of Daghestan and are presented on the first graph. The location of their epicenters is limited by space with geographical coordinates: 38.93^0-40.0^0 n.w. and 45.1^0-48.1^0 e.l. It spreads comparatively for out the limits of the administrative borders of the Republic of Daghestan. The earthquakes happened on the territory of Daghestan are inflicted on the second graph (Fig.2).

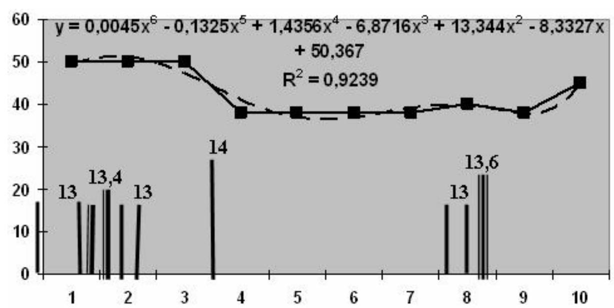

Fig.1: Temperature on mouth of the well 175 “Makhatchkala” in 1974-1983 years (all strong earthquakes in the Caucasus are marked on the graph). Conditional indications: on axis of abscissas – temperature, ^{0}C, on axis of ordinate – calendar years the graph of the unbroken line – variability of temperature the graph of the dotted line – multinomial trend; vertical straight lines with numerals n-class earthquakes.

The comparison of these two graphs graphically shows the warm-up anomaly in time with intensity ΔT=16.1^{0}C in the left part of the graph clearly correlates only with a series of strong earthquakes, happened for five mouths in the Daghestan region. These are: Bezhtinskoe – August 4, 1974 (coordinates: 42.04^0, 45.07^0; class 13, magnitude M=4.7; depth of the centre h=5-10 km; power 6-7

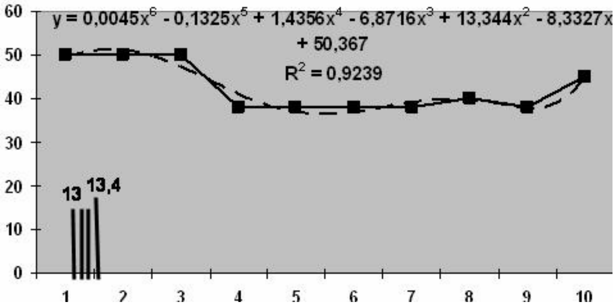

Fig.2: Temperature on mouth of the well 175 "Makhatchkala" in 1974-1983 years (only strong earthquakes in the Daghestan region are marked on the graph). Conditional indications the same.

balls); Kilyatlinskoe – November 3, 1974 (coordinates: 42.80^0, 46.80^0; class 13, M=4.7, h=5-10 km, power 7 balls); Salatauskoe – December 23, 1974 (coordinates: 43.3^0, 46.3^0; class 13, M=4.9; h=13 km, power 7 balls) and Buynakskoe – January 9, 1975 (coordinates: 43.1^0, 47.1^0; class 14.3; M=5.2; h=8 km; power 8 balls). Average annual temperatures on mouth of wells, as it follows from comparison of the graphs, can be informative parameters only in respect of series of earthquakes following one after another for the period of about six mouths.

But single earthquakes even of the 14-th class with magnitude M=5,6 as it was with the earthquake on January 16, 1977 do not reveal themselves.

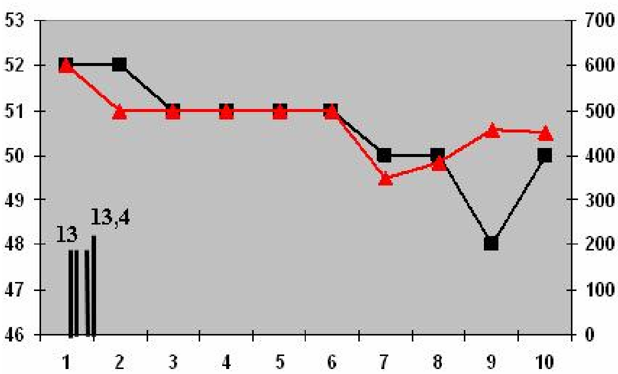

Fig.3: Temperature on mouth and consumption in the well 150 "Izberbash" in 1974-1983 years. Conditional indications: on the left axis of abscissas - temperature, ^0C; on the right axis – consumption; the graph of the unbroken line – variability of temperature; the graph of the dotted line – multinomial trend; vertical straight lines with numerals n-class earthquakes.

attitude to averaged background) $\Delta T=2\text{-}16^0C$ are formed only in those well where water inlet of little

The quantitative dependence is revealed between intensity of the usage of the wells of the wells of the deposit and presence or absence of seismic anomalies of temperature on mouth in wells on the 4 geothermal deposits in Daghestan. Seismic anomalies temperature with intensity (maximum on

intensity of thermal water from wells is realized. The consumption of thermal water in them is measured in tens in the first hundreds of m^3/day.

The absence of significant correlations between the temperature on mouth (Y) and consumption (X) exists in wells where the seismic anomalous effect exists. But a correlation takes place in absence of this effect and at intensity of consumption 350-800 m^3/day. For instance in the well 36 "Makhatchkala" the correlation is approximated by multinomial: $Y=-2E\text{-}11X^6+7E\text{-}08X^5\text{-}7E\text{-}05X^4+0.0441X^3\text{-}14.585X^2+2550.6X\text{-}184410$, where factor of validity of approximation $R^2=0.77\approx 0.8$. This is a correlation of the average tightness of relationship. The correlation of the temperature with consumption gains the nature of nearly functional dependence: $Y=4E\text{-}13X^5\text{-}2E\text{-}09X^4+6E\text{-}06X^3\text{-}0.0074X^2+4.6837X\text{-}1114.7$ with $R^2=0.97$ at intensity of consumption in the interval 800÷1600 m^3/day.

The multiple types of variability of hydrochemical parameters of geothermal fluids on approximately 50 wells of the deposits were considered. But we hydrochemical anomalies on complex of hydrochemical factors, given at the beginning of the this article, to series of the strong earthquakes. The exceptions: 1). Seismic variability of water acidity (pH), that is variability of concentration in water hydrogen ions of functional dependence type; 2) seismic variability of thermal water acerbity (Ca^{2+} and Mg^{2+}), which is also approximated by functional dependence. The intensity of the selection of geothermal fluids from wells in mode of the industrial development, consequently, nearly completely levels any manifestations of seismic effects of hydrochemical factors.

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