

INTERNATIONAL GEOTHERMAL DAYS
SLOVAKIA 2009
CONFERENCE & SUMMER SCHOOL

VIII.2.

DEPENDENCE OF GEOTHERMAL WATER QUALITATIVE PARAMETERS ON THE WELL YIELD IN THE CENTRAL DEPRESSION OF THE DANUBE BASIN

Marián Fendek*, Miroslav Babjak**, Miriam Fendeková*
**Department of Hydrogeology, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia*
***NETAFIM Slovakia, Ltd., Trnava, Slovakia*

SUMMARY

The change in geothermal water exploitation (replacing of the free outflow by increased pumping) could cause changes in geothermal water properties not only in a respective geothermal well, but consequently, in the whole geothermal structure. As an example of such changes, geothermal well VZO-13 Zlatna na Ostrove (Slovakia) located in the central depression of the Danube Basin was chosen. Qualitative properties of geothermal water exploited by free outflow of 7.5 l/s were compared with those, exploited by pumping with the rate of 18.33 l/s. The value of TDS has increased from 2.5 g/l to 13 g/l. The change was accompanied by changes of gas composition and content. The total gas content increased from 274 l/m^3 to 1 117 l/m^3, nitrogen content decreased from 20 l/m^3 to 1.8 l/m^3, CO_2 content increased from 15 l/m^3 to 57 l/m^3 and the methane content increased from 239 l/m^3 to 1 058 l/m^3. The change in gas content resulted in the change of bubble point depth which decreased from 150 m (by the free outflow of 7.5 l/s) to the depth of 250 m below the surface (by the pumping rate of 18.33 l/s). Hydrodynamic calculations also documented that by the long-term abstraction of the 18 l/s, the free outflow will disappear and the piezometric head of geothermal water will decrease to the depth of 85 m below the surface.

1 INTRODUCTION

The central depression of the Danube Basin is enclosed by the Danube River in the southwest between the cities of Bratislava and Komarno, by the Male Karpaty Mountains in the northwest, by the Dobrá Voda fault (a branch of the Ludina fault) in the northeast, and approximately by the Nitra river in the southeast. A crystalline complex (schists, granitoids) has been identified in the pre-Tertiary base of its north-western and south-eastern part. According to the geological development of the Danube Basin it can be assumed that the whole pre-Tertiary base of the central depression is formed by the Carpathian crystalline. Therefore, there are no suitable sources of geothermal water in the pre-Tertiary base [Franko et al., 1995]. The depression is filled with the Quaternary and Rumanian gravels and sands, and mixtures of clays or sandy clays and sands to sandstones (Dacian, Pontian and Panonian). The depression developed between the Panonian and Pliocene ages and is of a brachysynclinal shape, with the deepest part in the area of Gabcikovo where the geothermal

borehole FGGa-1 is situated. The situation of geothermal wells in the central depression of the Danube Basin is shown in Fig.1.

The reservoir of geothermal water is overlain by 1 000 m of surface deposits. It contains laterally and vertically altering aquifers (sands and sandstones) and aquitards (clays and claystones). It is bordered from all sides and bottom by a relatively impermeable base with predominant clays (aquiclude) dipping from all sides into the centre where the reservoir probably lies at a depth of 3400 m (Gab□íkovo area). The main geothermal aquifer is formed by Panonian and Pontian sands and sandstones. In the central part of the depression, geothermal aquifers are also formed by Dacian sands and sandstones. Clays act as an aquiclude [Remšík et al., 1990].

Totally 40 wells were drilled until present in the central depression of the Danube Basin. The well depths range between 306 m and 3 303 m, the yield between 0.1 – 25.0 l/s. The temperature at the wellhead has the value between 19 °C and 91 °C, and the mineralization of geothermal water varies between 0.5 and 18.6 g/l [Fendek et al., 2004].

Based on the works performed in the central depression of the Danube Basin until now, the genesis and spatial distribution of the geothermal waters chemical composition is dependent on the depth, however, with some specifics.

The synclinal structure of the central depress-sion causes that the mineralization (TDS) gradient on the edges of the structure is higher than in the centre, but it always increases with the depth. In contrary, content of the sodium-bicarbonates compounds (A_1), calculated according to classification of Gazda decreases with the depth, together with the value of geochemical factor HCO_3/Cl. The sodium-chloride compound ($S_1(Cl)$) increases with the depth. These regularities are underpinned also by the light oxygen isotope content which values increase with the depth approaching the average value of the oceanic water. Vertical and horizontal zoning of the chemical and isotopic composition of the geothermal water manifests also by gradual desalinization of the sedimen-tary area. It can be stated, that up to the depth of about 1 500 m (at the edge) up to 2 000 m (in the center) are the original waters replaced by meteoric (precipitation) water [Fendek – Bodiš, 1992].

According to gases composition, geothermal waters of the central depression of the Danube Basin are of methane, nitrogen, methane-nitrogen, or methane prevailing type. The highest methane content is typical for waters of sodium-chloride type, the methane content increases with the depth. Carbon dioxide dominates among the acid gases, being bounded to the higher parts of the structure. Methane dominates in the free gaseous phase, carbon dioxide in the dissolved gaseous phase.

Geothermal water parameters as tempera-ture, yield, chemical composition, mineraliza-tion and presence of different gases (usually accompanying geothermal water by free outflow exploitation) do not change very much with the time – they are relatively stable. Parameters stability was proved by hydrodynamic measurements in the central depression. The geothermal water aquifers were tested by long-term (three weeks pumping including one week of the recovery test), half-exploitation (two to three months) and controlling (after one year) hydrodynamic measurements [Fendek et al., 1988].

In the past, geothermal waters in the central depression were used seasonally, mainly in the winter time for greenhouses and glasshouses heating, eventually for heating of administrative buildings of the collective farms. Most of the thermal energy was produced by classical sources (fossil fuels).

Increasing energy prices cause more intense utilization of renewable energy sources, among them also the use of geothermal energy sources. Therefore the free outflow from geothermal wells is often replaced by pumping of geothermal waters using submersible pumps. Geothermal well yield increase could cause changes in geothermal water parameters not only on single wells, but also on geothermal localities and consequently in the whole geothermal structure.

Practical examples of such changes are results documented by exploitation of the

geothermal well VZO-13 Zlatná na Ostrove which is located in the south-eastern part of the central depression of the Danube Basin in Slovakia [Fig.1.].

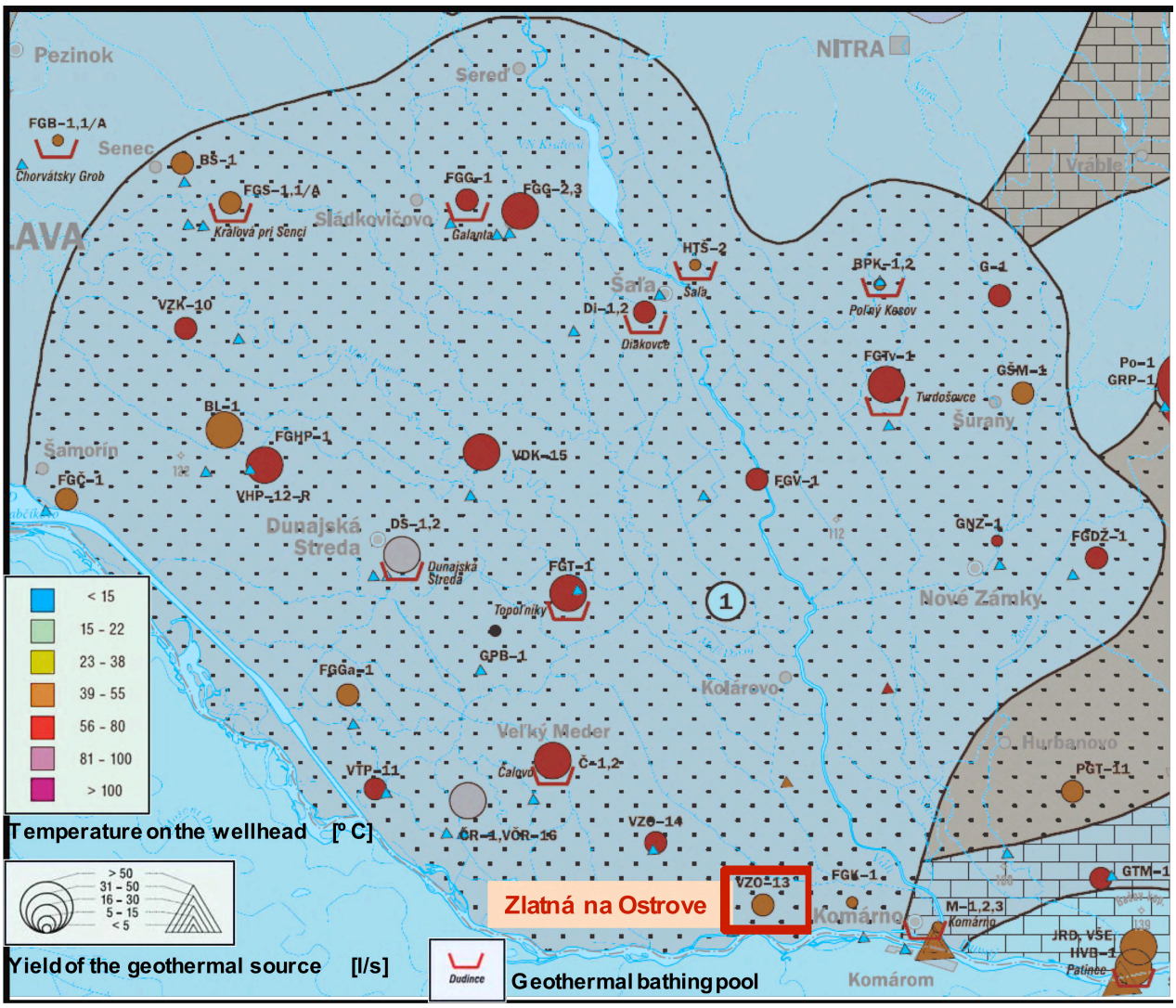

Fig.1. Location of geothermal wells in the central depression of the Danube Basin (Fendek et al. in Landscape Atlas of the Slovak Republic, 2002)

2 LOCATION AND BASIC PARAMETERS OF THE WELL VZO-13

Geothermal well VZO-13 is located in the south-eastern part of the central depression, 1 500 m to the east of the Zlatná na Ostrove village. The well was drilled in 1988 by rotary system up to the depth of 1 780 m and cased to the depth of 1 650 m. It was planned to use the geothermal water the whole year round. Within the heating season, greenhouses and glasshouses should be heated; out of the season, the thermal energy should be used for drying of agricultural products.

The first hydrodynamic measurements were accomplished in the period of 1988 – 1990 and they were summarized in the final report of Dzúrik et al. [1991]. Next measurements were done by VIKUV Rt, Budapest in the period 14.2.2006 – 16.2 2006 and they were summarized in the technical report of Gyurusi [2006]. Results of both series of hydrodynamic measurements were used for elaboration of this contribution.

The drilled perforation of 7“ diameter was installed in the depth interval of 1 090 – 1 625 m. Six sections with the total thickness of 251 m (minimum thickness of 12 m, maximum of 96 m) were cased. Geothermal water aquifers

are built by sandy sediments of Panonian and Pontian ages. The recommended yield was 7.5 l/s of geothermal water of Na-Cl type with the temperature on the wellhead of 51 °C and mineralization of 2.5 g/l [Dzúrik et al., 1991]. Methane, nitrogen and carbon dioxide gases were present.

3. CHANGES IN CHEMICAL COMPOSITION AND MINERALIZATION

Sampling of geothermal water from different sections in the well VZO-13 was performed during the period 1988 – 1990. The increase of mineralization from 2.2 to 13.3 g/l was documented. The total gas content increases from 274 l/m^3 to 1 117 l/m^3, whereby nitrogen content decreased from 20 l/m^3 to 1.8 l/m^3, content of CO_2 increased from 15 l/m^3 to 57 l/m^3 and distinct increase of methane content from 239 l/m^3 to 1 058 l/m^3 was proved. The methane content fits best the total gas content, as it can be seen in Fig.2.

Such vertical changes indicate that the chemical composition, mineralization, total gas content and composition is going to be dependent on distribution of inflows into the well, as it results from Fig.2.

Fig.3. shows the distribution of inflows into the geothermal well VZO-13 estimated by flowmetry measurements. There were also some older temperature gradient measurements done in 1988 – 1990 and 2006. Therefore results of flowmetry in Fig.3. are drawn together with the temperature gradient measured at the well yield of 7.4 l/s in 1990 and at the well yield of 26.16 l/s measured in 2006.

As it can be seen in Fig.3, almost all well yield (about 80 %) came from the inflows from the first well screen section at the depth interval of 1 090 – 1 180 m. Mineralization and gas content are distinctly lower in this section. At the depth of 1 050 m, the mineralization has the value of 2.58 g/l and the gas content the value of 104 l/m^3. No inflows into the VZO-13 well were proved at the well yield of about 8.0 l/s (1988 – 1989) from the last three well screen sections located at the depth intervals of 1 450.2 – 1 462.5 m; 1 474.4 – 1 486.2 m and

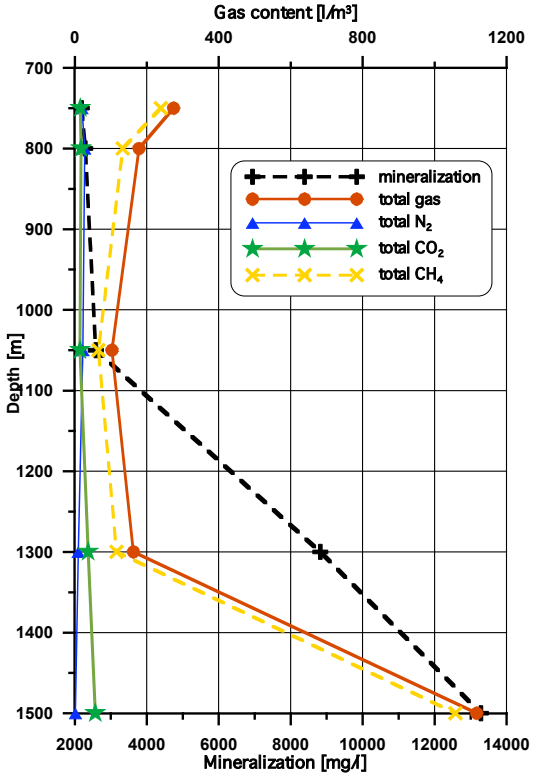

Fig.2. Change in mineralization and gas content with the depth

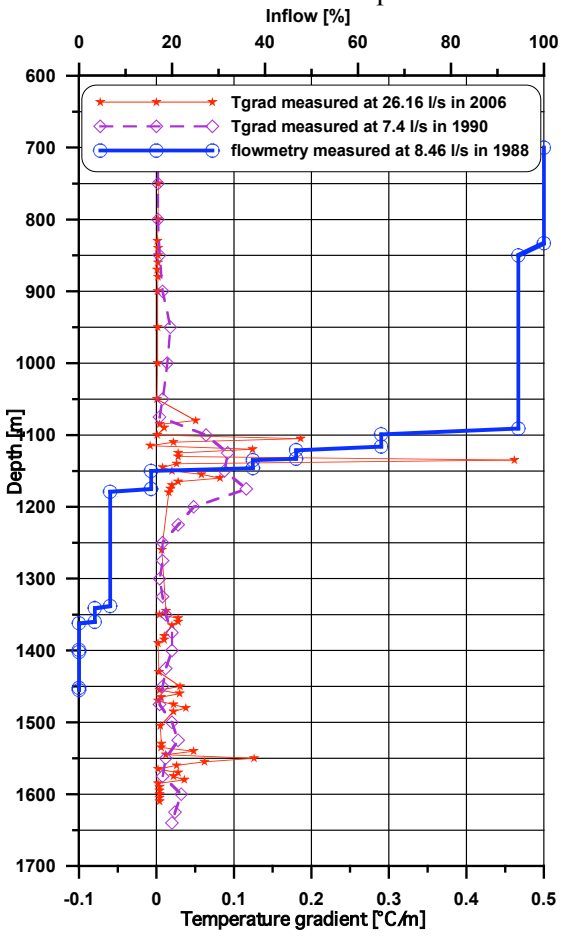

Fig.3. Course of yield and temperature gradient in geothermal well VZO-13

1 529.9 – 1 625.0 m on which geothermal waters with the higher mineralization and gas content are bound. The mineralization at the depth of 1 500 m reaches 13.28 g/l and the gas content has a value of 1 117 l/m^3.

The inflow into the well from the level of 9$^{5/8}$“ diameter casing overlapping with the 7“ diameter casing at the depth interval of 850 – 904 m was also an interesting piece of knowledge. The inflow from behind the 7“ diameter casing made about 4 – 5 % of the total well yield, contributing to lowering of the total mineralization and gas content values. This can be seen also from the temperature gradient values measured from the temperature profile at the well yield of 7.4 l/s in 1990. This makes it possible to inter-connect inflow measurements with the temperature change. It is evident that through the temperature gradient, the inflow changes into the well could be assessed.

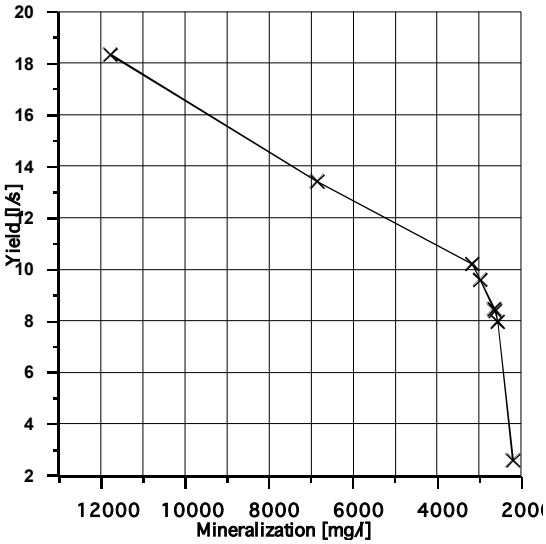

Fig.4. Relationship of mineralization and the well yield

No flowmetry was done during the series of measurements performed in the well VZO-13 in 2006; however, the temperature profile was measured at the well yield of 26.16 l/s. The temperature gradient at this yield has a different course as it used to have at the well yield of 7.4 l/s (Fig.3.). The main difference consists in indication of the inflow to the well from the depth of about 1 550 m, e.g. from the lowest well screen section (1 529.9 – 1 610 m). This was proved also by higher mineralization (11.7 g/l) estimated for geothermal water sample taken at the well yield of 18.33 l/s. The mineralization change together with the change in well yield is showed in Fig.4.

Fig.4. shows that the distinct decrease in mineralization starts with the yield value of about 10 l/s. The mineralization values between 2 – 3 g/l could be expected with the yield values being below 10.0 l/s.

On contrary, the values of mineralization from 3.0 g/l to 13.0 g/l and more could be expected in the well VZO-13 by the well yield higher than 10.0 l/s. The chemical composition and chemical type of geothermal water in the well shall change with the mineralization value, too. Tab.1. shows the change in chemical type at different yield values. Chemical type of water classified as Na-Cl basic, not distinct, was estimated at the lowest yield of 2.6 l/s (mineralization of 2.19 g/l). At the yield of 7.9 l/s and higher (mineralization values 2.56 g/l and more) the chemical type of water was classified as Na-Cl basic, distinct type.

The content of sodium-bicarbonate compound (A_1) decreases with higher mineralization of geothermal waters, the same is valid for the geochemical factor HCO_3/Cl. The content of sodium-chloride compound (S_1(Cl)) increases. The value of the genetic coefficient HCO_3/Cl could be used for classification of a geothermal structure. The value of the coefficient HCO_3/Cl at the well yields from 2.6 l/s to 10.2 l/s (Tab.1.) characterize a semi-closed geothermal structure, values estimated for the well yield of 13.4 l/s and more are typical for the closed structure of geothermal water from which the inflow into the well is realized.

Changes in mineralization and chemical type of geothermal water could influence the technology of geothermal waters utilization and liquidation, because their chemical-technological properties changes with the mineralization change. Technological testing in 1990 proved corrosion velocity of 0.109 – 0.059 mm/year [Dzúrik et al., 1991].

Tab.1. Chemical composition of geothermal water in the well VZO-13 at various yields

Sampling date	Yield [l/s]	Mineralization [g/l]	S_1(Cl) compound	A_1 compound	HCO_3/Cl coefficient
15.02.2005	18.3	11.77	92.33	0.00	0.03
27.10.1989	13.4	6.85	84.81	0.41	0.09
07.11.1989	10.2	3.17	75.18	17.44	0.33
05.01.1990	9.6	2.98	72.15	21.28	0.38
04.12.1989	8.4	2.64	68.71	24.30	0.45
19.12.1989	7.9	2.56	68.50	24.49	0.46
15.01.1990	2.6	2.19	63.24	30.25	0.58

4 CHANGE IN GAS CONTENT

Hydrogeothermal conditions in Slovakia (depth of geothermal aquifers, pressure, reservoir temperature, composition and content of gases) cause one-phase groundwater flow in reservoir conditions. This could change during exploitation of geothermal waters by wells.

There is a distinct change in pressure conditions during the upwards flow of geothermal waters from the reservoir towards the wellhead and part of the dissolved gas changes into a free phase. The change can be seen on the course of the gradient of dynamic values of the hydrostatic pressure [Fendek, 1993].

Increase of dynamic values of the hydrostatic pressure depends first of all on the depth interval and the measured values have a straight-line course in the case of a homogeneous liquid. When the measurement errors could be excluded, the deviation from the straight-line course could be caused by inhomogeneity occurrence, resulting from the change of liquid specific weight along the vertical profile of a well [Fendek, 1992]. Gradient of hydrostatic pressure, calculated from the data on vertical change in dynamic values of the hydrostatic pressure, was used in the first step for inhomogeneity identification. Gradient values were measured at the yields of 8.07 l/s (in 1989) and 18.33 l/s (in 2006) in the well VZO-13 (Fig.5.).

As it can be seen in Fig.5., values measured in 1989 at the yield of 8.07 l/s do not show any principal deviation and vary in the interval 9.5 – 10.0 kPa/m. The course of values measured in 2006 at the yield of 18.33 is different. At the depth from 175 m to 800 m the gradient of dynamic values of the hydrostatic pressure changes in the same interval of 9 – 10 kPa, but upwards from the depth of 175 m the course changes principally. The gradient values regularly diminish, what is evidence on decrease of the specific weight of geothermal water due to free gas content. Free gas loosing is accompanied by bubbles origination.

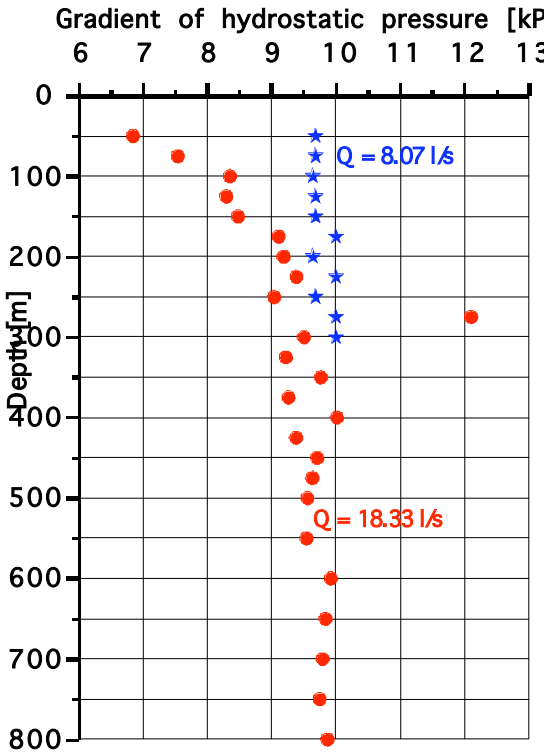

Fig.5. Course of the gradient of hydrostatic pressure hydrodynamic values in the geothermal well VZO-13 at different yields

Dynamic values of hydrostatic pressure could be used for estimation of the bubble point by analysis of residuals of a regression relation [Fendeková – Fendek, 1993]. Utilization of this method removes uncertainty of bubble point estimation which is typical for some other methods often used for this purpose. Residuals of dynamic values of hydrostatic pressure plotted against the depth are showed in Fig.6.

The same measured values as those showed

in Fig.5. were used. Values of residuals in Fig.6. (left and right) decrease in the beginning and reach the minimum (turning point) in the bubble point depth.

Bubble point estimated using residuals analysis method was estimated at the depth of 150 m for the yield of 8.07 l/s (measurements from 1989, Fig.6. left.) and at the depth of 250 m for the yield of 18.33 l/s (measurements from 2006, Fig.6. right). Residual values start to grow from the depth of 150 m, and 250 m respectively.

Taking into account changes in mineralization and gas content (Fig.2.), different values of the bubble points at different yields (Fig.6.) offer the possibility to make another conclusion on increase of gas content in geothermal water. The increase in gas content results in the decrease of bubble point to larger depths at higher yields.

The influence of gas composition and content on the bubble point is showed in Tab.2. The calculation was based on existing results of gas analyses for the well yield of 18.33 l/s (samples 1 – 4) and for the well yield of 8.5 l/s (sample 5 in Tab.2.). Labeling p_{ri} is used for the real instantaneous static value of the pressure on wellhead.

Calculated values of the bubble point depths, depending on the gas content (0.274 – 0.662 m^3/m^3) and gas composition given in Tab.2., vary in the range of 110 – 336 m. The bubble point depth of 110 m for the well yield of 8.5 l/s is in a good accordance with the value estimated using residuals analysis method (150 m, Fig.6.) and similarly, the depth of 235 m for the well yield of 18.33 l/s (250 m, Fig.7.). Results confirmed the assumption of the bubble point decrease towards the larger depths with the increasing gas content.

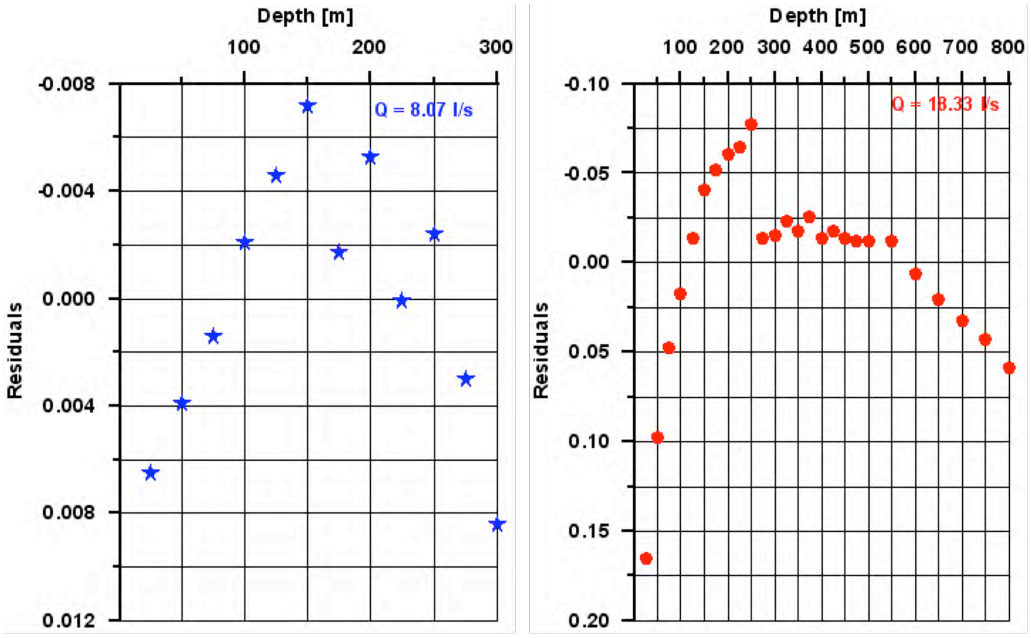

Fig.6. Course of residuals for geothermal well VZO-13 at the yield of 8.07 l/s (left) and 18.33 l/s (right)

Tab.2. Change in the bubble point depth depending on gas content and composition

Gas sample	Sampling date	Yield [l/s]	Pressure at the wellhead [MPa]	Gas content [m^3/m^3]				Bubble point [m]	P_{ri} [MPa]
				N_2	CH_4	CO_2	total		
1	15.02.2005	18,33	0,014	0,005	0,323	0,035	0,363	167	0,244
2	23.01.1990	18,33	0,014	0,020	0,415	0,019	0,454	235	0,298
3	22.01.1990	18,33	0,014	0,016	0,605	0,041	0,662	336	0,400
4	22.01.1990	18,33	1,000	0,016	0,605	0,041	0,662	210	-0,833
5	23.01.1990	8,5	0,050	0,020	0,239	0,015	0,274	110	0,189

The pressure at the wellhead (sample 4) for the total gas content of 0.662 m^3/m^3 has been increased to increase the counter-pressure, to be able to see its effect on the bubble point depth. The bubble point depth changed from the value of 336 m at the pressure of 0.014 MPa at the wellhead on 210 m at the pressure of 1.0 MPa, and, at the same time, the negative value of the real instantaneous static value of the pressure at the wellhead was reached [Fendek, 1989].

When comparing the real instantaneous static value of the pressure at the wellhead (p_{ri}) of the geothermal well VZO-13 (from -0,833 up to +0,400 MPa, Tab.2.) with the depression (p_m) measured at the depth of 1 050 m during the free outflow test at the yield of 8 – 26 l/s (0.249 – 0.555 MPa), the disproportion between measured depression and calculated depressions is visible. Calculated values of the real instantaneous static values of the pressure at the wellhead in the first two cases – sample 1 and 2 (0.244 and 0.298 MPa) are in a very good accordance with the depression value measured at the yield of 8 l/s (0.249 MPa). In the third case (sample 3) its value (0.4 MPa) approaches the values measured at the yield of 26.16 l/s (0.555 MPa), but the difference is still considerable. The difference could be caused either by a wrong depression measurement or by the low gas content. The negative value of the real instantaneous static value of the pressure at the wellhead (sample 4) is the result of the decrease of water level below the wellhead expressed in pressure units. It means that by long-term pumping of the excessive amount of geothermal water (18.33 l/s) the water level in the well VZO-13 shall vary around the level of 85 m below the surface.

5 GASLIFT AND THERMOLIFT CHANGES

Change in gas amount caused by the change in the well yield manifests consequently by changes in measure of influence of the free gas content and water temperature on the measured depression in the geothermal well.

Calculation results of the influence of free gas content (gaslift) and temperature (thermo-lift) on the measured depression value are given in Tab.3. It shows that the highest values of the gaslift (0.271 MPa) were calculated for

maximum values of the free gas content of 0.662 m^3/m^3 (gas sample No. 4, Tab.2.). The ratio of the gaslift on the measured depression is 21 – 50 %. Low influence of gaslift – only 5 % (sample No. 4, Tab.3.), shows the sup-pressing of the free gas influence by increasing the pressure at the wellhead.

Table.3. Comparison of gaslift and thermolift values with the measured depression p_m for various yields

Gas sample	Date	Yield [l/s]	Depression p_m [MPa]	Gaslift		Thermolift	
				[MPa]	[%] from p_{mer}	[MPa]	[%] from p_{mer}
1	15.02.2005	18.33	0.555	0.116	20.9	0.105	18.9
2	23.01.1990	18.33	0.555	0.170	30.6	0.106	19.1
3	22.01.1990	18.33	0.555	0.271	48.8	0.108	19.4
4	22.01.1990	18.33	0.555	0.028	5.0	0.105	18.9
5	23.01.1990	8.50	0.249	0.053	21.2	0.133	53.4

Thermolift according to stable temperature conditions in the well at the constant yield has an almost constant value of about 0.105 MPa, which makes about 19 % from the total measured depression. The thermolift value at lower yield of 8.5 l/s reaches up to 53.4 %.

Based on the total influence of the gaslift and thermolift it can be conclude that from the point of view of a long-term exploitation, the well yield of the geothermal well VZO-13 at the rate of 18 l/s cannot be secured by the free outflow.

6 CONCLUSION

Excessive increase of the abstraction of geothermal water amounts from wells situated in the central depression of the Danube Basin could cause the unwished changes in qualitative parameters of geothermal waters. They could manifest by changes in the value of mineralization because of changes in cation and anion composition of geothermal water. The reason could be in increased inflows from the lower sections of well screens, reaching the horizons with original waters of marinogene mineralization, typical for closed geothermal water structures. At the same time, changes in gas composition and content occur in both – dissolved and free gas contents consequently leading to change of the bubble point depth.

Increase of well yield in geothermal well VZO-13 Zlatná na Ostrove from the value about 8 l/s to 18.33 l/s caused the increase of mineralization from 2 – 3 g/l to more than 13 g/l with the change of chemical composition and type of geothermal water. The changes were accompanied by the change in gas content and composition. Nitrogen gas content decreased importantly, the multiple increasing in carbon dioxide and mainly in the methane content was proved. Consequently, the bubble point depth decreased in 100 meters.

All mentioned changes in qualitative parameters of geothermal water consequently could cause the need of technology changes by their utilization. Changes can also be connected to higher economic pretention of use and liquidation of geothermal waters.

REFERENCES

Dzúrik, Ján, Bondarenková, Zdena, Michali□, Ján, Roháčiková, Anna, Fendek, Marián, 1991: Vyhľadávací prieskum termálnych vôd medzi centrálnou časťou Podunajskej nížiny a Komárňanskou kryhou – JV časť (Zlatná na Ostrove – Ontopa a Zemianska Olča) [Inves-tigation of thermal waters between the central part of the Danube lowland and Komárno block]. Final report. Manuskript – archive of Geofond, ŠGÚDŠ, Bratislava, 95 p. (in Slovak)

Fendek, Marián, 1989: Okamžitá statická hodnota tlaku na ústí vrtu GRP-1 [Instantaneous static value of the pressure at the wellhead of GRP-1 well]. Správy o výskumoch Geologického ústavu Dionýza Štúra, Regionálna geológia Západných Karpát, Vol. 25, Geologický ústav Dionýza Štúra, Bratislava, pp 269-272. (in Slovak)

Fendek, Marián, 1992: Vyjadrujú hodnoty tlakového gradientu tlakové anomálie? [Do the values of the pressure gradient express pressure anomalies?] Zemný plyn a nafta, Moravské naftové doly, Hodonín, Vol. 37 (1992), No. 1, pp 31-42. (in Slovak)

Fendek, Marián, 1993: Metódy výskumu a prieskumu geotermálnych zdrojov Slovenska [Methods of research and investigation of geothermal resources of Slovakia]. PhD. thesis. Archive of the Dept. of Hydrogeology, PRIF UK, Bratislava, 125 p. (in Slovak)

Fendek, Marián, Bodiš, Dušan, 1992: Možnosti reinjektáže geotermálnych vôd v centrálnej depresii podunajskej panvy. [Possibilities of reinjection of geothermal waters in the central depression of the Danube Basin]. Regionálna geológia Západných Karpát, séria Hydrogeológia a inž. geológia, Vol. 10, GÚDŠ, Bratislava, pp 131-157, ISSN 0139-7583. (in Slovak with English resume)

Fendek, Marián, Franko, Ondrej, Remšík, Anton, 1988: Členenie nádrže geotermálnych vôd a hodnotenie hydrogeologických údajov v centrálnej depresii podunajskej panvy z hľadiska ich výskytu. [Spatial division of the geothermal water reservoir and evaluation of hydrogeological data in the central depression of the Danube Basin from the point of their occurrence. In: Conference proceedings: 9. celostátní hydrogeologická konference, Pardubice, 1988, pp 8-18. (in Slovak)

Fendek, Marián, Remšík, Anton, Fendeková, Miriam, 2004: Aktuálny stav preskúmanosti geotermálnych vôd na Slovensku. [Actual state of exploration of geothermal waters in Slovakia]. Geologické práce, Správy 110, ŠGÚDŠ Bratislava, pp 43-53.

Fendeková, Miriam, Fendek, Marián, 1993: Využitie analýzy rezíduí pri riešení hydrogeologických úloh. [Utilization of analysis of residuals by the solution of hydrogeological problems]. Geologický průzkum, Vol. 35, No. 7-8, NIS, Praha, pp 202-206. (in Slovak)

Franko, Ondrej, Remšík, Anton, Fendek, Marián, Eds., 1995. Atlas of Geothermal Energy of Slovakia. Dionýz Štúr Institute of Geology, Bratislava, 267 p. (in Slovak)

Gyurusi, Csaba, 2006: Zlatná na Ostrove, vrt VZO-13 – hydrodynamické merania. [Zlatná na Ostrove, well VZO-13 – hydrodynamic measurements]. Technical report. Manuskript – archive of NETAFIM Slovakia, Ltd., Trnava, 27 p. (in Slovak)

Landscape Atlas of the Slovak Republic. 1 st edition. Bratislava: Ministry of Environment of the Slovak Republic; Banská Bystrica: Slovak Environmental Agency, 2002, 344 p.

Remšík, Anton, Franko, Ondrej, Fendek, Marián, Bodiš, Dušan, 1990. Geothermal waters of the Danube Basin and Vienna Basin. Mineralia Slovaca, Vol. 22 (3), Alfa, Bratislava, pp. 241-250 (in Slovak with English resume)