SIMULATION AID TO THE SUSTAINABLE USE OF GEOTHERMAL PRODUCTION WELLS

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Abstract - **This paper presents results from a research project aimed at the study of the chemical characterization of waters from production geothermal wells. Two low-temperature geothermal wells were selected for this study. Damage of the equipment used for the production and distribution systems has occurred for these production wells. The purpose of this work was to study the relationship between the chemical composition, the temperature and the types of scales which can appear when different geothermal waters are used for heating. Firstly, the chemical composition of geothermal waters was determined in order to classify them. Based on chemical analyses of these waters, geothermometry was used for the determination of subsurface temperatures by assuming equilibrium between specific minerals and the geothermal fluids at depth. The silica-enthalpy mixing model was applied in order to calculate the temperature of the hot water component in the reservoirs. An interpretation of geothermal water compositions has been performed using a speciation program that allows evaluation of how changes in the temperature of geothermal waters affect mineral saturation and scaling tendencies. The structures of the solid deposits formed during utilization were analysed. The results were compared to those obtained by the simulation program.**

Keywords: mixing model, geothermometry, scaling evaluation

1. INTRODUCTION

Geothermal is energy available as heat emitted from within the earth, usually in the form of hot water. As a recoverable energy resource, geothermal one is very site specific. The geothermal industry worldwide grew rapidly in the later half of the last century. As competition grows and as the drive to improve reliability and performance with fewer resources continues, new maintenance techniques and technologies will be ever more important. As an integral part of any reservoir exploitation, a monitoring system must be set up, the main purpose being to provide information on the fluid produced and to allow long term monitoring of the physical and chemical changes that occur. Interpretation of this data and reservoir modeling is necessary for understanding the reservoir behaviour. The proper utilization of heat from the produced geothermal fluid is possible if scaling can be prevented for all temperatures.

In Romania, the main exploited area is located in the western part of the country. In this paper emphasis was placed on geothermal fields of Oradea and Felix. In the Felix Spa resort there are natural hot springs with temperatures between 35° and 50ºC. These waters have special therapeutic properties and have been used in treating degenerative and inflammatory rheumatism. Geothermal water from Felix, well 4003, was taken for study. The Oradea aquifer is exploited by 12 wells with wellhead temperatures of 70-105ºC [1]. Well 4797 from Nufărul is one of the production wells which supplies the space heating for several blocks of flats in Oradea town. In order to maintain the pressure in the reservoir, the waste geothermal water is reinjected into well 4081.

2. PHYSICAL-CHEMISTRY ANALYSIS OF FLUIDS AND SCALES

Geothermal waters from two low-temperature geothermal wells: Felix-4003 and Nufărul-4797 were sampled and preserved according to their particular conditions [2], [3]. The chemical analyses were performed by analytical methods [1], [3-6]. The pH was electrometric determined. The carbon dioxide was analysed by the use of a titrator 716 DMS Titrino. The silica content was spectrophotometric determined, the absorption being read at 410 nm. Boron content was also spectrophotometric determined, the absorption being read at 420 nm. Sodium potassium, calcium and magnesium were analysed by atomic absorption spectroscopy by direct aspiration. Absorptions were read at 589.6nm, 766.5 nm, 422.7 nm respectively at 285.2 nm at a Perkin Elmer 1100 B AAS. Aluminium and iron were detected by atomic absorption spectroscopy with graphite furnace. For aluminium, samples were dried 30s at 125ºC, ashed 30s at 1500ºC, atomized 3s at 2400ºC; for iron the samples were dried 30s at 140ºC, ashed 30s at 1200ºC, atomized 3s at 2100ºC. Purge gas was Ar. Absorptions were read at 309.3 nm, respectively at 248.3 nm. The fluoride content was determided by potentiometric analysis with selective electrode and the chloride and suphates anions were chromatographic determined at a Dionex DX-500 ion cromatograph. The total dissolved solids were gravimetric determined.

The solid deposition samples were ground using a mortar and pestle, and transferred to an aluminium sample holder with glass backing. The samples were identified using a Philips PW1710 Diffractometer. The raw data from the solid samples were handled using EVA software from Bruker AXS.

3. RESULTS AND DISCUSSIONS

Classification of the studied geothermal waters was established based on their chemical composition. The results of the analyses are summarized in table 1.

The ionic balances for the samples calculated using the WATCH program [7] gave values acceptable for equilibrium calculations; therefore the data could be used for interpretation. As seen from table 1, the mineralisation of the water from Felix is very low and the chloride content is low for both Romanian wells. The carbonate content of water from well-4003 is high. The highest anion concentration is recorded at well 4797 for sulphates. The geothermal water from well-4003 can be classified as calcium-bicarbonated water and that from well-4797 as a calcium-sodium-sulphated type.

Table 1 - Chemical composition of geothermal waters, in mg/l

Component	well 4003	well 4797
pH	7.8	7.5
CO_2	275	172
BO_2^-	1.6	0.03
SiO_2	28.2	49
Na^+	31	296
K^+	3.2	24.2
Mg^{2+}	24.3	51
Ca^{2+}	134	320
F^-	0.4	1.1
Cl^-	9.3	8.1
SO_4^{2-}	117	1207
Al^{3+}	0.001	0.006
Fe^{3+}	0.015	0.092
TDS	522	2170

The calculation of geothermal reservoir temperatures with the aid of chemical geothermometers involves various assumptions.

Chemical geothermometry, when applied to specific sites, can be expected to reveal the temperature of the aquifer feeding the respective well. One of the basic assumptions is that a temperature-dependent equilibrium is attained in the geothermal reservoir between specific solutes and minerals. It is further assumed that the respective solutes are not affected by chemical reactions in the upflow where the cooling occurs. Several geothermometers have been developed to estimate reservoir temperatures in geothermal systems. The results of the chemical analyses obtained in this study (table 1) were used to calculate temperatures based on these geothermometers using the WATCH aqueous speciation program. The results of the geothermometry calculations [7] are shown in table 2.
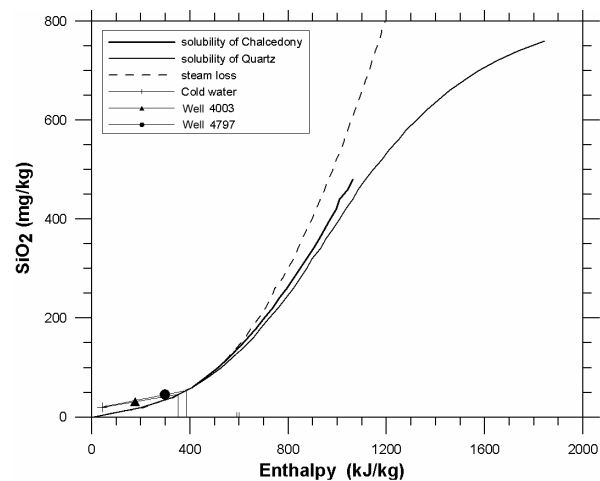
The temperatures of the reservoirs indicated by the calculated chalcedony geothermometer are close to the production temperatures of the waters.

Table 2 - Geothermometry calculations

Well	Wellhead temperatures, ºC	Chemical geothermometers, ºC		
		Quartz	Chalcedony	Na/K
4003	42	80.6	48.8	222
4797	71	97.7	67	172.5

The silica-enthalpy mixing model [8] was used in order to estimate the reservoir temperature. Because the cold ground water was not sampled and analysed, the cold water point was assumed to represent the hypothetical cold ground water (temperature: 10ºC and SiO_2: 20ppm) in the study area. The intersection point of the "cold water - geothermal water" line with the solubility of chalcedony curve gives the silica content and the enthalpy of the deep hot water component, and its temperature is obtained from the steam tables [9].

Based on this model, a temperature of 85ºC is obtained for the deep geothermal water from well-4003 and 93ºC for the hot geothermal water from well-4797 (figure 3). The temperatures obtained using this method are significantly higher than both those calculated from the chalcedony geothermometer and those measured at the wellhead. These differences of temperature are due to mixing with cold water in the upper layers. Colder water from the shallow feed zones can mix with hotter water from the deeper ones.

Fig. 3 - Dissolved silica-enthalpy diagram

Scaling prediction is useful for forecasting the behavior of the reservoir for different production scenarios. The potential scaling problems for geothermal well utilization depend on the type of water. Therefore, a reliable analysis of the water and a simulation of the changes occurring during the utilization were needed to predict possible scaling.

The WATCH program is commonly used for interpreting the chemical composition of geothermal fluids. In this paper, the program was used to compute the concentrations of resulting species, activity products and solubility products when the equilibrated fluid is allowed to cool conductively from the reference temperature to some lower temperatures, which can be reached during utilization. The scaling potential is estimated by calculating log Q/K, where Q represents the ionic activity corresponding to different minerals in the brine, and K the theoretical solubility of the respective minerals.

The WATCH program was used to calculate the solubility indexes [7] for several minerals for wells 4797 and 4003.

The diagram for well-4003 (figure 4) indicates a supersaturation for calcite, talc, chrysotile and quartz at the wellhead temperature of 42ºC. There is an equilibrium with chalcedony at all temperatures which were used, assuming conductive cooling during utilization. There is undersaturation with respect to the other minerals.
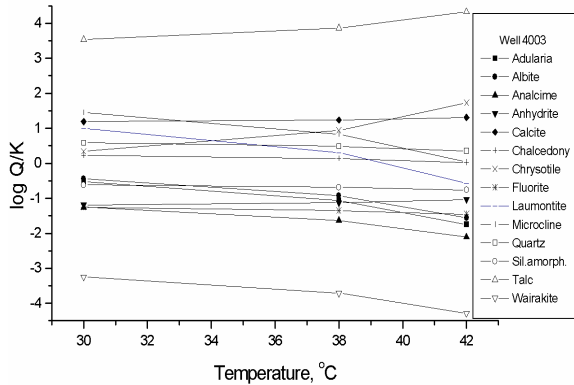

Fig. 4 - Log Q/K vs. temperature for geothermal water from well 4003

The diagram for well-4797 (figure 5) shows a possible scaling with respect to calcite at the wellhead temperature. There is also supersaturation for talc, quartz, microcline and laumontite, and anhydrite is close to the saturation line. There is equilibrium with respect to chalcedony. Most of the minerals tend to be fairly close to saturation at temperatures exceeding 60ºC. Most of the lines intersect between 45 and 55ºC, with the minerals in equilibrium at different temperatures within this interval.
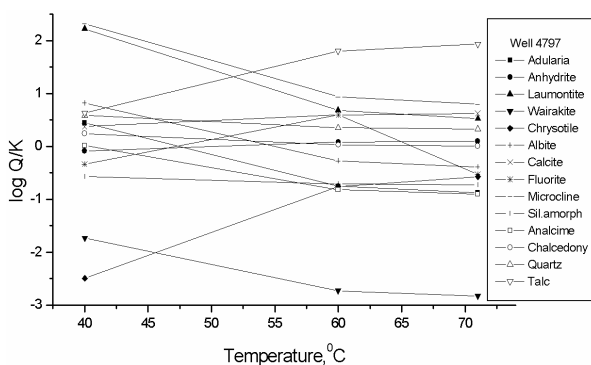

Fig. 5 - Log Q/K vs. temperature for geothermal water from well 4797

An assessment of potential scaling was obtained by using the WATCH program, problems due to scaling being expected in the system. Deposition had occurred in the well-4797 distribution system and in the pipeline casing of well-4003 after a period of four months of utilization. In order to determine the crystal composition of the solid deposits, fine grain samples were prepared and analysed by X-ray

diffraction. The solid sample from well-4003 consists mainly of calcite ($CaCO_3$). The amorphous phase has a high Fe content due to the corrosion of the pipe, and for this reason the scan has an elevated baseline on the XRD diagram (figure 6). Even though the chloride content of the water is low, it is possible that some oxygen entered the system and caused corrosion. The solid sample from well-4797 (figure 7) consists of calcium carbonate in the crystalline forms of calcite and aragonite and traces of calcium sulphate.
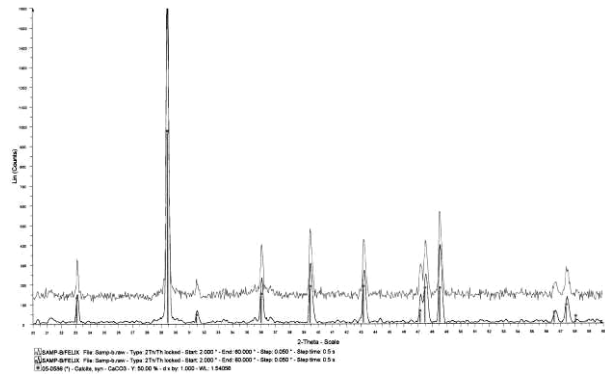

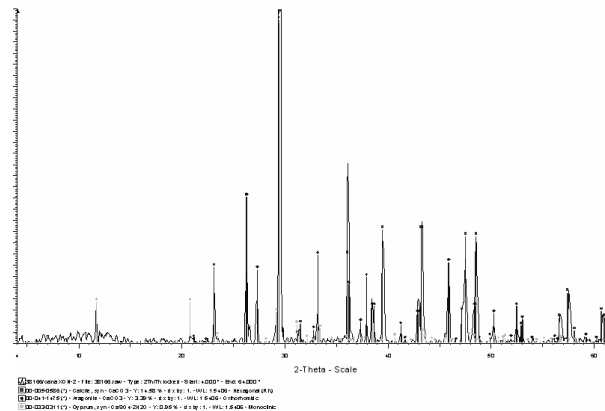**Fig. 6 - The XRD diagram for depositions from well 4003**

Fig. 7 - The XRD diagram for depositions from well 4797

4. CONCLUSIONS

The geothermal waters from the study areas can be classified as calcium-bicarbonate with a low mineralisation at Felix and calcium-sodium-sulphate at Nufărul.

The results from the silica geothermometers indicate that chalcedony controls the silica concentration in the studied reservoir waters, since for these low-temperature geothermal waters they give better values than the quartz geothermometers. The temperatures obtained from chalcedony geothermometers are very close to the measured temperatures. Temperatures calculated using Na/K equations deviate significantly from the measured temperatures for the two wells studied.

The dissolved-silica-enthalpy diagrams for determining the temperature of the hot water component mixed with cold water indicate higher temperatures than the results given by chalcedony geothermometers. This suggests a mixing of the hot water from the reservoir with infiltrating cold water before discharge from the well.

Chemical equilibrium calculations for the geothermal waters from the two production wells performed with the speciation program WATCH give the saturation indexes for minerals occurring in the reservoirs. At well-4003 and well-4797, there is an equilibrium with chalcedony at the temperatures which can be reached assuming a conductive cooling during utilization. The saturation index for calcite has a value more than one at well-4003, which indicates that calcite will precipitate. At well-4797, there was recorded supersaturation for calcite at the wellhead temperature, the saturation indexes in respect with calcite being lower than for the other studied well. The values of the saturation indexes for microcline, laumontite, quartz and talc are not high, except for talc, but this does not create problems.

Solid deposits formed during the utilization of wells 4003 and 4797 were XRD analysed. It was proved that the scale deposits from Felix is formed by calcite in the crystalline phase. At geothermal production conditions, from water from the well-4797 calcium carbonate was precipitated, calcite form being recorded as main. The scale products predicted using the simulation program were confirmed by the experimental results.

It is recommended that the geothermal waters be sampled at least twice a year. Based on good analytical results and thermodynamic data for the minerals that could precipitate, the scale potential can be predicted before problems occur.

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