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Fluid Chemistry of Geothermal Exploration Wells at NW-Sabalan Geothermal Field, Iran

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ABSTRACT

Sabalan geothermal field has substantial geothermal potential which reasonable prospects for electric power generation and direct use. Exploration studies in the Sabalan geothermal field started in 1978 by SUNA (Renewable Energy organization of Iran).Totally 11 wells were drilled in period of 2002 to 2011. In this report, chemical analyses of thermal fluids from wells were reviewed. The results show that wells produce predominantly from single –phase reservoir (liquid) with temperature from 225^{o}C to 240^{o}C.

The chemical composition of reservoir water was analyzed by standard methods and subsequently classified using Cl-SO_4-HCO_3 and Cl-Li-B triangular diagrams. Na-K-Mg triangular diagram was used to classify waters according to the state of equilibrium at given temperatures. The geothermal waters are sodium-chloride type and from relatively old hydrothermal system. Thermal fluid is almost in equilibrium with reservoir rocks at temperature 280^{o}C.

1. INTRODUCTION

Mt. Sabalan geothermal field is one of the prospective area in NW-Iran for geothermal exploration which has been initiated by SUNA (Renewable Energy organization of Iran) since 1978.The drilling program was started at 2002. Since that time 11 wells were drilled in different periods. Three deep exploration wells (NWS-1, NWS-4 and NWS-3) and one re-injection well(NWS-2R) have been drilled in period from 2002 to 2004 and seven more wells (NWS-5D, NWS-6D, NWS-7D, NWS-8D, NWS-9D,NWS-10D and NWS-11D) in period from 2008-2011 year. The production wells produces from a single-phase with reservoir liquid at depth 1400 to 3000m with a temperature about 226 - 240^{o}C (SKM, 2004).

2. CHEMICAL COMPOSITIONS OF THE WATERS

The geochemical study is based on chemical analyses of discharge water samples collected from the discharge brine line of 7 production wells (NWS-1 a NWS-4, NWS-6D, NWS-7D, NWS-5D, NWS-9D and NWS-10D) in period of 2004 to 2011 year. Samples were analyzed using standard methods. Partial chemical analyses of pH, Cl, HCO_3, SO_4, Ca, B and CO_2 for wells (NWS-1and NWS-4) were carried out in the site laboratory of SUNA and Li, Na, K, Ca, Mg and SiO_2 in laboratory of GNS Wairakei (New Zealand. Stable isotope analyses (σ18O and σ2H) were carried out in laboratory of GNS Welligton.

2.1 Classification of the thermal fluids

The average chemical compositions of the geothermal water from 7 production wells are presented in Table 2(see Appendix). The chemical analyses of Gheynarje and Ilando hot springs presented for comparison. The discharge water from studied wells is sodium chloride type with alkaline pH (8.1-8.5) with concentration of Cl and Na from 1887 to 3027 and from 1113 to 1903 mg/l respectively, whereas Mg is present only in trace (0.17-0.23 mg/l). By comparison, the chloride hot springs with concentration of Cl

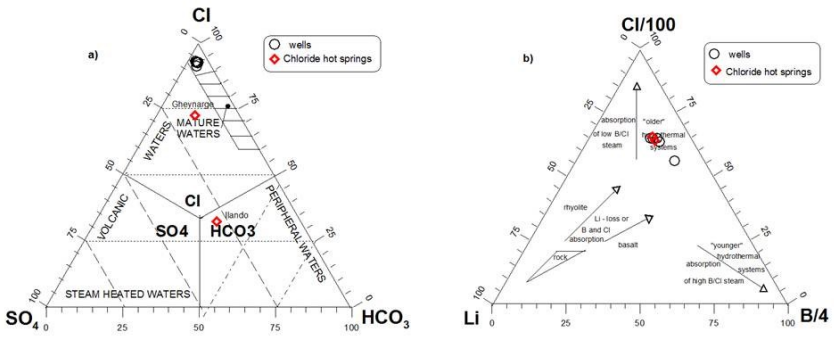


Figure 1: a) Cl-SO4-HCO3 classification diagram of Giggenbach (1991) for the studied fluids; b) Cl-Li-B diagram of Giggenbach for the studied fluids

from 381 to 1540 mg/l has higher concentration of Mg from 15 to 23 mg/l. The chemical composition of studied wells are similar with the exception of calcium concentration which is significantly high in well NWS-4 (27 mg/l) and extremely low (6 mg/l) in well NWS-7D and also somewhat lower bicarbonate (73 mg/l) and sulfate ion (71 mg/l) in well NWS-4 and NWS-6D respectively.

Triangular diagram Cl-SO_4-HCO_3 of Giggenbach (Figure 1a) was applied for classification of water according to major ions. All samples plots to area of mature waters and can be classified as Cl-rich geothermal water which formed by the interaction of geothermal fluids with the host rock and dilution with low-salinity water at depth (White and Muffler, 1971). Samples from Ilando hot spring fall to area of peripheral water suggesting mixing with cold water.

Cl and B are conservative elements in geothermal system. They are fixed in fluid phase and have not equilibrated. The conservative elements are the best geoindicators of the origin of geothermal system. B/Cl ratio and Cl-Li-B ternary diagram were used to indicate the source of the fluid. A plot of the relative concentrations of Cl, Li and B is show in Figure 1b. All geothermal water have high Cl content relative to Li and B, indicating that they are from old hydrothermal system and that fluid migrated from the old basement rock.

The B/Cl ratio of the studied fluids are in range of 34 to 40. High ratio can be representative of andesitic reservoir and rhyolitic system or due to absorption into alteration clays along the geothermal flow (SKM, 2004; SKM, 2005).

2.2 Isotopic characteristic

The stable isotope analyses were carry out for well NWS -4. Relation between σ18O and σ2H for the water from geothermal well NWS-4 is shown in Figure 2. Isotope data for hot springs and local cold surface water were also plotted. As seen from figure, the well presents a σ18O shift about 3,0‰ from local meteoric water which can be the indicative of geothermal origin fluid. The shift can be due to isotopic exchange at high temperature between reservoir water and the rock minerals which are richer in σ18O (Arno′rsson, 2000). Most of the hot springs are located on the line of world meteoric waters but have a smaller shift due to mixing with local meteoric water.

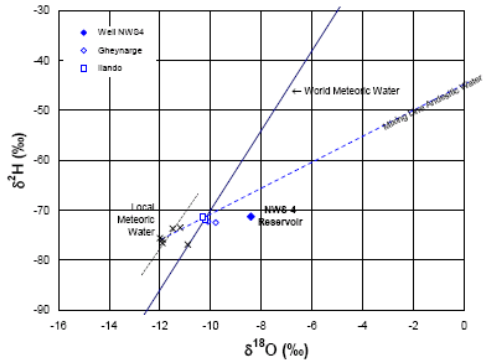


Figure 2: Relation of σ18O and σ2H stable isotope in the Sabalan geothermal field (SKM, 2005)

3. SUBSURFACE TEMPERATURE ESTIMATION

The silica and cation geothermometers were used for the evaluation of subsurface temperature for well discharges (Table 1). The silica geothermometers of Forner, 1977 gives reservoir temperatures ranging from 227 to 254 ^oC almost same with the measured reservoir temperature 226 ^oC to 240 ^oC. It may be inferred that quartz may control the dissolved silica concentration in the deep reservoir (D'Amore, 1991). The temperatures obtained from cation geothermometers significantly higher than from silica geothermometers. The Na-K geothermometers of Giggenbach (1988) gives temperature from 282 to 296 ^oC and Arnorsson et all. (1983 and 1983a) suggested reservoir temperature in range of 264-272 ^oC and 261-281 ^oC respectively, which are higher than measured temperature. The higher temperature values obtained by cation geothermometers reflect the initial liquid condition since the period of re-equilibration of the minerals (albite, feldspar) controlling these geothermometers.

Table 1: Geothermometers temperature for the studied thermal water (^oC).

well	NWS-1	NWS-4	NWS-5B	NWS-6D	NWS-7D	NWS-10D	Source
T_{meas}	226	223	240	240	240	240	
T_Q	253	257	n.d	227	252	254	Forner,1977
T_{Na-K}	286	290	298	284	292	282	Forner, 1979
T_{Na-K}	266	271	281	264	273	261	Arnorsson,1983a
T_{Na-K}	286	289	296	284	290	282	Giggenbach, 1988
T_{Na-K}	268	272	279	267	273	264	Arnorsson,1983

It can be deduced that a much higher temperature source can be found in the Sabalan geothermal system (Amistoso, A.E., Buscato, N.M, 2011).

The Na-K-Mg triangular diagram shows the equilibrium between the geothermal fluids and rock and reservoir temperature (Figure 3). Figure shows that samples from studied geothermal wells fall on partial equilibrium section near the full equilibrium line at temperatures about 280 C^{o}. The partial equilibration is result of higher level of magnesium concentration in the water samples as reason of inflow of cold diluting water in the reservoir or from steam addition due to the dilution of Na^{+} and K^{+} ions by steam condensation (Amistoso, 2011) The samples from hot spring plots in the area of immature waters suggesting not attainment equilibrium between water and rock.

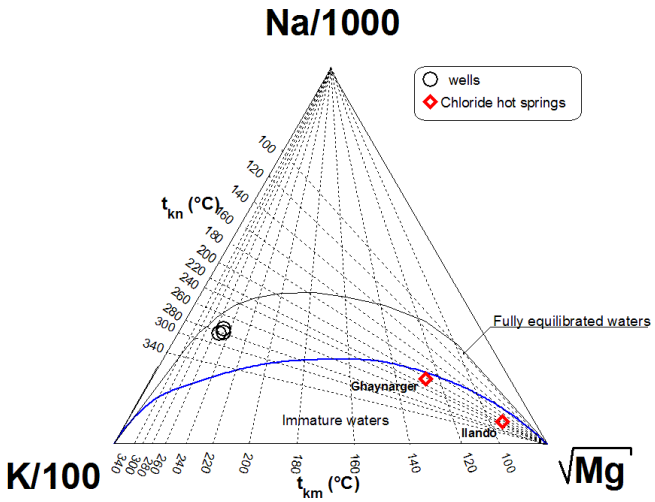


Figure 3: Na-K-Mg diagram of Giggenbach (1988) for the studied fluids.

CONCLUSION

The geothermal waters discharged from studied production wells of the Mt. Sabalan geothermal field is sodium-chloride type with a high concentration of Cl. Chemical compositions of reservoir waters indicates that the reservoir is located in the liquid dominant zone and geothermal waters from old geothermal system. The water compositions from studied wells are similar. The only significant difference being the higher calcium concentration and somewhat lower bicarbonate in NWS-4, low concentration of sulfate ion in well NWS-6D and low calcium concentration in well NWS-7D. Thermal fluid seems to be in equilibrium with reservoir rocks at temperature of 280^{o}C.

The isotope composition of well NWS-4 presents enrichment in ∂18O which can be product of water-rock interaction at high temperature.

The major geothermometers were used for estimating the subsurface temperature. The results from silica geothermometers indicate that quartz can control silica concentration in the reservoir or quartz geothermometers better indicate the reservoir temperature. The calculated temperatures using quartz thermometer is 227and 254^{o}C that almost same with measured temperature (226^{o}C and 240 ^{o}C). Cation geothermometers give temperature significantly higher than quartz geothermometers and higher than measured temperatures.

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Table 2. The average chemical composition of the studied thermal water in mg/l.

well	Date (yyyy)	pH	T ^{oC}	Cl	SO4	HCO3	Na	K	Mg	Ca	Li	B	SiO2	Cl/B
NWS-1	**2004**	**8.2**	**223**	**2750**	**122**	**90**	**1600**	**294**	**0.23**	**18**	**9.5**	**23**	**426**	**36**
NWS-4	**2004**	**8.5**	**236**	**2500**	**109**	**73**	**1413**	**269**	**0.23**	**27**	**8.6**	**21**	**528**	**36**
NWS-5D	**2012**	**8**	**240**	**3027**	**127**	**108**	**1903**	**389**	**0.19**	**18**	**12**	**23**	**ND**	**40**
NWS-6D	**2011**	**7.4**	**240**	**1887**	**71**	**111**	**1113**	**201**	**0.15**	**9.1**	**6.7**	**16**	**375**	**35**
NWS-7D	**2011**	**8**	**240**	**2807**	**110**	**114**	**1784**	**344**	**ND**	**6**	**17**	**21**	**500**	**40**
NWS-9D	**2012**	**8.5**	**240**	**2800**	**95**	**92**	**1455**	**261**	**0.13**	**13**	**8**	**21**	**458**	**0**
NWS-10D	**2012**	**8**	**240**	**2704**	**103**	**108**	**1694**	**299**	**ND**	**12.2**	**9.8**	**20**	**512**	**41**
spring														
Gheynarje	**1997-2008**	**6**	**87**	**1540**	**300**	**299**	**1045**	**116**	**15**	**26**	**4.7**	**12**	**134**	**37**
Ilando	**1997-2008**	**6**	**35**	**381**	**281**	**414**	**304**	**38**	**20**	**26**	**1.3**	**3**	**141**	**34**