

Distributions of Arsenic in Hot Springs and Geothermal Wells in Sabalan Geothermal Field, N-W Iran

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ABSTRACT

Sabalan geothermal field is a high temperature area under development which is rich in geothermal manifestation at the surface with a temperature in the range of 25–85°C. Most of the hot springs have their outlet into the river. Distribution of Arsenic in geothermal waters in Sabalan area has been studied. High As concentration (up to 3500 µg/l) was recorded in geothermal well fluids with sodium-chlorate type. Concentration of As in hot spring waters in the range of 0.8-890 µg/l. Concentrations of As are higher in the chloride hot springs than in the acid-sulfate features and increase with increasing temperature and salinity. Positive correlation As with Cl has been detected that validate for most geothermal fields in the world. In all samples concentration of As exceed the WHO limit for drinking water (10 µg/l) except one sample from Agh-su hot spring.

1. INTRODUCTION

Arsenic is one of the important trace components in geothermal systems which occur together with Hg, Sb, B, Li and F. Arsenic associated with geothermal waters has been reported in several areas, including hot springs from parts of the USA, Japan, New Zealand, Iceland, Kamchatka, France and Dominica (White et al., (1963); Welch et al., (1988); Criaud and Fouillac, (1989)). Hot springs always contain considerable amount of As produce an excess of fluid at the surface which usually drains unimpeded into the nearest catchments system. Using of these waters for drinking, stock watering and irrigation may have high As concentration in downstream of geothermal system (Webster and Nordstrom (2003)). In most active geothermal fields arsenic concentrations in the natural surface waters drainage can exceed 10 mg/l. The WHO (1993) limit for drinking water is 10 µg/l, for the protection of aquatic life of 19 µg/l and for stock watering and irrigation of 20 and 10 µg/l respectively. Evaluation of As in natural waters can be useful for understanding the pollution problem, rock leaching and water-rock interaction (Webster and Nordstrom (2003); Ballantyne (1988); Smedley (2002)). Development of geothermal fields for power generation tends to increase the rate and volume of geothermal features reaching the surface. Sabalan geothermal field is a high temperature area under development which is rich in geothermal manifestation at the surface with a temperature in the range of 25–85°C. The geothermal springs are used as a swimming pools and hot spa both for local residents and tourists. Most of the hot springs have their outlet into the river. In this study, the data on the distribution of As in the main hot springs and deep reservoir wells of Sabalan geothermal field will be presented.

2. STUDY AREA

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 to constructing the geothermal power plant. The geothermal field is located in a Moil valley terraces set within the outer caldera rim of the Mt. Sabalan complex of NW Iran (Figure 1).



Figure 1: Map showing location of Sabalan geothermal field (SKM (2000)).

Mt. Sabalan is a large stratovolcano and lies on the south Caspian plate, which underthrusts the Eurasian plate to the north. Exposed at the surface in the valley are altered Pliocene volcanism, an unaltered Pleistocene trachydacite dome (Ar-Ar dated at 0.9 Ma) and Quaternary terrace deposits. Caldera collapsing has caused a depression about 400m height and 12 km diameter. The lava flows consists of trachyandesite, andesite and dacite and pyroclastic deposits (Bogie (2000); SKM (2005)). The area is characterized by intensive geothermal manifestation at the surface which includes a hot springs, polls and geyser with temperature ranging of 28-83 °C.

3. SAMPLING

The geochemical study is based on discharge water samples collected from the discharge brine line of two production wells (NWS-1 and NWS-4) and samples collected from seven main hot springs. Samples were untreated and included acidified water. All chemical analyses (Cl, HCO₃, SO₄, Ca, B, CO₂ Li, Na, K, Ca, Mg and SiO₂) were carried out in the laboratory of SUNA.

4. ARSENIC IN GEOTHERMAL WATERS

The chemical composition of studied thermal waters is given in Table 1.

4.1. Deep reservoir waters

The discharge geothermal waters from two production wells (NWS-1 and NWS-4) are Na-Cl type and can be classified like Cl-rich geothermal waters with Cl concentration of 2460-2750 and Na concentration of 1413-1600 mg/l, whereas Mg is present only in trace (0.1-0.23 mg/l) (SKM (2005); Strelbitskaya and Radmehr (2010)). Temperature of these waters is 223 and 226 °C respectively. Cl-rich geothermal waters are formed by the interaction of geothermal fluids with the host rock and dilution with low salinity water at depth (White and Muffler (1971)). The concentration of As in these waters is 3.5 and 3.6 mg/l respectively that in three times more than in the studied hot springs.

4.2. Hot springs

There are several hot springs with temperatures ranging from 28 to 82 °C within Sabalan geothermal project. The chemical composition of these waters has been described in detail by Khosrawi (1996); Bogie (2002); Yousefi (2004); Haeri (2010) and Porkhial (2010). According to water chemistry geothermal waters can be classified into two main types:

Neutral Cl-SO₄ waters: These waters can be a mixture of alkali chloride water and acid sulphate water, or can arise from the oxidation of H₂S to SO₄ in alkali-chloride water or dissolution of S from rock followed by oxidation (Ellis and Mahon (1978)). Gheynargeh, Malek-su, Ilando and Khosrow-su hot springs are typically neutral Cl-SO₄ waters with temperatures from 28 to 82 °C. These hot springs have higher concentration of Cl (263-1337 mg/l) in comparison with acid-SO₄ waters and sulfate (89-309 mg/l) and relatively high concentrations of Mg (11-15 mg/l). The As concentrations in these waters are in the range of 1 to 890 µg/l that are higher than in acid-SO₄ waters.

Acid -SO₄ waters. These waters arise from the oxidation of H₂S to SO₄ near the surface and most of its composition is dissolved from surface rock (Ellis and Mahon (1978)). Acid -SO₄ waters include Moil (pool), Moil 2 and Agh-su hot springs with temperature ranging from 28 to 43 °C. These waters have pH 3-4. They are high in SO₄ (up to 530 mg/l) and have low concentration of Cl (from 1.19 to 6.9 mg/l). Concentration of As in these waters is 0.8-660 µg/l.

5. GENERAL TRENDS

The concentration of As in thermal fluids mainly will be depend on the thermal sources at depth and subsequent hydro-chemical evolution of water chemistry along its pathway up to the surface. According to Ellis and Mahon's (1964) As in geothermal fluids is derived mainly by host rock leaching and could be derived from the wall rock similar to chloride. Both elements remain in the fluid during sub-surface boiling and phase separation. The As/Cl ratio can be used as a tool to trace the effects of geothermal fluid dilution, concentration or mixing within a geothermal field. Many thermal waters show linear trends of As vs Cl that suggesting mixing with cool meteoric ground waters on their way to the surface (Webster and Nordstrom (2003)). The concentration of As in the studied hot springs are plotted as a function of Cl concentrations and temperatures in Figure (2-4). Analyses of As in hot springs reflected a positive correlation between As and Cl that suggest that they have similar origin.

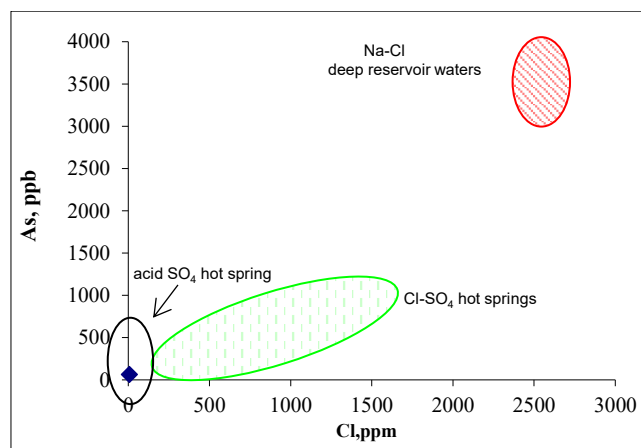


Figure 2: The relationship between As and Cl in studied hot springs.

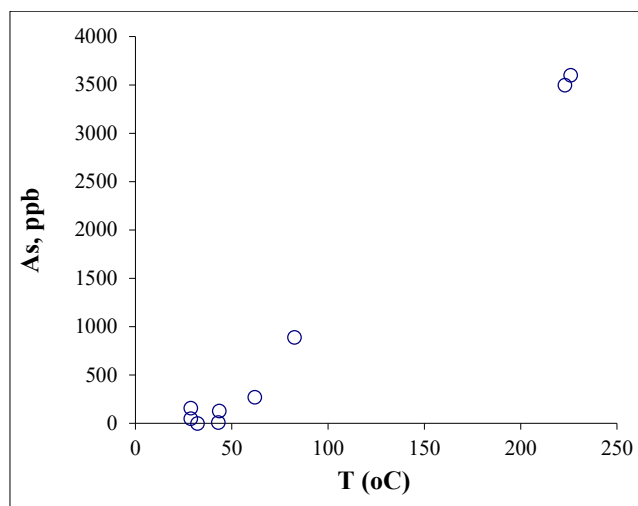


Figure 3: The relationship between As and T°C in studied hot springs.

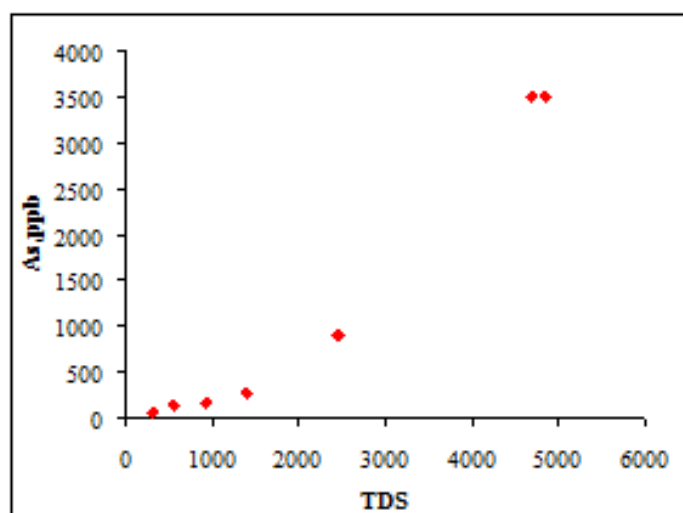


Figure 4: The relationship between As and TDS in studied hot springs.

The close geothermal association between Cl and As concentration has been confirmed for most geothermal fields. For example, linear trends between As and Cl were identified in Yellowstone geothermal waters (Stauffer and Thompson (1984)).

The As concentration tends to be increased with increasing temperature (Figure 3). Increasing temperature will lead to increasing of rock dissolution and leaching As from host rock in the fluid. The As concentration increases with temperatures increasing from 0.8 to 890 $\mu\text{g/l}$ at $t < 100^\circ\text{C}$ to 3600 $\mu\text{g/l}$ at higher temperatures. Positive correlation As with salinity have also been detected (Figure 4).

6. DISCUSSION

Results shows that significant As concentration with range of 1-3600 $\mu\text{g/l}$ occur in thermal fluids throughout the study area. Seven of the samples from hot springs exceed the WHO drinking water guideline for As (10 $\mu\text{g/l}$).

Geothermal wells. Significant concentration of As (3.5 mg/l) detected in studied production wells. Using this water for power generation requires substantial amounts of water to be extracted. During the separation of steam and bore water in geothermal power generation, As is retained in the waste bore water. Re-injection of thermal waters is necessary to prevent contamination of cold waters (Webster and Nordstrom (2003)).

Hot springs. The As concentration in studied hot springs ranging from 0.8-890 $\mu\text{g/l}$. Maximum concentration of As (up to 890 $\mu\text{g/l}$) detected in Gheynargeh boiling hot spring, minimum in Ag su (0.8 $\mu\text{g/l}$). Significant concentration of As (130-270 $\mu\text{g/l}$) noted in some hot springs such as Khosrow su, Ilando and Molek su. This high concentration of As can affects the area surrounding these springs. These hot springs have their outlet into the river. Mixing of these waters with cold water can increase the As content in the river water. Therefore additional investigation are needed to detect where the highest risk of mixing between thermal waters of high

As concentration and cold surface waters occur and investigate how this mixing process affects humans in the area in the long term.

CONCLUSION

Distribution of Arsenic in thermal waters of Sabalan geothermal field has been studied. Results show that high As (up to 3.5 mg/l) concentration occur throughout the studied area. Deep production wells have significant As concentration (3.5 mg/l). Therefore re-injection of thermal waters is necessary to prevent contamination of cold waters.

Concentration of As in studied hot springs ranging from 0.8 to 890 µg/l. Neutral Cl-SO₄ hot spring is rich in As (up to 890 µg/l) than in acid sulfate features with As concentration up to 66 µg/l. As concentration tends to increase with increase in temperature. Positive correlation of As with Cl concentration and TDS has been noted. Due to high As concentration (up to 890 µg/l) in hot springs which exceed the WHO level for drinking water (10 µg/l), irrigation (10 µg/l) and protected aquatic life (19 µg/l) there is a risk of contamination of cold water by arsenic. Mixing of thermal waters with cold water can increase the As concentration in the cold water due to flooding during rainy season, therefore monitoring of river water is recommended.

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Table 1. Average chemical composition of studied thermal waters, ppm

springs	TDS	pH	T	Cl	B	Fe	As	SO₄	HCO₃	Na	K	Ca	Mg
Pool(Moil)	458	4.8	43	1.19	0.3	0.72	0.01	560	22.5	63.53	28.8	92.38	23.8
Moil2	313	3.05	28.7	6.62	0.1	0.56	0.66	298	0	25.63	10.4	43.45	10.6
Ag-su	209	3.2	32.3	6.25	0.55	0.09	0.0008	162	0	20	13.5	30.8	4.5
Malek-su	559	5.9	43.5	263	0.92	0.1	0.13	89.5	172	204	42.8	33	15.8
Ilando	918	5.9	28.7	390	0.77	0.025	0.16	283	176	328	36.7	75.8	19.6
Khosraw-su	1398	6.62	62	836	2.87	0.019	0.27	249	127	508	49.5	58.8	11
Gheynarjeh	2456	6.5	82.5	1337	83.56	0.017	0.89	309	261	875	117	92.25	11.2
Well NWS-1	4854	8	226	2605	22	0	3.5	119	98	1524	279	16	0.17
Well NWS-4	4680	8.5	223	2500	21	0	3.6	109	73	1413	269	27	0.2