Scaling Potential Assessment in the Domes Wellfield, Olkaria-Kenya

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Keywords: scaling, saturation, equilibrium, mineral assemblages, modelling

ABSTRACT

Scaling is a major setback in the harnessing of geothermal resources. This paper presents results from a study aimed at assessing the potential of scale formation that can occur during utilization of geothermal fluid from the Domes wellfield, Olkaria-Kenya. The chemical composition of geothermal fluids from 4 selected high-temperature geothermal wells was determined. Data on the chemical composition liquid water and vapour discharged from these wells have been used to reconstruct the composition and species distribution in the initial aquifer fluid using the Phase Segregation Model for wells with excess discharge enthalpy. Aquifer fluid was then modelled to predict scaling occurrence when the fluid is cooled. Concentrations of reactive gases in relation to their approach to equilibrium with respect to selected mineral-gas reactions have also been examined. The results indicate that scaling potential of aquifer fluids at Domes wellfield differ from well to well and therefore each well need to be taken into consideration during planning of resource utilization for effective management.

1. INTRODUCTION

Scaling is a major setback in the harnessing of geothermal resources. This paper presents results from a study aimed at assessing the potential of scale formation that can occur during utilization of geothermal fluid from the Domes wellfield, Olkaria-Kenya. The chemical composition of geothermal fluids from 4 selected high-temperature geothermal wells was determined. Data on the chemical composition liquid water and vapour discharged from these wells have been used to reconstruct the composition and species distribution in the initial aquifer fluid using the Phase Segregation Model for wells with excess discharge enthalpy. Aquifer fluid was then modelled to predict scaling occurrence when the fluid is cooled. Concentrations of reactive gases in relation to their approach to equilibrium with respect to selected mineral-gas reactions have also been examined. The results indicate that scaling potential of aquifer fluids at Domes wellfield differ from well to well and therefore each well need to be taken into consideration during planning of resource utilization for effective management.

Conceptual model for Olkaria wellfields have been discussed and refined by number of authors (e.g. Ofwona, 2002; Kariuki, 2003; Kanda, 2010). The deep Olkaria geothermal reservoir is liquid-dominated, with most of the wells being two-phase

in Domes. The two-phase reservoir is overlain by a vapour-dominated steam cap (steam zone) with a temperature of about 240°C (Ambusso and Ouma, 1991). Geochemical assessment indicates that the excess enthalpy of well discharges at Olkaria is largely produced by phase segregation, either by gravity under natural conditions or in producing aquifers where extensive depressurizing boiling occurs (Karingithi et al., 2010; Kanda, 2010).
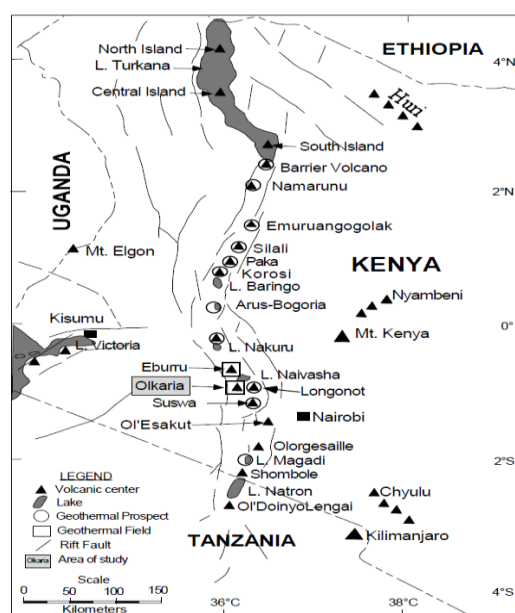
Figure 1: Map of the Kenyan rift showing the location of Olkaria geothermal field.

2. DATA HANDLING AND METHODS

A number of water and gas samples were collected from four discharging wells at the Domes wellfield. Fitting chemical data were selected based on ionic balance and the agreement between the quartz and Na/K geothermometer temperatures. Calculations were carried out with the help of the WATCH chemical speciation program (Bjarnason, 2010), with tolerance values of ≤ 10% and ≤ 20°C, respectively.

Corrections for pH for silica polymerization were made on the assumption that measurements might have been delayed and that all dissolved silica in excess of amorphous silica solubility had polymerized at the time of pH measurement. Correct pH is rather essential in modelling aquifer chemical composition; speciation distribution is essential for geochemical interpretation and assessing the state of mineral-solution equilibria for

minerals with pH dependent solubility, and also for mineral-gas equilibria involving CO_2 (aq) and H_2S (aq) irrespective of their solubility dependency (Busey and Mesmer, 1977; Arnórsson et al., 1982; Tossell and Sahai, 2000; Gudmundsson and Arnórsson, 2005; Angcoy and Arnórsson, 2010).

Correction of pH followed an iteration procedure that utilized the WATCH chemical speciation program to incorporate water sample analytical data and pH, assuming a liquid phase (without gas phase), water enthalpy and aquifer temperature (from geothermometers). The initial aquifer fluids feeding Olkaria Domes well field were then modelled using the analytical data of the wellhead samples with, again, the aid of the WATCH chemical speciation program, based on the Phase Segregation Model (PSM), a model discussed by Arnórsson et al. (2007; 2010), and Arnórsson and Stefánsson (2005), where phase segregation occurred at a temperature of 180°C (equal to 10 bar-a) (Karingithi et al., 2010).

The stepwise approach of reinstating aquifer chemistry started with the calculation of the composition and speciation of the vapour and liquid at 180°C from the selected analytical wellhead data of the water and steam. This step used measured enthalpy, ambient temperature and corrected pH. The second step used the WATCH output from the first run to calculate initial aquifer composition and speciation distribution taking the average of Na/K and quartz geothermometer temperatures to represent the initial aquifer liquid temperature and enthalpy.

With the initial aquifer fluid concentrations, the WATCH speciation program was used to calculate individual species activities. The results of these modelled fluids were used to assess their saturation conditions, with respect to calcite, fluorite, quartz, chalcedony and amorphous silica when temperature drops. Considerations were also conducted on the concentrations of the reactive gases H_2S, H_2 and CO_2 in relation to their approach to equilibrium with respect to selected mineral-gas reactions. Influence of temperature change on scaling was then assessed where adiabatic boiling is assumed to bring the equilibrated fluid, utilizing aquifer temperature (geothermometer) as the reference temperature and boiling down to different temperatures.

3. RESULTS AND DISCUSSION

3.1 Aquifer Water Chemistry

The chemical data show that carbon dioxide, sodium, silica, chloride and sulphate are in high concentrations in the geothermal water present in the aquifer, and hence characterized by Na-Cl-

HCO_3 water type. High HCO_3 is attributed to a high level of magma degassing giving rise to an elevated CO2 flux. This was also suggested by Karingithi et al. (2010) to be the basis of high HCO_3 at Olkaria West; thus, the maturity of these waters could not be categorized effectively based on the contents of contained anions. The pH values range between 6.5 and 7.7, displaying a near neutral average value at aquifer temperature. Liquid water enthalpies calculated for initial aquifer conditions are slightly above 1000 kJ/kg.

3.2 Chemical Composition of the Reactive Gases

The concentrations of H_2S, H_2 and CO_2 in the initial aquifer fluid are presented in Figures 2, 3 and 4. The source of the thermodynamic properties of minerals assemblages are from Karingithi et al. (2010). Apart from the sample from well D908A showing CO_2 concentrations that is generally higher with reference to the given assemblages, the other samples scatter closely matching with the assemblages, i.e., with reference to clinozoisite-calcite-quartz-prehnite (well D909) and clinozoisite-calcite-quartz-grossular (wells D907A and D908A). The CO_2 values for D908A are extremely high and this can be attributed to a high flux of CO_2 from the magmatic source that hinders its close approach to local equilibrium with the mineral assemblages given. This phenomenon has also been discussed by previous authors to occur in the Kenyan rift system (Arnórsson et al., 2007; Karingithi et al., 2010; Arnórsson, 2010).
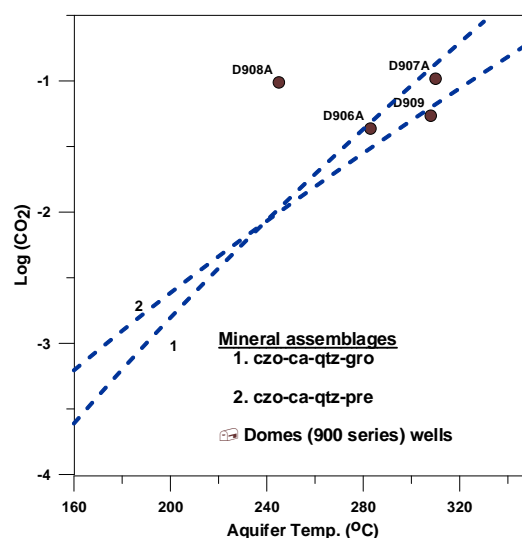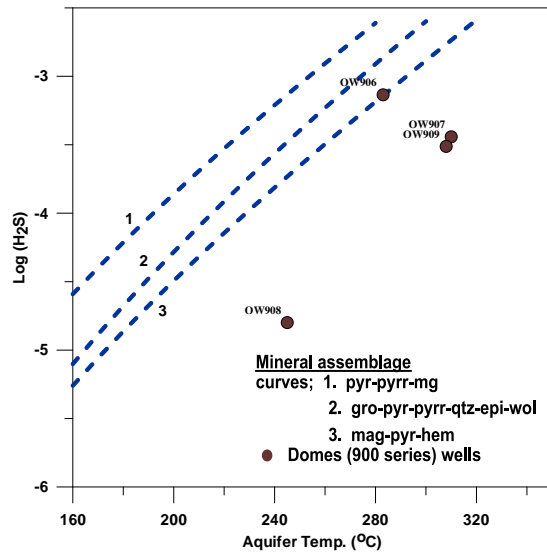
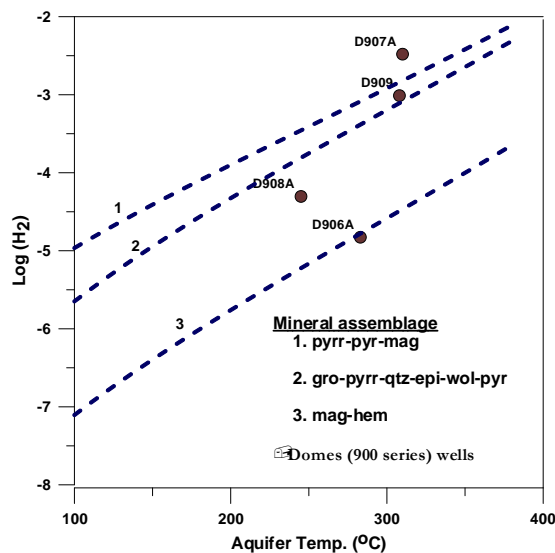**Figure 2: State of equilibrium between dissolved CO_2 with two mineral assemblages**

Table 1: Calculated composition of the initial aquifer fluid produced from wet-steam wells, in mg/kg

Well	Sample	pH	SiO$_2$	B	Na	K	Ca	Mg	CO$_2$	H$_2$S	SO$_4$	Cl	F	H$_2$	CH$_4$	N$_2$
OW906A	Discharge	9.29	865	6.60	541.6	115.5	0.41	0.26	117	6.8	196.7	1440.6	40.2	0.11		142.0
	Aquifer	6.89	520	3.96	325.8	69.5	0.25	0.16	2032	31.4	118.3	866.6	24.2	0.03		593.6
OW907A	Discharge	9.16	975	1.40	526.3	98.4	0.05	0.25	112	0.2	206.1	407.5	94.7	17.10	1.66	27.0
	Aquifer	6.87	614	0.88	331.4	62.0	0.03	0.16	4693	13.4	129.8	257.0	59.7	6.66	5.13	146.0
OW908A	Discharge	9.83	496	1.99	517.7	87.7	0.46		244	0.5	97.6	287.1	68.6	0.51	0.49	71.2
	Aquifer	6.52	383	1.53	399.8	67.7	0.36		4641	0.7	75.6	221.5	53.0	0.10	0.76	195.0
OW909	Discharge	10.20	926	4.70	892.9	340.2	0.10	nd	286	3.4	42.7	719.5	272.0	5.40	1.01	8.6
	Aquifer	7.73	599	3.04	577.5	219.9	0.06		2890	24.2	27.8	465.6	175.9	1.96	2.91	43.5

[a]Total: Carbonate carbon as CO$_2$; [b]Total: Sulphide sulphur as H$_2$S.

**Figure 3: State of equilibrium between dissolved H$_2$S with three mineral assemblages.**

The aquifer waters are typically low in H$_2$S relative to the equilibrium of grossular-pyrite-pyrrhotite-quartz-epidote-wollastonite, pyrite-pyrrhotite-magnetite and pyrite-magnetite-hematite mineral assemblages apart from well D906A closely relating to pyrite-magnetite-hematite mineral assemblage. It is likely that the relatively low amount of H$_2$S is due to oxidation or contamination of samples with atmospheric air or rather controlled by other different assemblages.

Figure 4: State of equilibrium between dissolved H$_2$ with three mineral assemblages

The H$_2$ concentrations in the calculated aquifer fluids display a significant scatter compared to CO$_2$ and H$_2$S. There is no apparent relationship between H$_2$ and the assemblages considered. A single sample showed a close relationship with the hematite-magnetite assemblage, whereas the rest displayed indistinct dispersion across pyrrhotite-pyrite-magnetite and grossular-pyrrhotite-quartz-epidote-wollastonite-pyrite mineral assemblages.

3.3 The Temperature Influence on Scaling

By using data from Table 1, log solubilities for the minerals (calcite, quartz, chalcedony, fluorite and amorphous silica) were calculated by the WATCH speciation program. The program also reports the theoretical log K by temperature for the corresponding minerals, which were combined with the calculated results for log Q to plot the saturation indexes (log Q/K) against temperature for different minerals.
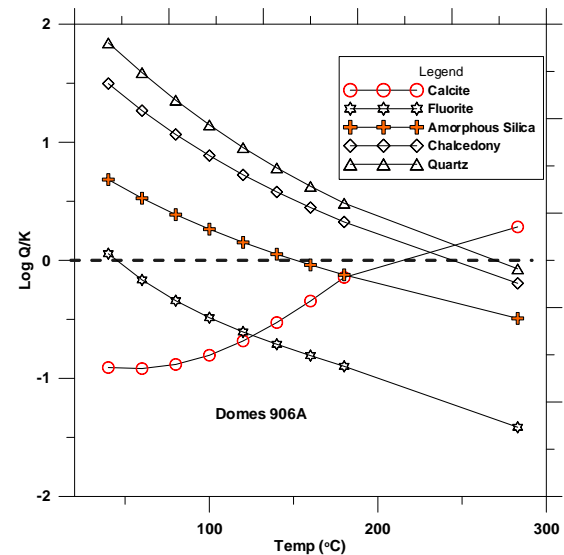
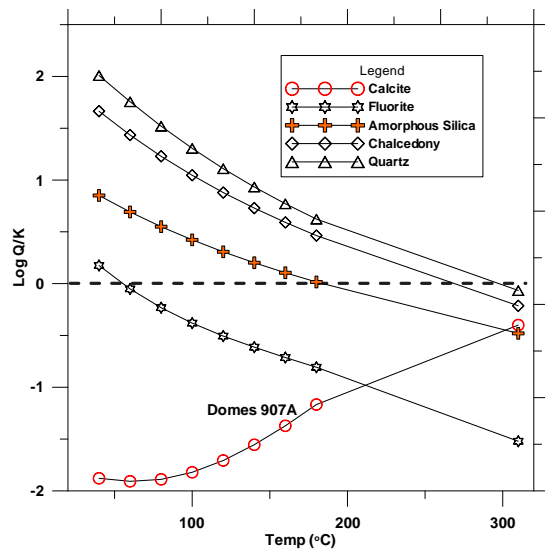**Figure 5: Log Q/K vs. temperature for geothermal aquifer water from well D906A**

Figure 6: Log Q/K vs. temperature for geothermal aquifer water from well D907A

The log Q/K diagram for aquifer water from the Domes well 906A (Figure 5) indicates supersaturation with respect to calcite at the aquifer temperature but undersaturation with respect to quartz, amorphous silica, chalcedony and fluorite. At bubble-point condition, calcite falls way below saturation line and persistently in undersaturated. Saturation of both quartz and chalcedony begins even before boiling and increases sharply with cooling, but still there would hardly be expected deposition of such minerals. Saturation of amorphous silica in the other hand begins after boiling at around 150°C and by further cooling through boiling; the water becomes supersaturated reaching 0.7 SI units at 40°C, and thus scaling problems with amorphous silica can be expected.
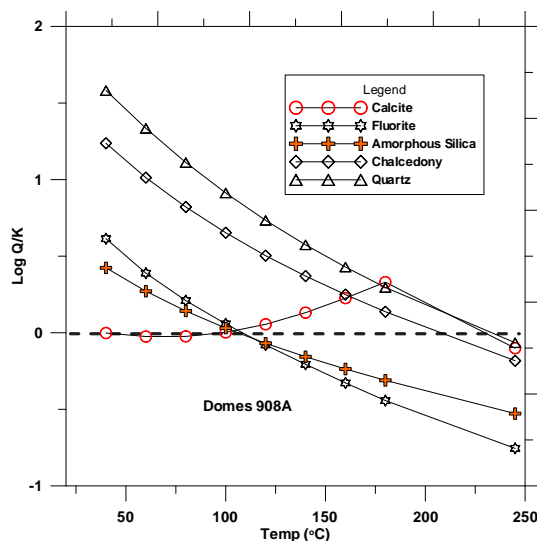

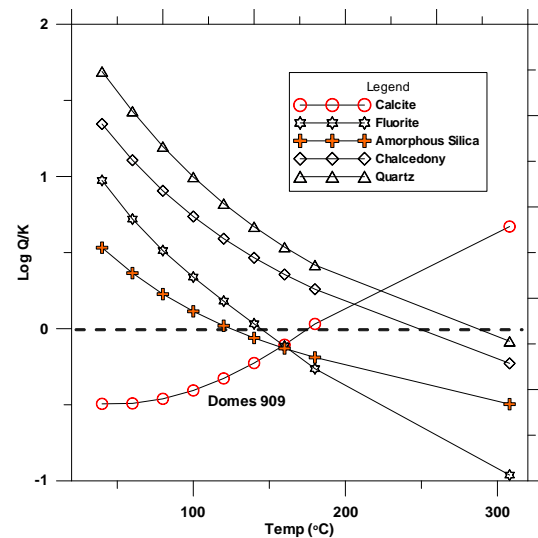**Figure 7: Log Q/K vs. temperature for geothermal aquifer water from well D908A**

Figure 8: Log Q/K vs. temperature for geothermal aquifer water from well D909.

Similar to well D906A, saturation with respect to quartz and chalcedony for wells D907A, D908A and D909 rises sharply with temperature decrease right from aquifer conditions way before boiling (see Figures 6, 7 and 8). For amorphous silica, saturation appears to increase slightly by cooling, crossing saturation line at bubble-point, 100°C, 120°C for wells D907A, D908A and D909, respectively. Further cooling below these temperatures, the fluids from these wells becomes saturated with respect to amorphous silica, which may lead to deposition.

In the diagrams for water from wells D906A and D907A (Figures 5 & 6) fluorite is in equilibrium at temperatures between 40°C and 50°C, and therefore fluorite scaling is not expected above these temperatures. When temperatures are lowered the water moves closer to saturation with fluorite. However, the diagrams for water from wells D908A and D909 (Figures 7 & 8) equilibrium temperatures are at 100°C and 140°C, respectively.

4. CONCLUSIONS

The chemical composition of the geothermal waters from the 4 wells at Olkaria Domes wellfield has been used to predict possible scaling problems at changing temperatures right from prevailing aquifer conditions. Based on the chemical data of the geothermal waters, the WATCH speciation program by calculating the saturation index for many minerals has proved a helpful tool in identifying minerals which could possibly form deposits at the wellhead temperature and at consequently lower temperatures reached during resource utilization. The 4 selected geothermal wells for the present study have waters displaying varying chemical composition that seems to depend on aquifers and local geological conditions, despite their proximity to one another. It is evident that all of them have a potential for scale formation. However, the minerals to watch are in particular amorphous silica and calcite, as the rest have been locally known not to

cause problems. Mineral deposition during phase segregation is largely the result of sudden increases in the pH in the hydrothermal solutions, due to exsolution of CO_2 and concomitant loss of H_2S. Monitoring of pH change with time is important to check the presence of pH-induced scaling.

ACKNOWLEDGEMENT

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