Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Scale Deposition Experienced in Olkaria Well OW-34

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Keywords: OW-34, Scale deposition, excess enthalpy, chloride.

ABSTRACT

After steam decline was experienced in the production field for the Olkaria I plant in the initial five years of its operation, Olkaria well OW-34 was drilled as a make up well alongside OW-33, OW-32, OW-31 OW-30 and OW-29 wells. It was drilled in 1992 and discharge tests were conducted most of 1993, part of 1996 and in February to March of 2003. The well was connected to the production system in March 2001 and after producing for about 18 months its steam output declined significantly. A thick deposit of scale was observed on inspection of the surface piping at the wellhead master valve, in the two-phase line, inside the separator and in the separated water line. This was unusual as no other well in the Olkaria East Field has ever experienced this magnitude of scale deposition. Most wells in the Olkaria East Production Field show dilute content of solute in the fluids. Typically, in the exploited Olkaria East Production Field, chloride concentration of the fluids sampled at the well weir box are in the range of ~ 300 to ~1000 ppm. Most wells in Olkaria East Production Field exhibit "excess enthalpy" conditions. Well OW-34 fluids showed "excess enthalpy" very close to the enthalpy of steam, very low water flow rates and very high solute content in the residual fluids sampled at the weir box. The chloride concentration of well OW-34 fluids is ~ 3000 ppm and differs greatly from the chloride content of other Olkaria wells. Processes that could influence the fluid composition and possible predictions for scale forming minerals using the speciation computer code WATCH were evaluated and an XRD run on the scales was performed. The XRD run showed 23 angstrom on the 2D-θ scale which is characteristic of amorphous silica. From investigations of flow tests it is thought that a leakage of colder water from shallow depths trickles into the well when it is on discharge. The shallow colder water with a modest silica concentration mixes with upflowing fluids with a much larger steam fraction and gets evaporated after absorbing the heat from the steam and subsequently supersaturating the fluid with respect to silica which leads to silica depositing out of solution.

1. INTRODUCTION

Well-OW 34 is located in the Olkaria East Production Field 9 (Figure 1) and was drilled as a make up well for the supply of steam to Olkaria I power plant. It was drilled between 15. 11.1992 and 16.12.1992 to a vertical depth of 2136 m and was cased at 596m. The well was flow tested from 20.5.1993 to 23.11.1993, from 18.12.1995 to 27.05.1996 and more recently from 13.02.2003 to 24.03.2003. The first flow test was routine flow test done on a newly drilled well to characterize its output and estimate its power potential. The second test's goal was to monitor tracer returns and the effects of injection in well OW-R3. The more the recent test investigated the cause of unusual silica deposition in the two-phase pipe work and surface equipment of this well. This well was connected to the power plant on 21st of March, 2001, and was isolated on 20th of September, 2003, after its output, as measured by the flow orifice plate, indicated a significant decline. On dismantling the flow pipes and well head equipment and during the subsequent inspection, a thick deposit of silica scale, almost 1 inch in thickness, was found in the two phase pipeline, about ½ inch in thickness inside the separator and separated waterline. The Olkaria East Production Field (OEPF) has been under exploitation since 1981 when the first unit was commissioned. No other well in the OEPF has had this kind of scale deposit that has lead to sharp decline in output.

In the OEPF the solute content of the well fluids is dilute and of low salinity. Chloride concentration in the well fluids of this field sampled at atmospheric pressure are in the range of ~ 300 to ~1000 ppm. Fluids from this reservoir are drawn from two zones: a boiling liquid dominated part and a steam zone. Generally, wells in this field exhibit a high " excess enthalpy" which is partly due to boiling in the formation with differential flow of steam and water. A few wells in the field showed `excess enthalpy' even on the initial discharge and these probably tap from a shallow steam zone. Well OW-34 fluids showed " excess enthalpy" very close to the enthalpy of steam, very low water flow rates and higher solute content than an average Olkaria well in the residual fluids sampled at atmospheric pressure. The chloride concentration of the well fluids ~ 3000 ppm – a very different fluid characteristics, which is not typical of any Olkaria well fluids. The well at times discharges dry steam as no separated water gets to the well weir box. This was observed during discharge tests conducted in February-March, 2003, and also during the time the well was on production. Fluid composition and the processes influencing it, possible predictions for scale forming minerals using the speciation computer code WATCH, and reservoir conditions that influence silica deposition are evaluated

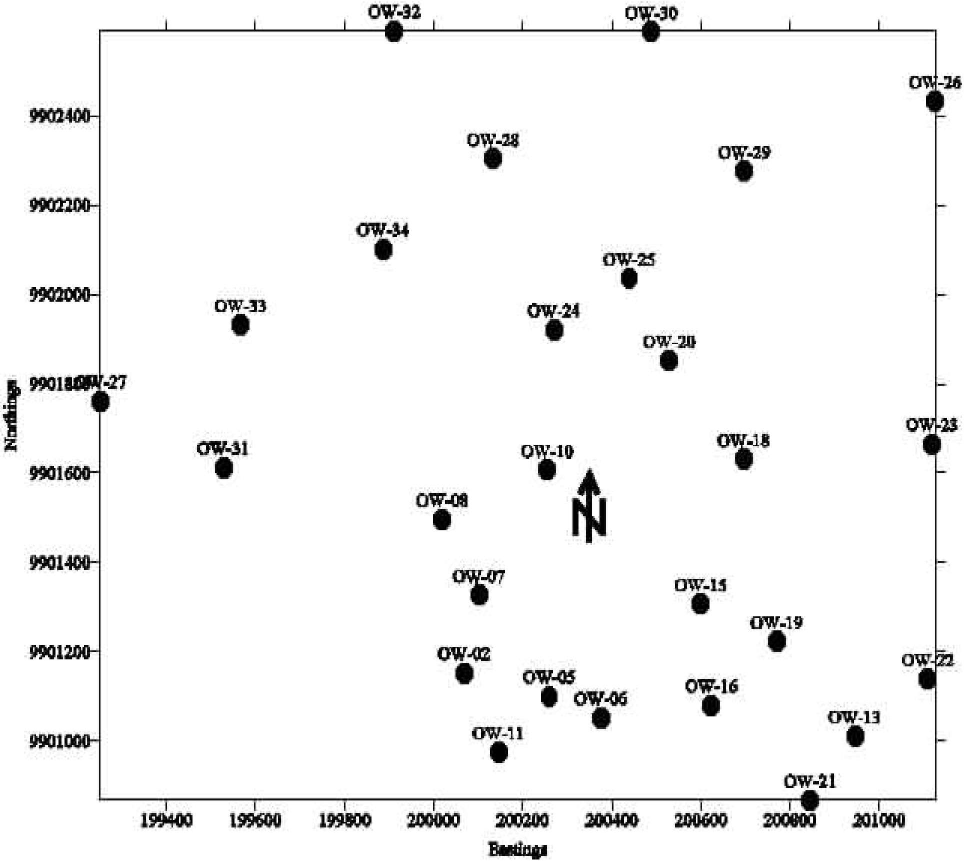


Figure 1: Location map of wells in the Olkaria East Production Field

2. GEOLOGICAL SETTING

The geology of rocks or lithology of rocks encountered when well OW-34 was drilled include pyroclastics, tuffs, rhyolites, trachytes and basalt which are typical of most wells drilled in Olkaria East Field. Hydrothermally occurring minerals encountered in this well consist of oxides, clays, silica minerals like quartz, calcite, epidote, pyrite dominate in most zones. These are described from cuttings by the use of a x 10 binocular microscope.

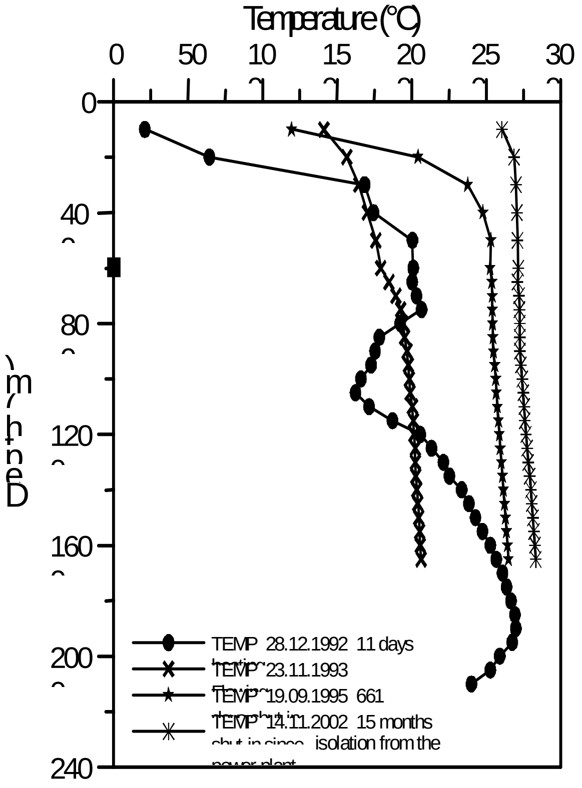
3. THE CHEMISTRY OF WATER FROM WELL OW-34

Well OW-34 fluid composition is summarized in Table 1 alongside the fluid composition of other make up wells drilled in the Olkaria East Production Field. Included in Table 1 is the composition of fluids of wells that have experienced the effects of boiling most during the exploitation of the field. (Samples were taken at well weir box). The processes that influence this fluid composition are described below. The discharge chemistry was evaluated under different flow conditions in Febraury-March of 2003, but generally the trends in fluid composition did not change. The flow conditions were changed by use of different lip pressure sizes.

TABLE 1: WATER COMPOSITION OF WELL OW-34 FLUIDS, MAKE UP WELLS AND WELLS AFFECTED MOST BY BOILING EFFECTS (SAMPLED 2000 AND 2001)

	OW-34	OW-33	OW-32	OW-31	OW-29	OW-25	OW-18	OW-10
WHP	5.6	5.5	6.5	6	9.3	9.9	7	6.2
SSP	5.6	2.07	6.2	4.14	4.14	4.8	5.3	5.1
ENTH	2728	2418	2332	2418	2203	2415	2625	2518
pH@20	7.83	7.84	8.76	7.99	8.58	8.76	8.75	8.48
SiO_2	924	825	769	550	751	507	650	633
B	9.6	7.7	0.8	5.4	11	3.6	4.8	8.2
Na	2411	715	572	751	603	601	813	865
K	549	129	138	129	78	111	113	141
Ca	0.004	0	0	0	0	0	0	0
Mg	0	0	0	0.03	0	0.01	0	0
Al	0.843							
Fe	0.51							
CO_2	302	90	72	27	51	128	35	25
SO_4	77	105	56	53	34	11	62	89
H_2S	0.24	0.95	0.68	0.68	2.9	1.7	0.5	0.3
Cl	4038	1031	849	1065	678	785	994	1122
F	262	73	82	58	101	87	89	70

Wells that have shown boiling effects on field exploitation and have high solute concentration in the residual fluid are wells located in the central part of the Olkaria East Production Field. These include wells OW-10, OW-18, OW-20, OW-25. Wells that were drilled as make up wells show high chloride concentration and include wells OW-33, OW-32 OW-31. The chemistry of well OW-34 fluids shows a much higher concentration of solute content in the residual fluids. The chloride concentration of this well is ~ 3000 ppm. In a KRTA (1984) report on the proceedings of the scientific and technical review meeting it is reported that an "upper saline lens" of ~ 3000 ppm cl was observed in the Olkaria East Field. Its origin described to be (may be) due to groundwater trickling into an underground trap and being conductively heated, resulting in slow evaporation and leading to increase in salinity. It is likely, the compositions of fluids tapped by well OW-34 are these ground waters that have under gone heating by the above process leading to the high solute concentration. This is also suggested from flowing profiles of the well conducted in 1993 that show that just below the casing shoe there is an entry of cooler fluid which substantially lowers the temperature of the upcoming fluid from depth by almost 40^0 C resulting in some pressure drop (Figure 2, Opondo and Ofwona,2003).



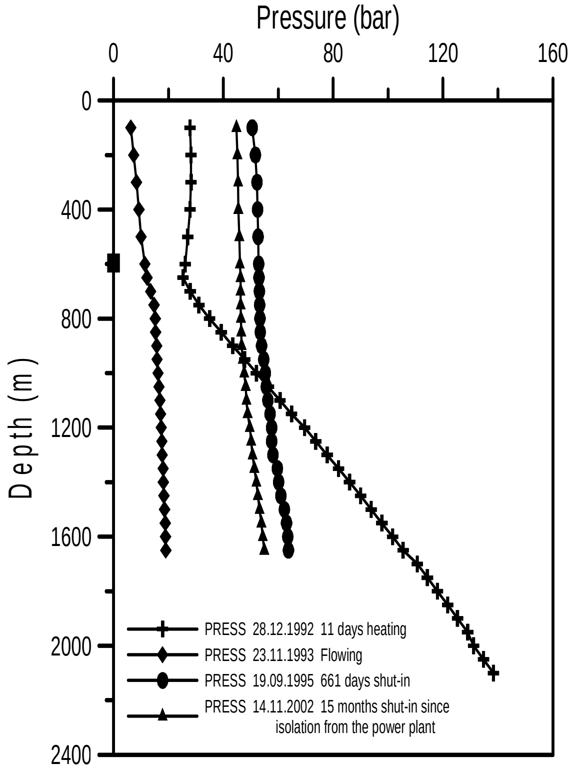


Figure 2: Downhole temperatures and pressures in well OW-34 (Opondo and Ofwona, 2003)

An attempt to model the process that predominates and influences the composition of the well fluids for well OW-34 is hereby made. As described by Arnorsson,(2000) there are two kinds of models that can be applied to calculate the composition of the acquifer water, namely 'closed systems' and 'open systems' for "excess enthalpy" wells. For wells with discharge enthalpy close to that of water at the acquifer temperature the total discharge composition calculated is representative of that of the acquifer fluid. Well OW-34 fluids show discharge enthalpy that is very close to the enthalpy of steam. Arnorsson (2000) describes a "closed system" model as a system where the total discharge may differ in enthalpy but not in mass. When the total discharge of the well differs in both the enthalpy and mass then the system is described as an "open system". For the 'closed system model' the discharge enthalpy corresponds closely to the enthalpy of saturated water at acquifer temperature when water evaporation is due to depressurisation plus heat transfer. The steam fraction (X_s) used in this case is one derived from the discharge enthalpy. For the 'open system'model the discharge enthalpy far exceeds that of enthalpy at acquifer temperature and the acquifer water composition recalculation is based on a two step processes where the concentrations of water and steam are recalculated at 180^0C and at acquifer temperature. The steam fractions of well OW-34 fluids recalculated at 100 ^{0} C, 180 ^{0} C and 270^0C using the discharge enthalpy are presented in Table 2.

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Table 2: Steam fractions of well OW-34 fluids recalculated at 100 ^{0} C, 180 ^{0} C and 270 ^{0} C using discharge enthalpy

OW-34	2001 J	2001 D	2002 J
WHP	5.6	6	5.8
ENTH	2672	2652	2675
X @$_{100}$ ^{0} C	0.998	0.989	0.999
X @$_{180}$ ^{0} C	0.948	0.936	0.950
X @ $_{270}$ ^{0} C	0.927	0.914	0.928

J= June D= December

Steam fractions recalculated at 100 ^{0} C would suggest steam that is close to superheating as most of the water is evaporated. These would suggest high concentrations of solute would deposit when the water flashes at atmospheric pressure. At 180 ^{0} C and 270 ^{0} C the fraction of steam declines but not significantly. The water fraction at the acquifer temperature is very small. The steam fractions calculated at the 180 ^{0} C and 270 ^{0} C could suggest the steam moved preferentially leading to depletion of water. The total discharge composition calculated from these steam fractions does not represent the composition of the acquifer fluid. In the case of well OW-34 the dominant processes contributing to the fluid composition is evaporation of water as it boils leading to steam separation that contributes to the high discharge enthalpy of the well fluids.

3.1Chemical Simulation for Scale Potential For Well OW-34 Fluids

The computer code WATCH (Bjarnson, 1994) is used in water–rock reactions. It takes in chemical analyses of water, gas and steam condensates of sample with pH, temperature and pressure at the sampling point. The computer code WATCH at any desired temperature is capable of calculating pH, aqueous speciation, partial pressure of gasses, redox potentials, ionic strengths, chemical equilibria and mass balance equations to get the fluid composition and distribution of species. In this study scale potential of three samples taken from well OW-34 is assessed after adiabatic boiling of the well fluids at selected temperature decrements as the fluids move from the reservoir to the surface. A plot of saturation indices for amorphous silica and temperature are shown in Figure 3.

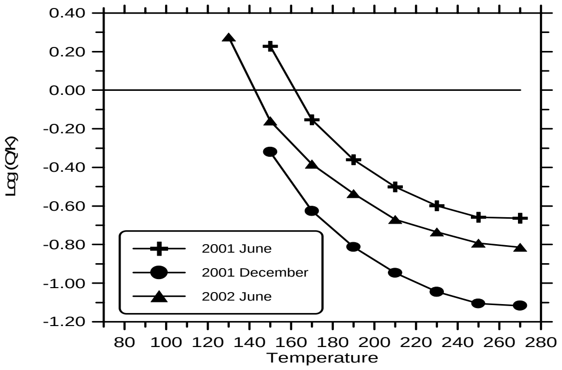

Figure 3: Well OW-34 silica saturation indices, log (Q/K) for three weir box samples versus temperature

The assessment for the potential for mineral scales to form from saturation indices is based on thermodynamic data and is calculated as the reaction quotient (Q) divided by the equilibrium constant (K). Three samples of fluid for wells OW-34 monitored over the period June 2001 to June 2002 were input into WATCH and the silica saturation indices were calculated from the acquifer temperature of 270 ^{0} C to 110 ^{0} C respectively when the fluid lost steam through adiabatic boiling. As well OW-34 fluids cool by adiabatic boiling and loss of steam, a state of saturation with respect to silica occurs between 140 ^{0} C and 160 ^{0} C. Silica super saturation occurs when the fluids cool further below the silica saturation temperatures of this well fluids. The fluid sample for June 2001 showed slightly higher silica saturation temperature of ~ 160 ^{0} C, while for the sample taken in June 2002 silica saturation temperature declines to ~ 140 ^{0} C. It appears that silica saturation temperature for the well fluids declined with time. Arnorssorn (1995) states that the solubility of amorphous silica is temperature dependent and separating the well fluids above the silica saturation temperature would keep the fluids under saturated with respect to silica. Silica deposition is likely to occur when the well fluids cool below the silica saturation temperature.

3.2 Silica Deposition

Well OW-34 experienced very low water flow rates ~ 0.5 t/h (Kariuki and Opondo, 2001), Kariuki and Wambugu (2002) . The water flow rate varied from 0.6 t/h in June 2001 to 0.2 t/h in June 2002 (Kariuki and Opondo 2001, 2002). Steam output from this well declined from ~ 42.8 t/h (Kariuki and Opondo 2001) when the well was hooked to the production system in June 2001 to 8.6 t/h in June 2002 (Kariuki and Wambugu 2002). The output for well OW-34 over time is shown in table 3.

Table 3: Output for well OW-34 between July 2001 and July 2002.

Year	Steam (t/hr)	Water (t/hr)	Mass (t/hr)	Enthalpy kJ/Kg
2001 July	43.15	0.3	443.45	2742
2001 Sept	37.4	0.8	38.2	2712
2002 mar	7.2	0.2	7.4	2743
2002 July	7.35	0	7.35	2756

This shows a sharp decline in steam output between July 2001 and July 2002. During routine maintenance of the well which was done in August 2002, scale deposits were observed at the T- connection close to the well head master valve, inside the two phase line, inside the separator and inside the separated water line. Steam decline in this well could most likely be attributed to scale deposition in the transmission pipelines of this well. Two scale samples, one from inside the separator and the other from the separated water line, were taken and analyzed in the XRD. The patterns of the XRD peaks could be identified for both samples. They occur at ~ 23^0 2θ. These peaks are characteristic of pure amorphous silica or opal A (Manceau et al., 1995). The XRD runs of the two samples from separated water line (A) and inside the separator (B) are depicted in Figure 4.

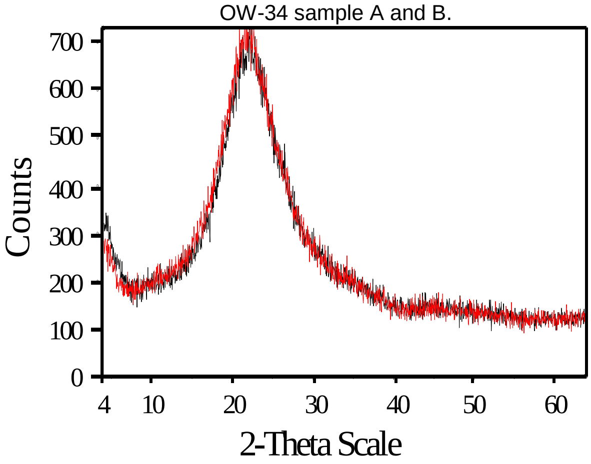

Figure 4: XRD peaks for scale samples from separated waterline (A) and inside the separator (B)

The peak is not shifted as it would be the case when high concentrations of other electrolytes like Al^{3+}, Fe^{3+}, Fe^{2+}, Mn^{2+} are present in the brines (Gallup, 1998). Scale deposition occurred at different locations and showed different thicknesses. Measured thickness of scale was done at the T-connection close to the well head master valve, two- phase line where there is a bend before an orifice, and in the separated water lines. The thickness was measured with the aid of a vernier caliper. The thickness of scales by location is shown in Table 4.

Table 4: Thickness of scale at different locations

Inside two phase line	~ 1 inch
Inside separated water line	~ ½ inch
At the well head T-connection	~ ½ inch

The highest deposition of scale appears to have occurred in the two-phase line. Modest deposition occurred in the separated water line while lower deposition occurred at the T- connection close to the well head. It is likely that most scale deposition occurred in the two-phase line due to further cooling of the two-phase fluid and further evaporation. The scale deposits and their locations are shown in figure 5 a , b, c and d

Figure 5a: Thickness of scale deposited in two-phase line

Figure 5b: Thickness of scale deposited in separated water line

Figure 5c: Thickness of scale at the T-connection of the well OW-34

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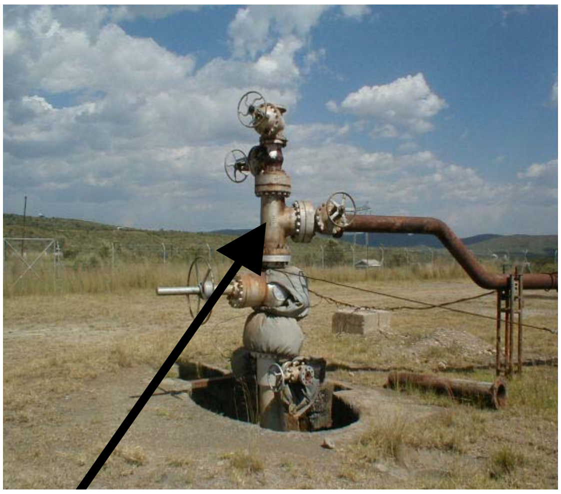

Figure 5d: T-connection on well OW-34

4. DISCUSSION AND CONCLUSIONS

Well OW-34 was drilled as a make up well in Olkaria East Production Field and was connected to steam gathering system in March 2001 to sustain steam supply to the power plant but was shut down after scales deposited in surface pipe work causing an apparent decline in its output. From XRD analysis, the scale has been identified to be that of amorhous silica. The solute content of well OW-34 fluids differs distinctly from the solute content of other make up wells drilled in the Olkaria East Field and other wells drilled generally in the Greater Olkaria Geothermal Area. The chloride content for Olkaria wells is generally in the range of ~ 300 to ~1000 ppm , but for well OW-34 fluids exhibit chloride concentration of ~ 3000 ppm. The distinct difference in the fluids of this well from the other Olkaria wells could be explained by processes of evaporation by conductive heating in place of ground water that trickles into an underground trap. This leads to slow evaporation and as the fluids ascend to the surface they transport with them a higher solute content. From the models of heat transfer either by 'closed' or 'open system', recalculated steam fractions at 100 ^{0} C, using the discharge enthalpy of the well fluids, suggest a situation where the steam fraction (X_s) exceeds 1. This could suggest probably that as the well fluids flash from the aquifer to atmospheric pressure, superheating could occur leading to high solute content in the well fluids. Equally, the steam fractions recalculated at 180 ^{0} C and 270 ^{0} C suggest preferential movement of steam leading to depletion of the fluids in the water fraction.

The fluids from this well have a small water fraction and could be very near saturation or supersaturated with respect to silica. With a drop in temperature or pressure in the surface pipe work, the liquid fraction will flush or boil leading to supersaturation with respect to silica that would end up in silica deposition. From temperature profiles the small water fraction from the discharge could be of a shallow origin. When it mixes with the larger steam fraction, the liquid fraction is largely evaporated leaving a supersaturated fluid that deposits silica. The thickness of the scale varied at different locations and this could have been due to different fluid processes contributing to the scale formation. Similar experience has been realized with some high enthalpy wells in the Tiwi Geothermal Field in the Philippines (Barnett 2003, pers comm). He suggests one solution to this problem is to inject more liquid upstream of the mixing location (e.g. brine or condense) or to simply leave it. The well will eventually dry out and with no more liquid the problem will go way. There has been no experience of scale deposition of the magnitude that has occurred in well OW-34 pipe work in the Olkaria East Field.

ACKNOWLEDGEMENTS

I thank the management of Kengen for permission to publish this paper and for valuable comments by colleagues in the geochemistry laboratory.

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