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Carbonate Scale Formed in Well Ow-202 in Olkaria Central Field, Kenya

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ABSTRACT

Olkaria well OW-202 was drilled as an appraisal well alongside wells OW-201, OW-203 and OW-204 in Olkaria Central Field, which is one of the seven sectors of the Greater Olkaria Geothermal Area. In the Olkaria Central Field other wells drilled are wells OW-101, OW-601, OW-102 and well OW-501. Wells OW-102, OW-203 OW-204 and OW-601 did not discharge when discharge tests were conducted. These wells were drilled as exploration wells in the Olkaria Central Field. Well OW-202 is currently under lease to Oserian Development Company (ODC) for power production since September 2006. This well supplys steam to an Elliot type back pressure turbine rated at a nominal power output of 1.4 MWe, operated by Oserian Development Company (ODC) since March 2007. Generally in the Greater Olkaria Geothermal Area the water composition encountered in the wells is variable, with dilute content and very low salinity. Typically, in the exploited fields of Olkaria East and Olkaria North East operated by Kenya Electricity Generating Company (KenGen), water composition is predominantly chloride while waters in the Olkaria West, operated by Orpower 4 Inc is carbonate dominated. Well waters in Olkaria Central discharge water type that is mixed sodium-chloride bicarbonate. Wells in the Olkaria Central Field mainly discharge liquid dominated fluid with a discharge enthalpy of saturated water temperature and a chloride range of ~ 300 ppm at separation pressures. Processes that could influence the fluid composition and possible predictions for scale forming mineral calcite using the speciation computer code WATCH was evaluated. Scales deposits flushed from the two-phase fluids indicated carbonate dominance after testing using hydrochloric acid. Well OW-202 experienced a drop in steam output since its production and it is thought scales deposition in the well could have contributed to this observation. A down hole dummy run indicated the well was blocked at a depth of ~ 955 metres. A sampler taken down the well recovered a scale sample at 908 meters suggesting the scale could have formed at a much shallower depth. From a steam supply equivalent of 1.4 MWe the well declined to a steam supply equivalent of less than 400KW. The well has to be stimulated to enable it to discharge. To understand the cause of the steam decline water and gas sampling was done for about one year to establish the cause of the decline.

1. INTRODUCTION

Olkaria well OW-202 was drilled as an appraisal well alongside wells OW-201, OW-203 and OW-204 in the Olkaria Central Field. Wells OW-201 had reversed discharge while, wells OW-203 and OW-204 did not discharge. Well OW-202 was drilled to a total depth of 2207m and cased at ~704 meters. The highest temperature recorded in September 1999 after about three years shut-in was ~ 237 ° C. Initial discharge tests gave a total mass flow of 144t/hr of which about 30t/hr was steam and a flowing enthalpy of 1041 kJ/kg. The calculated power potential then ~ 3.0 MWe. Injectivity tests indicated the well had an injectitivity of about 1200 lpm/bar an indication that the well cut a highly permeable zone. Major feed zones were encountered at between 850 to 1000m and also around 1800m.

The well remained shut in for many years until 2004 when Oserian Development Company (ODC) expressed interest to use the well. This was after successfully commissioning a heat plant on well OW-101 which was drilled by KenGen as an exploration well. KenGen agreed to lease well OW-202 to ODC for electric power generation on a steam sale agreement. The terms of the lease agreement was negotiated and a steam sale contract entered between KenGen and ODC. ODC designed and installed a 1.4 MWe power plant. At commissioning the power plant the well was supplying steam to an Elliot back pressure turbine for generation of electric power at a nominal rating of 1.4MWe. The Elliot back pressure turbine plant was commissioned in March 2007 . At commissioning in 2007 the well was performing close to the initial design of ~ 1.4 MWe of steam equivalent . However, the well has declined in output, from a steam supply equivalent of 1.3 MWe in 2007 to steam supply equivalent of 400 MWe in August 2010. The well was drilled and discharge tested first in 1998, in 1999 and in 2005 prior to the construction of the Elliot back pressure turbine by Oserian Development Company (ODC). Well OW-202 is drilled between wells OW-203 and OW-204. The wells in Olkaria Central Field are drilled to an average vertical depth of ~ 2200 meters and well OW-202 was cased at ~704 meters.

The well was flow tested from 19 .03.1998 to 20.04.1998, from 09.11.1998 to 08.12.1998 and recently from 17.11.2005 to 2.12.2005. The first flow test was the routine flow test done on a newly drilled well to characterize its output and estimate its power potential and the subsequent ones were done to confirm the results of the first tests for plant design and construction. This well was connected to the Elliot Power Plant in March 2007 and has been in production since. The well output declined as measured by the pressure drop across the flow orifice plate and the estimated output dropped from 1.4MWe in steam equivalent to less than 400 KWe steam equivalent by August 2010. Fluid composition of Olkaria Well OW-202, processes that could influence the fluid composition, possible predictions for carbonate scale formation using the speciation computer code WATCH and scale deposition formed on flashing the fluid in the two phase line have been assessed. Scales sampled from two phase line and at a depth of 908 meters were assessed and are the subject of this report.

The general location of wells in the Greater Olkaria Geothermal Area together with location of well OW-202 in the Olkaria Central Field is shown in Figure 1.

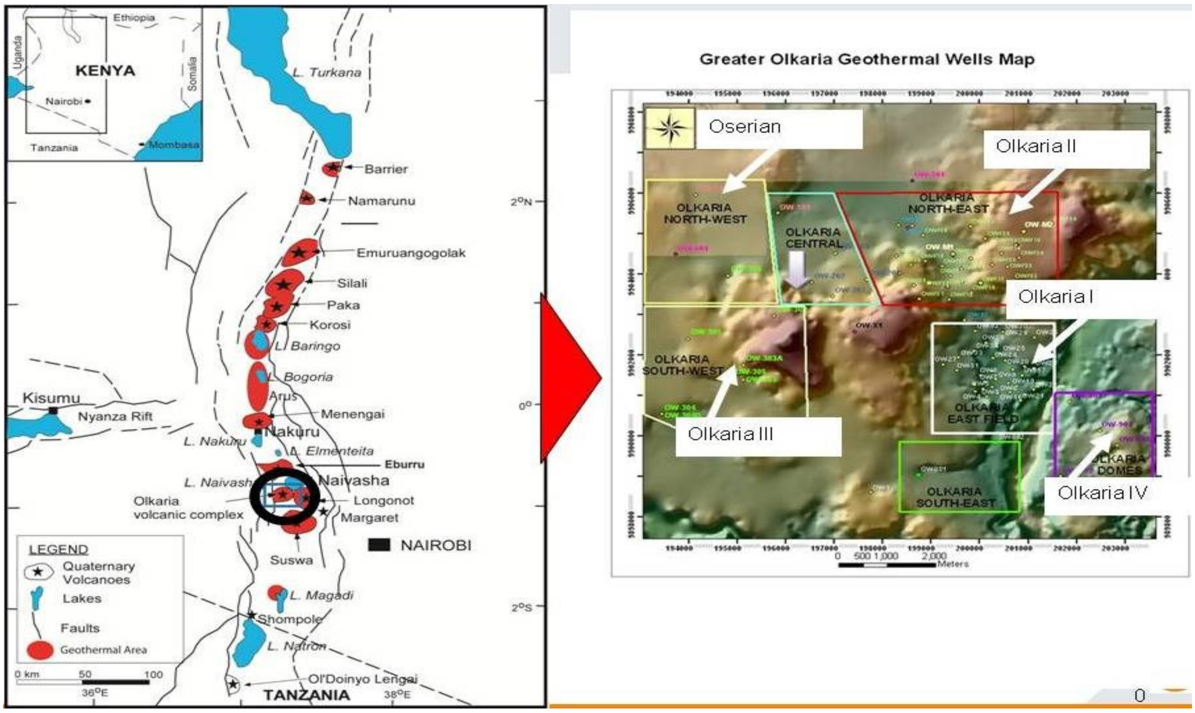

Figure 1: Map showing geothermal prospects in Kenya including the Greater Olkaria Geothermal Area

1.1 Geological Setting

The geology of rocks encountered in Olkaria Central Field in which well OW-202 falls can be described to consist of soda rhyolite, grains of quartz and alkali feldspars in the groundmass. Other rock formations consist of pyroclastics, observed as pumiceous tuffs containing a mixture of rock fragments, riebeckite rhyolite(Trachyte) riebeckite trachyte , basalts, and intercalations of tuffs/rhyolite. Hydrothermal alteration minerals encountered in wells in Olkaria Central Field consist of oxides, clays, silica minerals like quartz, calcite, flourite and zeolites. These were identified from rocks encountered by wells drilled in Olkaria Central Field. A notable exception is the absence of epidote in rocks in the wells in Olkaria Central. At slightly shallower depths higher concentrations of chalcedonic quartz is observed. Lower down the wells in Olkaria Central Field rounded grains of quartz were observed. Lithological descriptions were mainly done from cuttings by the use of a X10 binocular microscope.

2. THE CHEMISTRY OF WATER FROM WELL OW-202

Well OW-202 fluid composition is summarised in Table 1. Of the appraisal wells drilled in Olkaria Central only two wells were discharge tested. Wells OW-202 and OW-101 were able to be discharge tested and there fluids sampled. These were the only wells in Olkaria Central whose fluids could be characterized. Included in Table 1 is the composition of fluids from well OW-101. Water samples from well OW-202 were taken at the well weir box for the first three tests and steam sampled using a webre separator. During production the samples of both water and steam were taken by use of a webre separator. The concentration of carbon dioxide in solution on average for the well fluids is higher compared to the well fluids in Olkaria North East and Olkaria East. The processes that influence this fluid composition are described below. The discharge chemistry of well OW-202 fluid was evaluated under different flow conditions but generally the trends in fluid composition did not indicate much variation.

Table 1: Typical water composition of well OW-202 and OW-101 fluids discharged in Olkaria Central Field (in ppm)

Well	WHP	SSP	Enth (kJ/Kg)	pH @20° C	SiO_2	B	Na	K	Ca	Mg	Li	CO_2	H_2S	Cl	SO_4	F
OW-202	3.1	3.0	1061	9.0	388	1.4	559	131	1.4	0.6	2.2	1031	3.1	284	69	60.3
OW-101	5.3	4.3	1660	9.5	600	4.0	660	112	0.3	0.2	2.9	1108	4.8	357	57.0	61.0

Table 1 cont'd: Typical gas concentration in steam (mmoles/100 moles steam)

Well	WHP	SSP	Enth (kJ/Kg)	CO_2	H_2S	CH_4	H_2	N_2
OW-202	3.1	3.0	1061	641	1.7	0.2	0.1	0.7
OW-101	5.3	4.3	1075	882	1.4	0.8	0.4	0.05

Wells drilled in Olkaria Central Field and discharge tested include well OW-101 which is under lease by Oserian Development Company (ODC) from KenGen for use in greenhouse heating. The two wells whose fluids were sampled in Olkaria Central Field, are wells OW-202 and OW-101. They indicate similar fluid types. These are sodium bicarbonate waters with carbonate being the dominant anion component with low chloride values. The water types of well OW-202 and OW-101 are shown in the triangular Chloride-Sulphate- Bicarbonate ternary plot in Figure 2 below.

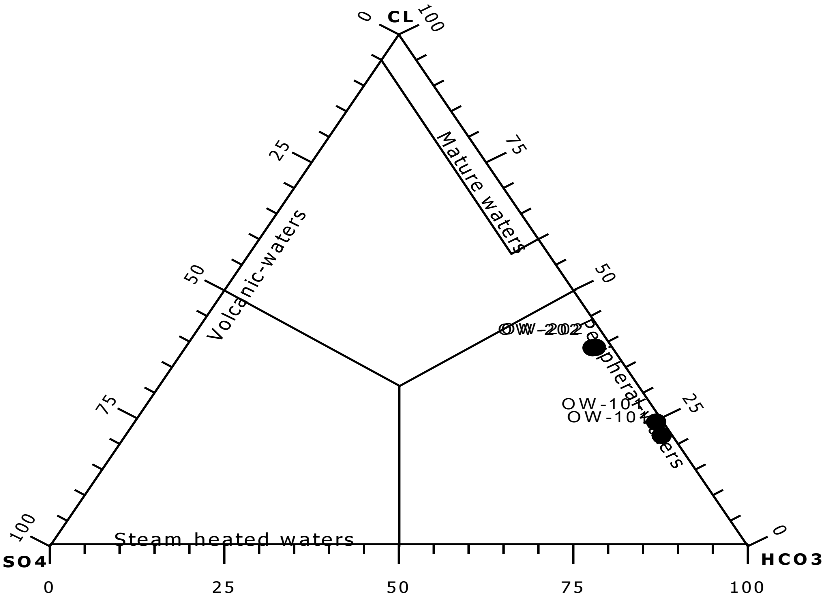

Figure 2: Chloride- Sulphate- Bicarbonate ternary plot for water from wells OW-101 and OW-202 in Olkaria Central Field.

2.1 Chemical simulation for calcite deposition potential for well OW-202 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 gases, 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 a representative sample taken from well OW-202 was assessed. The temperature dependence of the calcite equilibrium constant (K) is determined by the following equations.

$$CaCO_3 = Ca^{2+} + CO_3^{2-} \tag{1}$$

$$k = \frac{\left[Ca^{2+}\right]\left[CO_3^{2-}\right]}{CaCO_3} \tag{2}$$

The temperature dependence solubility of calcite is expressed by the following equation

$$LogK = 10.22 - 0.0349 \times T - \frac{2476}{T} \quad \text{(Arnorsson et al, 1983)} \tag{3}$$

K = the equilibrium constant at a given temperature

T = temperature in Kelvin

Calcite scaling potential during adiabatic boiling for fluids from well OW-202 was assessed at selected temperature decrements as the fluids move from the reservoir to the surface. The initial temperature selected for the calculation of the saturation indices was that measured in the reservoir. A plot of calcite saturation indices for well fluids from well OW-202 log (Q/K) and selected temperature decrements are shown in Figure 2a.

Figure. 2a shows the variation of calculated saturation index values during adiabatic boiling of aquifer fluids of well OW-202. The assessment for the potential for mineral scales to form from saturation indices is based on thermodynamic data and calculated as the reaction quotient (Q) divided by the equilibrium constant (K). One representative sample of fluid from well OW-202 was taken and input in the programme WATCH. Calcite saturation indices were calculated from the highest measured aquifer temperatures of ~ 240^0C to 90^0C respectively when the fluid lost steam through adiabatic boiling. This was at temperature decrement steps of ~ 20°C from the highest measured temperatures. As well OW-202 fluids cool by adiabatic boiling and loss of steam, a state of supersaturation with respect to calcite occurs throughout the boiling process from the aquifer temperatures of 240 ° C. As the fluids cool to much lower temperatures, close to atmospheric pressure the solubility of calcite increases, but not sufficiently for the fluids to be undersaturated with respect to calcite. This indicate the potential for calcite deposition to occur upon boiling in the well. Figure 2b depicts the equilibrium constant (K) as a function of temperature together with the reaction quotient (Q) at the same temperatures. The reaction quotient exceeds the equilibrium constant and suggests super-saturation with respect to calcite.

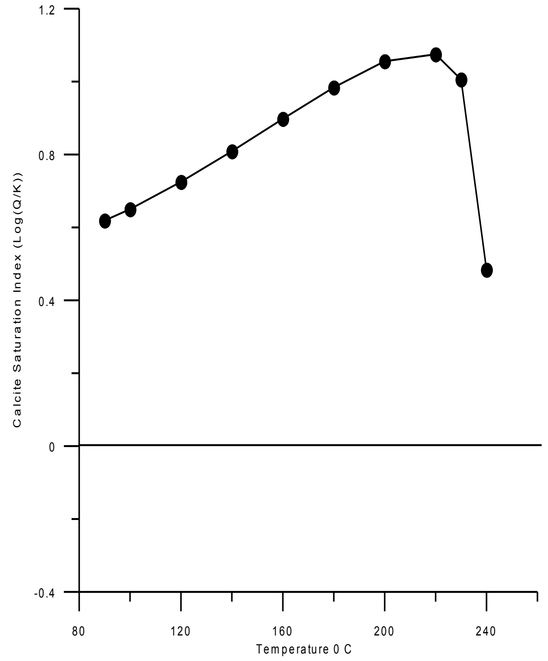

Figure 2a: Well OW-202 calcite saturation indices, log (Q/K) for a representative sample versus temperature

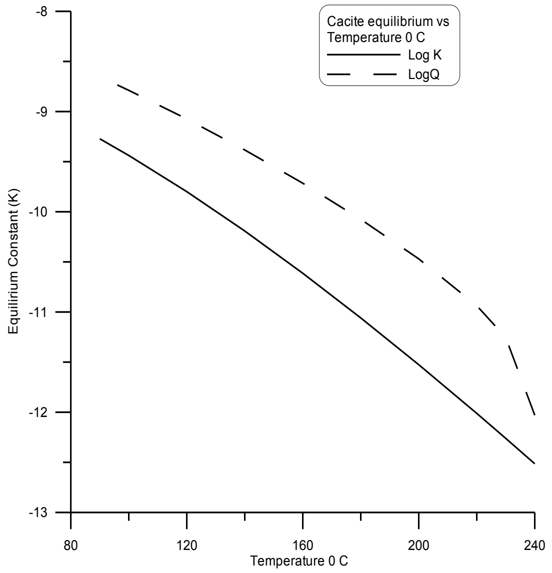

Figure 2b: Well OW-202 calcite saturation indices, log (Q) the reaction quotient and Log(K) the equilibrium constant for a representative sample versus temperature.

The shape of the SI_{cal} curve is more accurately defined than the absolute SI_{cal} value at each temperature. The effect of boiling with pressure drop upon the calcite saturation state is essentially two fold. Firstly, the water is degassed with respect to CO_2, which leads to an increase in the pH of the boiling water (Fig. 3) which in turn brings about an increase in the carbonate ion concentration and hence in the $[Ca^{+2}][CO_3^{-2}]$ solubility product (Arnorrsson, 1989). Boiling of geothermal water as indicated by the single step adiabatic boiling results in an increase in pH due to loss of carbon dioxide (CO_2) as depicted in Figure 3 below. The carbonate ions increase in this case.

Boiling of the fluids due to pressure drawdown causes cooling of the water. The solubility constant for calcite increases with decreasing temperature. Degassing caused by boiling due to pressure drawdown causes an initially calcite saturated solution to become supersaturated whereas the cooling by this boiling has the opposite effect. The solubility of CO_2 in water changes with temperature, being at minimum around 200˚C. Degassing during the early stages of boiling is accordingly most effective for aquifer waters with temperatures around 200˚C (probably within the temperature range 200-240˚ C). For aquifer waters with temperatures around 200˚C-240 ˚C early degassing with respect to CO_2 is rapid due to its relatively low solubility in water in this temperature range. Methods that affect calcite saturation have been summarized by Arnorsson (1995)

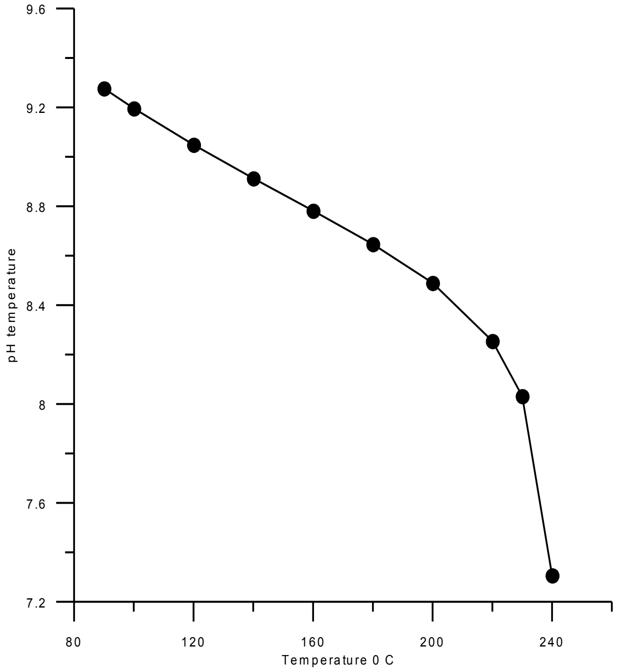

Figure 3: Calculated aquifer water pH for representative samples for well OW-202 and changes in pH during several intervals of single step adiabatic steam loss.

The shape of the curve in Fig. 2 can essentially be explained by a combination of three factors, (1) CO_2 degassing during boiling, (2) the solubility of CO_2 in water as a function of temperature and (3) the retrograde solubility of calcite with respect to temperature. The concentration of CO_2 in the initial aquifer fluid also has an influence. High CO_2 content of the aquifer waters of well OW-202 could contribute to the high SI_{cal} on the onset of boiling. For well OW-202 waters maximum SI_{cal} values are attained some 20-40 °C below the initial aquifer temperature of 240 ˚ C. At maximum the waters have largely been degassed and at temperatures below the maximum, SI_{cal} values become successively lower due to increasing calcite solubility with decreasing temperature. Continued high SI_{cal} values for well OW-202 fluids during boiling all the way down to atmospheric pressure is due to the high CO_2 content of the initial aquifer fluid which requires extensive steam formation for extensive degassing of the aquifer water.

In Olkaria Central Field calcite scale formation in wells may be a problem, depending on the depth level of first boiling. If it is within the well it may be relatively severe. Well OW-202 in Olkaria Central experienced decline in well ouput from ~ 1.4 MWe to ~ 400 KWe steam equivalent. Scales collected from flashed fluids in the two-phase line indicate that the scale was predominantly carbonate scale. A downhole dummy run conducted in the well on 24th August 2010 indicated the well was blocked at a depth of ~ 955 meters. A downhole sampler run down the well collected a scale sample at ~ 908 meters. This could suggest that scale deposition began at a much shallower depth . Chemical analysis for scales formed at ~ 908 meters indicated that the scale that formed was predominantly carbonate scale. Carbonate scaling has been troublesome in this well during production. This forms on the onset of boiling on depth of first level of boiling in the well. Troublesome calcite scaling in geothermal wells above the first level of boiling have been reported by (Benoit, 1989, Todaka et al, 1995, Evanoff et al, 1995).. Similar problems of scale deposition in the well bore were encountered at the Mahanadong –A sector of the Leyte Geothermal Field (Herras et al, 2000)

3. ANALYSIS OF SCALE DEPOSITS COLLECTED FROM WELL OW-202

Scales collected from the two phase pipeline of well OW-202 fluids and at a depth of ~ 908 meters in the well was studied by different analytical tools. This included dissolution of the scale in dilute hydrochloric acid (~ 0.5 g) , using a binocular microscope examination, thin section examination in a petrographic microscope, X-Ray powder diffraction (XRD) and chemical analysis by atomic absorption spectrophotometer (AAS). Brief descriptions of each technique are given below.

3.1 Binocular microscope descriptions.

The scale can be used to scribble on surfaces. They are white and off white scales, which appear like chalk. Euhedral structures with sharp edges and cleavages. The scales are easy to scratch and are soft. They can stick in fingers. The scales are platey in sharp and sub round. Could indicate carbonate scales in abundance.

3.2 Scale sample in thin section (petrographic microscope)

Thin section of scales obtained from well OW-202 were prepared and studied by use of a petrographic microscope. In thin section, the scales had a platey euhedral structure with angled cleavages. The mineral scales had low birefringence. Reflected light was greenish and this had low relief. The ground mass was brown to yellow crystals.

3.3 X-ray diffraction (XRD) measurements

Two scale samples, one from the two phase line and the other from a depth of ~ 908 meters in the well were taken and analysed in the X-ray diffraction (XRD). The samples were air dried, glycolated and heated as part of the treatment methods. The Scale sample from the two phase line did not indicate any characteristic peaks associated with clay minerals. No clay mineral features were distinguished from the XRD peaks for scale samples from the two phase line. The X-ray diffraction patterns revealed by the two scale samples from the two phase line and a depth of ~ 908 meters are depicted in Figures 4 a and b respectively.

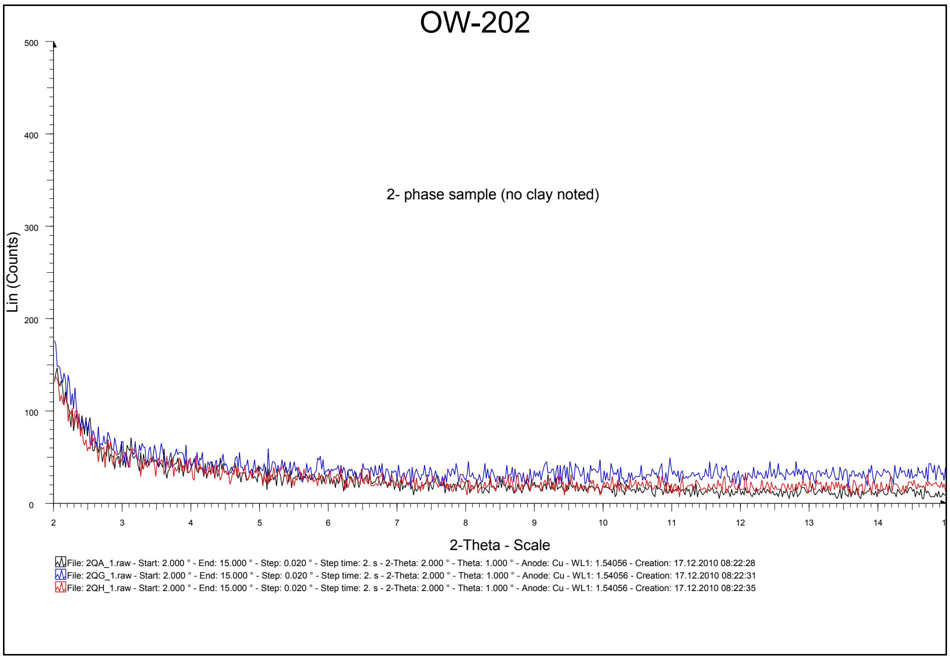

Figure 4a: X-ray diffraction pattern for scale samples from the two phase line

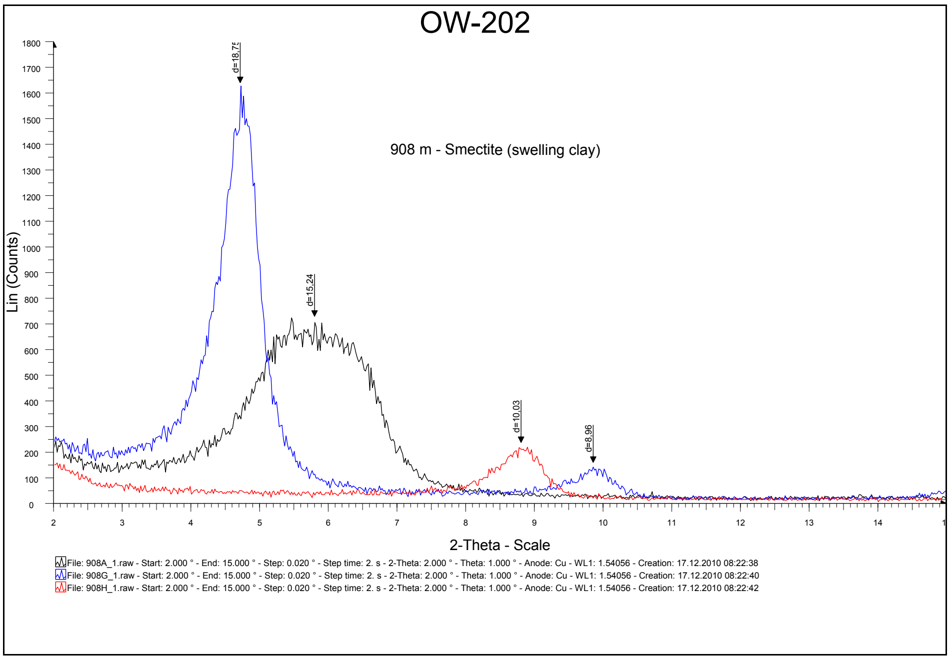

Figure 4b: X-ray diffraction pattern for scale samples at ~ 908 metres depth in well OW-202

Scales samples from ~ 908 metres indicated some clear diffraction peaks for the glycolated and the air dried samples. The peaks collapse for samples that are heated to 550 ° C. The collapse of the peaks for the heated samples indicated that the clays formed at this depth were swelling clays.

The smectite group of clays is commonly classified as swelling clays because they demonstrate high peak values in untreated (air dried) and glycolated samples but designate lower values when heated. This indicates that the structure collapses with less/decreasing moisture content. Generally, the peak values of the glycolated samples show values in the range of 12.56-18.92 Å, 13.36-17.46 Å for untreated/air dried samples and values of 9.04-10.22 Å for heated samples. However, this may vary depending on the quality of the sample. Smectite occur in low temperature environments usually in association with zeolites, indicating temperatures of less than 230°C.

Calcite is noted in the sample taken at 908 meters depth and occurs between 7.3Å and 7.4Å peaks. This can be deduced from XRD analysis

3.4 Chemical analysis of scales by the Atomic Absorption Spectrophotometer (AAS).

Weighed scale samples (~ 0.50 gm) from the two phase line and from 908 meters were dissolved in 10 mls of 6N hydrochloric acid (6N HCl) with effervescence of gas bubbles. This was diluted to 100 mls for analysis in atomic absorption spectrophotometer. The elements analysed in the scale sample were Magnesium (Mg), Iron (Fe), and Calcium (Ca), Potassium (K) and Sodium (Na) which could define better the type of carbonate scale. These were detected and concentrations shown in Tables 3a below. A summary of the calculated composition of the elements as oxides and carbonates are presented together with the chemical analysis of the scale in Table 3a, 3b and 3c respectively.

Table 3a: Results of analysis of scales (I) and (II) collected from well OW-202 (in ppm)

Scale I : Sampled from two phase drain

Ca	Mg	Fe	Na	K
1850	8.4	6.202	2.246	0.606

Scale II: Sampled at 908 meters

Ca	Mg	Fe	Na	K
2021.70	111.93	2986.69	281.07	50.97

Table 3b: Results of analysis of scales (I) and (II)collected from well OW-202 expressed as % oxides

Scale I: Sampled from two phase drain

CaO	MgO	Fe_2O_3	Na_2O	K_2O
0.2590	0.00196	0.00177	0.00061	0.00015

Scale II: Sampled at 908 meters

CaO	MgO	Fe_2O_3	Na_2O	K_2O
0.283	0.026	0.853	0.076	0.012

Table 3c: Results of analysis of scales from well OW-202,composition expressed as % carbonates

Scale I: Sampled from two phase drain

$CaCO_3$	$MgCO_3$	$FeCO_3$	Na_2CO_3	K_2CO_3
0.648	0.01176	0.00128	0.00279	0.00052

Scale II: Sampled at 908 meters

$CaCO_3$	$MgCO_3$	$FeCO_3$	Na_2CO_3	K_2CO_3
0.505	0.067	0.619	0.130	0.018

The analysed sample suggests that the scale essentially consists of calcium, magnesium and iron carbonates. The source of iron in the scale could originate from the mild steel casing as iron and magnesium get fixed in hydrothermal minerals that form when water and rock interact. The source of magnesium in the scale could originate from mixing of geothermal water with shallower ground waters that could be inflowing into the well. . The concentration of calcium ions in solution results from boiling effects as the fluid ascends to the surface. Calcium ions could be close to saturation but on boiling with steam loss, the ions become concentrated in the residual fluid. Armansson, (1989) suggests that some of the metal constituents are concentrated in the scale e.g calcium and magnesium and removed from the residual fluid. Calcium and magnesium concentrations in the scale are much higher compared to the concentrations in the water sampled at the weir box or by the webre separator.

4. DOWNHOLE CONDITIONS IN WELL OW-202

Figure 5 shows the downhole temperature profiles obtained from well OW-202 shut in profiles in 1994, 1996 and 1997. The downhole temperature profile indicates that these measurements were done when the well was clear and there was no obstruction. The temperature profile runs to the full depth of the well.

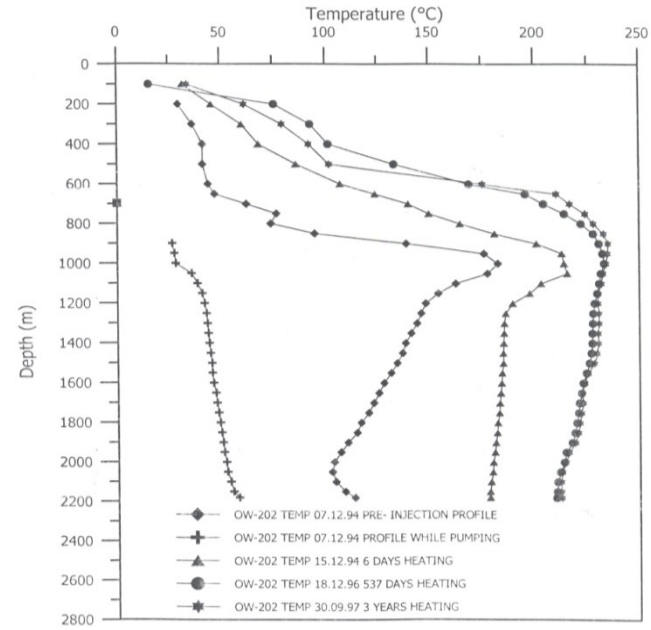

Figure 5: Downhole temperature profile in well OW-202 (Ofwona, 2000)

From shut-in temperature profiles, it was observed that a liquid feed zone existed around a depth of 900 metres (Ofwona, 2000). From the shut in temperature profile there is some indication of a slight reversal in temperature suggesting that the profile observed is from two-phase conditions that exist in the well below 900 m, and single-phase (steam) condition above this depth. This is shown in Figure 5

4.1 Flow test output results of well OW-202

Well OW-202 had high output i.e high mass flowrate (Ofwona, 2000) from the tests conducted in March 1998 and December 1999. The output from well OW-202 during these discharge tests of March to April 1998 and December 1999 are shown in Table 4 below. The other flow tests were done in 2005 before the well was handed over to Oserian Development Company (ODC) for utilization of steam for development of a back pressure steam turbine. The results of the flow tests are shown in Table 5 below. The two tests indicate almost constant output on the "8", "6", "5", and "4" lip pressure pipes.

Table 4: Output of well OW-202 between March and April 1998 and in December 1999 (Ofwona, 2000).

Lipe Pipe	WHP bara	Enthalpy kJ/kg	Power MWe
8" (a)	5.42	1035	3.0
8"(b)	5.28	959	2.2
6"	6.32	1027	2.4
5"	6.80	1032	2.0
4"	7.35	1045	1.4

Table 5: Output of well OW-202 in September to October 2005

Lipe Pipe	WHP bara	Enthalpy kJ/kg	Power MWe
8"	5.42	1061	2.8
6"	5.28	1062	2.4
5"	6.32	1105	2.1
4"	6.80	1130	1.6

The second flow test was done before leasing the well to Oserian Development Company (ODC). Ofwona, (2000) reports that from the output curves, these depict a water fed well from a reservoir of high permeability with flashing occurring further up in the well bore. as well head pressure is reduced, more water gets into the well flashing more steam.

4.2 Output of well OW-202 during production

The steam output of well OW-202 during production declined gradually from January 2008 to the lowest steam amounts around August 2010. The decline in steam production is depicted in Figure 6 below for the period between January 2008 to May 2010.

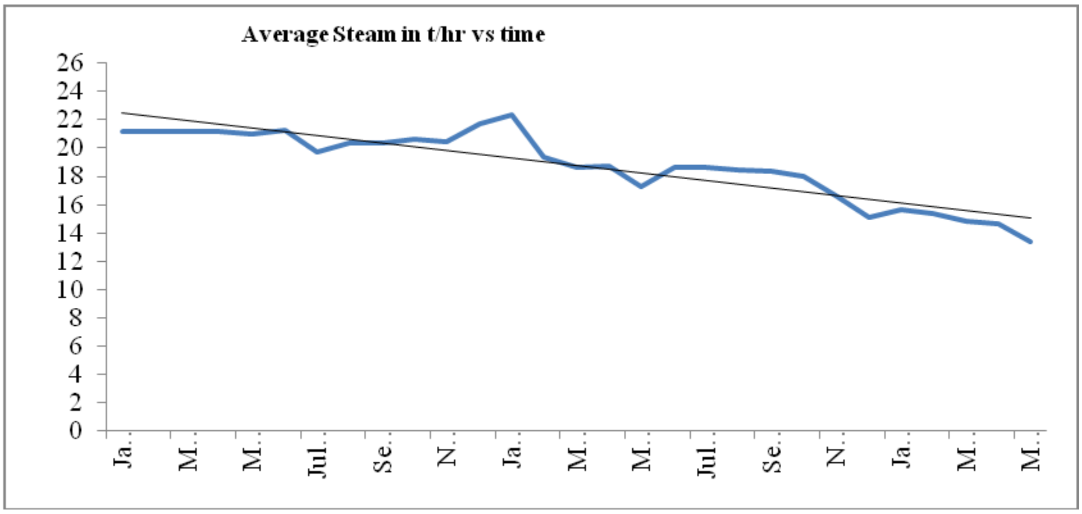

Figure 6: Average monthly steam flow in tonnes/hr of well OW-202 from January 2008 to May 2010

The cause of the decline in steam output was investigated and thought to be caused by scale deposition in the well bore. A down hole dummy run conducted in the well indicated blockage starting at 955 meters ,Kwambai, (2010). Below this depth the tool could not pass through the well bore. The ouput in steam declined from an average of 21.27 tonnes/hr per month in January 2008 to 13.38 tonnes/hr in May 2010. This caused the amount of electricity generated from the back pressure Elliot turbine to decline tremendously. Steam decline was attributed to scale deposition that formed in the wellbore due to flashing. This was indicated by results of a down hole dummy run conducted in the well in August 2010. Chemical analysis of the scale indicated the scale was predominantly carbonate scale. Precipitation of carbonate scale occurs due to super saturation of calcium and carbonate ions in the fluid.

5. DISCUSSION AND CONCLUSIONS

Well OW-202 was drilled as an appraisal well in the Olkaria Central Field. The well was leased to Oserian Development Company (ODC) by KenGen for the development of a back pressure Elliot steam turbine. The power plant was commissioned in 2007 after which on operating the plant for a short while steam output declined from a steam equivalent of ~1.4 MWe in January 2008 to less than 400 KW steam equivalent in August 2010. The well could not sustain the wellhead pressures. Investigations revealed the decline in steam output was caused by scale deposition in the wellbore with constriction starting at around 908 meters. A dummy run in the well bore indicated obstruction at a depth of ~955 meters. Chemical analysis of the scale taken from a depth of 908 meters in the Atomic Absorption Spectrophotometer and in hydrochloric acid suggests the scale was predominantly carbonate scale. Analysis of the same scale in the XRD indicated the presence of swelling clays whose peaks disappear on heating to 550 ° C. Chemical simulation by the WATCH computer code when well OW-202 fluids cool by adiabatic boiling with loss of carbon dioxide indicated a state of super saturation with respect to calcite through out the entire boiling process. The fluids do not cool sufficiently for calcite under saturation to occur. The measured temperatures in the well are relatively low (~240 ° C), being in the range where the solubility of carbon dioxide is lowest.

REFERENCES

Aŕmannsson, H.,: Predicting Calcite Deposition in Krafla Boreholes, *Geothermics,* **18**,(1989), 25-32

Arnorsson,S.,: Deposition of Calcium Carbonate Minerals from Geothermal Waters-Theoretical Considerations, *Geothermics,* **18**,(1989), 33-40

Arnórsson, S.,: Scaling problems and treatment of separated water before injection. In: Rivera, J.(ed), *Injection technology.* World Geothermal Congress (1995); IGA pre-congress course, Pisa, Italy, May 1995, 65-111.

Benoit, W., : Carbonate Scaling Characteristics in Dixie Valley, Nevada Geothermal Wellbores. *Geothermics,* **18**, ., (1989*)* 41-48.

Bjarnasson, J.Ö: *Computer code WATCH, version 2.1.* Orkustofnun, Reykjavík.,(1994), 56 pp.

Evanoff, J., Yeager, V., and Spielman, P., : Stimulation and Damage Removal of Calcium Carbonate

Scaling in GeothermalWells: A Case Study, *Proceedings* of World Geothermal Congress, Pisa, Italy (1995)

Herras, E. B., Salonga N. D., and Rossel, J.B.,: Mechanism of Calcium Carbonate Scaling in Mahanagdong Geothermal Field, Leyte, Philippines: Geothermal Resources Council Transactions, Volume,**24**, 665-670

Kwambai, C.,: Report on Investigative Tests on Well OW-202; *Unpublished Internal KenGen Report (2010)*

Ofwona, C.O.,: Completion and Discharge tests for well OW-202, *Unpublished Internal KenGen Report* (2000)

Todoka, N., Kawano., Y., Ishii, H., and Iwai, N., : Prediction of Calcite Scaling at the Oguni Geothermal Field, Japan: Chemical Modeling Approach: *Proceedings* of World Geothermal Congress, Pisa, Italy (1995)