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Pressure Transients Test Analysis of Well OW-918 at Olkaria Domes Geothermal Field

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Abstract: ***Evaluation of geothermal reserves involve numerous tests, information interpretation, checking and modelling. This starts from the interpretation of data gathered at the time of single wells testing to modelling of the reaction of geothermal basins to utilization for a number of years. The function of pressure transient's tests analysis is to determine the variables of the reservoir numerically. Step-rate injection test data and heat-up data from well OW-918 the Olkaria Domes field, have been interpreted by solicitations of sophisticated and current well test interpretations procedures through derivative interpretation using the numerical Well Tester and Mathematical Laboratory (MATLAB) Software. Well OW-918's total drilled depth is 3000m and Maximum clear depth is 2980m. Temperature reclamation, injection, and transient temperature shapes of the well exposed feeder areas at approximately 800m, 1300m, 2200m and 2700m depths. Hot fluids are encountered at around a depth of 2800m towards the bottom of the well registering temperatures in excess of 280^0 C. The well Injectivity index is low around 2.1 (l/s)/bar. The vital reservoir parameter values obtained from the pressure test analysis were as follows; transmissivity (T) of $1.17\times10^{-7} m^3/pa.s$, Storativity(S) of $3.54\times10^{-7} m/pa^{-1}$, reservoir thickness (h) of $1826.03m$, permeability (k) of $6.24mD$ and permeability-thickness (kh) of $11.4Dm$. Therefore these key reservoir parameters reveal that well OW-918 is a good producer which can be harnessed for energy generation. They also suggest that Olkaria Domes subsector is water dominated basin characterized by good permeability. Drilling of reinjection boreholes in the section around well OW-918 is not desirable. Finally I recommend that better drilling practices be adopted, i.e., drilling mud need to be changed for future wells that may be drilled in this sector for wells to be stimulated and enhanced connection of the well with the adjacent reservoir.***

Keywords: Geothermal, Olkaria, Reservoir parameter and well tester

1. Introduction

Investigation and expansion of geothermal reserve is alienated into several phases; beginning with surface survey, boring, assessment and lastly the reserve exploitation encompassing the mining steam pressure from geothermal reservoir. Steadfast statistics about geothermal reservoir is vital when determining the greatest and cost-effective way of utilization. To adopt this deduction, the supply and the properties of the reservoir must be acknowledged. This necessitates a perfect image of the reservoir features and properties. Analysis of wells will give main reservoir parameters for area expansion decisions.

Well analysis being the first procedure used in reservoir science to gauge the states and possessions of a borehole and its ambiances geothermal reservoir at bulk [1].

Completion testing is carried out during entire period of drilling or after drilling activity is achieved. This test is best known as injection testing which focuses on interrupting pressure conditions for the entire reservoir through pumping cold fluid into a borehole (well). Therefore from this kind of test, parameters that governs reservoir performance are evaluated.

[3] Posited that pressure in a well with altered flow rate or adjacent wells can be measured. Downhole measuring instruments permit recording temperatures and pressures in wells at various deepness to measure the reservoir enthalpy and pressure.

1.1Geothermal Pressure Transient Test Data

Injection step-rate and heat-up data of OW-918 at Olkaria Domes subsector in the Olkaria geothermal field was used to accomplish this study. According to [5], exploration drilling started in 1974 after a broad geo-scientific surveys in the beginning of seventies, and proceeded until 1977. Appraisal of the first drilling outcomes, viability feedback was made in 1977. Production drilling was launched in 1978 and proceeded till 1983. Abundant resource size was established for setting up of the first geothermal plant generating 45 MW electrical power.

Surveys were continuously conducted in Olkaria for extra volume of geothermal resource which was established and field size estimated to be roughly 80 km^2. It was realized judicious to fragment Olkaria area into seven zones for simplicity of expansion in the derivation geothermal energy. The zones were as follows; Olkaria East, Olkaria North East, Olkaria Central, and Olkaria South West, Olkaria North West, Olkaria South East and Olkaria Domes as presented in Figure 1.1.

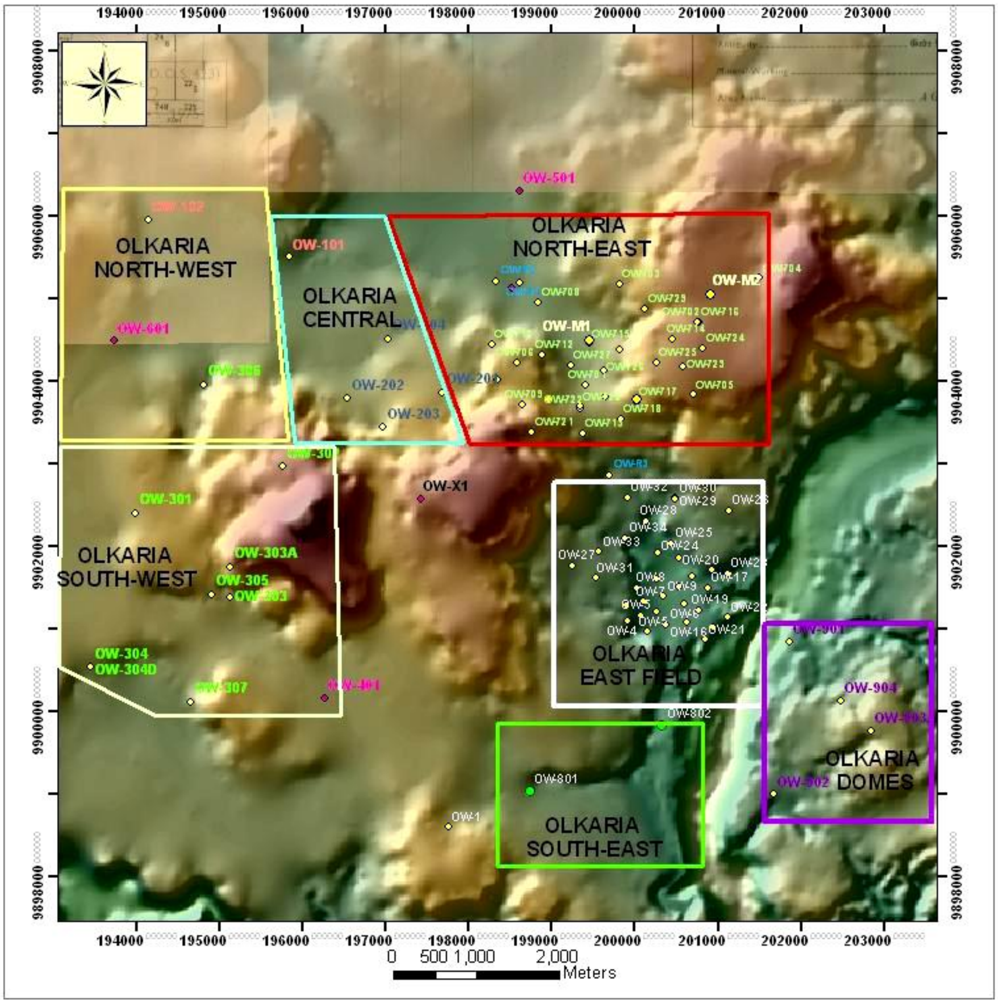

Figure 1.1: Geothermal blocks inside the Larger Olkaria Area, source: [5]

2. Methods and Materials

2.1 The Area of Study

OW-918 is vertical well located at 205719 Eastings, 9898585 Northings and elevation 2078 metres above sea level (m.a.s.l.). The total drilled depth is 3000 m and maximum clear depth is 2980 m. Furthermore 9 5/8” casing shoe at 940.19 m and top liner at 906.14 m. Pressure temperature surveys (PTS) profiles were conducted in the well straight away after completion of drilling to examine the conditions of the well. Figure 2.1 shows OW-918 well fitted with silencers at its well head.

Figure 2.1: Well head of OW-918. Source: Kenya Electricity Generating Company Limited (KenGen)

2.2 Data Collection

2.2.1 Data Collection Procedure

The temperature and pressure were measured using mechanical Kuster gauges or electronic logging tools.
The following procedure was employed in obtaining the well data;

1) A dummy run was conducted to determine the maximum clear depth (2980 m) and to ensure that the well was clear of any obstruction before running the down hole pressure and temperature logging tools.
2) A Pre-injection profile conducted to the optimum clear deepness to determine where to station the down-hole tool for step pumping.
3) Step pumping was done with the pressure and temperature tool stationed at 2700 m. Pumping was done at the rates of 1000 lpm and progressively increased to 1300 lpm, 1600 lpm and 1900 lpm at intervals of four hours, three hours, three hours and three hours respectively.
4) While still pumping at 1900 lpm, the tool was positioned at 2700 m for 10 minutes before turning off the pumps. The pressure fall off was then monitored for 8 hrs.
5) After fall-off, a temperature and pressure profile run was done.
6) Lastly, temperature and pressure recovery surveys were done after the completion test.

2.2.2 Data Processing Procedure

The following steps were followed for data processing of well OW-918;

1) The data was recorded in the logging tools during data collection and uploaded in the computer spreadsheet.
2) A program was designed which converted time in hours to date format, that is, yyyy-mm-ddHH: MM:SS particularly for step pumping data.
3) The data in Microsoft excel was further converted to DAT file which was compatible in running in numerical well tester software.

2.3 Data Analysis

To attain the objectives of this research the following computer software was used to analyze the completion well test data of geothermal well in Olkaria Domes field;

2.3.1 Matlab Software

Mathematics laboratory (Matlab) software was used for plotting the temperature and pressure profiles of particular, typical geothermal well of Olkaria Domes field for evaluation of the reservoir temperature and pressure and identification of permeable zones.

2.3.2 Numerical Well Tester Software

The mathematical software Well Tester V.1.0.0 was used for evaluation of formation parameters. The well tester program is executed as follows; Open the well tester software application, select file type ISOR database with heat column (*inn:*idb:*.dat), types 1 to 3, load raw data (time based pressure data) in DAT file format, the graph of pressure (bars) against time of day is displayed and also on well tester application window, six sections are displayed namely parameters, set steps, modify, model, model all and report [4]:

1) Select parameters tab and load well and reservoir properties, i.e., estimate values of reservoir temperature and pressure, wellbore radius, porosity which are the working estimates of the well test analysis by this software and the dynamic viscosity of the fluid compressibility of the fluid is automatically updated by the software. Also in this section the number of steps is specified.
2) Set steps by modifying steps through locating the start and end of each step. Also record the initial injection rates and the four injection rates (l/s) for the four steps and finally in this section redraw data to show injection rates on the axes on the right hand side of the graph of pressure in bars against time of the day.
3) Modify the data for each step by either excluding or including all or add points so that the curve for each step assume the best fit and resample data by sampling evenly in time and pressure.
4) Model by selecting appropriate models namely reservoir, boundary, well and wellbore. Select the appropriate points on graph for all reservoir parameters to be calculated for all the steps and the click calculate and improve the calculations.
5) Model all the steps jointly, here you select appropriate points on the graph displayed for all the parameters to be calculated. Then click calculate, improve and iterate.
6) Finally select report tab and generate the report about the well and statistical parameter values and graphics.

3. Results and Discussion

3.1 Temperature and Pressure Profiles

Figures 3.1 and 3.2 present temperature and pressure logs measured in well OW-918 during pre-injection, injection and heat-up. Warm-up period shows a water table and heating is centred about 500 m depth. At this permeable zone at 500 m, cooler and possibly large incursions feed the well quenching it to around $90^{0}C$ despite the short heat up. Inside the open section, conductive heating is observed to 1600 m depth when a feed zone is encountered feeding the well at $120^{0}C$. Another conductive heating region with a sharp gradient is encountered to 2550-2650 m depth, when a $250^{0}C$ feed zone is encountered with a short down flow which may turn out to be convective with the well recovery.

As whole, the main feed or permeable section of well OW-918 are situated around 800, 1300, 2200 and 2700 m depth as indicated in Figure 4.1. Also from the warm up profiles of 20.09.2016 as shown in Figure 4.1 revealed that the bottom hole temperature (BHT) is in excess of over $298^{0}C$ which may be associated with the hard formation and feed zone was observed at 2800 m which allow inflow of hot fluids into the well, thus suggesting that this may act as a deep heat source that may drive the wellbore to convection.

There is a temperature drop from 2100 m depth between injection and 9 hrs heat-up profiles. Hence, there could be a cold incursion. Well OW-918 is a hot well as indicated by temperature profile. In 15.06.2012, 20.07.2015 and 20.09.2016 heat up profiles temperatures were above 250^{0}C from the depth of 1300 m suggesting that Olkaria Domes zone is composed of high enthalpy geothermal resources.

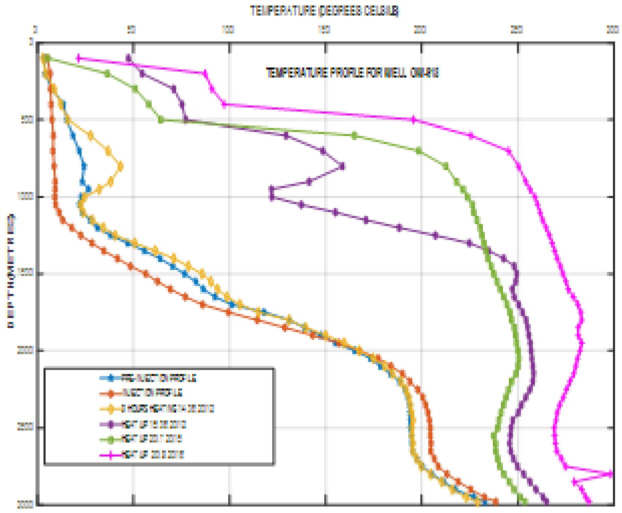

Figure 3.1: Temperature profile for well OW-918

The pressure fulcrum point is situated amid 1850 metres and 2150 metres deepness as per the heat recovery pressure outlines as indicated in Figure 3.2 and the formation pressure is approximately 125 bar-gauge which is pressure happening at around 2200 m depth , which is the estimated pressure believed to be responsible for governing the wellbore.

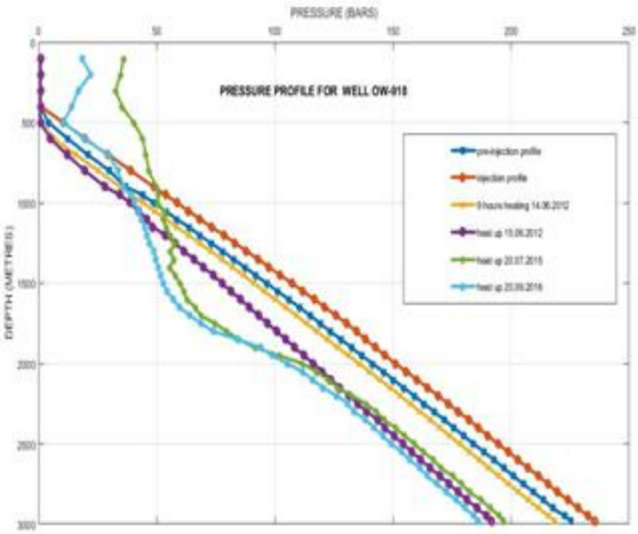

Figure 3.2: Pressure profile for well OW-918

3.2 Injectivity Index of Well OW-918

A four-rate step injection test was conducted on 10 July, 2015 lasting about 13 hours on well OW-918 in which first step lasted for 4 hours and the other subsequent steps lasted for 3 hours. Mechanical Kuster gauges was used to record the pressure variations in the Well was stationed at around 2700 m deepness at the locality of the deepest feed point of the well. The four step injection rates were 16.7 l/s, 21.7 l/s, 26.7 l/s and 31.7 l/s, respectively. Four injection steps yielded an injection index of (2.09 l/s)/bar. Injectivity index value (2.09 l/s) of Well OW-918 is low, suggesting that the well has an aquifer that has low permeability. Figure 3.3 shows OW-918 Injectivity plot.

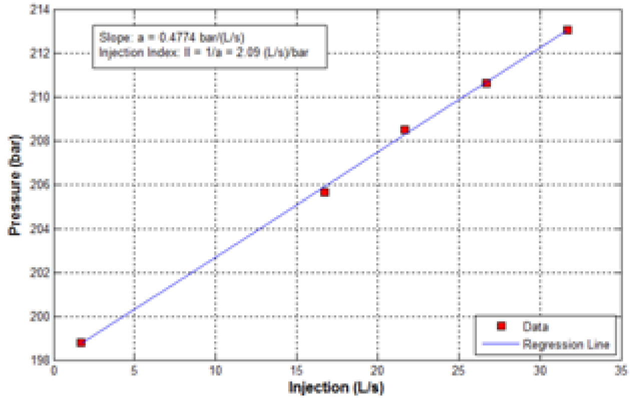

Figure 3.3: Determination of the Injectivity index for well OW-918

3.3 Well Test Results for OW-918

Throughout a pressure transiest test, the pressure reaction in a well due to a change in pumping is measured to deduce several parameters associated to the neighbouring reservoir. This is carried out by assuming a numerical model for pressure transitory reaction in the well and the formation, due to rapid stage variation in pumping. Numerical model depends on characteristic values of the formation parameters and altering these values for modelled response to resemble experimental data, one can deduce the typical parameter of the formation. Therefore, by prudently conducting the well test and bearing in mind the conceptual model of the geothermal systems and employing computer assisted interpretation, the vagueness in the outcomes can be minimized to a great extent. However, inaccuracy on the deduced reservoir variables can be acquired through nonlinear regression obtained from computer assisted technique. Evaluation of injection test was conducted using the Well Tester program which was developed at the Icelandic GeoSurvey (ISOR). This is a graphic user interface based program which permits an interpretation of the steps in a simpler way and displays the outcomes in graphs and tables.

3.3.1Modelling of All Steps Jointly

The fit of regression analysis of the all steps jointly modelled to the data is displayed in Figure 3.4 where both time and pressure are plotted on a linear scale.

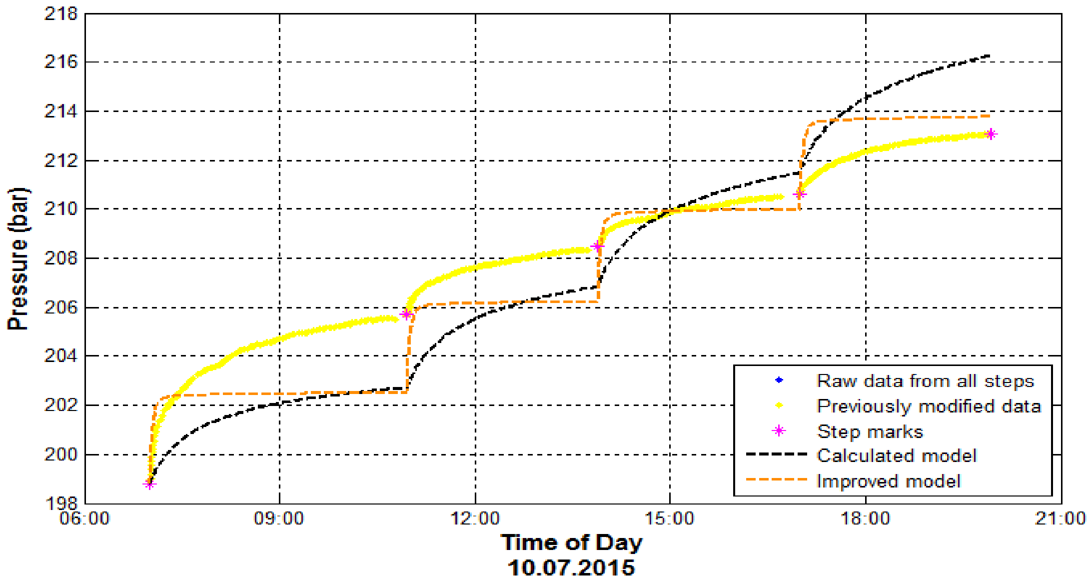

Figure 3.4: Graph pressure (bar) against Time of Day for all steps jointly of OW-918

Table 3.1 presents data on non-linear regression analysis of all steps simulated altogether

Table 3.1: Summary of outcomes from nonlinear regression parameter approximation for all steps altogether

Parameter Name	Parameter value	Parameter unit(s)
Transmissivity (T)	$1.165 x10^{-7}$	$M^3/Pa.s$
Storativity (S)	$3.543 x10^{-7}$	$M^3/Pa.M^2$
Skin factor (s)	29.802	
Wellbore storage (C)	$3.493 x10^{-6}$	M^3/Pa
Injectivity index (II)	2.148	(L/S)/Bar
Reservoir thickness (h)	$1.165 x10^{-7}$	M
Permeability (k)	$6.243 x10^{-15}$	M^2
Permeability-thickness(kh)	$1.14 x10^{-11}$	
Porosity (ϕ)	0.1	

Table 3.2: Moderated Coefficient of Determination (R^2adj) value of 0.809 is relative big and therefore the model fits with the pressure response of the reservoir. Table 3.2: Summary of statistical parameters for all steps jointly

Statistical parameter- all steps jointly	Value	Parameter Unit
Sum of Squares due to Error (SSE)	$9.936x10^{12}$	Pa^2
Coefficient of Evaluation (R^2)	0.809	
Degrees of Freedom (df)	442	
Moderated Coefficient of Determination (R^2_{adj})	0.809	
Root Average Squared Error (RASE)	$1.499 x 10^5$	Pa

Transmissivity, the main parameter that exemplifies the capability of geothermal aquifer to transmit liquid. Hugely, affected by the pressure slope between the well and limits of the geothermal reservoir. The field comprises mostly of trachytes rocks that are described by even fractures attributed by volcanic activities and rifting. In Olkaria Domes geothermal field, this fissures acts as a major recharge of geothermal aquifer. The outcome for transmissivity of the designate well was $1.165\times10^{-7} M^3/Pa.s$. The mobility of pressure wave within the reservoir is dictated by storativity besides transmissivity. Storativity rely on liquid compressibility, it changes significantly amongst reservoir categories, i.e. liquid-controlled versus dry vapour [2]. Normal values for liquid-controlled geothermal basins are about $10^{-8} M^3/Pa.M^2$ while two-phase have values of the magnitude of $10^{-5} M^3/Pa.M^2$ [6].

Outcomes for OW-918 recorded a Storativity size of $3.543\times10^{-7} M^3/Pa.M^2$. Therefore, it can be said that Olkaria Domes sector reservoir system is a liquid-controlled geothermal aquifer. Skin factor values are positive and negative for destroyed and active respectively. The studied well revealed skin values was 29.802; the value was highly positive suggesting that the wellbore is damaged. Injectivity index is majorly employed to give rough approximation of the connectedness of a wellbore with neighbouring aquifers. The injectivity index outcome for OW-918 was approximately 2.148 (l/s)/bar which is consistent with the value obtained from Injectivity plot as shown in Figure 4.4, which is moderate for the investigated borehole. Geothermal aquifer permeability-thickness, projected by Well Tester was 1826.026 metres for OW-918 which proposes that studied well had enormously approximated thickness of the reservoir system that dynamically swap over fluids with the wellbore but this value is too much which needs further investigation. Permeability change by a small magnitudes of values, however ideal values from completion testing in geothermal basins are on range of 10millidarcies (mD) to 100 millidarcies (mD). Outcomes for the investigated well at Olkaria Domes sector was approximately about 6.243 mD.

4. Conclusions

The well injection step-rate test revealed well parameters, estimated temperature and pressure are indicative of a good producer. Although injectivity index is on the lower end, the feed zone or productive zone tested was much deeper and all steps reveal a reservoir thickness may be sufficient to heat up fluids to boiling conditions.

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