Case Study: 'Hydraulic Fracturing Experience in the Wayang Windu Geothermal Field'

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ABSTRACT

Moment tensor analysis of micro earthquake data from the Wayang Windu geothermal field provides maximum/minimum stress orientation as well as the magnitude of the stress. Transient testing (fall off tests) conducted at several wells confirm the magnitude of minimum stress of the field. Further analysis of the fall off tests indicate that hydraulic fracturing could be a viable means to improve well productivity at Wayang Windu.

To test this conclusion an injection program to initiate hydraulic fracturing was conducted in two wells. A series of multiple injection rate followed by fall off tests gives the parameters for designing the hydraulic fracturing jobs to improve well performance. An injection program to produce hydraulic fracturing was then conducted. Post test treatment shows that new fractures were created and production improvements were achieved. Average steam mass flow production improved by 50 – 100 % (albeit from a low base).

1. INTRODUCTION

The Wayang Windu Geothermal Field is located approximately 35 km south of Bandung City, capital of West Java Province of Indonesia (Figure 1). The field is in a mountainous area (average elevation is between 1500 - 2100 meter above sea level). The productive vapor-dominated Darajat and Kamojang geothermal fields are nearby. Based on geological and well test data, the Wayang Windu geothermal field is interpreted as transitional between vapor-dominated and liquid-dominated conditions (Bogie et al, 2007). The enthalpy of the fluid ranges from 1300 kj/kg until 2788 kj/kg depending opon feed zone elevation.

The idea of this paper is based on the analysis of micro earthquake survey. The first MEQ survey was conducted from February to March 1998. The second survey was conducted on 19 May 2005 until 19 July 2005. The survey was a part of beyond unit-2 development to support well targeting. The following figure shows MEQ event on 2005.

The moment tensor of micro earthquake was interpreted to derive probable orientations of fault and fault system and distribution of stress. In general, moment tensor representation is necessary to deal with process such as opening cracks, explosions and collapsing cavities. The moment tensor is equivalent to the force system of an earthquake. This earthquake may occur in response to extraction of fluid from geothermal reservoir, contraction resulting from cooling of rocks in the geothermal reservoir, hydraulic fracturing or injection or extracting of magma in the roots of active volcanic systems.

2. METHODOLOGY

Cold water injection into geothermal reservoirs can be produce rock fracturing in the reservoir (Wojnarowski and Rewis, 2005). The objective of this paper is to document production improvement by creating hydraulic fracturing due to cold water injection.

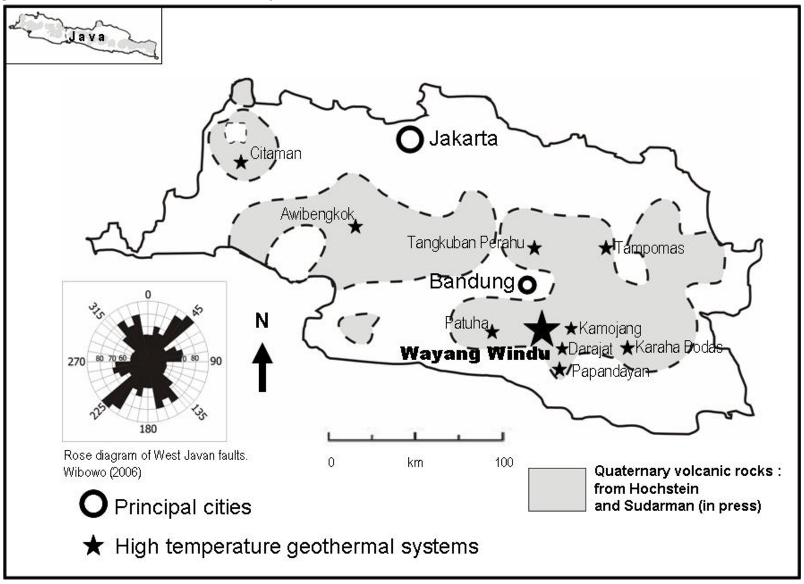

Figure 1: Wayang Windu Geothermal Field Location

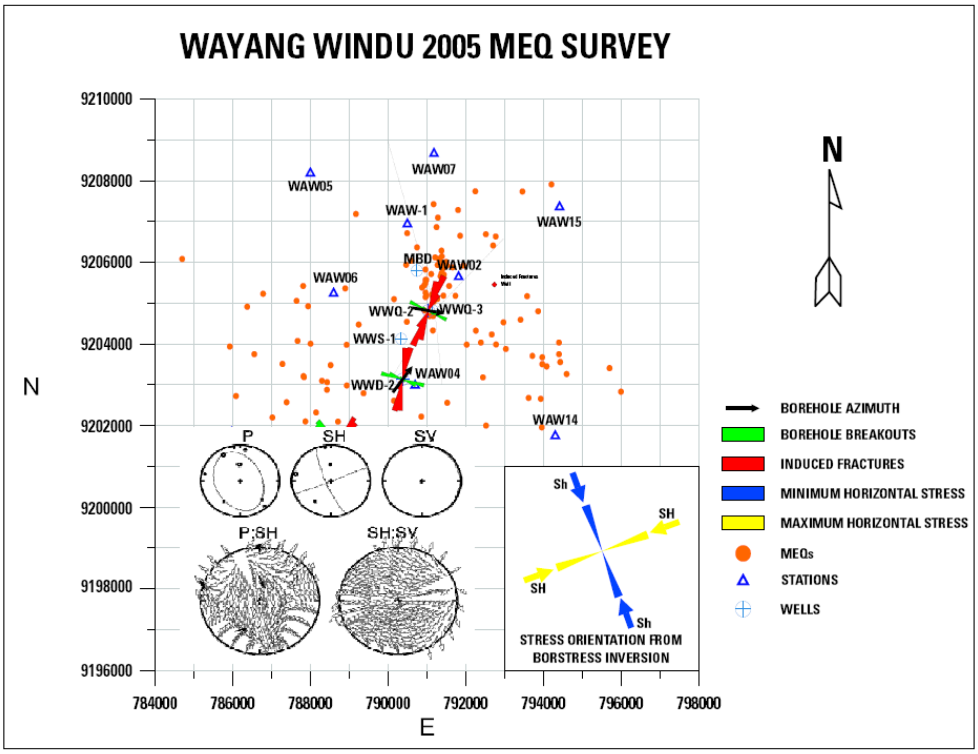

Figure 2: Wayang Windu 2005 MEQ Survey

One essential concept in production and injection reservoir geothermal operations is how to estimate the accuracy of maximum or minimum stress orientation. It is very useful because many geothermal reservoirs are fracture dominated rather than porous media. The change of stress will cause the opening and closing of existing fractures and permeability variations.

Geomechanical behavior of rock such as deformation or fracturing in general is very complex and primarily depends on the particular type of a rock and stress state to which the rock is subjected (Wojnarowski and Rewis, 2005). When the rocks structure,has changed dramatically it can affect the permeability. These conditions usually occur when a maximum or critical stress has been achieved.

The compressive effective stress will be decrease in the rock matrix when cold water is injected into the reservoir due to an increase in the pore pressure. This can affect the critical stress of rock so pore pressure will initiated the fracture pressure or closure fracture.

3. INJECTION TEST

Well testing either by production or by injecting fluid is normally conducted in order to obtain data for reservoir evaluation. One common technique to measure the reservoir characteristics (i.e. permeability thickness product (transmissivity) and skin) in the liquid dominated well is a fall off test. Analysis of this test can be complicated by two important effect such as multiphase and temperature effects.

The post injection program was conducted for evaluating reservoir characteristic at WWA-2, WWQ-2, WWQ-3, WWQ-4. The interpreted data include multiple rate test and fall off test. Pressure behaviors after the fall off tests are matched by a simulator well test.

Electronic Kuster downhole pressure temperature instruments were run to profile the pressure and temperature under injection. This survey is to identify feed zones and with spinner data used to determine the major feed zone. The tool was then stationed at the major feed zone to monitor fall off pressures. The total test takes around 2 – 3 days including killing well, multiple step injection rate and the fall off test. After the test, the well was shut in to heat up before the well is put back online to the power plant.

The multiple step rate injection (cold-water injection) and transient tests were conducted on WWQ and WWA-2 wells. WWQ wells are located at the mid part of the Wayang Windu Field while WWA-2 is located in the southern part of the Wayang Windu Field. Figure 3 is shown location and cross section between WWA well and WWQ wells. WWQ wells have thicker steam cap than WWA wells. The steam cap occurs above 400 m above sea level (asl) with the liquid zone below it. Almost all these wells penetrated both the steam and liquid zones.

Recently, WWQ wells are two-phase producers except WWQ-1 and WWQ-4. The enthalpies of those wells are around 2183 up to 2787 kJ/kg depending upon the feed zone. WWQ wells have low productivities of below 10 kg/s except WWQ-5 which produces 25 kg/s. The transient analysis was conducted to identify potential reservoir issues (i.e. low permeability) or wellbore issues (i.e. damage or scaling).

WWA-2 well is a two-phase producer with an enthalpy of 1369 kJ/kg. The well has had a production decline since January 2007. Production has decreased from 5 kg/s to 3 kg/s. The transient analysis was conducted to identify the whether its performance is affected by the reservoir or wellbore issues.

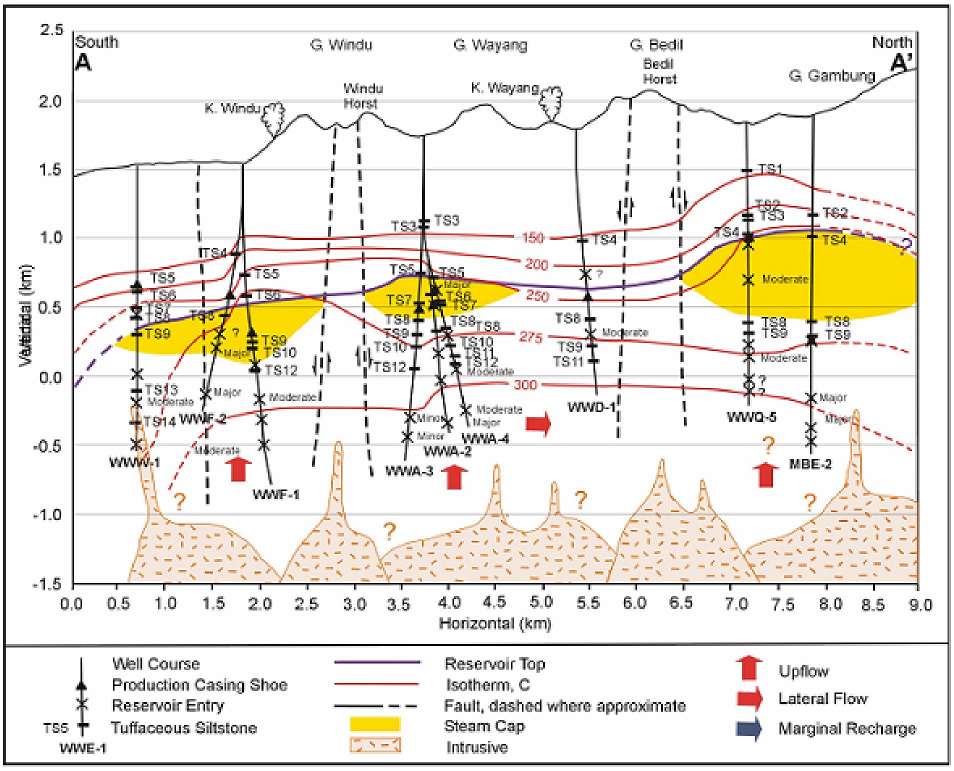

Figure 3: Cross Section of the southern part of the Wayang Windu Geothermal Field.

A series of multiple step injection rates followed by fall off tests were conducted on the WWQ-2 well on 25 April 2007. The test was continued at WWQ-3, WWA-2 and WWQ-4 on 8 May 2007, 10 May 2007 and 8 August 2007 respectively. The cold water (condensate fluid) was injected to the reservoir with multiple step injection rates. Design of multiple step injection rates was set from lower injection rate to high injection rate to initiate hydraulic fracturing due to effect of hydraulic thermal fracturing in the rock. The newly created fracture in the rock was initially from creating closure pressure in the fall off pressure period. Closure pressure performed due to injection rate exceeded maximum stress magnitude in the rock.

The test on WWQ-2 took around 68 hours including killing well 6 hours, multiple step injection rate 60 hours and fall off test 3.5 hours. Injection rate and bottom hole pressure is showed at figure 4. From this figure is difficult to set a fixed constant injection rate. After killing the well, the injection rate was not recorded till 4 hours after quenching the well. The test was increased by eight steps with injection rates around 22 liter/second up to 54 liter/second. It is difficult to set a constant injection rate at high rates due to a limited supply of condensate from power plant (the only available major supplier of cold water in the area). Total production of 110 MWe electric generation is about 60 kg/s. The last injection rate prior fall off test executed was 49 liter/second. The maximum injection rate is to initiate closure pressure. Total condensate injected into the well is around 36,332 barrel. The fall off pressure was recorded around 3.5 hours. This duration is very short to get fully reservoir characteristic due to incapability of tools to record long term better than capillary tube. However, the survey is not needed to record long fall off test pressure to get the boundary of well but focusing to get information about permeability and skin.

While the following figure 5 is showing multiple step rate injection and fall off test pressure (bottom hole pressure) at WWA-2 well. The total test duration is around 35 hours including 5 hours killing well, 22 hour multi-step injection rate and 6.8 hours fall off test. The injection rate was increased by nine step rates starting injection rate at around 10 liter/second up to 35 liter/second. Each step took around 2 hours with total injection condensate fluid of approximately 9761 barrel.

4. ANALYSIS INJECTION TEST

Pressure transient analysis was conducted to assess reservoir characteristic and to identify the issue of wellbore damage. The procedure usually is to assess the quality of data, to choose the appropriate model, the method to interpret data and finally to apply this methods to estimate formation parameter such as transmissivity and skin factor. The following figure is shown fall off pressure test at WWQ-2 and WWQ-3 wells.

The fall off test was recorded at 1671 meter MD. Fall off test at WWQ-2 is very short around 3.5 hours to get fully information about reservoir characteristic. On figure 6, is showing significant pressure decline after injection finished. After 2 hours after injection, the anomaly pressure decline was performed. The pressure declined more slowly. This point is interpreted as tye closure pressure when fractures in the rock start opening. It is effected due to injection rate exceed the maximum stress magnitude of the rock. For this well the closure pressure was created at 47.6 barg with the last injection rate around 49 liter/second.

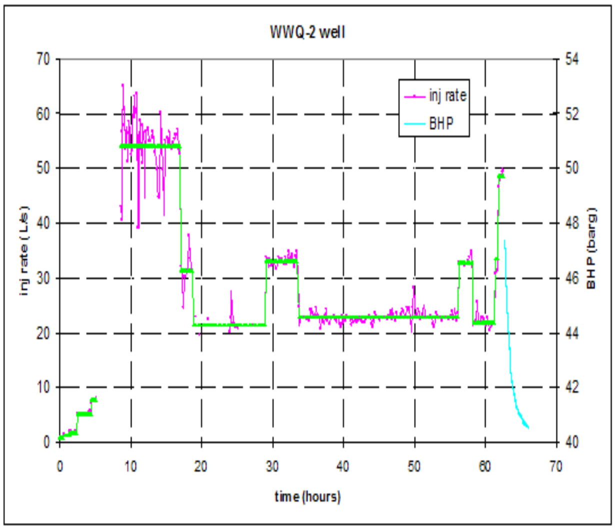

Figure 4: Multiple Step Injection Rate and Fall Off Pressure Test Profile on WWQ-2 well.

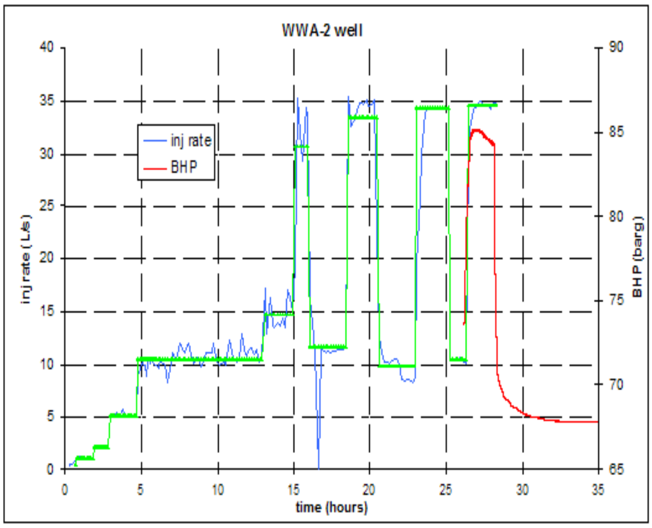

Figure 5: Multiple Step Injection Rate and Fall Off Pressure Test Profile on WWA-2 well.

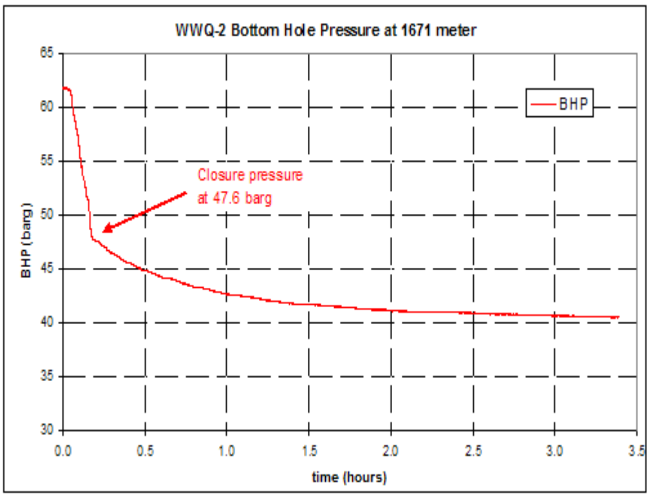

Figure 6: Fall off Pressure Profile at WWQ-2 well.

The WWQ-3 fall off test was recorded at 1435 meter MD. Duration of the fall off test at WWQ-3 is around 4 hours. On figure 7, the closure pressure is performed at WWQ-3 started at 1 hour after injection finished. This point is interpreted opening fracture on rock. It is due to the injection rate being sufficient to exceed the maximum stress magnitude of the rock. For this well the closure pressure was created at 51.2 barg with the last injection rate around 40 liter/second.

The analysis of pressure transient analysis was analyzed using a welltest simulator. The fall off test data is analyzed to try to obtain a match between the model and the actual data. Firstly graphical technique were used to get a first estimate of the parameters before matching the data and model. The pressure transient data was analyzed using a semi-log plot, and log-log plot between bottom hole pressure and time at WWA-2 and WWQ wells.

At WWQ-2 well semi-log and log-log plot shows the model of this well has dual porosity. From that plots the transmissivity on WWQ-2 well is 4.7 Darcy-meter and skin factor -2.97. It can be concluded there is no damage and the well was stimulated due to closure pressure creating new fractures. However, this well has low permeability. The fall off pressure indicates a closed boundary. However, this boundary cannot be identified as close boundary effect of impermeable boundary or pressure support. The following figure shown linear plot, semi-log plot and plot-plot of transient analysis of WWQ-2 well.

In the production profile for WWQ-2 in Figure 11, the well has decreased in production since January 2007 from 5 kg/s to 3 kg/s. The cause of this cannot be identified from the reservoir performance or the wellbore performance. After multiple step injection rates, it was shown that the well has achieved a production improvement. WWQ-2 mass steam production was improved by up to 50% from 4 kg/s up to 8.5 kg/s. The production improvement was reached due to new creating fracture at this well. The aperture of fracture is to longer and open. In the graph July – September 2007 period, the production decline is very drastic, it is due to transient period after the well has to be online to the power plant after shut-in 2 months.

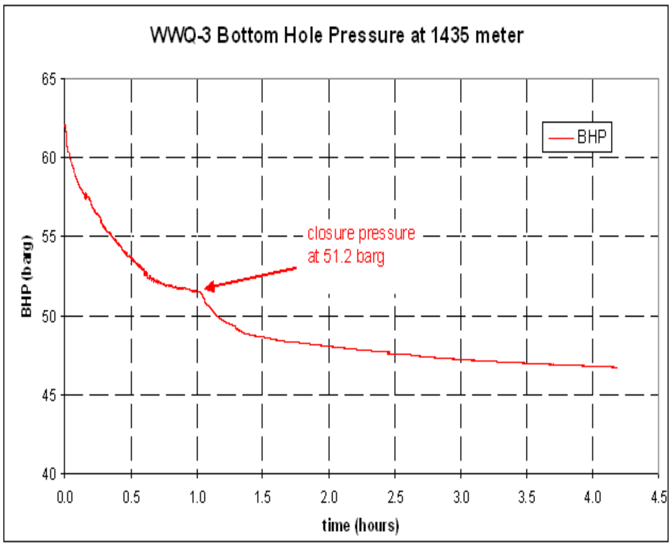

Figure 7: Fall off Pressure Profile at WWQ-3 well.

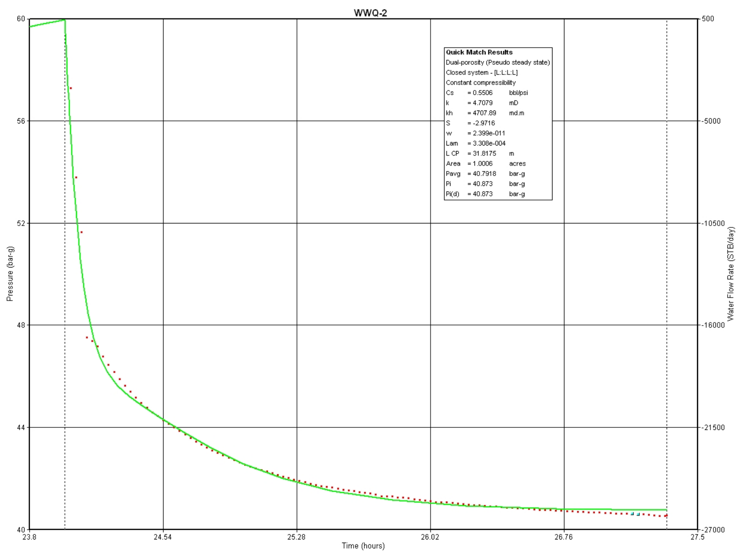

Figure 8: Linear Fall Off Pressure Plot with Time at WWQ-2 Well.

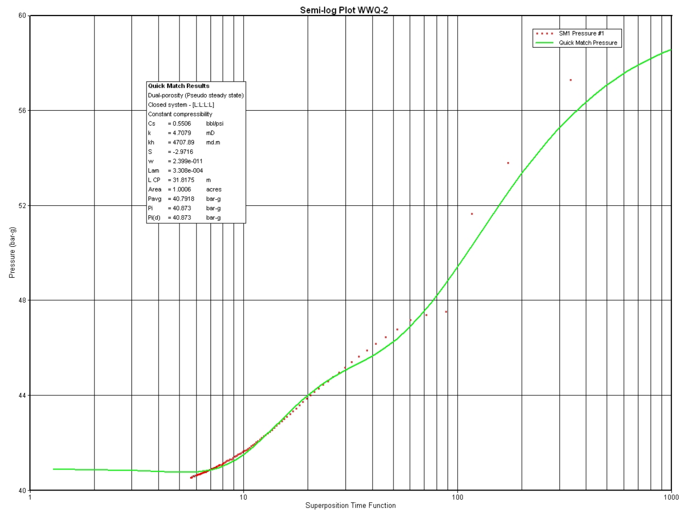

Figure 9: Semi-log Fall Off Pressure Plot with Time at WWQ-2 Well.

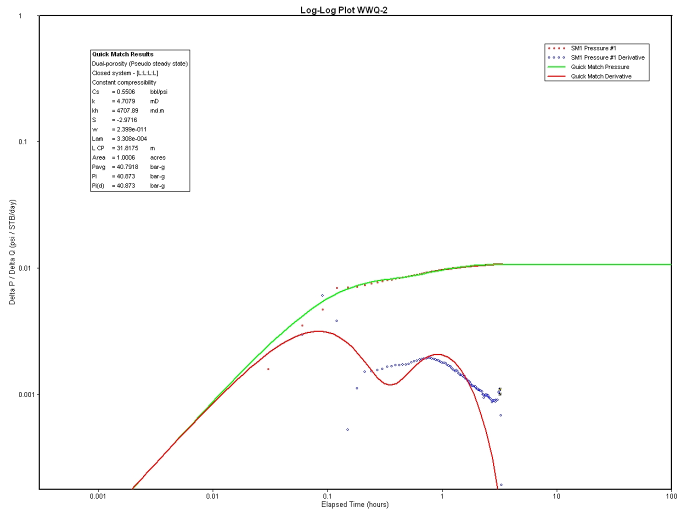

Figure 10: Log-log Fall Off Pressure Plot with Time at WWQ-2 Well.

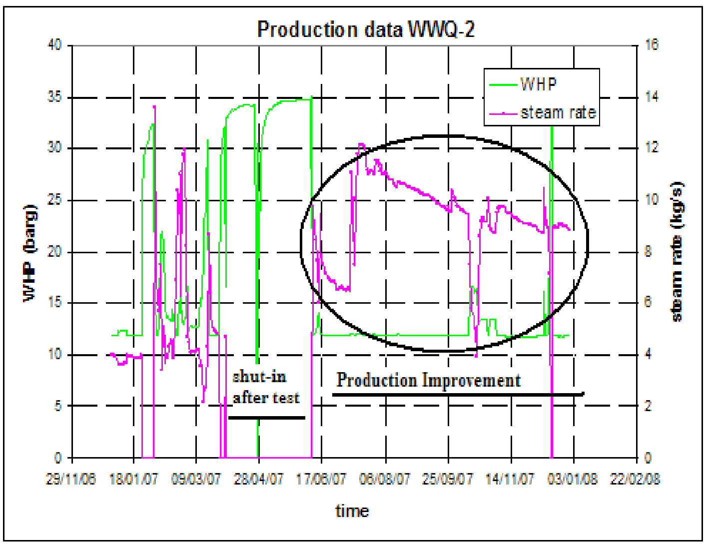

Figure 11: Production Profile at WWQ-2 well.

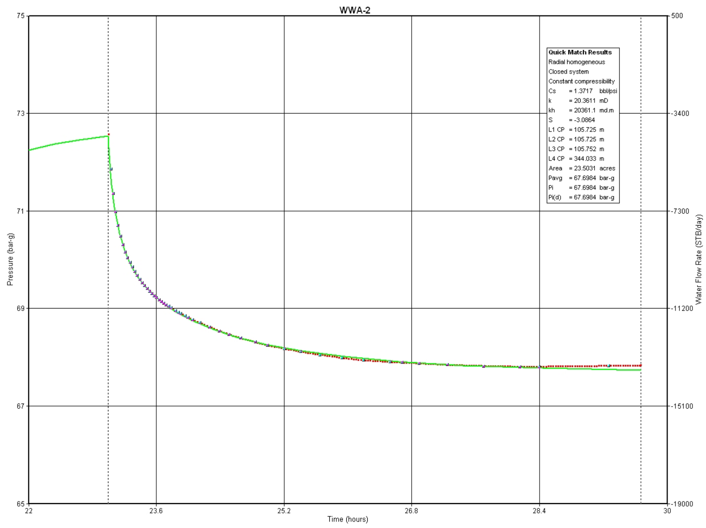

Figure 12: Linear Fall Off Pressure Plot with Time at WWA-2 Well.

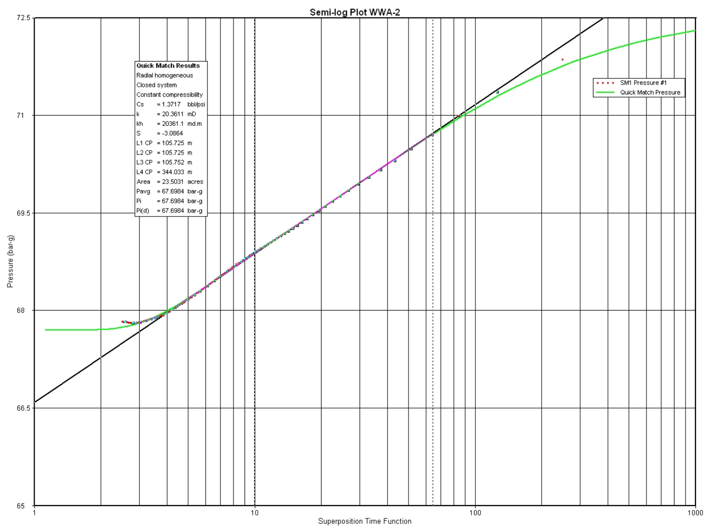

Figure 13: Semi-log Fall Off Pressure Plot with Time at WWA-2 Well.

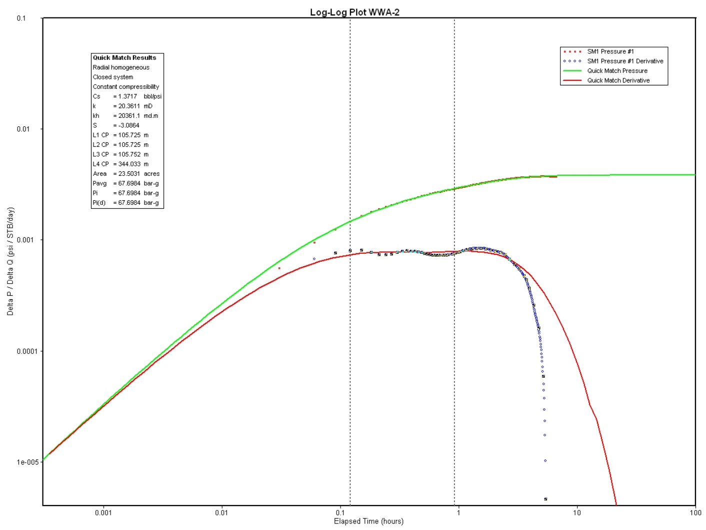

Figure 24: Log-log Fall Off Pressure Plot with Time at WWQ-2 Well.

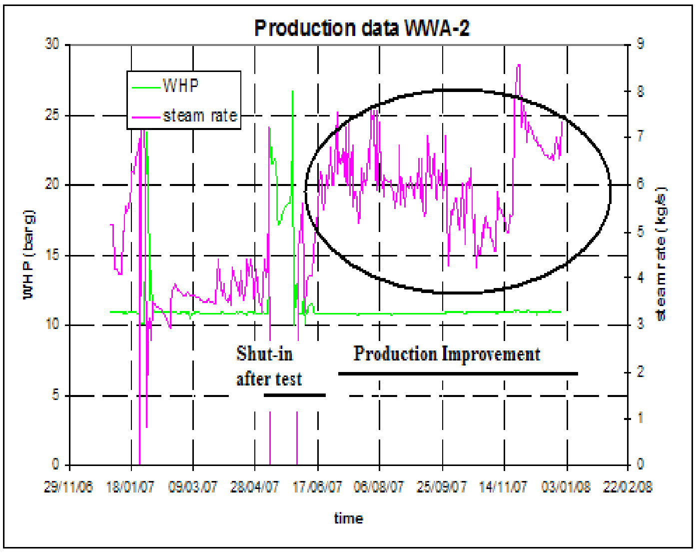

Figure 35: Production Profile at WWA-2 well.

In WWQ-3 well, open fracture has performed at 51.2 barg after 1 hour stop injection. However, the improvement production cannot be reached. This situation is affected due to WWQ-3 well has lower permeability.

In the WWQ-4, no open fracture occurred during the multiple step injection and fall off test data. The closure pressure cannot be created by the maximum injection rate can be initiate creating of open fracture by exceeding maximum of stress rock stress magnitude.

The pressure transient analysis at WWA-2 well indicates that the model is homogeneously radial. The semi-log plot shows the transmisivity of this well is 20 Darcy-meter and the skin factor is -3. This result is better than for WWQ-2. It can be conclude that the reservoir there is no damage in the wellbore and give good permeability. The fall off pressure indicates a constant pressure at end of fall off test data as indicated as closed boundary. However, this boundary cannot be identified as close boundary effect of impermeable boundary or pressure support. The following figure shown linear plot, semi-log plot and plot-plot of transient analysis of WWA-2 well.

In the plot of the production profile of WWA-2 in Figure 15, it is shown that WWA-2 well has achieved production improvement after multiple step injection rates. WWA-2 mass steam production was achieved production improvement up to 50% from 4 kg/s up to 6 kg/s. The production improvement was reached due to new creating fracture at this well. The aperture of fracture is to be longer and open.

5. CONCLUSIONS

The present series of tests demonstrated that it is possible to create of open fracture by inject the condensate fluid to reservoir in the Wayang Windu geothermal field. The choice of the maximum injection rate is the critical aspect in initiating fracture opening. The pressure transient analysis is part of method to confirm the improvement of productivity of the well.

Table 1: Summary of Pressure Transient Analysis

Well	Reservoir characteristic		Remarks
	transmissivity (Darcy-meter)	skin	
WWQ-2	4.7	-2.97	✓ Open fracture ✓ Production improvement ✓ Permeability improvement
WWQ-3	0.72	0.03	✓ Open fracture ✓ No production improvement
WWQ-4	15.84	-0.8	✓ No open fracture ✓ No production improvement
WWA-2	20.36	-3	✓ Open fracture ✓ Production improvement ✓ Permeability improvement

6. ACKNOWLEDGEMENT

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