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Monitoring Activities During Injection Testing: Case Study of Well B-2 at Darajat Geothermal Field

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ABSTRACT

Injection testing is one of the required tests after well completion and, as the name implies, used to estimate the injection capacity of a well. The injection test data could also be used to determine the connectivity of injected wells to nearby producers by monitoring the behavior of surrounding wells during the injection test. At the steam-dominated Darajat geothermal field, these monitoring activities during injection tests include observing the trends of Non-Condensable Gas (NCG in wt%), boron (ppm), superheat (°C), Flowing Well Head Pressure (FWHP in barg), flow rate (kg/s) and micro-seismicity.

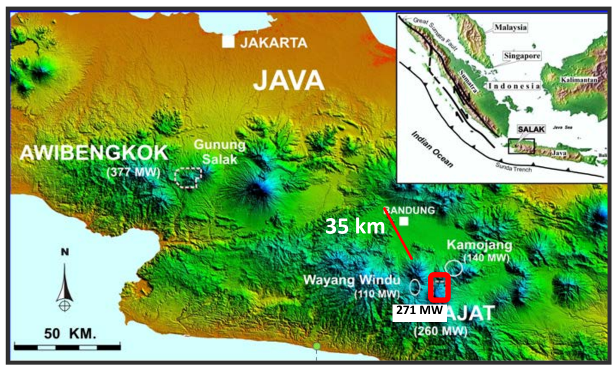
A case study of the Well B-2 injection test showed an obvious impact on a particular production well. The condensate was injected in Well B-2 at a rate of ~45 L/s for 18 days. The specific monitoring wells were selected based on their connectivity to injector Well B-1, located at the same pad as Well B-2, as defined by the 2008 tracer test results. The injected tracer at Well B-1 is migrating along the Cibeureum Fault and appearing in production wells at the southwestern part of the Darajat reservoir. Well C-1, located southwest of Well B-2, showed an increase in NCG concentration during the injection test but returned to normal levels within two weeks after condensate injection was stopped. There were no detrimental changes in the steam deliverability of Well C-1 and other surrounding wells both during and after the injection test. However, this observation confirmed the connectivity between Pad B and fluid migration towards the southwest part of the field.

INTRODUCTION

The Darajat Geothermal Field is located ~35 km southeast of Bandung about 1,750-2,000 m ASL (Figure 1). Geothermal investigations at Darajat began in the early 1970s and commercial generation started in 1994. Darajat is one of the biggest vapor dominated geothermal fields in the world with a total current capacity of 271 MWe from three generating units, namely, Unit I, operated by PT. Indonesia Power, with a capacity of 55 MWe, and Units II/III, both operated by Chevron Geothermal Indonesia, with capacities of 95 and 121 MWe, respectively. Now, Chevron Geothermal Indonesia has drilled a total 49 wells including six slim-hole observation wells.

The Darajat Geothermal Field is found on the eastern side of Mt. Kendang, which is part of an arcuate range of Quaternary volcanoes extending 25 kilometers from the Papandayan volcano in the southwest and to the Guntur Volcano in the northwest. This arcuate range of volcanoes hosts numerous eruptive centers and volcanic activity in historic times, e.g., Guntur Volcano (1840), Papandayan Volcano (1772, 1923-1926).

The Darajat geothermal system consists of mostly of andesitic lava flows which are intruded by dioritic rocks; Pasaribu et al. (2012) called this the “andesite complex.” The steam reservoir found in Darajat is encountered in this andesite complex. Pyroclastic rocks (breccias and tuff), presumably from surrounding volcanic centers, cover the andesite complex.



Source: SRTM West Java BSL 1841_Z48S

Figure 1: Map showing the location of the Darajat Geothermal Fields in relation with other cities and geothermal fields in West Java.

Structures in Darajat dominantly trend NE-SW, NW-SE, and N-S (Figure 2). The most significant structural feature in the area is the Kendang fault which strikes northeast from Darajat along the high axis of the volcanic range, disappearing on the north side of the Kamojang field about 10 kilometers away. To the west of the Darajat field, the Kendang fault is slightly offset by the Gagak fault, which is considered to control major permeability within the field. Other structures which have NE-SE trend are Cibeureum, Cipandai and S Faults. The major NW-SE structure is the Ciakut Fault which is believed to be a pathway of edge field fluids into the reservoir. Other minor NW-SE structures are believed to control fluid migration and permeability at Darajat. N-S trending structures were confirmed by surface mapping (Stimac et al, 2010; Pasaribu et al., 2012) and recent interpretations of geochemical observations and fluid flow during drilling combined with the interpretation of tracer test results.

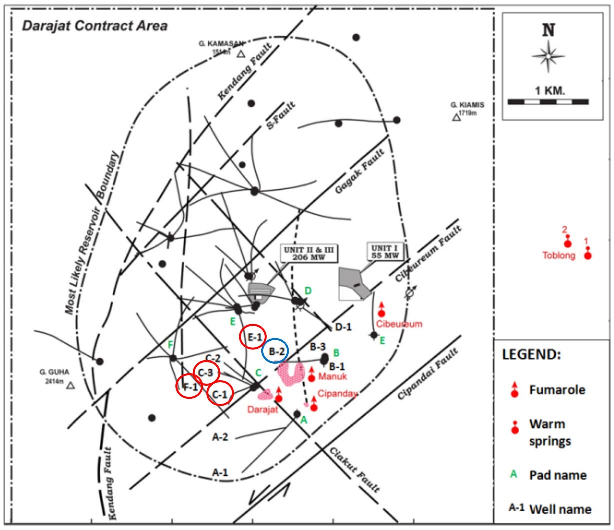


Figure 2: Map of the Darajat Geothermal Field showing the locations of B-2, where the injection test was conducted, and the surrounding wells that were monitored during the test.

METHODOLOGY

Regular reservoir surveillance activities are conducted in Darajat to monitor both subsurface and surface (in thermal manifestations) changes that result from mass extraction, injection, entry of edge field fluids or marginal recharge, etc. Surveillance activities consists of geotechnical, geochemical, geophysical, production rate monitoring and down hole wellbore surveys.

Specific monitoring activities are conducted especially during a particular field activity. Injection testing is normally conducted to estimate the injection capacity of a well. By monitoring surrounding wells during injection testing, the connectivity of a particular well to its neighboring wells can also be determined. The primary objective of the condensate injection in Well B-2 was to clean-out an obstruction (believed to be scale) inside the wellbore. A minor objective was to determine the injection capacity (or Injectivity Index, II) of B-2 as the II is a measure of a well's permeability. Injection of condensate on Well B-2 at a rate about 45 L/S was conducted for 18 days during December 2013 to January 2014. To determine if condensate injection in B-2 has no detrimental effect, neighboring wells were observed during the injection.

Four wells, namely, C-1, E-1, C-3 and F-1, were monitored during the injection testing at B-2 (Figure 2). Wells C-1, E-1 and F-1 were monitored due to their strong connectivity with B-1, located on the same pad as B-2, based on the results of a tracer test in 2008 which showed that the Cibeureum Fault is the conduit for tracer migration; thus, it was important to monitor wells that cross this particular structure (Rohrs et al., 2010). C-3 was monitored because it is located at the same pad as C-1 hence it might also be impacted by the injection test at B-2. Before the injection test, baseline data through regular monthly sampling were collated. Frequent geochemistry sampling (i.e., twice per week) was conducted starting January 8, 2014 or a week after the start of the injection test. Sampling of the monitoring wells was terminated on February 7, 2014, a week after the completion of the injection test. During the monitoring period, Non-Condensable Gas (NCG) in steam, surface superheat (SH), boron (B), Flowing Well Head Pressure (FWHP) and flow rate were all measured. NCG, SH and FWHP were measured on site; boron was estimated after laboratory analysis of the sample; and the flow rate data was downloaded from the online Distributed Control System (DCS). These data were measured because they were relatively fast and easy to collect, and deemed reliable to use for determining various reservoir processes.

DISCUSSION

Non-Condensable Gas (NCG)

NCG is gas that is not able to condense to the liquid phase. If there is condensation, the NCG concentration will increase because the proportion of the gas is higher relative to steam. If there is boiling process, the wt% NCG will decrease because the composition of NCG is lower relative to the steam. At Darajat, NCG has been utilized for tracking condensate injection breakthrough in production wells (Mahagyo et al., 2010). In saturated fractures, injection of cooler liquid could lead to condensation of steam hence surrounding wells may show increased wt% NCG.

Figure 3 shows the NCG concentrations in the monitoring wells at normal FWHP during the injection test at B-2. Note that C-1 showed an immediate steep increase in NCG concentration after injection in B-2 but returns to normal values two weeks after termination of the injection test. During and after the injection test, NCG in C-3 was stable. Both E-1 and F-1 did not show any changes in NCG concentration during and after the injection test. It is believed that the increase in NCG on C-1 is related to condensation of steam during the injection test.

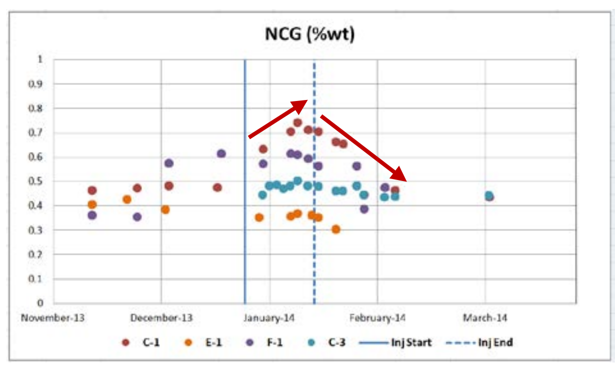


Figure 3: Geochemical plot of NCG showing the increase in NCG concentration at C-1 after injection at B-2 was started.

Boron (B)

Boron is routinely monitored in the produced steam as the primary chemical species to determine injection breakthrough (Mahagyo et al., 2010). This chemical species has a relatively high solubility and tends to remain in liquid phase hence it is measured in condensed steam samples. Figure 4 shows boron concentration for each of the monitoring well during the injection test at B-2.

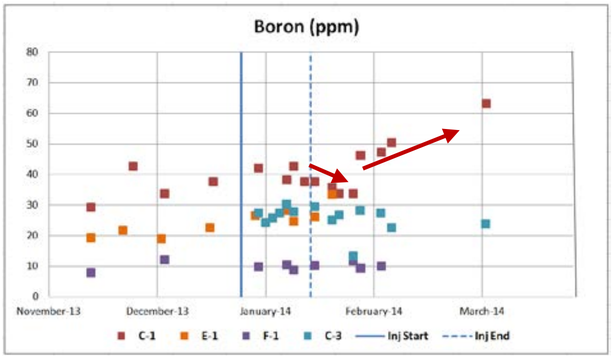


Figure 4: Geochemical plot of boron showing concentrations before, during and after the B-2 injection test. Note that C-1 was the only well that exhibited some change in boron during the injection test.

Except for C-1, all monitoring wells show relatively stable boron concentration before, during and after the injection test at B-2. After termination of injection at B-2, boron in C-1 decreased to pre-injection test concentrations temporarily but increased later. This behavior in boron concentration at C-1 was attributed to changes in FWHP or how the well was being operated. Increasing the FWHP resulted in condensation near the wellbore which stripped off the boron from the steam, thus decreasing its concentration in produced steam. Several weeks after termination of injection, the FWHP decrease thus it caused more boiling near the wellbore and increased the concentration of boron (Figure 5). The high boron concentration in March 2014 is not concluded yet, i.e., whether the trend of boron is increasing or it is just anomalous data. Therefore, it is necessary to check the boron data during April-June 2014.

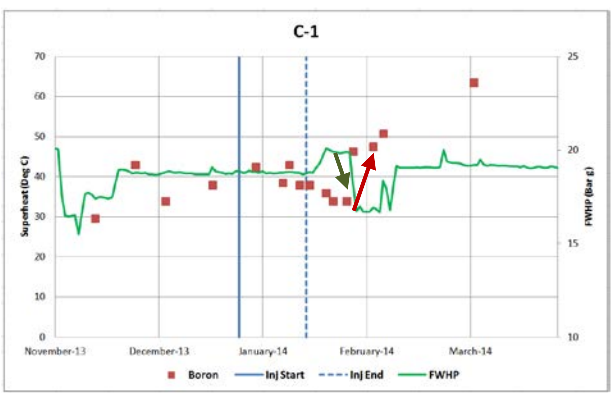
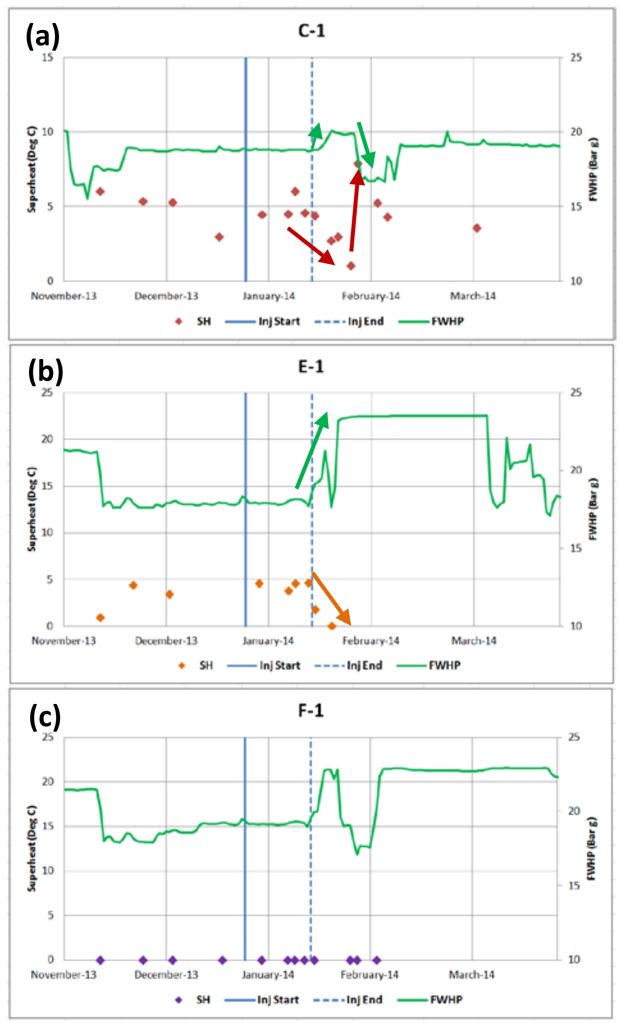


Figure 5: Plot of boron concentration vs. FWHP at C-1.

Superheat

Superheat is the condition where the measured temperature is higher than the saturation temperature. Surface superheat measurement is a convenient proxy to monitor superheat conditions in the reservoir because surface measurements are quick and easy to conduct and can be done frequently (Mahagyo et al., 2010). However, it should be noted that surface superheat depends on both subsurface reservoir processes and the operating conditions of a particular well. If there is condensation due to cooler liquid invading the reservoir, there should be no superheat because of saturated conditions. Also, if the FWHP is increased, it can cause condensation near the wellbore thus decreasing the superheat. Therefore, it is important to check the FWHP during surface superheat measurements.

Figure 6 shows the surface superheat of the monitoring wells during the injection test at B-2. Except for F-1, all monitoring wells showed changes in surface superheat estimates when the FWHP was changed. However, surface superheat did not significantly change during the injection test period where the wells were operating at stable conditions. Although C-1 superheat data seem erratic, comparison of the superheat estimates during the injection test with superheat values before the injection test shows that these superheat measurements are within the range of superheat estimates for this well (Figure 7). These results suggest that superheat was not affected by injection in B-2 but changes in the well operation impact surface superheat estimates.



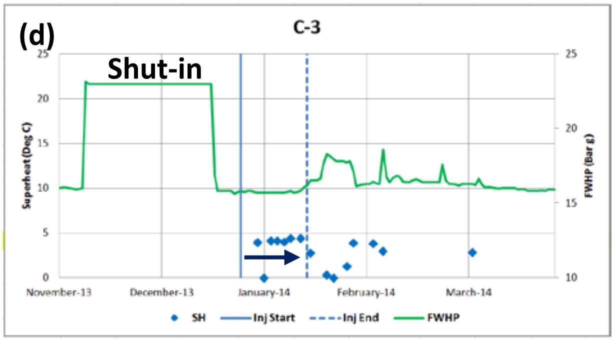


Figure 6: (a) C-1 shows stable superheat during B-2 injection; note that SH decreases at the same time with FWHP increases and increases when FWHP decreases. (b) E-1 also shows stable superheat during injection and decreases at the same time with FWHP increases. (c) F-1 is in saturated condition. (d) C-3 shows stable superheat during injection.

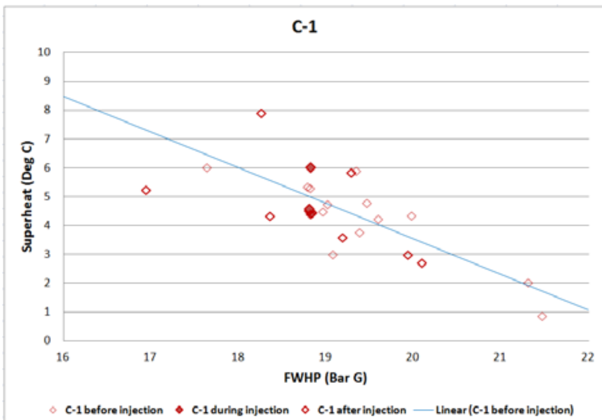


Figure 7: Chart showing the range of surface superheat estimates in C-1 before, during and after the injection test at B-2. Although "noisy," the estimated superheat values follow the trend prior to the injection test.

Flow Rate

Reservoir changes impact the flow rate (aka productivity or deliverability) of a well. If condensation occurs near the wellbore due to injection, it inhibits steam production resulting to a lower steam flow rate. Similar with surface superheat, the flow rate is also dependent on operating conditions. Increasing the FWHP creates condensation near the wellbore thus decreasing the well's flow rate. Increasing the FWHP also results to a decrease in flow rate as the shallow feed zone/s (with relatively lower reservoir pressure) are prevented from flowing and production come from the deeper feed zones only (with relatively higher reservoir pressure). This phenomenon is particularly true if a well penetrates both shallow steam and deep liquid feed zones. At Darajat, permeability appears to decrease with depth hence the deeper feed zones generally have lower permeability (and productivity) compared with the shallower permeable entries (Fitriyanto et al., 2012).

Figure 8 shows the flow rates of the monitoring wells before, during and after the injection test at B-2. Note that the flow rates of the monitoring wells behave similar with the surface superheat estimates. The flow rates are relatively stable during the injection test but changes in FWHP impacted the productivity of the wells.

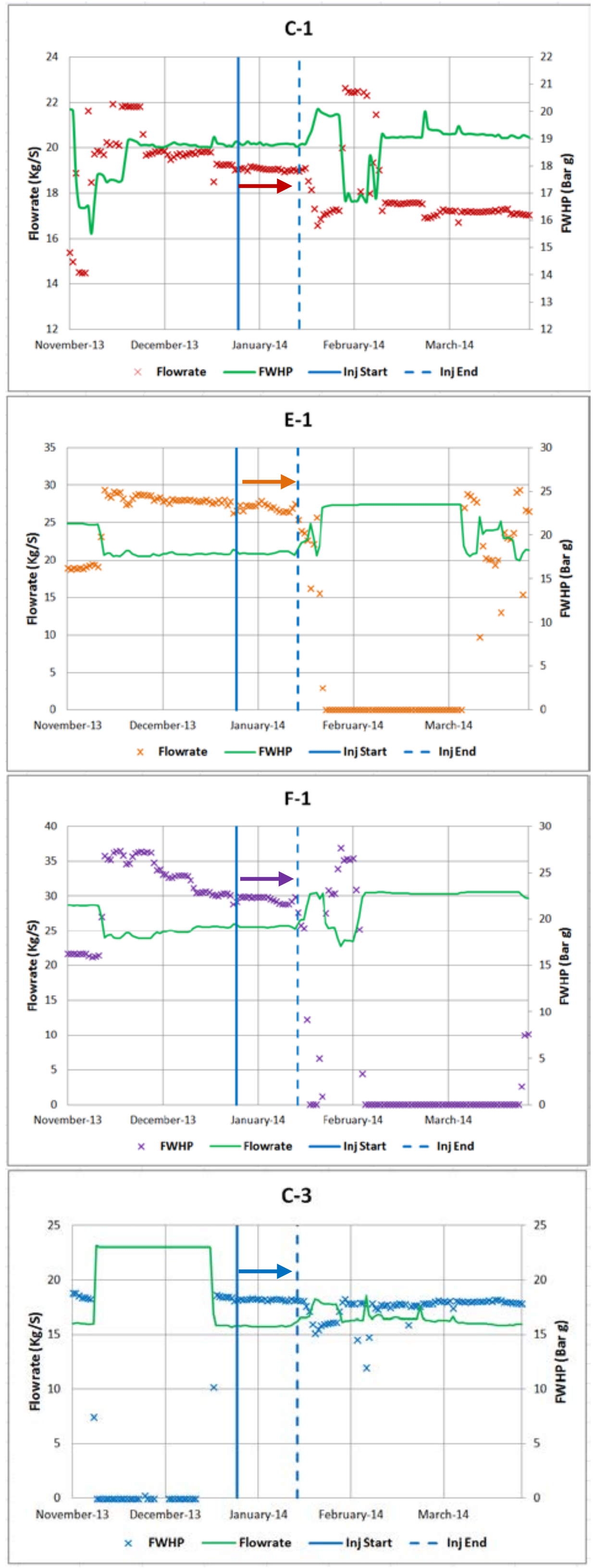


Figure 8: C-1, E-1, F-1, and C-3 have stable flow rate during injection. Decrease in flow rate occurs at the same time as FWHP increases.

CONCLUSIONS

NCG appears to be the best parameter to use to determine the impact of the injection test at B-2. The NCG concentration in C-1 increased after injection at B-2 started but returned to pre-test values after injection was terminated. This temporary increase in NCG in C-1 during the injection test indicates that there is condensation in the steam reservoir due to the injection of condensate. Although condensation occurs, only chemical breakthrough was observed and there was no impact on flow rates in monitoring wells suggesting that the condensation occurs relatively far from these wells. Production well C-1 appears to have the strongest connectivity with B-2, relative to other monitoring wells, and validates the results of the 2008 tracer test. Lastly, these monitoring results suggest that Well B-2 can be used as an emergency condensate injector at least for 18 days with injection rate ~45 L/s.

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