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Mitigation of Reinjection Returns in Palinpinon-II, Philippines

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ABSTRACT

Palinpinon-II production field has three sectors producing steam from separate modular power plants: 20MW in the Balasbalas sector, 20MW in the Nasuji sector, and 40MW in the Sogongon sector.

For the Nasuji sector, the simultaneous discharge test in 2012 confirmed that the excess steam can support a 45MW power plant. Seven (7) production wells in the Nasuji Sector will soon supply steam to a new 45MW Nasulo Plant that will be commissioned in 2014. The production sustainability at this high extraction rate was tested for a total of six months with 6 out of 7 production wells simultaneously discharged in 2011-2012. The required injection capacity for the 45MW production is 187 kg/s. Since the preferred injection capacity is only 80 kg/s from NJ1RD and NJ2RD, full operation would require an additional injection well.

Steam decline in the neighboring Balasbalas Sector was observed within two months after termination of the simultaneous discharge testing. This can be attributed to the overloading of the preferred load of injection wells in Nasuji that resulted to injection returns during the Nasulo simultaneous discharge testing to all of Palinpinon-II Sectors, i.e. injection returns were observed in five Nasuji wells and all of the wells in the Sogongon Sector.

To accommodate additional brine from full load operation of the 45MW Nasulo power plant and to disperse injection fluids farther to the north of the present Nasuji injection sink, it was recommended to pursue drilling of a new reinjection well NJ3RD.

1. INTRODUCTION

Steam supply for the 20MW Nasuji Modular Plant (NJMP) comes from three (3) to four (4) out of six (6) production wells in the Nasuji Sector in Palinpinon-II. Figure 1 shows the location and well tracks of the six wells: OK6, NJ4D, NJ5D, NJ6D, NJ7D, and NJ8D.

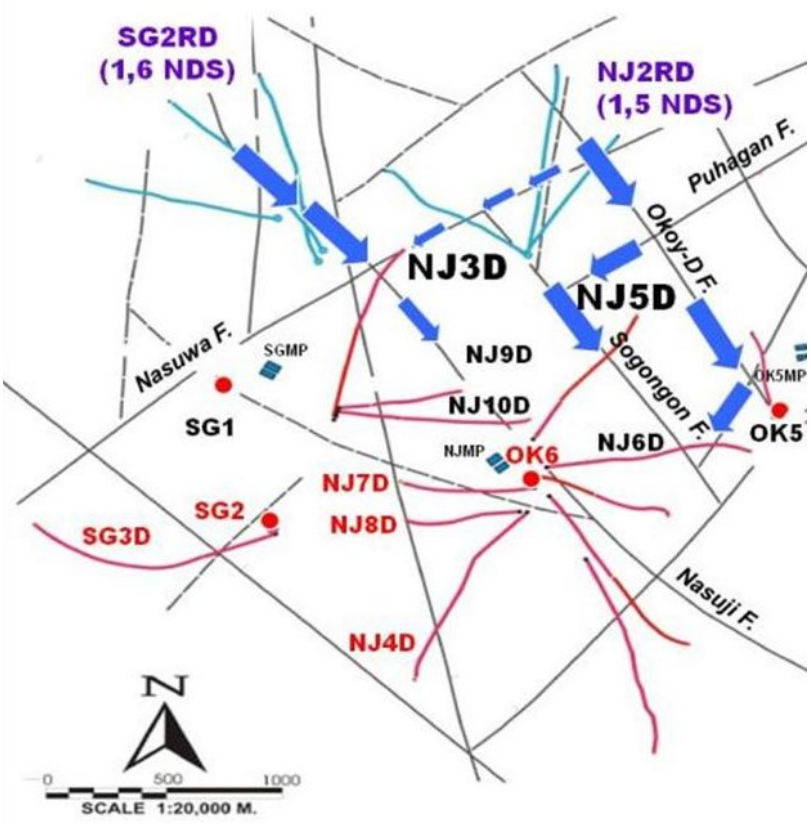

Figure 1: Map showing tracks of geothermal wells in Palinpinon-II

2. NASULO SIMULTANEOUS DISCHARGE TEST (NSDT)

2.1 Objective

The primary objective of the Nasulo simultaneous discharge test is to confirm the actual steam capability of the Nasuji Field to support the 45MW Nasulo Power Plant. The initial response of the reservoir to increased mass extraction will help assess long term sustainability of the field.

2.2 Discharge and Testing Program

The test started on 02Sep2011with 6 out of 7 production wells being discharged. OK6 was shut and used as pressure monitoring well. The initial program lasted for three (3) months. The test was extended for another month starting 02Dec2011 to establish stable output trends of NJ5D and NJ8D. However, the discharge testing was disrupted on 17Dec2011 by tropical storm "Sendong" which damaged most of the field facilities. The test resumed on 11Apr2012 with an initial duration of one (1) month. It was extended to two (2) months to attain stable physical and chemical trends. Thus, the "post-Sendong" discharge test lasted for three (3) months, culminating on 10Jul2012.

2.3 Physical Data

2.3.1 Reservoir Pressures

The discharge test had two dedicated wells for monitoring the reservoir pressures. These are well OK6 at the Nasuji field and PN28 at the Palinpinon-1 (Pal-1) field. These production wells were monitored to determine response of their respective sector to the increased mass extraction at Nasuji. Initially, downhole pressures were recorded using the mechanical Kuster Pressure (KP) tool. However, it was replaced by the Pruett interference instrument to record smaller changes in reservoir pressure (<0.1MPag). The Pruett instrument was installed in OK6 and PN28 on 28Jan2012 and 08Dec2011, respectively.

The monitoring tools were installed at 500m below the water level inside the wells prior to the start of the discharge test. In PN28, this depth is at 1800mMD. However, in OK6, it was set at 2200-2400mMD, or just 300 m below the water level due to the maximum pressure limitations of the Pruett instrument. The pressure trend of OK6 indicates minimal pressure drawdown. The reservoir pressure registered an overall drop of 0.04MPa from the 1st quarter of 2012 up to Jun2012, two (2) months after the resumption of the discharge test. Moreover, the pressure trend leveled off at about 5.2MPaa since May2012. This validates the results of the reservoir simulation.

On the other hand, the pressure changes in PN28 in response to the increased extraction at Nasuji were negligible. The pressure decline of about 0.3MPa starting in Jan2012 is related to the resumption of the 3-unit operation of the Palinpinon-1 Geothermal Power Plant (PGPP-1). However, since Apr2012, the pressures have been averaging at around 5.3MPaa.

2.3.2 Water Level

The use of KP instruments for pressure monitoring also allowed monthly measurement of water levels in OK6 and PN28. The KP tool was run in at 100m indices from the CHF down to the setting depth. However, using the Pruett interference equipment did not require pullout of the tool to gather data. It remained at its setting depth throughout the duration of the test.

Monitoring data from Aug2011 to Dec2011 did not show change in water levels in OK6 and PN28. The stable water levels can be attributed to minimal declines of reservoir pressures.

Based on pressure decline analysis, the expected increase in pressure drawdown for the additional 25MW production in Nasuji is approximately 0.96MPa and approximately 1.28MPa for the 45MW total (see Figure 2). For the three month-NSDT, the predicted pressure drawdown in OK6 was 0.075MPa. However, the pressure drawdown at OK6 was only 0.04MPa. The minimal pressure drawdown during NSDT confirms the >40MW field capability based on simultaneous discharge of six (6) production wells. However, injection returns may have contributed pressure support during NSDT.

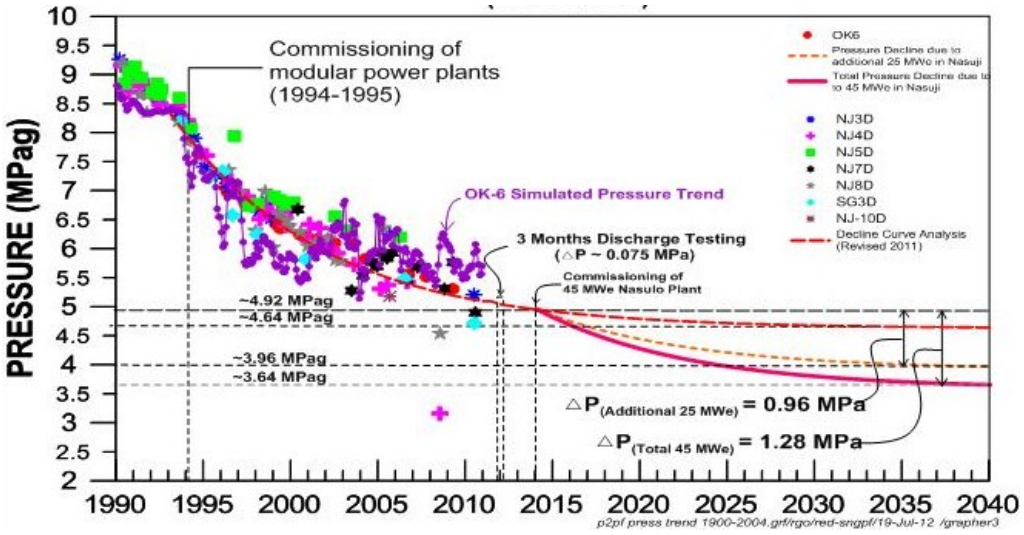

Figure 2: Palinpinon-II pressure decline curve analysis (-1000 mSL)

2.3.3 Bore Output Measurement (BOM)

During the test, the wells with high water flow, namely NJ4D, NJ5D, NJ7D, and NJ8D were cut in/online to the FCRS to prevent brine spillage problem. The wells with relatively lower water flow, NJ1D and NJ6D were discharged to the portable silencer. However, NJ6D was put online during the last month of the discharge test to support the steam requirement of the Nasuji Power Plant.

For each well that was online, weekly flow measurements were done using Tracer Flow Tests (TFT) and through horizontal discharge to pad silencers (James Lip Pressure Method) every four (4) days. The total steam flow from the wells online was also compared to orifice readings after the separator vessel.

Initially, declining trends of output were observed for most of the wells. However, the output eventually leveled off, indicating stabilization of fluid flows and pressure from the reservoir. Based on the stable trends of each production wells, the steam capability of the field is 47.8MWe. This considers a 3% steam loss along the FCRS and a target steam rate of 2.13kg/s-MWe for the Nasulo Power Plant. There was no update for OK6 since it remained shut for pressure monitoring during the NSDT. It was assumed that its output has been stable due to minimal pressure drawdown recorded during monitoring.

2.4 Fluid Chemistry

2.4.1 Mixing of Acidic and Neutral-pH Fluids in NJ1D

NJ1D was drilled and completed in 1982 but was not connected to the FCRS due to inflow of acidic fluids. It was included in the NSDT to determine if it can be similar to NJ6D which has become productive when fluid changed from being acidic to neutral-pH in 2004. During NSDT, the brine pH of NJ1D was closely monitored. The data showed pH becoming less acidic from pH 4.82 (Feb2011) to 6.31 (Aug2011). Figure 3 shows the pH trend from Feb2011 to Jun2012.

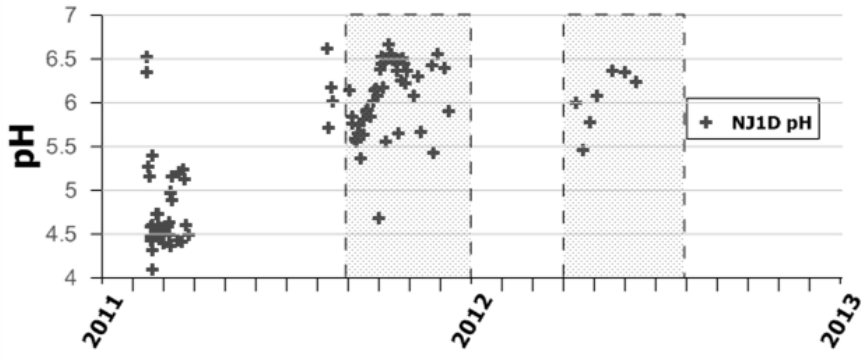

Figure 3: NJ1D pH plot (Feb2011 to Jun2012)

Based on Na-K-Mg ternary plot, the pH improvement indicates increasing component of neutral pH. Upon initial discharge, brine chemistry plots within the immature region. As discharge continued, data points shifted toward the equilibrium region, suggesting contribution from deep hotter, neutral-pH fluids. The trend is also characterized by declining sulphate (SO_4) and declining Magnesium (Mg). Based on these trends, it appears that there is mixing of acidic and neutral-pH fluids when NJ1D is at shut condition. At flowing conditions, the acidic fluids are suppressed by neutral fluids from deeper feed zone.

2.5 Injection Returns in Nasuji Production Wells

NJ5D discharge chemistry exhibited RI signatures. From 2009 to 2012, NJ5D T-Quartz dropped by 20°C. This is attributed to the cooling effect of reinjection returns. $Cl_{res,}$ however, showed variation. Blockage within wellbore may also cause such behaviour as mass flow is decreasing.

The NDS tracer test conducted in 2005 confirmed injection returns from NJ2RD to NJ5D thru Sogongon fault via Okoy D and Puhagan faults, and to NJ6D thru Okoy D and Sogongon Splay faults. First arrival of NDS tracer in NJ5D and NJ6D was between 5th and 7th day after injection in NJ2RD. With an average injection load of 60 kg/sec in NJ2RD, tracer recovery was 23.78% in NJ5D and 6.63% in NJ6D (Maturgo et al., 2010).

Southwestern wells (NJ4D, NJ7D and NJ8D) have also manifested RI signatures during the test. These wells were not monitored during NDS tracer test in 2005 because they were shut due to excess steam supply. NJ6D which was drilled towards the Balasbalas sector showed inflow of a relatively less saline, degassed fluid of cooler origin.

2.6 Mineral Scaling Potential and Non-Condensable Gases (NCG)

The mineral saturation of the brine produced by each well during NSDT was calculated using the geochemical software, Watchworks. Only NJ1D, where there is inflow of acidic fluids at shut condition showed saturation and potential for deposition of Anhydrite. Other wells (NJ4D, NJ5D, NJ6D, NJ7D, NJ8D) indicate potential for depositing Calcite.

The Nasuji sector is characterized by low level non-condensable gases (CO_2 and H_2S). Thus, there is no constraint at different separation pressures during power plant operations. However, the separated brine from the two phase-fluids has the potential of causing silica deposition at separation pressures lower than 0.65 MPaa. For the present production separation pressure of 0.63MPa with all the wells online, the total steam flow is equivalent to 47.8MW (at 3% line loss). The present operating pressure will result to a projected SSI of 1.10. This will pose potential problems with silica scales in the RI lines and RI wells. To control silica scale

formation in the future, the thermodynamically appropriate separation pressure should be set at 0.80MPaa to give an SSI of 0.99 and %NCG of 0.67%. The steam flow at 0.80MPaa is equivalent to 46MW with a 3% steam loss correction.

3. OPERATIONAL IMPACT OF INCREASED MASS EXTRACTION

3.1 Reinjection Capacity Requirement

The total steam flow from all existing production wells in Nasuji can supply the steam requirement of the 45MW Nasulo Power Plant. Through NSDT, the production capability was assessed with 6 out of 7 production wells discharging for 6 months. Pressure monitoring reveals minimal pressure drawdown, which can be attributed to injection returns as indicated by chemical trends characterized by increasing chloride and decreasing CO_2 in the separated brine. Although the chemical front of injection returns was observed during the NSDT, thermal breakthrough was not detected yet.

Brine production for full load operation (~180 kg/s) exceeds the existing current total injection capacity (~150 kg/s) of NJ1RD and NJ2RD in Nasuji. Hence, there is a need to drill additional injection well (NJ3RD) for the disposal of separated brine. Further, the current capacity cannot be utilized fully due to potentially adverse effects of injection returns. Based on previous NDS tracer test results in 2005, preferred injection rate in NJ1RD and NJ2RD is a total of only 80 kg/s.

Drilling of NJ3RD to accommodate additional brine would now require a RICAP of 100 kg/s. NJ3RD should be targeted away from structures that directly connect to the production sectors of Nasulo and Balasbalas. Risk assessment for drilling NJ3RD was endorsed. Acidizing operation will be one of the options if ever RICAP falls short of expectation. Other options like brine distribution through the use of cross-country interconnection line between Nasuji and Sogongon is being considered.

3.2 Potential Effect on Adjacent Production Sector(s)

Apparently, the higher mass extraction during the simultaneous discharge tests has enhanced pressure drawdown in Nasuji which could lead to preferential flow of injection returns towards this sector. After the termination of NSDT, the reduced mass extraction could have not only slowed down the rate of injection return towards Nasuji but also resulted to partial 'diversion' of flow towards Balasbalas (probably towards OK5 based on previous NDS tracer results). Within two (2) months, steam flow in Balasbalas started to decline. Steam decline in all production wells were observed from Sept2012 to Nov2012.

The steam decline in Balasbalas can be attributed to RI returns from Nasuji sector as manifested by geochemical behavior (OK5 and BL1D), established RI returns of OK5 from NDS tracer test. NJ6D, the production well closest to Balasbalas, also manifests quenching effect of injection returns. On the other hand, post-NSDT evaluation shows entry of cooler fluids in NJ5D at 2500mMD down to the bottom hole.

However, mineral deposition as a result of flashed injection fluid may have contributed also to steam decline in Balasbalas. This is suggested by recovery of amorphous silica scales from the total suspended solids in BL1D discharge. If the Balasbalas production wells will show output recovery with time when RI returns has diminished, then it is likely that mineral scaling was very minimal and has not progressed significantly to cause steam decline.

Increased RI return was also observed in Sogongon during NSDT. Significant increase in Clres, decline in CO_{2TD}, CO_2/H_2S ratio and Cl/Ca ratio as chemical manifestations in NJ3D, NJ10D, SG1, and SG3D were observed, however without the thermal breakthrough yet.

4. CONCLUSION

The Nasulo Simultaneous Discharge Test (NSDT) which lasted for a total of 6 months, discharging 6 of 7 production wells confirmed that the field capacity can support the 45MW Nasulo Plant. Well outputs indicate that the field has a maximum steam capacity of 47.8MW, assuming a steam loss of 3% along the FCRS. Downhole pressure monitoring reveals minimal pressure drawdown at increased mass extraction. The required RICAP for a 45MW production is 180kg/s. Since the preferred injection rate in NJ1RD and NJ2RD is a total of only 80 kg/s, Nasulo operation would require an additional RI well. Risk assessment and other options for drilling NJ3RD were proposed.

Wells that show RI return signatures are NJ4D, NJ5D, NJ7D and NJ8D. Future RI wells will be drilled away from structures with known connection with the production sector/s. NJ1D has turned into neutral-pH from acidic discharge. Putting NJ1D online will augment steam supply of the field.

The higher mass extraction during the simultaneous discharge tests showed response of the neighboring sectors. Increased RI returns was also felt in Sogongon as the result of increased Nasuji RI load. The steam flow decline experienced in Balasbalas is related to the discharge test as OK5 has established RI returns from Nasuji.

5. RECOMMENDATIONS

1. Pursue drilling NJ3RD to accommodate additional brine from full load operation of the 45MW Nasulo power plant, and to disperse injection fluids farther to the north of the present Nasuji injection sink.

2. Connect NJ1D to the FCRS as a production well. The acidic fluids in NJ1D are suppressed by neutral pH fluids from deeper feed zones at flowing condition.

3. To minimize/prevent silica scaling along injection lines and wellbore, a separation pressure of 0.80MPaa is recommended. This will result to an SSI of 0.99 and %NCG of about 0.67%.

4. Conduct NDS tracer test in other Pal-II RI wells to quantify injection returns, identify flow paths and predict cooling effect of injection returns. The results will be used to assess optimum RI loading. The proposed NJ3RD well will be included in the tracer test program during its utilization.

6. REFERENCES

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