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# OPTIMIZATION STUDIES ON WELL SP-4D MINDANAO GEOTHERMAL PRODUCTION FIELD, PHILIPPINES

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## ABSTRACT

*Well SP-4D has undergone three workovers because of formation of calcite blockages at its flash point depth at around 800-850 mMD. The calcite inhibition trials conducted in 1999 failed to inhibit the formation of calcite primarily because of the inability to reach proper inhibition point due to liner problems encountered prior to the set-up of the inhibition system.*

*During the workovers, obstructions were also encountered at deeper sections of the wellbore (>1250 m) while undergoing reaming operations. These obstructions were believed to be calcite, formed when calcium-rich low temperature fluids (220°C) from deeper feed zones (1300 mMD to bottom) were heated by hotter fluids (240°C) from the major feed zone (1200 mMD) of the well. This wellbore phenomenon in SP-4D presented two possibilities for the setting depth of the inhibition system, namely, (1) near well bottom at 1400 mMD or (2) at a shallower portion of the well thus letting the deeper but relatively colder section of the well to be totally blocked by calcite deposition.*

*An optimization study was performed using wellbore simulation to determine the setting depth of the inhibition system for SP-4D. Results show that the inhibition system should be set at around 1150 mMD, allowing the deeper colder sections to be naturally blocked by calcite deposition. Simulation results also shows that as long as the wells' discharge is dominated by single-phase liquid fluid the deepest flash point will take place at around 1000 mMD.*

## 1.0 INTRODUCTION

The Mindanao Geothermal Field (MGPF), located on the northwest flanks of Mt. Apo on the island of Mindanao, Philippines (Figure 1), begun its commercial operation when the first 52-MWe Mindanao 1 Geothermal Plant (M1GP) was commissioned on March 4, 1997. By June 17, 1999, the second 52-MWe double flash turbine unit Mindanao 2 Geothermal Plant (M2GP) was commissioned, increasing the total installed capacity to 104 MWe.

Since its start of commercial exploitation, production from two MIGP production wells drilled from the same pad, APO-1D (6.2 MWe) and SP-QD (6.0 MWe), had been persistently hampered by blockages caused by calcite deposition. These wells had undergone workovers to clear them of calcite blockages. In addition, calcite inhibition experiments were conducted to prevent the recurrence of calcite deposition. However, calcite inhibition trials in SP-QD conducted in 1999 failed to inhibit the formation of calcite primarily because of inability to reach proper inhibition point due to liner problems encountered prior to the set-up of the inhibition system.

In this study, the optimum setting depth of the calcite inhibition system (CIS) based on wellbore simulation will be discussed.

## 2.0 WELL HISTORY AND CHARACTERISTICS

Well SP-QD was drilled in February 1994 on the same pad as APO-1D to a depth of 1480 mMD (1288 mVD). Postdrilling tests indicated the main feed zone at 1150-1250 mMD and a minor feed zone at 900-1000 mMD. Early heat-up temperature measurements showed temperature reversals with depth, that is, from 1250 mMD to the bottom. The highest temperature measured was about 245°C decreasing to about 220°C at the bottom.

After ensuring SP-QD was clear to the bottom with GD surveys conducted in December 1996, the well was hooked to the FCDS in March 1997

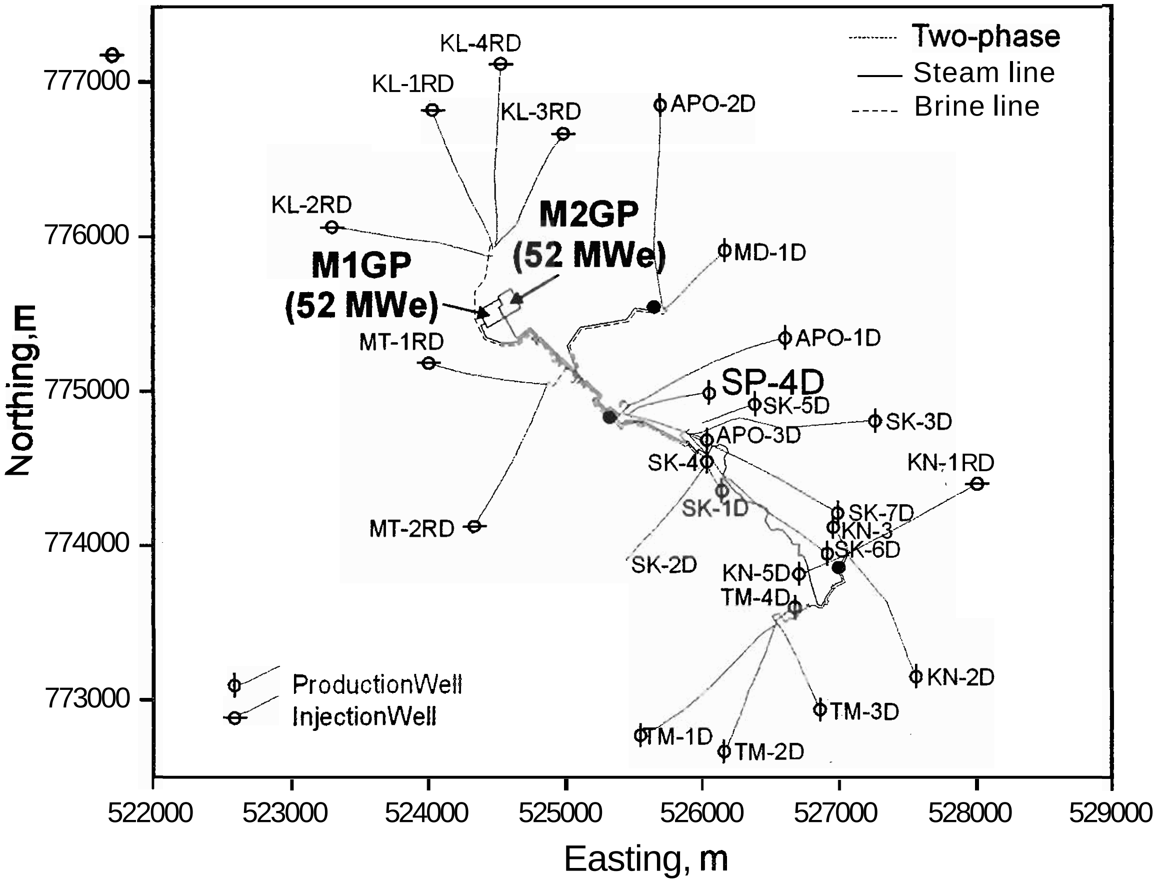

Figure 1. Mindanao geothermal production field fluid collection and disposal system (FCDS) and well location map.

with an initial supply of approximately 6 MWe to the power plant. However, massive calcite scales were detected as early as July 1997 at 697 mMD and 744 mMD. In February 1998, mechanical workover operations were performed in SP-4D to remove the calcite scales because the well had ceased supplying steam to the power plant. (Note: Post-workover tests indicated a different feed zone number and locations.) The well was again utilized continuously, causing another episode of massive calcite deposition that had to be removed by a second mechanical workover in April 1999.

Table 1 summarizes the depths of tagged obstructions during the workovers in 1998 and 1999. The scaling at shallow levels were related to the flashing of SP-4D brine at around 230-235°C. The brine expels $CO_2$ gas that cause increases in pH and calcite supersaturation resulting in deposition. The obstructions encountered at deeper sections of the wellbore (>1250 m) while undergoing reaming operations were believed to be calcite, formed when calcium-rich low temperature fluids (220°C) from deeper feed zones (1300 mMD – bottom) were heated by hotter fluids (240°C) from the major feed zone (1200 mMD) of the well. (Duke, et al., 2000)

The recurrence of calcite deposition in SP-4D led to the installation of a calcite inhibition system (CIS) in May 1999, after the second mechanical workover. The presence of an obstruction tagged at 825 mMD limited the injection depth to 815 mMD. The well was then operated under throttled condition to maintain flash point depths to shallower levels where inhibition could still be performed. In May 2000,

Table 1. Depths (mMD) of tagged obstructions during workovers in 1998 and 1999.

| 1998 | 1999 |
|---|---|
| 610-805 | 786-846 |
| 1309-1333 | 1218-1246 |
| 1423-1472 | 1312-1379 |
|  | 1408-1472 |

after more than 11 months of inhibitor injection, the test was terminated due to continuously declining wellhead pressure and water flow with time. Later analysis showed that the throttling effect of the initial obstruction at 825 mMD was not considered in the process of estimating the location of the flash point. The blockage constricted the brine flow and concentrated flashing at this depth, below the CIS setting depth (Nogara, 2000).

A third mechanical workover was conducted on SP-4D after the CIS was pulled out. Table 2 shows the locations of blockages tagged in comparison with 1998 and 1999 data. The new obstruction tagged at the shallow zone was believed to be related to the change in well configuration close to the top of liner at 729 mMD.

Table 2. Comparison of 2000 tagged obstructions with 1998 and 1999 data.

| 1998 | 1999 | 2000 |
|---|---|---|
| 610-805 | 786-846 | 730-754 |
| 1309-1333 | 1218-1246 | 816-848 |
| 1423-1472 | 1312-1379 | 1275-1356 |
| | 1408-1472 | 1372-1384 |
| | | 1454-1460 |

## 3.0 OPTIMIZATION STUDIES

To investigate the best setting depth for the SP-4D's CIS injection head for optimum well performance, wellbore simulation was applied on SP-4D using its current downhole characteristics and discharge data.

### 3.1 Bore Output Measurements

Bore output measurements at different wellhead pressures were taken after the mechanical workover of SP-4D in February 1998. The stabilized bore outputs are summarized in Table 3.

Table 3. Bore output summary (April 1998).

| WHP (MPag) | Mass Flow (kg/s) | Enthalpy (kJ/kg) |
|---|---|---|
| 1.35 | 34.7 | 1065 |
| 1.32 | 35.9 | 1059 |
| 1.08 | 57.5 | 1046 |

### 3.2 Flowing Surveys

During the output measurements in April 1998, flowing surveys were conducted using an electronic pressure-temperature spinner (PATS) logging tool to characterize and quantify the individual contributions of the different feed zones. Two surveys were taken at full discharge (WHP : 1.08 MPag) and at throttled (WHP : 1.35 MPag) conditions. The measured profiles are illustrated in Figures 2 and 3.

### 3.3 Flash-point depth

The profiles showed liquid conditions from the well bottom to about 790 mMD (just below the PCS) where flashing began and two-phase conditions developed. This was clearly shown by slope changes in the pressure profiles, accompanied by sharp increases in spinner response.

### 3.4 Temperatures

The measured temperature profiles reiterated the temperature reversals noted in earlier shut and flowing surveys. The bottomhole temperature recorded was around 220°C, several degrees lower than the temperatures of about 237°C measured at shallower levels. This indicated inflow of colder fluids (compared to the major feed zone) from the bottom feed zones. In effect, these cooler fluids mask the hotter inflow from the major zone from below.

### 3.5 Feed zones

Four production zones were identified from the spinner response profiles. The major zone was located at 1200-1205 mMD and the three minor zones at 810-815, 1300-1305 and 1445-1450 mMD, respectively.

The flows at the feed zones were calculated by correlating the spinner responses with the different logging speeds. The mass flows from the feed zones below 1200 mMD were lumped together due to very small spinner response recorded relative to the responses in other feed zones. Table 4 summarizes the individual feed zone contributions.

Table 4. Mass flow (kg/s) contribution of feed zones at different wellhead pressures.

| Depth (mMD) | WHP : 1.34 MPag (kg/s) | WHP : 0.98 MPag (kg/s) |
|---|---|---|
| 810-815 | 2.1 | 5.7 |
| 1200-1205 | 16.3 | 27.2 |
| 1300-1305<br>1445-1450 | 16.3 | 24.6 |
| Total | 34.7 | 57.5 |

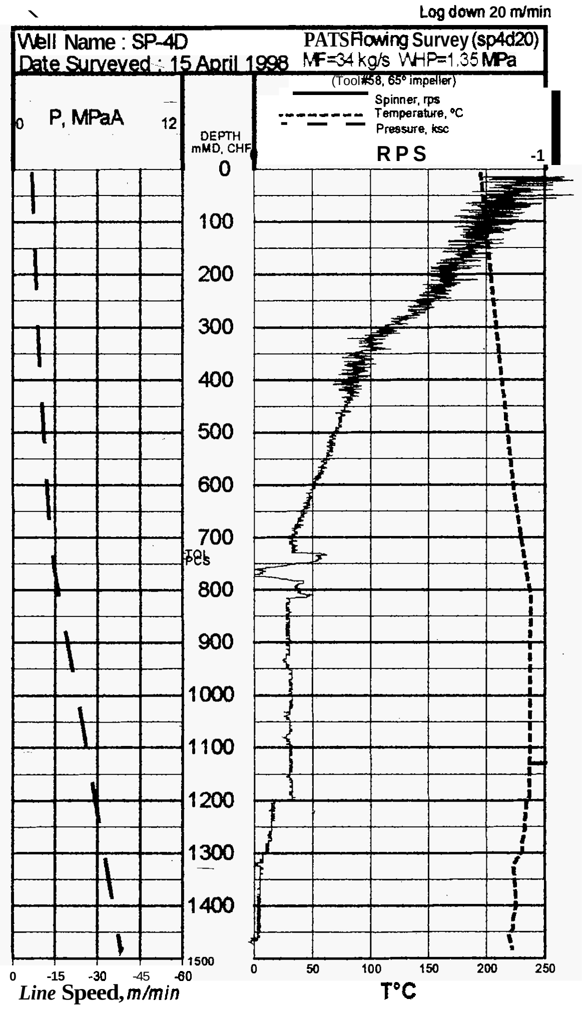

Figure 2. PATS log of SP-4D while discharging at 1.35 MPag.

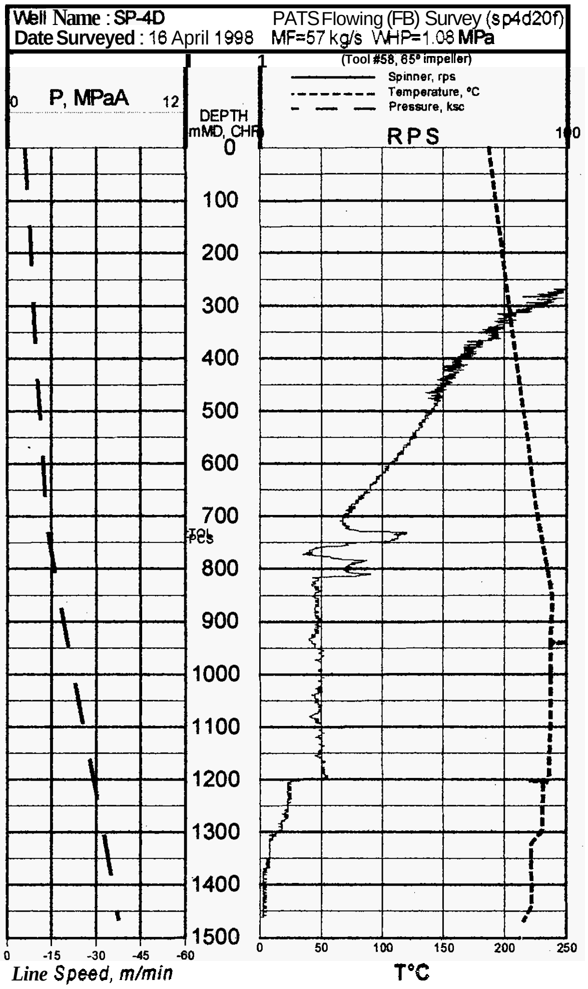

Figure 3. PATS log of SP-4D while discharging at 1.08 MPag.

## 3.6 Wellbore simulation

A steady-state wellbore simulation was performed on SP-4D to match the temperature and pressure profiles and the individual feed zone mass flows measured by the flowing surveys. This was done using the commercial wellbore simulator WELLSIM. NaCl and $CO_2$ contents were set to zero as actual values of these components are negligible. As a result of the simulation, feed zone enthalpies and productivity indices (linear relationship) and the individual mass flows of the two bottom zones were estimated. Figure 4 illustrate the temperature and pressure matches obtained for a discharge wellhead pressure of 1.08 MPag.

This result indicated that at a discharge pressure of 1.08 MPag, the major zone (1200-1205 mMD) and the two bottom zones (1300-1305 and 1445-1450 mMD) contributed liquid feed with enthalpies of about 1060, 1040 and 1000 kJ/kg, respectively. Two-phase conditions developed at about 805 mMD where mixing with the two-phase inflow from the topmost feed zone (810-815 mMD) occurred. Here, the enthalpy was estimated to be about 1400 kJ/kg. Table 5 summarizes these results.

| **Feed Zone** Depth **(mMD)** | **Mass Flow (kg/s)** | **Enthalpy (kJ/kg)** |
|---|---|---|
| 810-815 | 5.7 | 1400 |
| 1200-1205 | 27.2 | 1060 |
| 1300-1305 | 15.0 | 1040 |
| 1445-1450 | 9.6 | 1000 |

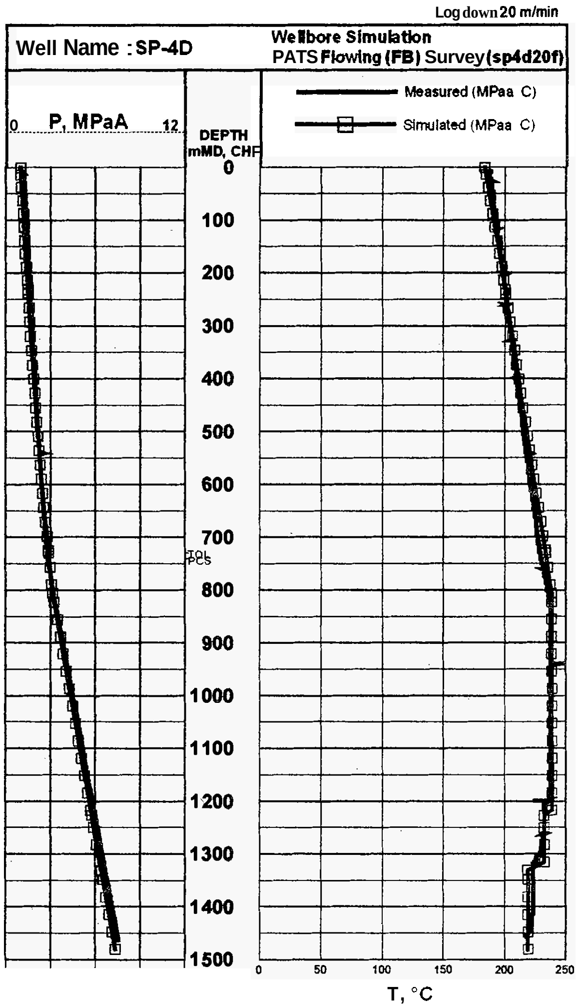

**Figure 4. Wellbore simulation of SP-4D while discharging at 1.08 MPag wellhead pressure.**

Assuming constant feed enthalpies and productivity indices, subsequent wellbore simulation was conducted to determine the best CIS injection head setting depth to optimize the utilization of SP-4D. Three cases were identified for this purpose:

Case 1 Set CIS at 1350 mMD (above the bottom feed zone) to inhibit calcite deposition throughout the wellbore

Case 2 Set CIS at 1250 (above the feed zone at 1300-1305 mMD) to inhibit calcite deposition above this depth and allow the bottom feed zone to be totally blocked by calcite

Case 3 Set CIS at 1150 mMD (above the major feed zone at 1200-1205 mMD) to inhibit calcite deposition above this depth and allow the two bottom zones to be totally blocked by calcite

Simulated output curves for these three cases are presented in Figures 5 to 9. These output curves indicated that the well geometry changes due to the introduction of the CIS tubing will have an negligible effect on SP-4D in terms of total mass flow, flash point depth, total steam flow, wellhead enthalpy and power potential. This was clearly shown by the nearly identical plots of these parameters for output curves based on measured data (CIS setting depth at 815 mMD) and simulated values (CIS setting depth at 1400 mMD).

In terms of total mass flow, Case 2 (3 feed zones) seemed to be the best option as the simulated values were higher than measured at the range of wellhead pressures presented. Case 3 (2 feed zones) indicated lower mass production at low wellhead pressures and higher mass production at high wellhead pressures. However, at the desired operating WHP of 0.80 MPag, total mass production in Case 3 estimates the actual value (Figure 5).

Simulated flash point depths at the different cases at different pressures ranged from about 806 mMD (near the topmost feed zone) down to about 1000 mMD. These depths were all located above the liquid major feed zone at 1200-1205 mMD (Figure 6).

As with the total mass flow results, both simulated steam flows and enthalpies for Cases 2 and 3 were higher than the measured values. These were expected because for these cases, the colder low-enthalpy fluids from the bottom zones were suppressed thus allowing the hotter high-enthalpy fluids from the upper zones to dominate production (Figures 7 and 8).

As a result of these increases in steam flow and enthalpy values, higher power potential values were realized based on a steam rate of 1.98 kg/s-MWe (Figure 9).

Table 6 summarizes the simulation results at an operating WHP of 0.80 MPag. Results indicated that the calcite inhibition system can be set at around 1150 mMD, just above the major feed zone. Its power potential will be almost the same to the three-feed zone case and is higher than the four feed zone case.

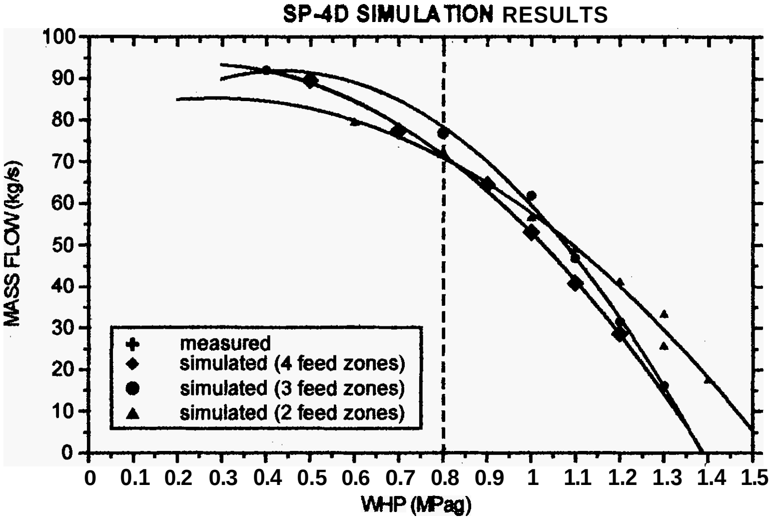

Figure 5. SP-4D mass flows at different wellhead pressures.

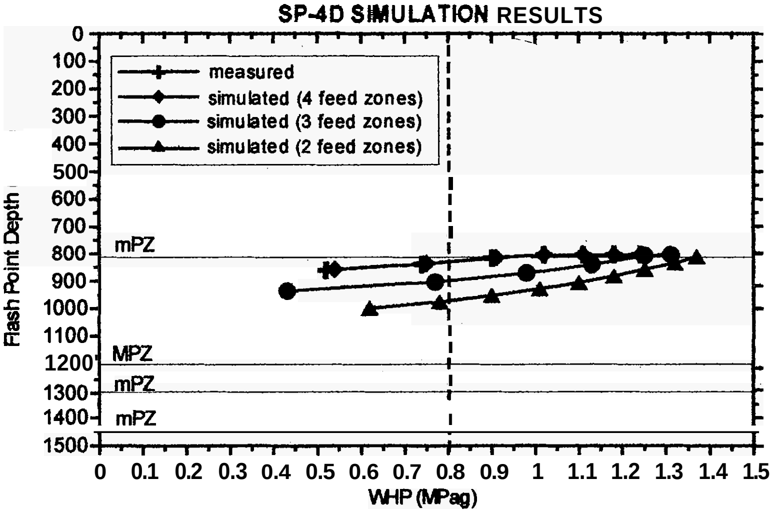

Figure 6. SP-4D flash point depths at different wellhead pressures

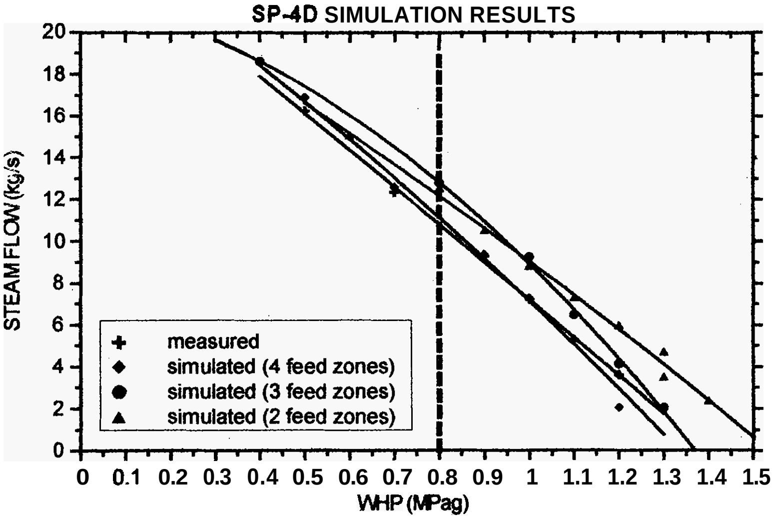

Figure 7. SP-4D steam flow at different wellhead pressures.

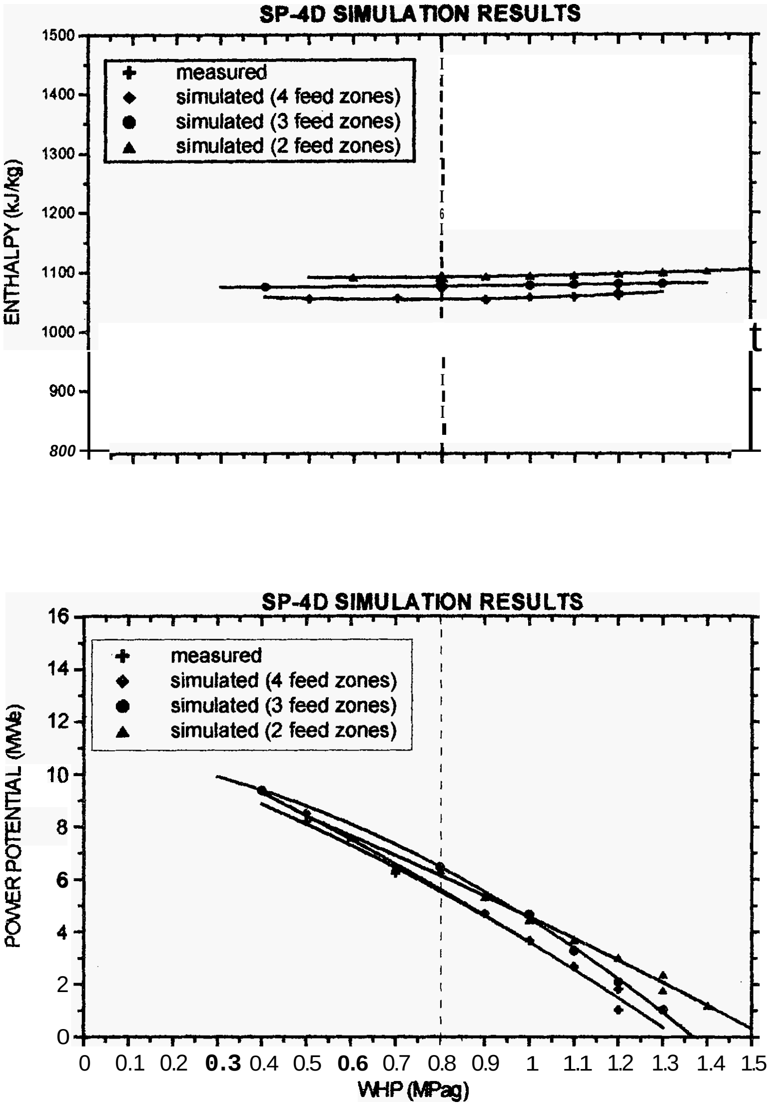

Figure 9. SP-4D power potential at different wellhead pressures.

| | Original Well | Case 1<br>(4 feed zones) | Case 2<br>(3 feed zones) | Case 3<br>(2 feed zones) |
|---|---|---|---|---|
| Flash-point depth, mMD | 838 | 829 | 904 | 977 |
| Setting depth, mMD | 815 | 1350 | 1250 | 1150 |
| Mass Flow, kg/s | 70.9 | 71 | 76.9 | 72.1 |
| Steam Flow, kg/s | 10.8 | 11 | 12.8 | 12.5 |
| Enthalpy, kJ/kgH | 1054 | 1055 | 1076 | 1092 |
| Power Potentiat, MWe | 5.5 | 5.6 | 6.5 | 6.3 |

## 4.0 CONCLUSIONS AND RECOMMENDATION

Wellbore simulation results for SP-4D results showed that at an operating WHP of 0.80 MPag the deepest flashing of geothermal fluids will occur at around 1000 mMD. This will only happen if the two deepest feed zones will stop contributing fluids to its total discharges. Letting calcite deposit naturally on its two bottom feed zones would be beneficial to the production output of the well. With the upper zones producing hotter high enthalpy fluids the wells' power potential will be about 1 MWe higher the original. Therefore, it is recommended that the calcite inhibition system for SP-4D be set at around 1150 mMD, just above the major feed zone.

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