

Sustaining Steam Supply in Palinpinon 1 Production Field, Southern Negros Geothermal Project, Philippines

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ABSTRACT

Steam supply to the 112.5 MWe power plant in Palinpinon 1 has declined after more than 20 years of continuous exploitation. Pressure drawdown combined with effects of injection returns has been the major reservoir process affecting steam production. The formation of mineral deposits within the wellbore further aggravated the problem. By early 2004, the steam supply can only support a maximum plant load of about 105 MW. To curb the declining trend, brine injection was shifted further away from the production sector and mechanical workovers were conducted. While mechanical workover alone had been successful in clearing mineral deposits within the wellbore, it is not capable in removing those that are in the formation. The inclusion of acid stimulation in conjunction with this workover has been proven effective in cleaning out mineral deposits within the wellbore as well as in the immediate formation of the open hole thus, significantly increasing the chances of restoring the original output of the well.

This paper presents the results of the recent workover/acidizing jobs in both production and injection wells in Palinpinon 1 and discusses some of the requisites and procedures in conducting an acid stimulation job vis-à-vis the wellbore characteristics of the well.

1. INTRODUCTION

The Palinpinon 1 Production field is located in the Northeastern area of the Southern Negros Geothermal production Field (SNGPF) in Valencia, Negros Oriental, Philippines (Figure 1).

The development of the Palinpinon 1 field began in 1981 after the exploration drilling in the area had proven an exploitable geothermal resource for electricity generation. A small 1.5 MWe pilot plant began operating late in September 1980, which supplied electricity to the city of Dumaguete, the capital of Negros Oriental province. In May 1983, the 112.5 MWe power plant in Palinpinon 1 commenced its commercial operation supplying electricity to the entire province of Negros Oriental. By 1984, the whole island of Negros was supplied with electricity from the Palinpinon 1 power plant and subsequently, the electrical power grid systems of Negros and Panay islands were interconnected. From 1993 to 1995, the 4 x 20 MWe modular power plants in the Palinpinon 2 area were commissioned and at the same time the electrical power distribution system of the island of Cebu were interconnected with that of the Negros and Panay islands. Since then, the geothermal power plants of Palinpinon 1 and Palinpinon 2 have been supplying electricity to these islands.

The steam supply for the 112.5 MWe Palinpinon 1 power plant has been declining since the start of commercial

production. Several measures were implemented to maintain sufficient steam supply for the operation of the plant. This includes the shift in the injection of the bulk of waste fluid away from the production sector, mechanical workovers, and acidizing in conjunction with mechanical workover.

2. CURRENT STEAM SUPPLY SCENARIO

The steam supply trend (Figure 2) of Palinpinon 1 geothermal production field at the start of commissioning of the plant was about 1400 tons/hr and has declined to the level of 950-1050 tons/hr. Despite the several management strategies implemented in the Palinpinon 1 supply (Orizonte, et. al., 2000), the steam supply continued to decline especially during the 3-turbine unit operation. The current steam supply of Palinpinon 1 is 970 tons/hr or equivalent to 105 MWe at a steam rate of 9.2 tons/hr-MWe.

3. FACTORS AFFECTING THE STEAM SUPPLY AND RESERVOIR MANAGEMENT STRATEGIES IMPLEMENTED

The significant factors that affected the steam supply were previously discussed by Amistoso, et. al., 2000. The steam supply had been affected by the following factors:

1. injection fluid returns
2. mineral deposition in the wellbore and in the formation,
3. and reservoir pressure drawdown.

The foremost effect on the steam supply was the injection fluid returns, which was hastened by the significant reservoir pressure drawdown (Figure 2) during the initial stage of production and the proximity of the injection wells that were utilized to the production wells. The effect of the injection fluid returns was manifested by the decline in discharge enthalpy and increase in mass flow of the affected production wells. The decline in enthalpy was caused by the inflow of relatively cooler fluid at the upper zones of the production wells preventing the formation of a shallow two-phase zone. This was clearly observed in wells PN-26, the first production well affected by injection fluid returns, which became non-commercial by 1987. It was decided in 1987 that the waste fluid should be injected much further away from the production area. Thus, in 1989, the bulk of injection was shifted into the Mala-unay and Ticala sectors of Palinpinon 1 area.

Aside from shifting the bulk of injection fluid away from the production area, the injection wells with good communication to the production wells were worked over to plug the communicating permeable zones, e.g., PN-2RD and PN-6RD. The cement plugging in PN-6RD had successfully isolated the upper permeable zone but eventually did not hold for so long when it was utilized after the workover. Thus, the injection fluid continued to

return back to the production sector. OK-7, which also became non-commercial early in 1995 was worked over in December 1995-June 1996 to plug the upper permeable zone. The well remained non-commercial after the workover since cement plugging of the upper permeable was unsuccessful.

The effect of mineral deposits in the wellbore was manifested by the decline in mass flow and increase in enthalpy of the affected production wells. The mineral deposits, i.e., calcite (PN-21, PN-15D, and PN-13D) and anhydrite (PN-13D, PN-20D and PN-22D), usually occur at the flashpoint in the well in which the lower producing zones were choked resulting in reduced mass flow. This has caused the sudden decline in steam supply for Palinpinon 1. For these well with mineral deposits, immediate mechanical workover were done once the output of the well had been reduced by less than 50 percent.

In spite of the mechanical workovers done, the steam supply continued to decline, hence, in-field drilling of maintenance and replacement (M&R) e.g., PN-32D, PN-33D, and drilling of step-out M&R production wells in the Lagunao area, e.g., LG-3D and LG-4D, were carried-out. The earlier M&R production wells in this area were cement plugged due to acidic discharge (LG-1D) and damaged casing (LG-2D). In recent workovers, the technology of well stimulation by acidizing was applied to geothermal wells to remove the mineral deposits behind the liner and in the near-wellbore formation.

The significant pressure drawdown during the early stage of production in Palinpinon I had affected the steam supply due to the interference between production wells. Initially, the total steam supply increased due to the increasing discharge enthalpy of most of the production wells, especially those drilled to the southwestern and southern sector of the production area in Puhagan. However, the steam supply started to decline when the mass flows of some production wells began to decline. Thus, it was decided to allow the injection fluid to return to the production sector as one of the field management strategy for Palinpinon 1. From 1993 to 2002, the strategy of maintaining the steam supply was to balance the injection fluid returns such that it would not affect the steam production of the majority of the production wells. This was done by shifting the injection fluid from the Puhagan sector (PN-5RD) to the Ticala sector (TC-3RD) and vice versa. Fortunately, the Palinpinon 1 power plant had some long turbine unit shut downs, e.g., April 1997-December 1998 due to maintenance of one of the steam turbines, which allowed the reservoir pressure to recover and thus, allowing the highly drawdown well to regain its steam production rate. It was observed that the longer period of production during the three-turbine unit operation i.e., near full load (95-102 MWe) the steam supply continued to decline due to the further pressure drawdown at higher production rate.

4. WORKOVER AND ACID STIMULATION JOBS IN PALINPINON 1

The main objective of the workovers of the production wells in Palinpinon 1 is to improve the steam production of wells with mineral deposits in the wellbore, i.e., by mechanical cleanout, and in the formation, i.e., by acid stimulation. In the injection wells, the objective of the workovers and acidizing is to clear the mineral deposits, i.e., silica scales, in the wellbore as well as in the formation. There were a total of 14 production wells and 2 injection wells that were worked over so far as shown in Table 1.

5. PRE-REQUISITES OF MECHANICAL WORKOVER AND ACID TREATMENT

The basis of the first mechanical workover, i.e., PN-13D (25Sep-01Oct1983), was the decrease in output due to the occurrence of mineral deposit (calcite and anhydrite). It was necessary for PN-13D to be worked over since it was the only well that supplied steam to the 1.5 MWe pilot plant, which provided electricity for the city of Dumaguete. The succeeding workovers in the production wells were done whenever the following criteria had been met:

- 1) The output of the well had reduced at least by 50 percent.
- 2) The decline in output is not primarily attributed to reservoir pressure drawdown.
- 3) The nature of obstruction in the wellbore whether it is purely mineral deposition or a casing break.
- 4) The integrity of the production casing warrants the drill string to be able to penetrate past the obstruction during the workover.

Perforation of the production casing was done only when a loss zone was encountered during drilling and was cased-off, e.g., PN-21D and PN-25D. This was indicated by the mud loss (TLC) during drilling. However, the perforation of PN-21D did not give satisfactory results since the perforation did not opened-up the cased-off permeable zone due the limited charges in the perforating gun used. PN-25D, which was not a commercial production well before the workover was able to produce steam at operating separator pressure after the perforation and subsequent acidizing.

Acid treatment was implemented in SNGPF with PN-32D (13-28March1993) as the first production well that was acidized to improve its steam production by increasing the near-wellbore permeability. The criteria in determining whether a production well is to be acidized or not, is similar to the aforementioned criteria for mechanical workovers. However, it was necessary that the well should have massive mud losses during its drilling if acidizing would be effective in improving its permeability, thus, its steam production.

6. LIMITATIONS OF MECHANICAL WORKOVER

As experienced during the early workovers, the mechanical cleanout of the mineral deposits was successful when such deposits were inside the production liner only i.e., OK-10D, PN-13D, PN-20D, and PN-22D. Enhancing the permeability of the nearby wellbore formation in production well could not be achieved by mechanical workover only. Likewise, if the deposit extends beyond the liners and into the near-wellbore formation, (e.g., injection wells) the mechanical workover was not effective. Hence, no significant improvement in steam production was observed e.g., PN-13D after the 3rd workover (Table 1).

Table 1: Palinpinon 1 Workover Summary Conducted from 1983 to 2000

| Well Name | Pre-WO Output (MW) | Post-WO Output (MW) | Remarks |
|-----------|--------------------|---------------------|-----------------------------|
| PN13D | 2.9 | 5.8 | MWO; remove block. @ 1739 m |

| | | | |
|-------|-----------------|-------------------------|--|
| PN22D | 4.9 | 7.0 | MWO; remove block. @ 1719 m |
| OK10D | 2.5 | 4.5 | 1 st MWO; clear block. @ 1673 m |
| | 3.3 | 5.1 | 2 nd MWO; clear block. @ 1500 m |
| PN20D | 5.5 | 6.8 | 1 st MWO |
| PN13D | 3.6 | 4.8 | 2 nd MWO; clear block. @ 1777 m |
| | 2.6 | 3.4 | 3 rd MWO; clear block. @ 1768 m |
| OK7 | 2.2 | 3.6 | 1 st MWO; clear block. @ 1341 m |
| PN20D | 2.5 | 6.3 | 2 nd MWO; clear block. @ 1433 m |
| PN21D | 2.9 | 3.2 | 1 st WO/Perforation of upper zone |
| PN32D | 1.8 | 4.1 | 1 st WO/Acidizing |
| PN33 | 1.4 | 2.4 | 1 st WO/Acidizing |
| PN25D | 3.2 | 6.2 | 1 st WO/Acidizing & Perforation |
| OK7 | *well discharge | wasn't & no longer used | 2 nd WO/Plugging of upper zone |
| PN29D | 1.4 | 2.6 | 1 st MWO; results based on '99 TFT measurements |
| LG3D | 1.0 | 4.1 | 1 st WO/Acidizing |

7. ACID TREATMENT IN CONJUNCTION WITH MECHANICAL WORKOVER

Acid treatment in conjunction with mechanical workover had been implemented in SNGPF to chemically remove the mineral deposits from the face of the formation and in the near well-bore formation. The acid treatment done by PNOC-EDC was previously discussed by Buñing, et. al.,(1995). Acid stimulation was applied in PN-32D and PN-33D and resulted in some improvement of the permeability of the well, however, steam production of these wells did not significantly improve due to the poor permeability of the formation to which these wells were drilled. Wells with tight formation and had cased-off permeable zones, e.g., PN-21D, were also worked over which included perforation of the casing. However, such workover was not successful since the permeable zone was not opened-up due to the low-density perforating gun used at that time. It was only in PN-25D that matrix acid treatment was conducted after the workover, which included perforation of the cased-off permeable zone. This resulted in improved steam output of the well.

Acid matrix treatment as practiced in PNOC-EDC is conducted after a mechanical drill-out of the mineral blockage within the wellbore. This pre-requisite will not only reduce the bulk of the mineral blockage to be "acidized" but also keep the cost of the acid treatment to a minimum.

The acid matrix treatment is carried out in three stages, namely; 1) pre-flush consisting of 10% hydrochloric acid (HCl) and inhibitors, 2) main flush, a mixture of hydrochloric acid and hydrofluoric acid (HF) and 3) freshwater overflush. The hydrochloric acid in the pre-flush reacts with calcium carbonate (calcite) and other calcareous materials in the wellbore and immediate formation reducing if not eliminating the reaction of the more expensive hydrofluoric acid with calcite and prevents the formation of calcium fluoride, which can precipitate from a HF-HCl mixture. The main-flush immediately follows the pre-flush. The 5% hydrofluoric acid reacts with clays, sand, drilling mud and cement filtrate within the wellbore and immediate formation while the 12% hydrochloric acid keeps the pH low and prevents unwanted precipitation of HF reaction products. The overflush is just pure water pumped into the wellbore designed to push the acid solution farther into the formation and thus, prevent prolonged acid exposure of the well casing.

Acid injection is usually done using the drilling rig and acid string with the open-ended borehole assembly run into the designated depths where the mineral blockages have been established. Acid pumps and tanks, usually operated by contractors are used to pump acid into these designated depths. The rate of acid injection is greatly dictated by the pump capacity and wellbore pressure, but should be as fast as possible so as to attain effective reaction with the mineral blockage.

8. RESULTS OF THE RECENT WORKOVERS AND ACID TREATMENT OF PALINPINON 1 WELLS

The results of the recent workovers in SNGF are tabulated in Table 2. The initial workovers in 1983 to 1992 (e.g., OK-10D, PN-13D, PN-20D, and PN-22D) were mechanical cleanout of the mineral deposits inside the production liners. However, the results of the third workover in PN-13D indicated that acid treatment was necessary to have better results. The successful matrix acid treatment in conjunction with mechanical workover of PN-25D, has made matrix acid treatment the standard procedure adopted by PNOC-EDC to improve the productivity of production wells and the capacity of injection wells.

The workover of the production well, PN-31D, was prematurely terminated due to the problem of the parted liner which could not be corrected during the workover. The drill string could not penetrate past the obstruction at 1700 m. (MD) below the CHF due to the accumulation of the drilling debris above the obstruction. Thus, the well only showed an improvement in steam production from the increased in the contribution of the shallow steam zone. The lower producing zones below the obstruction did not contribute to the discharge. The most effective workover/acidizing job was in LG-4D wherein the steam production increased significantly from 3.9 MWe to 6.7 MWe. The obstruction in this well, mostly calcite, was effectively removed.

Table 2: Results of the recent Palinpinon 1 Workovers and Acidizing in 2003

| Production. Well | Injectivity Index (l/s/MPa) | | Output (MW) | | |
|---------------------|-----------------------------------|------|----------------|------|---------|
| | Pre | Post | Pre | Post | Current |
| PN31D | 140 | | 6.0 | 8.3 | 6.5 |

| | | | | | |
|----------------|-----------------------------|---------|--------------|------|---------|
| PN27D | 76 | | 5.1 | 4.5 | 3.2 |
| LG4D* | - | 54 – 76 | 3.9 | 6.7 | |
| PN13D* | 106 | 106 | 2.1 | 2.1 | 2.5 |
| Injection Well | Injectivity Index (l/s/MPa) | | RICAP (kg/s) | | |
| | Pre | Post | Pre | Post | Current |
| ML2RD* | 42.5 | | 60 | 110 | |

Note: * Mechanical workover and acidizing.

9. SUMMARY AND CONCLUSION

The steam supply of the Palinpinon 1 112.5 MWe power plant had been declining since the start of commercial operation in June 1983. The main factor that caused the decline was the rapid injection fluid returns, which affected the production wells drilled near the injection wells. The injection fluid was reduced when the bulk of waste fluid was injected much further from the production wells. Injection into the Puhagan injection wells was shifted to the wells drilled in the Mala-unay and Ticala areas, which is much further from the production wells.

Despite the shift in injection of waste fluid, the steam supply still continued to decline due to the development of calcite and anhydrite deposits in the well bore of some production well. The steam production of these affected wells was restored by working over the wells by mechanically removing the deposits. However, it was then necessary that acid stimulation had to be done in conjunction with the mechanical workover to remove the mineral deposits outside the production liners and in the near well bore formation. Thus, the steam supply in Palinpinon 1 was sustained to support the operation of the power plant.

Although, some improvement in steam supply was seen in the production wells that were worked over and acidized, the improvement did not warrant the full load operation of

the plant. The decline in steam supply was also affected by the reservoir pressure drawdown. The steam production of the wells worked over and acidized could not be restored to its original output. Currently, the steam supply can only support the power plant at a maximum load of 105 MWe.

The continued operation of the power plant at maximum load would increase the pressure drawdown, which will affect steam production, and thus, necessitates the improvement of the steam supply. This could only be done effectively by the drilling of step-out make-up and replacement wells for the long-term solution of the declining steam supply.

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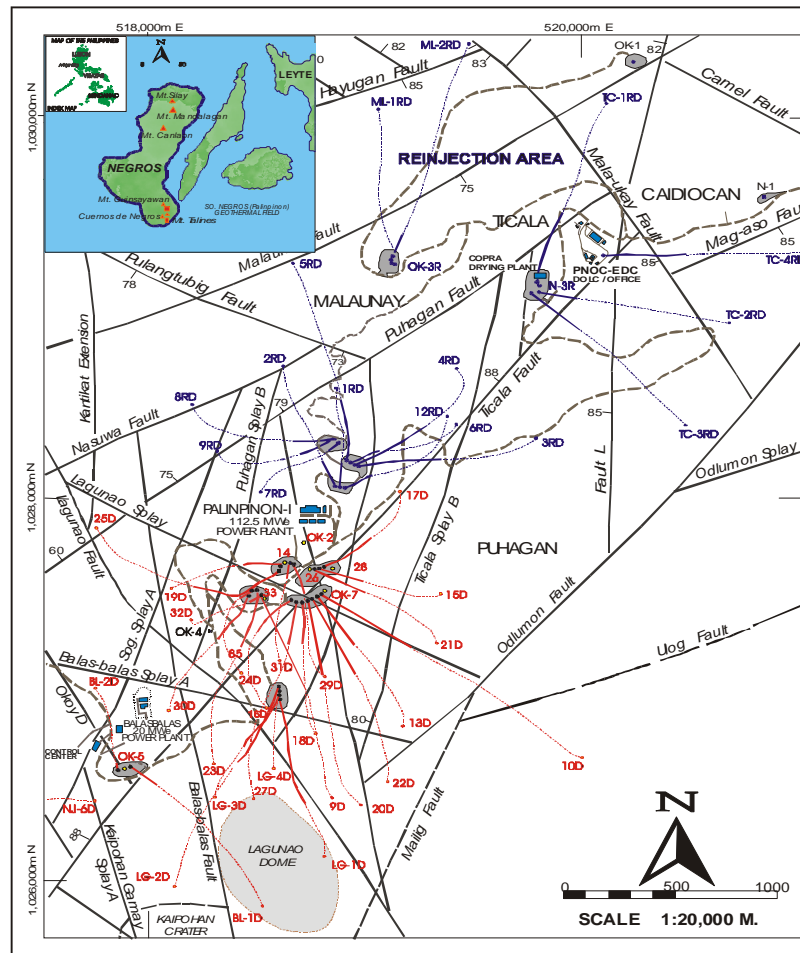


Figure 1: Palinpinon 1 Location Map

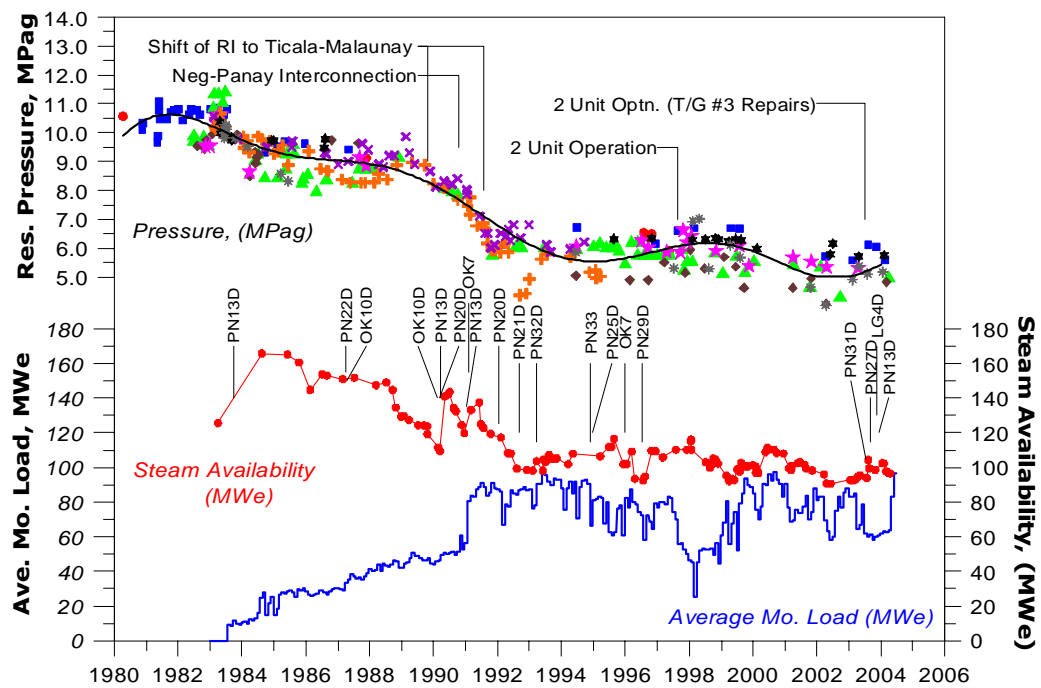


Figure 2: Palinpinon 1 Steam Supply vs WO/Acidizing Jobs