

FORKED-HOLE COMPLETION AT TIWI

Glenn U. Golla and Tom R. Haas

Philippine Geothermal Incorporated
12th Floor CitiBank Tower, 8741 Paseo de Roxas, Makati City 1226, Philippines

Abstract

Injection well Nag-66, located southeast of the main Tiwi production field, has been successfully forked by sidetracking at a depth of 861m (2828') and then reopening the original penetration. To our knowledge this is the first forked completion in a hot water-dominated geothermal field. The procedure called for identifying a suitable interval of competent formation for initiating the fork, setting a bridge plug and retrievable whipstock, milling a window through the 9-5/8" casing, and drilling the sidetrack to 1990 m (6526'). Following drilling of the sidetrack, 7" slotted liner was run into the sidetrack. The whipstock was then retrieved and the bridge plug was chased to bottom in the original hole. This relatively simple method was adapted from technology well-known in the oil and gas industry, and in barefoot forked geothermal completions pioneered by Unocal at The Geysers in California.

Prior to this forked completion, Nag-66 had declined to an injection capacity of 7 kg/s (55 kph) of hot brine at 1.0MPa (150 psig) wellhead pressure. Scale drillout improved the capacity of the original hole to 48 kg/s (380 kph). The sidetrack, tested separately, had a capacity of 40 kg/s (315 kph). The well in its final forked completion tested at 95 kg/s (750 kph). Thus, the operation was an economic as well as a technological success.

This method should be applicable to production wells in addition to injectors, and will be most valuable in mature fields where right-of-way for new drilling locations is limited and existing wells are available for forking. Forking costs little more than a sidetrack and preserves the productivity (or injectivity) of the original hole.

1.0 INTRODUCTION

The Tiwi geothermal field is located in the province of Albay on the island of Luzon, about 300 km southeast of Manila (Figure 1). Initial geothermal exploration started in 1964; discovery well Naglagbong-1 (or Nag-1) was drilled in 1978. In 1982, Tiwi became the world's first water-dominated geothermal system to produce more than 160 MWe (Gambill and Beraquit, 1993). Tiwi field has a current total installed capacity of 330 MW and produces about 16% of the power requirement in the Luzon grid.

The Tiwi resource is a mature geothermal system, where PGI's long operating experience allows new approaches to be taken to lower operating cost. This paper describes an innovative solution for increasing injection capacity at reduced cost.

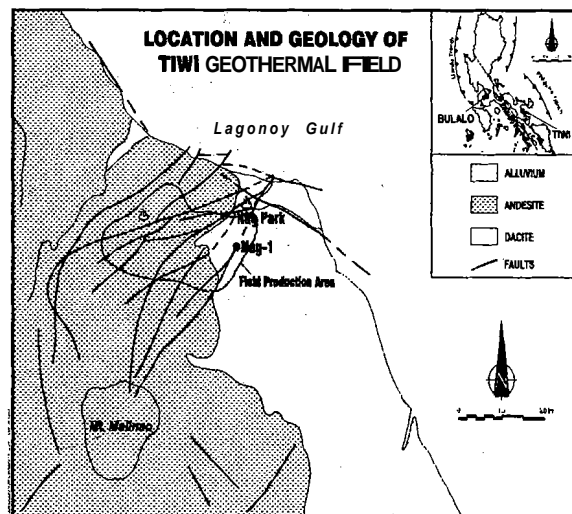


Figure 1. Location and geology of the Tiwi Field.

2.0 BACKGROUND

The commercial production area of Tiwi is approximately 18 km² located on the NE flank of Mt. Malinao, an eroded Quaternary composite volcano (Figure 2). In the early 1980s, steam production came mostly from the eastern lowlands (Naglagbong sector) but pressure drawdown in the reservoir allowed cold water to quench this part of the field. Currently, about 90% of steam production comes from the western highland portion of Tiwi field.

There are **three** main injection systems at Tiwi, namely the Matalibong Ridge Hot Brine Injection System (or MRHBIS), the Southeast Hot Brine Injection System (SEHBIS) and the Northeast Cold Brine Injection System (NECBIS) (Figure 2). There are also emergency injectors located inside and at the southern edge of the production area that are used during upset conditions.

Chemical monitoring shows that injection breakthrough occurs at the southern edge of the field due to the emergency edgefield hot brine injectors. **Thus** additional injection capacity in the SEHBIS is needed to minimize injection breakthrough. Options available to increase hot brine injection capacity were either (1) drill a new well or (2) redrill selected injector(s) in the SEHBIS. The redrill option was selected **because** of its lower cost. Among the four injectors in the SEHBIS, Nag-66 was selected for redrilling because it had the lowest capacity and the most potential for improvement.

Original well Nag66 was drilled to 2421m (7943') MD in January 1987 (Figure 3). The 9-5/8" injection casing shoe was set at 913m (3000') MD. Of all the active injectors in the SEHBIS, Nag-66 had the lowest injection capacity; 7 kg/s (55 kph) at 1.0MPa (150 psig) injection wellhead pressure (IWHP). The three other injectors in the SEHBIS (Nag-67, 68, and 69) have an average injection capacity of >50 kg/s (396 kph) at the same IWHP.

2.1 WORKOVER SELECTION AND PLANNING

PGI's Tiwi Workover Team determined that forking Nag-66 would be a cost-effective way of gaining additional injection capacity, and would test a completion technique that might have a significant economic impact in the development of PGI's (and other operators') fields.

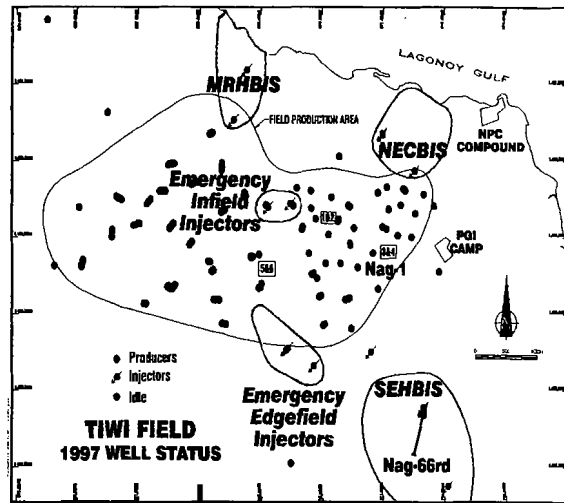


Figure 2. Production limit and location of injectors at Tiwi Field.

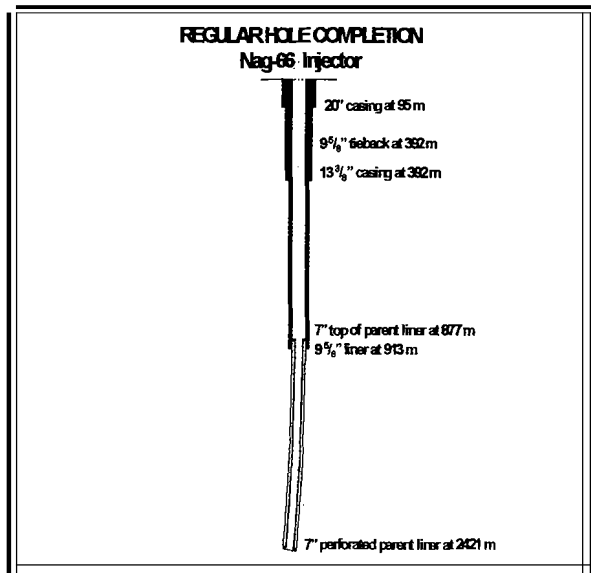


Figure 3. Well schematic of Nag-66 original hole.

In that a forked hole had never been successfully completed in a hot water geothermal field, but had been done extensively at The Geysers Steam Field in California, the Workover Team saw it as a realistic technical challenge for drillers, geologists and reservoir engineers to pursue. The Workover Team is a multi-disciplinary working group composed of geoscientists and reservoir and production and drilling engineers. This Team is tasked to identify, evaluate and implement well stimulation to maintain steam supply and injection capacity.

2.2 WELL FORKING HISTORY AND REQUIREMENTS

In the drilling industry, well forking is technically termed “dual lateral interval completion.” In simpler layman’s language, forking is drilling a sidetracked hole and completing the well so that both the sidetrack and original hole are open to feed a common wellbore. Forking of production wells is common practice in the petroleum industry.

In the geothermal industry, the drilling of forked wells was pioneered by Union Oil of California (Unocal Corporation) in 1979 at The Geysers Field in California. The technique was initially used to improve the production of borderline sub-commercial steam wells. The first well forked was well DX-44, whose original penetration, drilled to 2529m (8297’), produced only 6.8 kg/s (54 kph) steam at (0.9 MPa (130 psig) FWHP). The fork was drilled to 2609m (8560’) but, unfortunately, did not improve the productivity of the well. Subsequently, with the technology proven up, Unocal forked other wells as the opportunity arose. Yarter et. al. (1989) documented several successful forked wells drilled by Northern California Power Agency (NCPA) at The Geysers, and gives a good description of the method.

The added technical challenge of **forking** at Tiwi comes from the necessity for a slotted liner in the production interval of the well. At the Geysers Field, wells are commonly completed barefoot, without a production liner, because of favorable hole conditions within the reservoir. At Tiwi, as in most other geothermal fields, a slotted liner is needed in the production hole to prevent wellbore collapse. It was the design and installation of the production liner in the sidetracked hole that was the principal challenge at Tiwi.

A well is forked by drilling out of cemented casing at the pre-selected elevation in the existing wellbore. The construction of the joint, or junction, at the exit point determines the level of complexity of the procedure. The forked joint can range from a simple rock joint with no mechanical support, pressure control or method of access. to a completely cased, pressure-tight joint with access to either fork. In the case of a Tiwi injection well, the fork required no mechanical support or pressure control, but access to both holes was desired. The Nag-66 design called for a wellbore supported by slotted liner but no physical casing connection at the fork joint.

Two casing exit methods were available and considered: (1) cutting a section in the cemented casing and kicking off of a cement whipstock plug and (2) milling a window in the casing using a window mill and kicking off of a mechanical whipstock.

Although the capital expense of the first option was less, it was decided that the second was the more cost-effective. To fork the well by cutting a section is relatively time consuming because it requires: (1) complete removal of a 60’ section of casing; (2) setting and waiting on a cement whipstock plug to cure; (3) kicking off the plug to drill the fork; and (4) removal of the cement plug to re-enter the original hole. The laborious nature of this method often requires significant rig time. In the second option, which uses a retrievable whipstock, most of the above processes are completed by the whipstock itself. After setting a “drillable” plug in the well, the whipstock is **set** in the desired orientation and the well is “kicked off” with the mill cutting a window in the wellbore casing. The initial capital investment is greater with this system but the savings in rig time usually makes the overall operation more economical. The **use** of mechanical whipstocks is widely-accepted in the oil and gas industry.

3.0 NAG-66 FORKING

Rig operations at Nag-66 commenced on May 27, 1997. The first step was to evaluate wellbore injection integrity using a mechanical caliper. Near-surface scale deposits prevented running the caliper survey prior to rig arrival on site. The wellbore must also be in good condition to ensure that the whipstock can be set at the desired elevation and retrieved at the end of the operations. The caliper survey also provided this information. A pressure-temperature gradient survey was also conducted to measure the initial injection performance of the well. Figure 3 shows a well schematic of the original Nag-66 well.

During the initial well clean-out, hard silica scale was discovered and cleaned at 12-119m (40'-390') MD. Soft scale, which caused plugging of the bottomhole assembly, was encountered at 376-901m (1234'-2956') MD. The top of the 7" liner was tagged at 877m (2877') MD.

Following the clean-out and surveys, a bridge plug was set on top of the original 7" production liner, and the wellbore was filled with water and pressure tested. Problems running the bridge plug required that the wellbore be drifted with a full gauge watermelon mill prior to running the whipstock.

The whipstock was then run and oriented to the proper direction using a gyro. To set the whipstock in the casing it was set down and "tripped" on the bridge plug. This action anchored the whipstock in the casing. The whipstock was conveyed downhole with the initial milling assembly, which was used to cut a window on the 9-5/8" casing for the sidetrack hole (Figure 4). Three mill runs were required to complete the window. The third mill run was made to lengthen and dress the window in anticipation of the stabilized drilling assembly needed to complete the well.

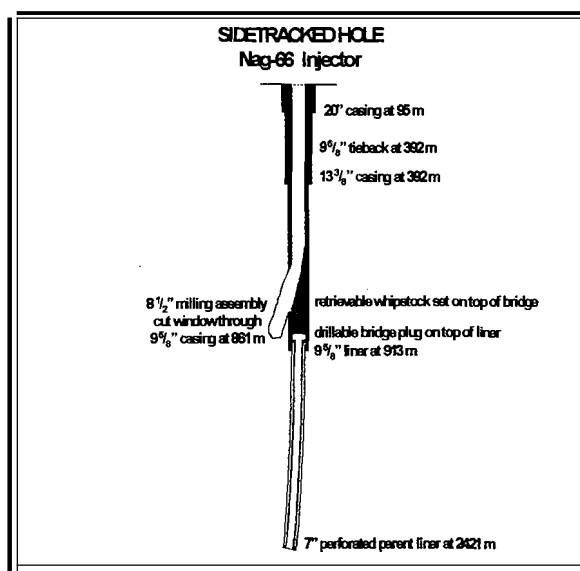


Figure 4. Well schematic showing initial sidetrack window for the forked hole at 861m.

The 8-1/2" sidetrack window was cut at 861m MD (2825') in hard, strongly silicified andesite. This formation was considered competent enough to support the fork based on the lithologic log from the original hole. With a competent formation, the possibility of hole collapse and sloughing at the fork junction is minimized. A conventional downhole mud motor with bent housing was used to get the additional departure needed to intersect the drilling target. The well was completed using conventional, stabilized, rotary drilling assemblies. The well was drilled with water with partial loss circulation. Mud sweeps were pumped as required to keep the hole clean. The fork hole was completed to 1990m (6529') MD, 422m (1385') out towards S9°W.

The 7" perforated injection liner was set on bottom at 1989m (6526') MD with the top of the perforated liner about 10m (33') out of the window at 861m (2825') MD (Figure 5). After an injection test in the fork, the whipstock was successfully retrieved on June 17, 1997. The workover rig was released on June 20, 1997 after drilling out and chasing the bridge plug to bottom in the original hole and conducting well completion tests.

3.1 RESERVOIR CHARACTERIZATION

The rocks encountered in the fork were very much the same as those intersected in the original penetration: intercalated andesite lava flows, breccias and tuffs that show fresh to weak hydrothermal

alteration (SETI, 1997). The low intensity of alteration suggested tight permeability in this part of the field. However, intervals of intense alunite + illite/sericite + quartz + pyrite alteration, indicative of locally higher permeability, characterize the horizon at 884-1171m (2900'-3841') MD.

Based on drilling circulation losses, Nag-66 fork encountered its shallowest permeable zone at the same depth as encountered in the original penetration. Intermittent partial lost circulation (PLC) was **first** encountered at 930m MD (3051') , close to the permeable zone identified in the original hole at 915m (3000') MD. Continuous PLC was encountered **from** 1014m (3327') MD to total depth.

Downhole testing equipment capable of selectively entering the fork was not available. Without heat-up pressure-temperature gradient surveys and spinner **data**, it was impossible to verify the depths at which permeability was encountered in the fork. Running affordable tools capable of selectively entering either penetration could **further** enhance the long-term benefits of forking.

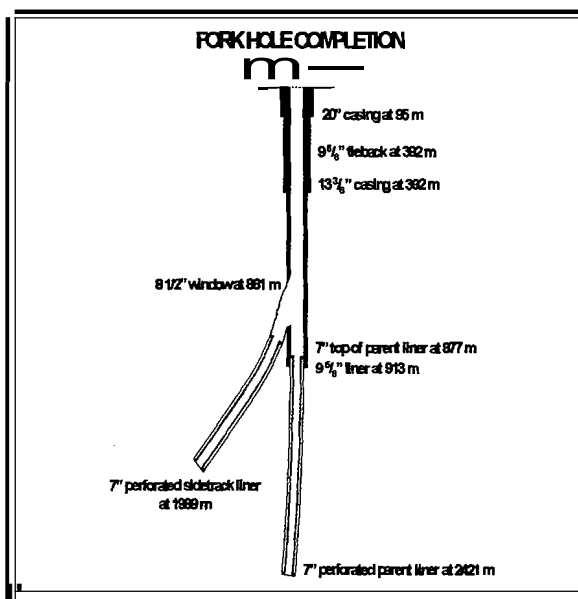


Figure 5. Schematic showing completed forked injection well Nag-66.

3.2 INJECTION CAPACITY ESTIMATE

Four separate injectivity **tests** were conducted in Nag-66. The **first** test was conducted before the redrilling operation; another **test** was done right after drilling and cleaning out the scale in the **original** hole; the third injection test was conducted after completing the fork (with original hole still plugged); and the last test when both original hole and fork were open. Table I shows the results of these injectivity tests.

Table L. Nag-66 Hot Brine Injection Capacity (1.0 MPa IWHP)

	Hot Brine Capacity, kg/s	Remarks
Before workover	7	estimated from injection simulation
Original hole	48	after cleaning out scale , from injection simulation
Forked hole	40	forked hole alone (old hole with bridge plug); from injection simulation
After workover	95	both holes open; actual hot brine injection

Before the recompletion, Nag-66 had a mediocre injection capacity of 7 kg/s (**55 kph**) of hot brine at 1.0 MPa (150 psig) IWHP (Table I; Toreja, 1997). **After** forking the well, the injection capacity increased to **95 kg/s (750 kph)** at the same IWHP. There was a significant increase in injection capacity after the scale clean-out in the original hole (**from** 7 kg/s (**55 kph**) to **48 kg/s (380 kph)**). This suggests that scaling inside the wellbore may **be** one of the culprits for Nag-66's low injection capacity. Alone, the **fork** accepted **40 kg/s (316 kph)** of hot brine.

The favorable injection capacity after the forking indicates additive capacity **from** the **fork** hole. **Also, this suggests** that there is little or no **interference** between the original and fork holes.

3.3 ECONOMIC EVALUATION

The total **cost** to fork Nag46 was about 40% lower than PGI's average **cost** to drill an injection well. Compared to the **cost** of a conventional sidetrack, forking Nag46 was about 20% higher. However, the learning experience gained in **this** forking and new technology in the future may lower the cost of forking some more.

Pre-redrill economic evaluation showed that increasing Nag-66's hot brine injection capacity to 50 kg/s (395 kph) at normal operating IWHP would give the National Power Corporation (NPC) an estimated 10-year Internal Rate of Return (IRR) of 15% (Golla, 1996). This economic analysis included **an** estimated benefit to production of shifting injection to the **SEHBIS**, instead of using edgefield injectors Nag-25, 29 and 33. Based on the tests after forking, the injection capacity of 95 kg/s (750 kph) at 1.0 MPa (150 psig) IWHP should yield a 10-year IRR to **NPC** of 58%, nearly four times greater than the pre-workover estimated IRR.

4.0 CONCLUSIONS

To our knowledge this is the first completed forked geothermal well outside The Geysers Field. The technical challenges of completing a forked hole with slotted liner were successfully addressed. The operation was economically successful in that the forked well provides much greater injection capacity than the original hole. Moreover the injection capacity of the forked well is greater than the sum measured for the individual penetrations, with no evident interference between the two penetrations.

The **successful** forking of Nag-66 opens a fresh option in future well drilling at Tiwi. The relatively low cost of forking makes **this** technology very attractive in drilling production and injection make-up wells at Tiwi, and in other geothermal fields as well.

5.0 ACKNOWLEDGMENTS

The authors would like to thank the support of management and **staff** of the National Power Corporation, Philippine Geothermal, Inc. and Unocal Geothermal Power Operations for making this paper possible. We would also like to acknowledge the review and suggestions by Mohinder Gulati, David Garcia, Loretta Mabinton, Ken Williamson and Mitch Stark and drafting work rendered **by** Awel Echano.

6.0 REFERENCES

- Aquino, B.G. (1997), Reservoir and Economic Evaluation of Big Hole Baris-10, PGI **in-house** memo.
- Bodell, J.M., L.F. Pittinger and Tiwi Injection Team (1988), Recommendation to Redrill Injector Naglagbong-66, PGI in-house memo.
- Buban, A.C. (1987), Naglagbong No. 66 Geological Well Completion Report, PGI in-house technical report.
- Gambill, D.T. and D.B. Beraquit (1993), Development History of the Tiwi Geothermal Field, Philippines, *Geothermics*, Vol. 22, No. 5/6, pp. 403416.
- Golla, G.U. (1996), Naglagbong-66 Redrilling, PGI in-house memo.
- Haas, T.R. (1997), Naglagbong Well 66 Redrill P r o m, PGI **in-house** technical report.
- Sigma Energy Technologies, **Inc.** (SETI) (1997), Nag-66 (Redrill) Geological Report for PGI.
- Toreja, J.S. (1997), Na9-66 Injectivity Analysis, PGI in-house memo.
- Yarter, R.E., P.E. Cavote and D.G. Quinn (1989), Forked Wellbore Completions Improve Development Strategy, Geothermal Resources Council, TRANSACTIONS, Volume 13, pp.431437.