INJECTION HISTORY AND STRATEGY - TIWI GEOTHERMAL FIELD, PHILIPPINES

S.L. SANTOS, AND B.D. CARANDANG-RACELA

Tiwi Geothermal Field, PGI, Manila, Philippines

SUMMARY

The Tiwi injection system progressed from zero brine injection in 1979, when commercial production began, to 100% brine injection in 1993. Total brine injection in Tiwi was difficult to achieve because injection had an adverse impact on production wells and there was a lack of permeability in the peripheral injection locations. Injection was moved from in-field to edge-field and, finally, to out-field areas in order to minimize the adverse impact. A combination of edge-field and out-field hot brine injection is currently the optimal disposal system for Tiwi.

1. INTRODUCTION

The Tiwi geothermal field is located in the province of Albay, approximately 300 km southeast of Manila on the main island of Luzon, Philippines (Fig. 1). Tiwi lies on the northeast flank of Mt. Malinao, an eroded Quaternary stratovolcano. Before field development started, the reservoir was over-pressured and liquid-fdled, and boiling springs and geysers were the predominant surface thermal manifestations. Tiwi was the first commercially developed geothermal field in the country and is operated by Philippine Geothermal, Inc. (PGI) for the National Power Corporation (NPC).

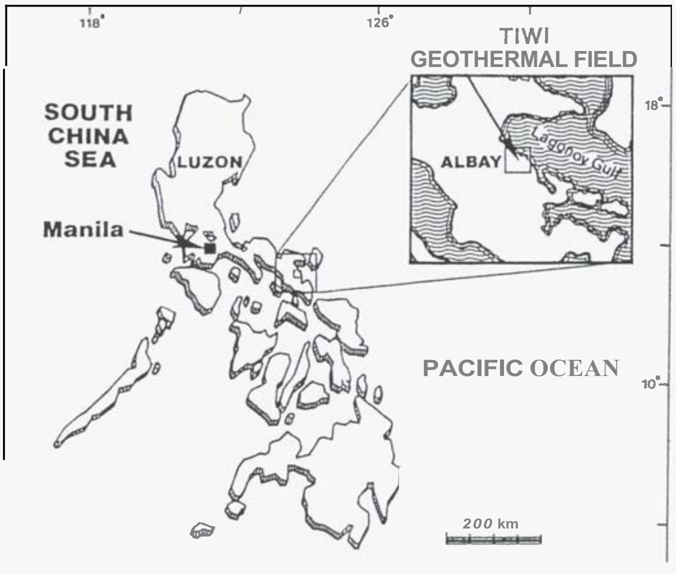

Figure 1 - Location of the Tiwi geothermal field.

The production area of the Tiwi Geothermal Field is about 13 km^2 and is divided into four geographic areas: Naglagbong, Kapipihan, Matalibong, and Bariis (Fig. 2). Naglagbong is a lowland area in the eastern part of the field. The Kapipihan area is in the rugged valley to the west. The Matalibong and Bariis areas occupy high ridges to the north and far west of the field, respectively.

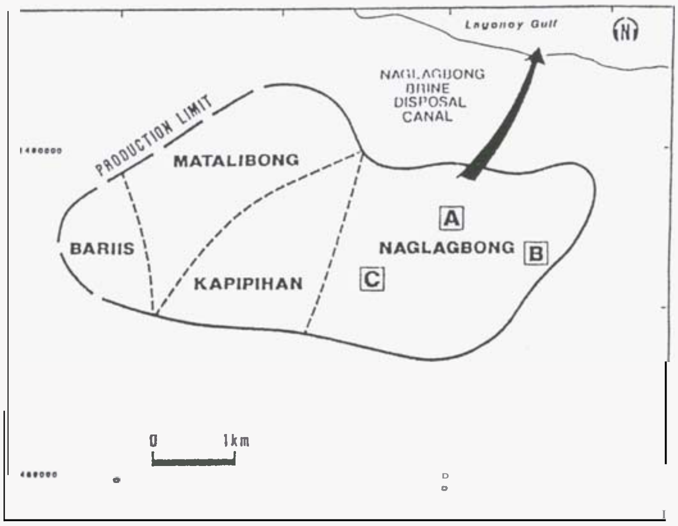

Figure 2 - The Tiwi production area showing its geographical subdivisions and the Naglagbong brine disposal canal.

Commercial production in the Naglagbong and Kapipihan started in 1979 with the commissioning of the first 110 MWe power plant. As these areas were depleted, development was shifted west towards Matalibong. Most current producers are in Matalibong and Kapipihan. Geothermal fluids are fed into separation facilities from which steam flows into three power plants with a total installed capacity of 330 MWe.

2.0 INJECTION HISTORY

During the early stages of commercial production at Tiwi, the waste brine was disposed into the Lagonoy Gulf via a canal. This was the most economical and environmentally acceptable method of disposing of brine at that time. In fact, brine is still being discharged into surface waterways in Wairakei, New Zealand and evaporation ponds in Cerro Prieto, Mexico.

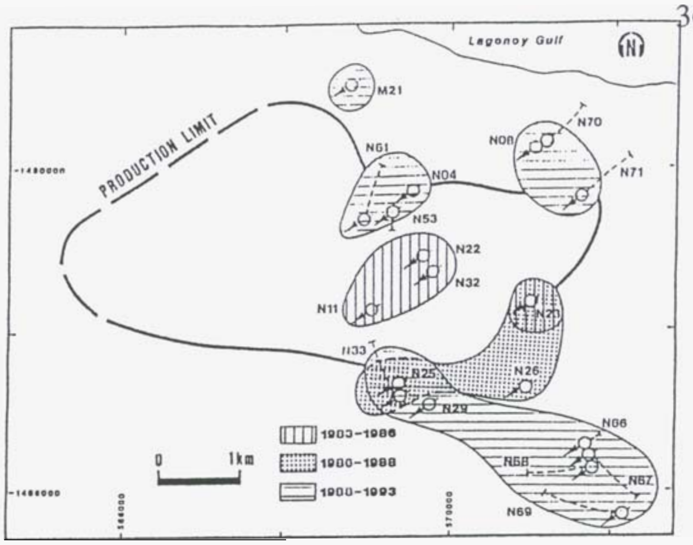

Figure 3 - Tiwi injection history.

2.1 In-field Injection (1983-1986)

As early as 1980, when the second power plant began operation, pressure draw-down in the Naglagbong sector became significant. Brine injection was then proposed both to enhance energy recovery in the field (Strobel, 1983) and to dispose of the water waste. A plan to pump brine from separators to carefully selected in-field injectors was formulated in 1981. Discrete layers of corrosive fluid were known to occur in Naglagbong, and the early injection wells were selected from these corrosive wells. Since corrosive fluids had not migrated into the benign production area, it was assumed that brine injected into these wells would migrate very slowly into the production area. In February 1983, in-field injection began at Tiwi in Nag-22 (Fig. 3). Soon thereafter, two other non-commercial producing wells, Nag-11 and Nag-32, were converted to injectors. Unfortunately, several production wells in the vicinity suffered from chemical and thermal breakthrough (Fallon, 1984). These production wells showed an increase in chloride content and a decrease in steam production rate and enthalpy. As a result of the breakthrough, injection into Nag-11, -22, and -32 was discontinued in 1986.

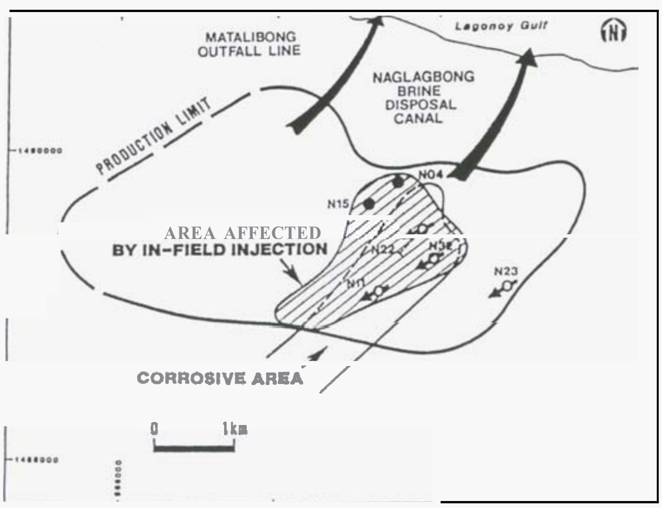

Figure 4 - Injection system in 1983-86, showing the corrosive area, and the area affected by in-field injection.

Production rates and reservoir temperatures recovered once in-field injection stopped (Pittinger, 1988). Examples of this behavior are exhibited by Nag-04 and Nag-15, located north of Nag-22 (Fig. 4). Figure 5 presents the steam production history of Nag-04. In addition to measured steam rates, a line showing the expected decline trend without injection breakthrough is dram to calculate lost production as a result of in-field injection into Nag-22 and -32. It is estimated that Nag-04 lost 0.45 x 10^9 kg of steam over a period of two years. The total lost steam from all wells affected by injection into Nag-11, -22, and -32 amounted to 3.7 x 10^9 kg. Another well affected by injection breakthrough was Nag-15. The maximum measured temperature of 260°C before injection decreased to 238°C after the well ceased flowing in 1986. After Nag-22 and -32 were shut-in, the temperature in Nag-15 increased by 32°C, providing a clear example of recovery after suspension of injection. Similar recoveries have been described for Palinpinon in 1985 and Bulalo in 1989 (Sussman et al., in press).

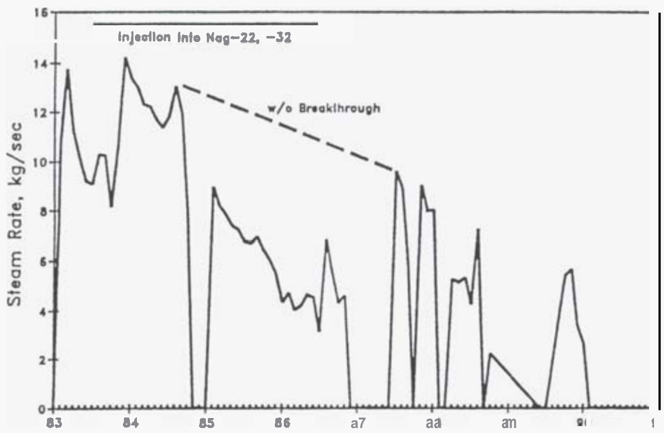

Figure 5 - Naglagbong-04 steam production history.

2.2 Edge-field Injection (1984 - present)

Since injection failed to provide a positive impact on the reservoir, PGI's rationale for injection became primarily waste water disposal. The objective was to address environmental concerns without adversely affecting steam production.

From 1984 to 1986, four other non-commercial wells were converted into injectors to either augment or replace the in-field injectors. These wells were Nag-23 (April 1984), Nag-25 and -33 (April 1986), and Nag-26 (May 1986). As shown in Figure 6, these wells are located at the margin of the production area and are classified as edge-field injectors.

Injection wells Nag-23 and -26 were found to cause chemical and thermal breakthrough to nearby producers. Tinopal-CBS and fluorescein dye tracers were used to define the direction and extent of breakthrough from Nag-23 (Beraquit, 1988). Results showed a strong connection between this well and nine producers in the immediate area. Tracer results and rapid steam decline of two producers led to shutting-in Nag-26 in February 1987 and Nag-23 in March 1988.

Positive tracer results did not always correlate with the detrimental effect on the production rates, and a specific example of this is Nag-14. The wellhead location of Nag-14 is north of Nag-33 (Fig. 6). However, their well courses are parallel and are about 300 m *apart* in plan view. A common permeable zone is found at a depth of 1340 m bsl. A strong tracer return was observed in Nag-14 10 days after fluorescein dye was injected into Nag-33, showing a clear indication of their connectivity. However, despite the rapid communication, only a minor decline in enthalpy and flowrate was observed at Nag-14.

Positive impact of edge-field injection was demonstrated by tracer, chemical, production and enthalpy data gathered during injection. Chloride concentration in several producers had verified the strong hydraulic communication between the edge-field injectors and several production wells. This was demonstrated by an increase of chloride in at least eight producers after the onset of injection. Coincident with injection breakthrough was the moderation in decline of several steam producers. As an example, the decline rate in Kap-11 (Fig. 6) reduced from 20%/year before injection to 9%/year during injection. These observations indicate that injectate was heated sufficiently in the formation before reaching the producers. Changes in chloride concentration, from a declining trend to an increasing trend, indicate that injection breakthrough may have also partially arrested the influx of cold water from the northeast (Aquino, 1992). Figure 6 shows the total area affected by edge-field injection.

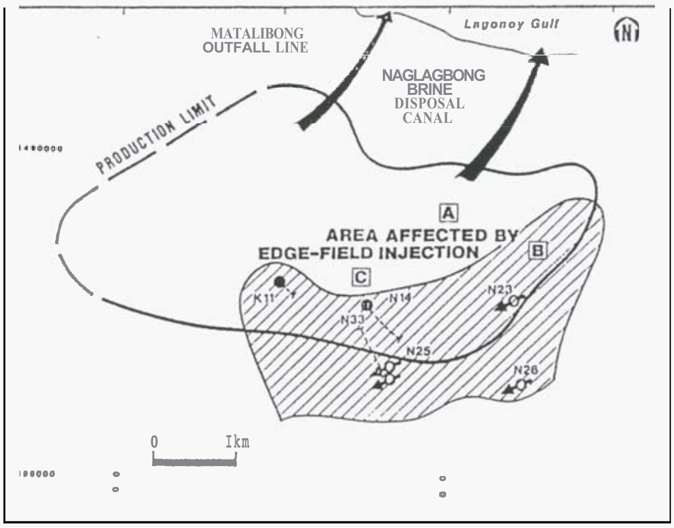

Figure 6 - Area affected by edge-field injection and the Matalibong ridge outfall line installed in 1984.

From 1984 to 1988, 45-50% of the brine produced was being injected and the rest was being disposed through two disposal systems leading directly to the Lagonoy Gulf: the Naglagbong Brine Disposal Canal and the Matalibong Outfall Line. The rugged terrain in the Matalibong area made it uneconomical to combine the two systems.

2 3 Southeast Hot Brine Injection System (1986-present)

Since edge-field injection was not capable of disposing all brine produced and injection breakthrough was significant in SE Tiwi, PGI started to explore for unconnected or poorly connected injectivity. In December 1986, the first out-field injection wells were drilled. Out-field injection began in the last quarter of 1987 using Nag-66 and -67. Nag-68 and Nag-69 were placed on-line in January 1988 and February 1990, respectively. *All* these wells are located southeast of the production area (Fig. 7). Nag-29, an edge-field non-commercial producer, was converted to an injector in June 1991. The above-mentioned wells, together with Nag-25 and -33, make up the Southeast Hot Brine Injection System **(SEHBIS).** Brine from wellsite separators and satellite stations in the Naglagbong and Kapipihan areas is disposed of here (Fig. 7). The present capacity of this system is 430 kg/s at 0.83 MPa injection wellhead pressure (IWHP). This represents approximately 80% of the brine produced in the field.

Tracer tests conducted on Nag-67 and -68 have shown that fluid migration into the production wells is minor. Micro-earthquake (MEQ) data collected at Tiwi show a concentration of MEQ events around the outfield injectors Nag-66, -67 and -68. There is a 2 km wide "aseismic" zone between these injectors and the production area, suggesting that injectate is moving southwest from the outfield injectors rather that towards the field (Rimando, 1993).

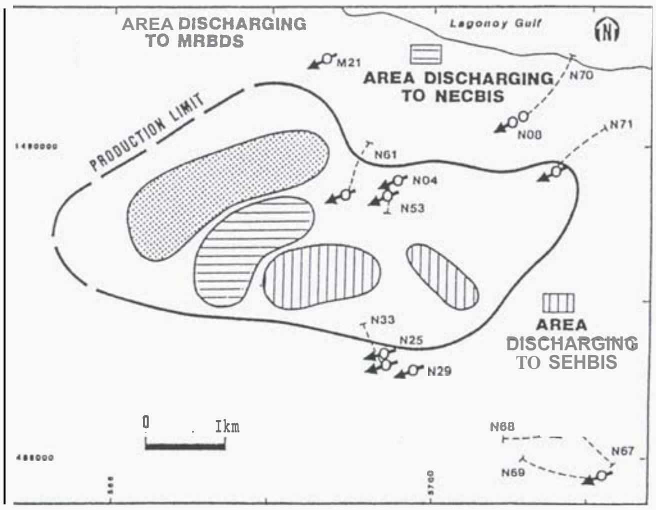

Figure 7 - Injection system used 1988 to present and the areas serviced by each subsystem.

2.4 Northeast Cold Brine Injection System (1987-present)

Additional injection areas were sought as an alternative to the Naglagbong Brine Disposal Canal in order to eliminate discharge into the gulf. Nag-08 (Fig. 7) was converted to an injector in April 1987, and Nag-70 was drilled and placed on-line in February 1990. The poor injection performance of these two wells required booster pumps to increase their injection capacities. Despite improved injection capacity, there was still 50 kg/s of fluid exiting through the canal. In July 1992, Nag-71 was completed and injection into the well started January 1993. Initial tests showed low injectivity.

The three injection wells, Nag-8, -70, and -71, compose the Northeast Cold Brine Injection System (NECBIS). The canal to which this system is connected accepts brine at 80°C from four wellsites in the Kapipihan area, as well as effluent from scrubbers and steamwash facilities. It is also used as an emergency injection facility for satellite stations in the Naglagbong area during upset conditions. The total capacity of this system is 50-57 kg/s at 2.75 MPa IWHP.

2.5 Matalibong Ridge Brine Disposal System (1992-present)

To inject the brine entering the Matalibong Outfall Line, a new injector was drilled north of the field. In July 1992, Miit-21 (Fig. 7), was completed and used to service all Matalibong wells, half of which produce 100% steam. At present, about 50 kg/s of cold brine is being disposed into this well at zero wellhead pressure. This allowed the permanent dismantling of the Matalibong Outfall Line. Mat-21 and one future well make up the Matalibong Ridge Brine Disposal System **(MRBDS).**

3.0 ACHIEVING 100% BRINE INJECTION

In 1992, about 80% of the brine produced was being injected into the three injection subsystems. The SEHBIS was accepting approximately 340 kg/s (82%); the NECBIS, about 44 kg/s (11%); and the MRBDS, about 31.5 kg/s (7%). Approximately 50-100 kg/s was being disposed into the gulf although the overall injection system capacity could accept all of brine produced. This was caused by mechanical problems such as scaling in the wells and clogging of pump strainers.

In November 1992, workovers were done to remove scale in Nag-08 and -70, and a program to clean strainers regularly was initiated. As a result of these remedial tasks, hooking-up of Nag-71, and decreasing brine production, Tiwi reached 100% brine injection in February 1993, exactly 10 years after injection began. However, operational problems in the system have resulted in the infrequent discharge of brine to the gulf.

Figure 8 shows the Tiwi injection history from zero injection in 1979 to 100% injection in 1993.

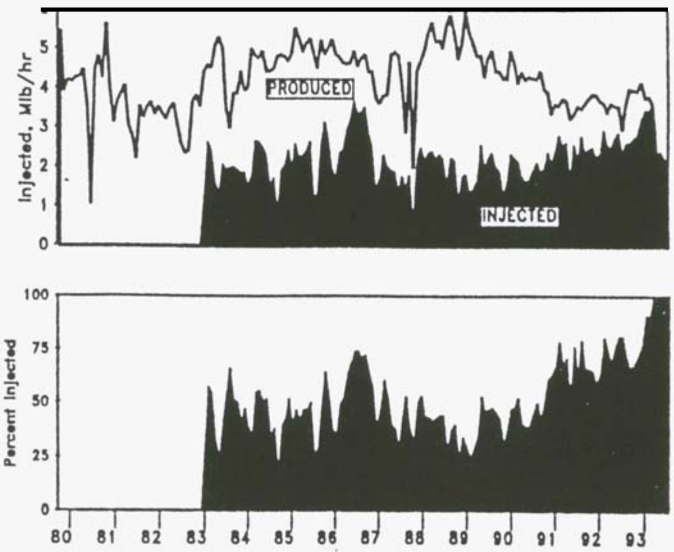

*Figure 8 - Tiwi brine production **and** injection history.*

4.0 MAINTAINING 100% INJECTION - IMMEDIATE AND LONG-TERM PLANS

Achieving 100% brine injection is only a part of PGI's and NPC's goal. The other part is to maintain 100% injection and eventually shut-off the Naglagbong Brine Disposal Canal. This entails maintaining excess injection capacity at all times in a cost effective manner without endangering the environment and the resource.

4.1 Northeast Back-up Injection System

Mechanical problems such as scaled-up wells and pipelines, clogged strainers, and unreliable pumps have been the biggest deterrents in maintaining 100% injection in Tiwi. A back-up system for the NECBIS was installed to augment brine injection in the northeast (Carandang, 1993). This system is used on an as-needed basis only until the brine going into the NECBIS is diverted to the SEHBIS and to a strategically located idle Naglagbong well.

About 80% of the wells in the Naglagbong area are idle due to either cold water influx or the natural decline of the wells' deliverability (Gambill and Beraquit, in press). *As* the back-up injection system required the use of former producers in the Naglagbong area, the concern of injection breakthrough and long term effects on the reservoir was raised. Therefore, careful well selection criteria and a program to monitor pressure and fluid chemistry were established to address these questions. To qualify, an injection well must be located at the edge of the production area and as far from the present producing wells as practicable. In addition, a well should be near the disposal line to minimize piping cost. The major permeable zone should be near the basement of the reservoir to minimize the possibility of thermal breakthrough and maximize reservoir heat sweep. Of the 10 in-field/edge-field wells evaluated, only Nag-04, 53, and 61 met the above criteria. Nag-61 has been selected as a permanent hot brine injector.

4.2 Long-Term Plans

Aside from the immediate plans to back-up the NECBIS, PGI is using a two-pronged strategy to maintain full injection at Tiwi.

First, the total injection capacity of the system has to be increased. A new injection well needs to be drilled in Matalibong and the injectivity of present injectors needs to be improved by redrilling or hydraulic fracturing. The SE booster pumps will be commissioned to increase injection pressure. For additional back-up capacity, edge-field idle wells need to be evaluated and connected to the system.

Second, high overall system efficiency needs to be maintained. Excess load in the NE needs to be diverted to the SE to make full use of excess capacity there. To ensure 100% availability, pump maintenance procedures need to be improved. When cold brine is injected, scaling in the wells is a persistent problem (Gambill and Beraquit, in press); therefore, cold brine injectors will be converted to hot brine to minimize scaling in the wells. Timely workovers are planned to maximize available injection capacity.

5.0 CONCLUSIONS

In early 1993, the Tiwi geothermal field finally achieved full injection of produced brine. From this experience, several important conclusions can be drawn:

1. In-field injection caused thermal and chemical breakthrough to production areas. No improvement in energy recovery was observed.

2. Edge-field injection caused both detrimental and beneficial effects on production, and needs **to** be monitored closely.

3. Out-field injection is recommended for most brine disposal as it has shown no adverse impact on the reservoir.

6.0 ACKNOWLEDGEMENTS

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