Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Handling the Problem of Rapid Reinjection Rreturns in Palinpinon-I and Tongonan, Philippines

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Keywords: steamfield management, brine disposal, reinjection returns, Philippines

ABSTRACT

Rapid return of reinjection waters is a genuine problem facing geothermal development, especially in "wet steamfields" such as those found in the Philippines. If left uncontrolled and unabated, it leads to quenching of individual production wells, and ultimately to significant reductions in power generation. In the geothermal industry steamfield management and power generation business, unforeseen or unprogrammed reduction in power output have immediate impacts and drastic consequences. This underscores the importance of proper steamfield management, especially on the problem of rapid reinjection returns.

All geothermal development in the Philippines are in liquid-saturated reservoirs, which has made the country the leader in wet steam technology. A major concern of wet steam development is reinjection management. The Philippine National Oil Co. – Energy Development Corp. (PNOC-EDC) has been in the Philippine geothermal business for over 25 years, mainly as steamfield developer and manager. Its experience in injection management has been diverse, beginning with in-field injection to scattered disposal of separated brine, which commonly have scaling potentials and problems of their own. The advent of stricter environmental laws has resulted in PNOC-EDC disposing not only of separated waters but power plant condensates as well. Nonetheless, the company's sound, dynamic and responsive injection strategy and overall steamfield management in the four production fields it has developed, has enabled it overcome these problems, resulting in sustained geothermal operations and power generation.

1. INTRODUCTION

Reinjection is an integral and critical part of geothermal steamfield management in both liquid-dominated and vapour-dominated reservoirs. In vapour-dominated fields such as the Geysers, injection provides much-needed pressure support to the geothermal system while under exploitation and large-scale mass extraction. The same is true for liquid-dominated reservoirs. In addition, environmental laws in countries like the Philippines requires reinjection as the only means of separated fluid disposal.

Of the six (6) operating geothermal fields in the Philippines, four (4) are operated by PNOC-EDC. These are, from north to south, Bacon-Manito, Leyte (Tongonan), Southern Negros (Palinpinon) and Mt. Apo. The Palinpinon and Tongonan fields have been under exploitation since 1983. Since the start of utilization of these two fields, reinjection of separated brine has been the normal practice. Many injection-related problems have been encountered and overcome in both fields todate. Because of the difference in the manner of utilization and extraction in both fields, reinjection problems as well as solutions are not the same. This paper presents the injection-related problems encountered by PNOC-EDC in both fields, and the solutions and strategies adopted to overcome these problems.

2. THE PALINPINON-I EXPERIENCE

The Palinpinon or Southern Negros geothermal production field is located at the southern tip of the island of Negros (Fig. 1) along the northern slope of dormant andesitic Cuernos de Negros volcanic complex. The field is underlain by a suite of extrusive, sedimentary and intrusive rocks aging from Middle Miocene to Recent. Young intrusive sequences are widely believed to provide the heating mechanism for the convective hydrothermal system. Fluid flow is mainly along permeable geologic faults trending northeast (NE)/ north-northeast (NNE) and northwest (NW)/ north-northwest (NNW). Lithologic permeability provides minor fluid flow channels in the field.

Figure 1. Location map of Palinpinon and Leyte (Tongonan) geothermal fields

Based on existing geoscientific data, the upflow of this liquid-dominated, high enthalpy geothermal system is believed to be in Lagunao near the so-called Lagunao dome (Fig. 2). Here, baseline measured and estimated fluid temperatures are in the range of 300-330°C, with a fluid chloride content of 4150 mg/kg.

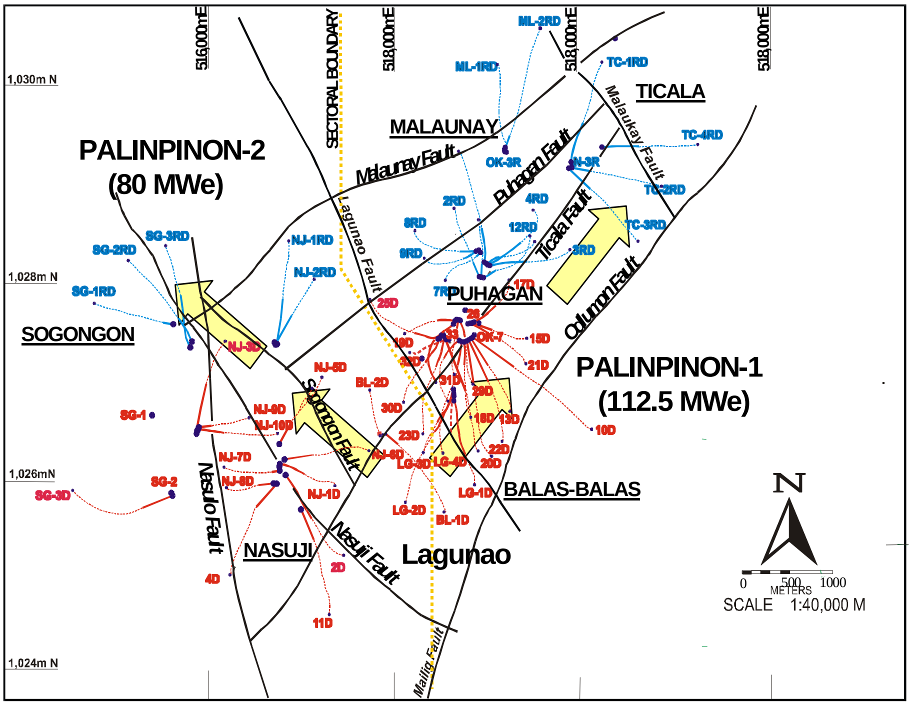

Figure 2. Palinpinon sectoral map showing production wells (red), injection wells (blue), sectors (underlined text), Lagunao upflow zone, outflow directions (yellow filled arrows) and major geologic faults (black lines)

The main outflow direction is towards the Okoy River valley to the northeast, while a secondary outflow direction towards Nasuji and Sogongon in the northwest is likewise present. Along both outflow sectors, fluid temperatures and Cl concentrations decline due to dilution with groundwater.

Discussions in this section will be limited to the Puhagan-Malaunay-Ticala (Palinpinon-I) sector of the field, where rapid reinjection returns were first experienced. Reinjection strategies for the later development of Palinpinon-II (Nasuji, Sogongon, Balas-balas) were derived from experiences in Palinpinon-I, and the problems associated with rapid reinjection returns have not been as severe here.

2.1 Production history

The field is divided into two production sectors – Palinpinon-I to the northeast and Palinpinon-II to the northwest. The former has been under production since 1983, with an installed capacity of 112.5MWe. Palinpinon-II, on the other hand, is made up of three (3) modular power plants – Balas-balas (20MWe), Nasuji (20MWe) and Sogongon (40MWe). Commissioning of these modular power plants occurred between 1993 and 1995. Todate, total installed capacity of Palinpinon is at 192.5MWe, supplying electricity not only to the whole island of Negros but likewise to neighboring islands of Cebu and Panay.

During its first year of operation, the Palinpinon-I power plant was operated at only 10-15 MWe with the lack of transmission lines to export power from the generating station. Mass withdrawal rate at this time was only about 325 kg/s, with the injection load ranging from 53-154 kg/s (Fig 3). Between 1984 to 1989, plant load was increased to 54MWe. Mass extraction and injection volume increased to 538 kg/s and 326 kg/s, respectively. In 1990, Panay Island was connected to the Negros grid, further increasing the extraction and injection rates to 500 & 300 kg/s respectively. By the year 2000, mass extraction rate in Palinpinon-I reached the 400-600 kg/s level, with injection rates at 250-400 kg/s (Pamatian, et al., 2001).

2.2 Injection Strategy

From 1983 to 1989, reinjection in Palinpinon-I was done infield, with all separated brine injected in wells <1km north of the Puhagan production sector. This strategy was found to be inappropriate as injection fluid breakthroughs in several production wells were detected by geochemical monitoring. Soon after the chemical breakthroughs, the affected wells showed declines in discharge enthalpies and increases in waterflows and Cl concentrations. In wells OK7, PN26 and PN17D, the adverse effect of rapid reinjection fluid return resulted in declines in output of these production wells to non-commercial levels (Pamatian, et al., 2003).

In 1989, an outfield injection strategy was adopted to arrest the detrimental effect of injection fluid return to the Puhagan sector. Between 1989 and 1991, new injection wells were drilled in Malaunay and Ticala sectors farther down the Okoy river valley, at distances of 2-3 kms from Puhagan. Commissioning of the new injectors resulted to reduced injection load in the Puhagan infield injection area, from a high of 326 kg/s in 1986 to 100 kg/s in 1990.

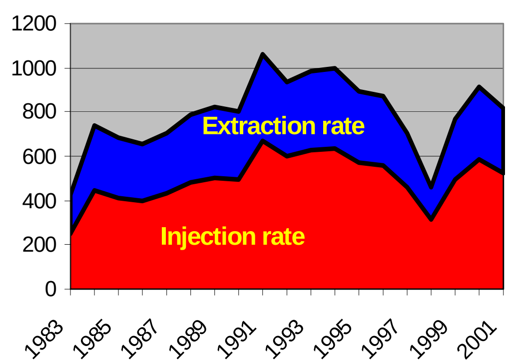

Figure 3. Palinpinon-I average yearly mass extraction and injection rates, kg/s

The combined effect of lower injection load in Puhagan and more distance between the main injection sink and the production sector was immediately felt in the previously affected production wells. Fluid chemistry, waterflows, discharge enthalpies and fluid temperatures recovered to near-baseline levels in most of the affected production wells. The field recovery from RI return was also manifested in the significant drop in reinjection line chloride from the 11,000 mg/kg level to about 9,000 mg/kg (Fig 4).

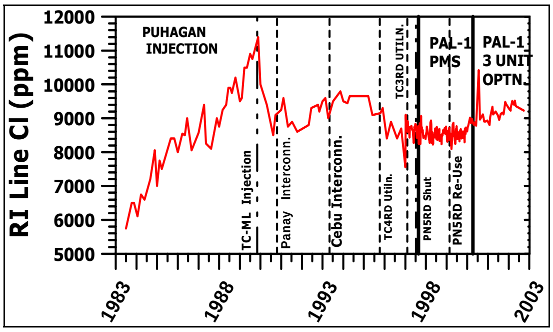

Figure 4. Palinpinon-I monthly RI Cl trend with time, reflecting operational milestones (vertical bars)

The inflow of reinjection (RI) fluid, however, was not totally eradicated as some wells still exhibited the signature of RI water inflows, albeit at much lower magnitudes. Furthermore, the utilization of Ticala fault by two (2) injection wells was identified as a major cause of RI return (Pamatian, et al., 2003). This fault provides a highly permeable connection between the Ticala RI sector and the Puhagan production area. The two (2) wells were subsequently decommissioned, and succeeding RI wells were designed such that the Ticala fault was either cased-off or intersected at deeper levels, allowing sufficient re-heating of the injection fluid before it re-emerges in the production sector.

As part of the new field management strategy, high enthalpy production wells in Puhagan were given utilization priority. This reduced the amount of separated brine reinjected into the injection sink, therefore reducing the volume of RI fluid returning to the production area.

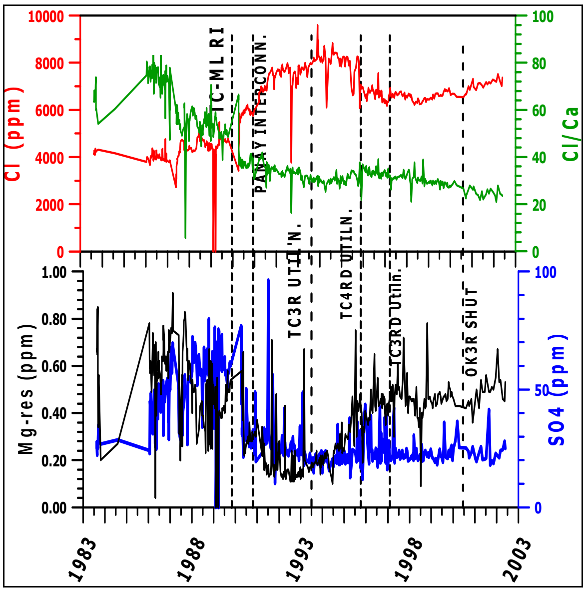

Figure 5. OK-10D fluid chemistry reflective of response to injection returns

A negative effect of outfield injection was the lack or reduction of pressure support to the geothermal system. As such, pressure drawdown was enhanced, allowing the entry of cooler peripheral waters into the production wells. To balance these effects, RI loads in the Puhagan and Ticala/Malaunay RI sinks were optimized. RI well PN5RD in Puhagan continues to be utilized todate at loads below 50 kg/s, to provide enough pressure support to production well PN27D and stop the ingress of cool water inflow. Ticala RI well TC3RD is likewise limited to a maximum load of 100 kg/s, where it provides pressure support to producer OK10D and prevent acid fluid coming into this well (Fig. 5).

3. THE TONGONAN EXPRIENCE

The Tongonan geothermal field in the central Philippine Island of Leyte (Fig. 1) is composed of three production sectors – Upper Mahiao, Tongonan-1 and Malitbog-South Sambaloran (Fig. 6). The heart of the system is in Upper Mahiao, where hydrothermal fluids with temperatures in excess of 320°C and Cl content of about 4000 mg/kg upflow. Preferential outflow direction is southeast, where the fluids are tapped by the Tongonan-1 and Malitbog production sectors.

The Tongonan geothermal system is bounded by NW-trending geologic structures that form part of the Philippine Fault system in Leyte. Like Palinpinon, structural permeability along normal faults provide excellent fluid channels for production as well as reinjection wells. Lithologic permeability within clastic beds at depth, meanwhile, is considered secondary or minor.

The natural-state model of the system shows an all-liquid reservoir across the upflow and outflow regions of the field. A natural two-phase zone does exist, but is confined to the upflow zone in Upper Mahiao.

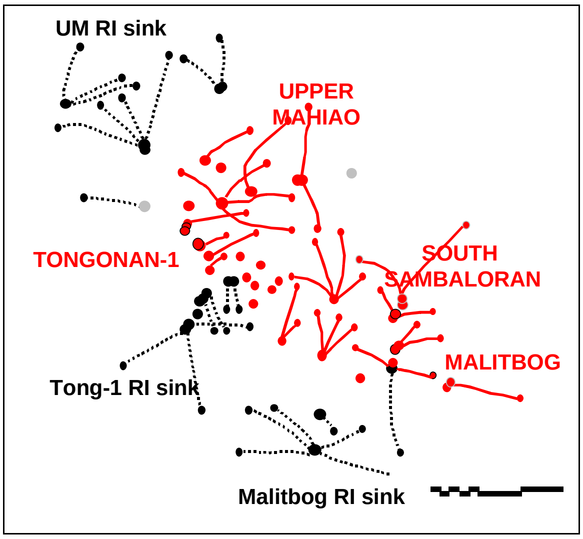

Figure 6. Tongonan sectoral map showing production sector/wells (in red) and RI sinks/wells (in black)

3.1 Production history

Although the Tongonan field has been under utilization for a little over twenty (20) years, its production history can be separated into two (2) major phase. The first phase, beginning in 1983 until 1995, is marked by the utilization and generation of only 112.5MWe from the first plant in Tongonan-1. Fluid extraction rates during this period ranged from 0.5-1.1 million tons/month (190-419 kg/s) while injection flows were in the order of 0.01-0.5 million tons per month (38-190 kg/s) (Siega, et al. 2000).

The year 1996 marked the beginning of full utilization of the field, with commissioning of the 125MWe Upper Mahiao (1996) and 231MWe Malitbog (1996-1997) power plants. In addition, the operation of the 50MWe steam interconnection to Mahanagdong (where excess steam from Tongonan is "exported" to adjacent Mahanagdong field in the southeast) began in 2000. The installation and utilization of these additional generating units had a huge impact on fluid extracted and injected. Extraction rates rose to 4.5 million tons/month (1712 kg/s) in 1998 and 5 million tons/month (1903 kg/s) in the year 2000 (Fig. 7). Peak separated brine injection rates were experienced in 1998 at close to 2 million tons/month (761 kg/s), although this has since declined to around 1.2 million tons/month (457 kg/s) currently. In addition to separated brine, about 250 kg/s of condensate is currently being disposed of in the injection sinks of the production sectors (Dacillo and Siega, 2003).

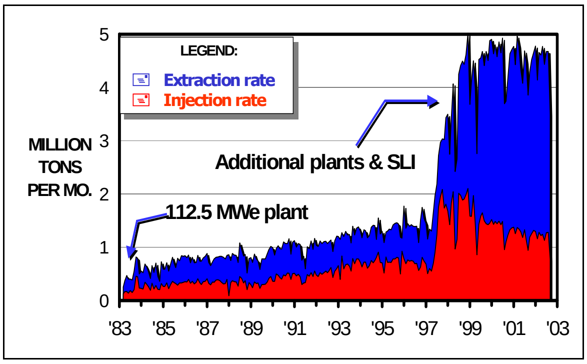

Figure 7. Extraction and injection rates (in tons/mo) in the Leyte geothermal production field showing increase correspondent to commissioning of various power plants and steam line interconnection (SLI)

3.2 Reservoir response to exploitation

The 112.5MWe power generation period from 1983 to 1995 was characterized by a 3MPa drop in reservoir pressure in the Tongonan-1 area, and a uniform <1MPa field drawdown in Upper Mahiao and Malitbog sectors (Siega, et al., 2000). Geochemical data showed increased mineralization, gas concentrations and discharge enthalpies, suggestive of localized boiling in certain production wells. Increased production since 1996 resulted to a field-wide pressure drawdown of around 4.5 MPa, the lowering of the system's water level and consequently the lateral and vertical expansion of the steam zone previously confined in Upper Mahiao. Todate, all of the wells in Upper Mahiao and most of the Tongonan-1 producers discharge dry steam. It is only in Malitbog-South Sambaloran where liquid fractions in production wells are still present (Fig. 8).

Although full exploitation of the Tongonan field did not begin until 1996, injection returns to the production sector was detected as early as 1989. This is because increased power demand in the country required the additional generation from Tongonan-1 power plant. Consequently, the injection load in the Tongonan RI sink also increased. Incursion and mixing of cooler (160°C) RI fluid with the in-situ production fluid resulted in the drop in field enthalpy in Tongonan-1 from 1900 J/g to 1600 J/g. Production fluid mineralization also increased, as reflected in the rise of Cl concentration by about 1000-2000 mg/kg from baseline values.

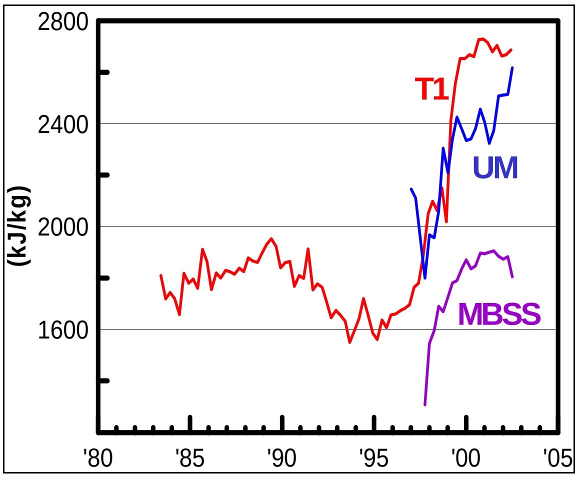

Figure 8. Sectoral discharge enthalpies in Leyte geothermal production field.

The field Cl contours (Fig. 9) clearly show the RI fluid front moving towards the production sector. In 1998, RI waters were also detected to affect the Upper Mahiao sector. Here, field enthalpies were already in the 2700 J/g range typical of steam discharge, but dropped and leveled off to about 2400 J/g as an effect of RI fluid encroachment. This was short-lived, however, as continuous expansion of the shallow steam cap eliminated or masked the RI fluid entry in Upper Mahiao in 2001.

Upon the commencement of production in Malitbog-South Sambaloran, boiling initially occurred in the sector wherein the production wells here showed rising enthalpies. Soon after, however, cooler waters (reinjection fluid from the Malitbog RI sink and peripheral waters in the area) started to encroach into the sector's production zones. Producers close to the Malitbog RI sink exhibited chemical behaviour reflective of RI fluid breakthrough, while production wells in the northwest showed declining mineralization, gas and temperature levels coupled with increasing sulfate.

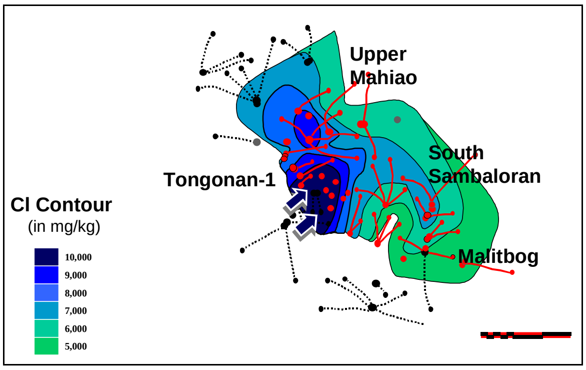

Figure 9. Current Cl contours across the Tongonan reservoir showing ingress of RI fluid from Tong-1 RI sink

3.3 Injection Strategy

When only the Tongonan-1 power plant was on-line, the Tongonan injection sink was located <1km southwest of the production area. Strictly speaking, this may be considered in-field injection, although the other sectors in Tongonan were not in operation. All of the brine from the Tongonan separator station – about 200 kg/s – were injected here. This strategy allowed for and provided pressure support to the geothermal system during the sole operation of the Tongonan-1 power plant.

Upon the emergence of the RI return problem in 1989, close monitoring of affected production wells was done. In 1995, an optimized injection scheme was implemented to reduce the adverse effect of RI return and continue to provide pressure support to the system. Wells in the Tongonan RI sink closest to the production sector (2R3D, 2RwD) were operated at reduced loads of 90 kg/s (from 140 kg/s), and the rest of the Tongonan separated brine was piped to the northwestern periphery of the sector (called the Mahiao RI sink). This optimized scheme resulted in the immediate recovery of affected production wells in Tongonan-1.

With full field utilization and the consequent expansion of the steam cap in Upper Mahiao and Tongonan-1, the Upper Mahiao RI sink was utilized for the South Sambaloran brine disposal. This lessened the amount of RI fluid injected into the Malitbog-South Sambaloran sector, which was found to be returning to the production area. But with the detection of RI returns in Upper Mahiao, all of the south Sambaloran brine was re-diverted to the Tongonan-1 RI sink. This strategy had a two-fold objective – to arrest the RI problem in Upper Mahiao and provide pressure support to Tongonan-1. In addition, the shorter distance "traveled" by the South Sambaloran brine to Tongonan greatly reduced the potential to deposit silica along the pipeline. The shift in RI strategy proved successful, as the RI return in Upper Mahiao was eliminated. In Tongonan-1, a number of high enthalpy wells showed declines in CO_2 contents, indicating the entry of RI waters. No declines in steam flowrates and enthalpies have been detected, which probably means that the RI fluid is boiled to a certain extent, hinting that the RI ingress in Tongonan-1 is beneficial to the sector.

The dispersion of RI load from the Malitbog-South Sambaloran sector has obviously resulted in positive impacts. Production wells, although showing increased mineralization, have not exhibited drops in fluid temperatures. Borehole pressures, although exhibiting steep drops in the early stages of commissioning, have tapered off and are now stable. This indicates that the RI fluid is providing pressure support to this sector of the geothermal system (Aleman & Saw, 2003). As long as the South Sambaloran brine is dumped outside this sector, the Malitbog separated water is manageable and beneficial to this portion of the field.

The primary RI concern at present is the injection of Upper Mahiao power plant condensate, about 290 kg/s at 60°C, in the Upper Mahiao RI sink. Although it has been proven that injection in Upper Mahiao has detrimental effects, there is no other location for condensate dumping to be accommodated. Close geochemical monitoring is currently being implemented in Upper Mahiao to provide an "early warning device" to management so appropriate measures can be implemented accordingly. Meanwhile, modifying the RI management scheme cannot arrest the entry of peripheral waters in the northern portion of Malitbog sector. The only thing that can be done to stop this phenomenon is to reduce extraction near this portion of the field, something the Tongonan reservoir can ill-afford at the moment.

4. CONCLUSIONS

Experiences from Palinpinon-1 and Tongonan highlight the need to properly manage separated brine disposal when exploiting geothermal fields. Massive fluid extraction ultimately leads to field-wide pressure drawdown, which significantly shifts the direction of fluid flow. Locating injection sinks very close to the production areas will result in the rapid return of injected brine into the production sector, affecting the output of production wells. Locating the injection sinks at least 2 kms. from production sectors greatly helps delay or retard, if not totally eliminate, the return of injected brine. However, this strategy also reduces the pressure support to the geothermal system under exploitation provided by the reinjection fluid. In this case, the reservoir may respond differently, and other problems may emerge.

Since each field has a unique response to a particular injection strategy, there is no hard and fast rule on which strategy should be adopted. It is a case of trial and error for most steamfields, and coping with the dynamics of reservoir response to exploitation and injection. It is imperative that sound monitoring tools are in place to provide "early warning devices" and aid in the formulation of the appropriate steamfield management strategy.

ACKNOWLEDGEMENT

The authors wish to thank PNOC-EDC for permission to publish this paper, and the geoscientific staff of Leyte and Palinpinon for all the assistance.

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