

IMPACT OF SEPARATED BRINE INJECTION AT THE MALITBOG SECTOR TONGONAN, PHILIPPINES

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ABSTRACT

Large-scale brine injection at the Malitbog sector, Tongonan, Philippines began in mid 1996 during the commissioning of the Malitbog Fluid Collection and Disposal System (FCDS). With the subsequent operation of the 231 MWe Visayas Geothermal Power Company main plant and the 14.56 MWe ORMAT bottoming plant, brine injection has been continuous except on some occasions when the FCDS was on shutdown for its preventive maintenance and servicing (PMS). The continuing mass extraction has caused the reservoir pressures to fall, with most production wells showing uniform drawdown. The declining pressures in effect increase the potential for reinjection fluid incursion into the production sector, as the pressure difference between the production and reinjection sectors increases. This paper examines the changes in the reservoir characteristic of the nearby production sector resulting from brine injection and establishes the possible movement of the injected fluids across the field.

Over the past years, changes in fluid movement across the Malitbog have been noted. Peripheral fluids in the northeast now recharge the northern Malitbog production wells initially showing evidence of injection returns. During the first quarter of 1998, thermal activity in the Bao-Banat-I thermal area waned and eventually ceased, implying possible shift in the natural flow pattern in the reservoir. Production wells close to the reinjection sink began exhibiting effects of reinjection returns in 1999. The presence of returning reinjection fluids in Malitbog however, have provided recharge to the sector. The reservoir pressures after initially showing steep decline have tapered off since 1999. Since the same period, the available brine for the second flash remained relatively stable. This proved to be beneficial to the bottoming plant as the supply of low-pressure steam

stabilized. On the other hand, the decline in high-pressure steam supply is relatively minimal and manageable.

1.0 INTRODUCTION

1.1 Historical Background

The Malitbog sector lies in the outflow region, southeast of the Tongonan Geothermal Field (Figure 1). Most of the wells in this area have been drilled and tested in the late 1970's and early 1980's and the sector is characteristically liquid dominated as reflected by the low discharge enthalpy of the Malitbog wells.

It was only in early 1990's that the sector was finally developed for commercial exploitation. A double flash system was adapted for the low enthalpy field at separation pressures of 1.2 MPaa and 0.7 MPaa for the high pressure and low pressure flash systems respectively. The main plant has a gross capacity of 232.5 MWe (77.5 MWe x 3) while the low pressure bottoming (optimization) plant has a gross capacity of 14.56 MWe.

Steam for the power plant is supplied by both the Malitbog and the South Sambaloran sectors. The former provides the steam requirement of one turbine unit, and the latter provides the requirement of the two other units. Brine from the South Sambaloran wells is injected in Upper Mahiao while brine from the Malitbog production wells is injected in the nearby Malitbog reinjection sink.

There are nine production wells supplying geothermal fluid to the Malitbog fluid collection and disposal system (FCDS) while seven injection wells were originally connected for the brine disposal requirement of the sector.

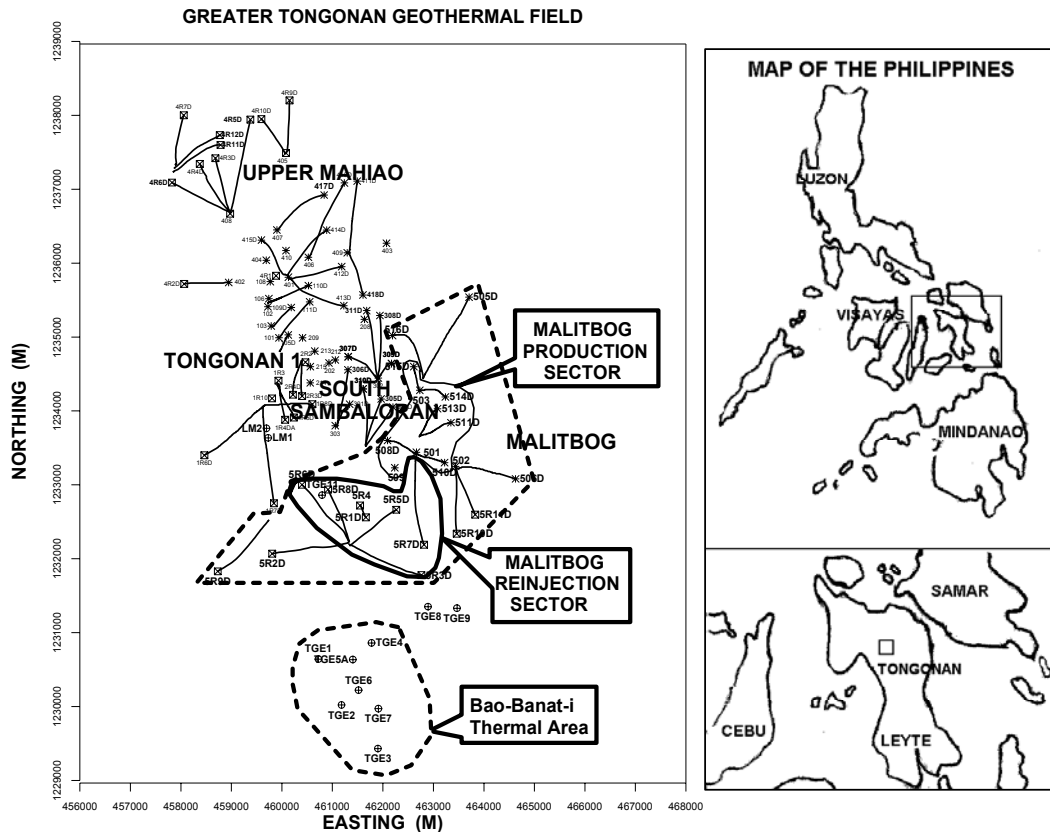


Figure 1. Location map of Tongonan geothermal field.

1.2 Early Tracer Injection Test

As early as 1982, studies have already been undertaken to determine possible hydrological connection between 5R1D and the surrounding surface features and with the nearby wells. A total of 500 mCi of ¹³¹I radioisotope were injected into 5R1D on December 08, 1982 (KRTA, 1983). Brine from discharging wells 509 and 5R4 was injected into 5R1D at a combined flow rate of 65-85 kg/s during the testing period. Fluid sampling was then carried out in wells 509, 5R4, as well as in 508D and 514D, which were also discharging at that time. Samples were likewise taken from the Bao springs, Malitbog River and Bao River for a period of 28 days. The 28-day monitoring period was based on the radioactive tracer half-life. Results of the analysis yielded no indication of any returns to the monitoring stations. Although no tracer returns were noted from the samples, the study however pointed out that the low injection rate at 5R1D may have influenced the negative response.

2.0 PRE-COMMISSIONING ACTIVITIES

2.1 Initial Injection

Initial large-scale injection began in early 1996 during the pre-commissioning activities of the Malitbog FCDS. Brine flow progressively increased from 50 kg/s to 500 kg/s as the FCDS load was raised for the line flushing and systems testing activities. One by one all the seven injection wells were connected to the system to cope with the increasing brine load. FCDS full load operation was conducted from June 14 to July 4, 1996 during which a maximum brine load of 500 kg/s was continuously disposed to the Malitbog injection wells. At that time, the second flash system was not yet in operation and wastewater from the high-pressure separator vessels was directly sent to the injection wells. Total brine injected into the Malitbog reinjection area from March 27 to August 14, 1996 is estimated to be about 2,590,000 tonnes.

Capacities of the injection wells were measured during full load operations. Well 5R1D had the

highest measured capacity of 221 kg/s, followed by 5R4 with an acceptance of 161 kg/s and 5R7D with a capacity of 64 kg/s. The capacities of the four other wells were in the range of 18 to 27 kg/s.

2.2 Tracer Testing

Further study of the hydrological connection between the Malitbog reinjection sink and the Malitbog production wells was again undertaken in 1996 during the Malitbog FCDS testing (Parrilla et al., 1996). A total of 25 kg of sodium fluorescein tracer were injected into 5R1D on June 21, 1996 while samples were collected from well 509 and the nearby surface features. Unlike the earlier tracer test, a high injection rate of 220 kg/s was attained as all production wells were discharging to the system. Samples were initially screened using black lamp, and in cases where fluorescence were detected, the samples were further analyzed using a UV-VIS spectrophotometer at 491 nm. Samples found to be positive of tracer returns were then analyzed using Perkin Elmer luminescence spectrometer. Positive returns were detected in the Hot Springs and well 509.

2.3 Surface Thermal Activities

Intensive monitoring of nearby Bao-Banat-i thermal areas was undertaken during the pre-commissioning activities of the Malitbog FCDS to determine any response with increased injection loading at the Malitbog injection sink. Parrilla et al. (1996) noted increased geysering activities in the hot spring area.

The report likewise pointed out that injection at 5R1D had the highest impact on the hot springs, which was supported by the positive tracer returns obtained during the tracer injection test at 5R1D.

2.4 Output Testing

After the FCDS shutdown on mid August 1996, six of the nine production wells were programmed for short-term discharge test (STD). This was aimed at updating the discharge output and characteristic of the wells prior to large-scale exploitation. Most of the output data then were based on the discharge tests conducted in the late 1970's and early 1980's. The STD was programmed for six days per well at three different well openings.

Results of the tests showed wells 503, 509, 514D and 515D to have higher discharge enthalpy than the original values by 250 kJ/kg. Only wells 515D and 501 showed a corresponding decline in massflow while the rest of the wells have relatively stable massflows. The rising discharge enthalpy of these wells is attributed to pressure drawdown after prolonged utilization during the pre-commissioning activities. It should also be noted that like the wells in the other sectors, these wells have experienced pressure drawdown in response to the exploitation of the Tongonan 1 production field.

Well 513D on the other hand exhibited a higher maximum discharge pressure and enthalpy than the original output.

3.0 RESERVOIR CHANGES WITH TIME

3.1 Downhole Temperatures and Pressures

Downhole temperatures and pressures were closely monitored to determine changes in reservoir conditions. Downhole measurements of production wells are usually conducted annually during FCDS shutdown which is scheduled simultaneous with the power plant preventive maintenance and servicing. It should be noted that the Malitbog production wells provide the bulk of brine for second flash for the supply of low-pressure steam to the bottoming plant. As such, these wells are operated at fully open condition and any alterations in well openings would significantly reduce the low-pressure steam supply. Peripheral wells not hooked up to the FCDS are monitored more frequently.

All three Malitbog injection wells revealed cooler downhole temperatures as a result of prolonged brine injection. Well 5R1D remains single phase with suppressed temperatures of 160 - 170 C at its major injection zone. Well 5R1D was previously displaying two-phase conditions prior to 1996. It was only during initial large-scale injection that the well reverted to single-phase condition. In the case of 5R4, cooler downhole temperatures are likewise noted although unlike well 5R1D, two phase conditions still persists in the wellbore. Both 5R1D and 5R4 likewise exhibit stable downhole pressures, which imply that the injected brine is dispersed away from the wellbore.

Well 5R7D on the other hand was only surveyed once after large scale injection began in 1996. This well was isolated in October 5, 1998 after it was believed that the well was responsible for the RI breakthrough in wells 508D, 503, 514D and 515D based on the changes in discharge chemistry. The 49 days shut downhole survey showed well to be still recovering from the effects of prolonged brine injection with temperatures lower than the measured stable temperatures. Its pressure profile however shows a rather peculiar drop in water level by as much as 100 m and a change in pressure gradient. This is seen as a combined effect of brine injection and drawdown. Like the two other RI wells, brine injected into the well is dispersed away from the wellbore. After injection was halted, the well began showing effects of pressure drawdown. The well was re-utilized in early 2000.

South of the sector and close to the other injection wells, no response to either injection or production was noted at well 5R2D. Well 5R2D is a low permeability well drilled to the southwest. Its downhole pressure was monitored from April 15, 1998 to February 16, 1999 through a Pruett capillary tubing set at 250 mMD. Downhole temperature measurements likewise showed no thermal decline. The negative response implies that there is no flow of injected brine towards the western flank of the sector.

Peripheral monitor wells 502, 5R11D and 5R10D have also been affected by pressure drawdown. Although the first two wells showed relatively stable downhole temperatures, well 5R10D registered a drop in temperature by as much as 15°C at depth while at the same time showing a 60 m drop in water level and a change in pressure gradient. This response closely resembles that of the response observed in 5R7D. This is attributed to the combined effect of incursion of cooler fluids and pressure drawdown. It should be pointed out that it was only in late 1998 that RI breakthrough was observed in this well. There is also a possibility that the well is affected by well MN2RD that is used by the Mahanagdong sector as a brine reinjection well.

Among the production wells, well 510D notably exhibits thermal decline at depth due to reinjection fluid breakthrough. Temperature reversal at interval -900 to -1100 mRSL became apparent in the year 2000 survey (Figure 2).

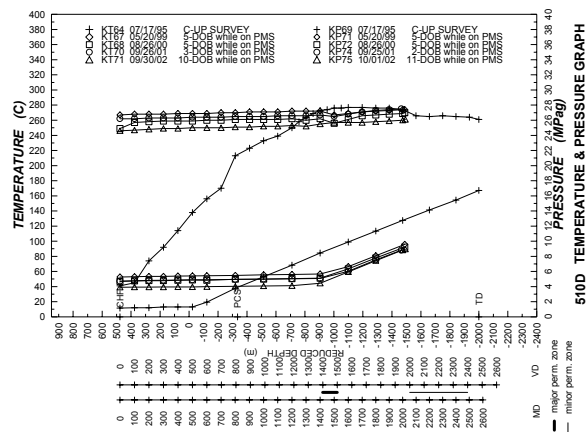


Figure 2. Well 510D temperature and pressure profile.

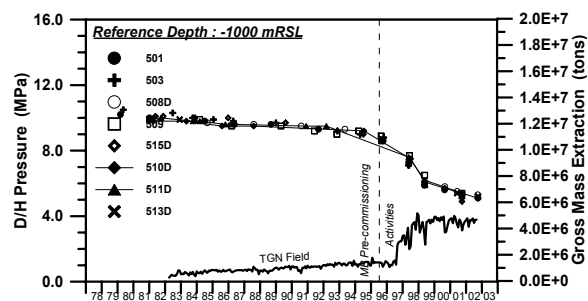


Figure 3. Malitbog downhole pressure versus time at -1000 mRSL.

Because of the entry of cooler fluids, the transformation of the zone at this depth from single-phase liquid to two-phase was stalled and eventually reverted back to its original state. The discharge enthalpy of this well initially increased from 1300 kJ/kg to a peak of 1700 kJ/kg in the early 1999 but eventually declined back to 1300 kJ/kg level. No recent temperature data is available for 511D, which like 510D, experienced enthalpy increase early on but is now on the declining trend.

Pressure drawdown across the sector is fairly uniform (Figure 3) with an average drawdown of 4.0 MPa in the Malitbog production sector since 1995. During the early stages of Malitbog-South Sambaloran commercial exploitation, pressure drawdown was relatively steep but eventually tapered off since 1999.

3.2 Output Trends

Since the start of continuous plant operations in 1997, the output of all Malitbog production wells have been regularly measured using chemical tracer method.

Initially, the output trends generally showed increasing discharge enthalpy as a result of pressure drawdown (Figure 4). While some wells have exhibited high enthalpy, the others have remained at lower levels. This distinction is related to the well's dominant feed. The high enthalpy producing wells are tapping more from the upper two-phase feed zones with some contribution from the lower liquid feed zones. In contrast, the low enthalpy producing wells have major contributions from the lower liquid feed zones. The effects of the increasing discharge enthalpy are reflected in the steadily declining brine availability for second flash.

Apparently, the wells closest to the Malitbog injection sink (501, 508, 509, 510D) began showing falling discharge enthalpy in 1999 which resulted to output declines.

The same falling enthalpy trend was likewise noted in the second closest group of wells, consisting of wells 511D and 513D, located north of pad 501. The recent deterioration of high enthalpy well 511D is possibly due to the increase in 5R7D RI load.

The wells farthest from the Malitbog injection sink were initially believed to be affected by reinjected fluids based on chemistry but no conclusive evidence had been indicated by the wells' output.

It should be pointed out that the effect of the reinjection fluid encroachment on the total Malitbog high-pressure steam is minimal and manageable. High-pressure water flow has also stabilized at 275 kg/s since 1999 that in effect stabilized the low-pressure steam for the bottoming plant.

3.3 Reservoir Chemistry Trends

In the early stages of the Malitbog sector steam field operations, the wells farthest from the injection sink indicated slight increase in reservoir chloride with a corresponding decline in CO₂td (Figure 5). The other well that exhibited the same behavior was 508D, a well relatively closer to the RI sink. It was believed that the increase in mineralization noted in these wells, accompanied by fall in CO₂td and Cl/Ca ratio was caused by incursion of fluids from the Malitbog injection sink. After the well chemistry of the farthest wells showed recovery in response to the outage of well 5R7D in late

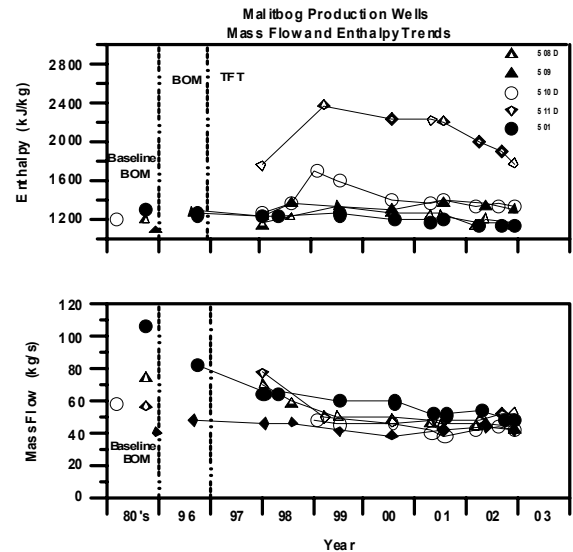


Figure 4. Output versus time plot of MB wells affected by RI returns.

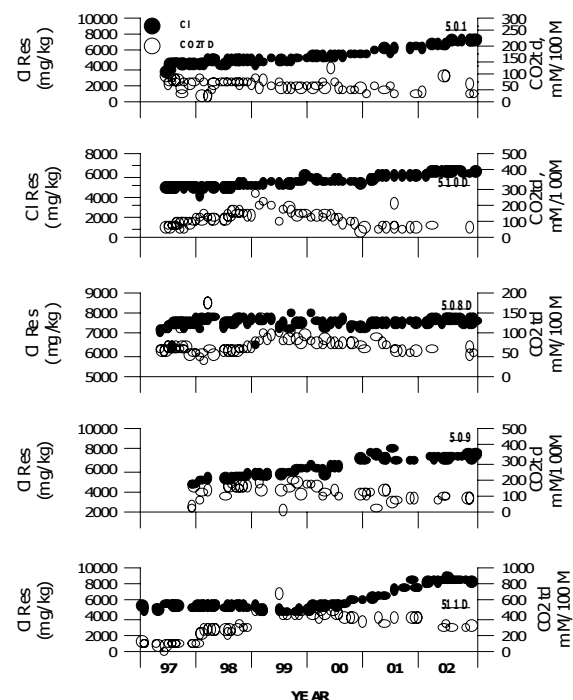


Figure 5. Fluid chemistry of MB wells affected by RI returns. (Data source: PNO-C-EDC Geoscientific Dept.).

1998 to early 2000 (Martinez et al., 1999), a different type of fluid originating from the periphery began migrating towards the northeastern part of the field (Dacillo et al., 2001b).

The wells closest to the reinjection sink only began showing signs of reinjection fluid breakthrough in 1999 when its reservoir chloride steadily increased (Figure 5) while at the same time showing declining CO₂ content and T(quartz) (Maturgo et al., 2000).

The same trend likewise became apparent in well 511D, located farther away from the injection sector, in 2001. (Dacillo, 2001). This well previously indicated signs of boiling in the reservoir with its CO₂ content as well as reservoir chloride increasing (Dacillo et al., 2001a).

3.4 Surface Activities

The Bao-Banat-i hot springs again responded to the resumption of 5R1D utilization on April 1997 upon full operation of the Malitbog power plant. Waste water was injected into 5R1D at a lower load ranging from 66 to 119 kg/s. Bolanos and Parrilla (1998) noted that breakthrough of reinjection fluids was again experienced as indicated by the increase in massflow and chloride. However, during the last quarter of 1997 and first quarter of 1998 increasing chloride trend and declining flowrate was noted in the hot spring area. This sudden reversal of mass flow trend was attributed to the lower rainfall due to the El Niño phenomenon and inferred migration of reinjection fluids to the production sector.

4.0 DISCUSSION

Changes in fluid movement across the field have been noted since the field was commissioned in 1996. During commissioning, chemical tracer test have identified the Bao hot springs and well 509 as hydrologically connected with well 5R1D. However, during the early stages of operation, well 509 indicated no signs of reinjection returns.

Instead, wells farthest from the injection sink, with the exception of 508, appear to have been affected by injection returns. Chemical parameters indicated influx of highly mineralized fluids although no significant decrease in silica temperatures as well as actual measured downhole temperatures was evident. It was inferred that well 5R7D was the source of this migrating fluids. The output of these wells though, showed no clear indication of the effect of reinjection breakthrough.

Two factors that could possibly explain the absence of thermal effects are: a.) the distance between 503, 514D, 515D and the reinjection sink and b) the absence of direct flow channels between these production wells and the injection wells. Waste brine injected into the injection sink at 160°C is possibly reheated before it finally reaches these production wells.

The affected wells showed recovery in fluid chemistry after reinjection well 5R7D was put off-line from the system from late 1998 to early 2000 but soon after became affected by a different type of fluid coming from the northeastern periphery of the field even with the re-utilization of well 5R7D.

The eastern peripheral monitor well 5R10D, located close to 5R7D was the only other well showing effect of reinjection fluid breakthrough in the early stages of operation. The thermal decline occurred more than a year after continuous injection began in mid-1997. This well could also be affected by the brine injection at MN2RD, a well utilized by the Mahanagdong sector for its brine disposal requirement.

During the first quarter of 1998, thermal activity in the Bao-Banat-I thermal area was observed to have waned and eventually ceased, implying possible shift in the natural flow pattern in the reservoir, especially in the outflow sector.

The western flank of the field, represented by well 5R2D, showed negative response to injection leaving the production sector in the north as a possible flow path of the reinjected fluids especially with the prevalence of pressure drawdown in the that part of the field.

It was only in 1999 that the wells close to the RI sink began showing signs of reinjection fluid breakthrough. This was indicated by physical as well chemical data. Some of the wells after initially showing increasing trend in discharge enthalpy due to pressure drawdown such as 510D started to decline as a result of reinjection fluid breakthrough.

More recent tracer tests will have to be programmed to pinpoint more accurately which specific injection well is the source of reinjection returns in each of the production wells.

There are two possibilities for the delayed breakthrough in the nearby production wells

after commissioning. These are: 1) the fluids are indirectly channeled and hence fluid breakthrough takes a longer period to occur and 2) the stoppage of RI flow towards the Bao-Banat-I either possibly induced by the continuing pressure decline in the production sector or by massive deposition in the flow path has caused the change in fluid movement, hence RI breakthrough in the other wells only began to manifest in 1999.

The recent entry of peripheral fluids in the northern part of Malitbog, replacing the reinjected fluids, also suggest that the flow of 5R7D reinjection fluids has now probably shifted and the possibility of these fluids encroaching the other production wells could not be discounted.

The presence of returning reinjection fluids in Malitbog however, have provided recharge to the sector. The reservoir pressures after initially showing steep decline have tapered off since 1999. Since the same period, the available brine for the second flash remained relatively stable. This proved to be beneficial to the bottoming plant as the supply of low-pressure steam stabilized. On the other hand, the decline in high-pressure steam supply is relatively minimal and manageable

5.0 CONCLUSIONS

The fluid movement across the Malitbog sector has undergone changes over the past years. Production wells farthest from the reinjection sink are now recharged by peripheral fluids in the northeast after initially identified as affected by reinjection returns. Production wells close to the reinjection sink only exhibited effects of reinjection returns in 1999.

The incursion of reinjection fluids in Malitbog have provided recharge to the sector, causing the reservoir pressure drawdown rate to taper off since 1999. The available brine for the second flash also remained relatively stable since that time, hence stabilizing the available supply of low-pressure steam to the bottoming plant. The decline in high-pressure steam supply due to the decline in discharge enthalpy on the other hand is relatively minimal and manageable.

ACKNOWLEDGEMENTS

The authors wish to thank the management of PNOC-EDC for allowing us to publish this paper. To Farrell L. Siega and Danilo B. Dacillo for providing some of the valuable geochemical data and references.

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