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Update on Reservoir Pressure Changes in the Matalibong Sector, Tiwi Geothermal Field, Philippines

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ABSTRACT

Monitoring and analysis of reservoir pressure changes in a producing geothermal field is a very important component of a resource management program as it helps determine how the reservoir is reacting to production and/or injection and therefore helps inform possible changes in the production and/or injection strategy to mitigate issues that are being encountered.

In the Tiwi geothermal field, Philippines, reservoir pressures have been monitored since before commercial production began in 1979 by combining data from intermittent downhole pressure surveys run in individual wells. Although the data are relatively sparce, by combining measurements from all available wells in a defined sector, a reasonable overview of the pressure changes occurring with time is obtained, although the precision of the measurements is limited.

In November 2005, capillary tubing was installed in Mat-25, an observation well located in the Matalibong production sector of the Tiwi field, to monitor pressure changes in the deep liquid reservoir on a more continuous basis and with improved precision. Since then, three other wells (Mat-29, 30 and 32) have also been used as observation wells at various times and the collected data from the four wells have provided a reasonably continuous record of downhole pressure changes from 2005 to the present. Since 2008, wellhead pressures have also been monitored to provide data on the pressure changes in the overlying steam production zone, which in the past has been an important source of production for the Tiwi field.

From 2005 to 2013, the measurements indicate that deep liquid reservoir pressure was generally increasing, while short-term changes correlated well with injection flow changes to the MatRidge Hot Brine Injection System (MRHBIS) wells, even though these wells are 1.2 to 1.8 miles (2 to 3 km) from the production area where the observation wells are located. However, it was possible to successfully match this interaction using both analytical and numerical models.

The main concern with the increasing deep pressure has been the associated rise in the steam-liquid interface, which has allowed the liquid to infiltrate the steam producing zones so that wells that previously produced superheated or saturated steam then started producing two-phase or liquid, as indicated by the change in measured discharge enthalpies.

With the apparent correlation between pressure changes and injection and with the positive results in matching the data with both analytical and numerical models, it was concluded that it should be possible to mitigate the rise in pressure and the steam-liquid interface and possibly reclaim steam production from some wells by reducing injection. A pilot field test conducted in 2011 also appeared to confirm that this was possible, and the decision was made to construct a pipeline to divert injection to the SouthEast Hot Brine Injection System (SEBHIS) from the Bariis production sector, which had previously been injected to the MRHBIS. The pipeline was commissioned in July 2013.

Modelling results indicated that it would be necessary to reduce the MRHBIS injection by at least 50% to stabilize the pressure. However, this was difficult to attain due to the design of the Tiwi injection system, which relies on gravity feed, but even with the reduction that has been achieved since 2013, deep liquid pressures have continued to rise, resulting in essentially all the Matalibong steam producing wells now producing at two-phase or liquid enthalpies.

With regard to defining recharge, the analytical model relies on flow from the overall defined area of the model to the pressure sink while for the numerical model, there is an attached shallow aquifer that was included to initially provide a pathway for outflow from the Matalibong sector and this later reversed to provide a source of inflow once the pressure dropped sufficiently. For both models, as mentioned above, the resulting recharge was sufficient to match the data to 2013.

More recent modelling work has shown that even though the reduction in injection has been less than the 50% target, reservoir pressure should have declined, which is contrary to the observed continued increase in pressure. To match the pressure increase from 2013 to 2016, a run using the numerical model indicated that up to 1,500 kph additional influx was required and this would have needed to continue or increase since then. Considering that the pressures are still significantly lower than initial pressures prior to production, it is certainly possible there are sources of recharge, from both shallow groundwater and laterally extensive aquifers that could provide the additional influx.

So, the question arises, why did the divergence in pressure occur and why was it only seen after 2013, considering that reasonable matches to the historical data had been obtained with both analytical and numerical models? We still don't know the answer, but it is a lesson to reservoir engineers and modellers that even with well-matched models, there will continue to be uncertainty in forecasting how a natural system will evolve.

1.0 INTRODUCTION

The Tiwi Geothermal Field is located on the northeast flank of Mt. Malinao in Albay Province, Philippines, approximately 220 miles (350 km) southeast of Manila and the steamfield is managed and operated by the Philippine Geothermal Production Company (PGPC). The field has a known productive area of 4.6 square miles (12 km^2) (Figure 1) and is divided into four geographic sectors: Naglagbong (Nag), Kapipihan (Kap), Matalibong (Mat) and Bariis (Bar). The area of focus for this paper is highlighted in Figure 1 and includes the Matalibong production sector and the MatRidge Hot Brine Injection System (MRHBIS), which includes the two injection wells located to the north.

The history of the Tiwi development and analysis of resource changes over time has been well documented in a number of previous papers (Alcaraz etal, 1989; Barker etal, 1990; Gambill and Beraquit, 1993; Sugiaman etal, 2004; Menzies etal, 2010a; Menzies etal, 2010b), including discussion of the many challenges that have occurred while managing this resource.

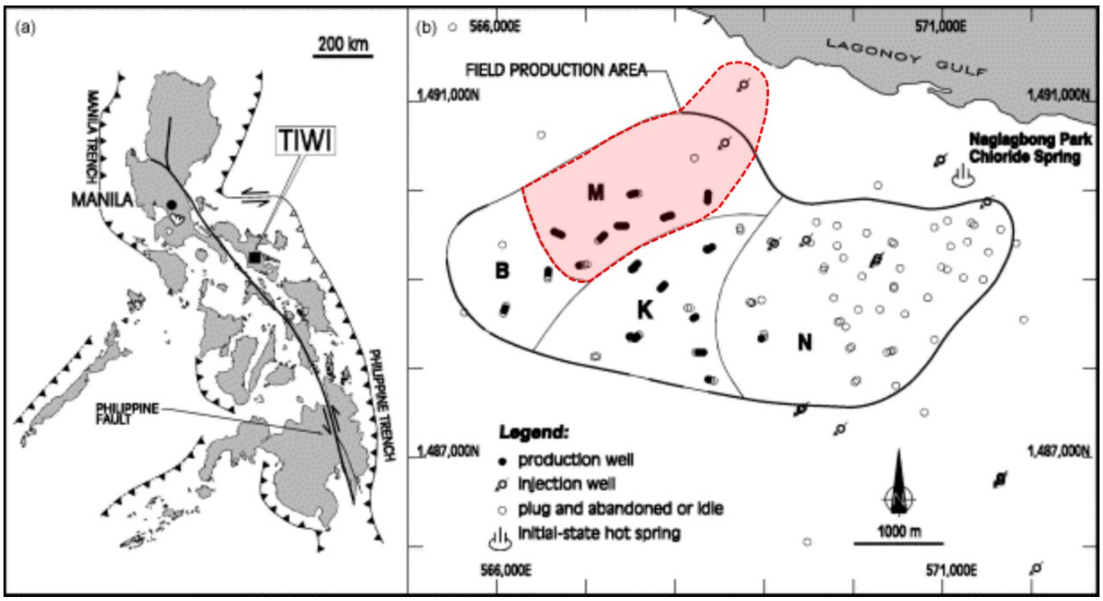

Figure 1: The Tiwi Geothermal Field and the Production Sectors (N=Naglagbong; K=Kapipihan; M=Matalibong; B=Bariis)

2.0 PRESSURE MONITORING IN MATALIBONG

The measurement and analysis of downhole pressure data is a very important component of a monitoring program in a geothermal reservoir that helps determine how it is reacting to production and injection, with the results being used along with other surface and sub-surface data to assist in understanding and managing the reservoir to maximize its potential.

Downhole pressure data have been monitored in Tiwi since production started in the 1970's but initially the data were obtained by running periodic downhole pressure/temperature profiles in available wells, using "Kuster" mechanical (KTG and KPG) survey tools and more recently, electronic PT or PTS tools. For "idle" wells, these surveys can be conducted on a regular basis but for active production wells, the surveys can only be run when the wells are shut-in, which does not occur very often. Hence, the number of surveys conducted on many of these wells over the years has been relatively small. However, by combining data from wells having similar responses, it has been possible to define the general pressure trends in the various sectors of the Tiwi field in response to production.

The available single survey pressure data from wells in the Matalibong sector of the field, which is the area of interest for this paper, are plotted in Figure 2 at an elevation of 2600 ftbsl (below sea level), which is within the deep liquid reservoir. Total field mass production, Matalibong mass production and Matalibong steam production (kph – kilopounds per hour) are also included and it can be seen that the pressures in Matalibong began to decline about 1982, even though at that stage, all of the production was coming from the Naglagbong (Nag) sector of the field (Figure 1). From 1982 to 1998, the pressure declined at approximately 50psi/year, resulting in significant boiling and formation of an extensive shallow steam zone covering most of the western production area, but particularly in the Matalibong area, where the majority of the wells were found to be producing superheated steam (Menzies etal, 2010b). The agreement between the Matalibong mass and steam production from the early 1980's to 2004 indicates that all of the production during that time was from steam wells. The pressure then stabilized and began to increase from about 2003 to 2005, at the same time as the mass and steam production started to deviate from each other, due to the start of two-phase or liquid production.

Continuous monitoring of the deep liquid reservoir pressure in Matalibong began in 2005 and over the past 20 years, four monitor wells (Mat-25, 29, 30 and 32) located within the production area have been utilized for this purpose, although Mat-29 was only used for a short time and the data are not included here. The downhole pressure is measured using capillary tubing installed in the observation well, connected to a chamber downhole. The tubing and chamber are purged with nitrogen and a pressure transducer/data logging unit is installed at the surface to measure and record the gas pressure, which is equivalent to the downhole pressure – the static pressure of the gas column. The system is simple and has generally proven to be reliable although there are gaps in the data due mainly to logistical issues. The measured data, corrected to a datum of 2600 ftbsl, are also plotted in Figure 2 and are consistent with the single survey measurements from other wells in the area.

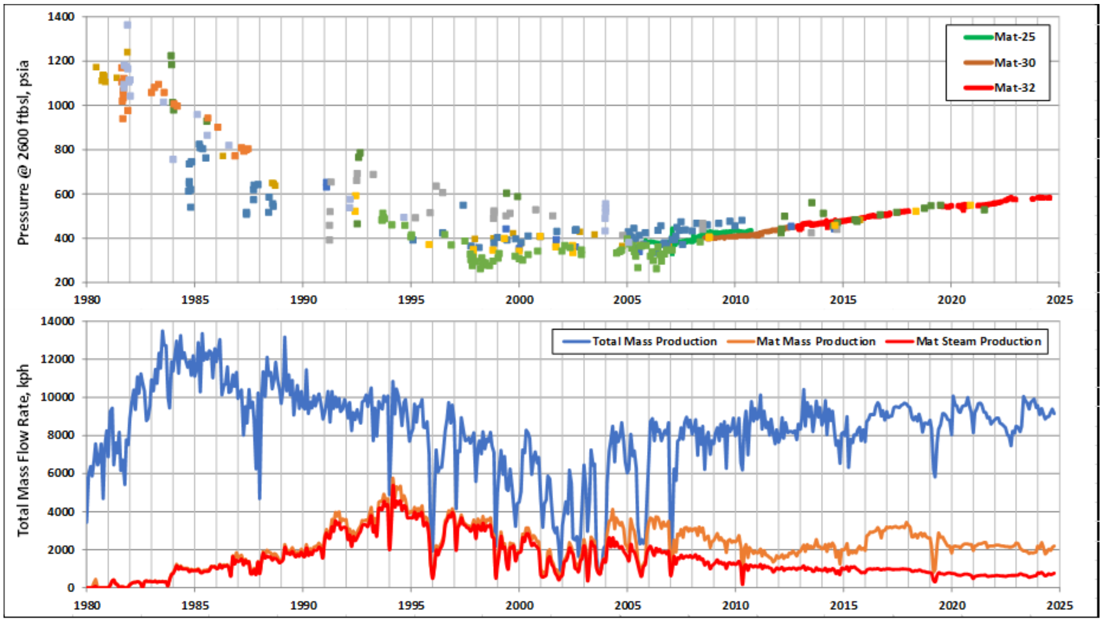

Figure 2: Measured Matalibong Pressure Data and Tiwi Production Flow Rates (1980 – 2024)

3.0 ANALYSIS OF PRESSURE DATA (2005 TO 2013)

Information on the collection and analysis of the downhole pressure data from 2005 to 2011 has previously been presented in Menzies etal (2011).

From 2005 to 2013, the collected data show the deep liquid reservoir pressure within the Matalibong production sector was generally increasing over time while short-term pressure changes were found to correlate well with injection flow changes to the two MRHBIS wells rather than changes in the production wells. The strong connection to the injection wells was unexpected, considering the observation wells are located within the production area and the injection wells are located 2 to 3 km to the north. Figure 3 provides examples of how short-term deep liquid pressure generally dropped when production wells were throttled or shut-in rather than increasing, indicating a stronger connection to injection. Note, however, that the shallow steam pressures did tend to react as expected to the production well changes.

In addition to the pressure data showing a strong hydrologic connection between the injection and production areas, there was also geo-scientific evidence (Calibugan etal, 2015) that further confirmed the interaction, including changes in production well chemistry and results from tracer tests, although there has not been any significant evidence of thermal breakthrough.

The pressure responses in the observation wells were analyzed and matched using the analytical and numerical modelling capabilities of the Saphir© Well Test Analysis software (KAPPA Engineering, 1990; Menzies etal, 2011) and the result for Mat-25 is shown in Figure 4, where the upper plot shows the match to the pressure data while the lower plot shows all the flow rate histories from the production and injection wells that were included in the analysis. It is appreciated that there are limitations regarding the use of this software for geothermal fields due to the assumptions of single phase, isothermal conditions, etc but it was felt that for this case of the deep liquid dominated reservoir, it would be reasonable to use for analyzing the noted interactions. Note also that it was possible to obtain similar matches using the fieldwide TOUGH2 numerical model of the Tiwi field.

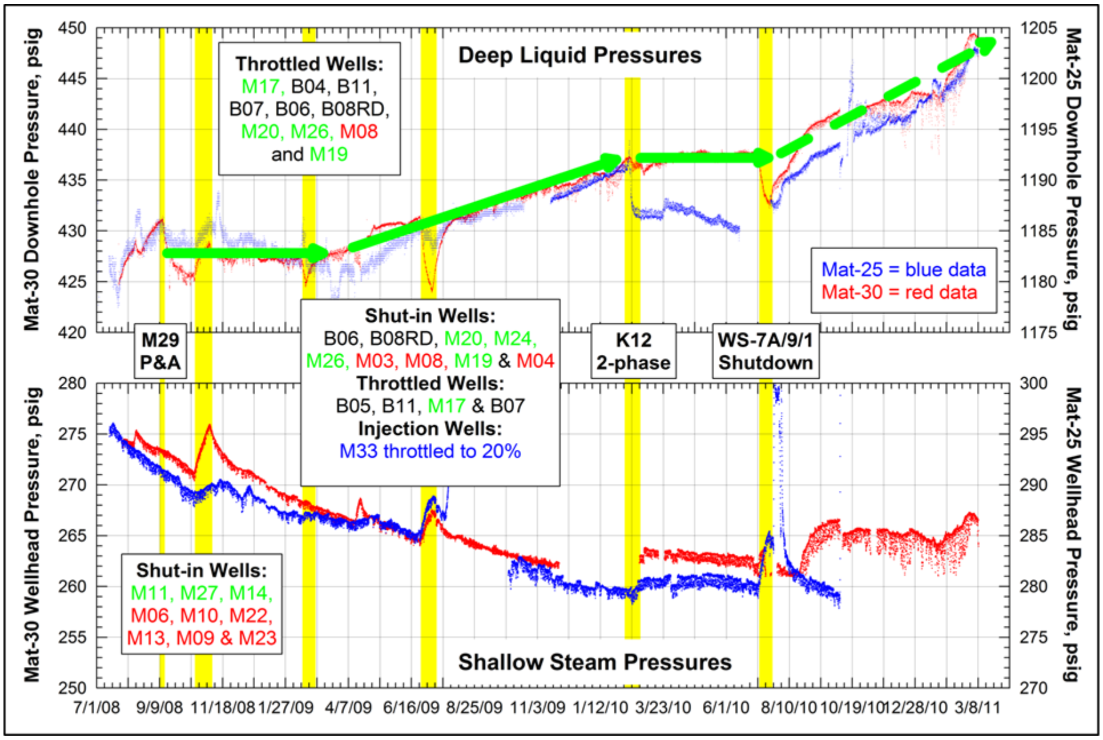

Figure 3: Deep Liquid and Shallow Steam Pressure Responses to Production Changes (2008 – 2011)

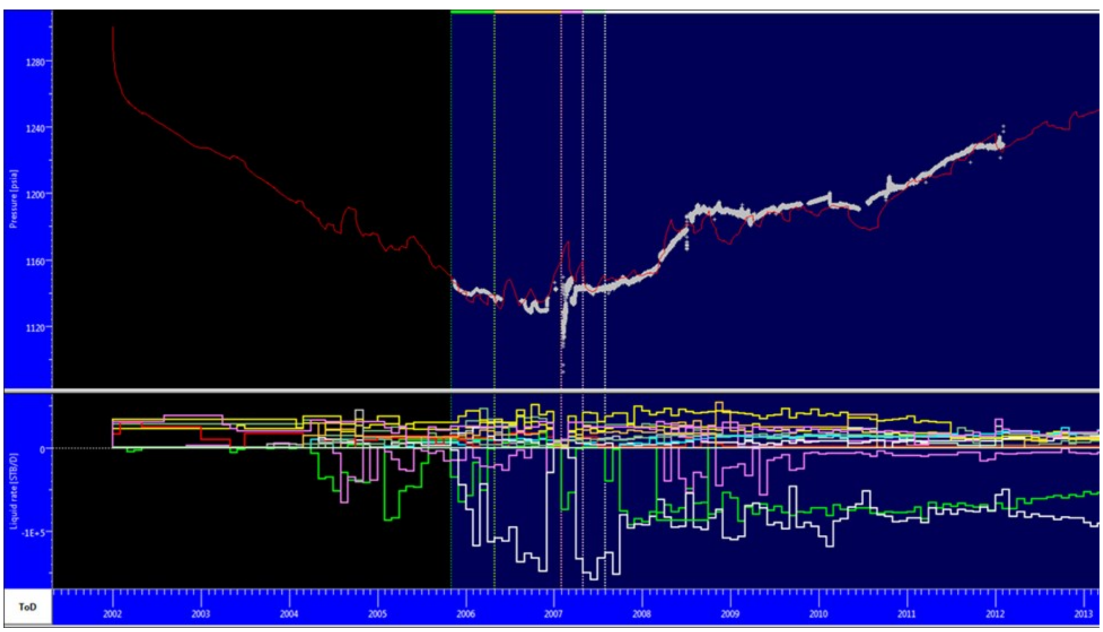

Figure 4: Analytical Model Match to Mat-25 Pressure Data Using Saphir© (2000 – 2013)

A major concern with the increasing deep pressure was the corresponding rise in the steam-liquid interface, which progressively infiltrated the shallow steam production zones, causing wells that previously produced superheated or saturated steam (Menzies etal, 2010) to produce at two-phase or liquid enthalpies, with the drop in enthalpy generally occurring as a step change. Calibugan etal (2015) estimated that the rise in the steam-liquid interface had resulted in a loss of ~60kg/s steam (~24MW) between 2004 and 2010. The rise has also been monitored using repeat micro-gravity surveys, which have shown a significant increase in gravity over the Matalibong area since 2003. This is interpreted to be in response to the change from steam to liquid dominated conditions as the steam-liquid interface has risen. The micro-gravity data is also used to improve calibration of the field numerical model.

With the noted correlations between pressure change and injection and the successful matching of historical pressure changes using both numerical and analytical modelling, it suggested that it should be possible to mitigate the rise in pressure and the steam-liquid interface by reducing injection to the MRHBIS, and this could also possibly resurrect steam production from some wells. To check if this was feasible, the Saphir© model was used to determine how the reservoir pressure would react to reduced injection, and it was estimated the injection rate would need to be reduced by at least 50% to stabilize and hopefully reduce the pressure (Figure 5). However, it was recognized that this would be a challenge as the injection system at Tiwi relies on gravity feed and the topography in the Bariis and Matalibong areas causes some limitations.

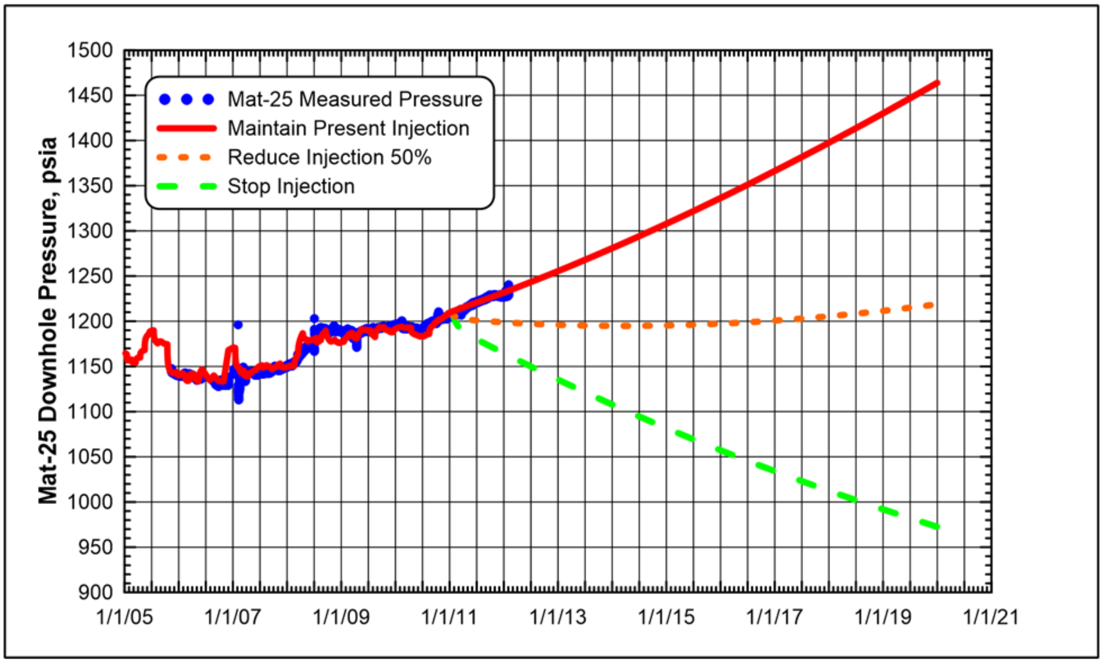

Figure 5: Saphir© Modelling of Pressure Changes in Mat-25 In Response to Injection Flow Changes

In addition to the modelling, a field test was conducted from March to August 2010 to determine what would happen if injection was reduced. During the field test, it was found that with the reduction in injection, the downhole pressure appeared to stabilize in Mat-30 and possibly declined in Mat-25, as shown in Figure 6 (Calibugan etal, 2015). In July 2010, a number of production wells were shut-in which then allowed one of the injection wells to also be shut-in and injection was reduced by more than 50%. In response, there was an instantaneous drop in downhole pressure in Mat-30, followed by an instantaneous rebound in pressure when injection was increased again in late July 2010. This further confirmed the hydraulic connection with the injection wells as if Mat-30 was being influenced more by the production wells that were shut-in, then the pressure responses would have been reversed. Injection was then increased and stabilized in August 2010 and downhole pressures in both observation wells began to rise again.

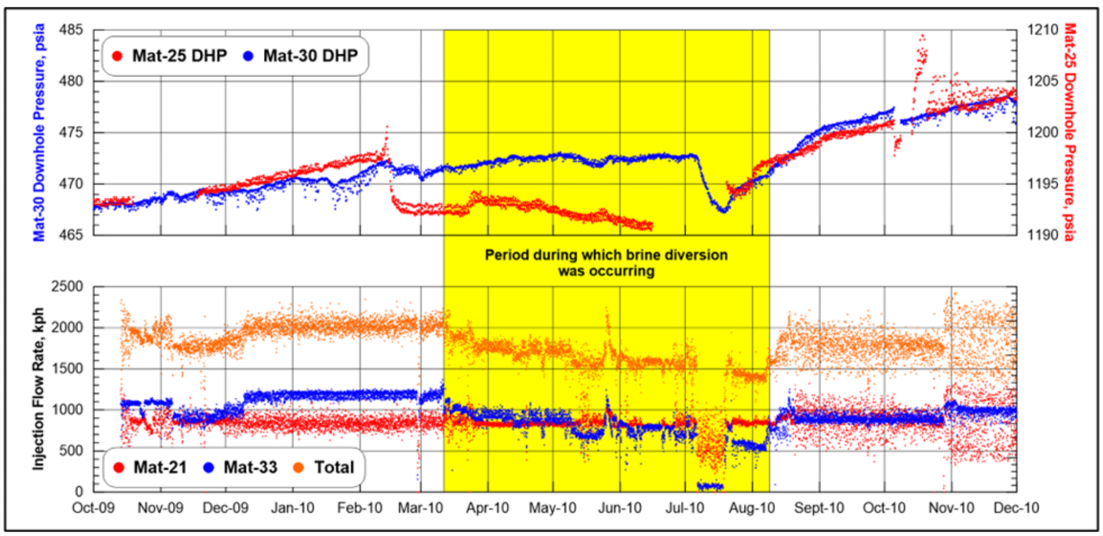

Figure 6: Results from Field Test to Check Effect of Reduced Injection on Deep Pressure (2010)

With the favorable results from the field test, combined with the modelling results, the decision was made to proceed with constructing a pipeline to divert separated brine from the Bariis sector to the SouthEast Hot Brine Injection System (SEBHIS) and thereby reduce the MRHBIS injection load. The pipeline was constructed in 2011-2012 and commissioned during July 2013.

4.0 ANALYSIS OF PRESSURE DATA (2013 TO 2024)

With the commissioning of the diversion line, injection to MRHBIS (Figure 7) was initially reduced from 1750kph to 1550kph in 2014 and then further decreased to 1000kph in 2015. However, it increased again to average 1750kph from 2016 to 2018, before declining to an average of 1200kph since 2019. Although it has been possible to reduce injection overall, it has never been to the desired 50% reduction for an extended period, due to operational issues with the diversion of brine to SEHBIS and also an increase in brine production from the Matalibong production wells, which must be injected to MRHBIS. Note also that deep production has also been consistently higher than injection since 2013, which is shown as a negative difference, and this should also have resulted in a decrease in downhole pressure in the observation wells.

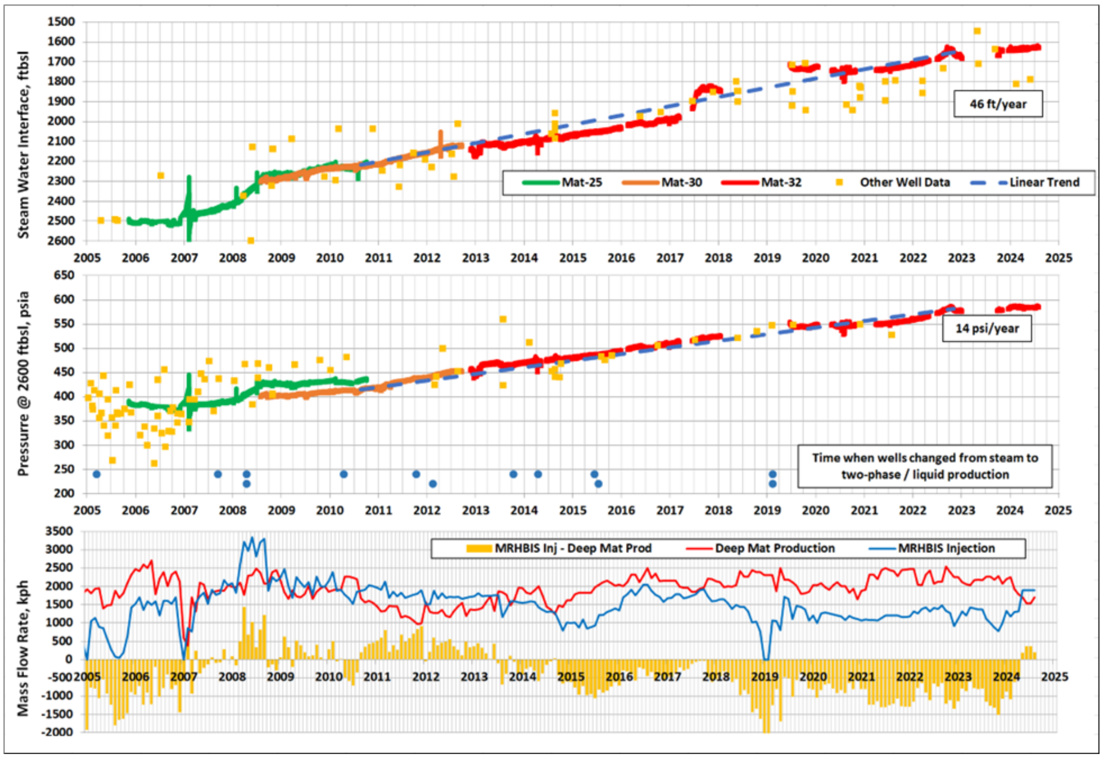

Figure 7: Steam-Liquid Interface, Reservoir Pressure and Production/Injection Flows (2005 – 2024)

Figure 7 shows that regardless of the changes to injection or production, the downhole pressure has continued to rise at a relatively uniform rate of 14 psi/year since about 2010, with a corresponding rise in the steam-liquid interface at a relatively constant rate of 46 ft/year. To confirm that the continuous observation well data truly reflect the changes in reservoir pressure and steam-liquid interface, data from individual well surveys are also plotted on Figure 7 and the data are consistent with the continuous observation well data. Also shown on Figure 7 are the dates when the Matalibong production wells changed from steam to two-phase / liquid production and the final two points are wells that produce two-phase fluid intermittently as these two wells have the shallowest production zones.

The continued increase in reservoir pressure at the same rate as previously observed was not the expected outcome, based on the earlier modelling and field test results. Additional analytical modelling was therefore conducted in 2019 to check how the pressure should have reacted to the changes in production and injection since 2013, based on the same modelling assumptions used previously. The results of that modelling for Mat-25 (Figure 8) confirmed that the deep reservoir pressure should have declined, even though the reduction in injection was not as high as desired. Similar results were obtained for the other observation wells.

The conundrum is then why had the pressure and the steam-liquid interface continued to rise. The most likely explanation is that there must be influx of additional fluid to the deep reservoir that has not been accounted for, and this has only become apparent after 2013. To help determine how much additional fluid influx is required to match the pressure responses, both analytical and numerical model runs were made and the results for one of the numerical model runs is shown in Figure 9. As shown, in order to obtain a match to the Mat-32 data, there needed to be a general increase from 700 kph in 2013 to 1,500 kph during 2015, with this remaining constant through to mid-2016. Considering the injection history since then, it is likely that continued influx of at least 1,500 kph would be required to continue to match the pressure data.

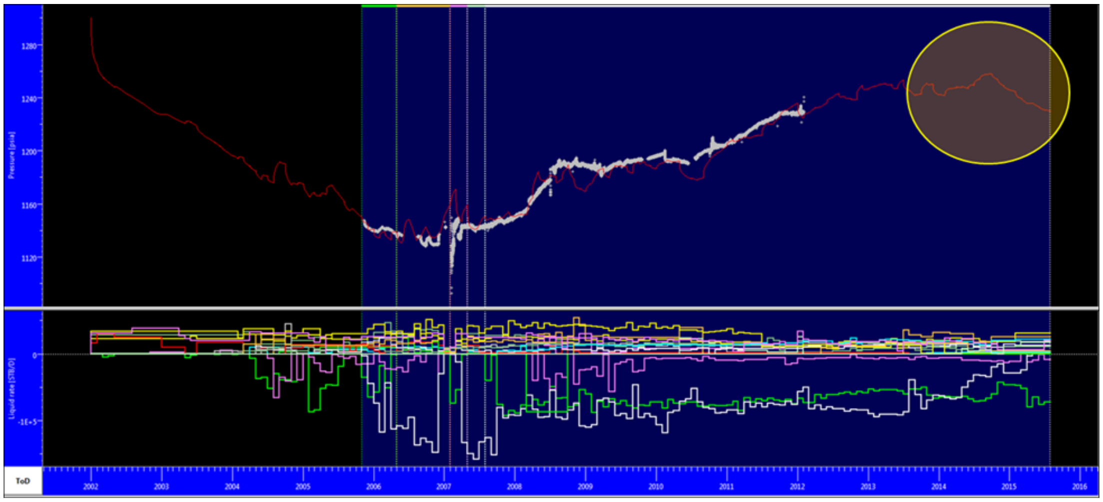

Figure 8: Analytical Model Match to Mat-25 Pressure Data Using Saphir© (2000 – 2016)

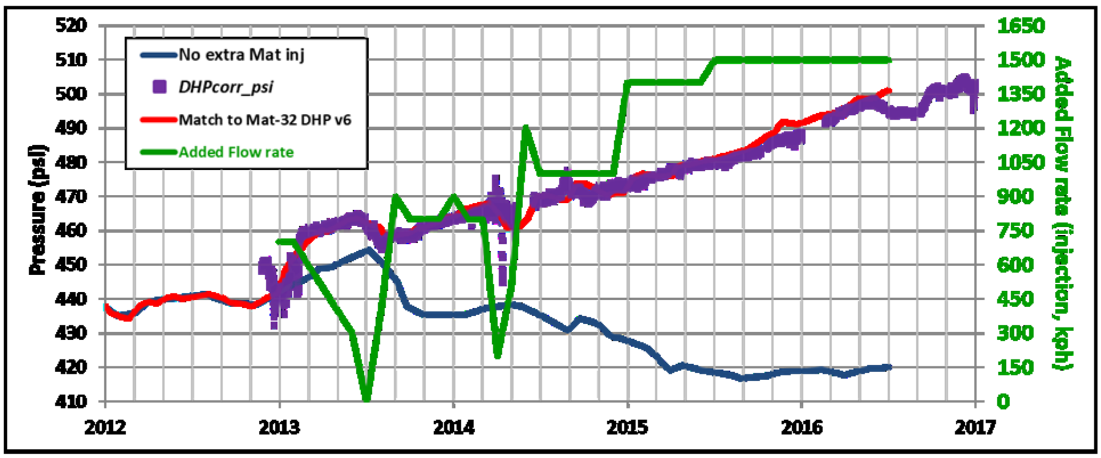

Figure 9: Additional Influx Requirement to Match Mat-32 Pressure Data (2013 – 2016)

Even with the increasing pressure, the present reservoir pressure is still significantly lower than the initial pressure prior to exploitation (Figure 2) and so there is still a significant potential for influx from surrounding fluid sources, such as shallow groundwater and more laterally extensive aquifers. Historic Tritium data has shown infiltration does occur into the Matalibong sector from shallow groundwater and this likely provided recharge to the wells when they were producing superheated steam as the well production decline rates were relatively low (Menzies etal, 2010b). However, the rate of influx could not have been too significant at that time, or it would have quenched the steam zone at a much earlier date. It is known that changes in fluid properties do have an effect on transmissivity and so the more recent changes from steam to liquid dominated conditions may be allowing additional influx to occur. This could also explain why the additional influx has only become apparent since 2013.

It is also possible that the original assumption in the modelling that the changes in pressure were mainly due to injection was not correct and maybe part or all of the increasing pressure trend was due to outside recharge sources and only the peaks and troughs in the measured pressure responses reflect the effect of injection changes. However, this would require that the transmissivity of the area would need to be significantly greater than the 33.5 Darcy.meters required in the analytical model (Menzies etal, 2011), which is already relatively high, and this would probably not be consistent with the productivity of the majority of the production wells. Note that the field wide numerical model includes an aquifer in the Matalibong area that was initially an outflow from the model and later changed to an inflow and so there is already a balance in that model between recharge and injection. However, the model does not include the influx from shallow groundwater mentioned above as it was not considered to be that significant. In view of the changes since 2013, it is apparent that further work is needed to see if it is possible to obtain a good match to the historical data by changing the balance between recharge and injection by modifying the models or adding additional recharge sources.

5.0 CONCLUSIONS

A wealth of information has been collected over the years in the Matalibong sector of the Tiwi field, including geochemistry, geophysics, downhole pressures and production data that show the MRHBIS injection wells are having some effect on the Matalibong production wells.

The major issue has been the increase in downhole pressure and associated rise in the steam-liquid interface, which has infiltrated the steam production zones and caused a decline in well productivity in many wells.

The good correlation between injection and pressure changes suggested it should be possible to mitigate the loss of production by reducing injection at the MRHBIS and this was confirmed by both analytical and numerical model results as well as results from a field trial.

Injection to MRHBIS was reduced starting in 2013 by diverting fluid from the Bariis sector to the SEHBIS injection wells but even with this reduction, the deep reservoir pressure has continued to rise in Matalibong, resulting in further productivity losses, while modelling has indicated the pressure should be declining.

The continued increase in pressure suggests there are additional fluid influx sources that have not been previously identified and only really started to affect the downhole pressure since 2013, with modelling indicating the rate of additional influx is now over 1,500kph. There are certainly potential influx sources from shallow groundwater and lateral aquifers but the reasons why this additional recharge started to occur after 2013 are unknown although it could be related to the change from steam to liquid dominated fluid conditions, which may have affected the transmissivity and allowed recharge to increase.

It is now apparent that the original assumption that injection was the main cause of the pressure changes was probably incorrect, even though good matches to the data prior to 2013 were obtained based on this model. Further work is therefore required to reconsider the balance between the effects of injection and natural sources of recharge in matching the historical data.

6.0 ACKNOWLEDGEMENT

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