

Early Identification and Management of Calcite Deposition in the Ngatamariki Geothermal Field, New Zealand

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Keywords: Reservoir management, reservoir surveillance, calcite scaling, Ngatamariki

ABSTRACT

The 82MW Ngatamariki geothermal power station started operating in 2013. Within a few months, two out of three in-service production wells were observed to decline faster than expected. A decline investigation plan using elements of the reservoir surveillance and monitoring program was carried out to investigate the cause of the decline and to plan the necessary tests. Investigation results identified calcite scaling in the wellbore as a main cause. The occurrence of calcite was not anticipated because pre-development assessment results found the calcite risk to be low. It was also found that a calcite saturation index (CSI) greater than 1 (oversaturated with respect to calcite) is not a reliable indicator to predict calcite deposition in Ngatamariki wells. The uncertainty in calcite deposition resulted in a broad approach to calcite management. It is recommended that additional work be carried out to improve the understanding of calcite deposition mechanisms, improve the design of downhole chemical injection system, and test calcite chemical inhibitors to optimise the calcite management plan.

1. INTRODUCTION

1.1 The Ngatamariki Geothermal Field

The Ngatamariki geothermal field shown in Figure 1 (Left) is located in the Taupo Volcanic Zone (TVZ) of New Zealand, surrounded by other important geothermal systems: Rotokawa to the southeast, Ohaaki to the east, and Orakei-Korako to the north (Chamberfort et al., 2016). It currently supports an 82 MWe (net) binary power plant operated by Mercury under a 60,000 tonnes per day geothermal resource consent awarded to the Rotokawa Joint Venture Ltd. (RJVL). The Ngatamariki geothermal field and power station were commissioned in 2013 and has been in operation for nearly four years. It has four production wells (NM5, NM7, NM11, and NM12) and five injection wells (NM4, NM6, NM8, NM9, and NM10) as shown in Figure 1 (Right).

The production wells tap a reservoir that is in a compressed liquid state, with reservoir temperatures of about 275-290°C and composed of generally near-neutral dilute chloride waters (Boseley et al., 2010). Near-boiling conditions have been observed around the outflow area (NM2 in Figure 1, right) but this area is currently not produced. Nearly all the produced fluid is re-injected back into the deep injection wells to manage the reservoir pressure drawdown, as the plant makes use of a binary plant. A comprehensive reservoir surveillance and monitoring plan is in place to observe the reservoir response to production and to identify emergent risks.

1.2 Reservoir Surveillance and Monitoring

The Ngatamariki reservoir surveillance and monitoring program is composed of surface and subsurface data gathering activities carried out either periodically or continuously. The reservoir surveillance activities include continuous production monitoring combined with regular tracer flow testing (TFT) to monitor production trends. It also includes geochemical analysis of produced liquid and steam to understand geochemical trends and infer reservoir processes that are happening in the geothermal system. Reservoir pressure is monitored continuously through a permanent pressure transmitter connected to downhole pressure tubing in a deep monitoring well and periodically through downhole pressure logging. Reservoir enthalpy is monitored through downhole temperature logging, regular TFTs, and with geothermometers calculated from geochemical sampling.

The reservoir surveillance and monitoring data sets are correlated and analysed by a multi-disciplinary team to ensure that the conceptual model of the reservoir processes is consistent with all data sets and that complex reservoir processes are well understood. Using this approach, notable changes to well performance and reservoir responses are recognized early, the reservoir management strategy is adjusted accordingly, and the field response to the changes in strategy are monitored and well understood.

1.3 Emergent Issue

Within the first few months of power plant and field commissioning, the reservoir surveillance and monitoring data indicated production decline in two wells, NM5 and NM11. The decline rates were estimated to be as high as 75% per year, following an almost linear decline curve. Potential generation losses due to declining production in two production wells required urgent identification of the decline mechanism and implementation of suitable mitigation measures to minimise generation losses.

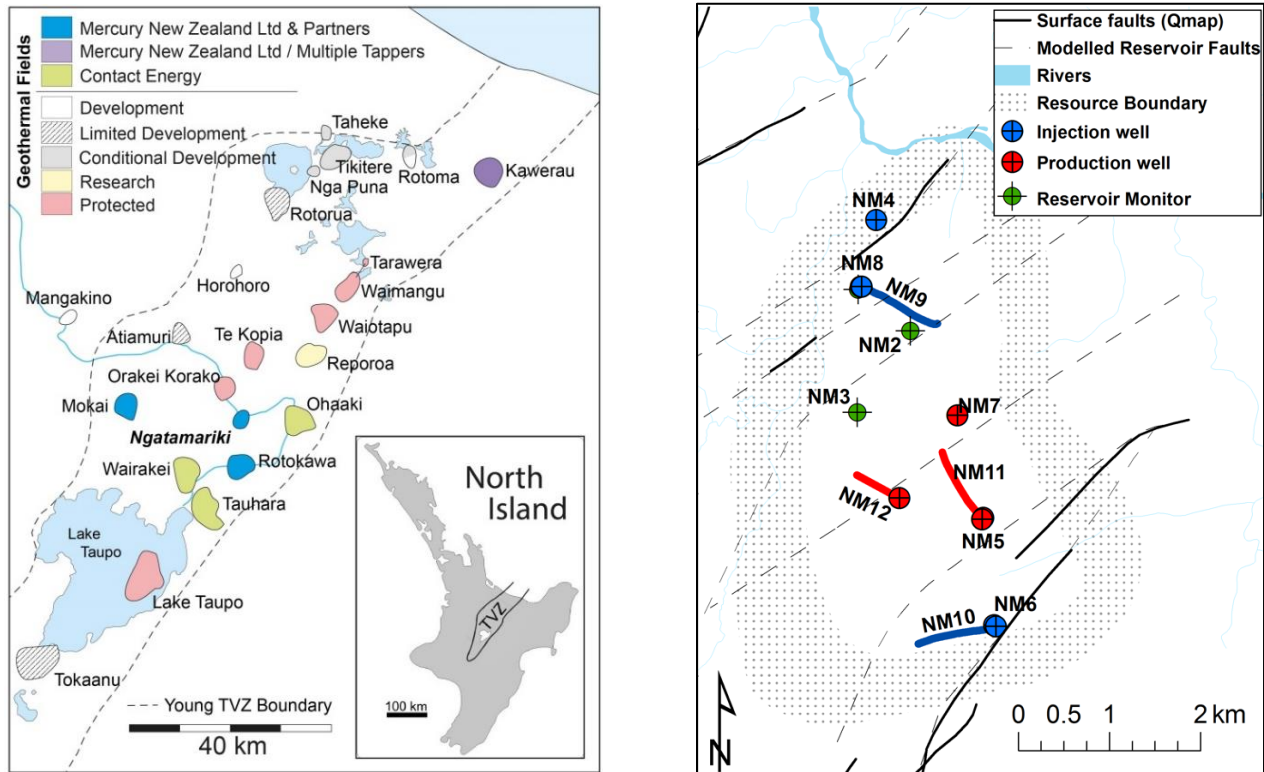


Figure 1. Left: Location of known geothermal fields in the Taupo Volcanic Zone (TVZ) on the North Island of New Zealand as identified by Schlumberger resistivity surveys (Bibby et al., 1995). The Ngatamariki field is shown in bold. Right: Ngatamariki geothermal field layout.

2. DECLINE INVESTIGATION AND RESULTS

An investigation plan was implemented (Figure 2), using elements of the reservoir surveillance and monitoring program, to test a number of production decline mechanisms. The transient state of the reservoir during the first year of field operation adds to the complexity of identifying the main decline mechanism. In this light, three decline mechanisms were investigated:

- Wellbore process (wellbore blockage)
- Near-wellbore process (permeability/skin damage)
- Reservoir-wide process (reservoir pressure decline)

The following sections discuss the relevant investigation results that led to identifying wellbore blockage by calcite scale deposition as a decline mechanism affecting NM5. A similar decline investigation plan was also carried out in NM11 with similar conclusions. The NM11 investigation results are not presented here.

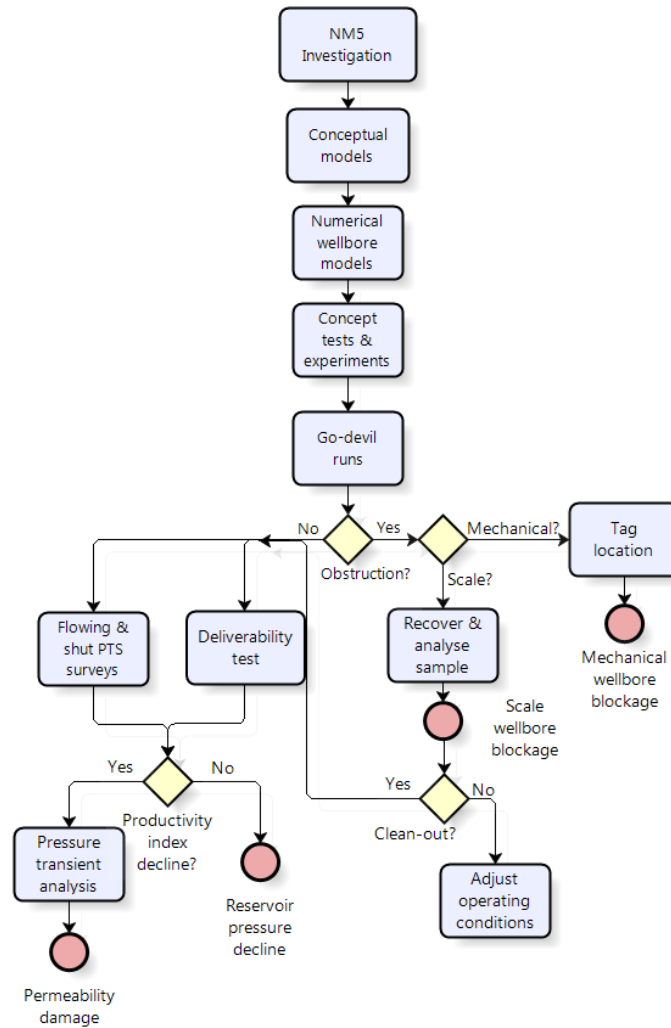


Figure 2. NM5 decline mechanism investigation plan

2.1 Numerical wellbore models

The decline mechanisms were initially investigated using numerical wellbore models. A baseline wellbore model calibrated with the original flow performance of NM5 was used to determine the required conditions for wellbore blockage, near-wellbore permeability damage, and reservoir pressure drawdown mechanisms that matched the observed decline. These results are shown in Figure 3 and summarised below.

- For wellbore blockage, a 90% reduction in the wellbore diameter available to flow
- For permeability damage, a 95% reduction in the feed zone productivity index
- For reservoir pressure drawdown, an 80-85 bar reservoir pressure drawdown

With the required wellbore and reservoir conditions known, the relevant reservoir surveillance data sets were closely monitored and additional data gathering activities were carried out to confirm the wellbore and reservoir conditions around the affected wells.

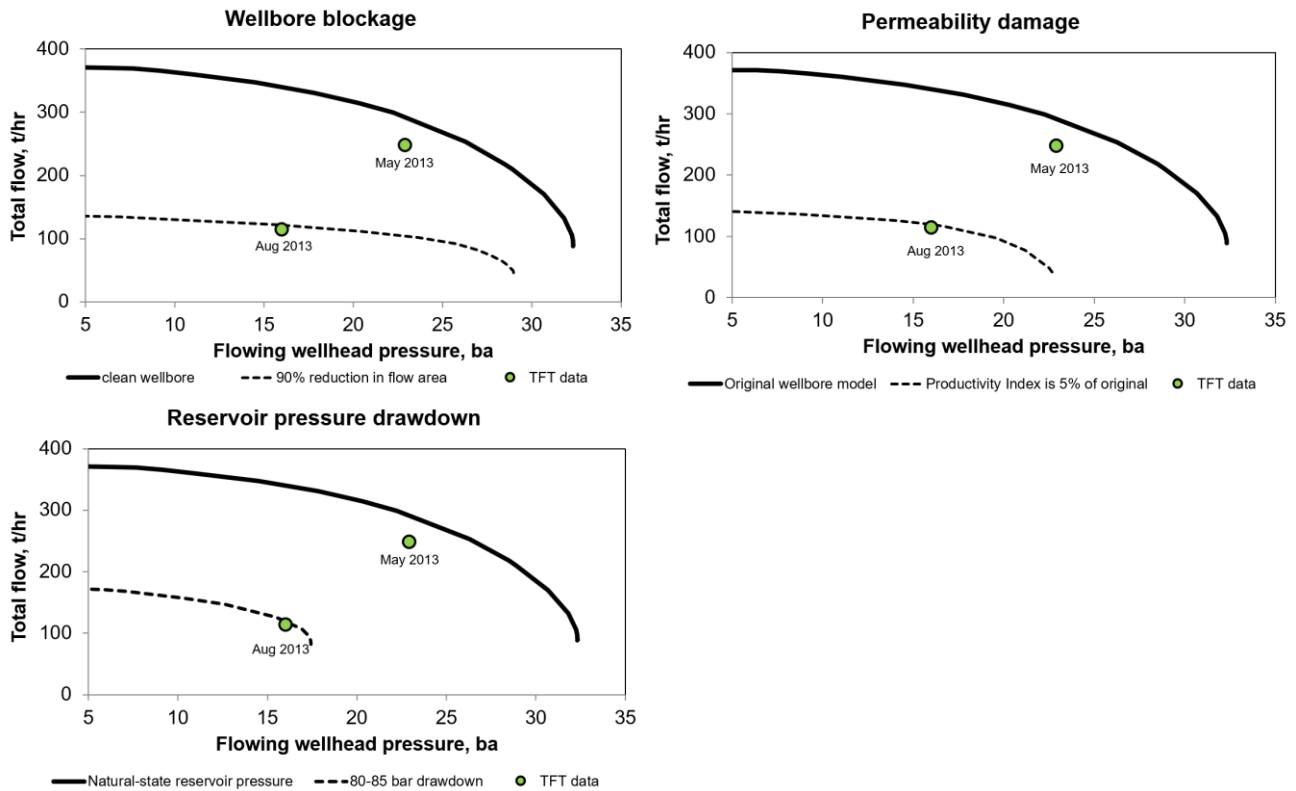


Figure 3. Wellbore model output curves generated using model conditions matching the observed production decline in 2013.

2.2 Relevant reservoir surveillance and monitoring information

Calcite saturation index

Wellbore blockage and permeability damage could be caused by calcite scale deposition. The calcite saturation index (CSI) is the main geochemical indicator used to monitor the reservoir fluid potential to precipitate calcite upon boiling. The CSI was calculated using WATCH 2.4 (ISOR, 2013). In 2013, the CSI data showed a slightly oversaturated index for all the Ngatamariki production wells, similar to the pre-2013 baseline CSI data. Calcite scaling is possible but the risk is similar in both declining and non-declining production wells.

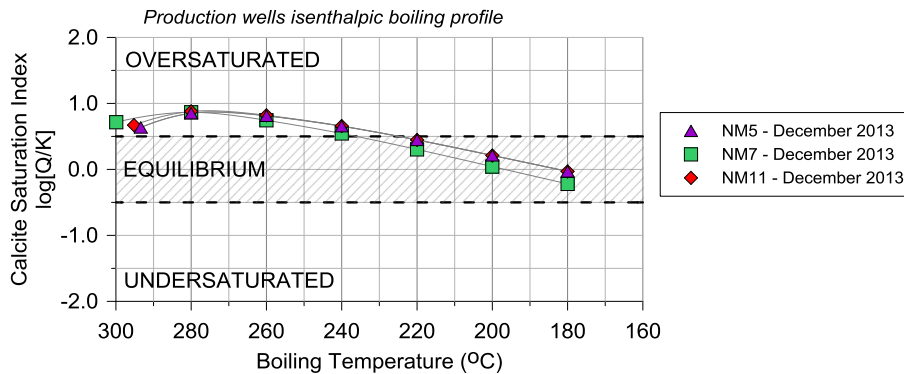


Figure 4. Calcite saturation index (CSI) monitoring in Ngatamariki

Reservoir pressure drawdown

The Ngatamariki reservoir pressure drawdown in 2013 as observed at monitoring well NM2 is around 2 bars (Figure 5), less than the required 80-85 bar reservoir pressure drawdown condition. Reservoir pressure drawdown is deemed an unlikely mechanism unless NM5 is located in a reservoir pressure compartment or is affected by severe well-to-well pressure interference.

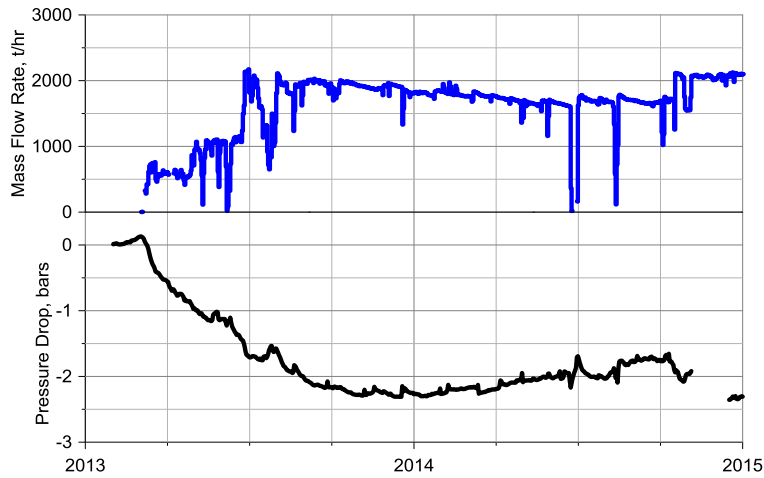


Figure 5. Continuous downhole pressure monitoring showing the reservoir drawdown in response to field start-up

2.3 Downhole surveys

Downhole surveys were carried out to determine the actual wellbore condition and compare it to the wellbore model conditions that matched the decline. A shut-in pressure, temperature and spinner (PTS) survey was also planned to determine the reservoir pressure in the NM5 area to rule out or confirm the presence of a reservoir pressure compartment in the area.

The first test conducted was a downhole ‘dummy’ run in NM5 with a 2.25-inch attached “bullnose” to verify the wellbore clearance. The dummy run tagged an obstruction inside the wellbore and could not reach the original depth of the well. The downhole tool was used to tag the obstruction and it left light-coloured marks on the bullnose, indicating scale.

A PTS survey under flowing conditions was carried out along the wellbore and down to the obstruction depth. The PTS results showed that the fluid flash point is found near the tagged obstruction. Calcite scale, a material that is light-coloured and thought to deposit at or near the fluid flash point could be the tagged obstruction, partly blocking the NM5 wellbore and resulting in production decline. Following the decline investigation plan, scale samples were recovered from the wellbore (Figure 6) and were sent to GNS Science for quantitative XRD analysis. The samples were found to be pure calcite.



Figure 6. Calcite scale material recovered from the well (bailer tool diameter: 1.5”)

2.4 Calcite scale cleanout

The calcite blockage was mechanically removed using broaching tools run on wire line. After successful broaching removed the majority of the calcite inside the wellbore, the recovered wellbore clearance was confirmed by running gauge-rings and by successfully running the maximum broach diameter down to the original well depth. The productivity of the well improved after the cleanout but was observed to be producing less than the expected capacity after blockage removal. The next steps in the investigation plan were carried out to determine if there are other decline mechanisms affecting NM5.

2.5 Deliverability test and repeat downhole surveys

The downhole surveys were required to verify the effects of near-wellbore and reservoir-wide processes to the well's decline, in addition to wellbore calcite scaling. PTS surveys at shut-in and flowing conditions were carried out to determine the reservoir pressure in the area and to determine the feed zone condition of NM5. The flowing PTS was carried out at the same flowing wellhead pressure as the 2009 PTS survey to better identify the key changes to well performance.

The shut PTS results showed that the reservoir around production well NM5 has good pressure support, with minimal (less than 0.5 bars) pressure drawdown from 2009. This pressure drawdown is less than the pressure drawdown observed in monitoring well NM2 and significantly less than the required 80-85 bar pressure drawdown to match the numerical wellbore model. The reservoir pressure drawdown decline mechanism, either through reservoir compartmentalisation or severe well-to-well interference, is not a major contributor to the well's production decline.

The flowing PTS results showed that the difference between the 2009 and 2013 production performance is due to decreased contribution from the deeper feed zone of NM5. There is a noticeable reduction in the flowing wellbore pressure between 2009 and 2013 at a similar flowing wellhead pressure (Figure 7). Noting the minimal reservoir pressure drawdown in NM5, the reduction in flowing wellbore pressure indicates a reduction in pressure differential to drive the flow from the reservoir, through the deeper feed zones and into the wellbore.

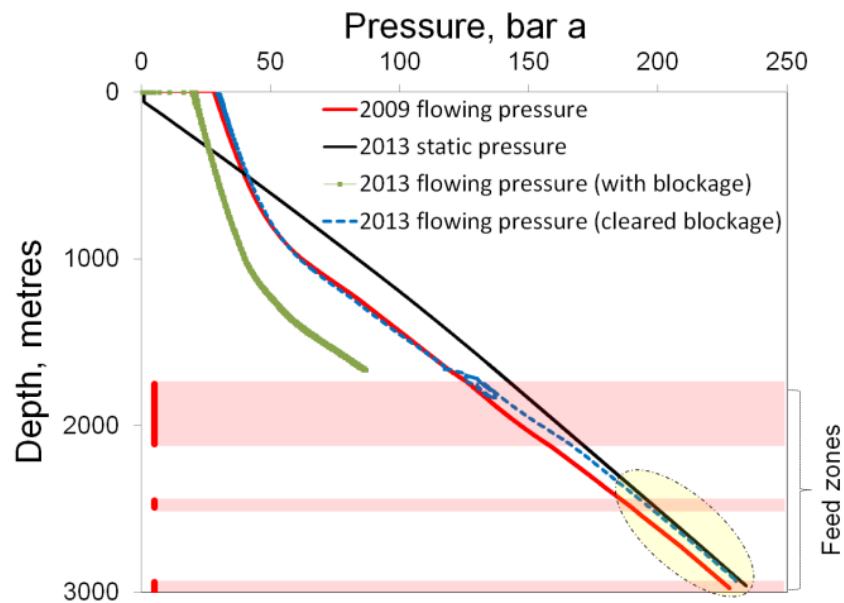


Figure 7. Flowing pressure profile showing reduced differential pressure at the deeper feed zones. Change in pressure gradient is due to non-flowing zones versus change in wellbore fluid temperature. Feed zones are shown in red with colored banding across the profile.

2.6 Investigation conclusions

Results of the investigation showed that both wellbore calcite scaling and reduced contribution from deeper feed zones were responsible for the declining performance in production well NM5. The decline in deep feed zone performance could not be directly explained by calcite scaling because the flash point depth is located higher in the wellbore. Results of the investigation in production well NM11 also confirmed the presence of calcite deposition partially blocking the wellbore. Production well NM7, while producing at a stable flow rate, was considered at-risk due to similar CSI levels with NM5 and NM11.

These results highlight that there is a possible field-wide risk of calcite scaling in Ngatamariki even though the pre-development calcite risk was assessed as low. This prompted a review of available pre-development information, calcite deposition indicators, and deposition mechanisms to improve the ability to forecast calcite risk in the future.

3. REVIEW OF CALCITE RISK INDICATORS

Information review showed that while the presence of calcite in the reservoir has been noted in some studies (e.g. SKM, 2000, Boseley et al., 2010, Horton et al., 2012, Chambefort et al., 2016), the potential for calcite scale deposition under development was not identified as a significant risk. Early samples collected in the Ngatamariki wells showed slight undersaturation with calcite or close to saturation, with little potential for scaling upon boiling.

In 2010, production well NM7 was flowed for more than a year to test a variety of power plant designs (Addison, 2010) and displayed no evidence of calcite scaling such as production decline, wellbore diameter reduction or presence of scales. The reservoir fluid gas content is relatively low as well, which reinforced the idea that the reservoir chemistry would not deposit calcite upon boiling. Production well NM7 has a production capacity of around 44MW (1050 ton/hr at 1240 kJ/kg). At this point, the plan for production well NM11 was to tap the reservoir area near NM7 to produce fluids of similar geochemistry. Production well NM11 was designed to produce at a higher production capacity than NM7.

Given that the historical assessments were inconclusive and with no clear evidence for calcite deposition in 2010 prior to full production in 2013, calcite scaling was not considered a significant enough risk to the Ngatamariki development to prompt the investment in the installation of a calcite anti-scalant system.

However, the subsequent geochemistry data collected after full-field production in 2013 showed that all the production wells have high calcite scaling potential (Figure 8 A). This suggests that calcite scaling is either a response to production or the historical data set is unreliable. With a reservoir pressure drawdown of less than 2 bars and full re-injection of produced fluids, the reservoir stress is minimal and no reservoir boiling process has been observed. If calcite scaling is a response to production, it is likely due to a fluid mixing process driven by the 2 bar reservoir pressure drawdown and the general transient state of the reservoir. If the calcite scaling risk was always present, this suggests that the CSI is not a reliable indicator of calcite scaling in Ngatamariki. While pre-development CSI data were less precise than subsequent CSI data gathered during operations, the presence of high CSI fluids did not result in calcite deposition in all wells but kept the risk level high.

At present, while calcite scaling is confirmed in production wells NM5 and NM11, it is not observed in production well NM7 and new production well NM12 even though all the production wells have similar CSI levels. This indicates that CSI might not be the only factor to consider in predicting whether a well will suffer from calcite deposition.

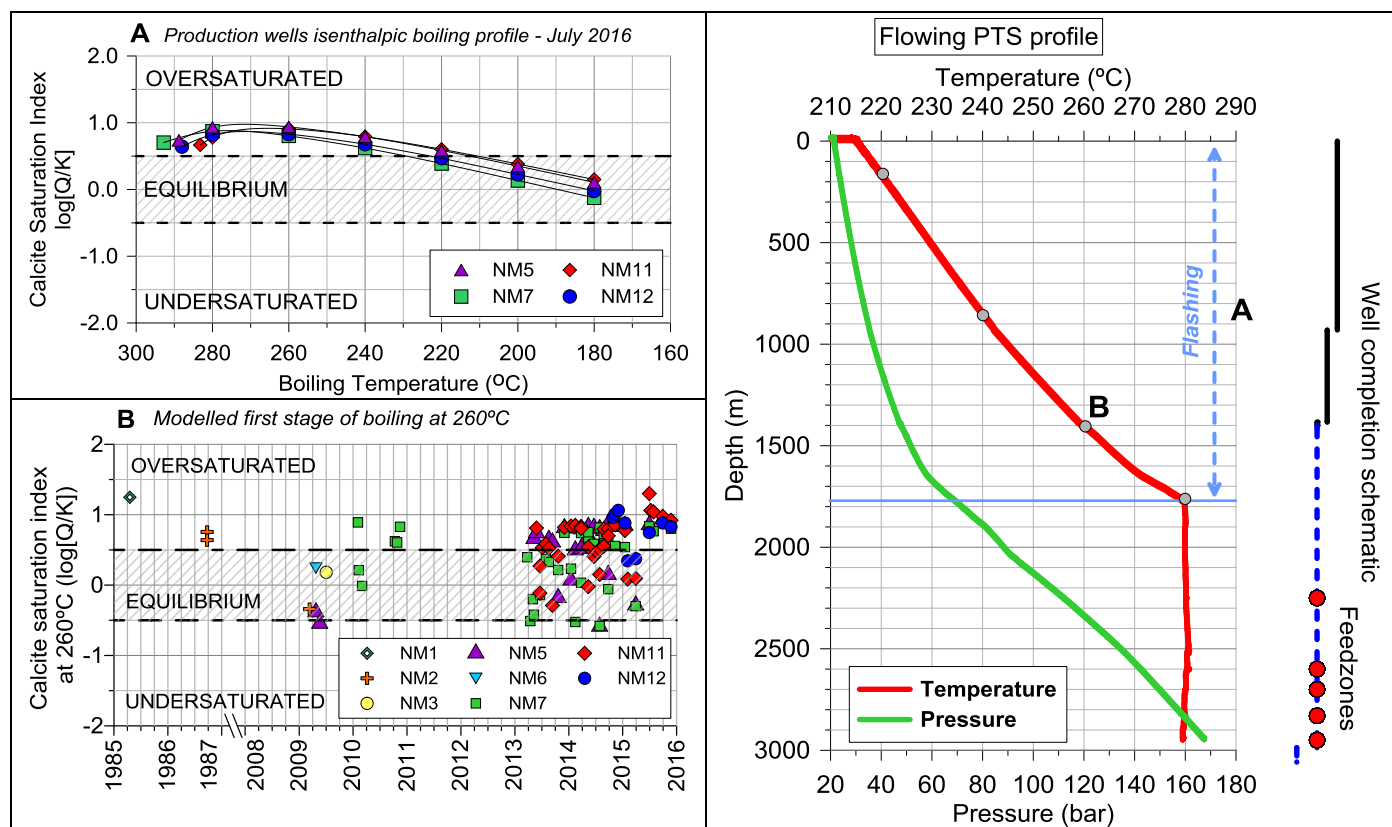


Figure 8: Representation of the calcite scaling potential upon boiling in the Ngatamariki production wells. PTS profile and well completion are taken from NM11 (as of December 2014) for illustration . A: CSI for a fluid subjected to isenthalpic boiling with single-step steam separation in 10°C decrement, from reservoir temperature to 180°C, corresponding to the temperature distribution A on the PTS profile. B: CSI time-series for the first boiling step (260°C), corresponding to point B on the PTS temperature profile.

4 CALCITE DEPOSITION MECHANISMS AND OTHER FACTORS THAT COULD INFLUENCE CALCITE DEPOSITION

In a producing geothermal well, degassing of the dissolved CO₂ of the fluid at the flash point induces calcite deposition according to the following reaction:



The above process is believed to be the dominant calcite deposition mechanism in geothermal production wells. As such, the generic calcite management plan involves monitoring the chemistry of the brine and steam, use of chemical inhibitors to impede calcite formation or if calcite formation is unavoidable, flash point location control to move calcite deposition away from the feed zone locations and into the more accessible cased sections of the wellbore.

The absence of calcite scaling in production wells NM7 and NM12 while producing high CSI fluids suggest that there are other factors influencing calcite deposition in Ngatamariki. These factors are currently subject of an ongoing study and include a review of differences in surrounding geology, influence of marginal fluids in some wells but not others, and differences in fluid dynamics along the wellbore to name a few. The uncertainty in identifying wells that will deposit scale resulted in a broad approach to calcite management.

5. RESERVOIR MANAGEMENT IMPLICATIONS

A variety of calcite management techniques are used to manage the effects and mitigate the risk of wellbore calcite scaling. Their effects on the productivity of NM5 and NM11 are shown in Figure 9. While both wells appear to improve their decline rates and extend their commercial lives, there is still a background decline that needs to be addressed.

Uncertainty in calcite scale occurrence resulted in proactive installations of anti-scalant injection systems even into wells with no confirmed calcite deposition, including new production well NM12. While the anti-scalant system improved the decline in calcite affected wells like production well NM11, it had reliability issues under the high velocity and variable flow conditions in production well NM7. The anti-scalant injection system in NM7 was exposed to variable flows of 800 to 1100 ton/hr. Also, the injection of chemical inhibitors appeared to negatively affect the performance of the preheaters in the power plant.

These issues could be better managed if a more appropriate and optimised calcite management plan is developed. An optimised management plan will only be possible through improved understanding of the calcite deposition mechanism and the factors that affect calcite deposition in geothermal wellbores.

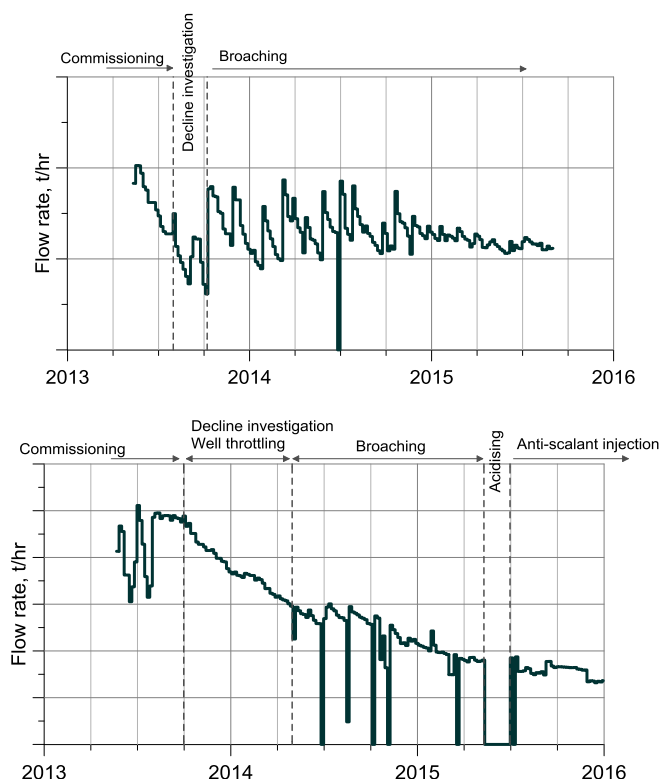


Figure 9. NM5 (Upper) and NM11 (Lower) production performance with calcite management

5. CONCLUSIONS AND RECOMMENDATIONS

There are three main conclusions from the Ngatamariki geothermal field experience presented in this paper:

1. Reservoir surveillance and monitoring activities in place prior to field commissioning was effective in the early detection of production decline in Ngatamariki wells during the transient state of the reservoir
2. An investigation plan that used elements of the reservoir surveillance and monitoring program identified calcite as a main component of production decline
3. The calcite saturation index (CSI) of the produced fluid indicating oversaturation with respect to calcite (CSI >1) is not a reliable indicator to predict calcite scaling at Ngatamariki

It is recommended that further studies into calcite deposition mechanisms in geothermal wellbores, anti-scalant tubing design and chemical inhibitors be carried out to improve and optimize calcite management practices. Calcite deposition mechanisms that are unrelated to boiling/flashing is of particular interest. Anti-scalant tubing design study for variable flow and high flow velocity wells are also encouraged. Developing or identifying chemical inhibitors that are effective in preventing wellbore calcite deposition with no adverse effect on the power station performance is also recommended.

ACKNOWLEDGEMENTS

We would like to thank Mercury and the Rotokawa Joint Venture (Mercury and Tauhara North No.2 Trust) for allowing us to share these results. We would also like to thank Western Energy Services and GNS Science for technical services rendered in the course of these field investigations.

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