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Mahanagdong Reservoir Response to the Termination of Infield Cold Reinjection

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ABSTRACT

The Mahanagdong geothermal resource has been continuously extracted to provide steam supply to the power plants since their commissioning in 1997. The resource experienced natural decline attributed to pressure drawdown, cooling and wellbore scaling for its 26 years of utilization. One of the main drivers of the Mahanagdong steam production decline was the reservoir cooling caused by the infield cold reinjection due to the limitation of both hot and cold brine/condensate conveyance to the distant reinjection pad. The condensate lines were upgraded as well as the maximization of the hot brine injection main line thereby reducing the dumped brine and transferring the cold reinjection outfield. Thermal recovery was observed after the termination of infield cold reinjection but led to an aggressive wellbore scaling as an outcome. The mixing of reservoir fluid with metal-ion and HCO3-rich peripheral water that encroached the production sector promoted the wellbore scale formation upon boiling. Treatment program using polymeric scale inhibitor is applied to address the wellbore scaling and the use of metal ion dispersant will also be tested in the field to inhibit the metal-bearing mineral scale formation.

1. INTRODUCTION

The Mahanagdong Geothermal Field is one of the two distinct resources located in the southern section of the Greater Tongonan Geothermal Field as shown in Figure 1. The field has been continuously utilized and developed since the commissioning of the 3-unit power plant operations with optimization plants in 1997. This is divided into two sectors: (1) Mahanagdong-A operating 2x60 MWe condensing turbine plant and 2x6.4 MWe topping cycle plants (2) Mahanagdong-B operating 1x60 MWe condensing turbine and 1x6.4 MWe topping cycle plant. Several geothermal wells have been drilled but some are offline due to the adverse impact of different reservoir processes. Around 30 production wells supply steam to the power plants while 11 wells are dedicated as reinjection accepting condensates, hot brines, and thermal pond mixed fluids.

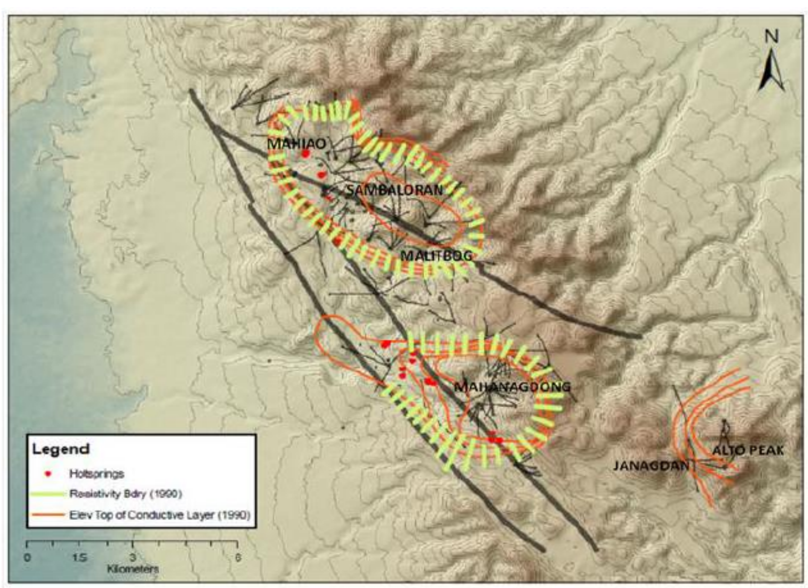

Figure 1: Resource boundaries of Mahiao-Sambaloran-Malitbog and Mahanagdong geothermal systems. Layugan et al. (1990)

The continuous mass extraction in Mahanagdong as shown in Figure 2 encountered natural decline attributed to pressure drawdown, reservoir cooling and wellbore scaling. There were a lot of challenges faced in the sustainability of the resource to operate the power plants for 26 regenerative years. One of these challenges is the emerging issue anchored in resolving the major decline driver.

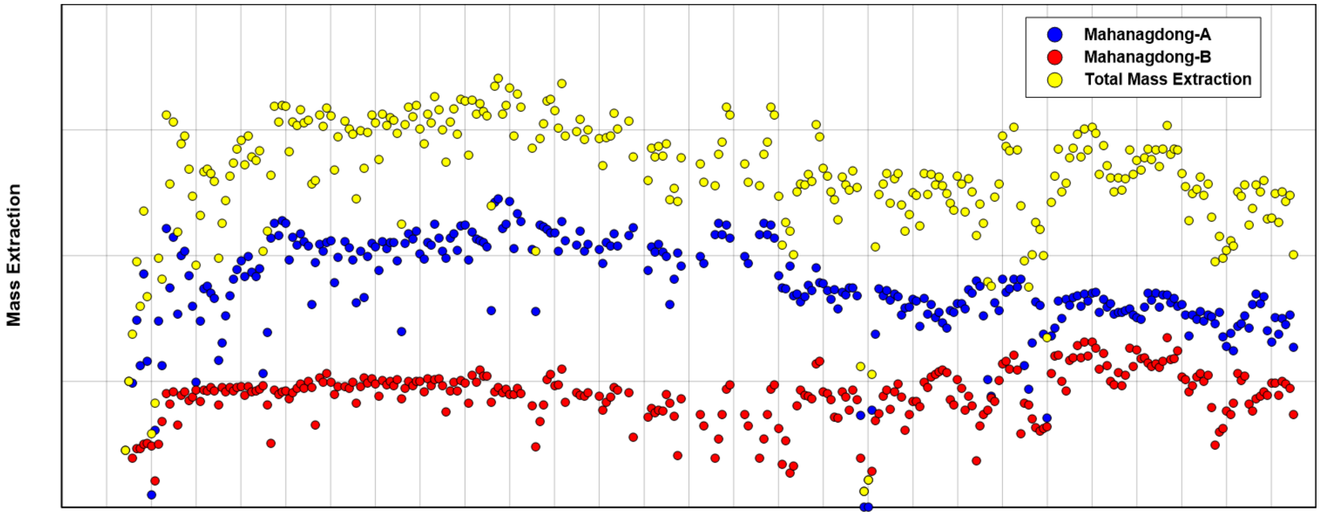

Figure 2: Mahanagdong mass extraction from 1997 to 2023.

This paper focuses on the resource re-assessment in understanding the aggressive wellbore scaling experienced in Mahanagdong resource as response to the termination of the infield injection. The reinjection management aimed to recover the high output decline and collapse of production wells attributed to reservoir cooling.

2. MAHANAGDONG RESERVOIR RESPONSE TO RESOURCE MANAGEMENT STRATEGY

The Mahanagdong geothermal reservoir is composed of a deep geothermal system overlain by a shallow cold claycap at the northwestern section of the field. Reservoir pressure drawdown is pronounced in the mid-section of the resource within the long-term production that would be favorable for the inflowing fluids from the pressurized reinjection sinks and the cooler peripheral waters from the northwest area. This preferential flow and entry of cooler fluids caused the decline in fluid enthalpy and reservoir temperature in some production wells leading to constraints in the steam production field. Gonzalez et al. (2005).

2.1 Cooler peripheral incursion and infield cold reinjection

A production well located towards the northwestern part of the field was temporarily utilized as a reinjection well in 1995 accepting well discharge fluids until pre-commissioning of the power plants then condensate reinjection well during the commissioning and operations. It is situated near the cooler peripheral water source in the northwest area and has proven to have a presence of downflow below the production casing shoe as shown in Figure 3 which strongly supported the need of isolating the conduit through cement plugging. However, the well failed to reach commercial wellhead pressure after the unsuccessful plugging of the cold inflow zone during its workover in 1994, thereby the temporary use as reinjection well.

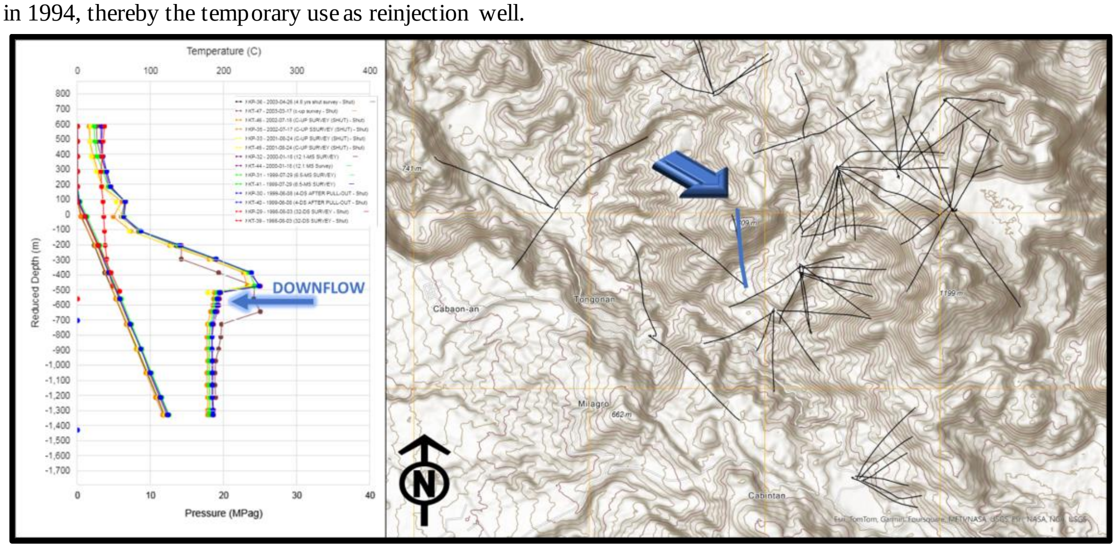

Figure 3: Location map and downhole pressure-temperature profile of converted production to reinjection well.

Tracer test using Sodium Fluorescein was conducted in 1994 and injected into this well to determine the hydrological connections with the production wells. Tracer results showed returns in two out of four monitored production wells implying high risk of cooling to resource when used as reinjection well. Consequently, this well was used in 2003 and 2011 tracer tests to further study the extent of cooler peripheral water incursion since it was established to have been strongly affected by the downflow. Comparison between both tracer tests as displayed in Figure 4 indicated that the peripheral water inflow has extended further to the southern and eastern parts of the field and faster as evidenced by the early arrival of tracer that was detected after 6 days. Mondejar (2012).

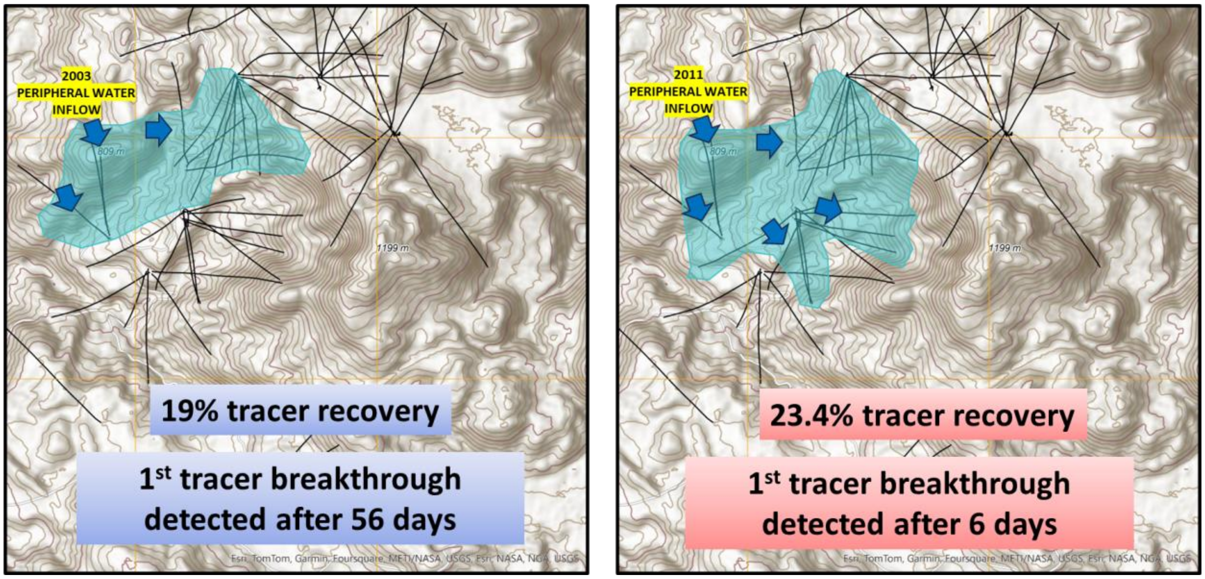

Figure 4: Comparison of the extent of peripheral water inflow, based on 2003 (left) and 2011 (right) tracer tests. Mondejar (2012)

It was again intermittently put online and utilized as cold reinjection well accepting mixed fluids that comprised condensates and thermal pond fluids from 2004-2020. There were limitations in the cold fluid conveyance to a reinjection pad located in the southern section of the field as shown in Figure 5 attributed to insufficient pipeline capacity and surface line silica scaling. Injection loads were only estimated since there were no actual flow measurements conducted due to vacuum wellhead pressure. These are calculated from the difference of combined total condensates and measured line flow of dumped brine with the measured flow of the main condensate line going to the reinjection pad. The estimated highest injection load peaked at approximately 214kg/s of mixed fluids in 2017 to accommodate the increase in dumped brine due to the workover in one of the hot reinjection wells having high acceptance capacity.

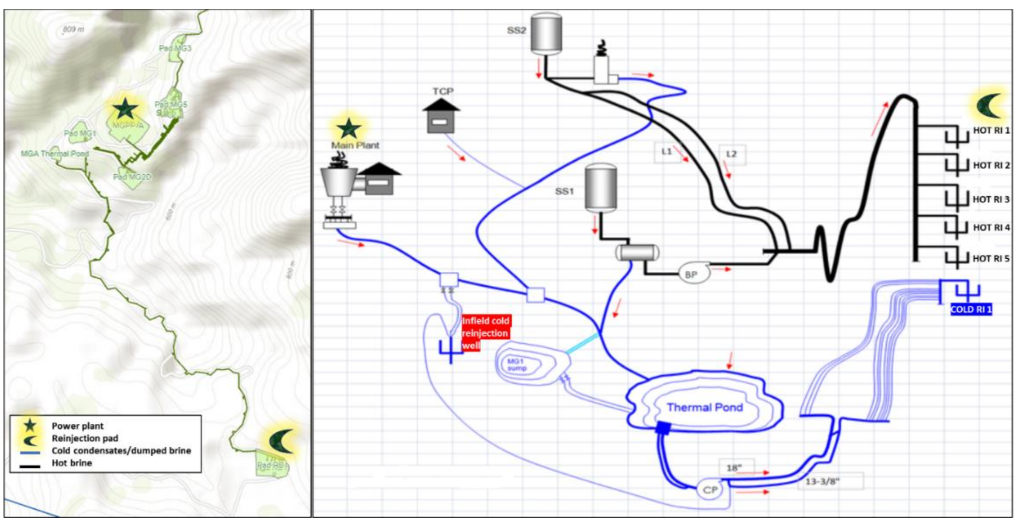

Figure 5: Location map and schematic diagram of condensate and brine disposal system.

The high infield reinjection of cooler mixed fluid contributed to the reservoir cooling leading to a total of 11MW loss from the top five production wells with relatively higher tracer recoveries in 2011. A gradual drop in silica-based temperature (T_{qtz}) in Figure 6 was initially observed from 1997-2005 due to the incursion of cooler peripheral waters from the northwest area then stabilized in 2005-2010. It further declined when the infield cold injection load increased, which resulted in collapse and non-commercialization of the three wells starting 2013.

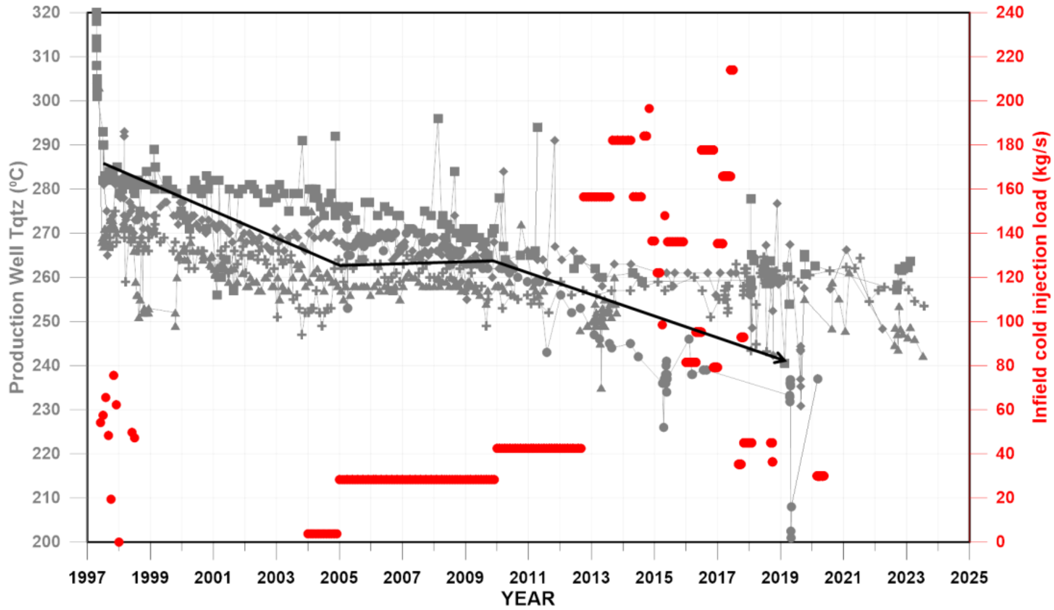

Figure 6: Production wells silica-based temperature (T_{qtz}) versus the infield cold injection load diagram.

2.2 Field Management Strategies

The infield cold injection caused significant impact to the steam availability of Mahanagdong that needs immediate resolution for the resource sustainability. The following initiatives were implemented to fully cut out the reinjection well for the recovery of reservoir performance.

2.2.1 Maximize the hot main reinjection line conveyance to reinjection pad.

Preventive maintenance of the hot main reinjection line was implemented in 2016 and there were no major constrictions that could limit the brine flow to the reinjection pad. Workover of one hot reinjection well in 2017 also resulted in an increase of hot brine conveyance along the line. It yielded positive results in minimizing the total infield cold injection load as shown in Figure 6 and showed thermal recovery in some of the wells. An additional hot main reinjection line was constructed in 2022 to eliminate the high silica index (SSI) dumped brine going to the cold injection lines. This prevents silica depositions when mixed with condensates and preserves the lines from scaling constrictions.

2.2.2. Maximize the cold injection line to reinjection pad.

Two additional reinjection wells were converted from accepting hot brine into cold mixed fluids to augment the cold reinjection capacity. A permanent condensate line was constructed and commissioned in 2018 as replacement to the installed temporary alvenius lines to increase the line capacity and improve the cold fluids conveyance to fully terminate the infield reinjection in Mahanagdong production area.

3. RESULTS AND DISCUSSION

The implementation of the field management strategies and initiatives successfully terminated the infield injection in 2020 located in NW section of Figure 7 and transferred the cold mixed fluids to the distant reinjection pad in the SE area. This milestone has gained positive results with the thermal recovery of the production field. Production wells with discharge and operational challenges were successfully discharged and commercialized. The field was able to recover a total of 8MW from the well revivals and cut ins, but it was short-lived due to the observed steam and mass flow declines in five (5) production wells.

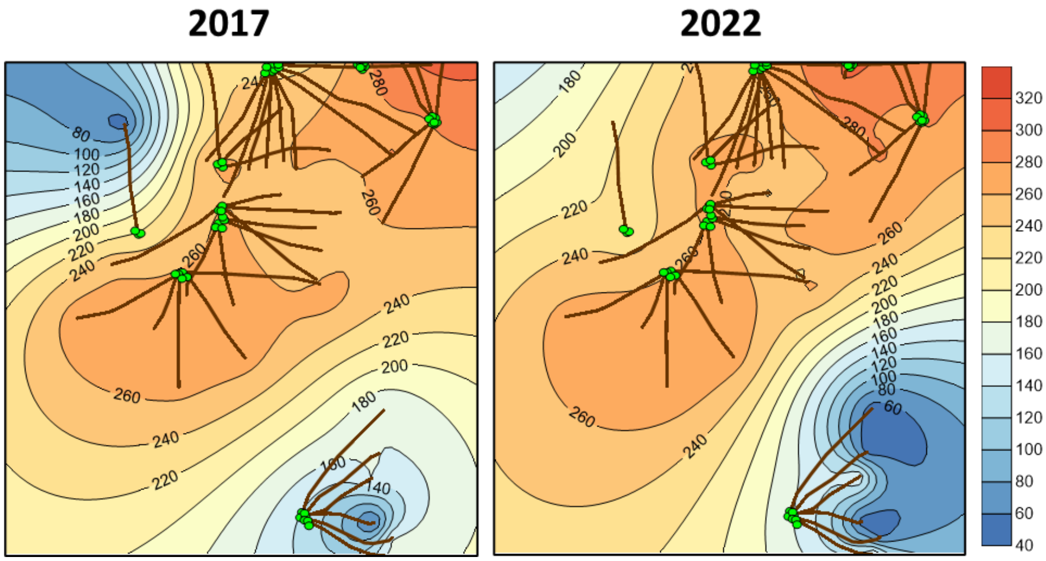

Figure 7: Comparison of the T_{qtz} contour plots before and after the termination of infield cold reinjection

The production wells that were identified to have output declines showed significant pH increases with neutral to basic pH levels as shown in Table 1. This indicates the potential calcite scale build-up within the wellbore causing the initial output decline and may result in a fully blocked wellbore with calcite scales if not mitigated. The calcite potential was evaluated through geochemical modelling using SOLVEQ/CHIM-XPT and detected supersaturation with respect to calcite (CSI>1) in all the production wells.

Table 1: Flow declines, pH and CSI of production wells affected by peripheral water incursion.

Well No	Steam Flow Decline (kg/s)	Mass Flow Decline (kg/s)	pH at 25°C	Calcite Saturation Index (CSI)
1	4.8	18.3	7.9	2.5
2	2.3	12.3	8.2	2.0
3	2.4	27.9	8.0	1.6
4	9.2	43.3	7.6	1.1
5	5.0	15.4	8.2	1.1

One of the production wells was further investigated to validate the wellbore scaling mechanism. In early production years, the well experienced pressure drawdown due to continuous mass extraction in the field. It has drawn out the cooler peripheral waters which led to the enthalpy decline from 2001-2002 as shown in Figure 8. It was already observed as early as 1998 as evidenced by the Clres decline. However, the drop in HCO3- indicated that the inflow was diluted with the cold mixed fluids reinjected infield during the pre- and post-commissioning of the power plants until 2000. It initially increased in 2010 due to the progression of peripheral water inflow as discussed during the 2011 tracer test and has likely affected the three feed zones which further drop the well enthalpy.

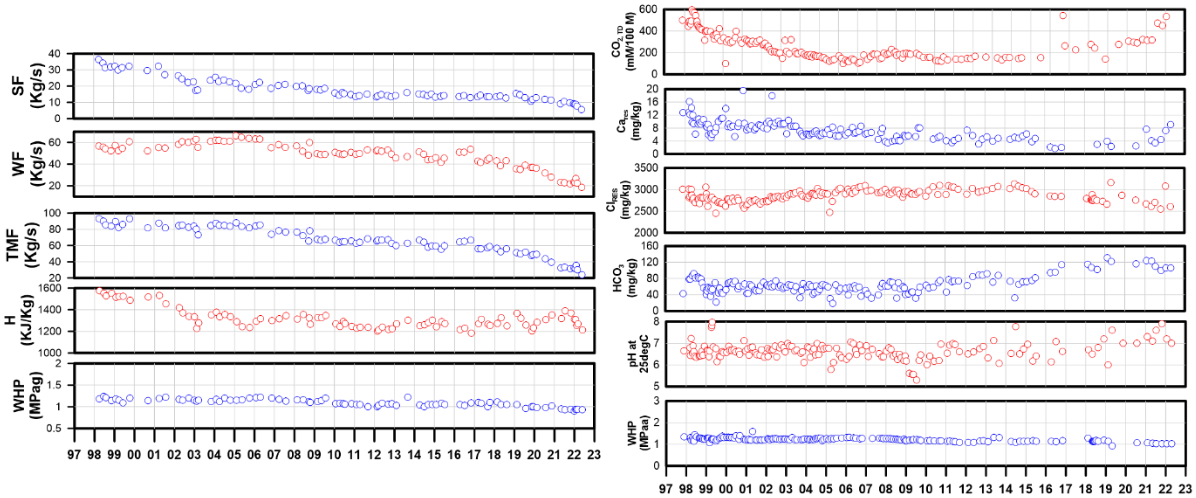

Figure 8: Flow (left) and chemistry (right) time plots of the production well affected by the peripheral water incursion.

An initial wellbore blockage was noted within 2006-2008 due to mass flow declines that was supported by the downhole blockage survey in 2007. The survey tagged blockage at 2053mMD partially blocking the major feed zone at the bottom. This partial blockage constricted and reduced the amount of inflow which could possibly explain the stable flow and chemistry in 2009-2016. The well mass flow has then tapered-off at increased and high utilization of the infield cold reinjection well at >40kg/s as shown in Figure 9. Subsequently, the mass flow drop was again observed after the reduced reinjection to zero. Wellbore blockage has progressed to a shallower depth at 1633mMD constricting the two bottom feed zones as displayed in the blockage profile. The downhole images captured in August 2023 confirmed that the blockages were mineral in nature due to the moderate to massive scales found deposited along the perforated liners. These 3 episodes suggest that the injected mixed fluid returns somehow slowed down the calcite formation within the wellbore.

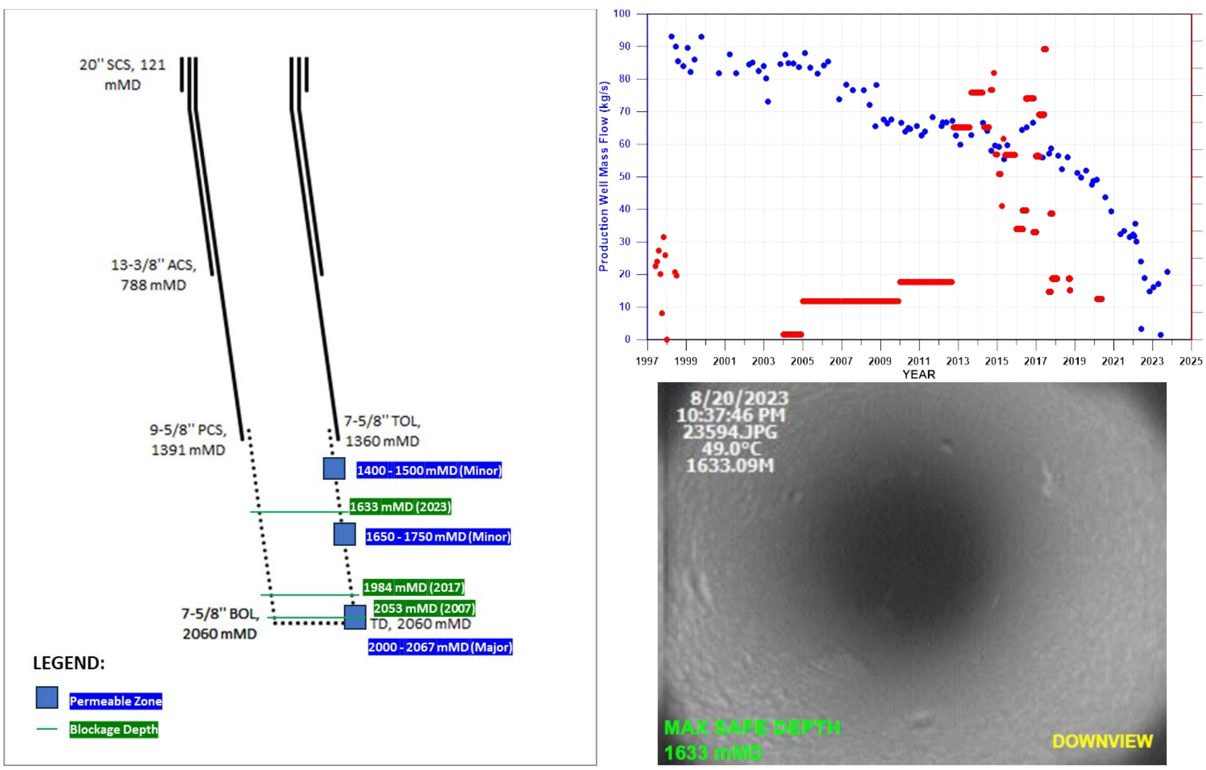

Figure 9: Blockage profile of the production well affected by peripheral waters inflow and cold mixed fluid reinjection returns.

Geochemical modelling using 3 sets of chemistry at different episodes were run to identify the main driver of the recent aggressive wellbore scaling and validate the effect of injected mixed fluids in impeding the calcite scaling. The 2012 chemistry only showed undersaturation with respect to calcite among the runs conducted. It implies that the calcite potential in this episode is unlikely which could explain the observed stable mass flow. On the other hand, mass flow declines were correlated to calcite saturation along the wellbore temperatures having the 2019 chemistry as highly oversaturated. Figure 9 shows that the simulated CSI increases with increasing value of calculated pH. The pH speciation was further investigated, and it was found that the controlling specie is HCO3- and the higher concentration brought up the calcite saturation index to above the saturation line. Thus, the addition of HCO3- from the peripheral water inflow in 2019 favors the calcite precipitation upon boiling that led to the fast calcite scale formation and progressed the wellbore blockages.

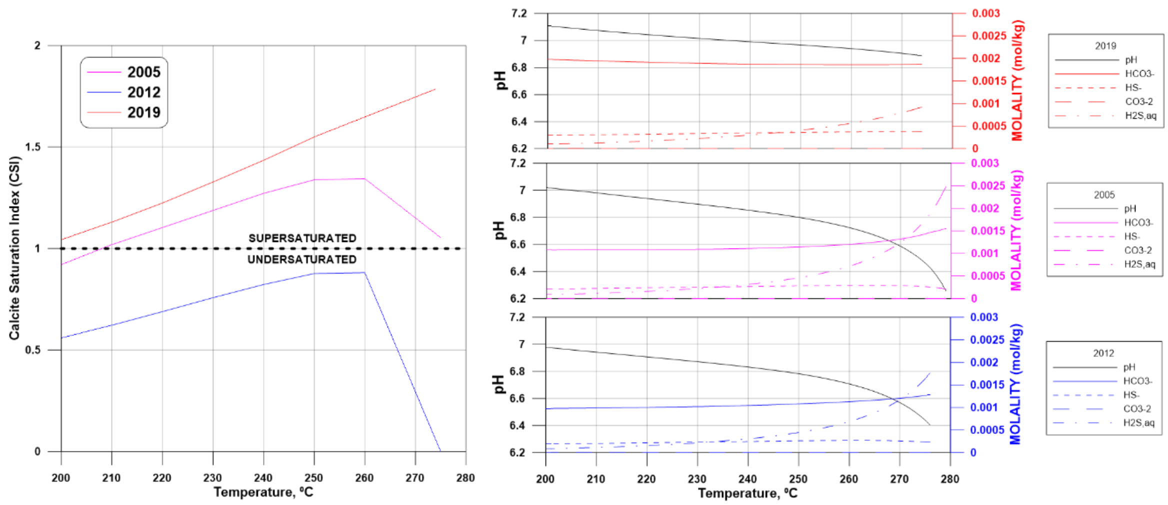

Figure 9: Comparison of geochemical modelling using 2005 (initial mass flow decline), 2012 (stable mass flow) and 2019 (continuous mass flow decline) well chemistry.

4. CONCLUSION

It appears that the infield cold reinjection mixing the peripheral waters was somewhat beneficial since it is carrying low HCO3- that dilutes the cooler fluid inflow chemistry upon arriving in the production field. After the dispersion of the cold mixed fluids outfield, the peripheral waters were left encroaching the reservoir causing the significant increase in HCO3- observed in the production wells which promoted the calcite wellbore blockages. Due to the thermal impact of these cold mixed fluid returns, it is more economical to permanently shut the infield reinjection well and manage the wellbore scaling with chemical or mechanical wellbore clearing and application of calcite inhibition systems. Treatment facilities using polymeric scale inhibitors were already implemented and proven successful in mitigating the calcite scale depositions and sustaining the well output. However, this program failed to treat some of the wells due to the development of new types of scales. Hence, this paper recommends conducting further assessment of metal-bearing mineral scales formation and exploring the use of polymeric inhibitors and metal ion dispersant.

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