UNDERSTANDING CALCITE SCALING AT WAIRAKEI GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND

Jose (Jun) Seastres Jr.[1], Abbie Dean[1] and Ed Mroczek[2]

[1]Contact Energy Limited, Private Bag 2001, Taupo 3352, New Zealand

[2] GNS Science, Wairakei Research Centre, PB 2000, Taupo 3352, New Zealand

jun.seastres@contactenergy.co.nz

Keywords: *calcite, scaling, Wairakei Geothermal Field, pressure drawdown, WATCH, reinjection*

ABSTRACT

The reservoir fluid at Wairakei geothermal field is generally oversaturated with calcite. Calcite deposition in the production wells was induced by reservoir changes in response to mass extraction and reinjection strategies. Since field production commenced in 1958, reservoir pressure has rapidly declined that facilitated the inflow of shallow, cooler fluids. Mixing with these low dissolved gas (CO_2) and low chloride fluids decreased the calcite saturation levels in the reservoir.

In 1998, when fluid reinjection commenced at Otupu, an increase in reservoir liquid pressure occurred which likely suppressed boiling at shallower part of the field; hence, the deep reservoir is less boiled resulting to higher gas content in the production wells. The higher dissolved CO_2 in these wells increased the calcite saturation levels.

The increase in energy generation in 2014 upon commissioning of Te Mihi Power Plant has resulted to further field pressure drawdown. This reservoir pressure drop enhanced boiling and consequently, calcite scaling that resulted in decline in mass flows of several production wells.

Applicable geochemical interpretation techniques were adopted in assessing the response of the production wells to calcite scaling. WATCH Automator was used to run several hundreds of geochemical data that modelled calcite saturation levels. A cross plot of Cl concentration and Cl/Ca ratio has clearly distinguished the wells affected primarily by calcite deposition.

Correlation of geochemical data with well test and production data confirmed calcite deposition in these wells. Understanding the mechanism of calcite formation has been proven to be valuable in formulating a scaling mitigation strategy to sustain fluid production at Wairakei.

1. INTRODUCTION

The Wairakei Power Station has been generating energy for almost 58 years to date since it was commissioned in 1958. Its production output reached as high as 192 MWe sometime in 1965. Wells from the Eastern Borefield (EBF) and Western Borefield (WBF) initially supplied the steam requirements of this plant (Figure 1). The 55 MWe (gross capacity) Poihipi Power Station, which utilised steam from the low pressure Southern Steam Zone, was commissioned in 1997. Additional 15 MWe (gross output) was produced in 2005 when the Wairakei Binary Plant started generating electricity using separated brine. In 2014, the 166 MWe (gross capacity) Te Mihi plant was commissioned.

Fluid reinjection commenced in 1998 at the Otupu sector through injection of separated water from Wairakei borefields. Prior to this, all extracted fluids were discharged to the Waikato River. The west injection wells at Poihipi are used for fluid disposal in this sector. Te Mihi separated fluids are reinjected at Karapiti wells.

While there has been no significant production problems due to calcite scaling prior to 1999, several wells encountered calcite scaling after this period primarily in the WBF sector. By 2005, eight wells were affected by scaling which required rig workovers at around 2-yearly intervals to sustain production (Dean et al., 2014). In 2014, several wells in Te Mihi encountered bore output deterioration attributed to calcite deposition.

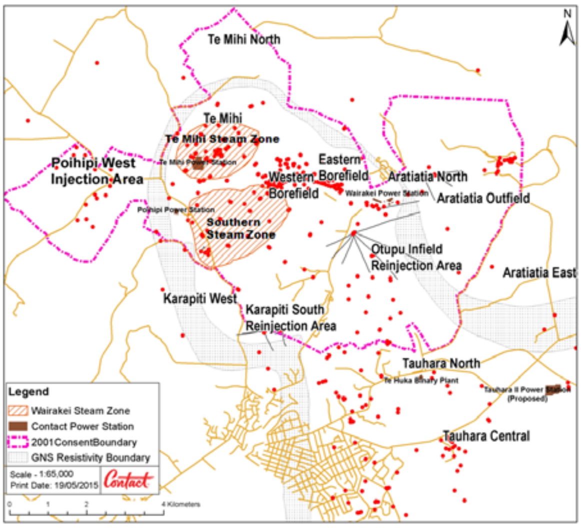

Figure 1: Location of Wairakei geothermal field showing the production and reinjection sectors.

Assessment of geochemical response of Wairakei and Te Mihi wells to changes in production and reinjection scenarios was conducted to understand the condition that has enhanced calcite deposition in these wells. Calcite saturation levels were determined using the WATCH Automator (Zeng et al., 2013) which is an Excel-based spreadsheet that runs in the background the WATCH program (Version 2.4, April 2010) originally developed by Arnorrson et al. (1982). The chemistry data was correlated with production and well test data to evaluate calcite deposition at Wairakei and Te Mihi production wells.

2. RESERVOIR RESPONSE TO EXPLOITATION

Reservoir pressure has rapidly declined by around 25 bars during the initial stage of production at Wairakei but subsequently stabilised for several years until it started to increase in 1998 when fluid reinjection commenced at Otupu (Figure 2). It eventually stabilised when reinjection load at Otupu was maintained within 20,000 kT/yr. However, reservoir pressure has declined again since production started at Te Mihi Power Station in 2014.

In 2011, the annual mass production at Wairakei was increased when the Poihipi Power Plant load increased from around 40 MWe (net) to 50 MWe (net). The resulting additional reinjection fluid was injected at Karapiti sector. The stabilisation of reservoir pressure during this period indicates that the field is responding more to Otupu reinjection rather than Karapiti.

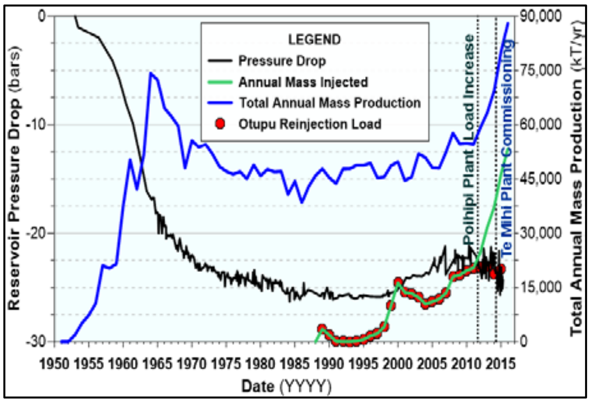

Figure 2: Production, reinjection and reservoir pressure trends

The decline in reservoir pressure at Wairakei that started in the early stage of production consequently induced the inflow of shallow, cooler fluids. This inflow resulted to decreasing temperatures that stabilised to ≤ 235°C in several production wells (Figure 3).

Though most WBF wells remained in production to date, several EBF wells encountered thermal deterioration and their production outputs decreased starting from early 1980s (Bixley et al., 2009). In fact, only WK59 in the EBF sector has been in service since 2008 until it was decommissioned in 2014. The temperature in WBF wells has remained relatively stable even when reservoir pressure increased since Otupu brine reinjection started in 1998.

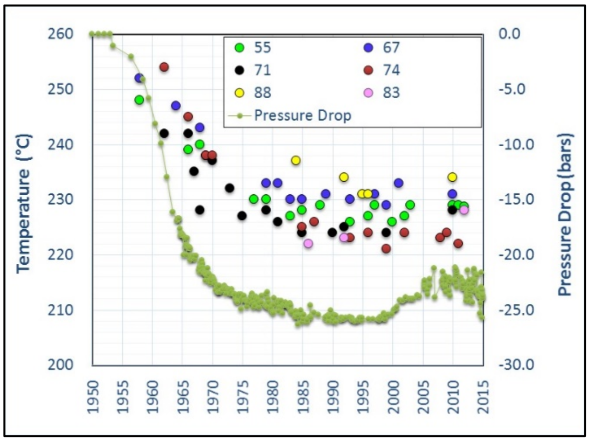

Figure 3: Temperature at the feed zone and pressure drop over time of selected WBF wells (solid circles)

While the bore outputs (total massflows) of the WBF wells gradually declined based on the last 20 years of production, rapid bore output deterioration occurred in several Te Mihi wells (e.g., 244, 262, 267, 268 and 269) since Te Mihi power plant was commissioned in 2014 (Figure 4).

3. CALCITE SATURATION CONDITION

The Calcite Saturation Index (CSI), which is defined as log Q/K, determines the deviation of calcite saturation from equilibrium concentration. Q is the activity product of mineral dissolution reaction and K is the corresponding equilibrium constant. WATCH Automator calculates the CSI based on the chemical composition of the wells and the thermodynamic data provided by Arnorrson et al. (1982). At Log Q/K of zero, equilibrium saturation with calcite is attained. Positive values suggest a potential for calcite scaling while negative values indicate that calcite will unlikely deposit.

In geothermal system, the following is the primary chemical reaction controlling the precipitation of calcite.

$$Ca^{++} + 2HCO_3^{-} \rightarrow CaCO_3 + H_2O + CO_2\uparrow$$

Calcite ($CaCO_3$) is precipitated when CO_2 is lost from the liquid phase during boiling. This reaction can be reversed when higher CO_2 dissolves calcite and convert it to soluble calcium and bicarbonate ions.

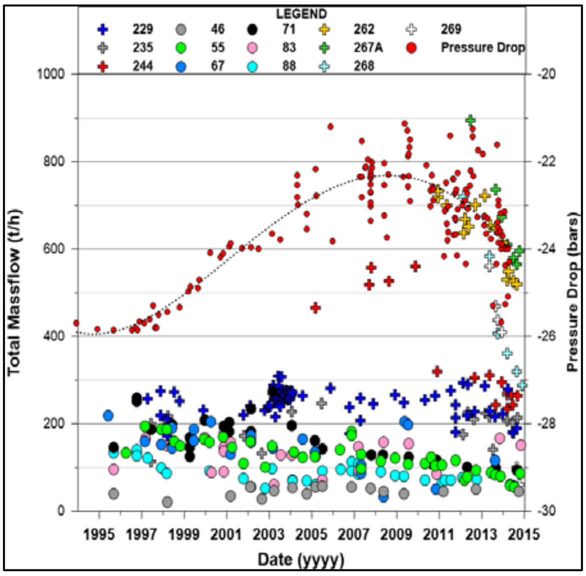

Figure 4: Total massflow and reservoir pressure drop over time. The solid circles and solid crosses are selected wells representative of WBF and Te Mihi sectors respectively.

The reservoir fluid at Wairakei geothermal field is inherently oversaturated with calcite. The CSI of wells representative of WBF and Te Mihi sectors were plotted starting in 1990 (Figure 5) as calcite saturation data prior to this period is limited. CSI trends in these sectors can be separated into three stages as described below.

1. Decreasing calcite saturation approaching equilibrium condition, from 1990 to about 2004, encountered by WBF wells (e.g., 46, 55, 71 and 83) and some Te Mihi wells (e.g., 229 and 235) located at the south-eastern margins of Te Mihi near WBF sector

2. Increasing CSI from 2005 to 2013 at relatively higher reservoir liquid pressure

3. Decreasing CSI starting from 2014 when Te Mihi power plant was commissioned.

4. NATURE OF CALCITE SCALING

It has been observed that the CO_2 gas concentrations over time, particularly for the WBF wells, generally correspond to reservoir pressure trends (Figure 6). In the early stages of field exploitation at Wairakei, gas concentrations progressively declined as gas is continually lost from the brine during boiling with continuing pressure drawdown in the reservoir. However, this reservoir pressure decline subsequently induced the inflow of shallow, cooler fluids (i.e. with low dissolved CO_2 concentration) resulting to further decline in CO_2 gas concentration. The gas levels in Te Mihi wells generally remained high which suggests that cooler fluids have not significantly affected most of the wells in this field.

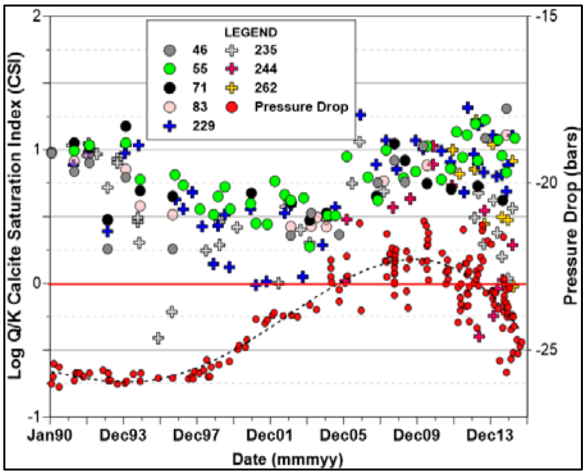

Figure 5: Calcite Saturation Index (CSI) of selected WBF and Te Mihi wells.

With persistent cooler fluid inflow, the reservoir fluid becomes increasingly less saturated with calcite; hence, the decreasing CSI from 1990 to 2004 (Stage 1) could be caused by mixing with cooler fluid low in dissolved gas concentration and less calcite saturated. This is probably the case for WBF wells and some wells at Te Mihi close to WBF sector (e.g. 229, 207 and 215).

The increase in reservoir pressure occurred when fluid reinjection commenced at Otupu sector in 1998 (Figure 2). It is likely that the increase in reservoir liquid pressure is driven by brine reinjection at Otupu as indicated by the following.

1. Increasing calcium and chloride concentrations often indicate reinjection fluid returns (Harper and Jordan, 1985; Seastres et al., 1995). This could be the case for calcium concentration at Wairakei (Figure 7) as calcium concentration progressively increased in WBF wells with continuing reinjection at Otupu.

   Though the chloride content did not show a corresponding increase in concentration, it has stabilised during brine reinjection at Otupu after consistently declining prior to the start of this injection. Simple mass balance calculations (E. Mroczek, pers.comm.) suggest that considerable amount of reinjection fluid inflow is needed before any significant chloride increase is observed (e.g. well 70 indicated 52 mg/L increase in chloride that is within the analytical uncertainty based on 13% reinjection fluid returns).

2. Preliminary data from the on-going naphthalene sulfonate tracer testing at Wairakei indicates positive tracer returns in WBF wells after around 200 days since this tracer was injected at Otupu. This relatively slow tracer return allows sufficient time for reheating of reinjection fluid from Otupu that the reservoir temperatures have not significantly deteriorated.

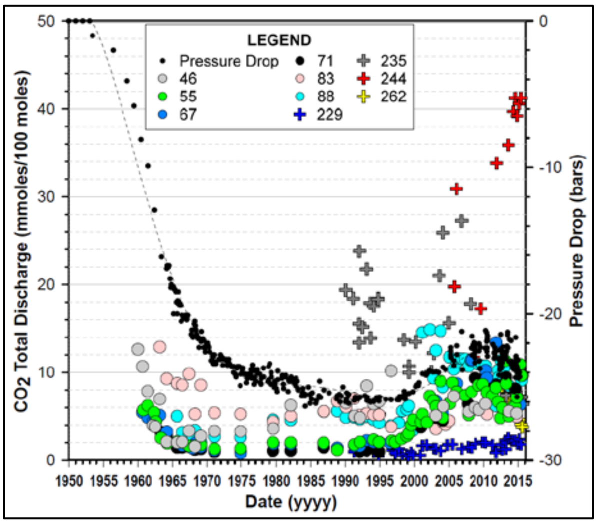

Figure 6: CO_2 total discharge concentration over time as correlated with the reservoir pressure drop.

If the reservoir pressure increase is due to reinjection fluid returns, then, why did the gas concentration increased during this period? The reinjection fluid is degassed at the flash vessels and decreasing gas concentrations should have occurred. Glover and Mroczek (2009) suggested that either an increase in condensation in steam zones by the infiltration of cooler waters caused the increase of gas concentration or a decrease in boiling and less gas is lost from the deep fluid due to increased liquid pressures. The latter case is consistent with the interpretation of Dean et al. (2014) that reinjection fluid probably suppressed boiling from the deep reservoir resulting to a less boiled recharge fluid.

Considering the scenario that reinjection brine suppressed boiling and that the upflowing reservoir fluid is less boiled (i.e. resulting to higher dissolved CO_2 gas concentration), an increase in calcite saturation will likely occur. This higher CSI, however, was encountered from 2005 to 2013 (Stage 2) when optimum increase in reservoir pressure occurred. The relatively high CSI has increased the calcite scaling potential and probably caused the increase in the intensity of calcite scaling during this period (i.e. work-over of wells to clear calcite scales were conducted).

When the Te Mihi power plant was commissioned in 2014, reservoir boiling was enhanced by field pressure drawdown and appears to have persisted to date. CSI has rapidly declined in this sector since 2014 (Stage 3) indicating significant calcite precipitation. This resulted to output decline in several wells particularly at the central sector within the Te Mihi Steam Zone (Figure 1).

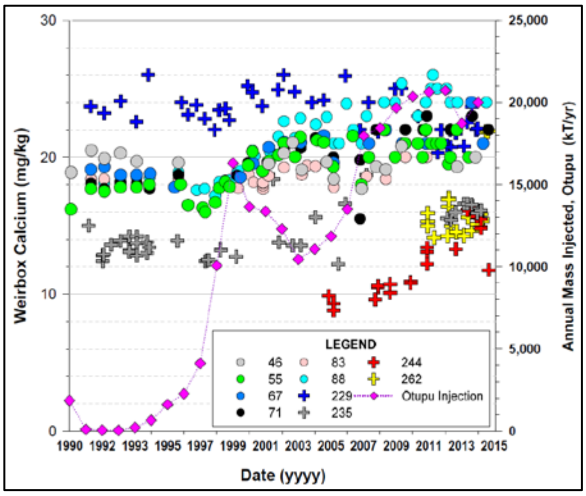

Figure 7: Weirbox calcium trends of selected WBF (solid circles) and Te Mihi wells (solid crosses).

A cross-plot of chloride concentration and chloride/calcium molecular ratio is useful in evaluating the extent of calcite scaling in production wells. A major increase in chloride/calcium ratio due to loss of calcium with no major change in chloride concentration indicates that significant calcite scaling in the well occurred. This geochemical response has been encountered by the Central Te Mihi wells (Figure 8). High output decline due to relatively rapid calcite scaling occurred in these wells.

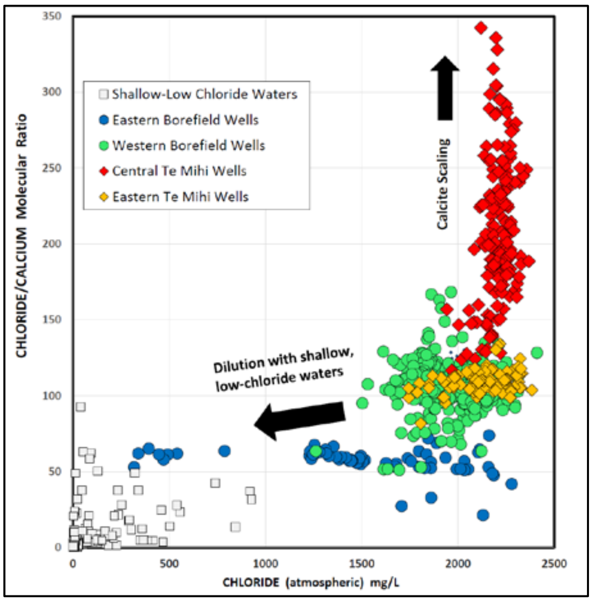

Figure 8: Chloride-chloride/calcium diagram

Installation of chemical anti-scalant dosing system has been programmed in the central production wells of Te Mihi (e.g. 245, 267, 268 and 269) to prevent calcite scaling and sustain steam production.

The WBF, EBF and Eastern Te Mihi sectors (i.e. located at the periphery of Te Mihi Steam Zone and near the WBF sector) are mainly diluted with shallow, low chloride waters. This is indicated by declining chloride concentration and generally lower Cl/Ca molecular ratio. The fluid chemistry of Eastern Te Mihi wells (e.g. 207 and 229) are compositionally similar to WBF wells.

5. CONCLUSION

The reservoir changes at Wairakei geothermal field in response to shift in field production and reinjection strategies have affected calcite saturation levels and the intensity of calcite deposition in the production wells.

Field pressure drawdown that started during the early stage of exploitation has consequently induced the inflow of shallow, cooler fluids with low dissolved CO_2 gas concentration. This resulted to a decline in calcite saturation and hence, decreasing the degree of calcite precipitation in the Wairakei wells.

When Otupu reinjection commenced in 1998, the calcite saturation levels have consequently increased likely enhanced by the increase in dissolved CO_2 content. However, it is not until the commissioning of Te Mihi Power Plant in 2014 that a relatively large decline in total massflow occurred. This decline is primarily due to increasing intensity of calcite deposition caused by reservoir boiling when field pressure drawdown was enhanced in this sector.

Although the Wairakei reservoir is generally oversaturated with calcite, significant calcite scaling occurring in wells was determined by CSI trends and Cl/Ca Ratio-Chloride correlation with bore output (total massflow) decline. The relative response of the wells to calcite scaling can be further assessed by a reactive transport modelling tool (e.g. TOUGHREACT).

ACKNOWLEDGEMENT

We highly appreciate the support of Contact Energy in publishing this paper to share geochemical information for better understanding of calcite deposition in the reservoir that will be useful in mitigating calcite scaling in geothermal wells.

REFERENCES

Arnórsson, S., Sigurdsson, S. and Svavarsson, H.: The chemistry of geothermal waters in Iceland. I. Calculation of aqueous speciation from 0° to 370°C. *Geochimica et Cosmochimica Acta 46*, 1513-1532 (1982).

Bixley, P.F., Clotworthy, A.W., Mannington, W.I.: Evolution of the Wairakei geothermal reservoir during 50 years of production. *Geothermics 38*, pp. 145-154. (2009).

Dean, A., Bixley, P., Lim, Y.W. and Mroczek, E.: Effects of reinjection at Wairakei geothermal field. Proc. 36th New Zealand Geothermal Workshop, 24-26 November 2014, Auckland, New Zealand (2014).

Glover, R.B. and Mroczek, E.: Chemical changes in natural features and well discharges in response to production at Wairakei, New Zealand. *Geothermics 38* (2009) 117–133.

Harper, R.T. and Jordan, O.T.: Geochemical changes in response to production and reinjection for Palinpinon-I geothermal field, Negros Oriental, Philippines. Proc. 7th New Zealand Geothermal Workshop, 24-26 November 1985, Auckland, New Zealand (1985).

Iceland GeoSurvey (ISOR): The Iceland Water Chemistry Group. http://www.geothermal.is/software WATCH software, (2013).

Seastres, J.S., Hermoso, D.Z., Candelaria, M.N.R. and Gerardo, J.Y. Application of geochemical techniques in evaluating the reservoir response to exploitation at Palinpinon geothermal field, Philippines. Proc. 1995 World Geothermal Congress, Florence, Italy (1995).

Zeng, Z., Seastres, J. and Mroczek, E.: WATCH Automator: an Excel based data processor for multiple geochemical samples. Proc. 35th New Zealand Geothermal Workshop, 17-20 November 2013, Rotorua, New Zealand (2013).