Scaling Rate Reduction at Wairakei Binary Through Application of Scale Inhibitor

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ABSTRACT

Silica scaling at the Wairakei binary plant heat exchangers increases resistance to flow and thus causes reduced flow of separated geothermal water through the facility, wastage of geothermal energy and reduced power generation.

Historically this has been managed by mechanical or chemical cleaning of the heat exchangers on a performance basis, with associated cost and loss of generation during the cleaning outage.

Following a system review and improvements to the asset surveillance program, periods of unusually high scaling rate were identified and, through integrated review, linked to downhole chemical injection (Nalco GEO907) deployed to inhibit calcite scaling in a production well.

Through plant trials, a link between the injection of this chemical and reduced silica scaling rate of the binary was demonstrated. This enabled an opportunity to reduce the scaling rate by over 90% through sustained injection of the chemical to the binary plant, independent of the production well flowing to the plant.

1. INTRODUCTION

1.1. Wairakei Binary Plant

The Wairakei binary plant is an organic rankine cycle plant, extracting waste heat from separated geothermal water (SGW) at 127 °C to generate electricity. The SGW flows from upstream flash plants, which supply steam to steam turbine power generation plants, via 2 pipelines (X and T lines) to the binary plant. Part of the SGW flows to the binary plant, with the remainder reinjected directly. After passing through the binary plant heat exchangers, the cooled water (at 87 °C) flows to reinjection wells and direct use consumers. The system flows under gravity from the upstream flash plants, through the binary plant and to the reinjection wells.

There are 2 parallel generation units, G15 & G16, each designed to generate 8.25 MW gross at 11 °C ambient temperature. There is a SGW bypass line in parallel to the generation units (Figure 1).

The SGW flow is metered at the combined plant inlet; plant inlet and outlet pressures are measured.

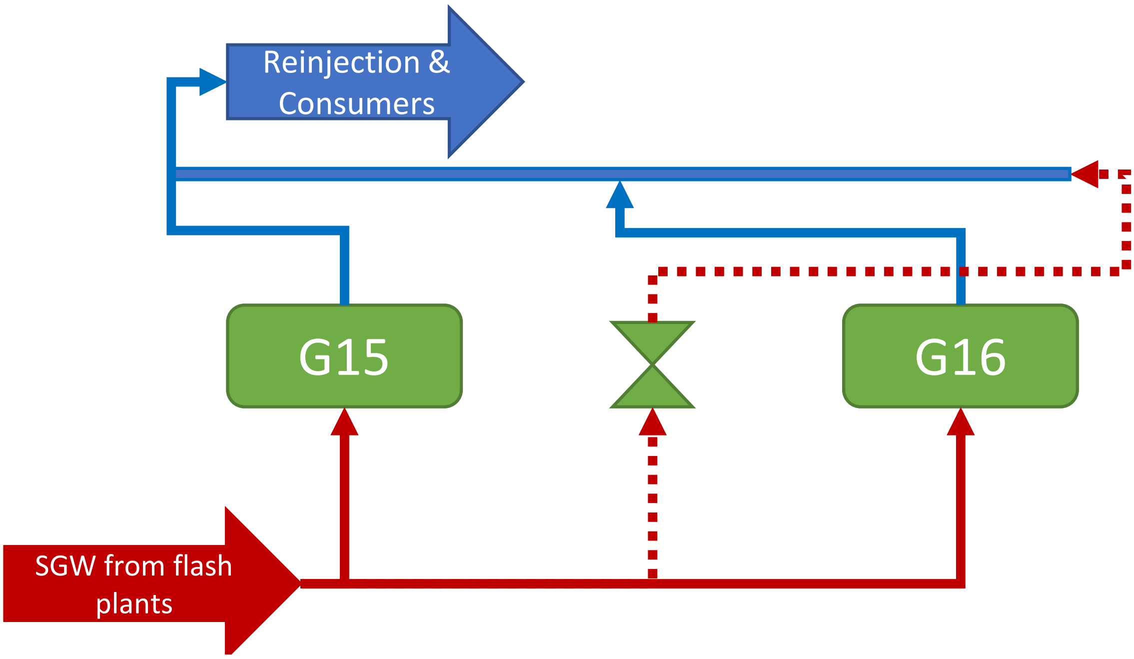

Figure 1 – Overview of the SGW flow through Wairakei binary plant

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When scaling occurs in the binary plant heat exchangers, the pressure drop over the binary plant increases and excess SGW is either diverted from upstream flash plants to a holding pond or, if the pressure drop exceeds the maximum allowable of 3.5 bar, it is bypassed around the binary plant through the bypass control valves. In the second scenario, the reinjection temperature rises, which reduces reinjection well capacity.

Iso-pentane is the motive fluid used in the Wairakei binary plant. Each generation unit has two levels i.e. two separate pentane circuits. The separated geothermal water flows through the level 1 and level 2 vaporizers in series, before splitting between the level 1 and level 2 preheaters (Figure 2). The SGW flows on the tube side of the exchangers to facilitate removal of scale through mechanical cleaning. The binary plant design parameters are detailed in Table 1.

Table 1 - Wairakei Binary Design Parameters (combined units)

SGW Flow	2800	t/hr
Inlet Temperature	127	degC
Inlet Pressure	5.9	bara
Outlet Temperature	87	degC
Outlet Pressure	3.7	bara
Gross Power @ 11 degC	16.5	MW

1.2. Water Chemistry

The silica saturation index (SSI) of the incoming SGW at 127 °C is in the range 0.97 – 1.03, as calculated in Geochemist's Workbench. At the outlet, the SSI of the fluid is in the range 1.50 – 1.59, due to the heat extracted through the binary plant. The risk of amorphous silica scaling within the heat exchangers is further enhanced by the presence of aluminium, which has been shown to co-precipitate and reduce the solubility of the silicate scales formed (Gallup, 1997). Analysis of the scale removed from the heat exchangers confirms that the scale is an amorphous aluminium silicate. The chemical composition of the incoming SGW is detailed in Table 2.

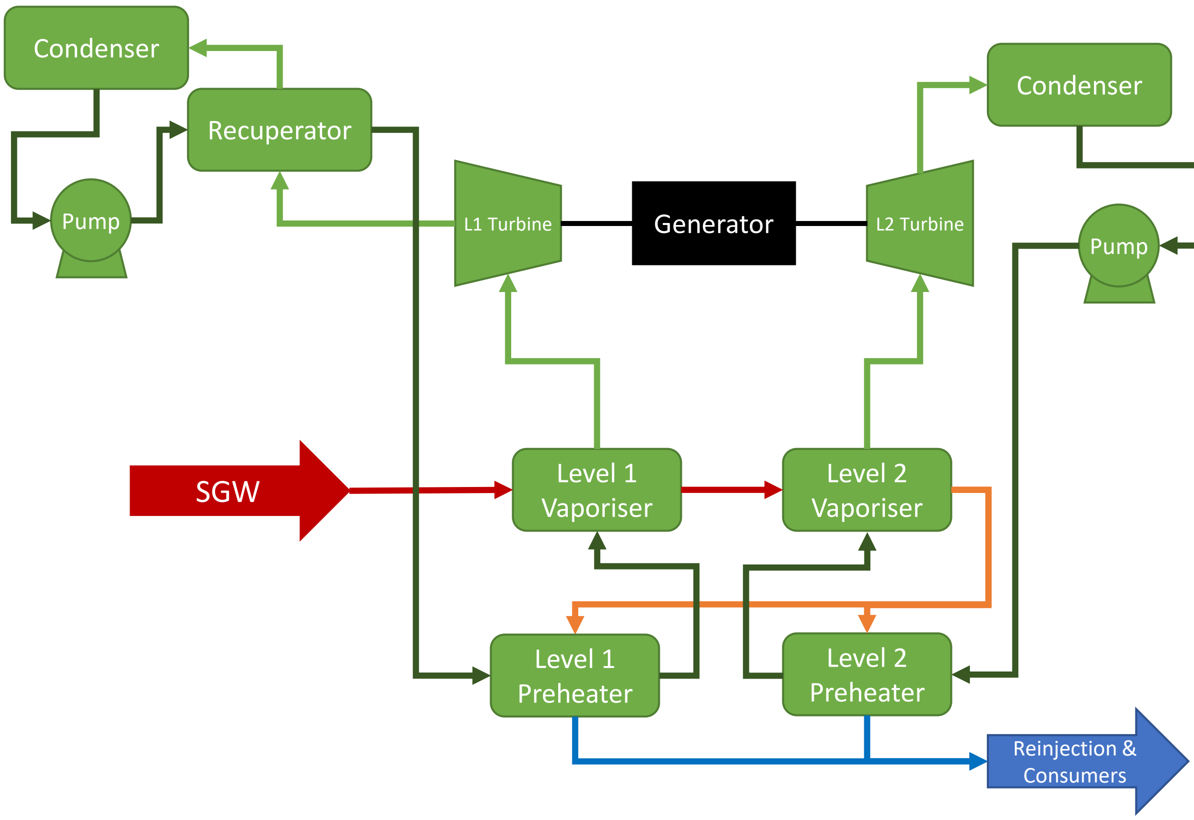

Figure 2 - Process Flow Diagram for a Generation Unit

1.3. Scale Management

As the binary plant fouls with silica scale, the SGW flow reduces for the same differential pressure. This can reduce generation in 2 ways:

- When the pressure drop reaches the maximum set point, excess SGW is bypassed around the binary plant, reducing flow through the units, heat input & power generation.
- If the binary plant inlet pressure increases to the point that the hydraulic capacity of X/T lines is reached, then SGW is diverted to a holding pond, upstream at the flash plants, rather than flowing to the binary plant.

Scaling at Wairakei binary plant is primarily managed through surveillance of resistance to flow through the plant and planned scale removal.

Table 2 - SGW Composition (units are mg/kg)

Location	X line U/S binary, before T-line tie in	T-line
Li	10.7	11.6
Na	1028	1102
K	159	190
Ca	15.4	14.1
Rb	1.8	2.3
Mg	<0.01	<0.01
Fe	0.06	0.08
Al	0.38	0.33
Cl	1671	1751
Br	4.7	5
SO4	43	45
B	23	24
SiO2	522	555
As	3.4	3.5

1.3.1. Surveillance

The gross power generation is tracked as a measure of overall binary plant performance. However, silica scaling of the binary plant is known to be one of the key factors influencing performance.

As the binary plant power output is dependent on ambient conditions, SGW flow from the field to the plant and the process operating efficiency of the plant, the key surveillance parameter for scale management is the resistance to flow through the plant. This parameter is derived from the Darcy-Weisbach equation for single phase, incompressible flows:

$$\Delta P = f\,(L/D)\,(\rho V^2/2)$$

Where P is pressure, f is the friction factor, L is pipe length, D is pipe diameter, ρ is SGW density and V is SGW velocity.

So, $\Delta P/V^2 \approx$ constant if resistance to flow is constant i.e. no active scaling. This is termed the "flow resistance" parameter.

The differential pressure is measured over the binary plant as a whole and flow is measured at the common inlet. This enables the flow resistance to be calculated for the whole binary plant, lumping together the pipework and fittings with the heat exchanger tubes. Due to the large number of heat exchanger tubes and the relatively small diameter of those tubes, the largest contribution to flow resistance is from the heat exchanger tubes.

Historically, when the binary plant units G15 & G16 are in a "clean" state, the flow resistance is as low as 4 and when the system is "dirty" and the binary plant bypass valve starts to open, the flow resistance is around 6.

1.3.2. Scale Removal

Two methods of scale removal have been applied:

- Mechanical cleaning, using high pressure water jetting equipment
- Chemical cleaning, using hydrofluoric acid

Both methods require the generation unit to be shut down for the duration of the clean.

Early in field life, mechanical cleaning was applied, typically high-pressure water jetting every 6-12 months for each unit. Chemical cleans were applied for 7 years from 2012 but were discontinued due to the risk to safety of people and risk to equipment integrity. Since this time, mechanical cleans have been applied, except for an online chemical clean, which was unsuccessful.

1.3.3. Previous Chemical Injection Trials

A chemical injection trial was conducted in 2016, in which an acrylic polymer chemical was continuously injected into the SGW for the purpose of reducing the scaling rate at the binary plant. This was discontinued as it was not economically viable.

2. INVESTIGATIONS

2.1. Field Data Observations

A review of binary plant performance was conducted in 2021 and a change in scaling rate in the period 2017 – 2019 was identified (Figure 4). Unfortunately, historical flowmeter data was not available in this period and so the exact time and nature of the change could not be studied further. This period also coincides with a change from chemical to mechanical cleaning of the heat exchanger tubes.

During the review in 2021, the flow resistance was identified as a key surveillance parameter and added to regular surveillance routines. As part of regular surveillance in April/May 2022, it was observed that there was a rapid rise in flow resistance of the binary plant (Figure 3).

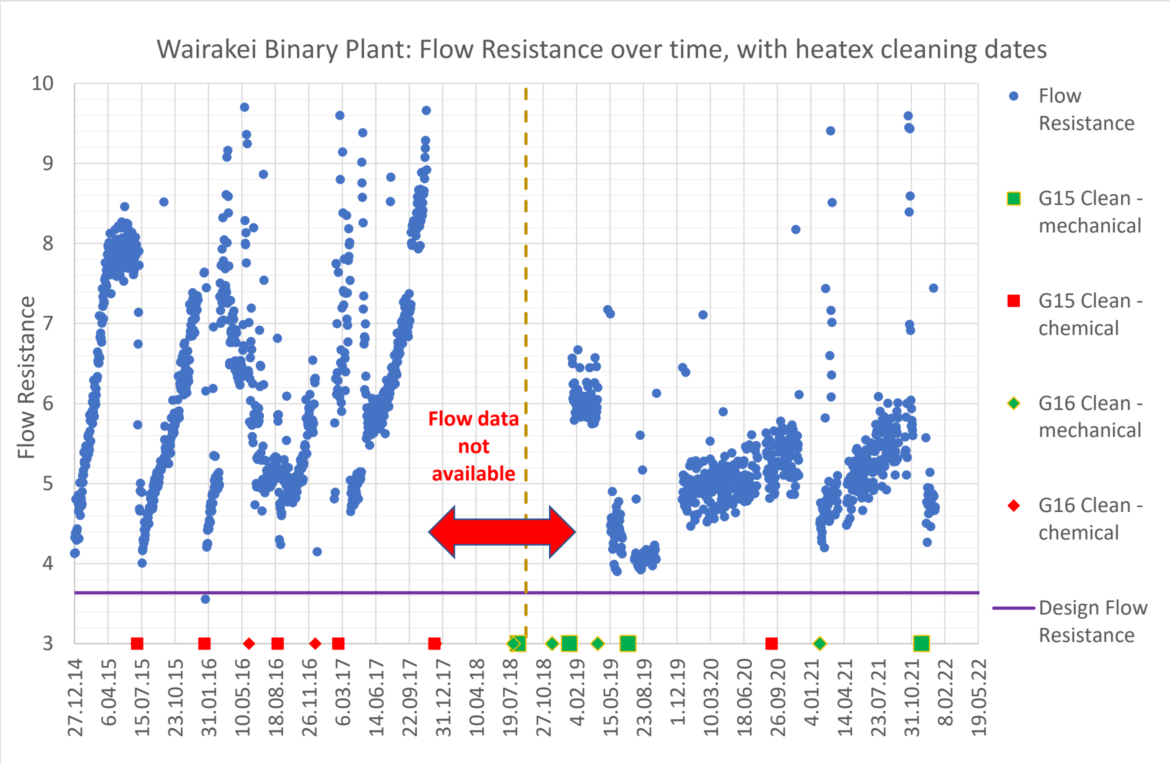

Figure 4 - Graph showing binary plant flow resistance from 2015 onwards. The dates of heat exchanger mechanical and chemical cleans are plotted, as is the date of downhole chemical injection installation at WK-123A.

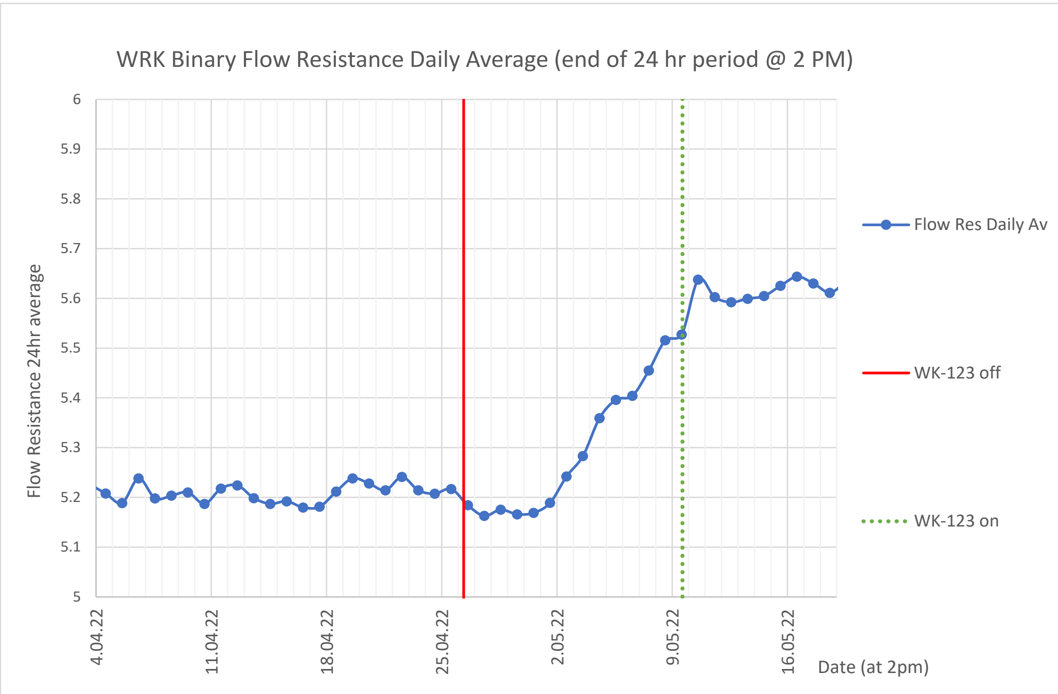

Figure 3 - Graph showing the rapid increase in flow resistance when WK-123A well is out of service

Concurrent activities in the steam field were reviewed and it was found that the increase in flow resistance coincided with a particular well (WK-123A) being taken out of service. WK-123A has downhole chemical injection for calcite scale mitigation and is the only well with a calcite inhibition system (CIS) that supplies the binary plant with SGW. When the well was returned to service, the rate of increase in flow resistance at the binary plant reduced. The WK-123A downhole CIS was installed in September 2018, coinciding with the observed reduction in scaling rate at the binary plant (Figure 4).

Review of the flow resistance parameter in conjunction with WK-123A outage dates resulted in another period of rapid increase in flow resistance being identified, in October 2021.

There were other periods of increased scaling rate of the binary plant, related to wells being brought into service after well workovers.

2.2. Downhole Chemical Injection Impact on Scaling Rate

WK-123A is dosed with Nalco GEO907 at a rate of 10 ppm by mass. This is equivalent to 1 ppm by mass of the total SGW flow to the binary plant. The chemical is designed to inhibit calcite scale but from inspection of the flow resistance data, it also appears to be inhibiting the rate of deposition of amorphous aluminium silicate scale in the heat exchangers, by around 90%.

In Figure 4, the increase in flow resistance accelerates 6 days after WK-123A is out of service. When the well returns to service, there is a 1-day delay before the flow resistance stabilizes (at a higher value, due to the scaling that occurred in the binary plant whilst the well was out of service).

2.3. Production Well Chemical Injection Trial

A field trial was conducted to test whether scale inhibition at the binary plant is related to the chemical injected at WK-123A or the SGW flow from the well.

In the trial, the chemical injection was stopped for just under 13 days from 26th May 2022, whilst WK-123A remained flowing to the binary plant. The flow resistance was monitored throughout the period. The trial duration was selected to enable sufficient data gathering whilst minimizing risk to the well from scale deposition. At the end of the trial, chemical injection at WK-123A was reinstated. Changes in production well line ups and flows were avoided during the trial period to minimize interference with the trial.

The flow resistance was observed to increase at a faster rate following 4 days without chemical injection at WK-123A, with a rapid increase after 11 days (Figure 5). The total increase in flow resistance was less than the previous occasion at the end of April 2022, when WK-123A was out of service. This could be because in this trial, WK-123A was still flowing and residual chemical from the well was produced to the binary plant.

The conclusion from this trial is that the chemical injection downhole at WK-123A is effective at reducing the rate of silica scaling at Wairakei binary plant, in addition to mitigating calcite scaling downhole. The scaling rate is reduced by around 90%, which significantly reduces the frequency of mechanical clean interventions, with associated benefits of reduced cleaning costs and reduced generation outages for the cleans.

Following this trial, a mechanical clean (waterblast) of the G16 unit preheaters was completed in July 2022, which removed an amount of scale equivalent to 4-6 months of scaling for the total binary plant. A scale sample was collected for chemical analysis, results of which are currently pending. Borescope images of the silica scale were captured prior to the water blasting and show the very rough scale surface, which causes significant resistance to flow (Figure 6).

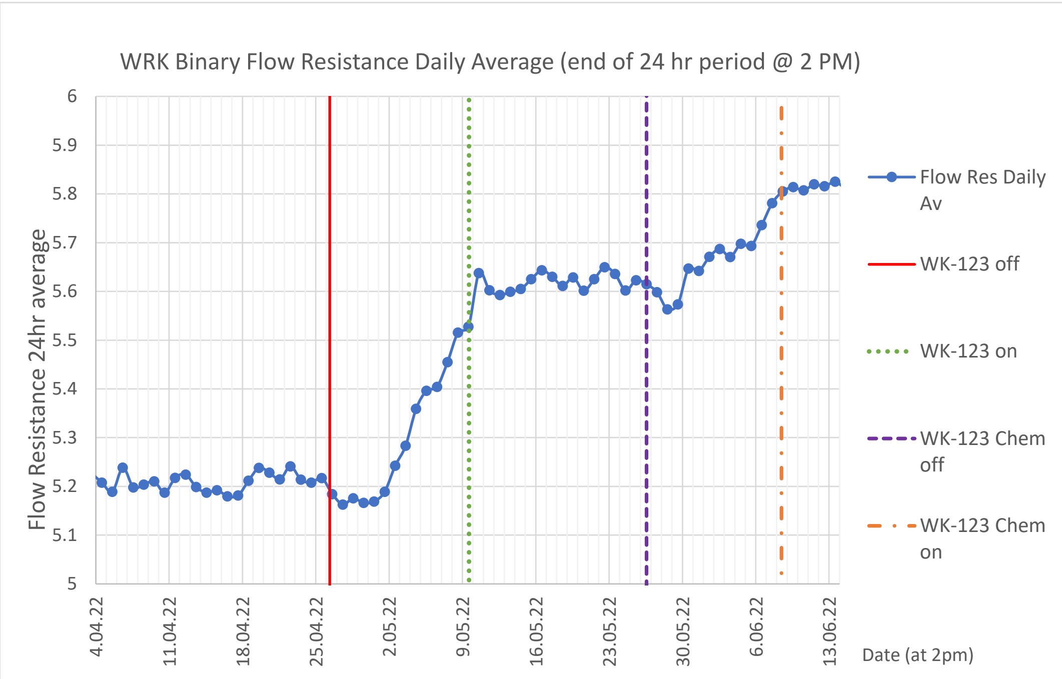

Figure 5 - Graph showing the increase in flow resistance when WK-123A chemical injection was switched off

Figure 6 - Image of scaling within a G16 pre-heater tube

2.4. Alternative Location Chemical Injection Trial

As WK-123A is the only well feeding the Wairakei binary plant that has downhole chemical injection, there are inevitably some periods when the well or its wellhead separator are out of service or the flash plant (FP1) into which the well flows prior to the binary plant, is out of service. To maintain low rates of scaling at the binary plant, an alternative injection location is required, that is not dependent on WK-123A or FP1.

The chemical injection project in 2016 installed an injection quill and associated chemical injection facilities upstream of the binary plant, on the pipeline (X line) providing the majority of SGW to the binary plant. This location was selected to trial injection of GEO907 during a maintenance outage of FP1. During the FP1 outage, WK-123A did not flow to the binary plant and thus there was no chemical treatment of the SGW flowing to the binary plant.

The aim of the trial was to establish whether injection of GEO907 in the pipeline feeding the binary plant was effective at maintaining a low scaling rate. The pipeline operates at a lower temperature and pressure than WK-123A and in the liquid phase; the trial aims to establish whether the chemical is still effective when injected under these conditions, rather than downhole.

Chemical injection at X-line started two days before the FP1 outage and continued for 13 days after the FP1 outage started, with WK-123A chemical injection stopped when FP1 returned to service. This provides an adequate period in which the chemical is injected only at X line.

The flow resistance remained low throughout the trial period (Figure 7). There are some small fluctuations due to changes in reinjection well line up during the trial but no overall increase in flow resistance. This indicates that injection of GEO907 directly into X line (SGW supply pipeline) achieves the same beneficial scaling rate reduction effect as injecting the chemical downhole at WK-123A. From assessing the previous increases in flow resistance when WK-123A was offline, it is estimated that the injection into X-line prevented 4-6 months of scale build-up during the most recent outage.

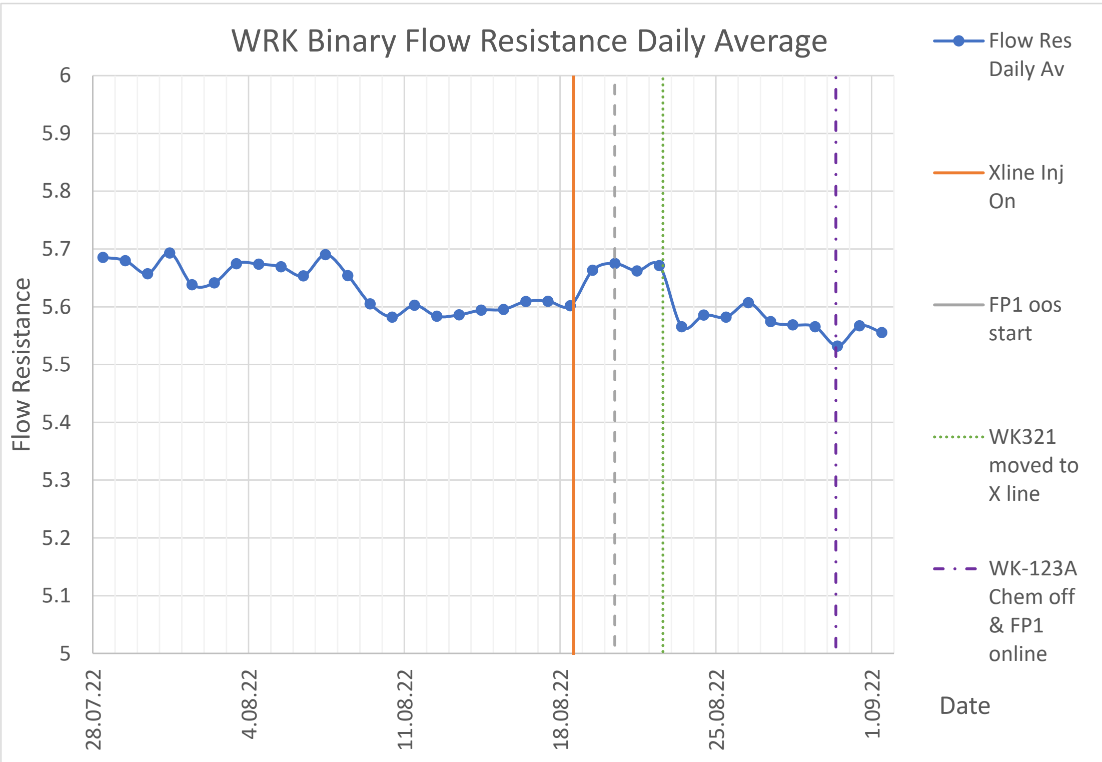

Figure 7 - Graph showing the stable flow resistance when GEO907 is injected at X line instead of WK-123A

2.5. Potential Mechanism of Inhibition

While still under investigation, the data currently collected may give some insight into the mode of action of Nalco GEO907, in terms of silica scale. Although the chemical is designed to inhibit calcite scaling, the binding sites on the polymer will also allow chelation of or binding to other metals in solution or on the surface of the scale. Analysis of the scale deposited in the heat exchangers has confirmed the presence of aluminium in the scale. The inhibitor could be chelating aluminium in solution, limiting its availability to form the scales seen in the heat exchanger tubes.

While this may be one of the potential mechanisms for the reduction in scaling rate observed in the plant, the flow resistance data suggests there may be another mechanism at play. As can be seen in Figure 5, there is a period of a few days after the chemical dosing is turned off before the scaling rate increases. This could indicate that the chemical binds to the surface of the scale already present in the heat exchangers, providing a barrier that inhibits further rapid scale growth. This protective barrier appears to survive for a few days but could eventually be stripped from the scale surface by the SGW flow.

Further research into the inhibition mechanism is currently underway and will be reported in due course.

3. CONCLUSIONS

The downhole calcite scale inhibitor injected at WK-123A also inhibits silica scaling at the Wairakei binary plant heat exchangers. This is an unexpected benefit of the downhole chemical injection and has resulted in reduced mechanical cleaning frequency since 2018, when downhole chemical injection was first installed. Now that the link between downhole calcite scale inhibitor injection and reduced scaling at the Wairakei binary plant has been identified, there is the opportunity to sustain the chemical treatment even when the well is not flowing and to optimise the dose rate.

A field trial was conducted to determine if the same scale inhibition effect is achieved from an alternative, surface injection location. This proved successful and will be implemented as a permanent plant modification, to enable injection at this point whenever WK-123A is not flowing to the binary plant. Adding surface injection will limit scale build-up during these WK123A outages and further reduce the frequency of mechanical cleans at the binary plant.

Given that we have seen a positive impact on scaling at the binary plant, there may also be further downstream benefits in the injection pipeline and injection wells. A study into any enhancements associated with chemical injection, including reinjection well decline rates before and after injection of GEO907, is currently ongoing and will be reported in due course.

Further research is planned with Nalco to better understand the mechanism of the silica scale inhibition. It is hoped this research will help identify other opportunities where this scale inhibitor could be used to reduce scaling in other power plant or well operations.

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