Evaluating Effectiveness of Calcite Antiscalant for Field Application

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ABSTRACT

Calcite scale deposition can significantly affect the performance of production wells supplying fluids to a geothermal power plant. Depending on the level of fluid oversaturation with respect to calcite and the rate of scale deposition, production from a geothermal well can decline by as much as 50% in one year. Mechanical clean-out and acidising are two commonly used options to recover loss in productivity due to calcite deposition inside the wellbore. These are however expensive options of managing calcite scaling in addition to cost of business interruption with wells needing to be taken off-line from the power plant.

Accurate assessment of the calcite saturation index based on the fluid chemistry analysis, and any early indication of calcite scale deposition, is very valuable as scaling within the wellbore can be proactively managed through the use of antiscalant chemicals. The antiscalant is normally dosed below the flashpoint using a capillary tubing to prevent blockage formation inside the wellbore and maintain production from a geothermal well. This option is considered cost-effective but requires a rigorous process of selecting the suitable antiscalant chemical for the chemistry of the fluid produced and the downhole temperature-pressure condition of the geothermal reservoir.

This paper will discuss the selection process of antiscalant chemicals available in the market and the subsequent laboratory testing required prior to an actual short-term field trial. This paper will also discuss the requirement for long term monitoring of well performance for an overall evaluation of the antiscalant effectiveness in controlling calcite scaling.

1. INTRODUCTION

Calcite scaling in production wellbores is one of the major operational problems encountered by many geothermal field operators. This process normally occurs just above the flash point inside the wellbore and in theory, is governed by the chemical reaction below (Arnórsson, 1989):

$$Ca^{2+} + 2HCO_3^- = \overset{solid}{CaCO_3\downarrow} + H_2O + \overset{gas}{CO_2\uparrow} \qquad \textbf{Eqn. 1}$$

Flashing can lead to loss of CO_2 and increase in the reaction activity of Ca^{+2} in the residual liquid. The degassing also increases fluid pH, and for bicarbonate to be converted into $CO3^{-2}$. This causes the oversaturation of the residual liquid with respect to calcite mineral, and the subsequent scale nucleation/deposition process is responsible for the calcite blockage found inside wellbores of production wells.

The location of the calcite blockage varies in each well but this coincides mostly with the flash point location as illustrated in Figure 1. For Well A, the flash point is located at shallower depth inside the wellbore, and this is the depth where calcite blockage was also tagged. In the case of Well B, calcite blockage was encountered at much deeper depth since the flash point location for this well is deeper compared to Well A.

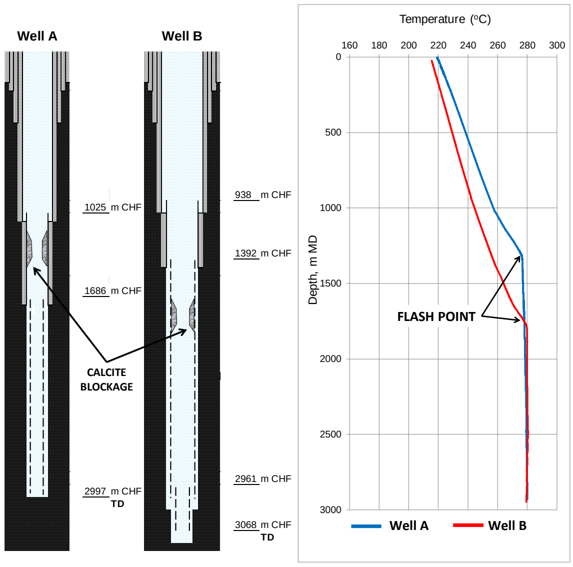

Figure 1: Location of calcite blockage in the wellbore coinciding with the flash point location.

The rate of scale deposition in the wellbore is mostly controlled by the level of fluid saturation with respect to a certain mineral in addition to the production massflow rate. For fluid saturation with respect to calcite, this is measured in terms of calcite saturation index (CSI) as plotted in Figure 2 against boiling temperatures.

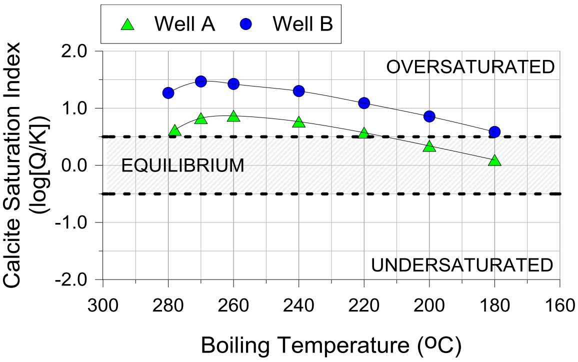

Figure 2: Fluid saturation with respect to calcite mineral at different temperatures.

A CSI above the equilibrium saturation level suggests high potential for calcite scaling in the wellbore where flashing occurs due to changes in pressure-temperature condition. The highest potential for scaling is usually within the flash temperature range of 240-280ºC in which the CSI is at the highest level, and this decreases below 220ºC due to retrograde solubility of calcite with temperature (Arnórsson, 1982).

There are special cases when even if the saturation level is close to equilibrium the scaling rate (based on production impact and wellbore inspection) is still significantly high (Quinao et al., 2017). But if the two conditions are present (e.g. high massflow production, high oversaturation level) then it is expected that scaling would occur at a rapid rate.

Figure 3 illustrates the effect on massflow of a production well due to scaling. The massflow can decline by as much as 50% in less than a year where scaling rates are particularly severe.

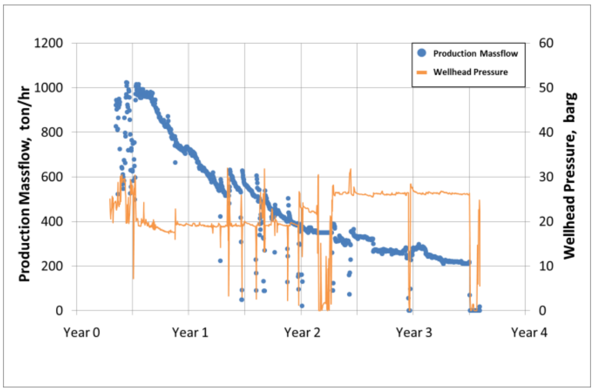

Figure 3: Effect of calcite scaling on well performance.

2. MANAGEMENT OF CALCITE SCALING

Mechanical clean-out and acidising are two commonly used options to recover loss in production from a well affected by calcite deposition inside the wellbore at flash point location. These options are however expensive to implement in addition to the cost of business interruption with wells needing to be taken off-line from the power plant. Expense costs can sometimes reach in the range of $0.5 to $2.0M for a major clean-out operation, with periodic frequency of at least every two years. Temporary mechanical broaching (running of different specially-designed gauge tools) maybe considered in a short-term but as calcite scale can harden over time inside the wellbore this become less effective, and a full mechanical and/or chemical clean-out is necessary.

Calcite scaling inside the wellbore can be proactively managed with the use of antiscalant chemicals. But this requires a rigorous process of selecting a suitable antiscalant chemical for the chemistry of the fluid to be treated. As the antiscalant needs to be dosed inside the wellbore at a certain depth and temperature-pressure condition of the geothermal reservoir, a carefully designed surface and downhole delivery system is also required.

The installation costs for a stand-alone system in a well can be between $300-500K, and higher if a centralized mixing system is needed or if there are other wells to be dosed with antiscalant. Annual chemical costs depend on the amount of fluid to be treated and the required dosage rate to effectively control scaling. However, considering less downtime and sustained performance of production well, proactive management of calcite scaling can still be considered as a cost-effective long term option.

The antiscalant chemical is ideally dosed using a capillary tubing set at a depth inside the wellbore of ~100m below the flashpoint (Figure 4). This ensures sufficient mixing of the antiscalant with the well fluids prior to flashing.

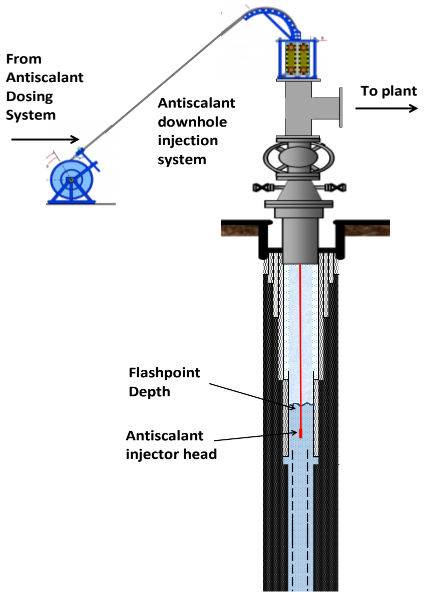

Figure 4: Schematic of antiscalant systems installed in production well.

3. SCREENING PROCESS AND FIELD TRIAL

The process of assessing antiscalant chemicals for field application may be done in three stages, and may take up to 3 months for the first two stages, and between 3-6 months for the last stage of assessment (Figure 5).

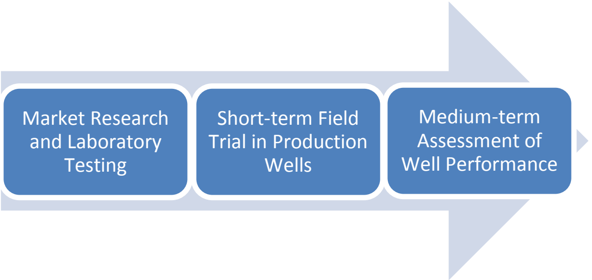

Figure 5: Stages of assessing antiscalant chemicals.

The first stage involves market research of available chemicals and their validated successful use in other geothermal fields. The short-listed chemicals can then be subjected to a laboratory testing designed specifically for the condition of the field of intended use.

Depending on the outcome of the first stage assessment, the chemical that shows the most promising performance is then programed for a field trial in actual production well downhole conditions. The field trial consists of frequent brine sampling from the production well two-phase line to monitor calcium levels, and monitoring the well massflow trend that is normalised at same wellhead pressure. If there is an existing antiscalant chemical being used, this will provide an additional comparative basis in assessing the performance of the new replacement chemical.

After the second stage assessment, and if successful control of scaling based on monitored parameters is observed, then final assessment will proceed by using the chemical over a long period of time while monitoring for the production well performance (e.g. massflow).

3.1 Chemicals Available in the Market

The most commonly used calcite antiscalant chemicals available in the market can be classified into two main base units as listed in Table 1.

Table 1: Calcite antiscalant chemicals.

Chemical Class	Description
Polyacrylic Acid (PAA)	Straight chain monomer with one carboxylic (COOH) group
Polymaleic Acid (PMA)	Monomer ring with two carboxylic (COOH) groups

The polymer of these antiscalant chemicals develop negative charge in water and attaches itself to the growing $CaCO_3$ micro-crystals causing distortion and interference with the ability of the crystal to keep growing in a precise geometric pattern. The large negative charge imparted on the aborted micro-crystal will cause it to repel other like particles. The net effect is that very small non-adherent crystals are formed which can be easily swept away by fluid flow inside the wellbore.

Both PAA and PMA are currently being used in several geothermal fields in New Zealand. The short-listing process of antiscalant chemicals in the market involves looking into the following factors:

- Known application in other fields – information around this can be gathered from other operators, conference proceedings, or directly from the chemical suppliers
- Temperature application or limitation - thermal stability test results are normally available from the chemical suppliers

Thermal stability is an important factor to consider in the selection process of antiscalant chemical to use especially in a high temperature geothermal reservoir. Degradation of the chemical can happen if it is not suited for the high temperature application. This can either result in blocking of the downhole capillary tubing used to deliver the antiscalant chemical inside the wellbore or make the antiscalant chemical less effective and therefore cause calcite deposition in the wellbore. A standard method of testing for thermal stability and inhibition effectiveness is discussed in the next section.

Once the above factors can be satisfied, other factors are also evaluated such as supply chain/security and chemical costs.

3.2 Laboratory Testing and Screening

Samples of selected antiscalant chemicals are provided to GNS Laboratory for thermal stability and NACE test (NACE International, 2007). These laboratory tests are designed to evaluate the calcite inhibition properties of these chemicals at high temperature application similar to actual downhole condition of production wells where these chemicals will be used.

The inhibition performance of the selected chemicals is first measured under no heat treatment condition. For this purpose, a 10% by wt solution is prepared, added to synthetic brine, and assessed following the NACE standard test (TM0374-2007) procedure relative to the blank (untreated control).

Another 10% by wt solution is prepared in a SS316 tubes, capped and blanketed with nitrogen, before being subjected to heat treatment in a forced-draft oven. The target temperature for heat treatment can be as high as 300-320^{o}C and the duration can vary between 2 to 6 hours. The heat treated solution is then added to synthetic brine and assessed following similar NACE standard test procedure. The target concentration for the NACE test can range from 5 to 10 ppm, and is based on the chemistry of the fluid to be treated particularly on the calcium concentration.

Typical results from a NACE/thermal stability tests are shown in Table 2. From the data, it is evident that without heat treatment, all antiscalant chemicals selected for testing have very high inhibition performance of >95% based on $CaCO_3$ retained in solution relative to the blank (untreated control). After heat treatment however, all chemicals have shown a decrease in inhibition performance which vary to a certain degree from one chemical to another.

The antiscalant chemical that shows the highest inhibition performance will either be subjected to further laboratory validation or evaluated in the field using a test rig or in an actual production well.

Table 2: Results of thermal stability and NACE tests.

No heat treatment	**Calcium Carbonate Retained in Solution (ppm)**	**Inhibition (%)**
Chem 1	4035	98.2
Chem 2	4048	99.0
Chem 3	4025	97.6
After heat treatment	**Calcium Carbonate Retained in Solution (ppm)**	**Inhibition (%)**
Chem 1	3835	85.3
Chem 2	3558	67.5
Chem 3	3255	48.0
Blank	**Calcium Carbonate Retained in Solution (ppm)**	
Before Precipitation	4063	
After Precipitation	2510	

3.3 Short-term Field Trial

Field evaluation of the selected antiscalant chemical can be done through a test rig that simulates the expected downhole conditions and using the actual fluid from a production well. This is usually the method employed before the full commissioning of a new geothermal power plant, with the production wells still on clearing discharge. Bump testing is done by measuring the calcium concentration in the brine that passed through the test rig with and without antiscalant dosing. During the field trial, a series of samples are collected over several days for calcium analysis.

For geothermal fields that have been operating for a certain period of time, substantial information on calcite scaling is available based on production well history. Hence, it is possible to conduct field trial to evaluate effectiveness of antiscalant chemical in actual test condition by using a particular set of production wells.

This is further enhanced if there is already an existing antiscalant system installed as the performance of the antiscalant chemical being used can provide a point of direct comparison. The same method of monitoring calcium concentration can be employed over the field trial period as long as there is a clear trend observed in calcium concentration during a bump test.

Figure 6 shows the results of the bump test and comparative assessment of two antiscalant chemicals conducted in production well B. This well has been known to develop calcite scale previously hence an antiscalant system was installed to mitigate this.

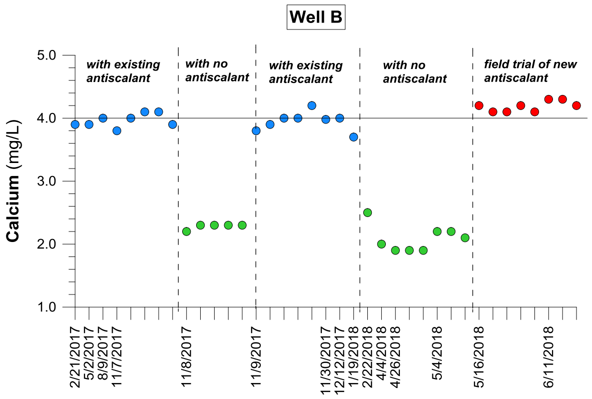

Figure 6: Results of bump tests and comparative assessment between two antiscalant chemicals.

The first bump test on the existing antiscalant chemical shows the response in calcium concentration when antiscalant dosing was stopped temporarily. From this simple check, it was confirmed that monitoring of calcium concentration can be used to assess the performance of the antiscalant and as an indication of calcite formation and deposition (e.g. calcium loss). This was further confirmed in early 2018 when antiscalant dosing was stopped in production well B due to downhole tubing maintenance. During this period, the calcium concentration has dropped again to a level similar to the calcium concentration measured during the first bump test.

After the recommissioning of the antiscalant system, the field trial of a new chemical being evaluated was started. The results showed that calcium concentration has increased back to a level even higher than previously measured when using the existing antiscalant chemical. From the trend in calcium concentration, it is clear that the new chemical also works, and even more effective in keeping the calcium in solution and in preventing the calcite from forming.

4. DISCUSSION

Subjecting a selection of antiscalant chemicals in the market to a combined NACE and thermal stability tests is a good process to identify an antiscalant chemical that is suitable for field application. These tests provide initial information on the temperature limitation and inhibition performance of the antiscalant chemical, in addition to increasing confidence to proceed with the field trial of the chemical. The field trial will further confirm if the antiscalant chemical will be effective in controlling calcite scaling at the actual downhole conditions.

During the field trial, monitoring of production well massflow can also be done to assist in the antiscalant performance evaluation. In some cases, it may not be possible to see a response in the massflow trend especially if the field trial period is less than 2 months duration. However, if the antiscalant chemical is really not effective in controlling calcite scaling then a massflow decline in a production well that has high scaling rate may be seen. In the case of well B in Figure 7, a step-change and then gradual declining trend in massflow was observed during the long period of no antiscalant dosing starting in March 2018. However, this has since stabilized after resuming antiscalant dosing with the new chemical being evaluated.

From the above discussion, both the laboratory test and field trial are considered as good first assessment processes to use. However, even if positive results from these processes are obtained, there is still uncertainty that exists on the long term performance of the antiscalant chemical. This is especially true if calcium concentration does not respond to a bump test and the only field assessment criteria is the well massflow normalised to same wellhead pressure.

With the above scenario, the validation of the antiscalant effectiveness in controlling calcite scaling also need to be done over a long period of time (e.g. >3-6 months) and may involve frequent monitoring of the production well massflow and downhole wellbore inspection.

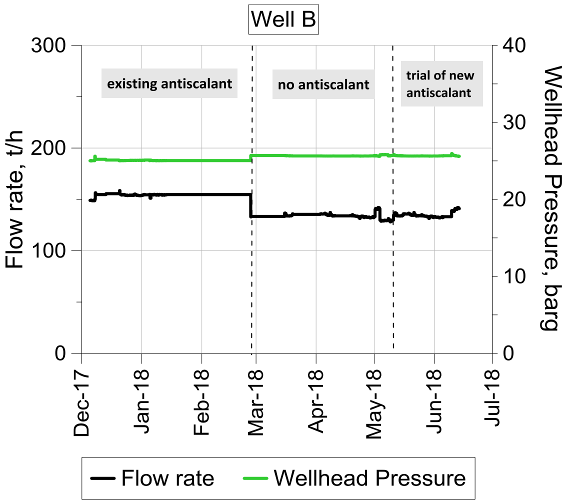

Figure 7: Historical massflow trend monitored during the field trial.

5. CONCLUSION

Calcite scaling in production wells can be proactively managed with the use of antiscalant chemicals. However, it is important to have a standard best practice process that will identify and evaluate a suitable chemical for the field conditions under which it is to be used.

A combination of NACE and thermal stability tests can be employed to determine the inhibition performance and temperature application of the antiscalant chemical. This information can be used as basis to proceed with a short-term field trial in an actual production well or with the use of a test rig.

It is however important that any positive results obtained from the initial screening processes (e.g. laboratory, short-term field trial) should be validated through long term monitoring of production well performance and wellbore condition (e.g. no tagged blockage).

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