REMOVING SILICA FROM GEOTHERMAL WATER - RE-DESIGN OF THE PILOT PLANT AND INVESTIGATION OF OPERATION AT ELEVATED PRESSURE

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ABSTRACT

The nano-structured calcium silicate hydrate (CaSil) technology has been developed as a solution for the formation of silica scale from geothermal brine. It has been matured from laboratory scale to pilot plant stage. The CaSil technology is successful in reducing silica in geothermal water to safe usage and re-injection levels, even at low temperatures.

However, while the initial version of the pilot plant built was useful as a proof of concept, it had several shortcomings. Namely it was work intensive, allowed little control over the products collected, and the separation process for recovery of CaSil from the brine was only designed to work at atmospheric pressure. Work on the first proof of concept plant proved that the process is very sturdy; none of the shortcomings had any significant impact on the plant operation.

In this paper we present our pathway towards the next iteration of pilot plant, which will address many of the issues encountered in the old plant. We are also outlining further research towards using the separator technology under elevated pressure.

1. GEOTHERMAL ENERGY AND THE FORMATION OF SILICA SCALE

The development and expansion of energy production from wet geothermal sources is held back by scaling and corrosion issues. Since the world's first wet source geothermal power plant in Wairakei, New Zealand started to operate more than 60 years ago the formation of especially hard intractable silica scale has posed a costly hurdle that restrains the geothermal industry to this day (Zarrouk and Moon, 2014).

Below ground in geothermal reservoirs rock dissolves due to chemical and biological processes releasing silica and other species into water depending on the temperature and rock structure surrounding the water. When the water is sourced to the surface for energy production, the silica and dissolved species can become supersaturated and precipitate as scale (White and Mroczek 1998). They can also lead to corrosion and abrasion issues. In a flashing plant the pressure and therefore the temperature of the geothermal water are lowered to produce steam for energy generation. About 30 % of the liquid is boiled off into steam phase to drive a turbine. Therefore, silica and other dissolved species remaining in the water are concentrated up above saturation levels (Iler 1979, Marshall and Chen, 1982). However, some fraction can be carried over into the steam phase and subsequently damage turbine blades. Therefore, the steam is scrubbed with cold water and channeled through cold traps, which entails a loss of energy from the steam (Arifien et al., 2015; Zarrouk and Muggang, 2015). Meanwhile the supersaturated material in the spent brine can precipitate to form scale. Downstream heat energy extraction through a binary cycle lowers the temperature of the brine further. Lowering the temperature in turn decreases the silica solubility to yield an even more supersaturated mix (Montague, 2013).

Current adopted approaches to prevent silica scaling only delay the onset of silica deposition (Gallup, 1999; Gill, 1998; Gunnarsson and Arnórsson, 2005). We have matured the nano-structured calcium silicate hydrate (CaSil) technology, which transforms silica into a silicate, leaving the dissolved silica concentration in the brine well below saturation levels (Borrmann et al., 2018; Johnston et al., 2018). The silicate forms micro-particles that due to their surface charge do not stick to metals and can trap calcite on their surface. CaSil provides a slightly passivating environment, which assists in protecting pipes and equipment from corrosion. The CaSil particles are too large and reactive to be left in the brine for reinjection as they could block the porous structure of the rock and need to be separated (Borrmann et al., 2009). However, after days of exposure to the down-well temperatures and slightly acidic or neutral pH levels they slowly release the silica again into solution and fall apart (Barassi, 2013). Small carryover from the separation process in form of micrometer scale particles are therefore non-threatening to operation.

In August 2017 we built and commissioned our first continuously operating pilot plant and operated it during 2017 and 2018, collecting data (**Figure 1**) (Borrmann et al., 2018). The plant sources spent geothermal brine from the Wairakei power plant located about 500 m away downhill. The brine is taken from the stream entering the binary plant. Due to this location and the comparatively low flow rate through our source pipe most silica precipitated already in our supply line. Only a small part of the silica (about half of that recorded at Wairakei directly) contained in the brine reached our pilot plant. As carbonate did not precipitate along with the silica, the brine contained a higher than expected amount of carbonate relative to the silica targeted in this project leading to the formation of side products (such as calcite). Despite these unfavorable conditions the plant demonstrates that we can transform dissolved silica from geothermal brine and establish safe operating conditions without risking silica scale. Depending on the dosing regimen we can lower the residual silica concentration below saturation level or transform almost all silica. This opens up the possibility of an enhanced energy extraction as well as downstream mineral and metal extraction methods. A lamella separator was successfully employed in the recovery of CaSil, calcite and gravel during normal operations, as well as already formed silica during a dosing pump failure. The field experiments were very successful with more than 90%w/w of the solids contained in the geothermal water being recovered (Schweig et al., 2018). Prior to this, laboratory scale experiments had shown that up to 99.8

%w/w of solids can be recovered for higher initial silica contents in the geothermal brine. The decline in separation efficiency can be explained due to the lower levels of solids in the suspension. The CaSil particles naturally agglomerate in calm flowing conditions. Due to the low levels of solids present the flocculation of the solids did not occur to the extent observed in prior experiments, which reduced the sedimentation velocity and hence the efficiency of the recovery. Additionally, high temperatures around 85 °C in the separator caused noticeable convection currents, which disturb the separation process.

Figure 1: Sketch and Photo of test rig.

Operation of the pilot plant showed several venues for improvement, which we are in the process of implementing. In this article we are presenting the changes to the plant, which will be implemented during Q2 and Q3 of 2019. Some developments like the implementation of solid-liquid separation under pressure require some further research. Our plans for the research and the questions to be answered will also be discussed below.

2 IMPLEMENTATION OF THE CASIL TECHNOLOGY IN A PRESSURIZED SYSTEM

The current CaSil plant operates at ambient conditions in the solid-liquid separation stage. While the dosing stage has already been adapted for low pressure, the separation stage occurs at atmospheric pressure (Figure 1). This flashing step was included to simplify separator design during the initial stages of our project. Operating under pressure at the separator outlet would have obvious advantages for plant operators. This enables the CaSil technology to be implemented in closed, fully pressurized systems, such as purely binary cycle plants. The retained pressure can also be used to propel the geothermal brine to remote reinjection wells with unfavorable geodetical differences. While we don't expect any significant influence of the pressure on the performance of the lamella separator, we have to prove and demonstrate this estimation. In contrast we have observed that thermal currents can disrupt the settling of CaSil particles significantly. Therefore, an operation of the separation process at comparatively low temperatures around 50 - 60 °C is desirable. This temperature range significantly decreases the likelihood of thermal currents, while the settling behavior still profits from a decreased viscosity of the brine. For this we are going to implement a heat exchanger into our process (see below). To prove the concept of CaSil separation under pressure a prototype build out of Perspex will be developed and tested in the laboratory. The transparent nature of Perspex allows observation of thermal and other currents using dye experiments and has been employed successfully in the past.

The dosing section of the CaSil technology can be readily implemented at comparatively high pressures and is only limited by pump technologies, as the dosing agent has to be injected as a slurry. However, CaSil can be formed under hot wellhead conditions during or prior to flashing for energy generation step. As CaSil is a micro-particulate and is sparingly soluble, it should prevent carryover of silica and other species like arsenic into the steam. If carryover can be prevented or at least mitigated turbine blades are protected from deposits and scale, which consequently damage the blades and reduce the efficiency. Steam scrubbing becomes less essential and the accompanying energy loss declines. However, using the CaSil technology prior to flashing for energy generation is so far unproven. Several research questions arise, which are listed below:

1. Does CaSil influence the vapor pressure of a geothermal water?

2. Is CaSil carried over into the steam?

3. Does it minimize or even prevent the carryover of silica and calcite in the steam phase?

4. How much does treatment with CaSil lower the temperature of geothermal water?

5. From before: Does lamellar separation under pressure incur any turbulence that impedes or prevents settling and recovery of CaSil particles from geothermal water?

Research to answer these questions is under way and results from the preliminary findings will be presented at the World Geothermal Congress in Iceland 2020 and GRC 2020. Question 1 to 3 will be answered using autoclave experiments. The answer to question 4 can be calculated and then measured and confirmed using an autoclave setup. Question 5 will be answered via prototyping (see above).

3. PILOT PLANT 2.0

Operation of our first pilot plant has shown the need for several re-designs and upgrades of the used components and general layout. The pilot plant commissioned in 2017 was designed for a flow of 8 L.min-1 of geothermal brine. It was operated successfully in the range of 2 to 16 L.min-1 due to large safety factors in the separation stage. The next iteration of the plant will be designed for 30 L.min-1. This allows us to produce more CaSil material for end use testing as well as observation of the process at higher flow rates. In the current plant 10 meters of pipe were used to provide about 1 minute of residence time and act as a small heat exchanger by natural convection. CaSil pilot plant 2.0 will use over 30 meters of piping to have a residence time of 32 seconds and also incorporate a separate heat exchanger to more efficiently lower the temperature of the brine. Target exit temperature of the heat exchanger will be 60 °C for the full brine flow rate. This allows us to prove the practicability of an enhanced energy recovery of supersaturated geothermal brines treated with the CaSil technology without inducing or promoting silica scaling on the cold end. Potential dead spots will be monitored for deposition of CaSil material, so a long continuous operation can be achieved. A set of measuring and sampling stations will allow collection of further data. Because the first plant was run purely empirically without any sensory equipment, monitoring and automation components will be introduced. A programmable logic controller (PLC) will be used to both monitor and control the plant with its actuated valves and dosing pump. The outline of the design of the pilot plant 2.0 is shown in the flow diagram in **Figure 2**.

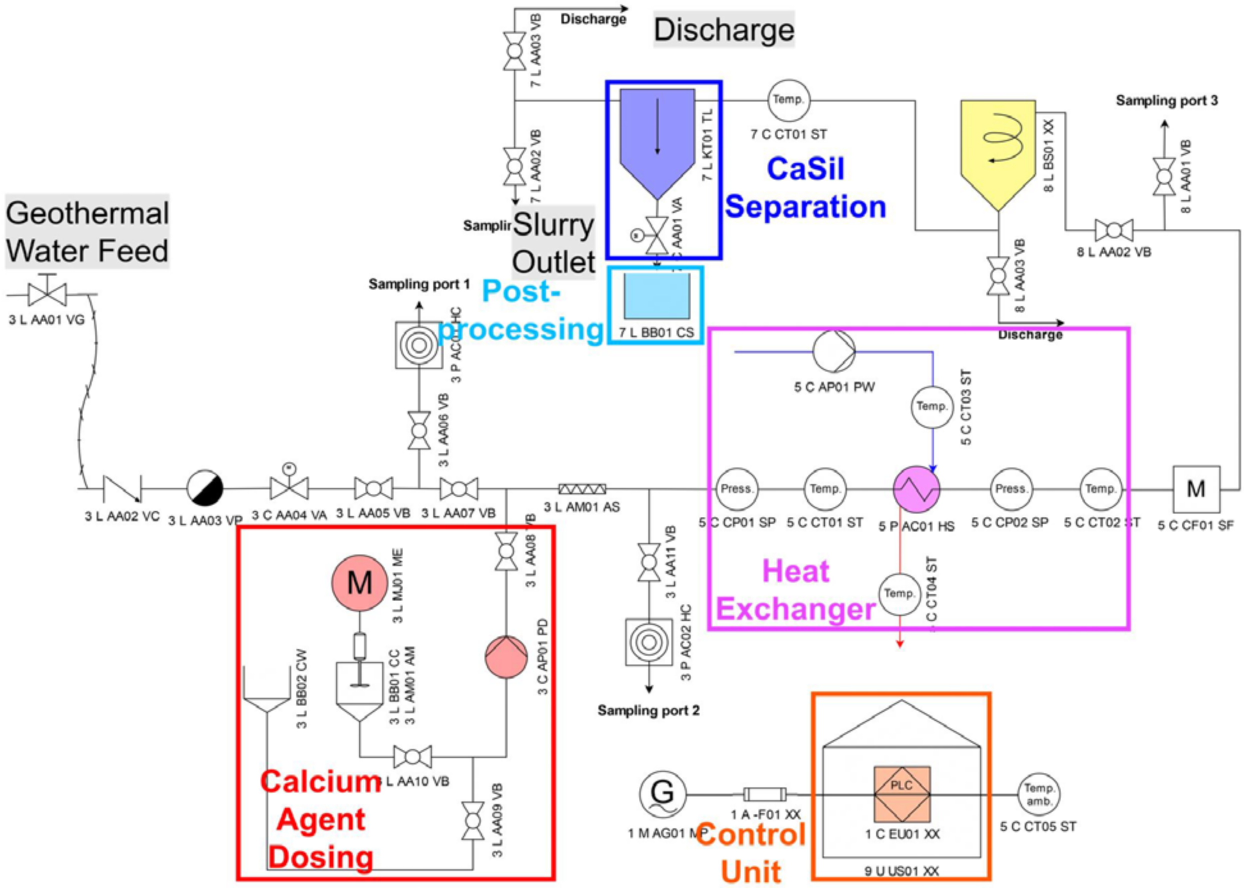

Figure 2: Process flow diagram of pilot plant 2.0.

The implementation of pilot plant 2.0 will be carried out in steps. First the pipework will be exchanged and upgraded. Then some of the new measurement equipment will be installed. Next a new lamella separator will be designed to accommodate the higher flow rate. The design process will be preceded by computational fluid dynamics (CFD) models, followed by laboratory models made out of Perspex. Dye test will be used to validate the simulated flow trajectories within the separator. Once a sufficient separator geometry is found a full-scale version will be built. A modular heat exchanger which can be easily disassembled and inspected will be designed and built as well. The design will follow a commercial tube and shell heat exchanger to make the system comparable to existing binary cycle heat exchanger systems. Tap water will be used as cooling medium, where flow rates, pressure and temperature differences will deliver the key parameters of the heat exchanger performance.

Pilot plant 2.0 will be fully commissioned in the third quarter of 2019 and results from its operation will be presented at GRC 2019 and the World Geothermal Congress in Iceland 2020. Late 2019 work will start to mount the pilot plant onto a skid for easy transport and use at various sites around New Zealand. Field trials and demonstration of the technology at different locations will build a solid and undisputable data basis for the versatility and robustness of the CaSil technology. Results will be presented at GRC 2020.

4. CONCLUSIONS

The second iteration of our CaSil technology in a pilot plant will advance the technology significantly. The operating range in terms of the flow of brine will be significantly increased. Automation will be useful in allowing overnight operation and control of the operating parameters. It will also bring the plant more in line with modern geothermal power plant operation. The pilot plant 2.0 will serve as a demonstration plant that can showcase the opportunities and advantages offered by the CaSil technology to plant operators and power companies.

In parallel to the plant upgrade we are advancing our knowledge base by investigating the separation technology and overall CaSil performance under pressure. While the CaSil technology is disruptive in a business sense, it is aimed to integrate smoothly without any disruption into the normal operation of a power plant. Increasing the range of applicability in terms of pressure will bring the technology closer to this aim. Furthermore, by exploring the impact of the CaSil technology on steam generation new opportunities for its use will be revealed.

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