SCALING PREVENTION EXPERIMENTS IN THE HELLISHEIÐI POWER PLANT, ICELAND

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ABSTRACT

The Hellisheiði Power plant produces electricity by separating geothermal fluid at 9 bar-a where steam is conducted to turbine units and the resulting separated water is flashed to 2 bar-a for additional production of steam. The 120 °C separated water is then conducted to heat exchangers for production of 88°C water for district heating. During these processes, silica super-saturation of these waters is elevated and a correct fluid handling is vital for a successful disposal of the geothermal brine.

Silica deposition experiments with varying brine/condensate ratios, acidification and brine temperature were carried out to propose a methodology to prevent scaling from the brine in pipes and injection wells. These results were then combined with selected operational and environmental parameters in order to optimize the re-injection system of the power plant.

INTRODUCTION

A successful utilization of geothermal energy depends to large extent on the ability of geothermal reservoirs to deliver fluids efficiently to production wells. Likewise the reservoir should receive spent geothermal fluids through injection wells without considerable amount of scaling to occur during the lifespan of the power plant. The amount of scaling in pipes and immediate vicinity production and injection wells may be the most determining factor on the efficiency of power production. Reykjavik Energy aims to produce electricity and hot water for district heating with minimum impact on the environment while keeping the efficiency of production and energy prices to the end user at a minimum.

POWER PRODUCTION AT HELLISHEIÐI

The power plant

The Hellisheiði Power plant is located on the Hengill central volcano which is located in the western volcanic zone SW-Iceland, approximately 20 km southeast of Reykjavík (Figure 1). Currently the Hengill area has two producing geothermal fields, Nesjavellir in the northern part and Hellisheiði in the southern part of the area. Hengill area also has two potential future production sites which are Bitra towards the east and Hverahlíð towards southeast of Hengill area. The power plant extracts the majority of its steam from the Hellisheiði heath and disposes of the spent geothermal waters to two re-injection zones, Gráuhnúkar and Húsmúli (Figure 1).
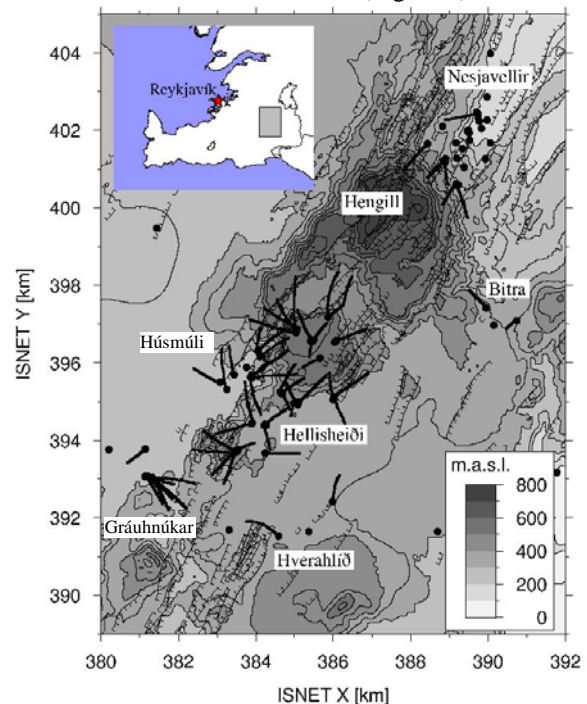

Figure 1: Location of the Hellisheiði power plant. Spent geothermal fluids are injected in Gráuhnúkar and Húsmúli regions.

Two 45 MWe units were commissioned in 2006 (Figure 2) followed by a 30 MWe low-pressure turbine extension and installation of two 45 MWe units in 2008. In 2010 heat exchangers were commissioned and the power plant will be fully developed in 2011 with the addition of two 45 MWe units. The installed net capacity will be 287 MWe and 400 MWth (Figure 2).
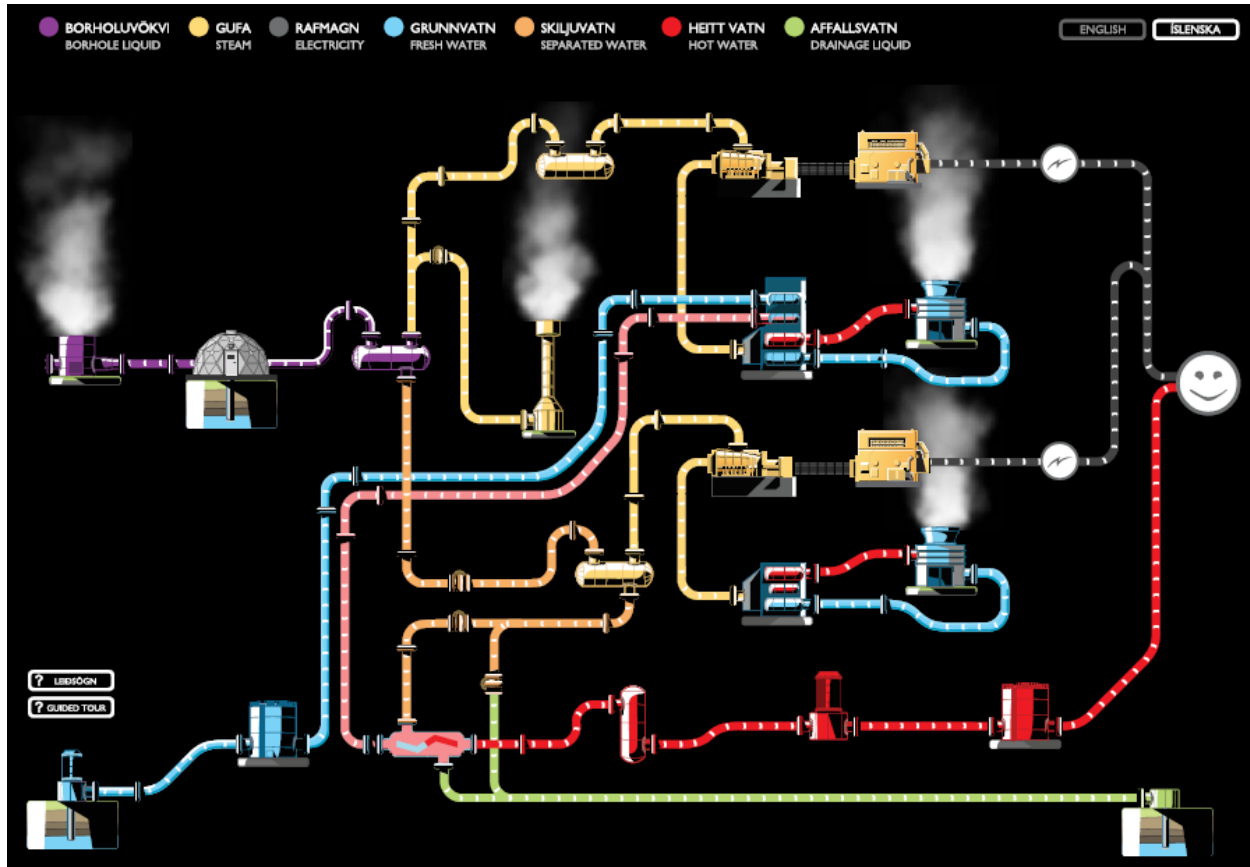
Figure 2: Overview of the Hellisheiði Geothermal Power Plant. The borehole liquid is separated at 9 bar-a and separated water (the scope of this study) flashed to 2 bar-a prior to being partially diverted to heat exchangers before being pumped to deep re-injection wells (source: www.or.is).

Fluids for power production

The Hellisheiði power plant utilizes fluids from approximately 30 wells with a mean enthalpy of 1675 kJ/kg and a mean discharge of 37 kg/s. Wells are operated at 15-25 bar well head pressure and the fluid is separated at 9 bar-a to produce 540 kg/s of steam and 650 kg/s of separated water. At full capacity, 600 kg of brine are then flashed to 2 bar-a to generate additional 60 kg of steam for the low-pressure turbine. During flashing the silica saturation state shifts from 140 ppm SiO_2 undersaturation with respect to amorphous silica to 200 ppm SiO_2 supersaturation (Figure 3). Since commission of the power plant majority of the separated water has been passed through a 3.3 km retention pipe to Gráuhnúkar where silica polymerization lowers the supersaturation to 140 ppm SiO_2 prior to re-injection to the geothermal reservoir (Gunnarsson et al., 2010) (Figure 3). Since 2008 increased proportion of separated water has been mixed with condensates to cool down the water and hence facility ate re-injection (Gunnarsson, 2011) and to lower amorphous silica supersaturation of the water to 75-150 ppm SiO2 and diverted to the Húsmúli re-injection zone (Figure 3). Although the saturation state of minerals provides indication of the risk of scaling, the timeframe observed in the interiors of power plants may not suffice for reactions to proceed to equilibrium and kinetic factors and mechanical engineering hence play important part in the scaling prevention process.
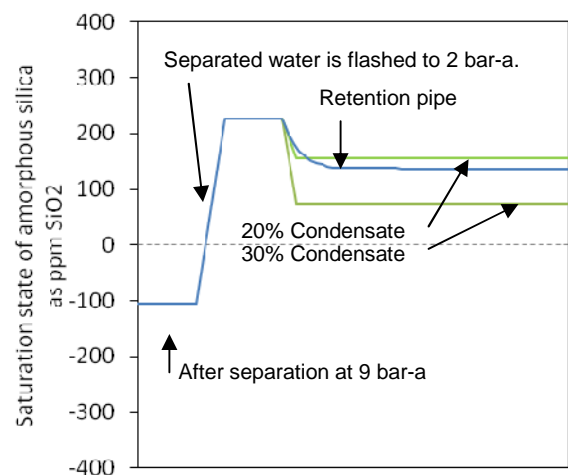

Figure 3: Amorphous silica saturation state of separated water through the Hellisheiði power plant.

Turbulent flow induced by pumps or narrow pipelines may promote silica precipitation on the expense of silica polymerization under laminar flow conditions (eg. Gunnarsson et al., 2010) and similarly alteration of pH may amend the silica polymerization and precipitation dramatically. Spent geothermal fluids may be treated with materials such as complexing agents and/or acid purchased from external sources or as an alternative, the chemicals contained in the fluids may be treated on-site with the aim of minimizing operational difficulties, facilitating re-injection and hence minimize the environmental impact of the power production (Gallup, 2003). Reykjavik Energy has commissioned extensive research on the treatment of non-condensable gases, condensates and separated waters following energy production with the aim of minimizing the release of these components to either the atmosphere or shallow groundwater reservoirs. The current contribution describes preliminary results from a series of laboratory experiments carried out to determine optimum brine/condensate/acid mixing rations during to re-injection of spent geothermal fluids at the Hellisheiði geothermal power plant. Future work will focus on the effect of temperature changes (induced by heat exchangers) on scaling processes.

MATERIALS AND METHODS

Experimental apparatus to study the effect of temperature, pH and brine/condensate ratio on the rate of silica depostion was setup adjacent to main pipelines of flashed brine and condensates from the power plant (Figure 4).

Experimental section

The retention tank was constructed of carbon steel while all other pipelines in the experimental equipment were constructed from 316 stainless steel. This was to minimize the risk of corrosion due to acid injection with resultant Fe contamination interfering with the silica scaling reactions. For pH modification experiments, concentrated hydrochloric acid was injected to the separated water through Teflon pipe inserted into the center of the stream. All pipelines were 50 mm inner diameter except pipes connecting the reaction columns which were 8 mm inner diameter. The reaction columns were composed of 50 mm inner diameter stainless steel filled with quartz sand to promote scaling reactions. The construction allowed some flexibility in the mixing and flow paths of water types to mimic possible scenarios in the industrial scale. The current contribution describes experiments where separated water (122°C) was always directed through the
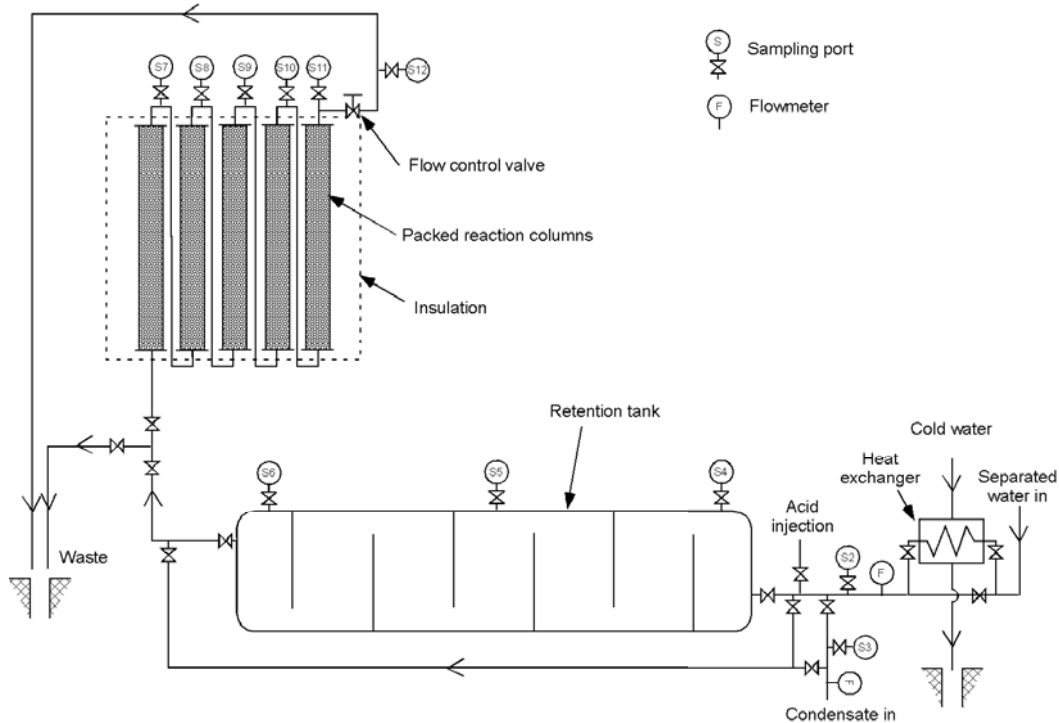

Figure 4. Experimental setup (not to scale). Flow of separate water was maintained close to 1 kg s^{-1} through the retention tank yielding 4 hours retention similar to full scale power plant conditions and between 10 and 250 mL s^{-}1 in the reaction columns yielding reaction times of 1-24 hours.

retention tank prior to entering the reaction columns.

Furthermore, during mixing experiments, condensate (35°C) was always introduced to the separated water prior the retention tank. Each experimental condition was allowed to stabilize for 24 hours prior to sampling.

Sampling and analysis

For sampling, solutions were passed through a stainless steel cooling loops prior to handling. pH was measured in a flow cell with Metrohm Aquatrode pH electrode connected directly to the cooling loop. Following pH measurement, 2 x 5 ml were pipetted into a beaker for H_2S titration with $HgAc_2$. Monomeric silica was determined on site by measuring the absorbance of the silica-molybdate blue complex in a spectrophotometer. For the analysis of total Si, total S, Cl, Na, K, Ca, Fe, Al and B, 1 ml of filtered sample was pipetted to 9 ml of 0.5% HNO_3 solution.

RESULTS AND DISCUSSION

The effect of pH adjustment on silica scaling rate

The decrease in silica concentration in untreated separator water following flashing to 122 °C was 0.15 mg SiO_2 L^{-1} hour^{-1} at pH 9.2 (Figure 4). The silica predominantly formed amorphous silica scaling but to some extent poorly defined aluminum silicates (Mean concentration of 80% SiO_2, 10% Al_2O_3 and 10% Na_2O+K_2O+CaO) were observed in the experiment and in the power plant pipelines.
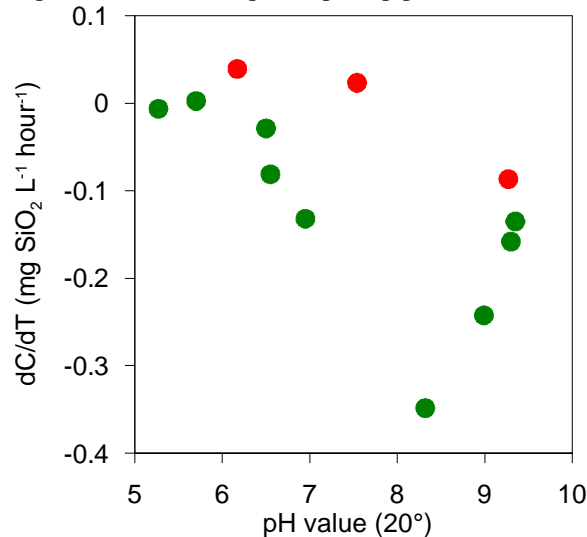

Figure 5: *Effect of pH on dissolved Si concentration changes in the separated water. Green symbols represent acidification experiments carried out at 122°C. Red symbols represent experiments were separated water was acidified and diluted with 15% condensate water.*

Acidification experiments were all carried out at 122°C, hence the saturation state of amorphous silica was not altered but rather the formation rates. Small addition of acid elevated the scaling rate and maximum rate was observed at pH 8-8.5 hence increasing precipitation rate (Figure 4). At lower pH the rate of silica scaling decreased considerably and at around pH 6.3 no scaling was observed. Below 6.3 the surface of the precipitates was sufficiently protonated to slow down the formation of amorphous silica precipitates and increase the solubility of aluminum silicates. From these results, it can be concluded that acid injection to inhibit silica scaling from geothermal brine from Hellisheiði power plant should be carried out prior to the flashing unit where silica supersaturation is elevated. pH of the water is then converted quickly from around pH 9.3 to below 6.3 to inhibit silica scaling in the pipelines between the flash tank and re-injection boreholes.

The effect of dilution of separated waters with condensates on silica scaling rate

The effect of diluting the separated water with 35 °C condensate is displayed on Figure 6. The condensate water that is low in all dissolved solids dilutes the separated water, hence lowering the silica supersaturation and which leads to decreased precipitation rate (Figure 6).
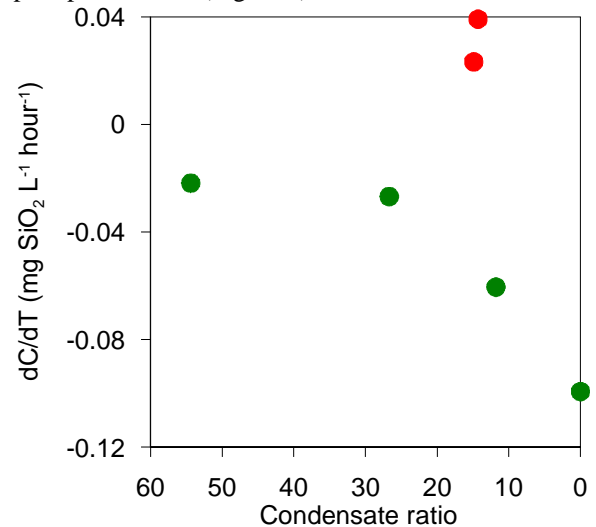

Figure 6: *Effect of condensate additions to separated water on dissolved silica concentration changes in the mixture. The green symbols to the far right on Figures 5 and 6 represent corresponding experiments. The red symbols represent experiments where the mixture was acidified to pH 6.1(top) and 7.5(bottom) respectively.*

Cooling of the brine-condensate ratio also decreased the rate of precipitation. Dilution with condensate was linearly proportional to precipitation rate until the condensate was 30% of the mass. Some decrease

in silica concentration was evident even when the mixture was 50% condensate but it is difficult to say whether it was caused by errors in the mixing ratio which also lowers silica concentration or silica deposition. pH value of the mixture did not change significantly because of to the buffering capacity of the brine due to dissolved silica and lack of acids (H_2S and H_2CO3) in the condensate water.

Combined effect on of pH adjustment and dilution with condensates on silica scaling rate

Although pH adjustment to below 6.3 slows down silica scaling in pipelines without causing too much risk of pipe corrosion it may not stop scaling and a dilution of the separated water with condensate may decrease the risk even further. Condensate addition decreases the supersaturation of silica and cools down the water mixture and both factors slow down the precipitation rate significantly. Slowing down precipitation rates is of importance since turbulent flow induced by narrow pipelines favors silica precipitation over silica polymerization under laminar flow conditions as the water enters the feed zones adjacent to re-injection wells there is plenty of rock surface where precipitation may occur. Results from experiments where the separated water was initially acidified and then diluted with condensate water are displayed in figure 7.
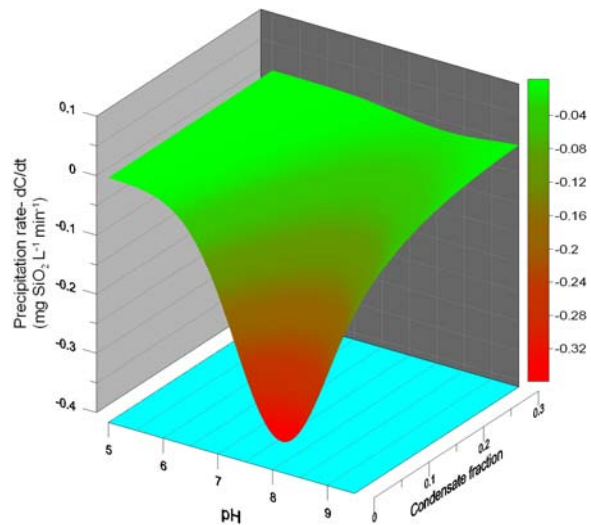

Figure 7: The combined effect of acidification and dilution with condensate on the precipitation rate of silica. The highest risk of scaling is observed if a small amount of acid is added to the separator water and without any dilution. The risk may be lowered most effectively by decreasing the pH to below 6.3 and diluting the separated water with condensate.

CONCLUSION

The separated water of Hellisheiði power plant is supersaturated in amorphous silica following flashing from 9 to 2 bar-a to produce additional steam for low pressure turbines. The rate of silica precipitation from the separated water was slowed down substantially under laboratory conditions by lowering the pH of separated water from pH 9.3 to below 6.3. Dilution of the separated water with 15 % condensate water additionally decreased the precipitation rate making it a favorable inhibition method to prevent silica scaling from spent geothermal brine at Hellisheiði power plant. Prevention of silica scaling is in the case of Hellisheiði a key element for successful injection of brine.

Future experiments to prevent scaling from the geothermal brine involve injecting sulfuric acid produced in other experimental facilities at the Hellisheiði power plant in the separated water and pumping the water to re-injection wells.

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