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Calcite Scaling at Selfossveitur Hitaveita, S-Iceland, when Mixing Waters of Different Chemical Composition

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ABSTRACT

The Selfossveitur district heating company in South Iceland has utilized the Thorleifskot and Laugardælir low-temperature reservoir for over fifty years. The geothermal water from the reservoir is relatively dilute, with chlorine content of 200 to 400 mg/l, silica content 60 to 120 mg/l and pH 8.5 to 9.0. The reservoir temperature is 100 to 120°C at the depth of 1000 m. In the year 2000 an exploration/production well was drilled into a nearby reservoir at Ósabotnar with a temperature of 90 to 100°C at 1000 m. The water is more dilute, with chlorine content of 50 to 60 mg/l, silica content 70 to 75 mg/l but pH as high as 9.8 to 9.9. Pumping from the Ósabotnar well started early 2002 and the water was mixed with waters from producton wells in the Thorleifskot and Laugardælir fields. Soon scaling problems were encountered in the central pumpstation were calcite was deposited in the pumps that feed the distribution system. Calculations showed that a mixture of the two water types, although rather similar in composition, became more supersaturated with respect to calcite than water from individual wells. To respond to this problem experiments were performed in 2003 where water from the Ósabotnar well was acidified with sulfuric acid to lower the pH value before mixing. The results were promising and today the water from Ósabotnar is acidified with concentrated sulfuric acid and mixed with waters from other production wells utilized by Selfossveitur, without scaling problems.

1. INTRODUCTION

Selfossveitur electric utility and district heating services (*hitaveita* in the singular and *hitaveitur* in plural), supplies electricity and hot water to the town of Árborg, including Selfoss, Stokkseyri and Eyrarbakka, South Iceland, with approximately 6200 inhabitants.

The district heating service draws water from two reservoirs, the Thorleifskot and Laugardælir reservoir and the Ósabotnar reservoir (Figure 1). The Thorleifskot and Laugardælir reservoirs have been the main source of hot water from 1948, when the town of Selfoss began the utilization of thermal water for domestic heating. Initially water was pumped from shallow wells at Laugardælir, and later at Thorleifskot. The early production wells had to be abandoned one by one due to the inflow of cold groundwater (Tómasson, 1980; Tómasson and Halldórsson, 1981). New wells were drilled and cased to a greater depth and today, Selfossveitur utilizes six main production wells (Table 1), four in Thorleifskot, one in Laugadælir and one in the newly discovered Ósabotnar field.

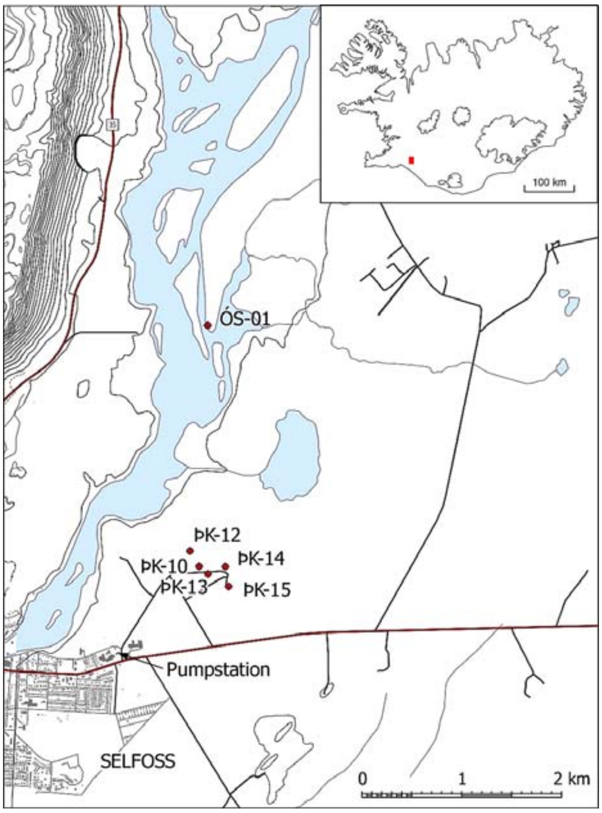

Figure 1: Selfossveitur, geothermal fields and production wells.

Table 1. Present production wells of Selfossveitur.

Well	Depth (m)	Casing depth (m)	Year of drilling
Thorleifskot			
ÞK-10	1860	311	1979
ÞK-13	1715	540	1985
ÞK-14	1433	464	1989
ÞK-15	2381	626	1999
Laugardælir			
ÞK-12	1936	305	1983
Ósabotnar			
ÓS-01	804	150	2001

Downhole temperature and water chemistry of the reservoirs are monitored on a regular basis and at present cooling has been observed to the depth of 650 m in the Thorleifskot reservoir (Sigurðsson et al. 2002). In order to explore for new geothermal reservoirs in the neighbourhood of Árborg, Selfossveitur engaged in a rather extensive geothermal exploration program by drilling a number of shallow temperature gradient wells. This led to the discovery of the Ósabotnar reservoir, some 4 km north of Selfoss (Figure 1) with a reservoir temperature of approximately 90°C. The production well ÓS-01 was drilled to 386 m in May 2000 and to the final depth of 804 m in January 2001.

2. CHEMISTRY OF THERMAL WATER

The geothermal water from the Thorleifskot and Laugardælir reservoirs is relatively dilute, with chlorine content of 200 to 500 mg/l, silica content 60 to 120 mg/l and pH 8.5 to 9.0. However, with respect to most other low-temperature geothermal areas in Iceland the salinity is relatively high. The reservoir temperature is 100 to 120°C at the depth of 1000 m. The Ósabotnar reservoir has a temperature of 90 to 100°C at 1000 m. The water is more dilute compared to the Thorleifskot and Laugadælir reservoirs, with a chlorine content of 50 to 60 mg/l, silica content 70 to 75 mg/l, and pH around 9.8 to 9.9. Table 2 showns recent, and representative, analysis of geothermal waters from each reservoir. The salinity of the water is believed to originate from sea water which covered the area in early post-glacial time and percolated into the bedrock.

Table 2: Chemical compostion of geothermal water from three production wells, one from each reservoir (mg/l).

Reservoir	Thorleifskot	Laugardælir	Ósabotnar
Well	ÞK-13	ÞK-12	ÓS-01
Date	2001.01.29	1999.03.02	2004.02.04
Temp. °C	71.7	118	79.5
Disch. (L/s)	71	5	38
pH/°C	8.5/23	9.0/22	9.8/23
CO_2 (t)	25.5	8.2	9.9
H_2S	0.07	0.21	0.16
SiO_2	59.8	110.7	71.0
B	0.10	0.32	0.19
Na	152	273	73.7
K	3.61	10.3	1.24
Mg	0.102	0.009	0.002
Ca	31.3	31.9	7.13
F	0.21	0.20	0.67
Cl	230	376	70.0
SO_4	51.1	143	29.7
Al	0.016	0.148	0.097
Mn	0.002	0.001	0.001
Fe	0.009	0.005	0.004
TDS	522	890	285
δD (‰)	-64.4	-78.1	-65.6
δ^{18}O (‰)	-9.28	-10.27	-9.65

Downhole temperature and water chemistry have been monitored on a regular basis for the Thorleifskot and Laugardælir reservoirs for a long time and for the Ósabotnar area from the beginning of production. The Thorleifskot reservoir has experienced continous cooling from the start of production, as cold groundwater percolates from the top downwards, lowering the temperature in the uppermost several hundred meters. At present the cooling rate in the uppermost part amounts to approximately 1°C/year measured in stagnant observation wells (Figure 2) and has reached the depth of 650 m (Sigurðsson et al., 2002).

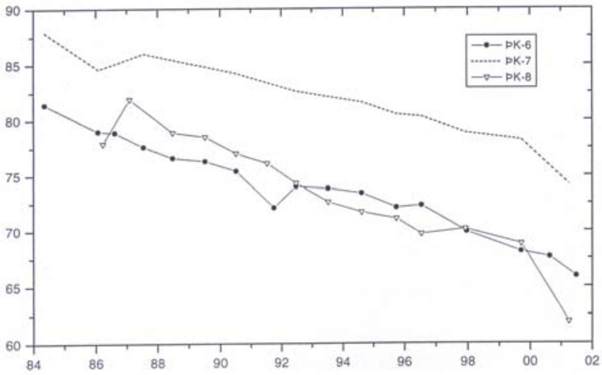

Figure 2: Temperature of the Thorleifskot resevoir at 400 m depth, 1984 - 2001.

The water from each production well is sampled once a year for total chemical analysis. Samples for selected elements, e.g. chloride and silica, are collected more frequently if needed. A modern SCADA system is used for the whole system and the well output temperature and discharge recorded.

Well ÞK-13 started production 1986 and has since been the main production well. Figures 3 and 4 show the silica and chloride content of water from well ÞK-13 and ÓS-1 and Figure 5 shows the pH of the water. The figures demonstrate clearly the chemical differences between the Thorleifskot water on one hand and the Ósabotnar water on the other, especially with respect to salinity and pH.

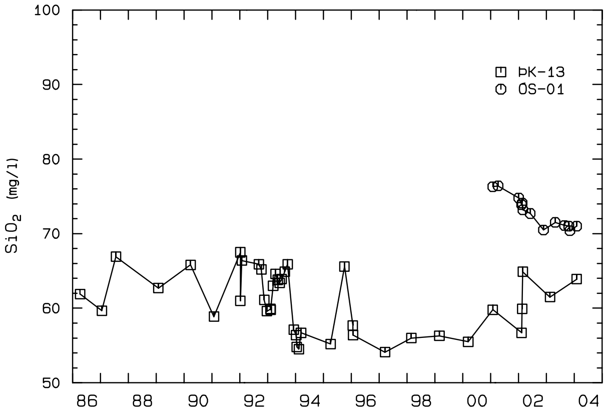

Figure 3: Silica content of water from wells ÞK-13 and ÓS-01.

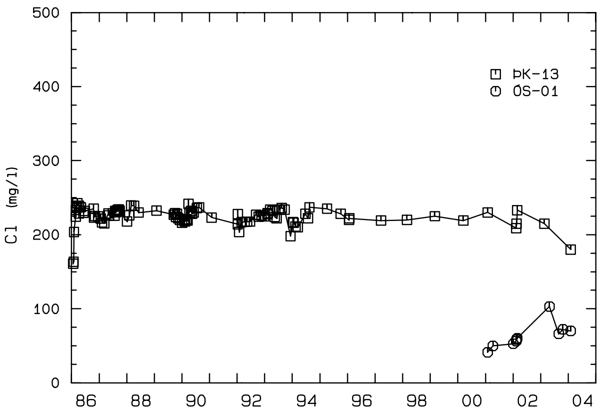

Figure 4: Chloride content of water from wells ÞK-13 and ÓS-01.

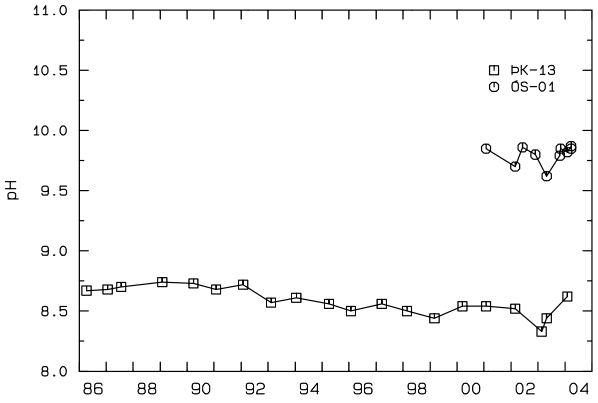

Figure 5: pH of water from wells ÞK-13 and ÓS-01.

It is also evident from Figures's 3-5, that the chemical composition of the geothermal water from the wells at Thorleifskot has not changed to the same extent as the temperature of the reservoir (Figure 2). This may be explained to some extent by heat mining from the reservoir rocks and a continous inflow of cold groundwater replacing the hot water pumped from the reservoir. The main reason for this differens is however that the production wells have been cased to great depths blocking the inflow, whereas the downhole temperature monitoring is performed in stagnant observation wells with perforated casings.

3. CALCITE SATURATION AND SCALING

Well ÓS-1 went into production in January 2002 and the water is mixed with waters from Thorleifskot and Laugardælir in the main pipeline feeding water to the central pumpstation (Figure 1). Soon scaling problems were encountered in the pumstation were the scale deposited in the pumps that feed the distribution system. Analysis of the scaling showed that it consists of calcite. The main pumps had to be dismantled and cleaned and the operation was continued without using water from well ÓS-1. During the summer of 2002, when the demand for hot water was less than during the cold months of winter, water from well ÓS-1 was mixed with water from well ÞK-14, one of the wells at Thorleifskot. The chemical composition of water from well ÞK-14 is to some extent similar to the composition of water from well ÓS-1, and it had been demonstrated that these two wells could be used simultaneously, without scaling problems. During the winter 2002 - 2003 the ÓS-1 well was disconnected and in the spring of 2003 a decision was made to run some experiments with acid injection into water from the ÓS-1 well to lower the pH of the water.

Experience in Iceland of utilization of low temperature reservoirs has shown that geothermal waters are in general slightly supersaturated with respect to calcite and for most waters scaling problems are not encountered as long as the water has a saturation index (log(Q/K)) below 0.36. Calculations of the saturation index for calcite, as well as other minerals, with the WATCH speciation programme (Bjarnason, J.Ö. 1994), for water from all production wells used by Selfossveitur were performed. The calculations showed that the waters are at equilibrium or supersaturated to some extent as shown in Figure 6 but still significantly lower than the reference value of 0.36. In most cases the well ÞK-12 has the highest saturation index. This well is also the hottest well of the area. Samples from the main pumpstation representing various mixed waters from different production wells are indicated by a black star on Figure 6.

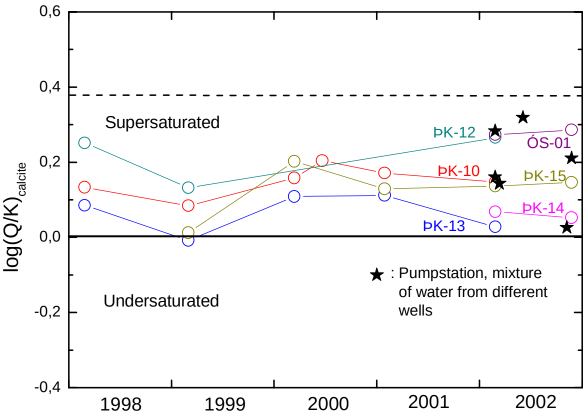

Figure 6: The calcite saturation index of water from production wells and pumpstation.

In order to study the calcite saturation index of waters formed by mixing the water from the ÓS-1 well with waters from the Thorleifskot and Laugadælir wells, speciation calculations were performed and the saturation index for calcite calculated (Ólafsson and Hauksdóttir, 2002) for different mixing ratios . The results are shown on Figure 7. From the calculations it became evident that the mixtures became rather strongly supersaturated with respect to calcite, which could explain the formation of calcite scale. This was especially evident when the ratio was 0.4 to 0.2 (i.e. the amount of water from the Ósabotnar well was in the range 40 to 20 %). However, calculations where the pH of water from the ÓS-1 well was lowered by 0.4 pH-units, to a pH = 9.5, showed the water from the ÓS-1 well to be slightly undersaturated and mixed waters only slightly supersaturated (Figure 8). Based on these calculations it was decided to perform experiments with acid injection and study the scaling potential of the mixed water after acid injection. Scaling/corrosion coupons were inserted into the pipeline after mixing in order to observe immediately whether scaling products would form during the test period.

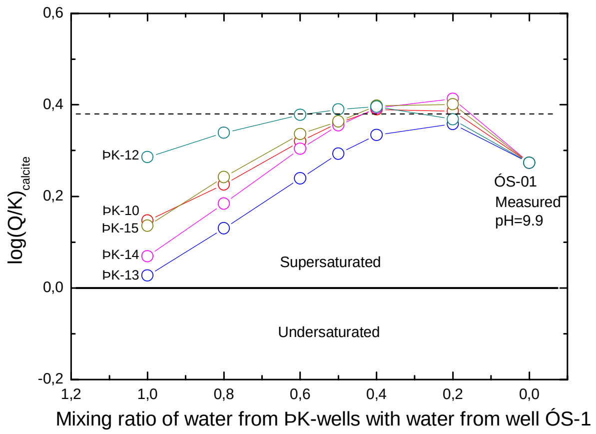

Figure 7: The calcite saturation index of water mixtures, ÓS-01 and the Þ-wells, using measured pH of water from well ÓS-1.

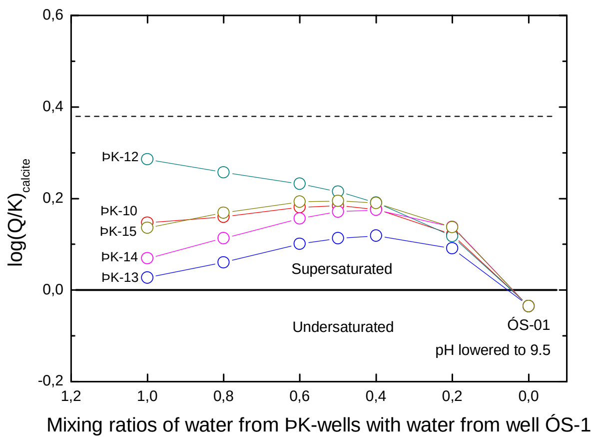

Figure 8: The calcite saturation index of water mixtures, ÓS-1 and the Þ-wells, where pH of water from ÓS-1 has been lowered by 0.4 pH-units.

4. ACID INJECTION

Before the acid injection tests started calculations were performed in order to estimate the amount of either concentrated hydrochloric acid (12N HCl) or concentrated sulfuric acid (18.8M H_2SO_4) to be used in order to lower the pH. The calculations were based on titriations of carbonate in water from well ÓS-1 (Figure 9) and the discharge from the well fixed at 40 L/s.

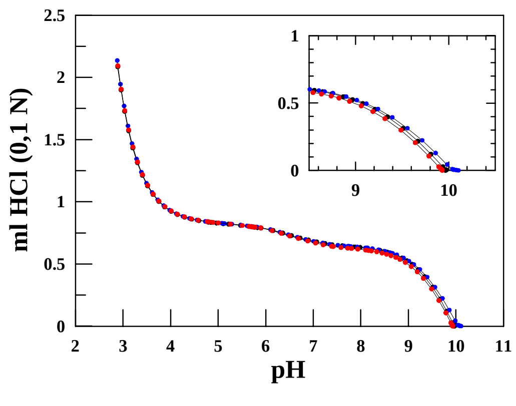

Figure 9: Titration curve of water from well ÓS-1.

The calculations showed that in order to lower the pH of the ÓS-1 water by 0.4 pH-units (from 9.9 to 9.5) 4.6 L/hour of hyrochloric acid were needed and 1.5 L/hour of sulfuric acid. On the other hand, in order to lower the pH by 0.2 units (from 9.9 to 9.7) the acid injection needed would be 3.0 L/hour of hydrochloric acid and 0.95 L/hour of sulfuric acid. Based on the evaluation and other matters it was decided to use sulfuric acid for the injection.

Three experiments were performed before the acid injection was put into operation in January 2004 by doing full scale tests over a short period. The first one took place in April 2003. Sulfuric acid was injected at the wellhead of well ÓS-1 and pH monitored in the main pipeline at the pumpstation. At that time the discharge from the ÓS-1 well was fixed at approximately 20 L/s. The injection took place upstream from the magnetic flowmeter of the well and it was soon observed that the acid affected the meter in such a way that it gave erroneous results. Results of the pH monitoring are shown in Figure 10. At the time of this first test the ÓS-1 well had not been in operation for few months and the pipeline and the well had been kept warm by the reverse flow of water from the Thorleifskot wells to the ÓS-1 well. This explains the realtively long time it took for the pH in the main pipeline at the pumstation to increase from 8.9 to 9.7/9.8 as shown on Figure 10. The acid injection started at 16:00 and an hour later the pH had lowered to 9.1 or 9.2 and stayed fixed for the rest of the test. The sulfuric acid was injected at the rate of 0.65 L/hour, which amounts to 1.3 L/hour for a discharge of 40 L/hour from the ÓS-1 well and the pH was lowered by 0.6 pH-units. The pH change was larger than planned, due to problems with measuring the acid dosage.

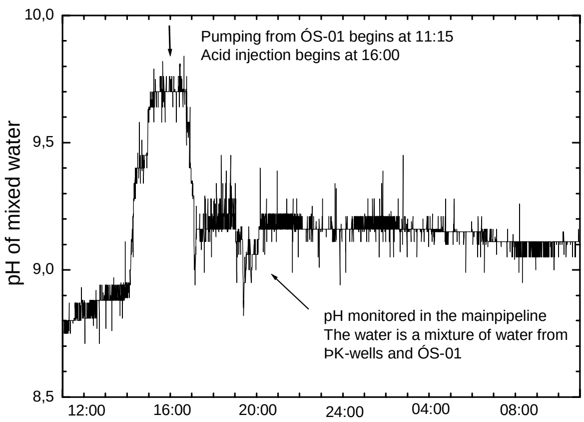

Figure 10: The first acid injection test in april 2003.

In May 2003 a second acid injection test was performed giving similar results to the first one. Still, there were problems with the flowmeter, but the acid dosage was lowered and the pH of the mixed water responded according to the calculations.

The third acid injection test was performed in November 2003. The acid injection had been moved to a spot downstream from the flowmeter, outside the wellhead house because it had been established that the acid did affect the flowmeter, and causing the erroneous readings.

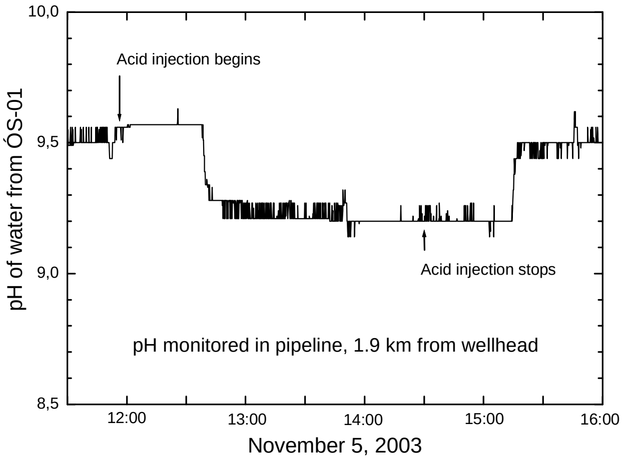

Figure 11: Acid injection test in November 2003.

During the test the pH monitoring took place in the pipeline from well ÓS-1, approximately 2 km downstream from the wellhead, before the water mixed with waters from other production wells.

The discharge from the ÓS-1 well was fixed at approximately 40 L/s and the acid dosages set at 1.3 L/hour. The results are shown in Figure 11. The pH was lowered by 0.35 pH-units in accordance with the calculations. The response time was about 45 minutes.

In January 2004 the acid injection was put into full time operation. A new injection pump was installed and the acid injection controlled by the flowmeter which regulates the pump rate from the well. A tank with sulfuric acid was stored outside the wellhead as shown on Figures 12 and 13.

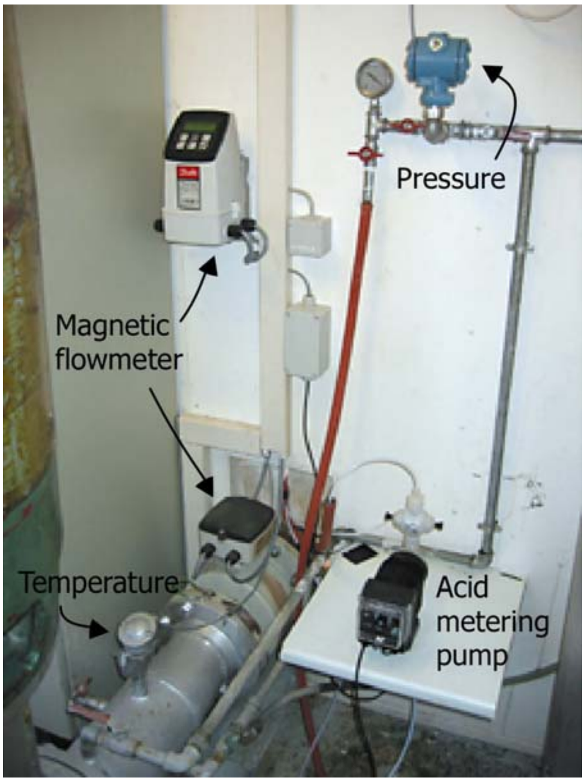

Figure 12: Pump for acid injection at well ÓS-1. Flowmeter for water from the well is located on the wall.

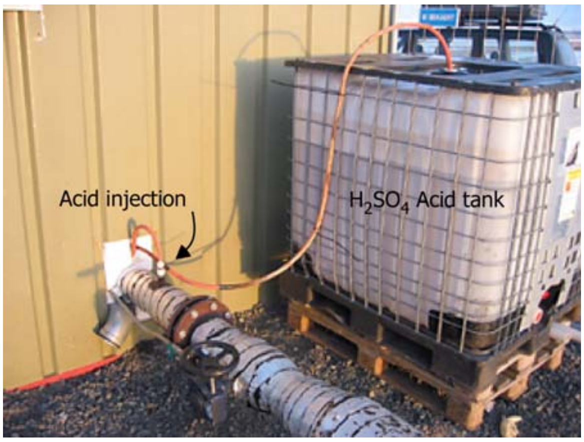

Figure 13: Acid tank and acid injection at well ÓS-1.

The pH was monitored during the first two days of operation in the same manner as in November 2003 and the results are shown in Figure 14. The dosage was set at 1.3 L/hour for the discharge of 40 l/s and is controlled linearly by the flowmeter at wellhead.

In the beginning the pipeline from well ÓS-1 was full of water from the Thorleifskot wells, with pH approximately 8.5. Soon after pumping started from the ÓS-1 well, with acid injection the pH rose to 9.0 and the gradually to 9.3. The discharge from the well is shown with the red line on Figure 14. The value of pH was measured in several wellhead samples prior to acid injection. The results are shown as open circles on Figure 14, demonstrating that the acid injection did lower the pH of the water by approximately 0.3/0.35 pH-units as prescribed based on calculations and the experiments.

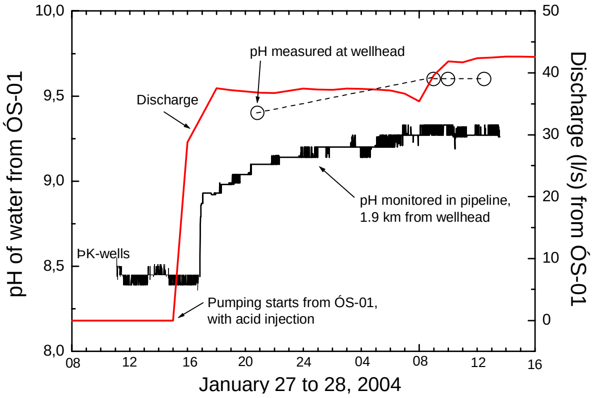

Figure 14: Injection put into operation in January 2004.

To date the ÓS-1 well has been in use with the other production wells of Selfossveitur for a few months now and no scaling has been observed. The scaling/corrosion plates are inspected on a regular basis

5. CONCLUSIONS

Selfossveitur district heating in South Iceland has utilized the Thorleifskot and Laugardælir low-temperature reservoirs from 1948. Due to severe cooling of the reservoirs the company engaged in an extensive geothermal exploration program and a new reservoir at Ósabotnar was discovered some 4 km north of Thorleifskot. A production well was drilled at Ósabotnar in 2001 and production from the well began in January 2002.

The water from the new well is more dilute compared to waters from previous wells and within weeks of mixing waters from the new well to waters from the existing wells severe calcite scaling was encountered in the main pumps distributing the hot water to the towns of Árborg.

Calculations showed that various mixtures of waters from Thorleifskot and Laugardælir on one hand and Ósabotnar on the other became supersaturated with respect to calcite. The calculations also demonstrated that the supersaturation could be lowered sufficiently to prevent calcite scaling by lowering the pH of the Ósabotnar water from 9.9 to 9.5 pH units with acid.

Based on the calculations it was decided to try acid injection into the water from the Ósabotnar well. Several short full scale tests were performed and lowering of the pH of the mixed waters was established as well as prevention of calcite scaling.

At present the water from the Ósabotnar well is mixed with waters from the Thorleifskot and Laugardælir wells and the dosage of sulfuric acid is 0.033 L/hour for each L/s produced from the well. No calcite scaling has been observed.

Acknowledgement

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