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SILICA DEPOSITION DURING INJECTION IN SVARTSENGI FIELD

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ABSTRACT

An injection/tracer test was carried out in Svartsengi field in 1984. The silica deposition part of the study is reported in terms of silica chemistry, deposition measurements in surface pipelines, water level recording, and downhole caliper logging. The deposition of silica was controlled through dilution and pH lowering by condensate mixing for most of the test period. Short-term lack of steam condensate resulted in silica deposition in the wellbore, such that the well's injectivity decreased considerably and the injection/tracer test had to be stopped. The concept of brine/condensate mixing appears feasible for long-term injection, provided acid injection is used to supplement the pH effect of steam condensate.

INTRODUCTION

The water level in monitoring wells in the Svartsengi liquid-dominated field have been falling by about 20 m each year. From the start of production, the spent brine has been disposed of into a pond, which steadily increases in area. A fall in reservoir pressure will affect the output of production wells, lowering their flowrate and wellhead pressure. It will also result in the influx of cold water into the main reservoir. Another concern in Svartsengi, is the lowering of depth of flashing in production wells. If the start of flashing falls below the casing depth, so will the calcite deposition; the flashing could even move into the liner slots and the formation, where the calcite cannot be cleaned.

The injection of spent brine in Svartsengi offers a partial solution to the fall in reservoir pressure. This was recognized early on; the first injection test was 1982. The purpose of this paper is to report the silica

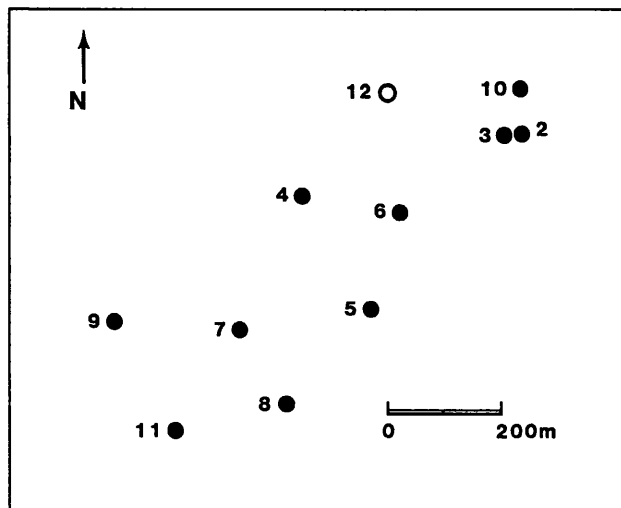


Figure 1 - The Svartsengi wellfield

deposition aspects of a two months injection and tracer test carried out in 1984. The main results of the tracer part of this test have been reported by Gudmundsson and Hauksson (1985). Other relevant studies of the Svartsengi reservoir are those of Kjaran et al. (1979), Georgsson (1981), Franzson (1983), Gudmundsson (1983a, 1983b), Gudmundsson et al. (1984) and Gudmundsson et al. (1985).

Svartsengi is a liquid-dominated steam-cap system with temperature in the range 235-240°C. The fluids are 2/3 seawater and 1/3 rainwater in composition. The wellfield in Svartsengi is shown in Figure 1. It is owned and operated by the Sudurnes Regional Heating Company. The two-phase mixture produced by the wells is piped to a combined thermal and electric power plant, where the steam and brine are used to heat fresh water for district heating. The steam is first passed through back-pressure turbines. The capacity of the power plant is 125 MW-thermal and 8 MW-electric.

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SILICA CHEMISTRY

The reservoir brine in Svartsengi contains about 450 mg/kg of silica (Bjarnason, 1983). The brine flashes in the wells and pipelines, and is separated at two pressures in the power plant. Primary separation at 4.5 bar-g causes the silica concentration to increase to 550 mg/kg; secondary separation under vacuum conditions of -0.7 bar-g increases the concentration to 630 mg/kg, and lowers the temperature to 70°C. During flashing the brine is stripped of such gases as carbon dioxide and hydrogen sulphide, causing the pH to increase from about 5.5 to 7.8 (Arnórsson et al. 1982). The solubility of silica at 70°C is about 245 mg/kg, so the brine is highly supersaturated with silica after secondary separation. This brine is disposed of into a pond by the power plant. In general, pH above about neutral and high salinity, facilitate silica deposition (Gudmundsson and Bott, 1979).

The rate of silica deposition depends strongly on pH (Kitahara, 1960). The rate is high when the pH is in the range 7-9, and low when the pH is in the range 1-3 (Owen, 1975). It has been shown that the rate of polymerization and deposition decreases 100-times when the pH is lowered from 7.5 to 5 (Weres et al. 1980), who also stated that pH below 3 would practically eliminate the polymerization reaction.

Titration experiments were carried out to investigate how much hydrochloric acid (HCl) would be required to lower the pH of Svartsengi brine to 5, 4 and 3 units from 7.8. The experiments showed that 16, 21 and 52 mg/kg of HCl would be required. For a brine flowrate of 300 kg/s, therefore, 430, 560 and 1390 tonnes of acid would be required per year, respectively, when using 35% hydrochloric acid. The behavior of silica in Svartsengi brine after secondary separation, has been reported by Gudmundsson (1982). It was found that lowering the pH to about 5.5 would slow down the polymerization reaction sufficiently.

In the Svartsengi power plant, the steam passes through back pressure turbines, and is then condensed in plate heat exchangers. Therefore, steam condensate at low pH is available in the Svartsengi power plant - the basic flow diagram is shown in Thórhallsson (1979) and Gudmundsson (1983c).

Faced with the need to inject silica laden brine from secondary separation, it was decided to try the least expensive option in the 1984 injection/tracer test. This consisted of mixing the steam condensate with the spent brine, which has two effects: dilutes the

silica and lowers the pH. Based on the literature on silica chemistry and deposition and the experiments carried out in Svartsengi field and power plant, it was decided to use the available steam condensate, and then adjust the silica laden brine flowrate to a point where deposition would not be expected. This was considered a reasonable approach to ensure enough flowrate and brine stability so that the accompanying tracer test could be run long enough for breakthrough to occur (Gudmundsson and Hauksson, 1985). If this brine/condensate mixture could be injected successfully, it was likely that the total brine flowrate could also be injected by using all available condensate from the power plant. Furthermore, acid could be added to the mixture to achieve the desired pH value.

TEST DESCRIPTION

Wells 6, 7, 8, 9, 10 and 11 were in production during the 1984 injection and tracer test. Well 4 is a monitoring well; well 5 is damaged and not in use. All the wells are two-phase, except for well 10, which is shallow and penetrates the steam zone. Well 6 was not connected to the power plant, but discharged directly into atmosphere and disposal pond. Well 10 produces steam only and did not contribute to the injection mixture.

The experimental setup is shown in Figure 2. The two-phase mixture from wells 7, 8, 9 and 11 was separated in two stages: high-pressure (primary) and low-pressure (secondary). The brine from secondary separation normally at 70-75°C flowed into the disposal pond. In the 1984 injection and tracer test, the secondary brine was in part diverted to a mixing tank, where it mixed with steam condensate, and then pumped to well 12, the injection well. The temperatures and flowrates in Figure 2, are typical values during the test. Stainless steel pumps were used to pump the condensate from the power plant, and the brine/condensate mixture for injection; they were lubricated by deaerated district heating water. An ultrasonic meter was used to measure the mixture flowrate. The temperature of all streams was measured; this provided a measure of mixing ratio. The power plant is located south-west of well 4, the main water level monitoring well. The pipeline from the pumps was 9" diameter the first 240 m (to near well 4), and then 16" the 230 m distance to well 12. At the wellhead of the injection well, there was a 70 mm orifice plate, to maintain pressure in the pipeline. The mixture flashed on the

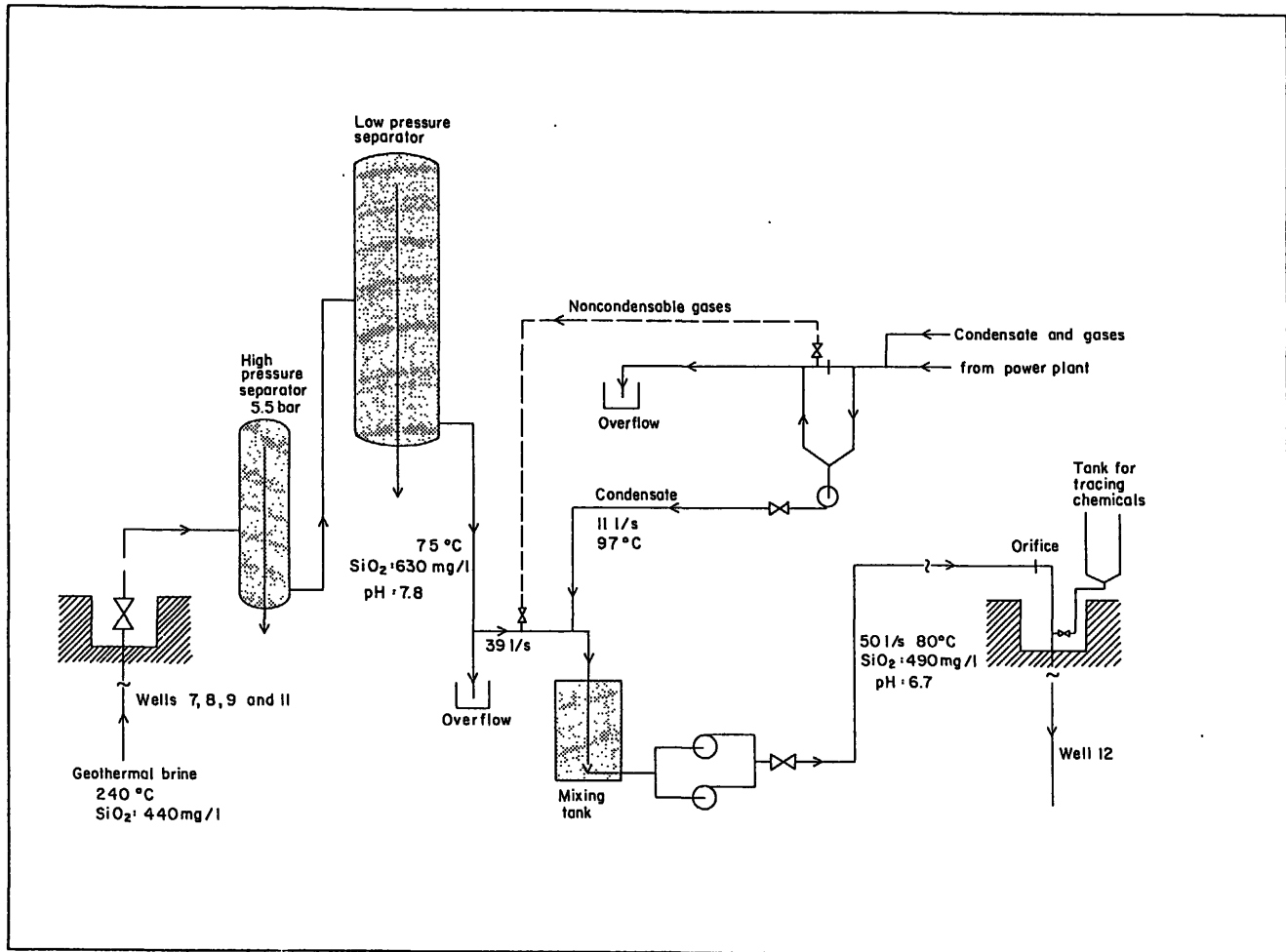


Figure 2 - Experimental setup

downstream side of the orifice plate; the injection well operated with vacuum at the wellhead.

POLYMERIZATION EXPERIMENTS

The brine/condensate ratio for the injection and tracer test was to be determined after silica polymerization experiments for a range of mixtures. The setup in Figure 2 was used; the mixture was discharged into the disposal pond; each mixture was tested for about 24 hours; the main results are shown in Table 1. The concentration of monomeric silica was measured in the brine and three mixtures with different brine/condensate ratios. The monomer concentration decreases with time because of polymerization; the results are shown in Figure 3. Note the effect of dilution. The brine only curve starts at about 620 mg/kg at a silica supersaturation ratio of 2.5 at 72°C, the others at lower silica concentrations.

In test number 1, the mixture flowrate was 20 kg/s, of which 48% was condensate. As shown in Figure 3, the initial concentration of silica in the mixture was about 375 mg/kg and supersaturation ratio of 1.25 at 84°C. The monomer concentration remained nearly constant the first two hours. In test number 2, the silica values were not regular because of analytical difficulties, but remained near the initial concentration of approximately 420 mg/kg and supersaturation ratio of 1.5. In test number 3, however, the behavior was different. The concentration remained nearly constant at 450 mg/kg and supersaturation ratio of 1.6 at 79°C the first hour, but then it dropped. This kind of behavior is well known for silica in geothermal water, indicating an induction period, the length of which depends on pH and supersaturation ratio. The polymerization curve for brine alone was typical for high silica supersaturation, the monomer concentration

Table 1 - Mixtures used in silica polymerization tests

No.	Flowrate (kg/s)	Temperature (°C)		Mixture Cond. (%)	pH
		Cond.	Brine		
1	20	97	72	48	6.0-6.3
2	40	97	72	32	6.4-6.7
3	52	98	73	24	6.8-7.1

decreasing in exponential fashion, with a very short induction period.

The pH of the brine/condensate mixtures was found to be higher than expected. It was discovered that most of the non-condensable gases did not flow with the steam condensate to the mixing tank, but by-passed to exhaust. This could not be fixed for the purpose of the test because the power plant was in operation and would have to be shut-down to fix the problem; a gas compressor was also needed. Therefore, it was decided to proceed with the injection and tracer test using a minimum of 20% condensate and 80% brine. A mixture of 50 kg/s was judged necessary to obtain reasonable tracer breakthrough if at all, and to evaluate the pressure response of the reservoir due to injection. At this flowrate, it took the mixture about 15 minutes to flow from the power plant to wellhead 12, and 20 minutes to flow to 1000 m. The pH of the mixture during the test was in the range 6.4-6.8. A pH of 5.5 was considered most desirable to prevent silica deposition. For the test conditions selected, the silica was expected to stay in solution for at least one hour.

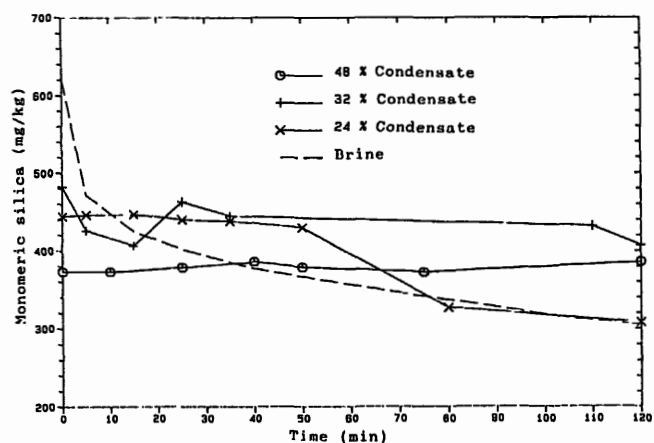


Figure 3 - Results of silica polymerization experiments

WATER LEVEL MONITORING

The injection and tracer test started June 19, 1984. The mixture temperature was on average 80°C at the pumps, and a few degrees lower at the wellhead of well 12. Water level monitoring in well 12 was not operational until 6 days into the test, unfortunately. The pumping was stopped temporarily at that time. The water level in well 12 after the 6 days, is shown in Figure 4. Also shown is the percent condensate in the mixture.

After six days of pumping, the water level was at 294 m depth. Although not accurately measured during the first six days of the test, the water level is likely to have behaved similar to that observed during a cold water injection test in well 12 in 1982 (Gudmundsson 1983b). It increased the first hour and then started to fall, and continued to fall for the rest of the test. The reason is likely the opening of fractures due to thermal contraction of rock. In the 1984 test, when the monitoring tube had been installed, the water level increased rapidly, as shown in Figure 4. After about one week the water level was at 165 m depth; then it fell to 180 m in about one month. The next four weeks the water level increased gradually, then it rose suddenly 30 m in two weeks. After two months of the injection test, the water level jumped from 150 m to 25 m in about one week. The injection test was terminated October 4, 1984, after 77 days. Presumably, the injectivity of well 12 suffered silica deposition. In this respect, note the fall in condensate percentage during the injection in Figure 4. The condensate production was decreasing because of lower demand for district heating water during the summer. For example, in the latter half of the test it was in the range 10-20% rather than above 20% as planned. Note also the correlation between a falling water level about one month into the test, and the more than 20% condensate in the same period.

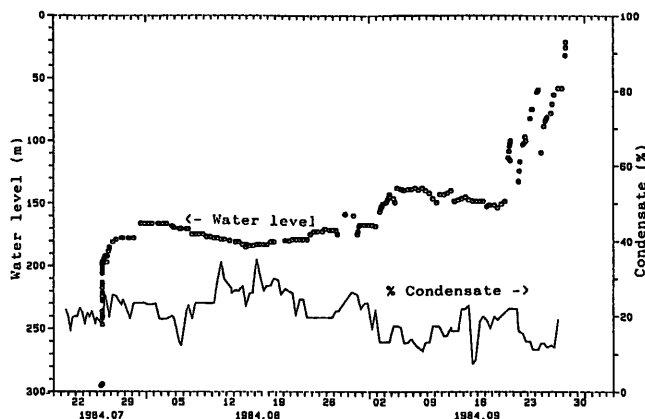


Figure 4 - Water level in well 12 and % condensate

DEPOSITION RESULTS

Deposition coupons were put into the pipeline between the pumps and injection wellhead. They were inserted through a specially designed sealing mechanism, making it possible to remove and inspect the coupons at any time. The coupons were placed downstream of the pumps, and upstream and downstream of the 70 mm orifice plate at the wellhead. The coupons were 50x20 mm and 1 mm thick, and made of carbon steel; several holes were drilled in the coupons; they were screwed to a teflon holder on a smooth removable rod; the coupons were put into the center of the pipe, and oriented broad-side to the flow.

The deposition coupon results are shown in Table 2. The rate of deposition downstream of the pumps was 2.8-3.0 mm/year, both on the front and back of the coupons. At the wellhead, upstream of the orifice plate, the rate of deposition was 4.6-6.6 mm/year on the

front, and 1.5-2.2 mm on the back. The rate of deposition on the coupons downstream of the orifice (where the mixture flashed because the wellhead was at vacuum conditions) was negligible at about 0.04 mm/year. When pumping was stopped on August 28, 1984, the orifice plate at the wellhead was inspected. The deposition was mainly on the front of the plate, on average 0.5 mm, and clearly thicker near the orifice itself. It was concluded that the rate of deposition depends on the turbulence of the flow, as reported by Gudmundsson and Bott (1979). After the injection test, the pipes and other equipment were inspected. There was no deposition in the mixing tank; there was measurable deposition in the pipe a few meters downstream of the pumps; there was less deposition in the pipe where the 9" and 16" lines met (about half the distance between the power plant and wellhead 12).

When the rapid water level increase in well 12 occurred the injection was stopped (August 24, 1984), and the well caliper logged. No measurable scale was in the casing and the measured diameter of the well below the casing was greater than the drillbit diameter at all depths, except in the range 1250-1300 m, shown in Figure 5. This narrowing of the well was most likely caused by silica deposition. The main feedzone of the well is below 1200 m depth (Gudmundsson 1983b). Well 12 is 1488 m deep, cased 13-3/8" to 607 m, and 12-1/4" open hole (barefoot) to bottom.

When the well was caliper logged August 24, 1984, and later when the injection test was over (after October 4, 1984), the water level measuring tube had to be removed from the well. In the first instance, there was 0.76 mm grey silica deposit on the tube, corresponding to 4.5 mm/year. In the second instance (measured October 6,

Table 2 - Silica deposition on removable coupons in pipe

Key	Period (day/ month)	Time (days)	Thickness (mm)		Dep. Rate (mm/year)		Density (kg/m ³)
			Front	Back	Front	Back	
A	20/7- 2/8	13	0.10	0.10	2.8	2.8	795
A	2/8-27/8	25	0.19	0.19	2.8	2.8	1118
A	27/8-20/9	22	0.18	0.18	3.0	3.0	898
B	20/7- 2/8	13	0.22	0.08	6.2	2.2	-
B	2/8-27/8	13	0.45	0.10	6.6	1.5	456
B	27/8-20/9	22	0.28	0.12	4.6	2.0	221
C	27/8-20/9	22	0.0025	0.0025	0.04	0.04	-

A: Downstream of pumps after mixing
 B: Upstream of orifice at wellhead
 C: Downstream of orifice at wellhead

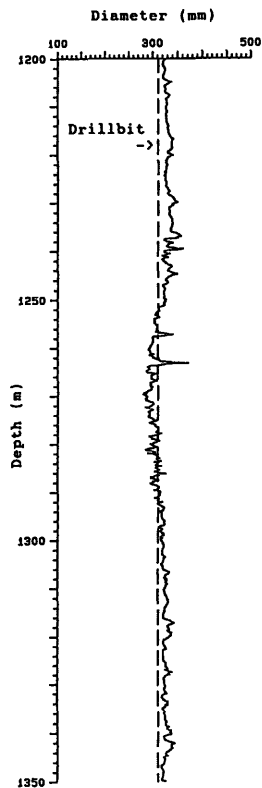


Figure 5 - Caliper log of well 12

1984), the deposition was white and much coarser, about 1.4 mm thick, which corresponds to a deposition rate of 23 mm/year. This increased rate of deposition, was most likely caused by the much lower condensate percentage in the last weeks of the injection test. It is also considered possible that not all of the condensate mixed with the brine in the final days of the injection test, so untreated brine may have been injected for some time.

After 10 weeks constant pumping, one of the two pumps failed on September 27, 1984. The second pump failed the same day shortly thereafter. Both had white silica deposits on the pump bowl and housing, which supports the idea that most of the deposition occurred late in the test.

CONCLUDING REMARKS

It was shown by experiments that silica polymerization, and hence silica deposition, could be reduced in the injection lines in Svartsengi by mixing steam condensate from the power plant with the silica supersaturated brine. The condensate affects the polymerization reaction by diluting the silica laden brine

and lowering the pH value, both of which reduce the rate and amount of silica deposition. Acid could also be added to suppress the rate of silica polymerization further.

The condensate mixing gives rise to an induction period, where the silica concentration remains constant, before the polymerization reaction starts. The length of the induction period was found to be sensitive to the supersaturation ratio, which is the measured concentration over solubility limit. At a supersaturation ratio of 1.6 and pH of 6.8-7.1, the induction period was about one hour. This was approximately the time needed to inject the brine and condensate mixture into the reservoir.

In the first 6 weeks of the injection and tracer test in 1984, the condensate percentage was on average 25% and never below 20%. This corresponds to a saturation ratio of about 1.6. During this period the water level in the injection well was stable; there was no apparent reduction in injectivity. In the last 4 weeks of the injection test, however, the supersaturation ratio decreased to below 20%, and even below 10% for short periods. During this period the water level in the injection well increased rapidly, and well damage was apparent. It was concluded that the rate of silica polymerization and deposition in Svartsengi is highly sensitive to the mixture pH and supersaturation ratio.

Silica deposition on coupons in the pipeline after mixing was 2.8-3.8 mm/year; deposition on coupons in the pipeline before the wellhead was 1.5-6.6 mm/year. Although these rates of deposition were similar during the injection period, it was observed that the highest rate was consistently on the front of the coupons near the wellhead. It indicates that the potential for deposition increased with distance from the power plant; with time after the mixing of brine and condensate. This agrees with the observation of an induction period for silica polymerization in the brine/condensate mixture. It follows that the potential for deposition in the wellbore was greater than at the wellhead, which in turn was greater than at the power plant. The caliper log in well 12 agrees with this interpretation.

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