Direct Use of Boiling Saline Water in the Öxafjördur Heating System in NE Iceland — Production Problems and Solutions

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ABSTRACT

In 1994 a geothermal heating system was built in Öxarfjörður (NE Iceland), serving the village of Kópasker and surrounding rural area. This heating system was built following and based on 15 years geothermal exploration of the area. The geothermal system Skógalón utilized for the Öxarfjörður heating system, is a boiling geothermal field with a reservoir temperature, of about 150°C. The wellhead temperature has increased over time from 96°C to 116°C. The water is saline, about 3‰, devoid of oxygen and with a low concentration of hydrogen sulfide. Such as all Icelandic low-temperature geothermal waters, the Skógalon water is in equilibrium with calcite at the reservoir temperature. Geothermal water of similar chemical composition as the Skógalon water has been used in two other heating systems in Iceland without significant problems. In those heating systems both original design and later improvements have prevented major corrosion and scaling problems. In the Öxarfjördur heating system, however, there have been extensive production problems, both due to steel corrosion and calcite scaling. The rate of steel corrosion is higher than in any other heating system in the country. The troubles in production are partly due to an increase in temperature in the geothermal field over time, but mainly due to improper design and material choice. At present considerable energy is wasted to pump the water through a cooling unit in order to cool it below 100°C, thus avoiding boiling and cavitation in the system pumps. This prevents supersaturation and successive precipitation of calcite in the distribution system, however, it is very costly and a waste of energy. A good solution to improve the efficiency and profitability of the heating system as well as minimizing scaling and corrosion problems, would be to install a binary unit at the well head to produce electricity by cooling the water from 116°C to about 80°C. By doing that, the water cooling produces energy instead of wasting it. Due to the high capital cost this has, so far, not been a financially feasible option in the sparsely populated rural area.

Introduction

The village of Kópasker is located on the east coast of the Bay of Öxarfjördur (Figure 1). The Bay of Öxarfjördur is located in NE Iceland in the northern end of the active zone of rifting and volcanism (Georgsson et al. 2000, Saemundsson, 1974). There the crustal plate boundary is offset towards the west by the Tjörnes transverse fracture zone (Saemundsson, 1974). The extensive geothermal activity in the area is mostly confined to three fissure swarms transecting the NE volcanic zone (Georgsson et al., 1989, 1993, 2000). The geothermal heating system in Öxarfjördur that serves the village of Kópasker and the nearby rural areas was built in 1994. Prior to that, geothermal exploration had been conducted on and off in the area for about 15 years, mainly with the purpose to build up the fish farming industry as well as a heating system for the village of Kópasker and surrounding rural areas. Locating the assumed high-temperature fields (high-temperature fields have a shallow magma chamber or cooling intrusion as a local heat

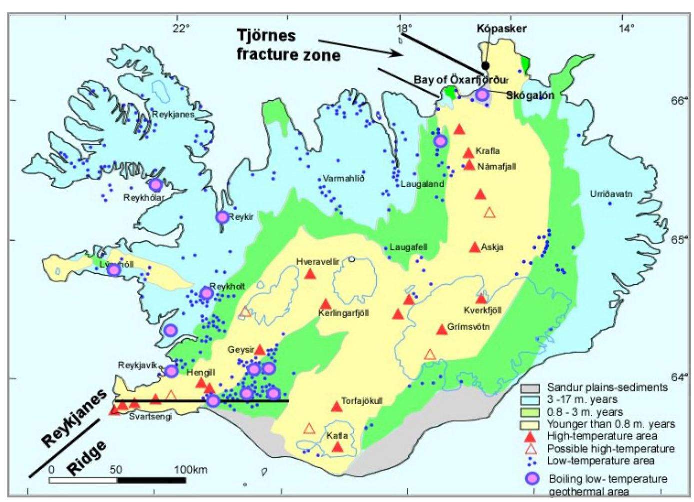

Figure 1. The Location of the geothermal field at Skógalón. The map shows the main geological features of Iceland and the location of geothermal fields, both high-temperature, low-temperature and boiling low-temperature fields (Saemundsson, 1974, Björnsson et al., 1990).

source) in the area were also partly the purpose of geothermal studies in the region (Fridleifsson et al., 2007). Following this exploration, two boiling, low-temperature geothermal fields (low-temperature fields are characterized by local convection of water in near vertical fractures in high temperature gradient regions, not linked to magma or intrusions) in the area were identified, but no active high-temperature systems were found (Karlsdóttir and Flóvenz, 2005, Georgsson et al., 2000, Kristmannsdóttir et al., 2006, Kristmannsdóttir et al., 2007). The location of the Skógalón geothermal field is on the edge of the active volcanic zone where it is offset towards the west by the Tjörnes fracture zone. In the past, it is possible that the field may have been a high-temperature geothermal field with a local heat source, but at present it is a typical boiling, low-temperature geothermal field. However, further south, in the fissure swarms cutting through the active zone from south to north there are several powerful high-temperature geothermal systems (Björnsson et al., 2007).

The groundwater system in the area is rather complicated due to the fact that sea water has easy access into the fractured young and highly permeable basaltic lava formations. There are also extensive sedimentary formations filling up the Öxarfjördur trough, some of which may act as aquicludes (Hafstad, 1989, Kristmannsdóttir and Ólafsson, 1989). Fully saline water, brackish and fresh groundwater as well as some runoff water from the volcanic high-temperature systems in the volcano-tectonic zone, are intermixed in the Öxarfjördur basement. Wells located close to each other may thus yield completely different kind of waters (Georgsson et al., 1989, Hafstad, 1989).

The Skógalón Geothermal Field

The Skógalón geothermal system utilized for the Öxarfjördur heating system, is now classified as a boiling low-temperature geothermal field. Four wells have been drilled into the field and the heating system utilizes one of them, well AER-3. The wellhead is located at a river mouth a few meters from the ocean shore. During winter a sand reef forms closing the river mouth and thereby creating a lagoon between the reef and the bank (Figure 2). The well at this time is located inside the lagoon, surrounded by seawater and isolated from the deairation tank and buster pump station, which are located about 450 m away. The only way to access the well during winter is by boat, even though that may not always be possible due to ice covering the lagoon. The ice cover is not safe to pass by foot due to numerous hot springs at the bottom of the lagoon.

At the start of production the wellhead temperature was 96 °C, but has increased over time by 20 °C to 116 °C. The water is saline, about 3‰, devoid of oxygen and with low concentration

Figure 2. A view towards west over the Öxarfjördur bay with the Skógalón geothermal field inside the lagoon built up during winter time at the coast. Steam from the production well, AER-3, is clearly visible.

Table 1. Chemical composition of the geothermal water in Öxarfjördur. Composition of production water in the Seltjarnarnes heating system is shown for comparison.

Place	Öxarfjördur	Seltjarnarnes
Sample no.	2006-001	HK-11-011
Date	30.01.06	18.10.11
T °C	116	118
pH/°C	6.9/22	8.39/20
SiO_2 mg/L	172.0	147
B µg/L	1260	251
Na mg/L	949	577
K mg/L	46	14.2
Ca mg/L	178	486
Mg mg/L	0.311	0.485
Sr mg/L	0.73	2.24
Al µg/L	26	36
Fe µg/L	45	5.5
Mn µg/L	23	10.4
CO_2 mg/L	23.2	4.5
Hg µg/L	0.14	0.008
H_2S mg/L	0.24	0.26
SO_4 mg/L	119	321
Cl mg/L	1671	1650
F mg/L	0.28	1.1
Cond. µS/cm at 25°C	5615	5210
TDS mg/L	3136	3201

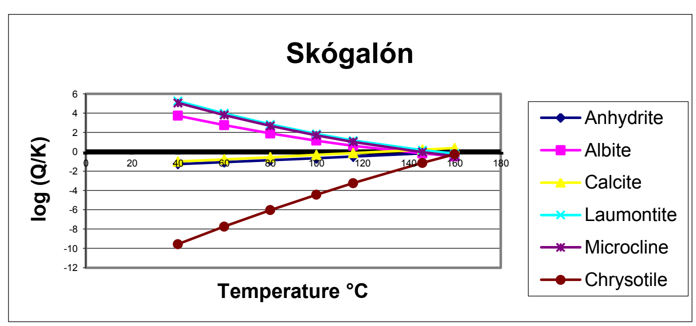

Figure 3. The relation between calculated activity products in the water from well AER-3 at Skógalón, and corresponding equilibrium constant for the formation of selected alteration minerals (log Q/K) against temperature.

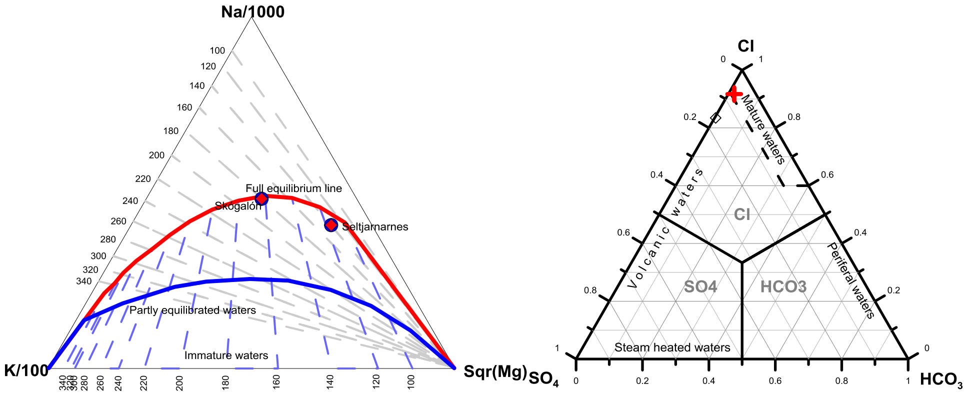

Figure 4. The composition of geothermal water from Skógalón plotted on Na-K-Mg and Cl-SO_4-HCO_3 ternary diagrams (Giggenbach 1988, 1991). A sample from Seltjarnarnes (Table 1) is plotted for comparison. On the Cl-SO_4-HCO_3 ternary diagram the Skógalón sample is shown as a red cross and the sample from Seltjarnarnes as a black rectangle.

of hydrogen sulfide (Table 1). The chalcedony geothermometer (Fournier, 1977) indicates reservoir temperatures of about 150 °C as well as the relation between calculated activity products in the water and corresponding equilibrium constant for the formation of selected alteration minerals (log Q/K) against temperature in the area (Figure 3). Alkali (Na/K and K/Mg) geothermometers (Arnórsson, 1991, Giggenbach, 1988) indicate somewhat lower reservoir temperatures, but the water is classified as fully equilibrated and mature according to the plot on the Giggenbach Na-K-Mg and Cl-SO_4-HCO_3 ternary diagrams (Figure 4).

As all Icelandic low-temperature geothermal waters, the Skógalón water is in equilibrium with calcite at the reservoir temperatures (Kristmannsdóttir et al., 2010).

The gas concentration of the water is rather low, but about 2-6 % (vol) of the emanating gas is organic, mostly methane and partly of higher hydrocarbons (C_2H_6, C_3H_8) (Ármannsson et al., 1998). The Öxarfjördur trough is filled with sediments and probably thermal formation of biogas has occurred.

Geothermal water of similar chemical composition as the Skógalón water has been used in two other heating systems in Iceland without significant problems (Kristmannsdóttir et al. 2010). In those heating systems both original design and later improvements have prevented major corrosion and scaling problems.

Production History of the Skógalón Heating System

Over time extensive production problems in the Öxarfjördur heating system have occurred, both due to steel corrosion and calcite scaling.

The heating system in Öxarfjördur was built in 1994. The distribution net was laid mainly in polybutylene plastic pipes. This was the cheapest choice and considered the only one affordable for this small community. As explained in the previous chapter, the wellhead is located inside a lagoon and surrounded by seawater during winter. Due to this, part of the pipeline from the well is surrounded by highly saline water during that time of year, making steel pipes unfavorable due to the corrosion risk. Therefore, the first 450m of the pipeline, from the wellhead and to the deairation tank and buster pumps, was first laid in relatively thick walled polybutylene pipes (Figure 5). At that time the well-head temperature was 96 °C which was high for the use of polybutylene pipes, but it was the cheapest choice and safer than steel due to the danger of steel corrosion. Stainless steel was also not a good choice due to danger of corrosion cracking from the outside.

During the years 1994-2005 the temperature increased by 20 °C putting a heavy strain on the polybutylene pipes, but those pipes still lasted for 12 years. In 2005 they had to be replaced due to cracking and leakage. Then the administration of the heating system got poor advice and exchanged them with 160 mm pipes of stainless steel. As, it should have been anticipated by experts, an environment of

Figure 5. The well head of the production well in Skógalón. The polybutylene pipes are seen in the foreground. A steam separator used in the years 2005-2006 is seen in the background.

Figure 6. A View towards north to the well, showing the steel distribution pipe being dug up for replacement in 2006.

Figure 7. Outward corrosion of the steel pipes.

Figure 8. Tension cracks with water seeping out.

wet, saline hot fluid rich in oxygen will most certainly induce corrosion cracking. As to have been expected, the stainless steel pipes were heavily attacked by corrosion cracking from the outside and lasted only for one year (Figures 6, 7 and 8). This was a heavy financial burden for the community served by the heating system, but fortunately only 50 m of the distance of 450 m had already been replaced by stainless steel pipes at that time due to high cost. This replacement was, therefore, not pursued further. Instead the whole distance from the well head to the deairation and pumping station was replaced by a specially made thick walled 160 mm wide polybutylene pipes.

When the water temperature went up above boiling some difficulties were encountered, especially due to boiling and cavitation in the buster pumps inducing calcite scaling. To try to mitigate the problem a steam separator was installed at the well head and was operated in the years 2005-2007. This did not solve all problems and created some new ones as described in the following chapter.

The distribution system from the deairation and pumping station was in the beginning, mostly laid in polybutylene pipes. The pipes used were not protected by an airtight metal foil cover to prevent the uptake of oxygen. As the water is saline, some corrosion was thus anticipated and installation of heat exchangers in every house was made customary from the beginning of operation. Later parts of the distribution net have been replaced by steel pipes as the plastic pipes did not hold very long at the high temperatures nearest to the tank and pumping station. This is mostly within the first 3 km from the pumping station where the temperature of the water is near 100 °C and where the most scaling occurred after the installation of the steam separator. It is planned, to replace the polybutylene pipes in the whole distribution system from the pumping station with steel pipes over time.

After the steam separator was disconnected in 2007 the problems due to cavitation in the pumps became very bad. The temperature of the water was also much too high in the first part of the distribution system as well in the farms nearest to the pumping station. As a remedy it was decided to cool the water under pressure to below 100 °C. In 2009 a cooling unit was installed and since there has been much less production problems in the system. The operating cost for the unit is rather high as the electricity for running the cooling device is quite costly. Considerable energy is also wasted by cooling the water.

Production Problems

Over time, there have been extensive production problems in the Öxarfjördur heating system, both due to steel corrosion and calcite scaling. These problems have changed from time to time and often induced from the design of the system, choice of material and changes made without proper consideration. However, natural changes in the system also play some part, as the temperature of the water has increased by 20°C during that time. The water was just below boiling when the heating system was designed and installed, but is now well above boiling, which has changed the production properties considerably.

Corrosion

In water of such high salinity as in Skógalón there is a danger of corrosion by even the slightest uptake of oxygen. Uptake of

Figure 9. Corroded joints from the distribution system in the heating system in Öxarfjördur.

air will happen in the hot water flowing through the polybutylene pipes as they are not shielded by a metal foil or other methods of preventive measures. In the intake frames of the houses, there is often a slight oxygen uptake, enough to induce corrosion of steel radiators in saline waters. Corrosion, due to oxygen uptake, has always been a problem in the distribution system of the heating system in Öxarfjördur and will probably be a problem as long as the distribution net is mainly laid in polybutylene pipes unprotected for oxygen uptake. The rate of steel corrosion is higher than in known heating systems anywhere else in the country. Figure 9 shows typical steel corrosion in pipe joints from the system after a few years. Both input frames and heat exchangers of the houses have also been quickly corroded and heavily damaged.

In the village of Kópasker it is not possible to use steel in the intake frames of the houses as the steel construction only holds for a very short time. The intake frames have to be made from polypropylene pipes and connections. The temperature at the intake is maximally about 76 °C so polypropylene is a suitable choice for pipes in the distribution net of the village and intake frames of the houses.

Scaling

Severe scaling problems have occurred in the heating system in Öxarfjördur over time. The management of the heating system claims that scaling in the distribution system increased by the increase of well head temperature. There is, however, no written record on this and the scaling has not been monitored by test plates in the distribution system. After complaint from the users, it was discovered that the first part of the distribution system from the pumping station was severely clogged and in 2005 it had to be cleaned with acid washing. After that, the steam separator was installed, lowering the production temperature. No scaling was found inside the separator, however, some scaling was found in the pipeline from the separator towards the deairation tank and pumping station.

Even though geothermal water is saturated with respect to calcite, deairaton and boiling of the water may lead to supersaturation and possibly successive precipitation of calcite, especially in saline water.

The water at Skógalón is found to be in equilibrium with calcite or even slightly undersaturated at the present well head temperature, but by boiling and deairation it will become supersaturated (Figure 10). Originally the water was more supersaturated with respect to calcite at well head temperature, probably due to boiling in the reservoir. The supersaturation has reached values equal to values previously inducing scaling in other Icelandic heating systems (Kristmannsdóttir, 2004). Therefore, it is of no surprise that scaling occurred in the system, especially since the water could boil both at the well head and by cavitaion in the pumps. The same applies to the boiling in a steam separator at the well head. The scaling products are found dispersed around in the system, especially in the intake sieves. This is due to the fact that the scales pile up in the system and are transported through it after break off from original location when the system is shut down and then repressurized. As the water is not supersaturated at the well head, there should be a way to avoid any scaling during utilization by a proper design. As the supersaturation of calcite is lowered by cooling, the water should be cooled under pressure to avoid supersaturation with respect to calcite and consequent scaling. This is what has been done by installing a cooling device prior to the water entering the deairation tank and buster pumping station. That seems to have solved the calcite scaling problem and scaling has not been reported much since that. The calcium concentration of the water was monitored in the years 2007-2010 and did not indicate any scaling in the system as it was constant from the well head through the system to the Kópasker village. This solution is, however, rather costly as it requires the use of ample electricity for pumping. It also wastes valuable energy by cooling the water without using the energy for either heating or electricity production.

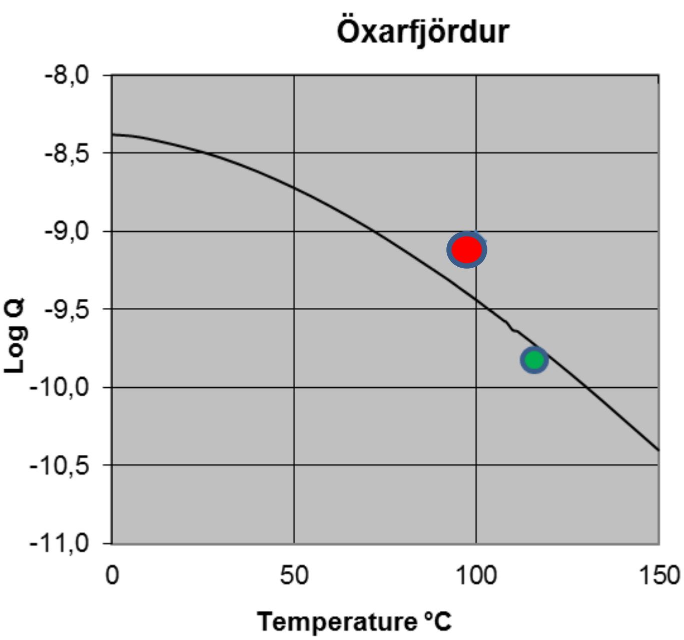

Figure 10. The calcite equilibrium condition for the present Öxarfjördur water at reservoir conditions (green circle) and after boiling and excessive deairation at 100 °C (red circle).

Discussion

As the water in Öxarfjördur is not excessively saline, devoid of oxygen at the well head and with low concentration of hydrogen sulfide, one would not expect too much corrosion problems by utilization of the water. Similar waters have been used in heating systems elsewhere in Iceland without any great problems. The design and material choice in the heating system has not been suitable for this kind of water and not adapted to the environmental surroundings or previous constructions. The water temperature has increased over time making problems and partly changed the original basis for the design of the heating system. By the use of plastic pipes without metallic protection there is continuous uptake of oxygen into the water. Outside crack corrosion of the stainless steel pipes installed in 2006 from the well head was to be expected as the hot pipes were surrounded by oxygen saturated highly saline water, but were still recommended to be installed. Even though the temperature is high for the use of plastic pipes it is still the only viable choice for this first part of the distribution system. At the time when the plastic pipes from the deairation tank and buster pump were replaced by steel pipes, there was excessive oxygen uptake in the steam separator more susceptible to the danger of steel corrosion. Hence, most of the corrosion incidences seem to be due to improper choice of material and/or wrong design.

The Skógalón water is in equilibrium with calcite at the reservoir temperatures, but becomes supersaturated by boiling and deairation of the water. In the system this has taken place both in the steam separator, by cavitation in the pumps and by deairation in the tank. The case for scaling in the system seems to be mostly the result of improper handling of the fluid in the system. Scaling could probably have been avoided by proper design of the system. At the moment scaling in the system is negligible so it seems like later improvements by installations of cooling device are working.

Conclusion

The lesson learned from the study of the Öxarfjördur system is that under such difficult conditions much care has to be taken when a system is designed and material choices made. The reason for the troubles in production may partly be blamed on the increase in reservoir temperature and changed conditions in the geothermal field over time, but mainly on the repeated mistakes in design and material choice for the heating system. To minimize the corrosion problems, the distribution net has to be improved and partly replaced. At present, considerable energy is wasted to pump the water through a cooling unit to cool the water below 100°C to avoid boiling and cavitation in the system pumps, causing supersaturation and successive precipitation of calcite. A good solution for the heating system would be to install a binary unit at the wellhead and utilize the energy by cooling the water from 116 °C to about 80 °C. This would prevent scaling problems and produce electricity instead of using it.

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