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SCALING IN GEOTHERMAL INSTALLATION IN ICELAND

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ABSTRACT

Low-temperature geothermal fields in Iceland are mostly used for space heating. Scaling problems due to exploitation have only occurred in few cases. The most common precipitation is calcium carbonate both in downhole pumps and surface installations mainly caused by mixing of saline water. Magnesium silicate scaling has occurred when fresh groundwater is heated up or by mixing of low-temperature geothermal water and fresh water. In high-temperature geothermal fields calcite scaling is known in drillholes at shallow depth where boiling occur. Silica scaling occurs in high-temperature fields where geothermal water is cooled either in heat exchangers or during boiling. Scaling can be prevented by knowing the processes and avoiding boiling of the fluid. In this paper some examples are shown where scaling has occurred. Research projects at the Hellisheidi power plant aim to precipitate carbon dioxide and hydrogen sulphide as minerals at different depth and temperature in the bedrock.

1. INTRODUCTION

Iceland is at a plate margin characterized by high heat flow. Due to the high heat flow hot springs are abundant in the country. About 1000 geothermal localities have been recognized in Iceland. Geothermal water is generally of meteoric origin, i.e. it is rainwater which has fallen to earth and sinks deep beneath the earth's surface where it is heated up by hot substrata and magma intrusions.

The high-temperature geothermal fields are all located within the volcanic zone (Figure 1) and there the temperature is higher than 200°C at 1000 m depth. The thermal manifestations are boiling water, mud pools, fumaroles and steam vents. The low-temperature fields are located at the flank of the volcanic zone, and there the temperature is lower than 150°C at 1000 m depth. The thermal manifestations are warm water to boiling hot springs.

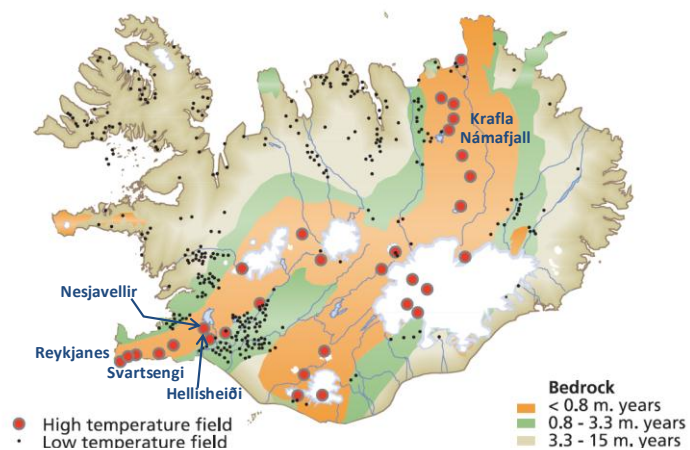


FIGURE 1: Location of geothermal fields in Iceland. The developed high temperature geothermal fields are shown with blue text.

The most significant use of geothermal energy in Iceland is for space heating and the low-temperature geothermal fields are the main source for this utilization. In few cases high-temperature geothermal fields are used for generating electricity but also to supply hot water for district heating. This is the case at Nesjavellir, Hellisheidi and Svartsengi all high-temperature geothermal fields in the SW Iceland.

The chemistry of the geothermal fields differs in composition mainly according to temperature. In the low-temperature fields the water is usually dilute and low in dissolved solids. In the district heating utilities the water is usually used directly in flow through system. Most of the high-temperature geothermal fields are also of the dilute type except the fields on the Reykjanes peninsula. The water flows through basaltic lavas resulting in high pH of the low-temperature waters, usually pH between 9 and 10. The geothermal water is in equilibrium with calcium carbonate and the silica content is governed by the solubility of the silica mineral chalcedony at low temperature and quartz at higher temperature. Saturation with respect to amorphous silica is not reached in water from the low-temperature areas although it is cooled in the district heating systems down to about 20°C.

2. SCALING IN GEOTHERMAL INSTALLATIONS

The most common precipitation from Icelandic geothermal waters are calcium carbonate (CaCO_3) and magnesium silicate ($\text{MgSiO}_3 \cdot \text{H}_2\text{O}$) in waters from low-temperature geothermal fields and amorphous silica (SiO_2) and calcium carbonate (CaCO_3) as well as sulphide minerals (mainly FeS_2 and FeS) in high-temperature fluid. Figure 2 shows the main precipitation formed in geothermal installations in Iceland.

2.1 Calcite scaling from low-temperature water

Calcite scales forms if the water boils in the well or mixes with saline water and magnesium silicates are formed due to mixing of surface water and geothermal water. Here three examples will be given of scaling in low-temperature fields in Iceland.

Sudureyri district heating

Sudureyri geothermal field is located in Northwest Iceland. This district heating started operation in 1978 serving the village of Sudureyri with about 350 inhabitants. Two drillholes are productive and both with calcite scales (Ólafsson, 1999). During exploitation chloride concentration increased up to 300 mg/l during 1975-1987 but reduced when a new well was drilled to 70 mg/l leading to supersaturation of calcite (Figure 3). The scaling has been overcome by injection of phosphate inhibitors to reduce scaling forming polymers with the scaling compounds.

Laugarnes geothermal field Reykjavík

Exploitation from the Laugarnes geothermal field in Reykjavík was initiated in 1930. In the beginning only artesian flow was used from relatively shallow drillholes. Deep drilling began in 1958 and the first downhole pump was installed

Types of scales	Low temperature fluids	High temperature fluids
Calcium carbonate Calcite/Aragonite/Vaterite	X	X
Amorphous silica (SiO_2)		X
Magnesium silicate	X	
Iron silicate		X
Aluminium silicates		X
Zink silicates	X	
FeS_2 (pyrite/marcasite)		X
FeS (pyrrhotite)	X	X
Other sulphides		X

FIGURE 2: Main types of scales in Icelandic geothermal installations

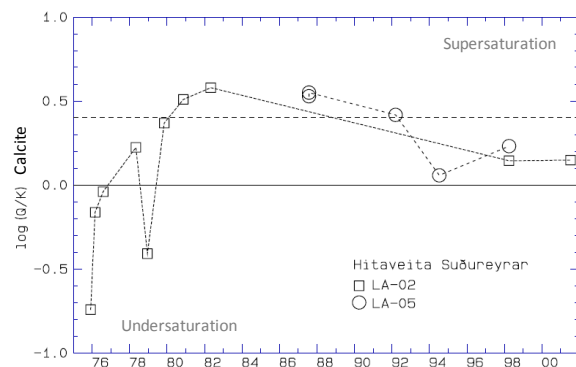


FIGURE 3: Calcite saturation for water from Sudureyri district heating (from Hardardóttir, 2002)

a year later. Artesian flow ceased in 1965 and since then downhole pumps have been operated in the wells (Gunnlaugsson and Ívarsson, 2010). The maximum production during the coldest part of the year is about 330 l/s. The fluid from the field was low in total dissolved solids, about 350 mg/kg, of which about 35 mg/kg was chloride.

Production from the field has caused pressure draw down within the production well field. The exploitation of the field has not had any effect on the production temperature, but some gradual changes have been measured in the fluid chemistry after 1980 when production was increased in the western part of the field. The concentration of chloride has doubled in some of the wells while other remains as initially. Two wells produced water in excess of 100 ppm chloride concentration. The changes in chemistry are most likely caused by infiltration of highly saline water into the uppermost part of the reservoir.

The mixing of the reservoir fluid with more saline water has caused calcite deposition in downhole pumps where the chloride concentration is higher than 100 ppm. Figure 4 shows the equilibrium curve for calcite as a function of temperature and comparison of calculated activity product for calcite for water samples from all wells in the Laugarnes field (Gunnlaugsson, 2004). Most samples are close to equilibrium at given temperature but water samples with higher chloride concentration (some of the red dots) show deviation from equilibrium. Figure 5 shows a graph where the solubility product of calcite for samples from one well with increasing chloride concentration is plotted against chloride concentration. The calculations are performed at 120°C and the equilibrium constant for calcite at that temperature is shown on the graph as horizontal line.

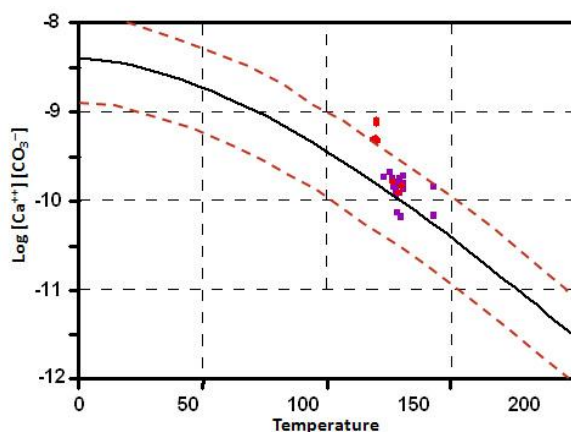


FIGURE 4: Solubility of calcite and degree of saturation of water from the Laugarnes field

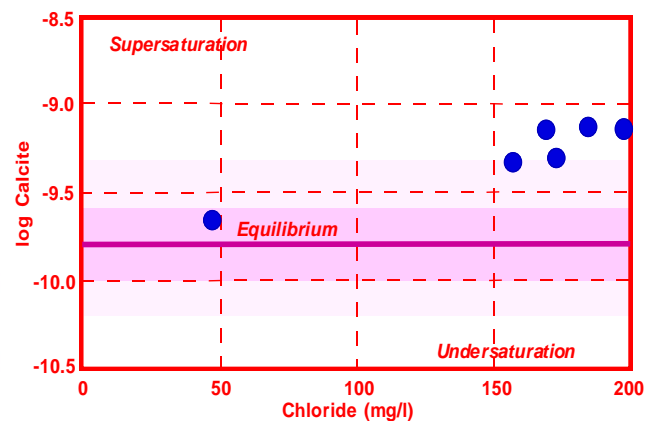


FIGURE 5: Changes of the solubility product of calcite with increasing chloride concentration

Some of the saline water enters the reservoir through wells due to shallow casings. To avoid scaling leakage of saline water into the reservoir has been stopped by plugging by cement some of the older drillholes in the field which showed inflow of saline water.

2.2 Magnesium silicate scaling

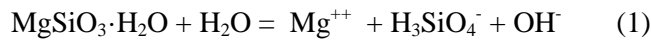
Magnesium silicate scaling has been encountered in several geothermal district heating systems in Iceland. The scaling occurs in heated freshwater after thermal deaeration and also when geothermal and fresh waters are mixed.

Magnesium-silicate scaling in Icelandic district heating systems was first encountered in Hveragerdi where high temperature geothermal water and fresh water were mixed. In other district heating systems where magnesium rich fresh water is heated, precipitation of magnesium silicate may occur.

In 1990 the Reykjavík District Heating began utilizing the heat from the Nesjavellir high temperature geothermal field. Previously, the company had only used low temperature waters from the geothermal fields in Reykjavik and the surroundings. Pilot plant experiments had indicated that some mixing of the deaerated freshwater and geothermal water could be tolerated if the mixing ratio was carefully controlled (Gunnlaugsson and Einarsson, 1989). After introducing the water from Nesjavellir, the deaerated water was allowed to mix with the geothermal water, but control of the mixing ratio was insufficient and heavy scaling occurred in the pipeline system. It soon became evident that scaling was more severe than expected. The results of experiments soon lead to the abandonment of any mixing and the distribution system had to be modified slightly to keep the waters separated at all times.

The presence of magnesium silicate can be explained by studying the chemical composition of the water and compare it to the solubility of magnesium silicate precipitate.

The solubility of magnesium-silicate can be described by:



The solubility constant for the reaction depends on what precipitate is formed. The material has showed to be near amorphous magnesium silicate. In experiments in connection with magnesium scaling in Reykjavík the solubility of the precipitate was determined at few temperature values from 60 to 120°C (Hauksson et al., 1995). The equilibrium constant can be described by the equation:

$$\log(K_{sp}) = -12.90 + 0.00262T - 0.00006212 * T^2 \quad (2)$$

where T is in °C. The solubility of magnesium silicate is shown Figure 6.

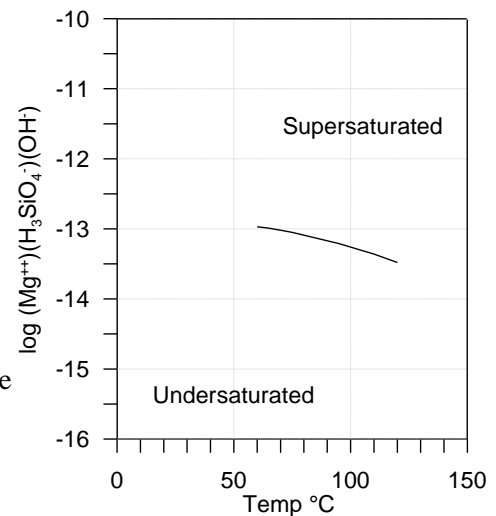


FIGURE 6: Solubility of magnesium silicate in the temperature range 60 to 120°C

2.3 Silica scaling in high temperature geothermal fields

Silica scaling is well known in utilization of high temperature geothermal fluid. The silica concentration in geothermal systems at 200-350°C is controlled by the solubility of quartz (Fournier and Rowe, 1966; Mahon, 1966) and increases with increasing temperature. During cooling and boiling saturation with respect to amorphous silica is reached. Its precipitation rate is fast resulting in potential deposition of this compound. In the combined heat and power geothermal plants the precipitation of amorphous silica can occur when the separated water flows through heat exchangers. In the heat exchangers the separated water is cooled down and becomes supersaturated with respect to amorphous silica. This commonly causes scaling in the tubes of the heat exchangers which have to be removed regularly. In the dilute high temperature fields where the chloride concentration is low the precipitation of amorphous silica can be postpone by slow flow rate through heat exchangers allowing the aqueous silica to form polymers in the solution. This has been applied at the Nesjavellir power plant reducing silica scaling in the heat exchangers. After heat exchangers the separated water flows through retention tank for further polymerisation of the silica before condensate is mixed with the separated water and re-injected into subsurface.

3. Reduction of gas mission by precipitation

Two pilot projects are now in process in Iceland where the aim is to reduce gas emission from geothermal power plants by dissolving the gases in water, injecting into the bedrock and form minerals

the same way as nature. These projects are connected and both run at the Hellisheiði power plant (Figure 7). A gas separation plant is used to separate different stream of gases. The carbon dioxide is then diverted to relatively shallow drillholes (CarbFix project) but the hydrogen sulphur is injected into the geothermal reservoir (SulFix project).

3.1 Carbfix project

The basic concept of CarbFix (Aradóttir et al., 2011) is to dissolve carbon dioxide gas in water before it is injected as a single phase fluid into the basaltic formation. The CO_2 dissolves to form carbonic acid (H_2CO_3) which then dissociates into bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). When the primary minerals in the basaltic rocks like feldspars and pyroxene come in contact with the injected acidic fluid dissolution reactions occur and cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}) and iron (Fe^{2+}) are leached out of the rock matrix. At certain concentrations, the water becomes supersaturated with respect to secondary minerals like carbonates causing precipitation of minerals like calcite (CaCO_3), dolomite ($\text{CaMg}(\text{CO}_3)_2$), magnesite (MgCO_3) and siderite (FeCO_3). These precipitations are predicted by comparing the water chemistry to the solubility of the minerals. On the other hand it is difficult to predict the rate of precipitation and to what extent they will form.

This is a natural process occurring in all high temperature geothermal fields. The cap rock consists of alteration minerals, predominately carbonate like calcite. The main goal of the CarbFix project is to increase measurably the understanding of the long term fate of CO_2 injected into the subsurface, to develop new technology to facilitate the safe and permanent geological storage and to publicize the results to allow the method to be applied internationally.

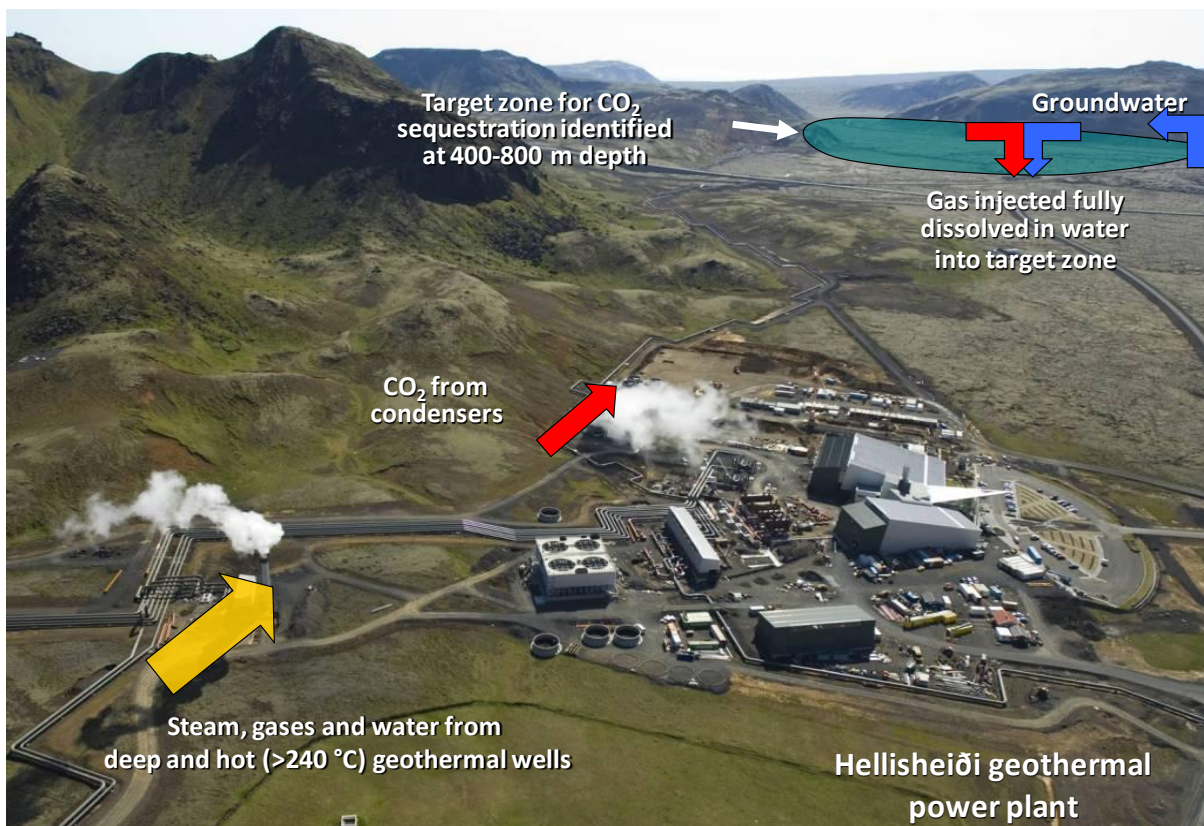


FIGURE 7: Aerial photograph of the Hellisheiði geothermal power plant and the CarbFix injection site which includes an injection and several monitoring wells

3.2 The SulFix project

Hydrogen sulphide (H₂S) is one of the principal geothermal gases. During exploitation of high temperature geothermal fields in Iceland the gases have been released through cooling tower to the atmosphere. Hydrogen sulphide has unpleasant smell and therefore the request of cleaning it from the gas stream has been set forward. There are many conventional methods available all having the disadvantage that large amount of either sulphur or sulphuric acid is formed and have to be disposed with environmental disadvantages. The SulFix project aims to use natural processes and re-inject the hydrogen sulphide into the reservoir. The difference between the SulFix project and the CarbFix project is that the sulphides and the carbonate minerals are stable at different temperature. The carbonate minerals are stable at temperatures below 240°C but the sulphides at temperature >290°C. For this reason the hydrogen sulphide has to be injected deep into the reservoir however the carbon dioxide into the cap rock zone.

After separation of the gases, hydrogen sulphide is dissolved in the separated water and then injected into the deep injection well. According to mineral solubility sulphide minerals should precipitate.

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