PROCEEDINGS, Thirty-Sixth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 31 - February 2, 2011
SGP-TR-191

INJECTION OF H_2S FROM HELLISHEIÐI POWER PLANT, ICELAND

Ingvi Gunnarsson[1], Bergur Sigfússon[1], Andri Stefánsson[2], Stefán Arnórsson[2], Samuel Warren Scott[2] and Einar Gunnlaugsson[1]

[1] Reykjavík Energy, Baejarhalsi 1, 110 Reykjavík , Iceland
e-mail: ingvi.gunnarsson@or.is
2 Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík, Iceland

ABSTRACT

The toxicity and foul smell of hydrogen sulfide creates one of the main environmental problems associated with geothermal utilization. Hellisheiði Power Plant annually emits around 13000 tons of H_2S into atmosphere. Under certain weather conditions the hydrogen sulfide from the power plant reaches nearby towns and cities, annoying the inhabitants. Reykjavík Energy is preparing injection of the H_2S from the power plant back into to hydrothermal system. As a first step towards that goal, experimental injection of around 2-3% of total H_2S from Hellisheiði power plant will start in the spring of 2011. H_2S will be separated from other geothermal gases at a pilot gas separation plant, dissolved in separated geothermal brine and injected back into the geothermal system. The aim of the project is to use the same governing water-rock reactions that control concentrations of H_2S in high temperature geothermal systems to mineralize the H_2S in the geothermal reservoir. The concentration of H_2S in the injected geothermal brine is considerably higher than the aquifer concentration at the injection site and theoretical calculations indicate sulfide mineralization will have tendency to occur in the aquifer, but the rate and quantity of sulfide mineralization under aquifer conditions is however unknown. In this paper the experimental H_2S injection project is introduced, and design of the injection, preparation work and data collection prior to injection are described as well as the scientific outline of the project.
.

INTRODUCTION

The emission of hydrogen sulfide from geothermal power plants is one of the main environmental concerns of geothermal utilization. Hydrogen sulfide is a colorless flammable and toxic gas with the characteristic odor of rotten eggs. Exposure to it can cause health problems depending on levels and duration of exposure. Low level, prolonged exposure can cause inflammation and irritation of the eyes whereas high levels of exposure for brief periods of time can cause dizziness, headache, nausea and even death if the concentration of H_2S in atmosphere goes above 300 ppm.

Concentration of hydrogen sulfide in geothermal fluids is usually in the range of few ppb to several hundreds ppm (Arnórsson 1995a, 1995b). During utilization of high temperature geothermal fluids the hydrogen sulfide is concentrated in the steam phase and subsequently released into atmosphere after the steam condenses. Annually Hellisheiði power plant emits 13000 tons hydrogen sulfide into atmosphere. The hydrogen sulfide is released on top of the cooling towers to lower the risk of high concentration of hydrogen sulfide close to the power station. The hydrogen sulfide is carried by winds away from the site of the power plant and can in some weather conditions cause foul smell in nearby communities. Constant monitoring of H_2S concentration in atmosphere is performed by Reykjavík Energy in three locations in these communities and the highest reported 10 minutes average value is 101 $\mu g/m^3$.

A review of the processes available for H_2S abatement in geothermal power plant is provided by Sanopoulos and Karabelas (1997). Most methods involve oxidation of H_2S to elemental sulfur or sulfuric acid. The value of these products is low as there is too little demand or excess supply. Disposal of these products is costly and can create environmental problems. Reykjavík Energy plans to inject hydrogen sulfide back into the geothermal system and by doing so lower the environmental impact of geothermal utilization. The injection project aims at using water-rock reactions already taking place in natural geothermal systems controlling the concentration of hydrogen sulfide to remove dissolved H_2S from solution and mineralize in the form of sulfide mineral. As a first step towards that goal experimental injection of H_2S is planned in the spring of 2011. If the injection is successful and

hydrogen sulfide is mineralized in the geothermal reservoir Reykjavík Energy intends to inject back into the ground majority of the hydrogen sulfide currently emitted from Hellisheiði power plant and future power plant of Reykjavík Energy.

In this paper the experimental project of injecting H_2S into high temperature geothermal systems is described. Injection site and preparation work prior to injection is detailed as well as the scientific outline of the project.

HELLISHEIÐI 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 (Fig. 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 Hellisheiði power plant is a dual flash power plant currently producing 213 MW_e and will be further expanded by 90 MW_e in the fall of 2011.

49 production wells have been drilled into the Hellisheiði geothermal field providing valuable information about its stratigraphy and alteration zones. The sub-surface basaltic strata in the Hengill area comprise mostly hyaloclastite volcanic formations down to some 1000 m below sea level depth and underlain by a more dominant lava succession (Franzson et al., 2005). Hydrothermal alteration ranges from fresh rocks in the overlying cold groundwater system through zeolite assemblage and into high-temperature mineral assemblage including epidote, wollastonite and actinolite (Helgadóttir et al., 2010).

PROJECT DESCRIBTION

Geothermal gas from Hellisheiði geothermal field consists primarily of CO_2, H_2S, H_2 and to a lesser degree of N_2, CH_4 and Ar. A pilot gas separation station is being built next to Hellisheiði power plant and is currently in its testing phase prior to long term operation. The pilot station will separate the geothermal gas coming from the condensers of the power plant into CO_2, H_2S and light gas (H_2, N_2, Ar, O_2 and CH_4) streams. The oxygen in the light gas stream comes from possible atmospheric contamination of the geothermal gas. Approximately 3% of the total geothermal gas coming from the power station will be separated this way. The H_2S stream will be used for the H_2S injection experiment described in this paper, the CO_2 will be used for the Carbfix project (Gíslason et al., 2010) but the light gases are to be released into the atmosphere along with rest of the geothermal gases coming from the condensers of Hellisheiði power plant.

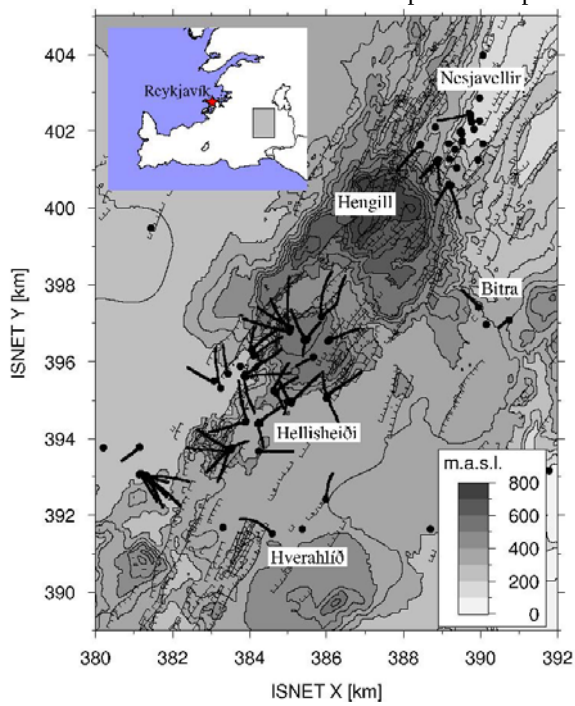

Figure 1. Map of Hengill central volcano, Iceland. The black dots are location of wellheads and black lines are well tracks of directionally drilled wells.

The H_2S gas will be dissolved in geothermal water together with potassium iodide tracer close to the injection site and subsequently injected back into the geothermal reservoir. The aim of the project is to use the same governing parameter that are controlling concentrations of H_2S in the geothermal reservoir to remove H_2S from solution and store it in minerals in the geothermal reservoir.

INJECTION SITE

The site chosen for the experimental injection of hydrogen sulfide is in Sleggjubeinsdalur approximately 2 km northeast of Hellisheiði Power Plant (Fig. 2). It was chosen on the bases of favorable reservoir temperature, proximity to the power plant and therefore the source of H_2S, tracer tests and the fact that on the site high temperature liquid enthalpy wells were available for injection experiments. H_2S gas will be transported from a pilot gas separation station, dissolved in geothermal water near the injection site and subsequently injected in well HE-08 (Fig. 2).

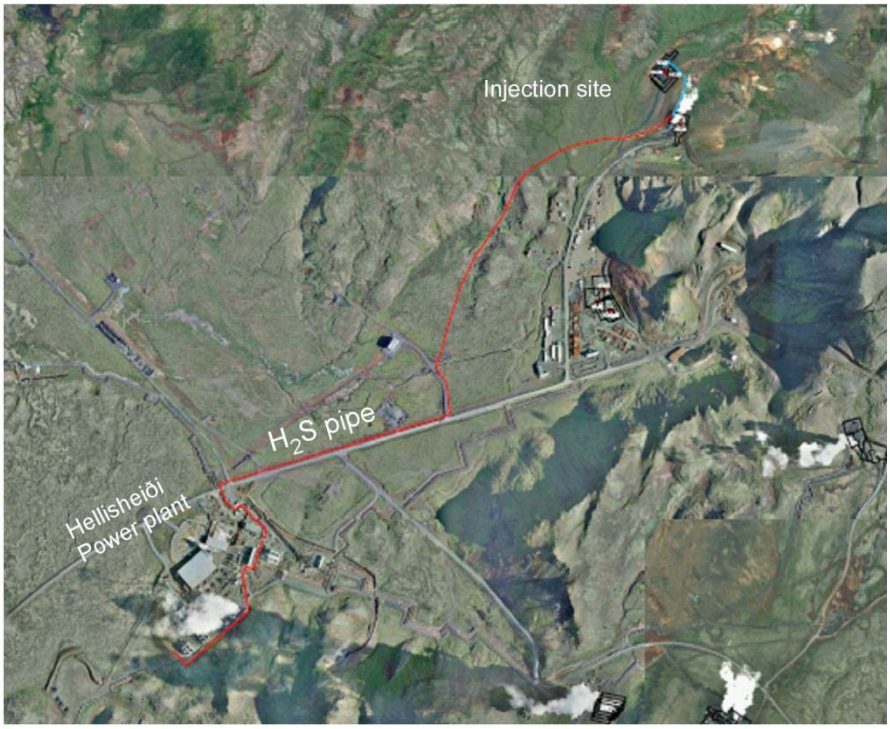

Figure 2. Experimental injection of H_2S. Location of injection site and power plant. The red line is the position of the H_2S gas pipe.

HE-08 is a vertical well 2808 m deep drilled in 2003 for production but turned out to be unusable as a production well. This well was selected for injection because during drilling of nearby wells a clear connection between the wells and HE-08 was observed. The connection between the wells was further studied in a tracer test described below.

The stratigraphy and alteration of Hellisheiði geothermal field and the injection site has been studied by Franzon et al., (2005) and Helgadóttir et al., (2010). The main rock formation in the injection site is sub-glacially formed hyoloclastite with occasional lava series. Below around 1400 m below sea level lava series are dominating (Fig. 3) (Helgadóttir et al., 2010). Aquifer temperature at the injection site is between 260° and 270°C as indicated by the application of the quartz geothermometer of the discharged fluid and calculated formation temperature. The dominating aquifer in HE-08 is at 1350 m depth where formation temperature is around 270°C which is in good agreement with the quart geothermometer. The rock formation at the injection site go through all typical alteration zones of high temperature areas from fresh rock to epidote-amphibole zone (Helgadóttir et al., 2010).

.

TRACER TEST

During drilling of HE-08 a pressure relationship was observed between HE-08 and KhG-1 which is a nearby well used for water level measurements. During drilling of HE-31, HE-46 and HE-52 pressure relationship was also observed between the drilled well and well HE-8 and KhG-1. Tracer test was performed to revile and quantify possible flow paths of the H_2S rich geothermal brine to nearby wells and the result used to compose a monitoring program of the possible monitoring wells.

The tracer test was performed by dissolving 250 kg Na-benzoate ($NaC_6H_5CO_2$) in 1000 liters water followed by injection into well HE-8. After injection of the tracer geothermal brine was pumped in the well at the rate of 4 l/s for 56 days. Wells in the vicinity of the injection well were discharging at the time of the test. The wells, shown in Fig. 4 are HE-5, HE-31, HE-46 and HE-52. Periodically samples were collected either from their weirbox or with the use of Webre separator and analyzed for the benzoate ion using an ion chromatographer. The concentration of benzoate was under the detection limit in all the samples for wells HE-52, HE-5 and HE-31. Elevated levels of benzoate concentration were only evident in well HE-46 (Fig. 5). Modeling of the tracer test reveals that close to 40 % of the injected water discharged in well HE-46 when taking into account the reported 20% breakdown of benzoate in two

weeks at 270°C. The rest of the benzoate was not accounted for. The benzoate injected into HE-08 started to appear in HE-46 after only two days reviling a fast flow path between the two wells. According to the quartz geothermometer, the aquifer temperature is 266°C which is close to the aquifer temperature in HE-08 and all the wells in the vicinity of the injection site.

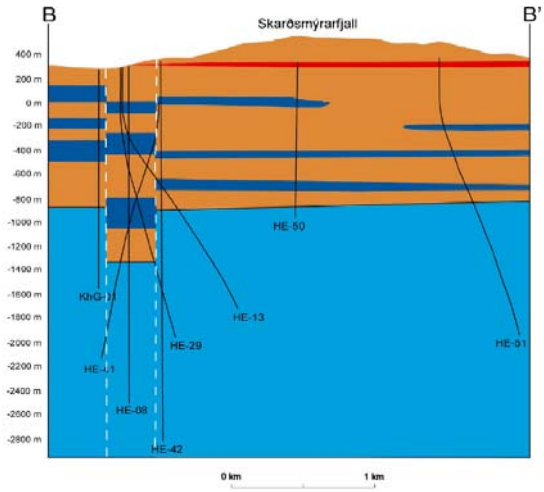

Figure 3. Volcanic successions in the injection site. Blue formations are interglacial lava series, red formation is postglacial lava series and brown formation is hyaloclastite (from Helgadóttir et al., 2010).

H_2S GEOCHEMISTRY IN GEOTHERMAL WATERS IN HELLISHEIÐI GEOTHERMAL FIELD

The concentration of hydrogen sulfide in aquifer fluids in Hellisheiði geothermal area has been extensively studied, both as a part of this injection project and as a part of general geochemical monitoring of the well in the area (Stefansson et al., 2011, Scott et al., 2011). The calculated H_2S concentration in the high temperature aquifer fluids is in the range of 15-264 ppm. The concentration increases with rising temperature and appears to be controlled by mineral buffer assemblages (Fig. 6). The majority of data points are close to equilibrium lines for the pyrite, pyrrhotite, prehnite and epidote or pyrite, pyrrhotite and magnetite mineral buffers. Stefansson et al., (2011) concluded that H_2S concentration equilibrate to the prehnite bearing mineral assemblage because Icelandic geothermal areas are usually low in magnetite indicating that it is unstable in Icelandic geothermal systems.

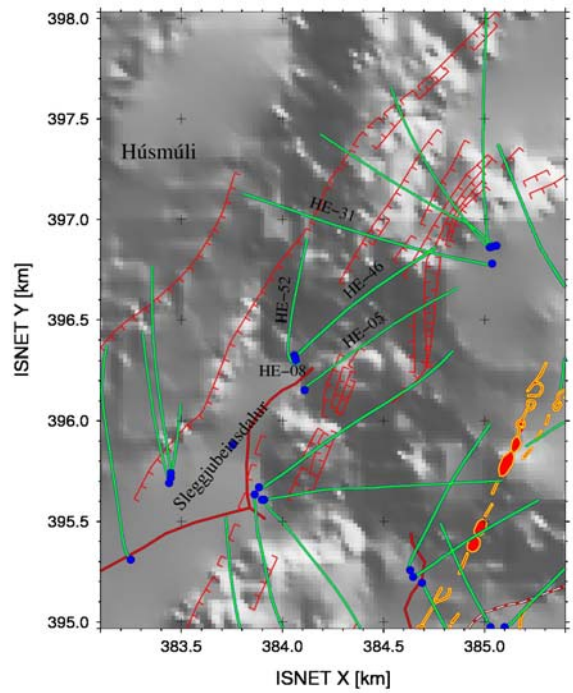

Figure 4. Wells at the H_2S injection site. Blue dots are position of the wellhead and green lines are well tracks. Faults in the area are indicated by the red lines.

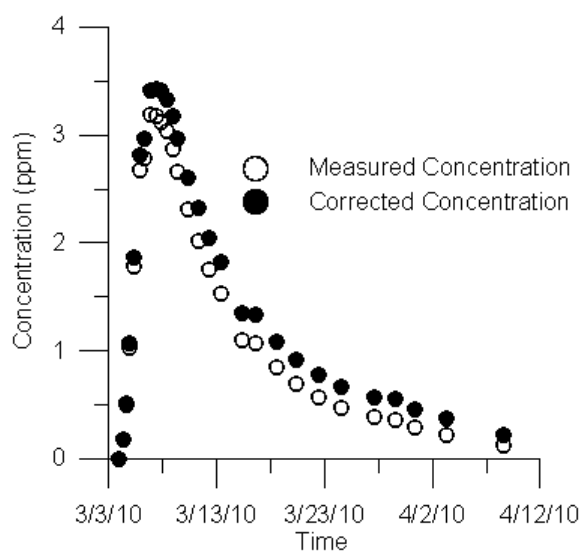

Figure 5. Concentration of benzoate ion ($C_6H_5CO_2^-$) in well HE-46 in Hellisheiði geothermal field. (from Scott, 2011). Corrected concentrations are values that have been corrected for thermal breakdown of benzoate corresponding to 20% decrease in two weeks.

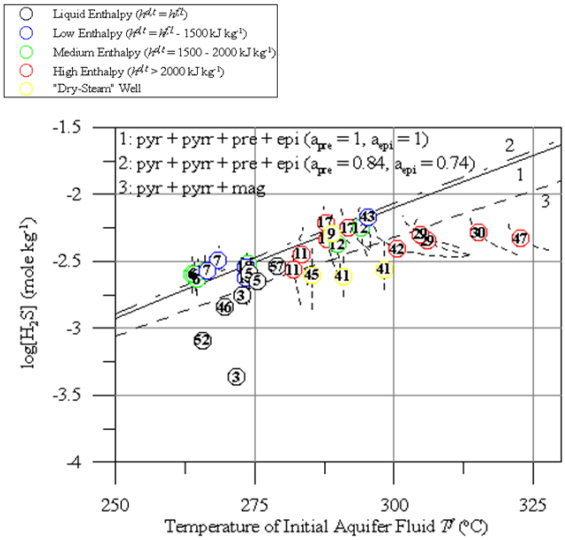

Figure 6. Concentration of H_2S in aquifer fluids in Hellisheiði geothermal area, Iceland. Number represent well number (from Scott et al. (2011).

DISCUSSION

H_2S abatement in the geothermal industry is an important factor in making geothermal utilization more environmentally friendly. Often geothermal areas and power plants are close to densely populated areas and emissions from power plants can cause environmental problems and friction between the inhabitants and geothermal power companies. Although health effects of long time exposure of low levels of H_2S have not been thoroughly studied more emphasis on solving the H_2S emission problem from geothermal power plants is being made in the geothermal industry in Iceland. Reykjavík Energy intends to experimentally inject part of the H_2S emitted from Hellisheiði Power plant back into the geothermal reservoir and utilize water rock reaction to mineralize H_2S in the geothermal reservoir.

The success of this method of H_2S abatement depends on the rate of the chemical reactions needed to take place for successful H_2S mineralization. The H_2S needs metals to form the secondary minerals to be permanently stored it in the geothermal reservoir. Reaction path modeling indicates that the main factors affecting the capacity of H_2S mineralization are related to the mobility and oxidation state of iron (Stefánsson et al., 2011). Above 250°C mineralization of pyrite is reduced upon formation of epidote resulting in more basaltic rock needed to be dissolved to mineralize the H_2S. The optimum temperature for H_2S sequestration would then be below the stability zone of epidote or below approximately 230°C (Stefánsson et al., 2011). The rock formation temperature at the injection site is between 260-270°C making the formation of epidote favorable. The injected water is around 100°C and will presumably heat up to above 260° before entering the monitoring well (HE-46). Due to many uncertainties associated with many parameters of the whole injection process and relevant chemical reactions that determine whether H_2S will be successfully mineralized in the geothermal reservoir, the feasibility of this method of H_2S abatement needs to be experimentally determined by experimental injection of H_2S

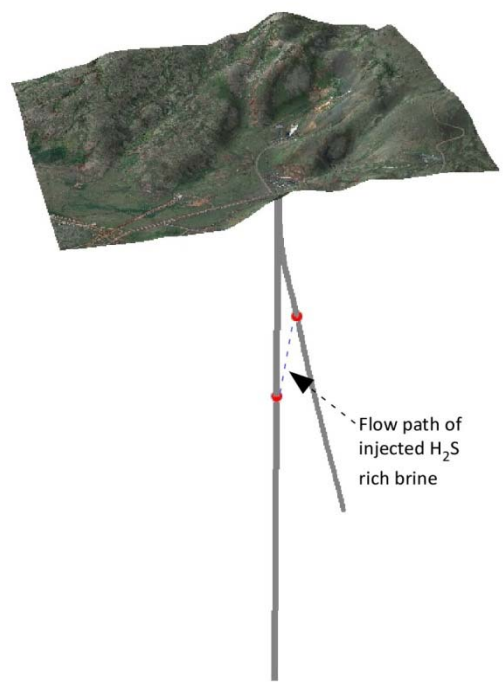

Figure 7. Position of main aquifers (red dots) in the injection and monitoring well at the H2S injection site Hellisheiði , Iceland. The distance between the aquifers is around 450m.

Tracer testing of the injection site reviled a direct and fast flow path from the injection well and the monitoring well. The distance between main aquifers is around 450 m (Fig. 7). This indicates that the main flow path between the wells is through a fracture in the reservoir which is to be expected in fracture dominated geothermal reservoir like Hellisheiði geothermal field. For the experimental injection to be successful the rate of H_2S mineralization may not be too fast as sulfide minerals might fill up the aquifers in the vicinity of the injection well making it unusable for injection. Circumstances like that

would call for measures to slow down the mineralization reaction. These measures might be for example lowering the concentration of H_2S in the injected brine and therefore lowering the supersaturation of the brine with respect to the depositing sulfide minerals. On the other hand, the rate of H_2S mineralization might be too slow for any mineralization to take place when the brine flows from the injection well to the monitoring well. A response to that could be to close down the monitoring well for some time but continue with the injection of H_2S. This would increase the retention time in the geothermal reservoir allowing more time for H_2S sequestration.

If this segregation method of dissolving H_2S in geothermal brine followed by injection back into the geothermal reservoir is successful it is relatively low cost H_2S abatement method. It is environmentally friendly as there are no byproducts that need to be disposed of. Returning the H_2S back to where it came from has to be considered as an ideal method for reducing gas emission from geothermal power plants.

REFERENCES

Arnórsson, S. (1995a) Hydrothermal systems in Iceland: Structure and conceptual models. 1. High-temperature areas. Geothermics 24, 561-602.

Arnórsson, S. (1995b) Hydrothermal systems in Iceland: Structure and conceptual models. 2. Low-temperature areas. Geothermics 24, 603-629.

Franzson, H., Kristjánsson, B. R., Gunnarsson, G., Björnsson, G., Hjartarson, A., Steingrímsson, B., Gunnlaugsson, E. and Gíslason, G. (2005) The Hengill-Hellisheiði Geothermal field. Development of a Conceptual Model. Proceedings Worls Geothermal Congress 2005.

Gislason S.R. , Domenik, W. B., Stefansson, A., Eric H. Oelkers, E. H., Gunnlaugsson, E., Sigurdardottir, H., Sigfusson, B., Broecker, W. S., Matterd, J. M., Stuted, M., Axelsson, G. and Fridriksson, Th. (2010).Mineral sequestration of carbon dioxide in basalt: A pre-injection overview of the CarbFix project. Int. J. Greenh. Gas Con. 4, 537-545.

Helgadóttir, H. M., Snæbjörnsdóttir, S. O., Níelsson, S., Gunnarsdóttir, S. H., Matthíasdóttir, T., Hardarson, B. S., Gunnlaugur M. Einarsson, G. M. and Franzson, H. (2010) Geology and Hydrothermal Alteration in the Reservoir of the Hellisheidi High Temperature System, SW-Iceland. Proceedings, World Geothermal Congress 2010.

Sanopoulos, D. and Karabelas A. (1997). H_2S abatement in geothermal plants: Evaluation of Process Alternatives. Energy Sources, 19, 63-77.

Stefansson, A., Arnorsson, S., Gunnarsson, I., Kaasalainen, H. and Gunnlaugsson, E. (2011). The geochemistry and sequestration of H2S into hydrothermal system at Hellisheidi, Iceland. J. Volcanol. Geoth. Res. (in press)

Scott S., Gunnarsson, I., Stefansson, A. and Gunnlaugsson, E. (2011). Gas Chemistry of the Hellisheiði Geothermal Field, SW-Iceland. Proceedings 36th Stanford Geothermal Workshop.