Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Tackling the Challenge of H2S Emissions

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Keywords: Hydrogen sulfide, emission, regulation, air quality, injection, Iceland

ABSTRACT

Although geothermal power plants produce renewable energy with very little emissions compared to their fossil fuel counterparts, emission of non-condensable gases is an inevitable part of high temperature geothermal power production. The major gases in geothermal fluids are CO2, H2S, H2, N2, CH4 and Ar. Concentration of these gases varies from one geothermal field to another and depends on temperature, composition of fluid and geological setting.

In 2014 stricter standards will take effect in Iceland that lower the allowable levels of atmospheric hydrogen sulfide (H2S). The H2S levels stipulated in the regulations are significantly lower than the current World Health Organization guidelines and require the Icelandic geothermal industry to take action to reduce its H2S emissions. To tackle this challenge, three Icelandic energy companies that all produce power from high temperature geothermal fields, Reykjavik Energy, Landsvirkjun and HS Orka, joined forces to develop the best abatement solution. The group began by surveying conventional abatement processes but found that because the Icelandic market for the products of those processes (sulfur and sulfuric acid) is small, conventional solutions are a very expensive option for the Icelandic geothermal industry. It was therefore decided to build on research and development of reinjection methods for CO2 at Reykjavik Energy to develop an abatement method called SulFix.

The aim of the SulFix project is to develop a sustainable and environmentally friendly H2S abatement method with lower operation costs than commercially available abatement options. The process dissolves H2S in condensate water and injects it back into the high temperature geothermal reservoir. Once injected, water-rock reactions taking place in the high temperature geothermal reservoir will mineralize the H2S. The method is being tested at industrial scale at the Hellisheiði Power Plant.

1 INTRODUCTION

Emission of geothermal gas from geothermal power plants is an inevitable part of geothermal power production. The main components of geothermal gas are CO2, H2S, H2, N2, CH4 and Ar. Concentration of individual gases can range from ppb levels to several thousand ppm depending on geological settings, temperature and composition of the geothermal reservoir. The origin of the gases is either magmatic, meteoric or they are formed in the geothermal reservoir in water rock reactions. The gases have different physical and chemical properties, some are environmentally important and their emission increases the environmental impact of the geothermal industry.

Since the commissioning of the Hellisheiði Power Plant, in SW Iceland, in 2006, an increase of hydrogen sulfide concentration has been detected in the communities close to the power plant. The characteristic smell of H2S, in Iceland referred to as “the geothermal smell”, was in some cases strong enough to annoy the inhabitants of the communities and more focus was put on environmental issues related to geothermal power production. As a consequence of the increase in atmospheric H2S levels, a new regulation on H2S levels in inhabited areas was implemented in 2010 with tighter standards taking effect in 2014. The new regulation put high demands on Icelandic geothermal power companies to lower gas emission from their geothermal power plants. The three Icelandic geothermal power companies, HS Orka, Landsvirkjun and Reykjavik Energy, joined forces and decided to collaborate to work on solutions best suited to Icelandic conditions to reduce gas emissions, analyze weather conditions when high H2S concentrations occur in nearby communities and coordinate measurements of H2S atmospheric concentrations.

Hydrogen sulfide is a colorless, flammable, corrosive and toxic gas with the characteristic odor of rotten eggs. The odor threshold is variable but is thought to be between 0.5 to 30 ppb for most people (Schiffman and Williams, 2005). Exposure to H2S can cause health problems depending on the level and duration of the exposure. Low level exposure for a long time can cause inflammation and irritation of the eyes whereas high levels exposure for a short time can cause dizziness, headache, nausea and even death if the concentration of H2S in atmosphere goes above 300 ppm. The health effects of prolonged very low level (<2000 ppb) exposure are being debated (Bates et al, 2013; Carlsen et al., 2012; Campagna et al., 2004, Jappinen et al., 1990). In modern societies the demand for air quality is more than ever. The discussion on whether H2S has a negative impact on quality of life is ongoing and no matter whether that discussion is fair or not, it will over time affect the good reputation of the utilization of geothermal industry in Iceland. Reducing the emission of H2S from geothermal power production is therefore an important step to increase public acceptance of geothermal utilization.

2 GEOTHERMAL POWER PRODUCTION IN ICELAND

In 2013, 29.0% of the total installed capacity in Iceland was geothermal, which is the highest share of total installed capacity in the world. There are six geothermal power plants located in the south west and north east part of the country.

Reykjavik Energy operates the Nesjavellir and Hellisheiði Power Plants which are combined heat and power plants located to the north and south of the Hengill central volcano which is located in the western volcanic zone SW-Iceland, approximately 20-25 km southeast of Reykjavík (Figure 1). Operations began at Nesjavellir in 1990 with the production of 100 MWth for district heating in

Reykjavík. Hot water production has since been increased in several steps up to 290 MWth by 2005. Electricity production started in 1998 with two 30 MWe turbines. The third 30 MWe turbine was installed in 2001 and the fourth in 2005. Currently the Nesjavellir Power Station produces 290 MWth and 120 MWe. The Hellisheiði Power Plant was commissioned in 2006 with the installment of two 45 MWe turbines. In 2007 a 33 MWe low pressure turbine that uses steam from a second stage flashing of the separated geothermal water was started. Two additional 45MWe turbines were started in 2008 and another two in 2011. Heat exchangers were commissioned in 2010 producing 133 MWth for space heating in Reykjavík. Total installed capacity in Hellisheiði power plant is 303 MWe and 133MWth.

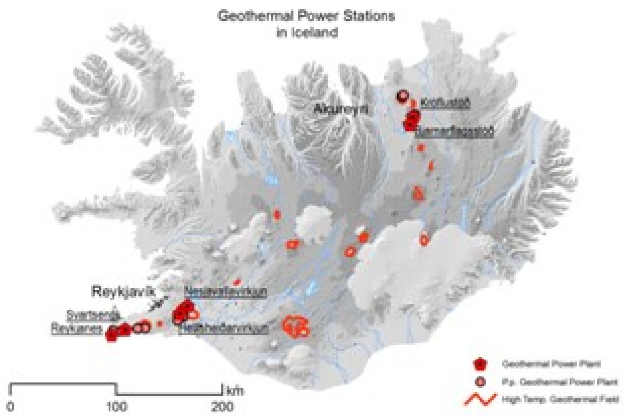

Figure 1: Location of high temperature geothermal fields and geothermal power plants in Iceland.

HS Orka hf, located at the Reykjanes peninsula in south west Iceland, delivers hot water for district heating and ground water to the municipalities at the peninsula. Power generated is fed into the national electricity grid. Installed geothermal power capacity is 175 MWe from the company's two CHP geothermal power plants at Svartsengi, 75 MW, and Reykjanes, 100 MW. In addition, HS Orka generates 150 MWth hot water for district heating to the municipalities at the peninsula.

Landsvirkjun operates two geothermal Power Plants, Krafla and Bjarnarflag, located in north east Iceland. The Bjarnarflag Power Station is the country's first and oldest geothermal power station, with a 3 MW backpressure turbine commissioned in 1967. The Krafla Power Station was commissioned in 1978, with only one unit. However, it was not until 1984 that it had enough steam to reach full 30 MW capacity. The second turbine was installed in 1996, giving full 60 MW capacity in 1999.

3 EMISSION OF NON-CONDENSABLE (NCG) GASES

Gas emissions from current and planned geothermal power plants in Iceland are shown in Table 1. Emissions vary between geothermal areas both in magnitude and composition, which is dependent on geological settings in each area.

Table 1: NCG emissions from Icelandic power plants in tons/year.

Icelandic geothermal power plants in operation	MW	CO_2	H_2S
Hellisheiðarvirkjun	303	44,934	12,374
Nesjavellir	120	14,794	8,709
Reykjanesvirkjun	100	25,090	860
Svartseingi	75	53,840	1,020
Krafla	60	39,683	5,180
Bjarnarflagstöð	3	1,292	1,603
Total emissions:	661	179,633	29,746

Estimated emissions from planned geothermal power plants	MW	CO_2	H_2S
Hverahlíð	90		5,370
Reykjanesvirkjun	80	13,000	460
Eldvörp	50		550
Bjarnarflagstöð	45	2,980	2,744
Þeistareykir	90	19,690	9,845
Total emissions:	355	35,670	18,969

3.1 Dispersion of Hydrogen sulfide

Most of the Icelandic geothermal power plants are located near cities or towns. Consequently, increased emission of the NCG from the power plants leads to increased hydrogen sulfide (H2S) concentration levels in inhabited areas. An attempt was made to model the distribution of H2S in the capital city of Reykjavik. An air distribution model to predict the H2S concentration in the atmosphere, dependent on the weather and amount of emissions, was constructed (Figure 2). However, the study found that in order for reliable results, distribution modeling needed to take into account landscape and disturbances and better resolution is needed. (Ólafsdóttir et al., 2013; Thorsteinsson, et al., 2013).

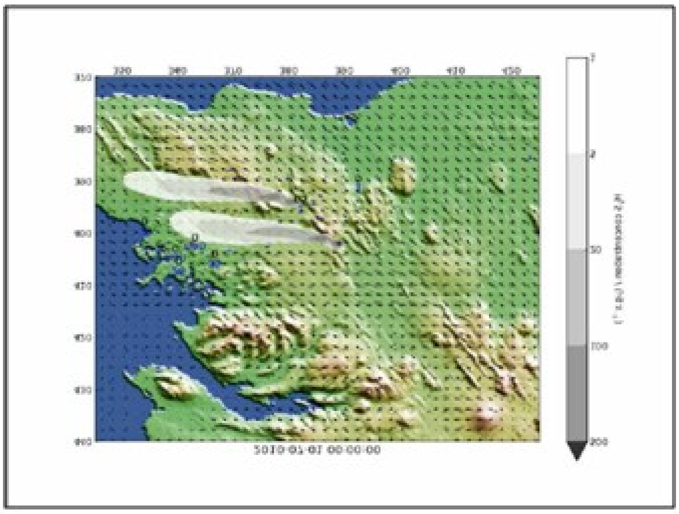

Figure 2: An example of H2S distribution from Hellisheiði and Nesjavellir power plants.

In Bjarnarflag, the strongest factor controlling the atmospheric concentration of H2S is thermal inversion of air above the geothermal field. Figure 3, shows an example of an event where deep thermal inversion layer was formed over the area. The inversion layer caused a buildup of H2S in the trapped air and rising of H2S concentration in the following hours. These events have been identified as the major cause for formation of concentration peaks of H2S and all major peaks in the year are caused under such conditions.

Figure 3: Example of an event where deep thermal inversion layer was formed in Bjarnarflag.

3.2 Atmospheric hydrogen sulfide regulations

In 2014 new standards will take effect in Iceland that lower the allowable level of atmospheric hydrogen sulfide (H2S). The H2S new standards stipulated in regulations are significantly lower than the current World Health Organization guidelines and require the Icelandic geothermal industry to take action to reduce its H2S emissions.

Table 2: Environmental limits for H2S according to Icelandic regulation.

Environmental limits	Reference Guidelines	Guidelines $[\mu g/m^3]$	Allowed repetitions over limits	Apply
Public Health limits	Max average concentration for 24 hour	50	5	From adoption of the regulation
Public Health limits	Max average concentration for 24 hour	50	0	July 1st 2014
Public Health limits	Year	5		

Atmospheric H_2S concentrations were first regulated in Iceland in July 2010 (regulation nr. 514/2010) and the regulations apply to monitoring and measuring environmental and public health limits as well as information flow concerning atmospheric H_2S concentration. The regulation applies to business activity in Iceland. The regulation does not apply for areas defined as an industrial estate in the master plan of the respective municipality. According to the regulation, business activity is allowed to define and get approval for a dilution area surrounding the origin of the release, where concentration may be higher than defined in Table 1. Residential areas may not be located inside a dilution area. Environmental limits for work places where H_2S can be emitted or used are defined under separate law (nr 46/1980).

4 TACKLING THE CHALLENGE

4.1 The collaboration of the Icelandic Power companies

HS Orka, Landsvirkjun (LV) and Reykjavik Energy (OR) have, since May 2012, been formally working together to deal with the new Icelandic standards for H_2S emissions from power plants. The standards stipulate H_2S atmospheric concentration levels in urban areas.

In November 2012 the companies hired a project manager for their collaboration project to evaluate possible solutions for this new challenge, followed with the development of a project master plan to reduce H_2S atmospheric concentration levels. The project steering group applied in February 2013 for a delay on the adoption of tighter emission standards, that take effect in July 2014, while they were working on tackling this challenge.

On April 26th 2013, the Minister of Environment denied the request. The reason: According to available information only one power plant, Hellisheidi (Reykjavik Energy's power plant), will have difficulties fulfilling the tighter emission standards. Therefore the Minister considered it irrational to delay adoption for all geothermal power plants in the country. In the spring of 2014 Reykjavik Energy applied for an exemption from the tighter standards for the Hellisheiði geothermal power plant until the end of 2019. On Jun 5th 2014, the Minister of Environment approved that exemption for two years with several conditions.

4.2 Possible mitigation methods

Hydrogen sulphide is a known pollutant in a number of industries and is formed where sulphur reacts under anaerobic conditions such as in oil reservoirs and geothermal systems. The petroleum industry has used abatement technologies for H_2S mitigation for a long time. Commonly the H_2S is oxidized by burning it in the atmosphere, forming SO_2 or by oxidizing it to elemental sulphur. The methods of producing elemental sulphur, such as by the Claus method where H_2S is partly burnt followed by catalytic oxidation over to elemental sulphur, or the liquid redox method where H_2S is oxidized with metals such as iron or vanadium, results in formation of solid sulphur. In most cases sulphur is a commodity and can be utilized for a wide industrial application such as production of sulphuric acid, one of the most used industrial chemical on earth (Matthiasdottir, 2007). However due to the remote location of Iceland and absence of industries that use sulphur, the specific conditions in Iceland lead to further studies on possible mitigation methods.

Trimeric Inc. studied the options for abatement of non-condensable gases at Bjarnarflag (Mamrosh et al. 2012) and concluded that the most feasible way was to focus on scrubbing the gas with water and re-injecting it back into the ground. However further studies on that technology where suggested. This was in line with the findings of Reykjavik Energy that started studying water absorption of geothermal gases in 2007.

4.3 SulFix II

Since 2007, Reykjavík Energy has operated three gas separation and reinjection projects (Gunnarsson et al., 2011 and 2015, Aradóttir et al., 2011 and 2015). These projects are one pilot gas separation station and two gas injection projects, SulFix which aimed at the injection of H_2S into a geothermal reservoir and CarbFix which involved injection and sequestration of CO_2 into a basaltic reservoir.

The operational and practical experience gained from the pilot scale gas separation station and the two gas injection projects is the foundation of an scaled up gas separation station and injection that will be commissioned in the summer of 2014. This scaled up gas treatment and re-injection is called SulFix II. The design of the SulFix II station is focused primarily on dissolving the H_2S in the geothermal gas. The Sulfix II gas separation station is designed to take 400 g/s of the gas from the Hellisheiði Power Plant and dissolving 98% of the H_2S along with 57% of the CO_2 in 36 kg/s of condensate water in an absorption tower. The gas loaded condensate water is then injected back into the geothermal reservoir through one of the re-injection wells currently operated in the Húsmúli re-injection zone next to Hellisheiði power plant. Geothermal brine from the power plant is co-injected into the well where the two fluids mix prior to flowing into the well aquifer.

The reservoir temperature in the reinjection zone is 200-270°C. Tracer elements will be co-injected with the gas and the arrival of the injected geothermal gas back into the production field will be extensively monitored. Studying the fate of the re-injected H_2S in the geothermal reservoir is an important part of the SulFix II project and the success of this abatement method of re-injecting the H_2S back to where it came from depends partly on the extent of H_2S mineralization in the reservoir. Equilibrium calculations and field scale reactive transport modelling of H_2S injection show formation of iron sulphide minerals and full H_2S sequestration within a year, respectively (Aradottir et al., 2012).

5 CONCLUSION

Non-condensable gas emissions are an inevitable part of high temperature geothermal power production. In response to tighter H_2S air quality standards in Iceland the three largest power companies in Iceland decided that collaboration was the most effective way to tackle the challenge of reducing H_2S emissions. Dispersion models have shown that thermal inversion layers and landscape have a large impact on H_2S dispersion but more work is needed in this area. After surveying current abatement methods it was concluded that conventional abatement methods were not ideal for Icelandic conditions mainly because there is no market in Iceland for the byproducts of these processes. Consequently, the companies looked to innovative ways to solve the problem.

Utilizing results and experience gained from research and development projects involving gas separation and reinjection of gases into the reservoir, it was decided to scale an H2S gas reinjection method up to an industrial scale. Studies have shown that using the method should allow for full H2S sequestration within the geothermal reservoir. The industrial scale project, that has been named SulFix II, will be commissioned in the summer of 2014 and the next few years are critical in determining the feasibility and success of the method.

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