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

Design of a H2S Absorption Column at the Hellisheiði Powerplant

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Keywords: NGC abatement, H2S disposal, absorption column

ABSTRACT

Environmental regulations in Iceland impose conditions on disposal and abatement of H_2S release from geothermal power plants. At the Hellisheiði power plant several methods of H_2S disposal have been under investigations. After an initial screening the most suitable methods were determined to be absorption either with amine solvents or water. The water absorption method was selected due to cost and simplicity and elimination of danger due to spills.

A system based on a water absorption column and reinjection has therefore been built to handle H_2S from one 45MW unit. Once the technology is proven, plans to add similar systems for the other units have been made. This article discusses the main issues in the design and operation of the system.

Mannvit handled the design of the system. A basic system description is the following. Cooled condensate is used for the absorption. It is cooled with ground water which is plentiful in the Hellisheiði area before being lead to the absorption column. The water from the absorption column is then lead to a booster pump where the pressure is increased before reinjection.

Two system aspects reduce the risk of depressurization of the gas rich water during reinjection. The pipeline into the reinjection well is extended down into the well, below the casing. Secondly a separate water pipeline supplies water to the well head to maintain pressure in the well. It is assumed that 98% of the H2S will be cleaned with this method. Lighter gases, not absorbed and part of the CO_2 are vented at the top of the absorption column. The other part of the CO_2 is dissolved in the water in the absorption column and injected with the H_2S.

The initial operation experience is positive. The system has been operated at full capacity with success.

1 INTRODUCTION

Non condensable gases (NCG) are a natural component of geothermal fluids. The weight ratio of NCG in the geothermal steam can vary considerably from field to field. In the Kizildere geothermal power plant in Turkey (Gokcen, Kemal Ozturk, and Hepbasli 2004) an average NCG content of 13% by weight of steam entering the turbine was reported. The typical gases are CO_2, H_2S, H_2, N_2, and CH_4. In the case of a steam turbine with condenser, the gases are collected in the condenser from where they have to be extracted for treatment or release to the atmosphere.

Environmental regulations in Iceland impose conditions on disposal and abatement of H_2S release from geothermal power plants. In 2010 a governmental directive was set regarding the maximum levels of hydrogen sulphide (H_2S) in the atmosphere. The moving average over 24 hours shall not exceed 50 [$\mu g/m^3$].

The Hellisheiði power plant is located 20 km from Icelands capital Reykjavík and 11 km from the town of Hveragerði. The first 90 MW were commissioned in 2006 but by 2012 the total production was 303 MWe. Up until now the power plant has had an exemption regarding the limits on H_2S emissions. Since the commissioning of Hellisheiði Power Plant in 2006 was followed by an increase in H_2S concentration in nearby town and communities and the days that H_2S smell can be noticed in the city of Reykjavík have increased, more focus was put on H_2S abatement, see (Gunnarsson et al. 2013). Several methods of H_2S disposal have been under investigations.

Currently the NCG stream from the liquid vacuum pumps that pump it from the condensers is released to the atmosphere. To fulfill the requirements regarding maximum levels of H_2S set by the recent regulation, the H_2S from the plant in Hellisheiði has to be disposed of instead of releasing it to the atmosphere. For this purpose a H_2S absorption column has been designed and built at the Hellisheiði power plant and in May 2014 it was commissioned. The absorption column is the centerpiece of a system designed to dissolve the H2S into water and reinject the gas-water mixture into the bedrock.

Several research projects have been carried with the participation of Mannvit and ON, the power plant owner, with the aim of learning techniques for NCG abatement. Two of them were gas re-injection projects, namely SulFix and CarbFix (see (Aradóttir et al. 2011), (Gunnarsson et al. 2011) and (Aradóttir et al. 2012)) where the aim was to dissolve the geothermal gases in water and injected into the reservoir or into the bedrock. Pilot plant installations were tested in these programs.

The research projects were considered to reduce the technical risk sufficiently to go ahead with tests in industrial scale. The system presented in this article can be seen as a scale-up to industrial dimensions of these earlier pilot plant installations.

The absorption of H2S and reinjection into the bedrock has been discussed in the literature as a method for H2S abatement. Similar approaches are discussed in (Mamrosh et al. 2012), (Rodríguez, Harvey, and Ásbjörnsson 2014). In (Mamrosh et al. 2012) the water absorption method was characterized as not proven with some technical risks. In (World Environment Center 1994), problems related to gas injection at the Coso geothermal power plant were discussed. There, brine from the separators was used as the bulk medium. After 7 years of operation this method was abandoned due to gas breakthroughs in the field, vapor lock in at the reinjection wells due to insufficient liquid for reinjection and corrosion problems in the gas lines and well casings. However, the authors point out that the method should not be discarded but rather that reinjection can be an effective method depending on the conditions of the field and the geothermal fluid.

The use of brine as a bulk medium was tested in the Sulfix project but its use discarded due to danger of scaling. Oxygen free condensate is considered a much more suitable bulk medium. Its availability for reinjection was due to the use of indirect steam turbine condensers at the Hellisheiði power plant. The importance of having the bulk media oxygen free is vital as scaling problems due to elemental sulfur are quickly expected with the presence of oxygen in the bulk media.

It was pointed out in (Gunnarsson et al. 2011) that the success of this method depends on the rate of chemical reaction 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. Several assumptions regarding the injection process and the relevant chemical reactions will be answered when the system described in this article will be operated at full capacity for a longer period of time.

This report reviews the criteria that led to the decision of building the H2S absorption column, the engineering design problem and solution by Mannvit and the experience after commissioning of the operation. The system has been operated at full capacity and first indications are very positive. It is expected that further operational experience can be presented at the conference.

The structure of this report is the following. The selection of this system is discussed in section 2. The system is described in section 3 and a 3D layout is shown. Finally operation experience is briefly discussed in section 4 before conclusions are presented in section 5.

2 TECHNOLOGY SELECTION

2.1 Criteria for selecting a H2S abatement system

Several criteria have been mentioned for selecting H2S abatement systems. Some are discussed in (Sanopoulos and Karabelas 1995) and (Mamrosh et al. 2012)

- **Efficiency of the abatement system.** This parameter shows the total reduction of released H2S to the atmosphere.
- **Capital and operating cost.** This reflects total cost of construction, engineering and equipment. Operating cost should include price rate of all feed materials, cost of disposal of waste materials, energy requirements and staff among other things. Maintenance due to scaling and corrosion should be included.
- **Technical risks**. This factor reflects at what level the technology used is at in terms of commercialization and experience and weather further development is needed. Key question is if the technology is considered proven in the industry. Risks to take into account could include system failure and shutdown due to corrosion or scaling. Risks regarding reservoir should be considered as well such as gas breakthrough in the field.
- **Process complexity, flexibility and turndown.** This factor reflects the ability of the process to work efficiently at reduced capacity, perhaps due to changing conditions of the field or other factors.
- **Environmental impact and risks.** This factor includes land use for the installation, environmental impact on atmosphere, groundwater etc and also environmental risks for example due to spills of feed or waste materials.
- **Health and safety**. Issues such as explosion and health effects on staff or populations in nearby towns.

2.2 H2S abatement method selection at the Hellisheiði power plant.

In (Mamrosh et al. 2012) a screening of H2S abatement options for geothermal power plants in Bjarnarflag were presented. The conditions at Bjarnarflag were expected to be similar to the conditions at the Hellisheiði power plant.

The system presented in this article was selected after comparison with other suitable methods of H_2S abatement. The main advantages with this process were that no waste materials are created by the process and no special feed materials are needed. The capital cost is low compared to many other methods. The simplicity of the process using only water and electricity was considered important as well. Note that in this regard, the experience gained in the earlier research projects CarbFix and SulFix was vital and aided considerably in selection of equipment and materials.

3 TECHNICAL DESCRIPTION OF SYSTEM

3.1 Design basis

The main quantities related to the design basis for the absorption system is presented in Table 1. These numbers correspond to gas outlet from one 45 MW turbine in the Hellisheiði power plant. Condensate from the turbine is used as the bulk phase in the absorption. The condensate-gas mixture from the absorption system is then reinjected into a well.

The ratios in the table above are found from the composition of the NCG as it enters the turbine. The actual composition can be slightly different as pointed out in (Gunnarsson et al. 2013). There it was also pointed out that air mixes with the geothermal gas in the condensers of the turbines as the vacuum in the condensers is used to draw air along the turbine axis to prevent geothermal steam escaping into the turbine hall. For this reason the amount of air in the geothermal gases pumped out of the condensers can be considerable. This on the other hand represents abnormal operating conditions that the system presented in this article was not designed to handle.

Table 1. Design basis for absorption system.

Condensate	
pH at 20°C	5.7
CO2	1 mg/kg
H2S	2 mg/kg
Inlet temperature	40°C
Inlet pressure	9 bar_a
Non Condensable Gas mixture	
CO2	48.5% v/v
H2S	25.5% v/v
H2	24.4% v/v
N2	1.55% v/v
CH4	0.31% v/v
Mass flow rate of gas	0.4 kg/s

3.2 Process flow diagram

Figure 1 shows the process flow diagram for the H2S absorption system. The gas enters the absorption column close to the bottom. Below the entrance of the gas a water level is maintained. The gas flows upwards in the column that is packed with a filling designed to increase the surface area between the gas and the water. With the contact with the water the H2S and CO2 are dissolved in the water. Other gas types like H2, N2, O2, argon and methane dissolve poorly in water at the conditions in the column and flow upwards. At the top of the column these gases are released with a control valve. This top control valve controls the pressure in the column.

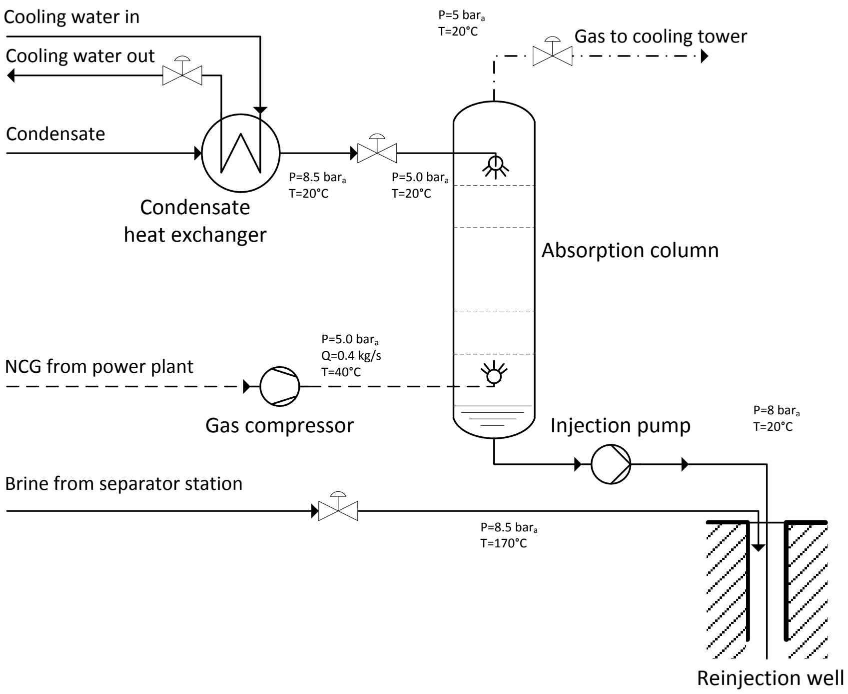

Figure 1. Process flow diagram.

The condensate stream from the indirect condensers of the power plant enters the column close to the top and flows downward counter flow to the gas. Not shown on the figure are booster pumps for the condensate to bring the pressure up to the level of the gas from the gas compressor. The booster pumps are used for all of the condensate from the plant to enable mixing with the brine that is reinjected in other parts of the power plant. The condensate is cooled by using groundwater before it enters the absorption column. The pressure of the gas is increased in a compressor before entering the absorption column. This is to increase the absorption into the water.

The condensate with the dissolved gases falls to the bottom of the column. The water level there is controlled with a pump that pumps it to a reinjection well. It is important that pressure in the pipeline into the well does not fall below the pressure in the column since this causes immediate release of the gas from the water solution as when a soda bottle is opened.

The abatement efficiency with the described setup depends on the amount of condensate used but at full capacity the efficiency is 95%. Notice that the condensate from the turbines is especially suitable since it is without oxygen which reduces the danger of scaling and corrosion. This is not the case with groundwater. Despite this, the gas-water mixture that is reinjected is acid and highly corrosive and special care has to be taken regarding material selection in all the components. Notice that with this solution a considerable amount of CO2 is also dissolved in the liquid.

One of the special features of the system is the arrangement in the reinjection well. The corrosive gas-water mixture is channeled in a pipe below the casing (750m) in the reinjection well. To protect the casing, high pH brine from the separation station is pumped into the annulus of the well. The idea is therefore that the acid water never comes into contact with the casing. Furthermore, the flow of brine is used to control the reinjection pressure for the gas-water mixture. In this way, pressure after the injection pump is maintained high.

The system is controlled automatically but with SCADA supervision. The main control loops are the pressure control inside the absorption column by using the exhaust valve at the top. The level in the column is controlled with the injection pump. Finally to guarantee pressure in the reinjection pipeline, a control valve controls the flow of brine to the annulus of the reinjection well. Notice that for the correct amount of control authority the injectivity curve of the reinjection well had to be taken into account when designing the system. The flow rate of condensate is controlled with a control valve.

3.3 Safety issues

Some important safety had to be taken into account in the process design. The gases that are collected in the top of the absorption column can be explosive. A HAZOP study was performed as part of the Essential Safety Requirements [ESRs] of Directive 97/23/EC, the Pressure Equipment Directive [PED]. All equipment had to have the correct ATEX rating.

To avoid too high pressure in the absorption column in case the control valve fails to control the pressure, a pressure safety valve is installed on the column that will release to the atmosphere.

3.4 Equipment and layout

The basic equipment list includes the following items:

- Absorption column
- Condensate heat exchanger
- Booster pumps of gas-condensate mixture
- Gas compressor

In addition there are several control valves, manual valves and instrumentation that are not counted. The absorption column is around 12,5m high and 1m in diameter. Figure 2 shows a rough 3D layout of the absorption column.

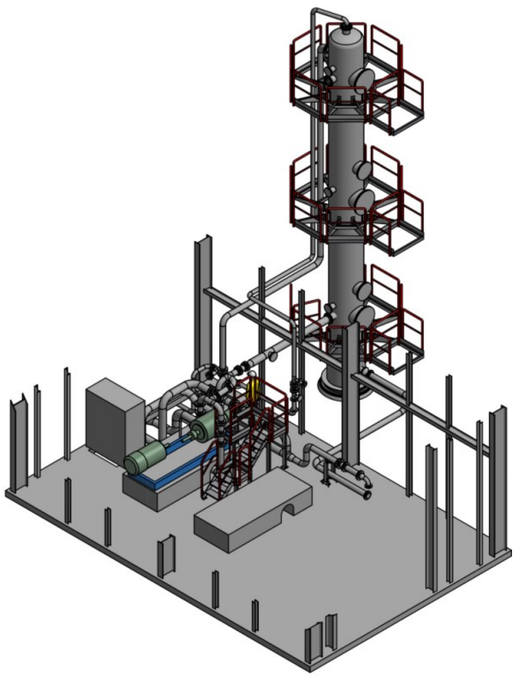

Figure 2. Layout (3D) of absorption column.

4 OPERATIONAL EXPERIENCE

The system was commissioned in April-May 2014 and the first operational experience is positive. The first step in the commissioning included stabilizing the reinjection of the condensate and the brine. The condensate was passed through the absorption tower. Finally the gas compressor was started.

The system has been operated at full capacity without problems. Long term problems due to corrosion and scaling have not been detected. It should be noted that probably more operating experience is needed for these problems to appear. Furthermore, the sequestration of H_2S in the reservoir will be tested as the system is operated for longer periods on time.

5 CONCLUSIONS

This article describes a design of a H2S abatement system for geothermal plants. It is based on absorption of H2S in condensate and reinjection into the bedrock.

A basic system description is the following. Cooled condensate is used for the absorption. It is cooled with ground water which is plentiful in the Hellisheiði area before being lead to the absorption column. The water from the absorption column is then lead to a booster pump where the pressure is increased before reinjection.

Two system aspects reduce the risk of depressurization of the gas rich water during reinjection. The pipeline into the reinjection well is extended down into the well, below the casing. Secondly a separate water pipeline supplies water to the well head to maintain pressure in the well. It is assumed that 98% of the H_2S will be cleaned with this method. Lighter gases, not absorbed and part of the CO_2 are vented at the top of the absorption column. The other part of the CO_2 is dissolved in the water in the absorption column and injected with the H_2S.

The initial operation experience is positive. The system has been operated at full capacity with success.

Currently a large portion of CO_2 is dissolved with the H_2S and reinjected into the bedrock. Future plans include installing a gas separation column to separate gases such as CO_2 and H_2 and use for industrial purposes.

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