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# Experimental Geothermal Condensate Mixing into the Mývatn District Heating System, NE-Iceland to Eliminate Oxygen Content and Risk of Iron Sulfide Scaling

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**ABSTRACT**

The Mývatn District Heating System is owned and operated by the local community of the Lake Mývatn District. It has provided 60 to 90 °C water to the general public there for over half a century. Hot water for the system is produced at Landsvirkjun's geothermal powerplant, "Gufustöðin í Bjarnarflagi", located in the Námafjall geothermal field in NE-Iceland. Cold groundwater is heated up to 80 °C in a heat exchanger with geothermal brine. This 80 °C water is directed into the District Heating Station where geothermal steam heats the water further to 99 °C with a set of heat exchangers. Degassing tanks release vapor which allows most of the dissolved oxygen to be released from the hot water. The gathering pipe from the tanks has a small dose steam injection system. For the past decades, low pressure steam has been slowly released into the hot water with a set of orifices to dope the water with Hydrogen Sulfide ($H_2S$) gas. This has maintained no oxygen in the system in the past, due to its reducing chemistry, where $H_2S$ is partially oxidized into Sulphate ($SO_4$) until the water has no oxygen level. However, the dosing system has caused unreliable/fluctuating amounts of $H_2S$ in the district heating system, sometimes causing scaling problems of sulfur bearing minerals. Here we report the findings of a successful experiment; where the condensate from the steam filled heat exchangers was released into the hot water system instead of the low pressure steam. During this ongoing experimental period, $H_2S$ concentrations have been consistently low and no oxygen is present within the district heating system.

## 1 INTRODUCTION

District heating systems or networks, run by communities and municipalities countrywide in Iceland, have played a crucial role in the economy, the renewable and domestic energy shift, and public wellbeing in Iceland. Currently, geothermal energy supplies around 90% of all homes and businesses with space heating. Furthermore, these systems provide hot water for other direct uses such as swimming pools, spas, greenhouses, snow melting, and more (Orkustofnun, 2021). Most district heating networks derive their resources from low temperature geothermal fields (Axelsson, et al, 2010). However, several of the district heating systems are built around high temperature geothermal power plants. In such cases, effluent hot water from the power plant's boreholes, and/or excess steam is used to heat up groundwater for direct use. Such systems have two major chemical challenges that must be taken into account before utilization (Hauksson et al, 1995).

Firstly, the heated groundwater must go through a deaeration process to lower the content of dissolved gases, primarily oxygen, to prevent corrosion of the infrastructure of the heating system. One solution to eliminate dissolved oxygen in the hot water is to release $H_2S$ into the deaerated hot water, via small dose injection of geothermal steam. This method maintains a deaerated system due to its reducing chemistry: $H_2S$ is partially oxidized into $SO_4$ until there is no dissolved oxygen present in the water.

Secondly, the risk of scaling problems is considerably high in these systems. Most commonly, magnesium-silicates can cause major clogging issues (Hauksson et al, 1995). Historically, these challenges have been met by locating a groundwater source with a lower mineral content; controlling pH via small-dose steam injection; and subsequently regular chemical monitoring of the hot water's mineral content (Hauksson et al, 1995, Kristmannsdóttir et al, 1989).

The Mývatn District Heating started operation in 1971 by direct utilization of geothermal mineral water from Bjarnarflag's steam boreholes. After a few years of operation, the system was changed to steam heated groundwater from the Bjarnarflag site due to massive aluminum-silicate scaling problems (Thorhallsson et al, 1975). That heating system was operated for several more years, but after 1981 the Bjarnarflag groundwater

increased in temperature and changed in chemistry as a result of the Krafla Fires 1974-1984 (Kristmannsdóttir, 1981). In the years after, the current system was installed using cold groundwater with no geothermal input.

### 1.1 The Bjarnarflag geothermal power plant

The Bjarnarflag geothermal power plant is located within the Námafjall geothermal field, NE-Iceland. It is part of the Krafla volcano, which is one of the central volcanoes forming the North Volcanic Zone in Iceland (Fig. 1A). The power plant has an installed capacity of 5 MWe. It consists of several high temperature geothermal boreholes, two separator stations, gathering pipelines, steam pipelines, and effluent pipelines for mineral water (brine). Associated businesses utilizing the geothermal steam and mineral water are The Mývatn Heat Exchanger Plant, Mývatn Nature Baths, The Basalt Brick Factory, and the Landsvirkjun innovation site (Fig. 1B).

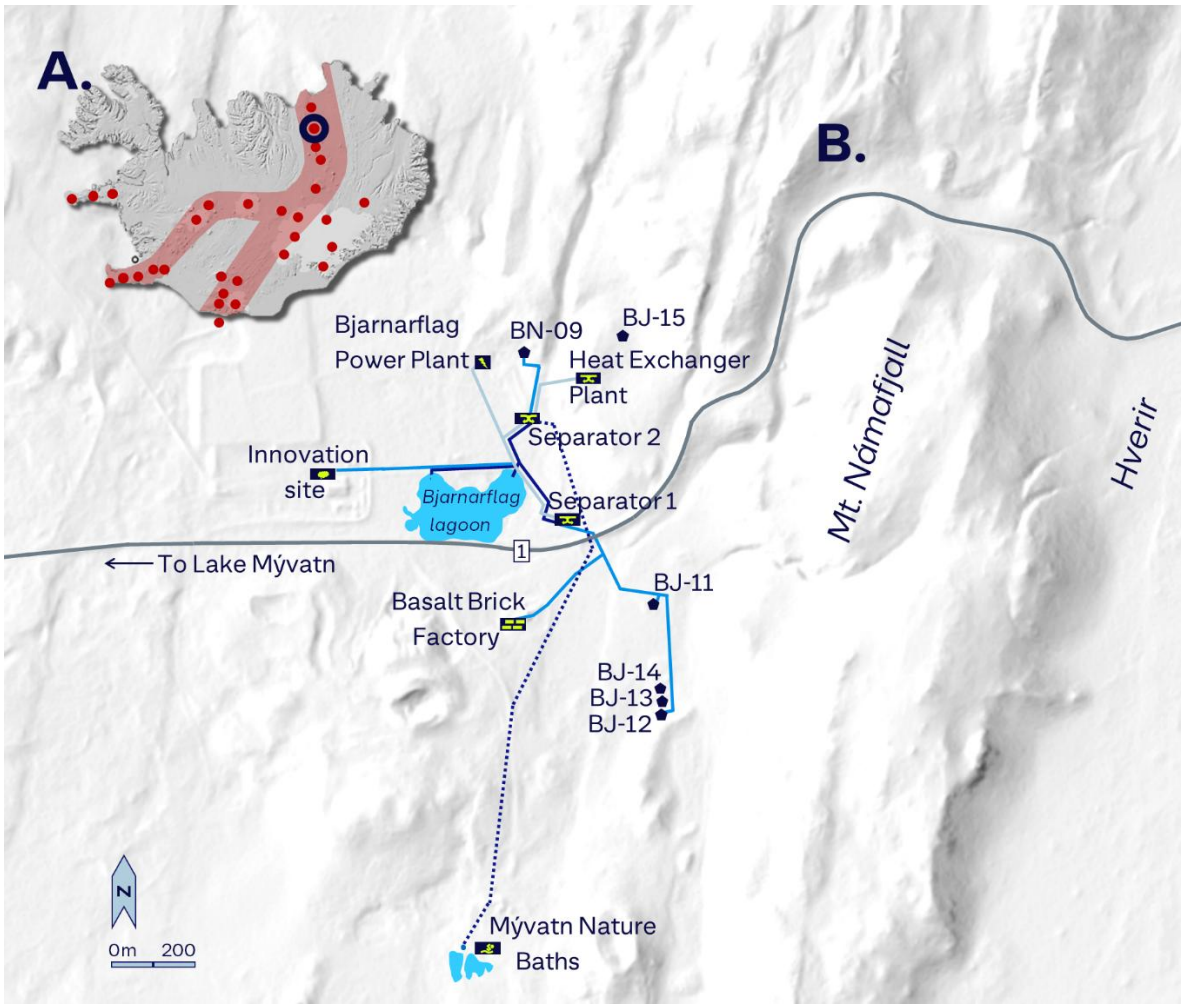



**Figure 1. A) Map of Iceland, its volcanic zone (red), and the study site (circled). B) A map of Námafjall geothermal field, NE-Iceland. Locations of Bjarnarflag Power Plant, The Mývatn Heat Exchanger Plant, The Basalt Brick Factory and Mývatn Nature Baths are presented. Geothermal lagoons are shown in blue, boreholes are shown as hexagonal shapes, gathering pipes as blue lines, steam pipes as grey lines, mineral water pipes as dark blue lines, and the central road 1 as a dark grey line (Modified map from Natural Science Institute of Iceland, 2025).**

### 1.2 Mývatn District Heating System

The borehole BN-09 produces steam and mineral water (brine), see figure 2A. Mineral water is separated from the steam phase within the Bjarnarflag' s separator station 2. Brine flows into a small heat exchanger, where 7 °C fresh water is heated up to 80 °C and pumped towards the Heat Exchanger Plant. During the heating process, mineral water from well BN-09 is cooled down to 120 °C and directed towards the Mývatn Nature Baths. Steam from the separator flows both into the high-pressure steam system for electricity generation and the Heat Exchanger Plant (Fig. 2B).

Heated freshwater is fed into two steam-filled heat exchangers. The steam cools rapidly down, to below 100 °C and forms steam condensate and geothermal gas. Already heated freshwater from the cooling process of mineral water for the Mývatn Nature Baths is further heated and reaches approximately 98 - 99 °C. This boiling freshwater is released into two tanks for degassing, where the hot water becomes deaerated.

The final step in the hot water production is a small dosing system for regulated steam release into the hot water degassing tanks, see figure 2B. Steam is rapidly dissolved into the hot water, elevating its dissolved $CO_2$ and $H_2S$ content. These two processes: the degassing tanks and small dose steam injection, are the steps needed to eliminate dissolved oxygen in the hot water and, if needed, to regulate its pH for lowering any risk of silicate scaling.

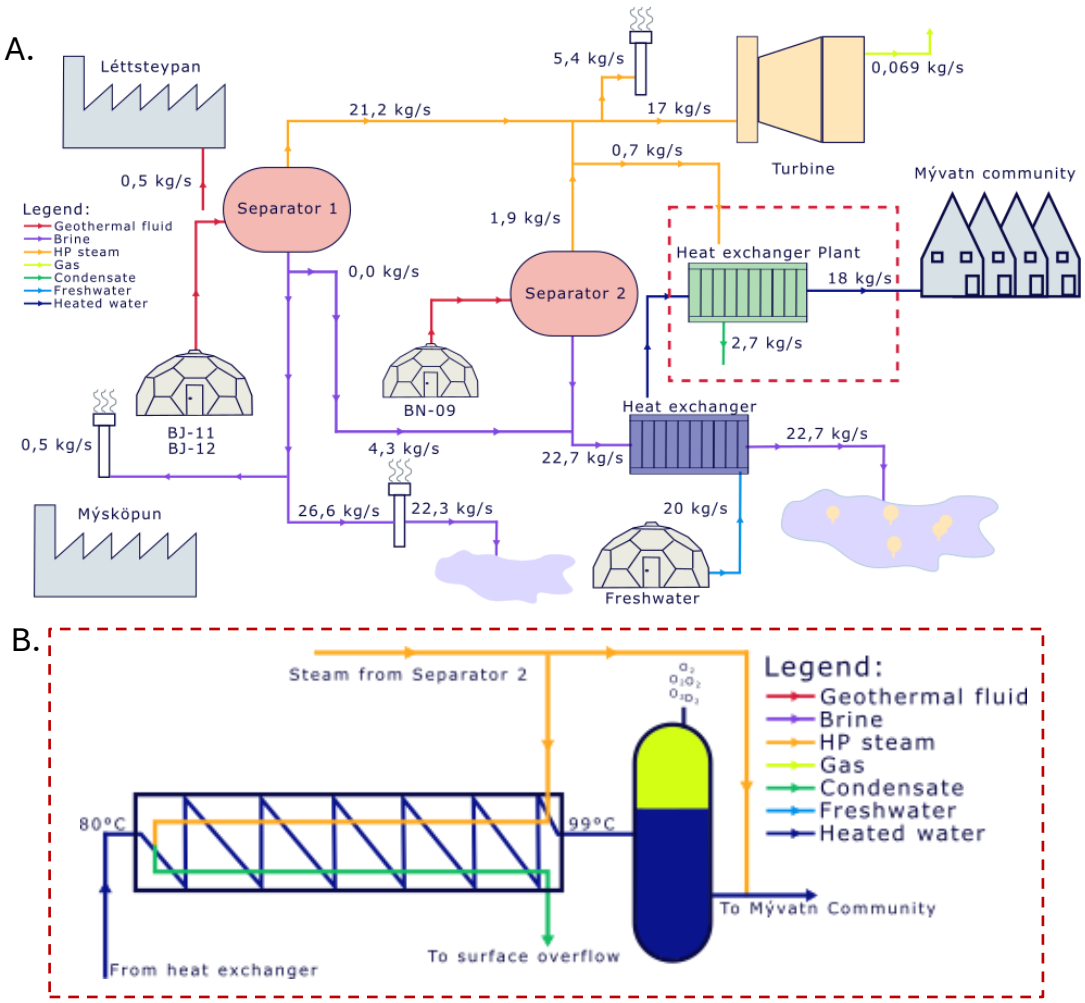



**Figure 2. A) Schematic diagram of the Bjarnarflag Power Plant. B) Schematic diagram of the Heat Exchanger Plant. The Plant consists of two heat exchangers (west and east), two degasser tanks, steam pipes (yellow), heated freshwater pipes (blue), condensate pipes (green).**

The district heating system is shown in figure 3. The main pipe distributes hot water to all the major communities of the Mývatn district; Reykjahlíð village, Vogar Farm, and Skútustaðir Farm. It also serves several other farms and businesses in the vicinity.

### 1.3 Challenges

The district heating system of Mývatn has faced many challenges over the decades. In its first years of operation, massive scaling problems were detected which resulted in a search for groundwater with lower Silica (Si), Calcium (Ca), and Aluminum (Al) content. The search was partially successful in that water with lower concentrations was found, but there was still a risk of magnesium-silicate scaling. As a result, the steam injection was increased, thus regulating the water at a lower pH, and decreasing the probability of Si-scaling.

This system worked better but required specialized workers to monitor the chemical content of the water. For a small community with a population of around 500 people, it turned out to be a challenge. The Diatom Factory of

Lake Mývatn located in Bjarnarflag, which produced pure silica from the lake's sediments, was operative from the mid 1960's. The factory needed chemical monitoring of its production line, and so its specialists took on the task of monitoring the hot water district lines. The silica factory closed in 2004, which meant that chemical monitoring of the district heating system became irregular.

For the last years, more frequent corrosion of pipes and increasing quantities of black solids have been noticed within the system. Solids were analyzed and found to be iron sulfide (FeS). During annual chemical monitoring program of Bjarnarflag Power Plant over the last decades, it was clear that the $H_2S$ content was unstable, and the system needed better monitoring. The Thingeyjarsveit Municipality and Landsvirkjun took on the task in a joint effort to fix the chemical problems of the system, through better chemical monitoring and minor experimentation on the production part.




**Figure 3. A map of the Mývatn District Heating. The Heat Exchanger Plant is in the slopes of Mt. Námafjall. The main pipe is drawn as blue lines. It feeds hot water to the communities of Reykjahlíð village, Vogar Farm and Skútustaðir Farm, along with all farms and businesses in its vicinity (Modified map from Natural Science Institute of Iceland, 2025).**

## 2 RESULTS

The monitoring of $H_2S$ and $O_2$ content of the hot water can be seen in figure 4a. The $H_2S$ content, measured at the Heat Exchanger Plant ranged from 2,7-5,8 mg/kg (ppm) from 2018 to 2024. The oxygen content ranged from 18-100 µg/kg (ppb) after the degassing tanks (Hauksson, 2019, 2020, 2021, 2022, 2024). Regular and more frequent chemical monitoring of the hot water in Reykjahlíð village was performed until 2021. It followed similar trends as the annual monitoring of the Heat Exchanger Plant, but with slightly lower $H_2S$ values, ranging from 1,5-3,2 mg/kg and no detected oxygen (Figure 4a). These values were considerably higher than normally measured in similar hot water plants, i.e. 0,4 mg/kg $H_2S$ in Reykjavík Energy's Nesjavellir hot water (Reykjavik Energy, 2025).

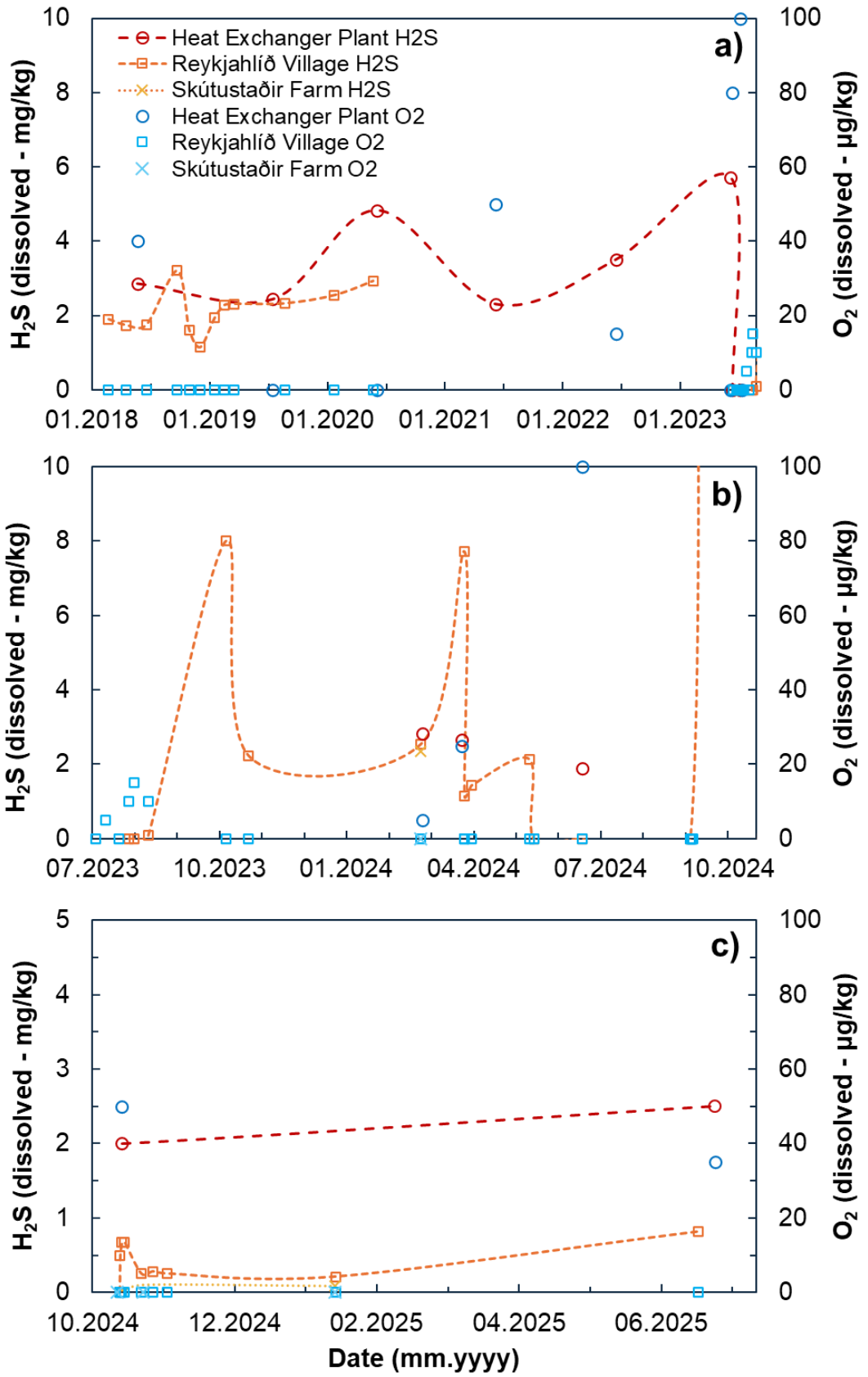



**Figure 4. a) Chemical monitoring of the hot water production in Mývatn Heat Exchanger Plant and Reykjahlíð Village before condensate experiments, b) the chemical monitoring of the same locations and Skútustaðir Farm, during the period of first two failed experiments, c) the chemical monitoring of all the three sampling locations during the third condensate experiment.**

The small dose steam injection was shut down for a period of 11 weeks in 2023 (see towards the end of figure 4a). Oxygen content was monitored frequently during that period. Oxygen content took a long time to rise to low levels in the village, suggesting that the pipelines were coated with sulfide-bearing minerals, continuously reducing the oxygen level in the water. When oxygen was detected, the steam injection was turned back on and the $H_2S$ content that was measured was above safe levels. To address this, the first condensate injection experiment was performed (see figure 4b and 5).

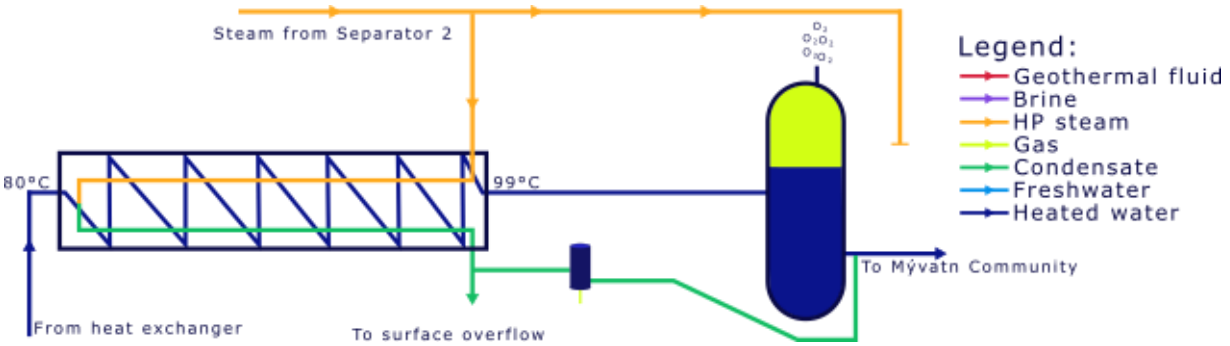



**Figure 5. Schematic overview of the condensate experiment. Steam condensate from the two heat exchangers partially flow into a Webre separator. Degassed condensate was injected into the hot water production by the degasser tanks.**

The first experimental run on the condensate injection was initiated in the spring of 2024. The experiment was connected to the Western Heat Exchanger at the Heat Exchanger Plant (Figures 5 and 6). Stainless-steel pipe was connected to the outlet flow and a Webre separator for final gas bubble removal. The water phase outlet valve of the separator was used to regulate the flow of condensate into the hot water system, connected with additional stainless-steel pipe (fig. 5). The flow was set after reaching $H_2S$ levels of around 2 mg/kg. Initial monitoring of the dissolved chemistry at the plant was within limits. All subsequent monitoring was canceled due to an unprecedented snowstorm in mid-June. After a couple of days' run, the $H_2S$ concentration was measured high (>8 mg/kg), and way above the set limit for the district heating during the experiment (2 mg/kg). The water became cloudy and had dense sulfur smell. The experiment was shut down and the setup inspected. Authors concluded that either the experiment ran out of condensate during the storm, or an unknown leakage within the separator's internal pipelines. Both scenarios would bleed geothermal steam or geothermal gas into the hot water production line and explain the elevated $H_2S$ content.

Later that year, the second experiment was initiated in September, using both heat exchangers as a condensate source. This would eliminate the risk of running low on condensate production. The same problem occurred within few hours, the $H_2S$ content rose above limit (fig 4b). The experiment was shut down and the $H_2S$ content lowered within the first day. The only possible conclusion left to the authors was that heat exchanger´s internal pipelines were in fact leaking, allowing steam and/or geothermal gas to bleed into the hot water system.

In October, the third experiment was initiated by connecting only the Eastern Heat Exchanger, hoping that the hypothesized leakage was only to be found in the Western Heat Exchanger. The condensate flow was regulated to give around 2 mg/kg $H_2S$ at the Plant like the last two experiments. The hot water production was monitored frequently in the beginning of the experiment, by observation at the Heat Exchanger Plant, and chemical checkups at the Reykjahlíð village, see fig. 4c. The $H_2S$ was measured around 2 mg/kg at the Heat Exchanger Plant, and the oxygen level around 50 ppb. The $H_2S$ level was measured 0,5-0,9 mg/kg during the first day of the experiment, reaching stable concentrations around 0,3-0,4 mg/kg during the first weeks of the experiment. Dissolved $O_2$ was never detected (0 ppb) in all chemical samples taken withing the District Heating system (from Reykjahlíð Village to Skútustaðir Farm – see fig. 3). The Weber separator was disconnected from the condensate flow in the spring of 2025, with slight increase of $H_2S$ content, measured 2,5 mg/kg at the production plant, and 0,9 mg/kg at the Mývatn Sport Center.

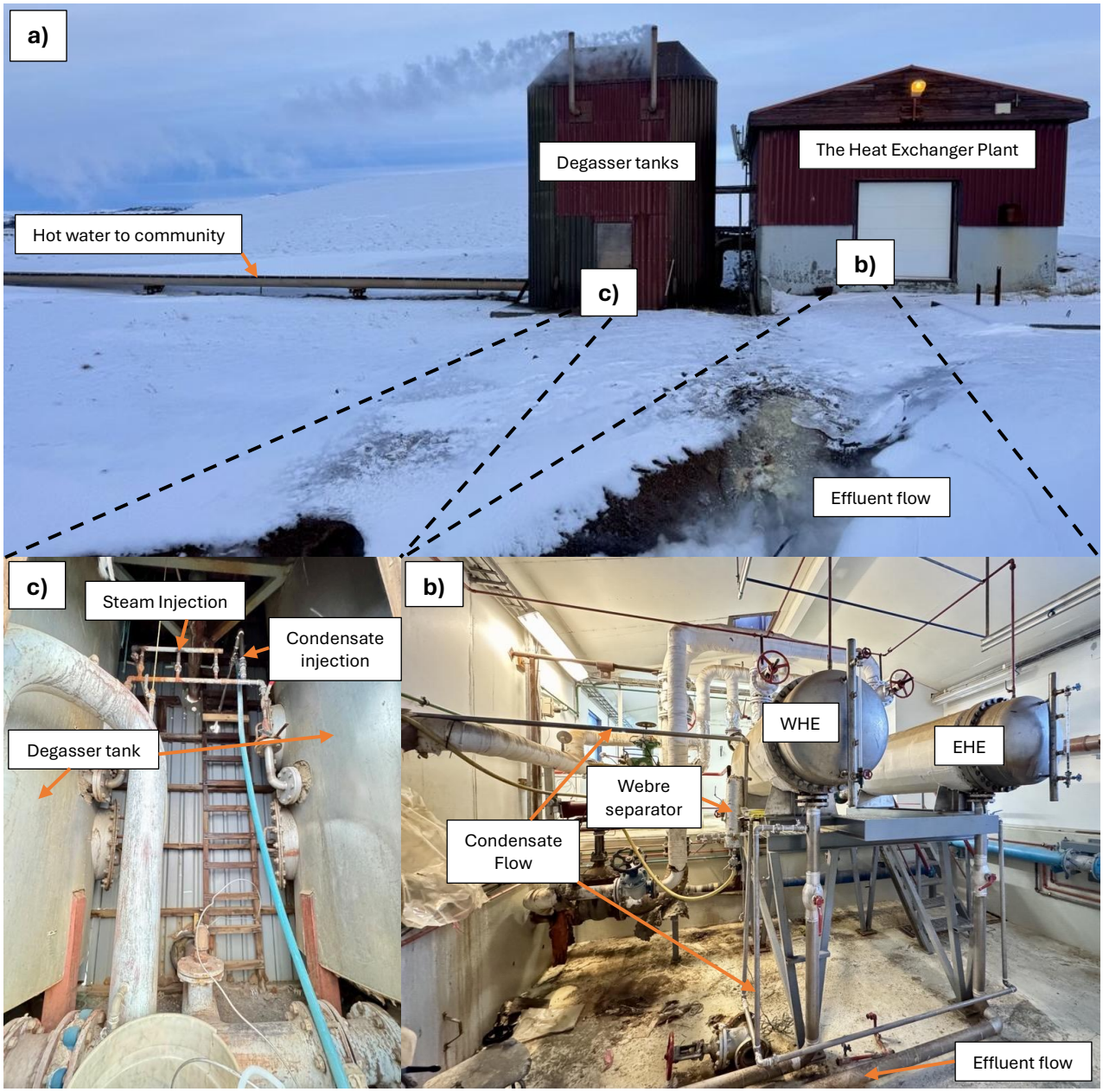



**Figure 6. Photographs of a) The Heat Exchanger Plant at Mt. Námafjall, Mývatn; b) the western heat exchanger (WHE), eastern heat exchanger (EHE), the condensate experimental setup; c) the hot water degassing tanks, steam injection system and experimental condensate injection line.**

## 3 CONCLUSIONS AND FUTURE WORK

The successful experiment of the condensate injection is still running at the Heat Exchanger Plant. This first year has been a success, $H_2S$ concentrations have been consistently low and no oxygen is present within the district heating system.

Proposed future work is mechanical fixing of the Western Heat Exchanger, by Thingeyjarsveit Community. Furthermore, chemical modeling with the aid of the PHREEQC computer code will be made, to calculate different condensate-hot water mixing ratios. The aim of the model is to predict the optimized mixing ratio, to lower the risk of silica-scaling, without compromising the stability of the low $H_2S$ content in the hot water.

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