

Project acronym:	Geo-Coat		
Project title:	Development of Novel and Cost-Effective Corrosion Resistant Coatings for High Temperature Geothermal Applications		
Activity:	LCE-07-17-Renewables		
Call:	H2020-LCE-2017-RES-RIA-TwoStage		
Funding Scheme:	RIA	Grant Agreement	LCE-GA-2018-764086
Project dates:	01/02/2018 – 31/01/2021	Duration in months:	36
WP1	End User Requirements Analysis and Adaptation		

D1.3: Report on characterisation of geothermal fluid

Due date:	31/06/2018 (M5)	
Actual Submission Date:	30/07/2018	
Lead Beneficiary:	Orka Náttúrunnar	
Main authors/contributors:	ON	
Dissemination Level¹:	PU	
Nature:	Report	
Status of this version:		Draft under Development
		For Review by Coordinator
	x	Submitted
Version:	01	



¹ Dissemination level security:

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DEVELOPMENT OF NOVEL AND COST-EFFECTIVE CORROSION RESISTANT COATINGS
FOR HIGH TEMPERATURE GEOTHERMAL APPLICATIONS

This project has received funding from the European Union's Eighth Framework Programme for research, technological development and demonstration under Grant Agreement No. LCE-GA-2018-764086. This publication reflects the views only of the author(s), and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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SUMMARY

The report provides the chemical composition of fluids of main concern in the Hellisheiði and Nesjavellir power plants. The sampling methods, locations and sample points are described. These analyses provide a reference for further studies on materials testing and modelling along with defining the testing environment for the Geo-Coat project, as summarised in the final chapter of this report.

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1. Introduction

Reykjavik Energy operates two co-generation power plants at Nesjavellir and Hellisheiði in the flanks of the Hengill volcano in SW Iceland. The plants are fed by over 50 production wells of variable composition, temperatures and flow rates. Most of the geothermal fluid is water that is returned into the geothermal reservoirs following heat extraction. The fluids are flashed, separated, condensed and mixed at various locations in the heat extraction process with the associated risk of scaling and corrosion if proper monitoring and mitigation methods are not in place. Figures 1 and 2 show overviews of the Hellisheiði and Nesjavellir power plants.



Figure 1: Overview of Hellisheiði power plant. 1) Turbines 1-4, 2) turbine 11, 3) heat exchanger, 4) turbines 5 and 6, 5) main building for fluid distribution, 6) boiler, 7) low pressure separators, 8) moisture separators, 9) workshop, 10) cooling towers (photo: Gretar Ivarsson).



Figure 2: Overview of Nesjavellir power plant [1].

This contribution gives an overview of the chemical composition of key streams flowing through the Nesjavellir and Hellisheiði power plants. The sampling procedure is described and information is provided on the analytical procedures.

2. Sampling methods

In this section, a detailed description of the sampling methods is provided. Samples were taken at the Hellisheiði and Nesjavellir power plants. All necessary safety instructions were followed including wearing visibility clothing, steel toed boots, helmet, earmuffs, safety glasses, heat resistant gloves and H₂S meter. Fresh air respirator and dust respirators are used when needed when sampling in very high H₂S concentrations.

The layout of the Hellisheiði power plant is provided in Figure 3 and the sampling points are outlined with red numbers.

1. Production well fluids sampled after control valve
2. Steam into turbines
3. Gas from turbines
4. Separator water after 1st flash
5. Separator water after 2nd flash
6. Separator water after heat exchangers
7. Condensate
8. Seal water
9. Sulfix water (sampling location not shown on figure)
10. Cooling water

11. Typical groundwater

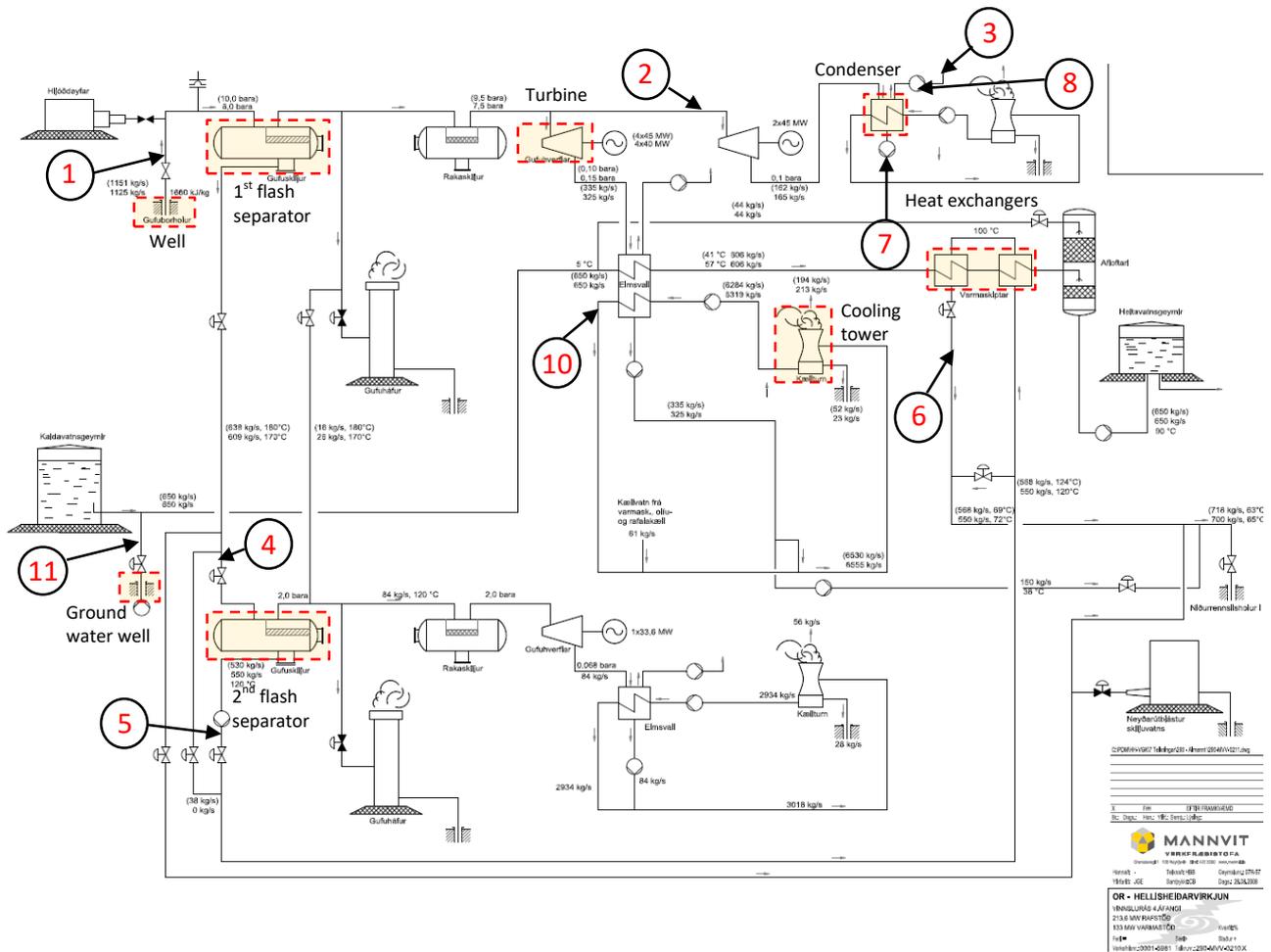


Figure 3: Layout of the Hellisheiði power plant.

In the following sections the specifications on the fluid sampling from the above locations will be provided.

2.1 Location 1: Production well fluids sampled after control valve

Once to twice a year samples of well fluids are taken at every borehole. This is usually done in association with tracer flow tests (TFT). A Webre separator is connected to the steam pipe enabling separate sampling of steam and separator water. Steam and water samples are collected as well as condensed steam (mainly for trace element analysis) when needed. For every borehole two 250 ml gas sampling bottles must be prepared in the lab. They are evacuated with 10 ml of 60% potassium hydroxide (KOH). It is important that every safety requirement is followed when sampling takes place. Figure 4 shows the setup when sampling the steam.

Method:

Every sample bottle needs to be cleaned three times before filling. Figure 4 shows the setup of the separator when sampling the steam phase.

1. Connect the Webre separator to the steam pipe of the production well. Open the valve on the steam pipe slowly with all valves on the separator closed to observe if any leak is visible.
2. Connect the pressure gauge to the top of the separator. Slowly open the valve to the pressure gauge. The sampling pressure is recorded while sampling takes place.
3. Connect the venting tube to the water valve and open the valve slowly.
4. Connect the silicone tube with the tee fitting to the steam valve on the separator.

5. Connect a gas sampling bottle to the silicone tube with the stopcock closed.
6. Slowly open the steam valve on the separator. Let the steam flow through the neck of the sampling bottle until condensation is negligible.
7. Use a clamp to close the flow of steam through the sampling bottles neck so steam only flows out of the check valve on the tee fitting.
8. Keep the bottle upside down and slowly open the stopcock. Collect steam while cooling it in the water bucket by swirling and moving it around. Close the bottle when the inflow of bubbles slows down considerably. Follow steps 5-8 for the second steam sample.
9. If condensed steam is also collected a cooling coil is attached to the steam valve and put into a water bucket for cooling.
10. For anion analysis: collect a sample into a 250 ml HDPE plastic bottle.
11. For major elemental analysis: collect a sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid (suprapure 69% HNO₃).
12. For trace elemental analysis: collect a sample into a 125 ml bottle and add 1 ml of concentrated nitric acid.
13. Close the steam valves and remove the silicone tubing and the cooling coil.
14. Close the water valve and remove the venting tube.



Figure 4: Setup when sampling for steam. Numbers on figure correspond to numbers in the method above (photo: Sigrún Sif Sigurðardóttir).

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Figure 5 shows the setup of the separator when sampling the water phase.

Method:

1. Connect the venting tube to the steam valve and open the valve slowly.
2. Connect a cooling coil to the water valve, open the water valve slowly and open the valve on the coil slowly and let water flow through the system for 1 min.
3. Insert the coil into the cooling water and swirl the coil around from time to time. If the cooling water gets too hot, change the water or add snow if there is any around. Make sure the water is approximately at room temperature.
4. Measure the temperature, pH and pH temperature of the water.
5. Collect 0.5-1 ml of sample for H₂S titration. It is important to do two titrations or enough for negligible difference between titrations.
6. Sample for CO₂ analysis: Collect a sample into a 300 ml brown glass bottle. Put the silicon tube to the bottom of the bottle and let water flow over the top for 5-10 sec before closing the bottle. No air bubble should be present in the bottle.
7. Insert a 0.2 µm filter paper into a 45 mm stainless steel filter holder. Only touch the outer edges of the paper. Spray deionised water on the paper before closing the filter holder.
8. Connect the filter holder to the cooling coil, evacuate the filter holder and rinse at least 1 L.
9. Sample for anion analysis: Collect sample into a 250 ml HDPE plastic bottle.
10. Sample for major elemental analysis: Collect sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid.
11. Sample for sulfate (SO₄) analysis: Collect a sample into a 100 ml HDPE plastic bottle. Add 2 ml of ZnAc₂. Keep sample in a dark place.
12. Sample for trace elemental analysis: Collect a sample into a 125 ml HDPE plastic bottle. Add 1 ml of concentrated nitric acid.
13. Connect a pressure gauge to the well head. Open the valve slowly and record the well head pressure. Close the valve. Very slowly remove the pressure gauge from the well head. Let the pressure drop slowly.



Figure 5: Setup when sampling for water. Numbers in figure corresponds to numbers in the method (photo: Sigrún Sif Sigurðardóttir).

2.2 Location 2: Steam into turbines

The steam going into the turbines is sampled 4 times a year. At Hellisheiði they are collected at the sampling sink at every turbine (1-6 and 11), in total 7 samples. At Nesjavellir the steam is collected at two locations; for turbines 1 and 2 and for turbines 3 and 4. Cooling water must be taken with you when sampling at Nesjavellir where there are no sampling sinks. The steam is high in H₂S so caution must be shown. For each turbine two 250 ml gas sampling bottles must be prepared in the lab. They are evacuated with 10 ml of 60% potassium hydroxide. Figure 6 shows the setup of the sampling procedure.

Method:

1. The injection of condensate into the steam pipes must be shut off before sampling can start. The power plant managers take care of that.

2. Connect a silicon tube with a tee fitting onto the steam valve and then connect the tube to the sampling bottle with the stopcock of the bottle closed.
3. Connect the overflow from the tee fitting to a tube which is led outside the turbine hall.
4. Slowly open the steam valve marked G, let the steam flow through the neck of the sampling bottle until condensation is negligible.
5. Use a clamp to close the flow of steam through the sampling bottles neck so steam only flows out of the check valve on the tee fitting.
6. Slowly open the sampling bottle and collect steam while cooling it under running water or in the water bucket. Close the bottle when the inflow of bubbles slows down considerably.
7. Repeat the procedure for the second sample.
8. Close the valve on the steam pipe.

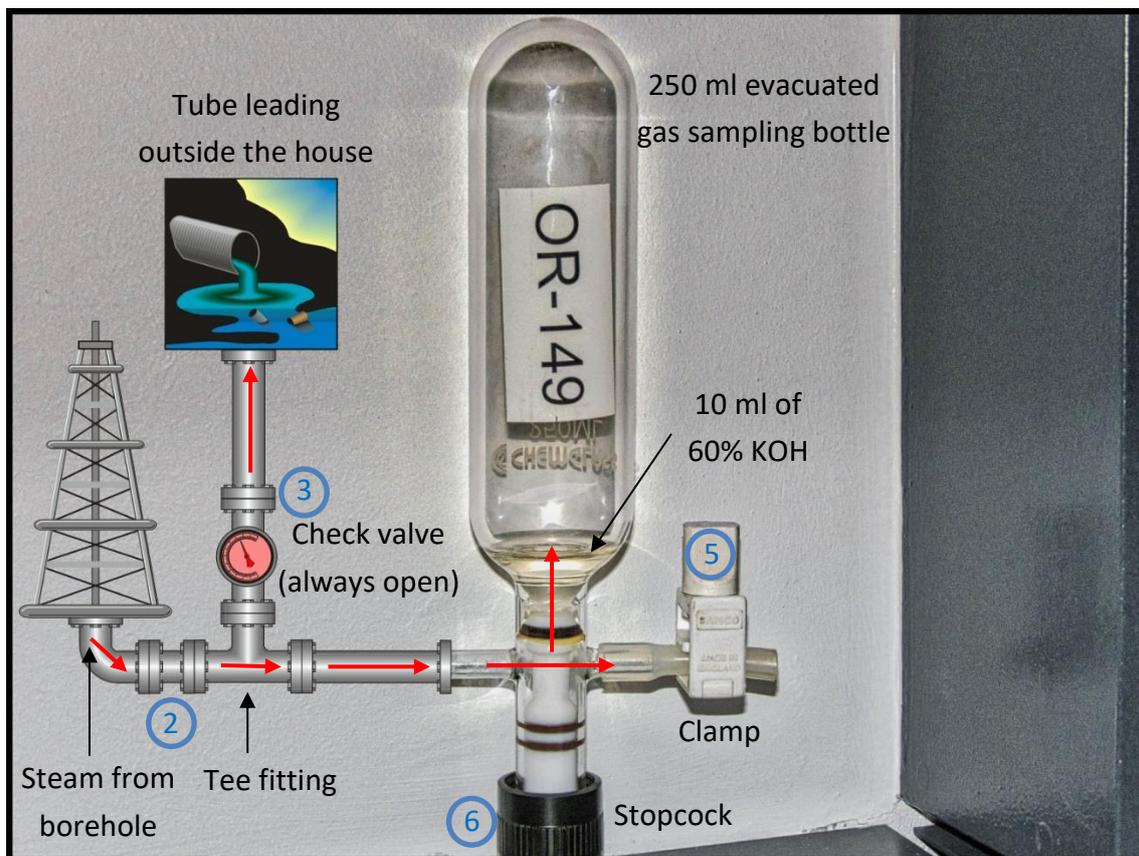


Figure 6: Setup of steam sampling. Red arrows indicate the flow of steam. Numbers correspond to numbers in sampling method [1].

2.3 Location 3: Gas from turbines

Gas is collected at every turbine at both power plants, in total 7 samples at Hellisheiði and 4 samples at Nesjavellir. When sampling gas under high pressure (over 1 bar-g) inside it's important to use an external air respirator for safety because of high concentration of H_2S in the gas. All tubing needed for sampling is located at the power plants. Two sampling bottles are collected at each turbine. Setup is shown in figure 7.

Method:

1. Connect a teflon tube to the gas sampling valve.
2. Connect the other end to an empty gas sampling bottle with both stopcocks open. Two bottles are often collected simultaneously by connecting them with a short silicone tube.

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3. Connect a silicon tube to the other end of the gas sampling bottle which is then led outside of the turbine hall and into a water bath where the gas flow can be observed.
4. If gas is under low pressure a pump is needed between the sampling bottle and the silicone tube in the water bath.
5. Open the gas sampling valve and let gas flow through the system for approximately 10 min. When sampling gas under low pressure it could be necessary to collect for 15 min.
6. Close the gas sampling valve, close the stopcock on the gas sampling bottle closer to the gas valve and then the stopcock further from the gas valve.
7. Disconnect all tubing and clean up.

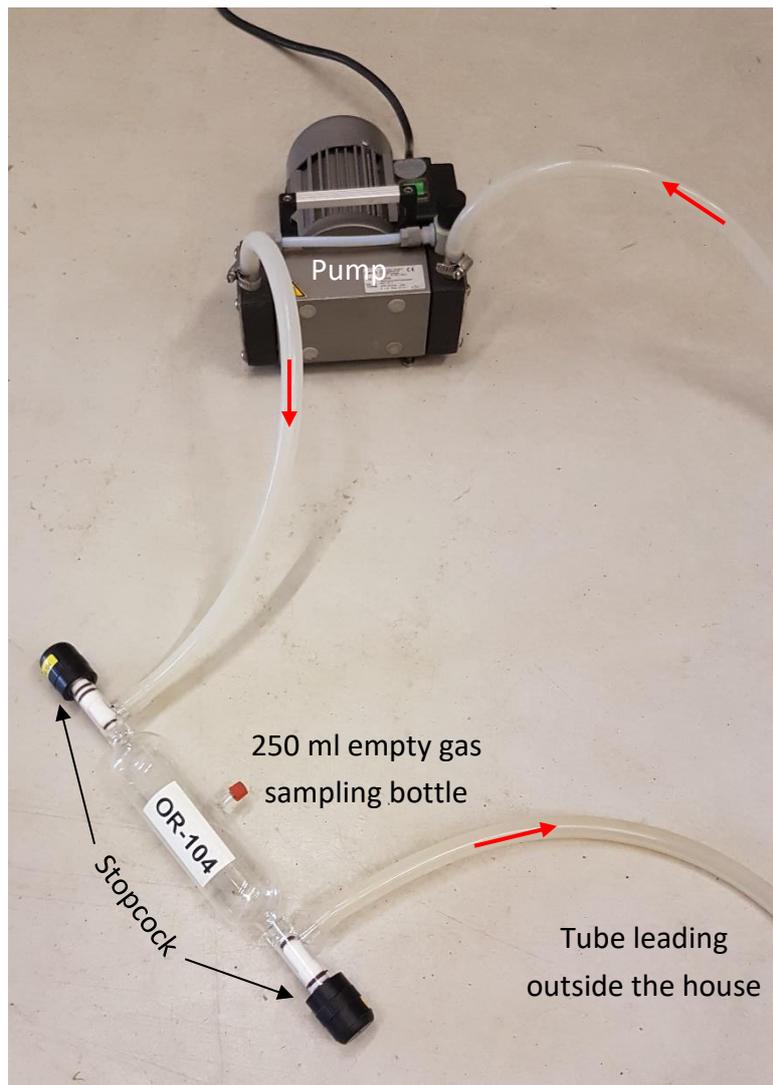


Figure 7: Setup of gas sampling from turbines. Red arrows indicate the flow of gas (photo: Pétur Már Gíslason).

2.4 Location 4: Separator water after 1st flash

The main building for fluid distribution at Hellisheiði accepts separator water from four separator stations and distributes the water to different parts of the power plant that makes use of it. Separator water after 1st flash is separator water before the water is boiled to produce low pressure steam which is then used for electrical production. Following the second flash, the majority of the water is used to heat up cold water in the heat exchangers. Samples of the separator water after 1st flash is collected inside the building (Figure 1). Figure 8 shows the locations of the sample valves.

Method:

1. Connect the cooling coil to the sampling valve and let water flow through the system for 1 min.
2. Put the cooling coil into the cooling water bucket. Make sure the temperature of the water is approximately at room temperature.
3. Measure the pH and the pH temperature.
4. Collect 0.5-10 ml of sample for H₂S titration. It is important to do two titrations or enough for negligible difference between titrations.
5. All sample bottles should be cleaned at least three times before filling.
6. Sample for CO₂ analysis: Collect a sample into a 300 ml brown glass bottle. Put the silicon tube to the bottom of the bottle and let water flow over the top for 5-10 sec before closing the bottle. No air bubble should be present in the bottle.
7. Insert a 0.2 µm filter paper into a 45 mm stainless steel filter holder. It is important to touch only the outer edges of the paper. Spray deionised water on the paper before closing the filter holder.
8. Connect the filter holder to the cooling coil, evacuate the sample holder and rinse at least 1 L.
9. Sample for anion analysis: Collect sample into a 250 ml HDPE plastic bottle.
10. Sample for major elemental analysis: Collect sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid.
11. Sample for trace elemental analysis: Collect a sample into a 125 ml HDPE plastic bottle. Add 1 ml of concentrated nitric acid.

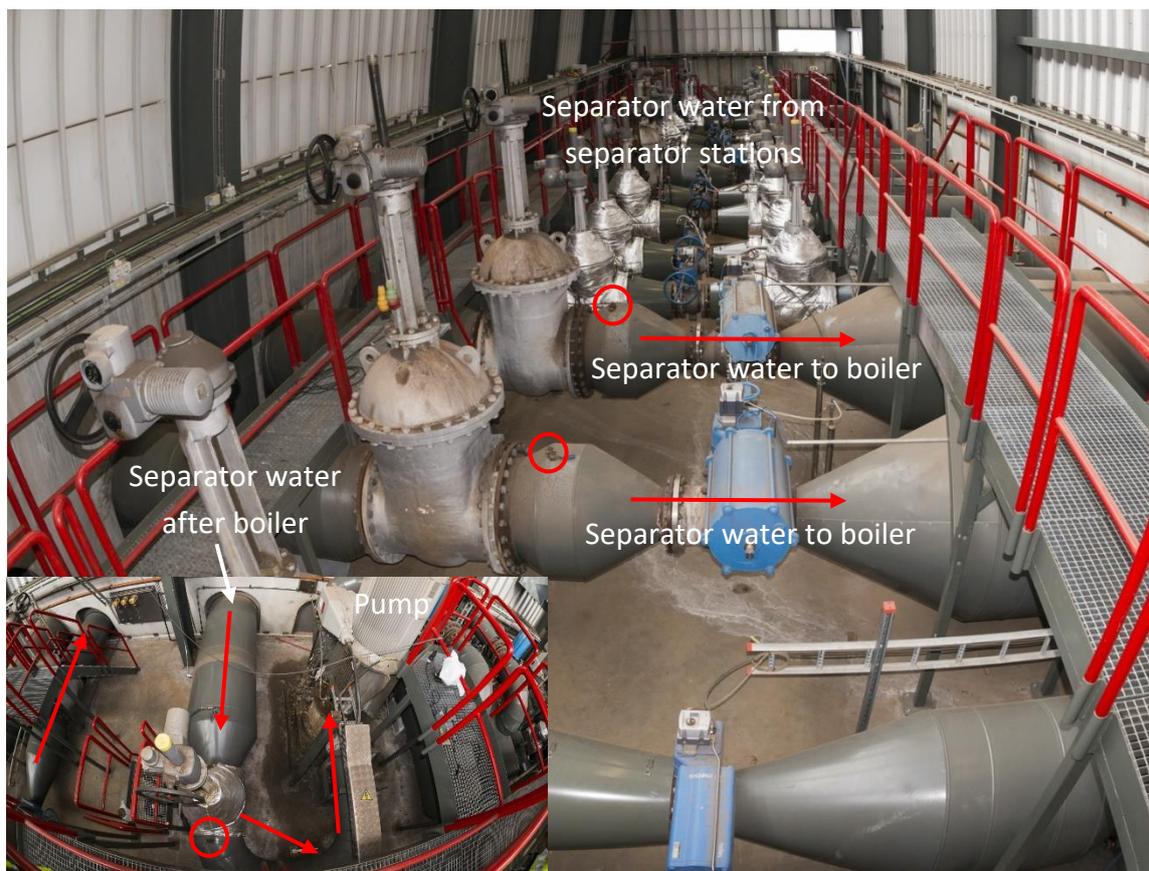


Figure 8: Sampling locations inside the main building of fluid distribution. Separator water goes through the pipes to the boiler before going to the heat exchanger. Red arrows indicate the flow of separator water. Red circles indicate sampling locations [2].

2.5 Locations 5 & 6: Separator water after 2nd flash and heat exchanger

As discussed in the previous section the separator water is boiled before it goes to the heat exchanger. By doing so the temperature of the water decreases from 180°C to about 120°C and the concentration of dissolved elements increases due to steam removal from the fluid. The water after 2nd flash is the separator water after boiling and before it is used to heat up the production water in the heat exchanger.

Separator water after 2nd flash and separator water after the heat exchanger is both collected at the thermal station at Hellisheiði with the same method. When the separator water has been used for hot water production it goes back to the main building for fluid distribution which then distributes the water to the injection system.

The sampling station for separator water and production water at Hellisheiði is shown in Figure 9. Sampling conditions at Nesjavellir are not as convenient (Figure 10). There it is necessary to bring a water bucket and a cooling coil. The sampling methods of the separator water therefore differs somewhat between power plants. At Nesjavellir only the separator water after the heat exchanger is collected.

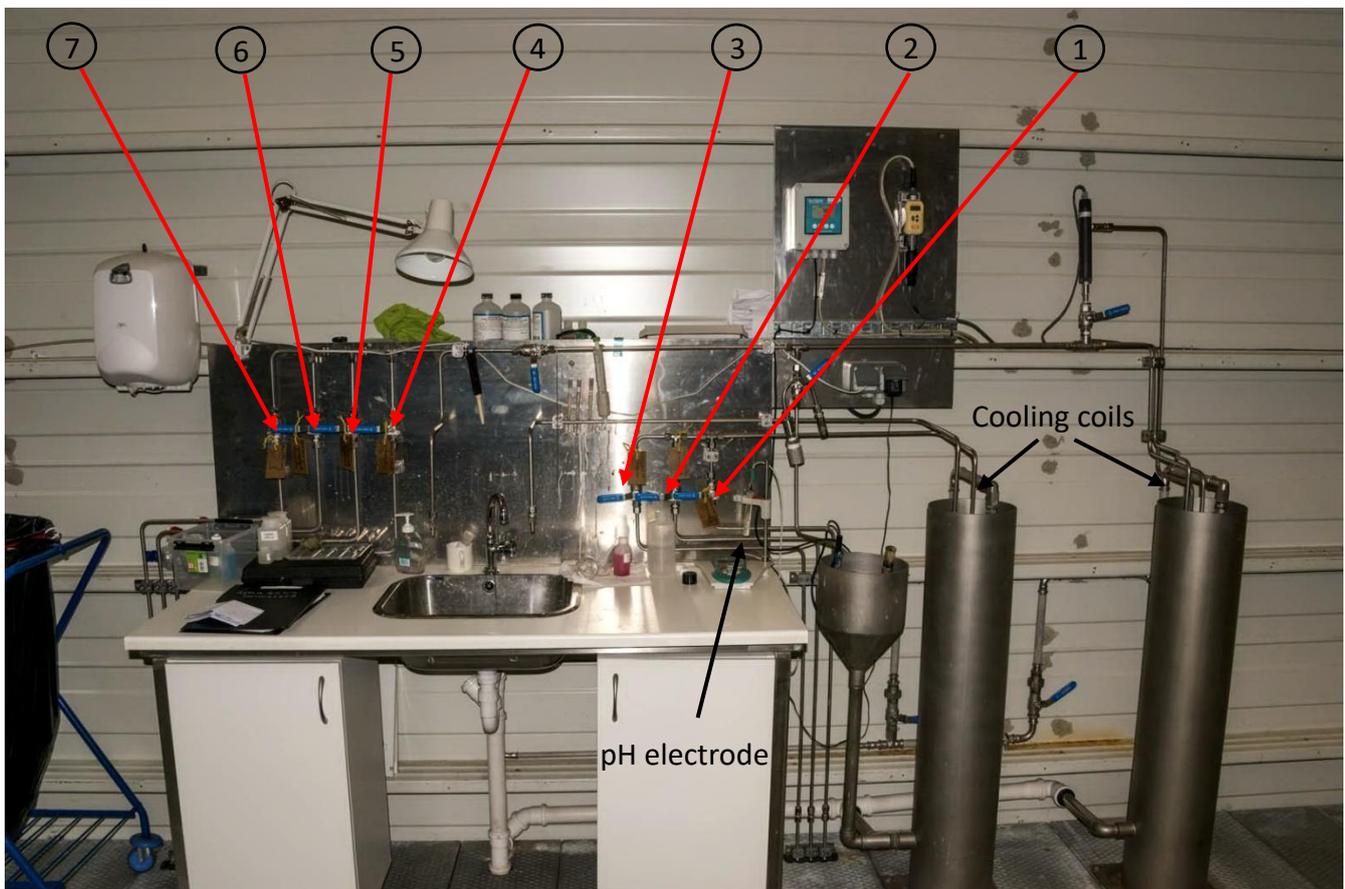


Figure 9: Sampling sink at the thermal station at Hellisheiði. 1) Separator water from heat exchanger 2 (after heat exchanger), 2) Separator water from heat exchanger 3 (between heat exchangers), 3) Separator water before heat exchanger (after 2nd flash), 4) Pre-heated water before heat exchanger, 5) Hot water from heat exchanger 2 (after heat exchangers), 6) Hot water from heat exchanger 3 (between heat exchangers), 7) Production water [2].

Method:

1. Connect a cooling coil to the sampling valve. Not necessary at Hellisheiði.
2. Put the cooling coil into the water bucket and make sure the temperature of the water is approximately at room temperature. Not necessary at Hellisheiði.

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3. Open the valve for the separator water and rinse the system for approximately 5 min.
4. Measure the pH and pH temperature on location.
5. Collect 0.5-10 ml of sample for H₂S titration. It is important to do two titrations or enough for negligible difference between titrations.
6. Rinse every bottle three times before filling.
7. Sample for CO₂ analysis: Collect sample into a 300 ml brown glass bottle. Put the silicon tube to the bottom of the bottle and let water flow over the top for 5-10 sec before closing the bottle. No air bubble should be present in the bottle.
8. Insert a 0.2 µm filter paper into a 45 mm stainless steel filter holder. Only touch the outer edges of the paper. Spray deionised water on the paper before closing the filter holder.
9. Connect the filter holder to the cooling coil, evacuate the sample holder and rinse at least 1 L.
10. Sample for anion analysis: Collect sample into a 250 ml HDPE plastic bottle.
11. Sample for major elemental analysis: Collect sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid.
12. Sample for sulfate analysis: Collect sample into a 100 ml plastic bottle. Add 2 ml of ZnAc₂ to the sample. Keep sample in a dark place.
13. Sample for trace elemental analysis: Collect a sample into a 125 ml HDPE plastic bottle. Add 1 ml of concentrated nitric acid.

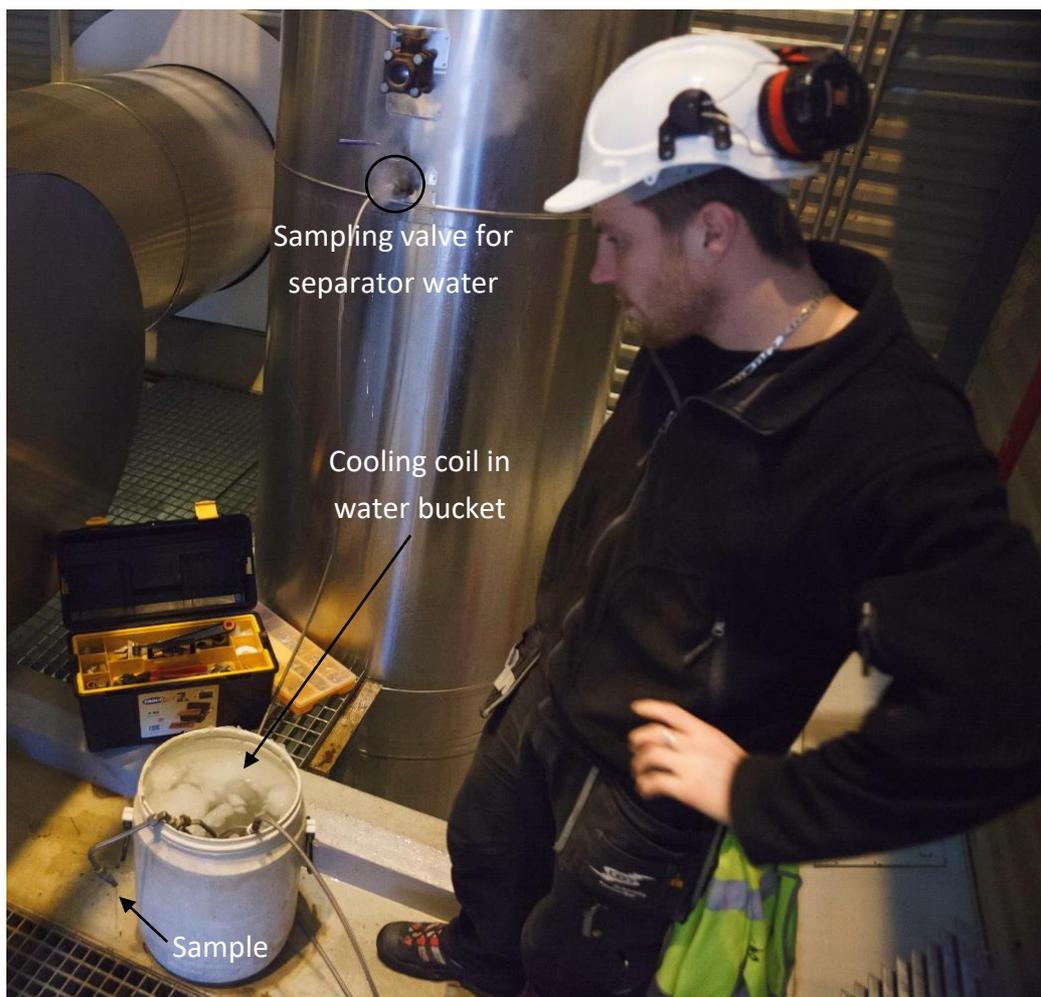


Figure 10: Sampling location for separator water at Nesjavellir [1].

2.6 Location 7: Condensate

At Hellisheiði the condensate from all turbines is combined with separator water before the water is reinjected at Húsmúli and Gráuhnúkar. The condensate is collected behind the main fluid distribution building at Hellisheiði (Figure 11) and at the so called Danish house at Nesjavellir close to the retention tank in front of the turbine hall. The condensate can also be sampled from each turbine. Then, the condensate is diverted in 10 mm stainless steel piping to the sink where steam is collected (Hellisheiði) and under the condensers (Nesjavellir).

Method:

1. Connect the cooling coil to the sample valve and rinse the system for approximately 5 min.
2. Put the cooling coil into the water bucket and make sure the temperature of the water is approximately at room temperature.
3. Measure pH and pH temperature at location.
4. Collect 0.5-10 ml of sample for H₂S titration. It is important to do two titrations or enough for negligible difference between titrations.
5. Rinse every sample bottle three times before filling them.
6. Sample for CO₂ analysis: Collect a sample into a 300 ml brown glass bottle. Put the silicon tube to the bottom of the bottle and let water flow over the top for 5-10 sec before closing the bottle. No air bubble should be present in the bottle.
7. Insert a 0.2 µm filter paper into a 45 mm stainless steel filter holder. Only touch the outer edges of the paper. Spray deionised water on the paper before closing the filter holder.
8. Connect the filter holder to the cooling coil, evacuate the sample holder and rinse at least 1 L.
9. Sample for anion analysis: Collect sample into a 250 ml HDPE plastic bottle.
10. Sample for major elemental analysis: Collect sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid.
11. Sample for trace elemental analysis: Collect sample into a 125 ml HDPE plastic bottle. Add 1 ml of concentrated nitric acid.

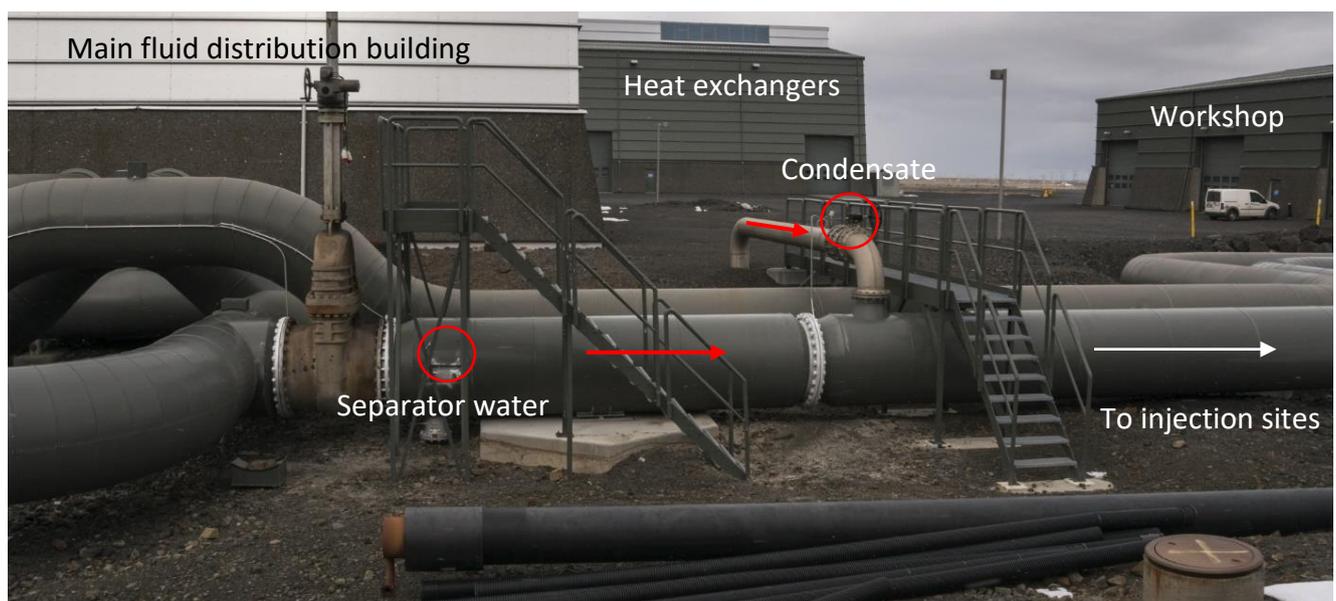


Figure 11: Sampling location for condensate at Hellisheiði before it is combined with separator water and then reinjected at Gráuhnúkar and Húsmúli. Red arrows indicate the flow of separator water and condensate [2].

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2.7 Location 8: Seal water

Seal water samples are taken at every turbine after the vacuum pumps at both Hellisheiði and Nesjavellir; in total 7 samples at Hellisheiði and 4 at Nesjavellir. These samples are always taken associated with the sampling of steam from turbines which has been explained above. Assistance is needed from the engineers on site at Nesjavellir to elevate the water level so sampling can take place. At Nesjavellir it is also important to use a pump because of the low pressure. One 500 mL Giggenbach bottle must be prepared in the lab before sampling. The bottle is evacuated with 20 ml of 60% potassium hydroxide. The seal water has a low pH and a high concentration of H₂S so all appropriate safety requirements must be followed. Seal water must be sampled outside of the turbine hall.

Method:

1. Record the flow rate of the seal water at the vacuum pumps that are running.
2. Connect a silicon tube to the sampling valve.
3. Open the valve and rinse at least 5 L.
4. Collect a sample into a 500 ml Giggenbach bottle with 20 ml of 60% potassium hydroxide inside. Connect the bottle to the silicon tube and keep the bottle upside down. Open the valve to the seal water and open the bottle quickly. Fill the bottle 80-90%. Close the bottle and remove the silicon tube quickly.
5. Oxygen must be measured with an oxygen ampoule. The ampoule is put straight into the sample valve and broken. The colour change of the ampoule is then observed and the corresponding oxygen amount is recorded.

When taking of a total chemical sample is needed, the next steps are followed:

1. Fill a 1 L bucket of seal water.
2. Connect a 45 mm teflon filter holder to a peristaltic pump. Insert a 0.2 µm filter paper into the filter holder, evacuate the sample holder and rinse for 1 min.
3. All sample bottles should be cleaned at least three times before filling.
4. Sample for anion analysis: Collect sample into a 250 ml HDPE plastic bottle.
5. Sample for major elemental analysis: Collect sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid.
6. Sample for trace elemental analysis: Collect a sample into a 125 ml HDPE plastic bottle. Add 1 ml of concentrated nitric acid.

2.8 Location 9: Sulfix water

Sulfix water is only collected at Hellisheiði power plant outside the gas abatement unit. The sample is always taken when samples of the “gas in” and “gas out” of the abatement unit is sampled. The water is very high in H₂S which can degas during sampling so every necessary safety precaution needs to be taken. The sample is taken into a 500 ml Giggenbach bottle that has been prepared in the lab. The bottle is evacuated with 20 ml of 60% potassium hydroxide.

Method:

1. Connect a silicon tube to the sampling valve.
2. Rinse the tube for 1 min.
3. Close the sampling valve.
4. Connect the silicon tube to the bottle and keep the bottle upside down.
5. Open the sampling valve and open the sampling bottle quickly. Fill up to 80-90%.
6. Close the bottle and sampling valve at approximately the same time.
7. Disconnect the sampling bottle.

2.9 Location 10: Cooling water

The cooling water at Hellisheiði is sampled inside the turbine hall next to the condenser. Figure 12 shows the sampling location. The water is a mixture of groundwater and condensate. The water is cooled at the cooling towers and pumped back to the condenser. It is important to clean every bottle several times before filling.

Method:

1. Open the valve to the cooling water and rinse for 2 min.
2. Measure the pH and pH temperature.
3. Collect 1-10mL of sample for H₂S titration. Sample size varies between condensers. It is important to do two titrations or enough for negligible difference.
4. All sample bottles should be cleaned at least three times before filling.
5. Connect a silicon tube to the sample valve.
6. Sample for CO₂ analysis: Collect a sample into a 300 ml brown glass bottle. Put the silicon tube to the bottom of the bottle and let water flow over the top for 5-10 sec before closing the bottle. No air bubble should be present in the bottle.
7. Insert a 0.2 µm filter paper into a 45 mm stainless steel filter holder. Only touch the outer edges of the paper. Spray deionised water on the paper before closing the filter holder.
8. Connect the filter holder to the cooling coil, evacuate the sample holder and rinse at least 1/2 L.
9. Sample for anion analysis: Collect sample into a 250 ml HDPE plastic bottle.
10. Sample for major elemental analysis: Collect sample into a 250 ml HDPE plastic bottle. Add 2 ml of concentrated nitric acid.
11. Sample for trace elemental analysis: Collect sample into a 125 ml HDPE plastic bottle. Add 1 ml of concentrated nitric acid.

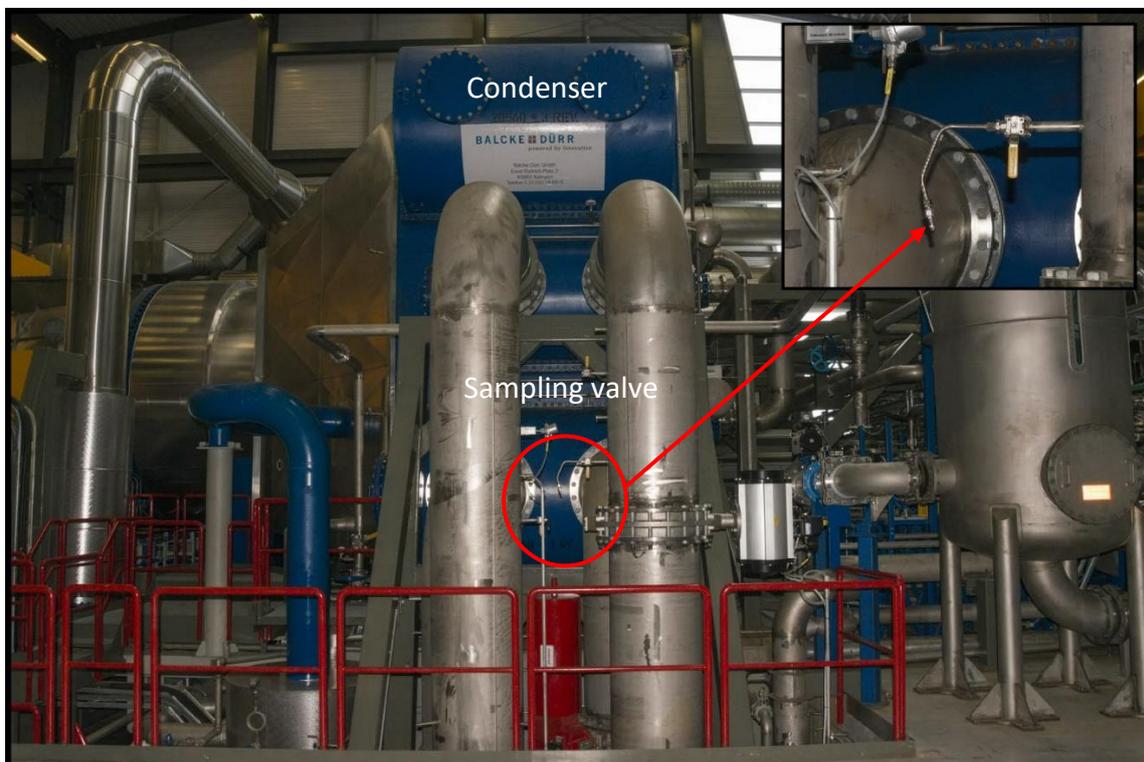


Figure 12: Sampling location for cooling water at Hellisheiði [2].

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3. Analysis and measurements

All steam samples are analysed at Reykjavík Energy by gas chromatography (GC) (Agilent 7890A, HP-Plot V and Q, HP-molsieve and a TCD detector). Gases measured are hydrogen (H₂), oxygen (O₂), nitrogen (N₂) and methane (CH₄). The condensed steam in the sample bottles is then titrated at Reykjavík Energy in a Metrohm 905 Titrando for carbon dioxide (CO₂) and hydrogen sulphide (H₂S). All gas samples are also measured in the GC at Reykjavík Energy for H₂, O₂, N₂, CH₄, CO₂ and H₂S.

Water samples collected into a 300 ml brown glass bottle are titrated for CO₂ and H₂S in a Metrohm 905 Titrando. The conductivity is also measured in an Oakton conductivity meter.

The samples for anion analysis are untreated. The sample is analysed at Reykjavík Energy by ion chromatography (IC) of the type Dionex ICS-1100. The elements quantified are fluoride (F⁻), chloride (Cl⁻) and sulfate (SO₄⁻). To analyse sulfate zink acetate (ZnAc₂) must be added to the sample to precipitate H₂S to ZnS. Sometimes the precipitation can be seen at the bottom of the bottle. The sample should be kept in a dark place and filtered before analysis.

Samples for major elemental analysis are analysed at the University of Iceland in an ICP-AES Spectro Ciros vision. The elements analysed are silicon (Si) reported as SiO₂, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), aluminium (Al), sulfate (SO₄), chloride (Cl) and boron (B). All samples that are analysed for major elements must be purged with N₂ gas before analysis to degas H₂S.

Samples for trace elemental analysis are analysed in an ICP-MS (ALS Global, Sweden) which provided lower detection limits than ICP-AES. The elements analysed are calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), silica (Si), aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), molybdenum (Mo), nickel (Ni), phosphorus (P), lead (Pb), antimony (Sb), selenium (Se), strontium (Sr), titanium (Ti), vanadium (V) and zinc (Zn).

4. Results

Different analytical methods are used to determine the composition, as has been previously explained. The following chapters show tables with the results of the above listed samples and analysis. The number of the sampling location corresponding to the numbering system used in Figure 3 is also included in the tables for clarification. Measurements that are not available are marked *n.a.*

4.1 Location 1: Production well fluids

The fluid from the boreholes is two phase and measurements were therefore done on both the water phase and the steam phase. The measurements of the water phase are shown in Table 1 but Tables 2 and 3 show the composition of the steam phase. The NGCs are measured from the gas sampling bottle (Table 2) whereas the major and trace elements are measured from sampling bottles collecting condensed steam from the cooling coil as described in the methods chapter.

Table 1: Chemical composition of borehole separator water, location no. 1 in Figure 3.

	Analytical method				
Date		25.5.2018	28.5.2018	6.6.2018	7.6.2018
Sample number		18-5194	18-5197	18-5213	18-5216
Borehole		HE-60	HE-58	HE-29	NJ-11

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P₀ [bar-g]¹		76.8	17.2	16.0	23.8
P_s [bar-g]²		18.5	8.9	8.5	13.0
T_s [°C]		208.6	176.8	177.1	194.3
pH		7.12	7.82	8.36	8.67
T-pH		11.4	17.9	20.4	20.1
CO₂ [mg/kg]	Titration	4.0	16.6	14.2	29.1
H₂S [mg/kg]	Titration	7.8	20.1	25.2	105.0
SiO₂ [mg/kg]	ICP-AES	204.1	1224.2	994.9	746.4
Na [mg/kg]	ICP-AES	9.50	113.17	165.37	168.65
K [mg/kg]	ICP-AES	< 4	31.65	35.60	32.21
Ca [mg/kg]	ICP-AES	0.32	0.36	0.42	0.46
Mg [mg/kg]	ICP-AES	< 0.05	< 0.05	< 0.05	< 0.05
Fe [mg/kg]	ICP-AES	< 0.05	< 0.05	< 0.05	< 0.05
Al [mg/kg]	ICP-AES	0.706	1.681	1.857	2.329
B [mg/kg]	ICP-AES	1.44	1.04	1.78	2.40
F [mg/kg]	IC	0.76	0.83	1.61	1.15
Cl [mg/kg]	IC	6.7	152.2	205.1	107,75.6
SO₄ [mg/kg]	IC	2.0	1.5	5.6	13.4
As [ppb]	ICP-MS	19.9	77.0	81.3	0.228
Ba [ppb]	ICP-MS	2.280	0.106	0.141	0.028
Cd [ppb]	ICP-MS	0.017	0.023	0.004	<0.002
Co [ppb]	ICP-MS	0.101	<0.005	<0.005	<0.005
Cr [ppb]	ICP-MS	0.848	<0.01	0.052	0.061
Cu [ppb]	ICP-MS	0.814	0.798	1.230	<0.1
Hg [ppb]	ICP-MS	<0.002	<0.002	<0.002	0.083
Mn [ppb]	ICP-MS	6.37	1.94	0.513	0.85
Mo [ppb]	ICP-MS	7.17	44.0	10.6	0.26
Ni [ppb]	ICP-MS	0.799	0.091	0.051	0.453
P [ppb]	ICP-MS	33.4	1.35	1.49	<1
Pb [ppb]	ICP-MS	0.087	0.03	0.014	0.021
Sb [ppb]	ICP-MS	0.233	4.0	2.5	0.274
Se [ppb]	ICP-MS	0.815	46.9	38.2	0.933
Sr [ppb]	ICP-MS	1.73	0.905	2.18	0.129
Ti [ppb]	ICP-MS	3.21	0.152	0.24	0.037

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V [ppb]	ICP-MS	1.83	6.86	9.38	0.027
Zn [ppb]	ICP-MS	5.78	0.670	0.832	5.33

¹P₀: Well head pressure (bar-g)

²P_S: Separator pressure (bar-g)

Table 2: Non condensable gases in borehole steam, location no. 1 in Figure 3.

	Analytical method				
Date		25.5.2018	28.5.2018	6.6.2018	7.6.2018
Sample number		18-5194	18-5197	18-5213	18-5216
Borehole		HE-60	HE-58	HE-29	NJ-11
Gas ratio [L _{gas} /kg _{steam}]		0.3861	0.3445	0.2644	0.9776
Temperature [°C]		22.7	22.8	22.6	22.5
CO ₂ [mg/kg]	Titration	442.74	3807.02	2044.29	2503.66
H ₂ S [mg/kg]	Titration	410.69	886.47	579.89	1172.73
H ₂ [%]	GC	82.64	83.27	88.36	90.29
O ₂ [%]	GC	0.89	0.31	0.00	0.00
N ₂ [%]	GC	10.81	6.82	4.85	5.51
CH ₄ [%]	GC	0.07	1.16	0.91	1.38

Table 3: Dissolved constituents of condensed steam, location no. 1 in Figure 3. Samples marked with * were analysed in an ICP-MS.

	Analytical method				
Date		25.5.2018	28.5.2018	6.6.2018	7.6.2018
Sample number		18-5195	18-5198	18-5214	18-5217
Borehole		HE-60	HE-58	HE-29	NJ-11
pH		4.42	3.95	3.97	4.13
T-pH		30.0	18.0	16.7	24.4
SiO ₂ [mg/kg]	ICP-AES	0.530	0.172* (Si)	0.228* (Si)	0.205* (Si)
Na [mg/kg]	ICP-AES	< 0.25	0.128*	<0.1*	<0.1*
K [mg/kg]	ICP-AES	< 0.4	<0.4*	<0.4*	<0.4*
Ca [mg/kg]	ICP-AES	0.052	<0.1*	<0.1*	<0.1*
Mg [mg/kg]	ICP-AES	0.009	<0.09*	<0.09*	<0.09*
Fe [mg/kg]	ICP-AES	0.034	0.009*	0.005*	0.01*
Al [mg/kg]	ICP-AES	0.015	0.565*	0.336*	0.849*

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B [mg/kg]	ICP-AES	0.03	n.a.	n.a.	n.a.
F [mg/kg]	IC	Not detected	Not detected	Not detected	Not detected
Cl [mg/kg]	IC	1.83	0.08	0.14	0.24
SO₄ [mg/kg]	IC	1.58	0.34	0.33	0.38
As [ppb]	ICP-MS	0.069	0.076	0.228	0.602
Ba [ppb]	ICP-MS	0.079	0.103	0.028	0.073
Cd [ppb]	ICP-MS	<0.002	0.011	<0.002	0.004
Co [ppb]	ICP-MS	0.013	<0.005	<0.005	<0.005
Cr [ppb]	ICP-MS	0.218	0.160	0.061	0.278
Cu [ppb]	ICP-MS	<0.1	<0.1	<0.1	<0.1
Hg [ppb]	ICP-MS	0.035	0.074	0.083	0.689
Mn [ppb]	ICP-MS	1.260	0.470	0.850	0.539
Mo [ppb]	ICP-MS	0.192	0.346	0.26	0.141
Ni [ppb]	ICP-MS	0.759	0.254	0.453	0.283
P [ppb]	ICP-MS	<1	<1	<1	1.65
Pb [ppb]	ICP-MS	0.06	0.09	0.02	0.03
Sb [ppb]	ICP-MS	0.014	0.037	0.025	0.035
Se [ppb]	ICP-MS	<0.5	1.43	0.933	0.673
Sr [ppb]	ICP-MS	0.267	0.171	0.129	0.087
Ti [ppb]	ICP-MS	0.120	0.197	0.037	0.059
V [ppb]	ICP-MS	0.035	0.247	0.027	0.030
Zn [ppb]	ICP-MS	1.0	8.97	5.33	3.91

4.2 Location 2: Steam into turbines

The concentration of the non-condensable gases (NCG) in steam entering the turbines is shown in Table 4. The composition of condensed steam was not measured but such information is expected to be available at a later time. The steam entering the turbine should not contain high concentrations of products as their majority is removed in the separator. The composition of the condensate (see Tables 6 and 7) can reflect the concentration of certain products previously present in the steam, such as Cl and SO₄, but the trace elements in this fluid are generally present due to corrosion in the system. The steam enters the turbines at 7.4 bar-g and 172°C at Hellisheiði and 11.6 bar-g and 191°C at Nesjavellir.

Table 4: Mean concentration of NCG in steam into turbines at Hellisheiði (HH) and Nesjavellir (NV), location no. 2 in Figure 3.

	Analytical method	Turbine 1 HH	Turbine 2 HH	Turbine 3 HH	Turbine 4 HH	Turbine 5 HH	Turbine 6 HH	Turbines 1+2 NV	Turbines 3+4 NV
CO₂ [mg/kg]	Titration from NaOH	1651.0	2478.5	1602.3	1671.7	3469.5	2798.4	1268.8	2609.8

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H₂S [mg/kg]	Titration from NaOH	676.4	601.0	583.4	600.3	383.9	561.6	944.0	977.6
H₂ [mg/kg]	GC	24.4	21.0	22.4	23.3	14.0	23.6	49.4	49.4
N₂ [mg/kg]	GC	26.2	23.5	17.2	26.6	39.3	30.6	54.4	41.0
CH₄ [mg/kg]	GC	2.9	3.4	3.1	2.4	3.6	3.4	4.3	4.0

4.3 Location 3: Gas from turbines

The gases present in the steam entering turbines are removed in the condenser to increase its efficiency. The composition of these gas streams depends on the NCG composition in the steam entering each turbine as well as any potential air leaks in the condensers, heat exchangers and vacuum pumps. The composition of different gas streams at Hellisheiði is shown in Table 5. These gas streams can be diverted to the Sulfix capture plant or vented to cooling towers. The gas concentration in steam enters turbines in Nesjavellir within the range of turbines 1-6 at Hellisheiði but the gas exiting the turbines at Nesjavellir can be expected to be 25-40% mixed with atmosphere hence diluting the concentration of NCGs accordingly. The gas composition from Turbine 3 in Nesjavellir is shown as an example in Table 5.

Table 5: Three different gas streams from turbines at Hellisheiði and from one turbine at Nesjavellir, location no. 3 in Figure 3.

	Analytical method	Turbines 1-4	Turbines 5-6	Turbine 11	Turbine 3 Nesjavellir
CO₂ [vol%]	GC	52	66	39.5	44
H₂S [vol%]	GC	34	12	29	14.8
H₂ [vol%]	GC	18	8.5	9	17
CH₄ [vol%]	GC	0.37	0.2	0.2	0.1
O₂ [vol%]	GC	0.9	2.7	4.5	5.1
N₂ [vol%]	GC	4.8	10.1	17.7	19

4.4 Locations 4 to 10: Water in power plants

Tables 6 and 7 show the chemical composition of all major liquid streams in the plants. The separator waters from locations 4, 5 and 6 in Figure 3 is first shown. This is the liquid phase of the geothermal fluid following separator stations. The condensate is the liquid sampled directly at the outlet of the condensers. Part of the condensate is diverted to the vacuum extraction pumps where it equilibrates with NCGs and is afterwards termed *seal water*. Another part of the condensate in Hellisheiði is diverted to the Sulfix capture plant. There it is used to capture H₂S and CO₂ under elevated pressure and is afterwards termed *Sulfix water*. The cooling water is water circulating between cooling towers and condensers.

Table 6: Typical chemical composition of separator water, different condensate waters (condensate, seal water and Sulfix water) and cooling water at Hellisheiði for some of the areas in Figure 3 (the corresponding number is marked in brackets).

	Analytical method	Separator water 1 st flash (4)	Separator water 2 nd flash (5)	Separator water after heat ex-changers (6)	Condensate (7)	Seal water (8)	Sulfix water (9)	Cooling water (10)
Pressure [bar-g]		8.4	2-10	10	1	1	7.5	n.a.

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Temperature [°C]		172	119	60 – 90	40 - 60	40 - 60	15	4
pH		8.7	9.2	9.2	6.9	n.a.	n.a.	7.3
Temperature @pH		26	23	25	13	n.a.	n.a.	23
CO ₂ [mg/kg]	Titration	30	20	19.8	2	920	7100	25.7
H ₂ S [mg/kg]	Titration	50	30	30	1	560	4000	0
SiO ₂ [mg/kg]	ICP-AES	676.0	735.0	735.0	< 0.06	< 0.06	n.a.	24.0
Na [mg/kg]	ICP-AES	206.0	203.0	206.0	< 0.1	< 0.1	n.a.	6.3
K [mg/kg]	ICP-AES	35.0	38.2	35.5	< 0.4	< 0.4	n.a.	0.9
Ca [mg/kg]	ICP-AES	0.74	0.85	0.78	< 0.1	< 0.1	n.a.	4.56
Mg [mg/kg]	ICP-AES	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	n.a.	5.67
Fe [mg/kg]	ICP-AES	0.050	0.002	0.003	0.007	0.090	n.a.	0.020
Al [mg/kg]	ICP-AES	1.70	2.10	1.90	0.39	0.39	n.a.	0.004
SO ₄ [mg/kg]	IC	16.0	21.5	24.4	1.0	7.0	n.a.	1.4
Cl [mg/kg]	IC	186.0	186.0	186.0	< 0.1	< 0.1	n.a.	5.8
F [mg/kg]	IC	1.15	1.43	1.52	< 0.005	< 0.005	n.a.	0.04
As [µg/L]	ICP-MS	n.a.	40.2	37.1	< 0.05	0.448	n.a.	< 0.05
Ba [µg/L]	ICP-MS	n.a.	0.267	0.330	0.025	0.239	n.a.	0.413
Cd [µg/L]	ICP-MS	n.a.	0.003	< 0.002	< 0.002	< 0.002	n.a.	< 0.002
Co [µg/L]	ICP-MS	n.a.	0.022	0.027	0.007	0.045	n.a.	0.009
Cr [µg/L]	ICP-MS	n.a.	0.071	0.071	0.096	16.7	n.a.	0.59
Cu [µg/L]	ICP-MS	n.a.	0.422	0.40	< 0.1	< 0.1	n.a.	0.119
Hg [µg/L]	ICP-MS	n.a.	< 0.002	< 0.002	< 0.002	0.086	n.a.	< 0.002
Mn [µg/L]	ICP-MS	n.a.	0.502	0.605	0.232	4.66	n.a.	< 0.03
Mo [µg/L]	ICP-MS	n.a.	4.42	4.69	< 0.05	0.074	n.a.	0.169
Ni [µg/L]	ICP-MS	n.a.	0.092	0.171	0.742	1.04	n.a.	< 0.05
P [µg/L]	ICP-MS	n.a.	< 1	< 1	< 1	1.31	n.a.	43.9
Pb [µg/L]	ICP-MS	n.a.	< 0.01	< 0.01	0.029	0.067	n.a.	< 0.01
Se [µg/L]	ICP-MS	n.a.	16.0	15.3	< 0.5	0.535	n.a.	< 0.5
Sr [µg/L]	ICP-MS	n.a.	4.33	4.31	0.056	0.229	n.a.	8.6
Ti [µg/L]	ICP-MS	n.a.	0.059	0.079	0.02	0.086	n.a.	0.007
V [µg/L]	ICP-MS	n.a.	3.97	4.20	0.019	0.357	n.a.	5.87
Zn [µg/L]	ICP-MS	n.a.	2.29	0.30	1.579	1.08	n.a.	2.95

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Table 7: Typical chemical composition of separator water, different condensate waters (condensate and seal water) and cooling water at Nesjavellir for some of the areas marked in Figure 3 (the corresponding number is marked in brackets).

	Analytical method	Separator water (4)	Separator water after heat exchangers (6)	Condensate (7)	Seal water (8)
Pressure [bar-g]		12	12	1	n.a.
Temperature [°C]		180	85	60	n.a.
pH		8.94	8.83	5.1	n.a.
Temperature @pH		22	22.8	28	n.a.
CO ₂ [mg/kg]	Titration	22.15	23.7	20.9	365
H ₂ S [mg/kg]	Titration	74.8	82	98.3	331
SiO ₂ [mg/kg]	ICP-AES	757.5	764.0	4.44	n.a.
Na [mg/kg]	ICP-AES	168	159	1.78	n.a.
K [mg/kg]	ICP-AES	33.2	31.6	0.3	n.a.
Ca [mg/kg]	ICP-AES	0.296	0.268	0.860	n.a.
Mg [mg/kg]	ICP-AES	0.05	0.005	0.440	n.a.
Fe [mg/kg]	ICP-AES	0.002	0.025	0.287	n.a.
Al [mg/kg]	ICP-AES	1.91	1.99	0.016	n.a.
SO ₄ [mg/kg]	IC	12.4	18.1	3.9	n.a.
Cl [mg/kg]	IC	155.5	118.0	1.0	n.a.
F [mg/kg]	IC	1.28	0.90	0.01	n.a.
As [µg/L]	ICP-MS	n.a.	58.3	0.088	n.a.
Ba [µg/L]	ICP-MS	n.a.	0.245	0.066	n.a.
Cd [µg/L]	ICP-MS	n.a.	< 0.002	< 0.002	n.a.
Co [µg/L]	ICP-MS	n.a.	0.016	0.054	n.a.
Cr [µg/L]	ICP-MS	n.a.	0.433	3.87	n.a.
Cu [µg/L]	ICP-MS	n.a.	2.47	< 0.1	n.a.
Hg [µg/L]	ICP-MS	n.a.	< 0.002	0.013	n.a.
Mn [µg/L]	ICP-MS	n.a.	1.26	1.73	n.a.
Mo [µg/L]	ICP-MS	n.a.	2.62	< 0.05	n.a.
Ni [µg/L]	ICP-MS	n.a.	2.44	4.47	n.a.
P [µg/L]	ICP-MS	n.a.	< 1	< 1	n.a.
Pb [µg/L]	ICP-MS	n.a.	0.012	0.026	n.a.
Se [µg/L]	ICP-MS	n.a.	7.6	< 0.5	n.a.
Sr [µg/L]	ICP-MS	n.a.	2.11	0.097	n.a.
Ti [µg/L]	ICP-MS	n.a.	0.06	0.025	n.a.

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V [$\mu\text{g/L}$]	ICP-MS	n.a.	2.46	0.048	n.a.
Zn [$\mu\text{g/L}$]	ICP-MS	n.a.	8.19	2.39	n.a.

Additionally, the composition of the groundwater used for example as make-up water in cooling towers and for the district heating system at Hellisheiði and Nesjavellir is included in Table 8. This location is number 11 in Figure 3.

Table 8: Chemical composition of groundwater at Hellisheiði (HH) and Nesjavellir (NV), location no. 11 in Fig. 3.

	Analytical method	HU-01 (HH)	K-3 (NV)
pH		7.72	8.3
T-pH		21.9	22.8
SiO ₂ [mg/kg]	ICP-AES	24.07	34.93
Na [mg/kg]	ICP-AES	6.22	14.81
K [mg/kg]	ICP-AES	0.88	1.67
Ca [mg/kg]	ICP-AES	4.812	9.515
Mg [mg/kg]	ICP-AES	2.796	5.429
Fe [mg/kg]	ICP-AES	<0.005	0.008
Al [mg/kg]	ICP-AES	<0.0075	0.103
Cl [mg/kg]	ICP-AES	7.01	13.24
SO ₄ [mg/kg]	ICP-AES	2.65	11.76
B [mg/kg]	ICP-AES	<0.01	0.074
F [mg/kg]	IC	0.073	0.127
Cl [mg/kg]	IC	6.94	12.72
SO ₄ [mg/kg]	IC	2.15	10.54
As [ppb]	ICP-MS	0.054	0.061
Ba [ppb]	ICP-MS	0.467	0.161
Cd [ppb]	ICP-MS	0.005	<0.002
Co [ppb]	ICP-MS	0.006	<0.005
Cr [ppb]	ICP-MS	0.553	0.843
Cu [ppb]	ICP-MS	0.277	0.417
Hg [ppb]	ICP-MS	<0.002	0.017
Mn [ppb]	ICP-MS	0.171	<0.03
Mo [ppb]	ICP-MS	0.175	0.181
Ni [ppb]	ICP-MS	0.313	0.076
P [ppb]	ICP-MS	40.9	30.9
Pb [ppb]	ICP-MS	<0.01	0.013
Sb [ppb]	ICP-MS	n.a.	<0.01

Se [ppb]	ICP-MS	<0.5	0.262
Sr [ppb]	ICP-MS	9.29	6.21
Ti [ppb]	ICP-MS	0.023	n.a.
V [ppb]	ICP-MS	6.17	n.a.
Zn [ppb]	ICP-MS	21.9	9.1

5. Summary and application to the Geo-Coat project

The measurements gathered in this deliverable provide an overview of the conditions in various locations within the Hellisheiði and Nesjavellir power plants. An overview of the results from the measurements from both areas is shown in Table 9 for some of the elements.

Table 9: A combined overview of the range of the properties and chemical composition at the different sampling locations at Hellisheiði and Nesjavellir.

no. on Fig. 3	Location	State	T [°C]	P [bar]	pH	CO ₂ [mg/kg]	H ₂ S [mg/kg]	SiO ₂ [mg/kg]	Na [mg/kg]	K [mg/kg]	Ca [mg/kg]	Cl [mg/kg]	SO ₄ [mg/kg]	Se [mg/kg]
1	Wellhead	Water	176-209	16-77	7.12-8.67	4-29.1	7-105	204-1224	9.5-168.7	<4-36	0.32-0.46	5-205	1.5-13.4	0.82-46.9
		NCG	-	-	-	443-3807	410-1173	-	-	-	-	-	-	-
		Cond. steam	-	-	3.95-4.42	-	-	0.172-0.53	<0.1-0.13	<0.4	<0.1	0.08-1.8	0.3-1.6	<0.5-1.43
2	Steam into turbines	NCG	172-191	7.4-11.8	-	1268-3470	384-978	-	-	-	-	-	-	-
3	Gas from turbines	NCG	-	-	-	37-66 [vol%]	12-34 [vol%]	-	-	-	-	-	-	-
4	Separator water after 1st flash	Water	172-180	8.4-12	8.70-8.94	22-30	50-75	676-758	168-206	33-35	0.30-0.74	155-186	42705	n.a
5	Separator water after 2nd flash	Water	119	2-10	9.2	20	30	735	203	38	0.85	186	21.5	16
6	Separator water after heat exchangers	Water	10-85	10-12	8.83-9.2	19.8-23.7	30-82	735-764	159-206	31.6-35.5	0.27-0.78	118-186	18.1-24.4	7.6-15.3
7	Condensate	Water	40-60	1	5.1-6.9	2-20.9	1-98.3	<0.06-4.4	<0.1-1.78	<0.4	<0.1-0.86	<0.1-1	1-3.9	<0.5
8	Seal water	Water	40-60	1	n.a.	365-920	331-560	<0.06	<0.1	<0.4	<0.1	<0.1	7	0.535
9	Sulfix water	Water	15	7.5	n.a.	7100	4000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
10	Cooling water	Water	4	n.a.	7.3	25.7	0	24	6.3	0.9	4.56	5.8	1.4	<0.5
11	Typical ground-water	Water	-	-	7.72-8.3	-	-	24.1-34.9	6.2-14.8	0.88-1.67	4.8-9.5	7.0-13.2	2.2-10.5	<0.5

A breakdown of the composition at each wellhead analysed in this deliverable is shown in Appendix A. The composition of these wells is supposedly typical for these geothermal fields but they do not provide the ultimate range for the composition of all the wells in these areas. The chemical composition of 33 two-phase wells at Hellisheiði was measured in the years 2008-2010 to provide an understanding of their overall characteristics [3]. The ranges of some of these measurements are shown in Table 10 and the chemical composition of each well can be found in Appendix B.

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Table 10: The range of the chemical composition for different wells at Hellisheiði, measured from 2008-2010 [3].

no. on Fig. 3	Location	State	T [°C]	P [bar]	pH	CO ₂ [mg/kg]	H ₂ S [mg/kg]	SiO ₂ [mg/kg]	Na [mg/kg]	K [mg/kg]	Ca [mg/kg]	Cl [mg/kg]	SO ₄ [mg/kg]	Se [mg/kg]
1	Wellhead	Liquid	-	9.6-25	7.25-9.42	7.4-93.3	22.9-77.4	613-1010	22.6-255	4.9-47.7	0.17-1.27	26-362	2.8-42.5	-
		Vapor	-	9.6-25		758-7587	119-1607	-	-	-	-	-	-	-

Comparison of these ranges to the measured ranges in this report shows that there is a difference; the ranges of these newest measurements have lower values. The low values of the lower limit appear mainly due to the composition of well HE-60 which generally showed lower chemical concentrations compared to the other wells. This well also distinguishes itself from the others due to its high temperature and pressure. It was however not amongst the wells described in the article and any potential change in composition can therefore not be observed. Only well HE-29 was measured in both cases and the results can therefore be compared. These results show that there are differences between the measured values for this well, see Appendix A and B. In addition to the pH showing lower values, the chemical concentrations appear to have generally diminished. The analytical methods used to measure the samples are similar and this therefore shows that the concentrations are subject to change. The older measurements also generally have higher upper limits which is understandable since a larger number of wells was tested. The average values for the older samples are also higher, see Appendix C. These differences are acknowledged but they could either be due to more samples being taken but also due to changes in the fluid.

The measurements shown in Table 9 provide the newest information available for the composition and properties of the fluid at the different locations in the power plants. This information will therefore be used to confirm the geothermal models being developed in Task 1.3 and to help in choosing the chemical composition of the simulated geothermal environment in the laboratory experiments based on the substrates being focused on.

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6. References

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7. Appendix

A. The chemical composition of the samples at the wellheads at Hellisheiði and Nesjavellir measured in Task 1.2.

no. on Fig. 3	Location	Well	State	T [°C]	P [bar]	pH	CO2 [mg/kg]	H2S [mg/kg]	SiO2 [mg/kg]	Na [mg/kg]	K [mg/kg]	Ca [mg/kg]	Cl [mg/kg]	SO4 [mg/kg]	Se [mg/kg]	
1	Wellhead	HE-60	Water	208.6	76.8 (18.5)	7.12 @11.4	4	7.8	204.1	9.5	<4	0.32	6.7	2.0	0.815	
		HE-60	NCG	-	-	-	442.74	410.69	-	-	-	-	-	-	-	-
		HE-60	Condensed steam	-	-	4.42 @30°C	-	-	0.53	<0.25	<0.4	0.052	1.83	1.58	<0.5	-
		HE-58	Water	176.8	17.2 (8.9)	7.82 @17.9	16.6	20.1	1224.2	113.17	31.65	0.36	152.2	1.5	46.9	-
		HE-58	NCG	-	-	-	3807.02	886.47	-	-	-	-	-	-	-	-
		HE-58	Condensed steam	-	-	3.95 @18°C	-	-	0.172	0.128	<0.4	<0.1	0.08	0.34	1.43	-
		HE-29	Water	177.1	16 (8.5)	8.36 @20.4	14.2	25.2	994.9	165.37	35.6	0.42	205.1	5.6	38.2	-
		HE-29	NCG	-	-	-	2044.29	579.89	-	-	-	-	-	-	-	-
		HE-29	Condensed steam	-	-	3.97 @16.7°C	-	-	0.228	<0.1	<0.4	<0.1	0.14	0.33	0.933	-
		NJ-11	Water	194.3	23.8 (13)	8.67 @20.1	29.1	105	746.4	168.65	32.21	0.46	5.6	13.4	13.4	0.933
		NJ-11	NCG	-	-	-	2503.66	1172.73	-	-	-	-	-	-	-	-
		NJ-11	Condensed steam	-	-	4.13 @24.4°C	-	-	0.205	0.1	<0.4	<0.1	0.24	0.38	0.673	-

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B. The chemical composition of the samples taken at Hellisheiði between 2008-10[3].

Well #	p^{wh} [bar-g]	Liquid										Vapor	
		pH	/°C	CO ₂ [ppm]	H ₂ S [ppm]	SiO ₂ [mg/kg]	Na [ppm]	K [ppm]	Ca [mg/kg]	Cl [ppm]	SO ₄ [ppm]	CO ₂ [ppm]	H ₂ S [ppm]
HE-47	24	8.14	21	46.7	22.9	1010	148	36.3	0.27	203	6.4	2281	767
HE-19	20.2	8.8	23	10	66.8	632	196	31.2	0.58	187	8.2	2306	871
HE-30	16.1	8.25	22	22.1	35	974	164	36	0.34	203	9.7	3736	865
HE-15	22.5	8.79	20	16.4	55.5	684	182	30	0.49	167	9.6	3660	823
HE-17	21.8	8.48	23	13.7	64.5	784	189	36.6	0.32	205	12	2938	1229
HE-11	19	8.71	22	47.4	52.1	744	173	32.9	0.22	161	11.9	4352	737
HE-06	18.5	8.67	23	87.8	57.3	628	162	25.7	0.49	101	9.1	7587	723
HE-46	16	9.26	22	29.5	33.3	668	177	30.8	0.52	63	42.5	4256	206
HE-52	9.6	9.22	27	20.1	26.4	678	178	28.5	1.27	78	30.5	3922	119
HE-18	13.7	8.92	21	34.9	52	678	170	29.5	0.31	144	19.7	2435	639
HE-09e	13	7.25	186	29.4	74.7	819	172	34.6	1.18	204	-	2593	1412
HE-57	12.5	9.14	20	46.7	50.9	743	195	36.4	0.99	155	19.1	2904	405
HE-03	12.7	8.8	20	10	45.3	665	255	47.7	0.73	362	11.1	998	398
HE-12	19.5	8.66	24	22.1	73.4	783	193	36.7	0.32	193	17.9	2504	933
HE-07	21	8.89	23	16.4	73.6	636	198	33.2	0.36	185	8.3	1638	754
HE-45d	24.5	-	-	-	-	-	28	5.4	-	179	-	1785	856
HE-42	24.5	8.35	19	13.6	35	874	139	30	0.24	169	3.1	758	1030
HE-41d	24.5	-	-	-	-	-	22.6	4.9	-	26	-	2123	769
HE-43	16.1	8.42	24	33	50	877	143	28.1	1.05	90	10.6	3886	965
HE-05	17	9.2	22	66.8	46	676	161	29.1	0.4	77	16.2	3670	245
HE-06	16	8.7	23	74.8	60.1	613	160	25.4	0.49	104	11.3	7173	735
HE-17	25	8.37	23	15.4	68.7	786	190	37.3	0.35	216	5.6	2790	1586
HE-29	20.5	8.67	22	18.1	52.1	885	132	27.6	0.59	105	2.8	2552	1117
HE-41	17	8.7	15	93.3	57.6	710	72	14.7	0.17	41	2.9	1980	723
HE-07	20	9.13	17	7.4	76.1	659	201	32.7	0.35	199	7.5	1309	822

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HE-12	17	8.66	19	11	77.4	816	188	35.5	0.28	196	13.7	2325	1147
HE-17	20.8	8.47	17	10.6	68	796	177	36.2	0.27	207	5.5	3161	1607
HE-11	18	8.74	17	22.9	55.7	754	168	31.8	0.17	158	8.6	4373	952
HE-29	20.8	8.71	21	11.9	57.5	931	128	25.7	0.23	104	3.9	2446	930
HE-05	16.2	9.42	20	33.1	37.7	698	157	27.9	0.32	77	19.2	3558	210
HE-06	18	8.82	21	34.5	56.9	633	160	24.9	0.37	107	10.4	6831	654
HE-18	15.2	8.97	19	18.9	57.9	682	165	27.6	0.31	144	8.8	2853	617

C. Average values for the concentrations at the wellhead for the new and older measurements

Measurement	State	T [°C]	P [bar]	pH	CO2 [mg/kg]	H2S [mg/kg]	SiO2 [mg/kg]	Na [mg/kg]	K [mg/kg]	Ca [mg/kg]	Cl [mg/kg]	SO4 [mg/kg]	Se [mg/kg]
T1.2	Water	189.2	33.5	8.00	16.0	39.5	792.4	114.2	25.9	0.39	92.4	5.63	21.71
	NCG	189.2	33.5	-	2199.4	762.4	-	-	-	-	-	-	-
	Condensed steam	189.2	33.5	4.12	-	-	0.284	<0.25	<0.4	<0.1	0.573	0.658	<1.43
2008-10 [3]	Liquid	-	18.5	8.71	20.6	54.7	750.5	160.7	29.7	0.47	150.3	11.9	-
	Vapor	-	-	-	3177.6	807.7	-	-	-	-	-	-	-