GeoEjector: Extracting geothermal fluid from a low-pressure geothermal well

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ABSTRACT

In the GeoEjector project, we investigate the potential to connect a low-pressure geothermal well to a nearby high-pressure well with an ejector system. The aim is to induce flow from the low-pressure well which cannot sustain high enough pressure for the operating conditions of the geothermal plant. A rudimentary ejector was tested in Theistareykir Geothermal Power Plant in Iceland in 2021. The results were promising, as the measurements showed entrained flow from the low-pressure well and subsequently increased fluid pressure up to 0.55 bar as it mixed with the stream coming from the high-pressure well. However, it was found that the existing design of the ejector cannot handle the real operating conditions of the wells for the plant, where higher back pressure is required. To address this challenge, an improved ejector design has been made and is planned to be tested in 2023. Also, a down-scaled laboratory ejector is being set up to collect measurements of combined low- and high-pressure water and steam flows. We have used an analytical model to improve the ejector's design and Computational Fluid Dynamics (CFD) models to simulate its flow. This paper will introduce this project and show the preliminary results.

1. INTRODUCTION

Geothermal drilling contributes highly to the overall cost of developing geothermal power plants, with 32 to 37% of a project's total investment (Gehringer, M. and Loksha, V.C., 2012). Some drilled wells are unusable due to insufficient pressure and/or insufficient flow rate of the fluid from the wells. The reported success ratio (number of successful wells that can be used as production wells to the total number of wells drilled) is 59 to 83% depending on the project phase (IFC, 2013) for geothermal power projects. Also, during utilization of the geothermal wells, the performance of wells can decrease due to various reasons like changes in the reservoir or overload, and they can no longer sustain the working pressure of the plant. This leads to the increased need for drilling of make-up wells which can add substantially to the cost of the plant.

In the scope of this project, we are studying whether connecting high- and low- pressure geothermal wells using ejector equipment can extend the lifespan of weakening wells. An ejector is a static device that combines flows from two different pressure conditions into one stream. The pressure of the high-pressure (primary flow) is converted into kinetic energy, enabling flow entrainment from a low-pressure secondary source. At the ejector outlet, the two streams are mixed, and the kinetic energy is converted back into increased pressure downstream. Ejectors are commonly applied in different industries such as refrigeration, power generation, and chemical industry. In geothermal plants, ejectors are used to extract non-condensable gases from condensers using steam as the primary fluid. Ejectors are relatively simple, non-expensive, low maintenance due to non-moving parts, and have relatively low operating costs (Besagni, G., 2019).

In the literature, there is not much found regarding previous uses of such ejector devices in fluid extraction from geothermal wells. In a patent from 1999 (Jung, 1999), an ejector apparatus was described, and its purpose was to increase the fluid recovery from geothermal wells. Still, no further information has been found regarding the use of that design. In 2012 Reykjavik Energy used an ejector for managing scaling in a turbine which got steam from a new well with dry steam and high enthalpy. The flow from that well was used in an ejector as the primary flow and fluid from low enthalpy two-phase wells was used as a secondary flow. This seems to have washed the high enthalpy steam and solved the scaling issue in the turbine. (G. Kjartansson, personal communication 2023).

In 2021 a rudimentary ejector device was installed at Theistareykir power plant in Iceland, where the flow from two wells ThG-11 and ThG-15, was connected with an ejector. The high enthalpy fluid from well ThG-11 acted as the primary flow to entrain flow from well ThG-15, which has insufficient pressure to be used for the plant's operating conditions.

In this paper, we describe the results from test runs for the ejector device at Theistareykir, describe the improved design of the ejector, and predict the flow characteristics of a geothermal fluid flow through such a device using analytical and numerical methods. Laboratory and field measurements for the said geothermal applications within the project's scope are also described in the paper.

2. INITIAL EJECTOR TESTS AT THEISTAREYKIR

Theistareykir geothermal plant is located in Northeast Iceland and has installed power of 90 MW_e and an estimated capacity of 200 MW_e (Knútsson et al., 2018). The plant was commissioned in 2017, and in 2020 there were 18 wells drilled, 12 of which were in use, giving a success rate of 82% since 14 out of 18 wells could be used as production wells (Hardarson et al. 2021). Wells ThG-11 and ThG-15, shown in Figure 1, are located on the same well pad and have different characteristics, as listed in Table 1. The wellhead pressure of ThG-11 is currently reduced to the steam gathering system pressure (which is 9.5 – 10 bar-g) using orifice plates. The wellhead pressure of ThG-15 is not high enough to sustain the working pressure of the system and has therefore not been used (Knútsson et al., 2018, Andal, 2023).

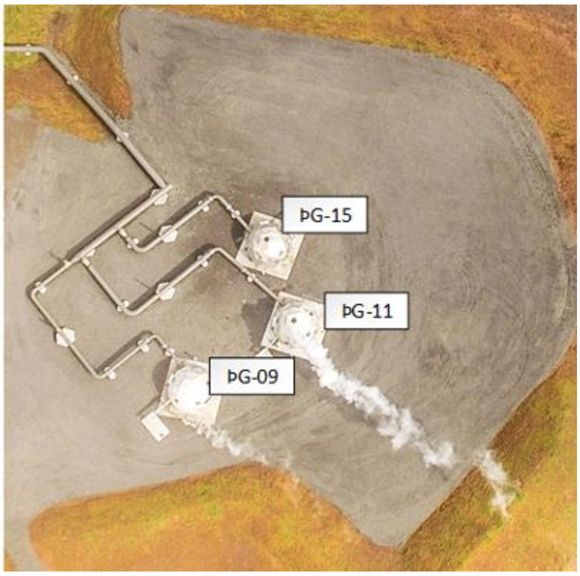


Figure 1: Representation of the two wells ThG-11 and ThG-15 that were connected using an ejector setup.

Table 1: Parameters of wells THG-11 and THG-15 (Egilson, T., 2019, Knútsson et al, 2018).

Well	Depth (m)	Measured mass flow rate at reported wellhead pressure(kg/s)	Reported well head pressure (bar-g)	Enthalpy (kJ/kg)	Well head potential (MWe)	Status
THG-11	2224	26	30	2700	14.4	In use
THG-15	2260	14	8.7	950	2.0	Not in use

In 2021, Landsvirkjun, which owns and operates the Theistareykir power plant, built and installed an ejector device (hereafter referred to as geoejector) connecting the two wells ThG-11 and ThG-15 to explore if the primary flow from the high pressure well (ThG-11) could induce secondary flow from the low pressure well (ThG-15). Figure 2 shows the setup for these tests.

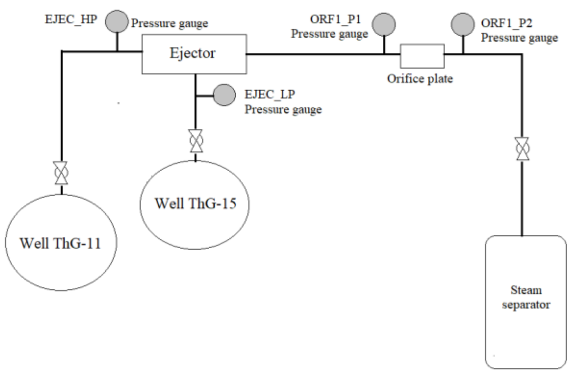


Figure 2: Schematic showing the setup of the geoejector tests at Theistareykir power plant in 2021.

A schematic, showing the design of this rudimentary geoejector design is shown in Figure 3.

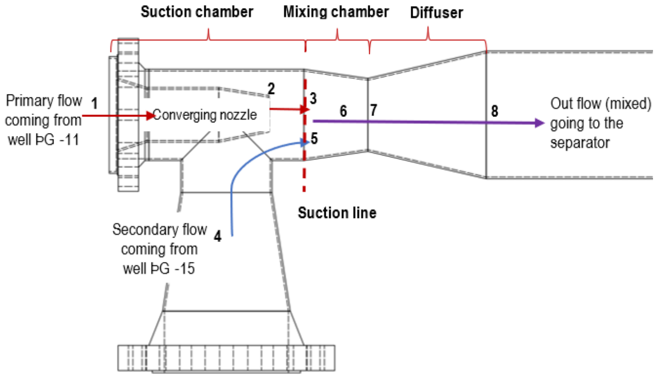


Figure 3: A schematic showing the design of the rudimentary ejector tested at Theistareykir in 2021

During the tests in 2021, the average enthalpy of the primary flow from well ThG-11 (state 1, as shown in Figure 3) was 2787 kJ/kg and the pressure of the flow was in the range of 12.6 to 15.4 bar-g. The enthalpy and pressure of the secondary flow from well ThG-15 (state 4 in Figure 3) were 950 kJ/kg and 9.4 to 11.2 bar-g, respectively. The output of the ejector (state 8, as shown in Figure 3) showed a variation in enthalpy from 1637 to 2361 kJ/kg and pressure ranging from 9.9 to 11.5 bar-g (Guardia et al., in press).

Figure 4 shows the induced pressure (p_8-p_4) versus the entrainment ratio (m_4/m_1) for the tests performed at Theistareykir in 2021. The subscript numbers refer to the state numbers in Figure 3. The induced pressure indicates how well the ejector is performing in increasing the final pressure compared to the initial pressure value of the secondary flow.

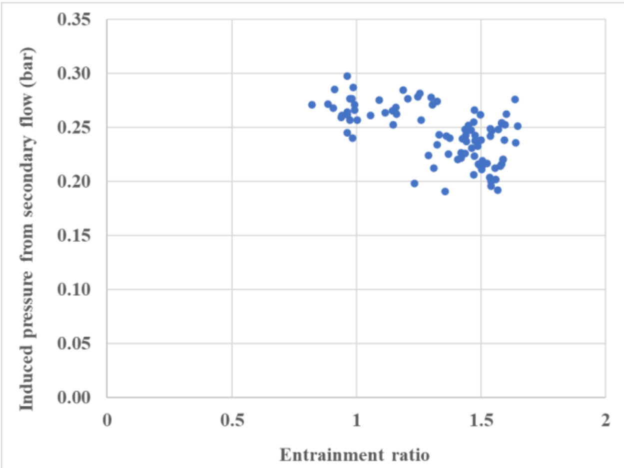


Figure 4: Geoejector measurements showing the induced pressure in relation to the entrainment ratio.

The results show that when entrainment ratios are above 0.8, the induced pressure up to 0.3 bar can be reached which can lead to a substantial increase in power production (Guardia et al. (in press)). Although the value of the induced pressure is marginal, the results showed a success for this rudimentary ejector which was built without thorough analytical or numerical analysis prior to its design and operation.

During these tests, the high-pressure well (ThG-11) was operating below its nominal operating pressure due to the limitation of the separator used (see Figure 2). This resulted in the pressure difference between the wells being significantly lower than it would be under real operations. Further analysis of the geoejector flow and revised design was therefore needed.

3. ANALYTICAL AND NUMERICAL MODELS OF A GEOEJECTOR

Analytical methods that can determine the performance of ejectors are found in literature for various applications. The assumptions used in the analytical model described here are based on the information gathered from the first geoejector field tests and available literature, primarily Chen et al. (2017) and Huang et al. (1999). The model is described in more detail in Guardia et al. (in press) and Andal (2023). Using this model requires a few assumptions and simplifications. Among them is the fact that the model is based on ideal gas equations to maintain the momentum balance, using a constant specific heat ratio $k = 1.33$. Also, the flow of the two phases through the ejector device is homogeneous and no heat losses through the walls of the device is assumed. A coefficient for mixing and friction loss of 0.84 had to be assumed for the flow as well.

The model's results for the pressure of the flow through the geoejector described in the previous section showed a deviation from the measured values from -0.2% to +9.9% (Guardia et al. (in press). The pressure and velocity profiles predicted by the analytical model is shown in Figure 5.

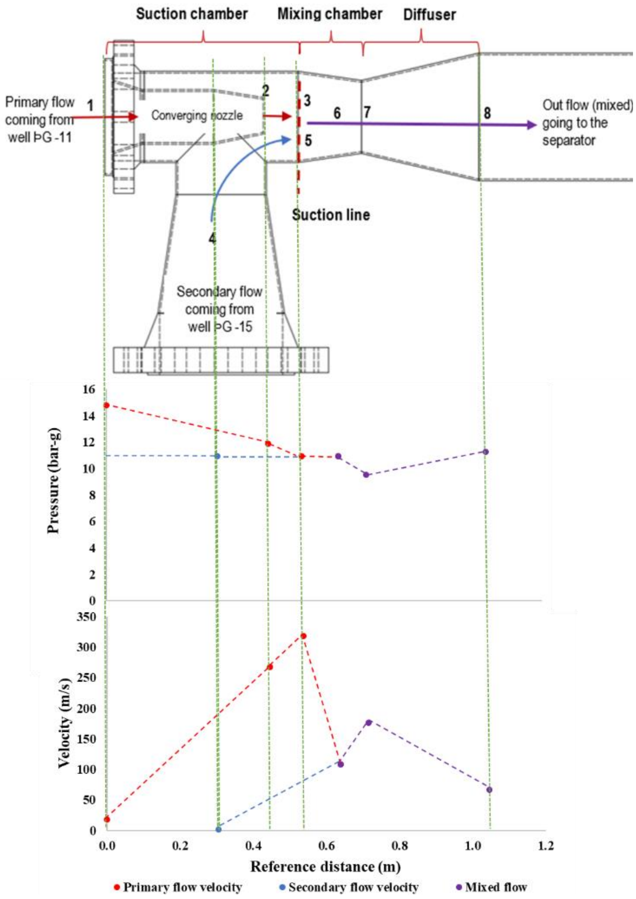


Figure 5: Pressure and velocity within the rudimentary geoejector as predicted by the analytical model.

The pressure of the primary fluid in the tests as well as the ejectors back pressure was well below the real operating conditions. The analytical model was used to design a geoejector that could sustain the working conditions of the plant, i.e. a desired pressure and mass flow from the wells and a sufficiently high back pressure, see Andal et al. (in press) and Andal (2023). This geoejector works under supersonic conditions and the setup is shown in Figure 6.

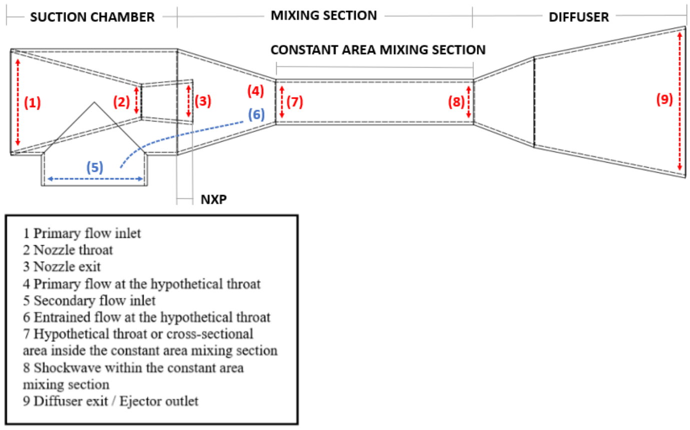


Figure 6: Design of a revised, supersonic geoejector.

The results of the model are promising, and the new setup could potentially increase the pressure of the geothermal fluid from the low-pressure well by 2.4 bar, which would add up to 0.8 MWe for power generation. This updated design from the rudimentary geoejector, described in the previous section, enables operation conditions as shown in Figure 7 which are results from the analytical model of the geoejector.

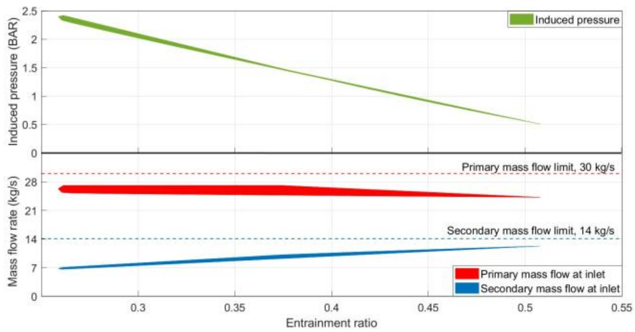
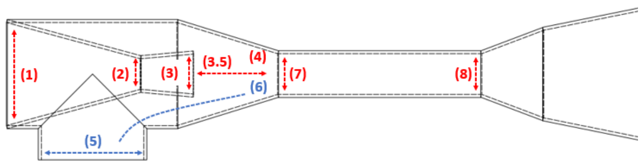


Figure 7: Operating conditions and performance of the updated design of the geoejector as predicted by the analytical model.

Further experimental tests and CFD simulations need to be executed to understand the flow behaviour of the geoejector under different conditions.

Figure 8 shows results of the supersonic geoejector flow shown in Figure 6 where the results from the analytical model and CFD simulations are compared.



(a)

Legend:
1 Primary flow inlet
2 Nozzle throat
3 Nozzle exit
3.5 Mixing chamber
4 Primary flow at the hypothetical throat
5 Secondary flow inlet
6 Entrained flow at the hypothetical throat
7 Hypothetical throat or cross-sectional area inside the constant area mixing section
8 Shockwave within the constant area mixing section
9 Diffuser exit / Ejector outlet

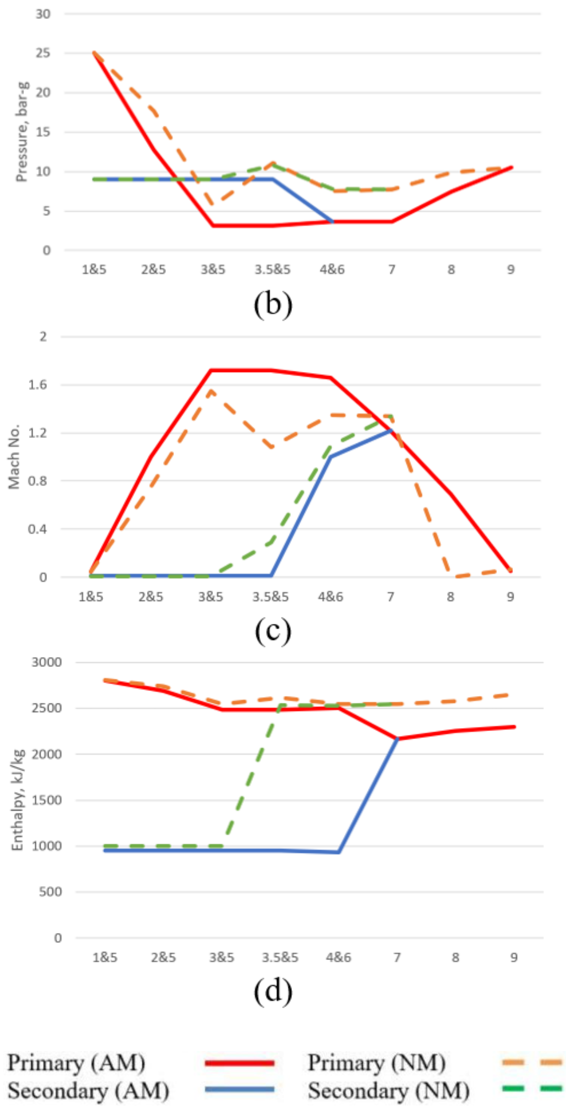


Figure 8: (a) Updated design for the geoejector. Comparison of results of analytical model (AM) and numerical model (NM) for (b) pressure, (c) Mach No., and (d) specific enthalpy.

Figure 8 shows similarities of the modelled parameters, however, as described in Andal (2023) the models are highly sensitive to friction factors and steam quality of the secondary fluid. The friction factor greatly influences the mass flow difference between the analytical and numerical model while the steam quality of the secondary fluid has minimal impact on the mass flow difference. However, it was observed that the enthalpy difference between the models improved as the steam quality of the secondary fluid increased.

4. LABORATORY TESTS OF A GEOEJECTOR

To validate the numerical and analytical models, measured values from laboratory experiments are needed. Under this project's scope, a laboratory-scale test rig has been installed and will be operated using steam and a mixture of steam and water flow. Figure 9 shows a schematic of the setup for the steam flow tests.

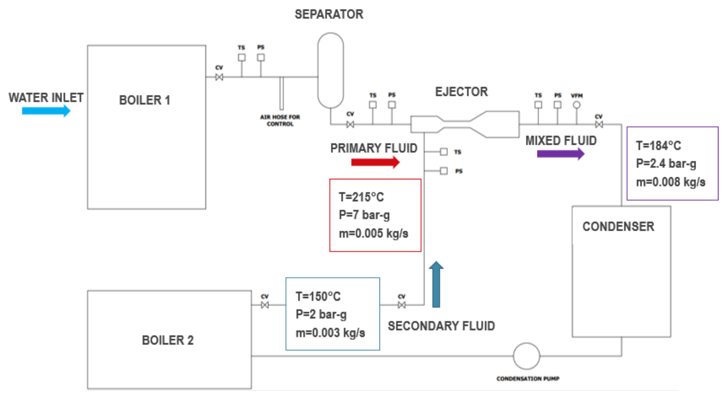


Figure 9: Schematic of the experimental set-up for steam and water tests

Different geometrical configurations of supersonic ejectors will be tested using saturated steam as a primary fluid (higher pressure) and a mixture of liquid water and steam as a secondary fluid (lower pressure). The entrainment ratio will be evaluated for different pressure conditions and geometrical parameters like the area ratio between the nozzle throat and the constant-area mixing section throat, the nozzle exit position, and the length of the constant-area mixing section; to find the best design parameters that could work for geothermal power plant conditions.

Figure 10 shows the first design of the laboratory scale supersonic ejector for the conditions given in Figure 9 and its pressure profile.

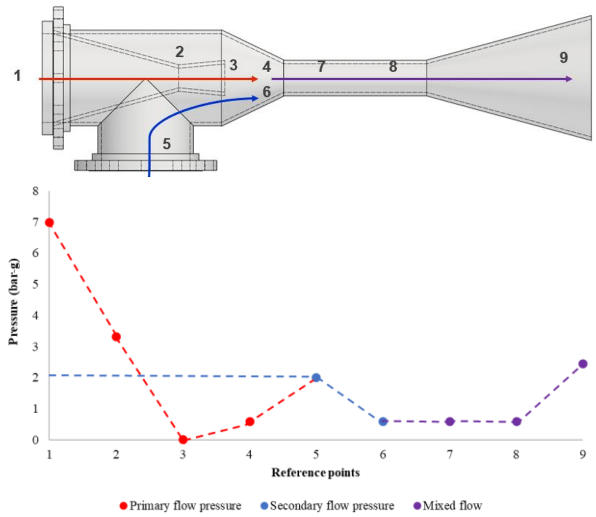


Figure 10: First design of the laboratory scale supersonic ejector and modelled pressure profiles.

5. FIELD SCALE TESTS AT THEISTAREYKIR

The rudimentary design of the ejector in Theistareykir described in Section 2 showed promising results. This ejector design had a converging nozzle and operated under subsonic conditions which needs to be changed for it to comply with the operating conditions of the plant. As mentioned before, the analytical model shows that the pressure reduction for the high pressure well (ThG-11) would be insufficient with a subsonic nozzle when the well is operating at normal working conditions. Therefore, a supersonic nozzle would be needed to create sufficiently low pressure to induce flow from well ThG-15 under normal operating conditions. Also, the rudimentary ejector used did not have a constant area mixing section, which ensured proper mixing of the primary and secondary flows, with approximately uniform pressure.

To improve the geoejector performance and gather more information about the operation of such a device for geothermal wells, new field scale experiments are planned in 2024. For this setup the geoejector will only use part (3 kg/s) of the total flow from well ThG-11 to minimize potential disruption risk to the operation of the well and the plant. Table 2 summarizes the parameters used for calculating and simulating the flow through the supersonic geoejector.

This setup has been designed using the analytical model described in the previous section to calculate the pressure and velocity. The result from that calculation is shown in Figure 11. A 2D axisymmetric CFD simulation using steam and neglecting condensation was also run for this setup to aid the design process. The velocity field from the simulation is shown in Figure 12.

Table 2: Summary of well parameters for the proposed tests at Theistareykir.

Description		Unit	3 kg/s primary flow inlet
THG-11	Pressure	Bar-g	>29.0
	Enthalpy	kJ/kg	2802.0
	Mass flow	m/s	3.0
THG-15	Pressure	Bar-g	>7.0
	Enthalpy	kJ/kg	950.0
	Mass flow	kg/s	1.6

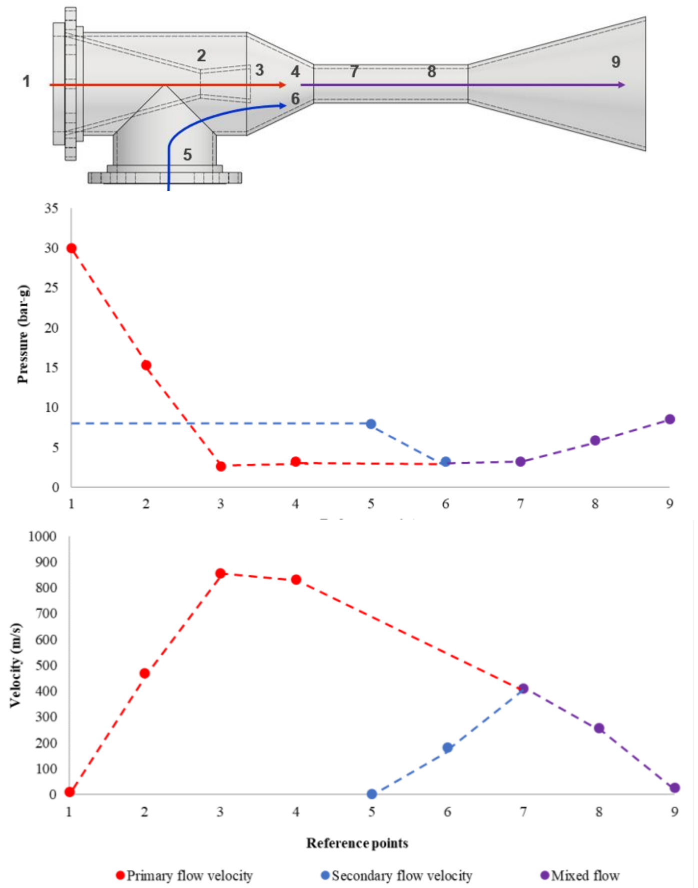


Figure 11: Top: Geoejector and state numbers for the flow. Middle: Pressure profiles from the analytical model. Bottom: Velocity profiles from the analytical model.

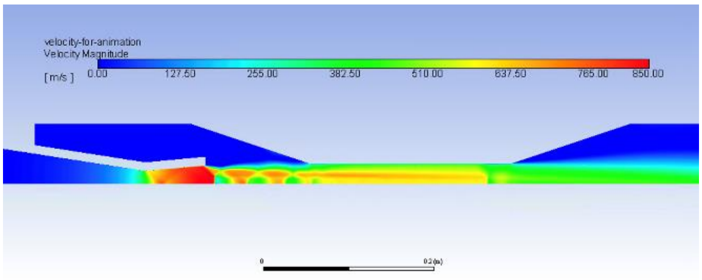


Figure 12: Velocity field from a 2D axisymmetric one-phase CFD simulation.

According to the models for the final design, the geoejector achieves the required back pressure of the steam gathering system of the power plant (9.5 bar-g) and a minimum of 29 bar-g inlet pressure is required from the primary flow. However, 30 bar-g is desirable to account for uncertainties.

The one-phase CFD model predicts that the nozzle can draw about 0.5 kg/s of steam from Well THG-15, with 30 bar-a primary pressure, 7.5 bar-a secondary pressure and 10.5 bar-a back pressure and 3 kg/s from well ThG-11.

6. CONCLUSION

This paper summarizes the scope and the initial results from the GeoEjector project. The aim of the project is to study whether high-pressure (primary flow) and low-pressure (secondary flow) geothermal wells can be connected using an ejector to induce the pressure of the fluid from the low pressure well to the working conditions of the plant.

A rudimentary ejector was installed at Theistareykir power plant, which delivered induced pressure under the conditions that it was tested for. However, the downstream pressure was kept lower than needed for the operation conditions of the plant. It is therefore important to upgrade the system to deliver higher induced pressure that could support the operation conditions of the plant.

An analytical model was developed that can predict the performance of the ejector. This is a valuable tool for the design phase of the geoejector.

CFD simulation is an important tool for predicting the flow behaviour of the geoejector system and can give valuable information about its performance. Measurement data for geoejector flow are essential for model validation.

Laboratory tests and further field tests are planned to gather more information about the geoejector flow.

If successful, the geoejector has a potential to increase the power output of the plant substantially.

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