Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Ósabotnar Geothermal System, SW Iceland: Low-Temperature Geothermal Exploration and Utilization for District Heating in Árborg

Heimir Ingimarsson[1)], Helga Tulinius[1)], Thórólfur H. Hafstað[1)], Gudni Axelsson[1)] and Sigurdur Th. Haraldsson[2)]

1) ÍSOR, Iceland GeoSurvey, Grensásvegur 9, 108 Reykjavik, Iceland

2) / Selfossveitur, Austurvegur 2, 800 Selfoss, Iceland

heimir.ingimarsson@isor.is

Keywords: Ósabotnar, geothermal exploration, geothermal utilization, reservoir assessment, district heating, Árborg

ABSTRACT

The paper presents and describes the exploration and utilization of the Ósabotnar low-temperature system. Following geothermal exploration at Laugabakki in Ölfus, which indicated that the highest heat anomaly was below or east of Ölfusá, the area in Ósabotnar north of Selfoss was studied extensively by drilling exploration wells. Production drilling then began in 2000 when well ÓS-1 was drilled to address the potential decline in energy due to a decline in the output from wells in the Thorleifskot-Laugardælur low-temperature system. Since then, three more production wells have been drilled, wells ÓS-2 in 2007, ÓS-3 in 2013 and ÓS-4 in 2019. The latest well ÓS-4 was completed in January 2019 and is the deepest well in Ósabotnar with a total depth of 2429 m. The well was drilled to meet the growing demand of geothermal water for house heating in Árborg and to explore the geothermal system to greater depth. The drilling was very successful as the well intercepted permeable fractures down to the depth of 2300 m. Temperature profiles in the well indicates that reservoir temperature of 105-110°C can be reached below 1700 m depth. The Ósabotnar reservoir has a temperature of 90-100°C at 1000m depth. Imaging with acoustic televiewer in the well shows that convection of water is mainly in northeasterly striking fractures. Well test analysis indicates that the reservoir has a constant pressure boundary, homogeneous porosity and constant well skin. The permeability in the reservoir is quite large and model calculation indicate that it is possible to increase the production in the area.

1. INTRODUCTION

Geothermal energy plays an important role in Iceland and has been produced on commercial scale for space heating since 1928 and for electricity since 1969. About 90% of the space heating energy is supplied by geothermal energy (Axelsson et al., 2010b). The country is rich in geothermal resources and encompasses high temperature magmatic geothermal systems (>200°C) as well as low temperature systems (<150°C). The main difference between high temperature and low temperature fields in Iceland is reflected in geological and tectonic settings and physical properties. The largest low-temperature systems are located in SW-Iceland on the flanks of the volcanic zone, but smaller systems are found throughout the country. The surface manifestations of the low-temperature activity are in most cases hot or boiling springs, while a few such systems have no surface manifestations.

The low temperature geothermal systems are almost all outside the axial rift-zone though some can be found within the rift-zones. Normally their reservoirs are fault and fracture dominated in otherwise low-permeable basaltic rocks or hyaloclastites. The heat is extracted from the relatively high background temperature gradient by convection in permeable faults and fractures (Flóvenz & Sæmundsson, 1993).

The Ósabotnar geothermal field is one of many low-temperature geothermal areas in Iceland situated outside the volcanic zone which passes through Iceland. It is used by the Selfoss district heating company (Selfossveitur) to provide geothermal energy for space heating for the municipality of Árborg. The municipality of Árborg encompasses the towns of Selfoss, Eyrarbakki and Stokkseyri as well as the surrounding rural areas. In recent years there has been a lot of development in Selfoss because of rapid population growth in the municipality. Population in the municipality today is about 10,000. Therefore, the municipality is facing an increased demand for geothermal water for space heating. One of the option for obtaining more geothermal water in recent years were drilling of new production wells in the Ósabotnar geothermal field. The Thorleifskot-Laugardælir system has been utilized by Selfossveitur since 1948, and currently the average yearly production is 70-80 l/s. The geothermal system is a few kilometers east of the town of Selfoss (Axelsson et al., 2010a).

2. THE ÓSABOTNAR GEOTHERMAL SYSTEM

2.1 General

The Ósabotnar geothermal field is located in SW-Iceland, on the east bank of the river Ölfusá about 4 km north of the town of Selfoss. Selfossveitur, the Selfoss district company utilizes the Ósabotnar geothermal system for district heating along with the Thorleifskot-Laugardælir low temperature system and Selfoss geothermal system (Figure 1). Following geothermal exploration at Laugabakki in Ölfus, which indicated that the most pronounced geothermal anomaly was below or east of Ölfusá, the area in Ósabotnar north of Selfoss was studied extensively by drilling several exploration wells in 1995 and 2000. Exploration resulted in drilling of the first production well ÓS-1 in 2000. Well ÓS-1 was drilled to address the potential decline in available energy due to a decline in the output from wells in the Thorleifskot-Laugardælur low-temperature system. After the earthquakes in 2000 and 2008, cold water inflow from shallow, open fractures within the seismic zone in Thorleifskot-Laugardælir lowered the temperature of the extracted fluids. Three more production wells have since been drilled in the Ósabotnar area.

Production from the Ósabotnar field started in early 2002 and the water was mixed with waters from production wells in the Thorleifskot and Laugardaelir fields. Soon, scaling problems were encountered in the central pump station where calcite was deposited in the pumps that feed the distribution system. Calculations showed that a mixture of the two water types, although rather similar in composition, became more supersaturated with respect to calcite than water from individual wells. To respond to this problem, experiments were performed in 2003 where water from the Ósabotnar well was acidified with sulfuric acid to lower the pH value before mixing with waters from Þorleifskot-Laugardælir (Ólafsson et al., 2005). Results of this experiment were promising and this method has since been used.

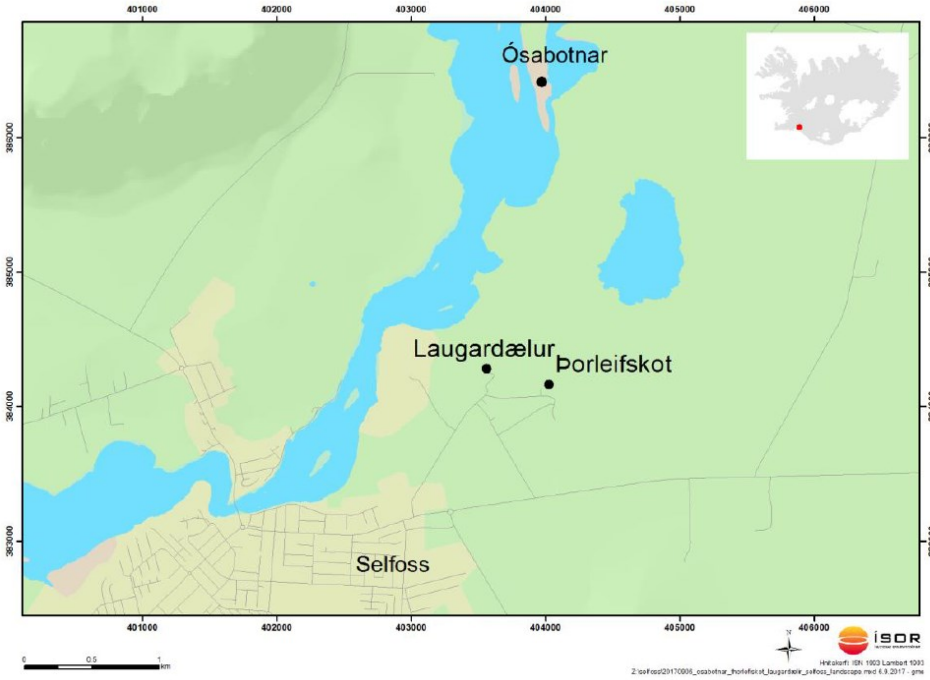

Figure 1: Location of Ósabotnar and Þorleifskot-Laugardælir geothermal fields.

2.2 Production wells in Ósabotnar

The four production wells in Ósabotnar geothermal field are ÓS-1, ÓS-2, ÓS-3 and ÓS-4 and were all drilled to address the growing demand for more geothermal water for the municipality of Árborg (see location of these wells in figure 2). All the wells are productive. The drilling of the latest well, ÓS-4, was finished in January 2019 and it is the deepest of the four and in fact one of the deepest low-temperature wells in Iceland. Further coverage of the well, drilling and step-test can be seen in the last chapter.

- *Well ÓS-1*. Drilling of well ÓS-1 began in late 2000 and was finished in January 2001 at a depth of 804 m. It is lined with a 10¾" casing to 150 m depth, and all colder water feed zones above 360 m depth in the well were cemented. It was clear the well was very productive immediately at the end of drilling.
- *Well ÓS-2.* Was drilled in the summer of 2007 to a depth of 1722 m. It is lined with a 14" production casing to 412 m. Because of loose strata, which were a problem during drilling, the well was lined with a 10¾" hanging casing from 364 m down to 472 m depth. Testing of the well at the end of drilling showed further collapse in the well which also proved necessary to case off. Therefore, an 8" perforated liner was placed from 354 m depth down to 550 m.
- *Well ÓS-3.* Was drilled in 2013 to a depth of 1500 m. It is lined with 14" production casing to 470 m. Originally it was planned to drill down to a depth of 1700-2000 m but drilling was stopped at 1500 m as it was clear that sufficient flow of water had been obtained from the well.
- *Well ÓS-4.* Drilling was completed in January 2019 and is the deepest well in Ósabotnar with a total depth of 2429 m. It is lined with a 14" production casing to 458 m depth. Further coverage of the well, drilling and step-test can be seen in the last chapter.

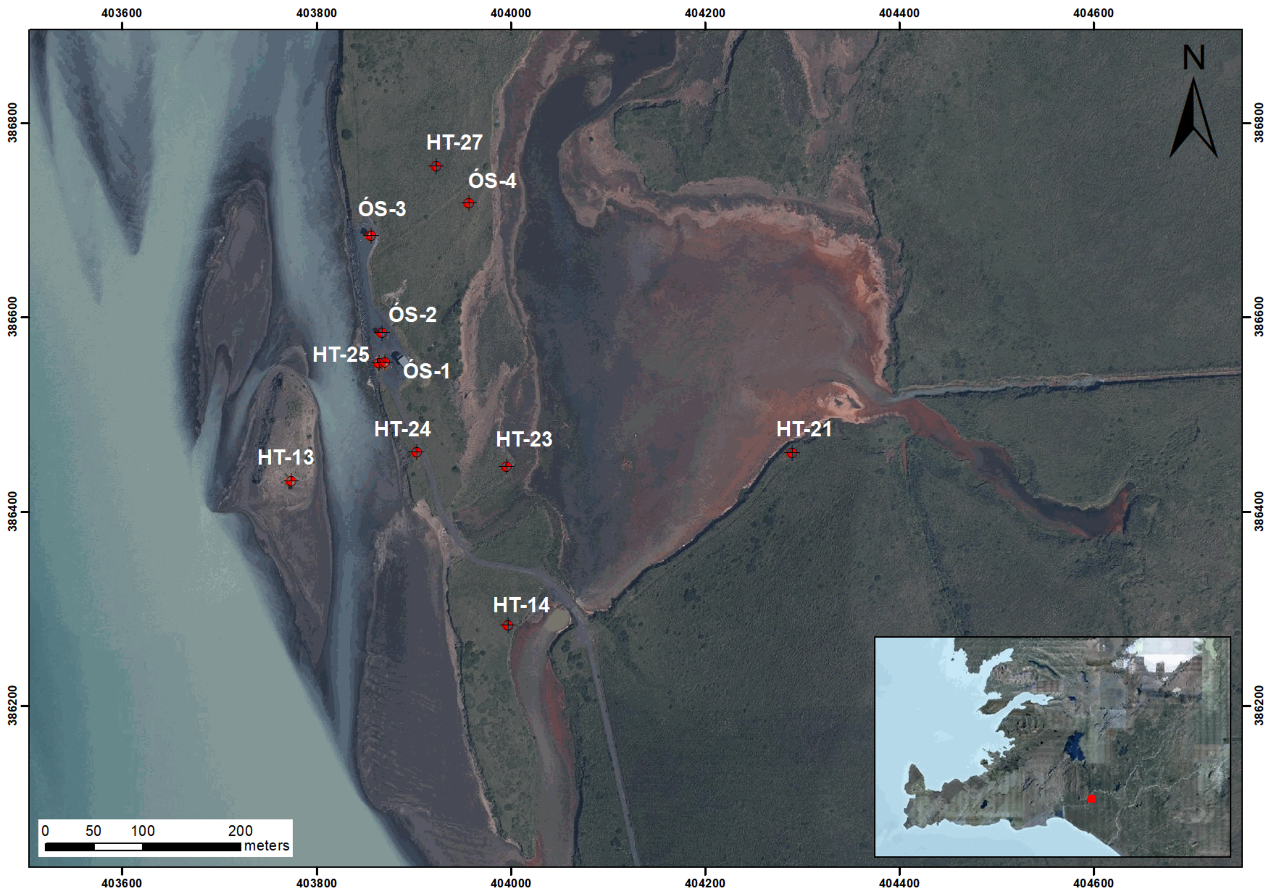

Figure 2: Location of production and exploration wells in Ósabotnar geothermal field.

2.3 Geology and reservoir features

The Ósabotnar system is inside the South Iceland Seismic Zone and is highly permeable. The geothermal system is liquid-dominated reservoir and is fracture-controlled with the main upflow appearing to be associated with northeasterly trending faults or fractures. At shallow depth there are many open fractures which allow cold inflow and cause cooling in the system. Therefore, deeper casings are necessary compared to some other low-temperature geothermal fields in Iceland (Xianghui, 2012). The tectonic origin of the permeable fractures is not always clear. In some cases, they are linked to the shear zones of the transform faults between rift segments like in the South Iceland Seismic Zone. There have also been speculations that the geothermal system in Ósabotnar might be linked to the Grímsnes fissure swarm. This swarm is spatially related to the Grímsnes volcanics, a group of small lava eruptions issuing from about 10 separate vents and short fissures. The southern part of the fissure swarm partly overlaps with the adjacent South Iceland Seismic Zone, which is distinguished from the Grímsnes fissure swarm by its strike-slip features (Hjartardóttir et al., 2016).

The lithological strata in the geothermal system consists of sequence of dominant basaltic lava flows. The lava flows are intercalated by various thin interbeds, consisting of siltstone, sandstone and breccia, which mark periods of volcanic hiatus. The post-glacial Þjórsá lavas form the topmost formation in the area and contains cold groundwater system. Above 300 m depth there is a 150-200 m thick sequence of hyaloclastite formation. Thinner hyaloclastite formations can also be seen in the deeper parts from 800 to 1400 m depth (Snæbjörnsdóttir, 2009; Hafstað and Gunnarsdóttir, 2014).

Two stages of alteration are observed, an older high-temperature alteration where epidote minerals are abundant (alteration temperature 250°C) and younger alteration of a cooling geothermal system where laumontite (alteration temperature 120°C) has overprinted the epidote crystals. Laumintite can be found to a depth of 2400 m in the system (Snæbjörnsdóttir, 2009, Ingimarsson et al., 2019).

Temperature profile of the deepest production well ÓS-4 indicates that reservoir temperature of 105-110°C can be reached below 1700 m depth. The Ósabotnar reservoir has a temperature of 90-100°C at 1000m depth (Figure 3). Imaging with acoustic televiewer in the well shows that convection of water is mainly in northeasterly striking fractures.

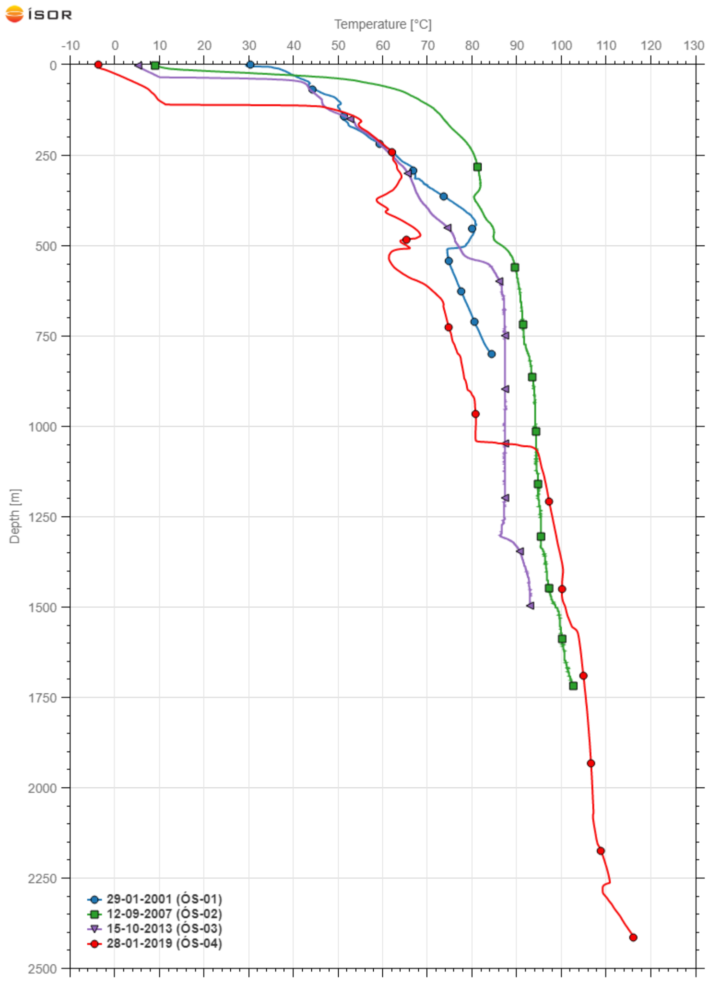

Figure 3: Temperature profiles in production wells ÓS-1, ÓS-2, ÓS-3 and ÓS-4.

3. RESERVOIR ASSESSMENT

3.1 General

Many methods have been used during the last several decades to assess geothermal reservoirs, during both exploration and exploitation phases. Different geothermal models play essential roles in geothermal resource development and management. The most important purpose of a geothermal model is to obtain information on a geothermal reservoir as well as on the nature and properties of the system. Because of its many benefits, including time and cost effectiveness, high precision and their basis being easily grasped, lumped parameter models have been used extensively to simulate data on pressure (water-level) changes in geothermal systems in Iceland as well as in many other countries and regions like China, Central America, Eastern Europe, The Philippines and Turkey. They can simulate such data very accurately if the data is sufficient (Axelsson et al., 2005). Also, through modelling, one can predict the response of the reservoir several years ahead and evaluate the production potential of the system in question (Xianghui, 2012).

3.2 Previous modelling

An assessment, aimed to assess the capacity of the geothermal system in Ósabotnar, was made in the early years of exploitation of Ósabotnar as a production field (Axelsson and Ólafsson, 2006). It was based mainly on the examination of changes in water levels in wells ÓS-1 and HT-24 which was then used for forecasts of water level changes for different production scenarios. Well HT-24 is located 100 m south of well ÓS-1 (Figure 2) and mainly used for observing the water-level in the system. The main conclusion of the prediction calculations was that the Ósabotnar geothermal system would most likely support three production wells with a total average production of up to 100 l/s and maximum production during winter about 50% above the average production. Water-level forecasts indicated that such production would result in a drawdown of 200 m after 30 years of continuous production (Figure 4). The initial water-level was -8 m (8 m below surface) at the beginning of production (Tulinius et al., 2016; Xianghui, 2012).

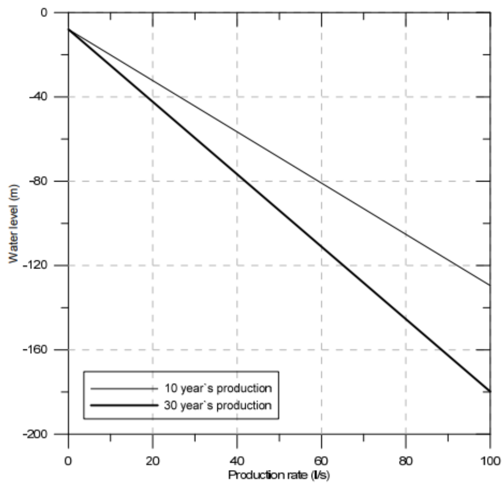

Figure 4: Water level forecasts for the geothermal system in Ósabotnar according to an early modelling study based on well ÓS-1 only (Axelsson and Ólafsson, 2006).

Another assessment was done in 2012 to evaluate the capacity of the geothermal system on the basis of production data that had been collected since 2005. In addition, detailed data were collected separately in 2011. Both two-tank open and three-tank closed lumped models were used to simulate the monitored production data and pressure. The two models were also used to predict different production scenarios. The results from a well test that was done on well ÓS-2 indicated that the reservoir has a constant pressure boundary, homogenous porosity and constant well skin. The results also showed that the potential of the Ósabotnar geothermal system was promising and could provide more thermal water than was being extracted at that time, when the average production was 45 l/s (Axelsson and Halldórsdóttir, 2012; Xianghui, 2012; Tulinius et al., 2016).

3.3 Modelling 2016

An extensive reservoir modelling was done in 2016 for the geothermal system in Ósabotnar (Tulinius et al., 2016). The modelling program LUMPFIT was used to simulate the water-level in observation well HT-24 based on total production rates from the production wells (Axelsson and Halldórsdóttir, 2012). This program solves the simulation problem as an inverse problem and will automatically fit the analytical response functions of lumped models to the observed data by using a nonlinear iterative least-squares technique for estimating the model parameters (Axelsson, 1989).

Both open and closed two-tank models were eventually used to predict changes in water level in the geothermal system during different production. Although the open model is more likely to resemble the reservoir, predictions based on both models were made to get a sense of the range of changes in water-level and uncertainty. The two-tank closed model is far more pessimistic than the open one. Water level changes were predicted in well HT-24 for 45, 60 and 80 l/s average production from the reservoir. Results are shown in figures 5 and 6. As can be seen in the figures, the water level lowers much faster according to the closed model than the open one. Accordingly, the water level will lower steadily according to all predictions, and will be at 80 m depth in well HT-24 in 2033 if average production increases to 80 l/s. In contrast, predictions of the open model show that the water level will reach equilibrium in two to four years in all three predictions.

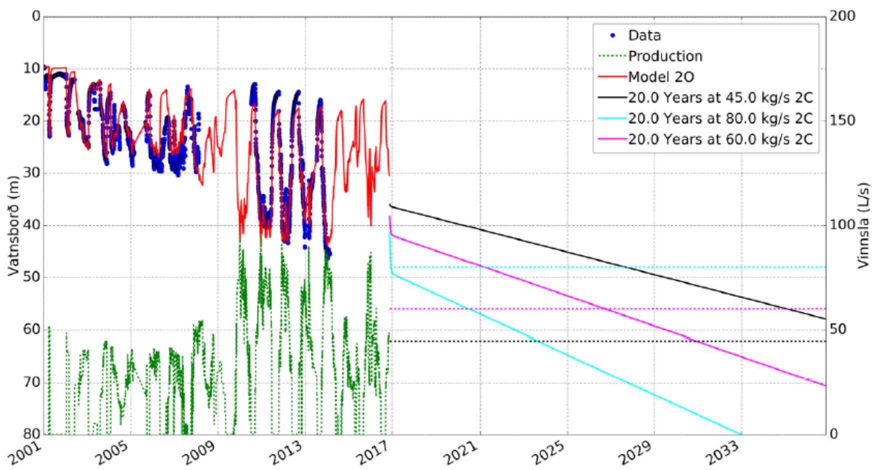

Figure 5: Closed two-tank model predictions of water level changes in well HT-24 for 45, 60 and 80 L/s average production (Tulinius et al., 2016).

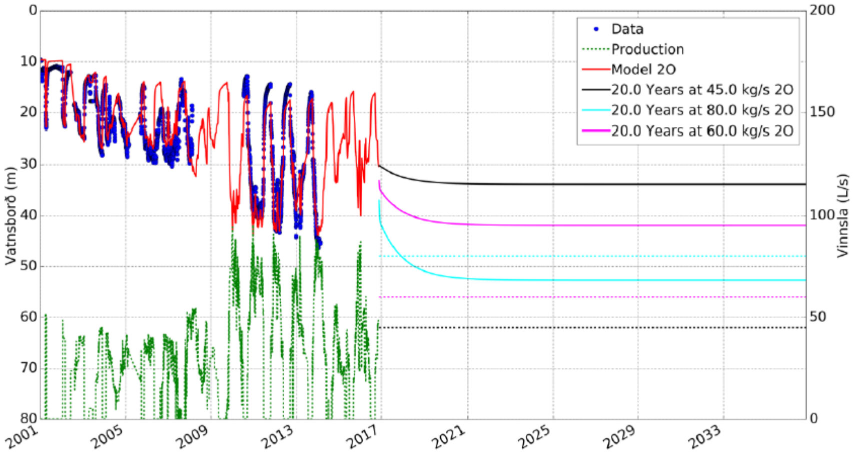

Figure 6: Open two-tank model predictions of water level changes in well HT-24 for 45, 60 and 80 l/s average production (Tulinius et al., 2016)

The permeability values that were obtained in the newest assessment are very similar to values from previous assessments, 40–46 mDarcy, for a two-tank closed and open model. The permeability in the geothermal system is quite high compared to what is common in geothermal systems in Iceland. The reason for that is most likely because it is situated in a very active seismic zone. Furthermore, the water storage capacity of the system is so high that it cannot be explained solely by the compressibility of water and rock in the geothermal system, as is often the case, but the water capacity is also likely to be controlled by the mobility of free water level in the water system. It causes slower long-term drawdown but could otherwise indicate an easier connection to shallower and colder groundwater systems above.

Main results indicated that production from the system can be increased. It is likely the area can sustain up to 80 l/s annual average production, or more, but it is necessary to increase the production in moderate steps. It was recommended that the maximum production over the coldest months should be distributed on all the production wells. It should be kept in mind that the highest turbulence pressure drop is in well ÓS-2 resulting in more drawdown of the water table compared to well ÓS-1 during similar production from each well. It is expected the drawdown in well ÓS-3 is less, although data was limited when the model was done.

3.4 WELL ÓS-4

The latest well ÓS-4 was completed in January 2019 and is the deepest well in Ósabotnar with a total depth of 2429 m. The well was drilled to meet the growing demand of geothermal water for house heating in Árborg and to explore the geothermal system to greater depth. It is lined with 14" production casing to 458 m depth. Below the casing the well was drilled with a 12¼" drillbit down to 1386 m depth, 9⅞" drillbit to 1854 m depth and then 8½" drillbit to 2429 m. Below the casing the well, aerated drilling was used meaning it was carried out with a fluid mixture made up of water-air or water-air-foam. The main objective of this operation was to achieve return of circulation to the surface, preventing the accumulation of the cuttings in the production or reservoir zones.

Originally it was planned to drill the well near well ÓS-1 and replace it as a production well with deeper and wider casing. The production casing in well ÓS-1 extends down to 150 m depth and is only 10¾" wide. Those plans were postponed where it was considered unwise to drill so close to the production wells ÓS-1 and ÓS-2 at winter time when there is higher demand for geothermal water. Pumps in the wells would have to be switched off at some point while drilling the new well. Instead, the northern part of the geothermal field was investigated further with the possibility of placing a production well there. Exploration well HT-27 was drilled in the summer of 2018 about 100 m northeast of well ÓS-3, down to a depth of 358 m (see location on figure 2). It was drilled to reveal how thermal gradient was in the bedrock in the northern part of the area as well as to measure the strike and dip of fractures in the well with borehole acoustic televiewer imaging. The televiewer results showed prevailing northnortheasterly to northeasterly striking fractures with dipping to southeast and northwest. In the top part of the well, the fractures generally dip to southeast but dipping to northwest becomes more prevalent in the deeper part of the well. The main water bearing fractures in well HT-27 were dipping to southeast. With all that information considered, well ÓS-4 was placed about 50 m southeast of well HT-27 (Ingimarsson et al., 2018).

The drilling of well ÓS-4 was very successful as the well intercepted permeable fractures down to the depth of 2300 m. The purpose of drilling so deep was to explore further into the geothermal system as temperature profiles in wells ÓS-2 og ÓS-3 had indicated that convection of heat flow could extend further down. It is now clear that the reservoir thickness is much bigger than previously anticipated.

Seven temperature logs were conducted in the well while drilling (Figure 7). Measure of temperature profiles in the well indicate that reservoir temperature of 105-110°C can be reached from 1700 m down to 2300 m depth. Below that depth, heat conduction is most likely dominant in the well. Major feed zones can be observed at 1050-1100 m, 1400-1600 m and 2250-2300 m depth. That fits well with drilling reports as total loss of circulation happened at these depth intervals while drilling.

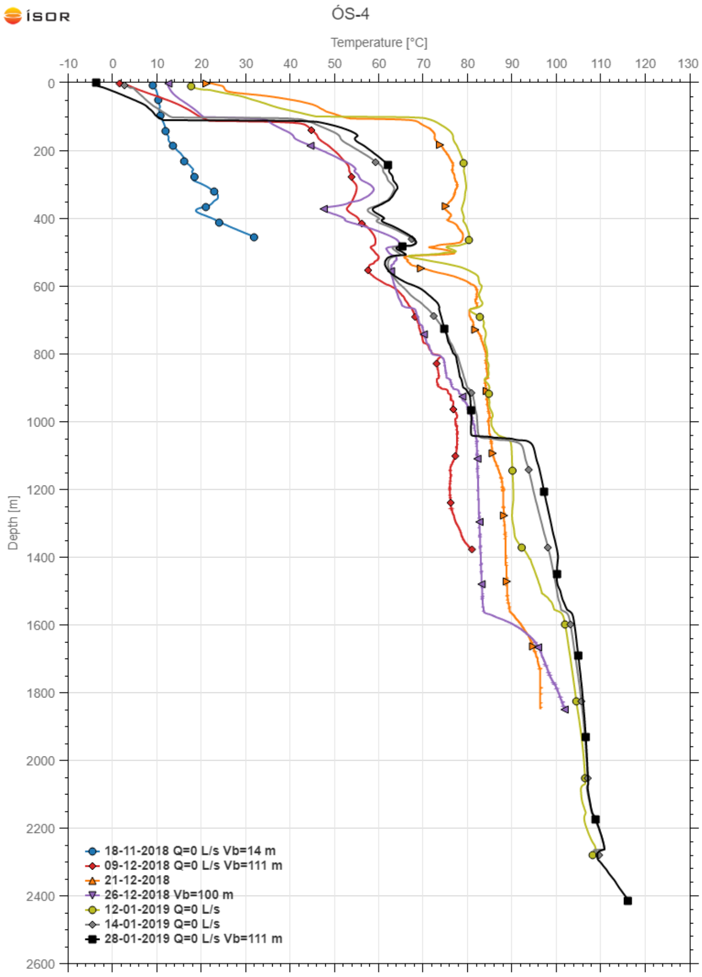

Figure 7: Temperature profiles in well ÓS-4.

At the end of drilling well ÓS-4, a short airlift pumping test was conducted in the well. Airlift pumping test is a relatively fast, simple and accurate method of obtaining information about the drawdown of water-level with different pumping rates. The static water level in the reservoir was at 100-110 m depth while the well was being drilled from late October to late January. These months were very cold so production of geothermal water from the system was around 80-90 l/s from the other wells while well ÓS-4 was being drilled. It is a good indicator that it didn´t come to a point of reducing or stopping production from the area while drilling. Results from the pumping test (Figure 8) show that the well is very productive. Pumping rates of 90-100 l/s resulted in a drawdown of water level in the well from 100 m to 180 m depth. Estimated turbulence pressure index in the well is 0,0093 m/(l/s)^2. This clearly shows that the well is highly productive and, in many ways, resembles well ÓS-3 regarding well efficiency (Hafstað and Gunnarsdóttir, 2014). It should be kept in mind though that this was only a short pumping test and the plan is to do a long term pumping test on the well later to see how the reservoir reacts to increased production and the relationship between all the production wells (Ingimarsson, 2019).

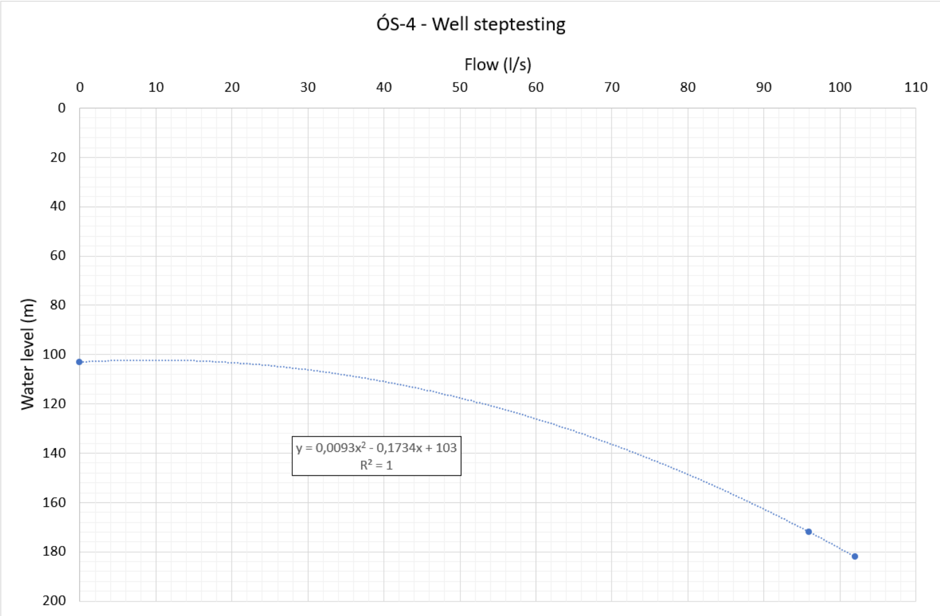

Figure 8: Step drawdown test showing the relationship between pumping rates and water level.

4. CONCLUSIONS

- Exploration in Ósabotnar resulted in drilling of the first production well ÓS-1 in 2000. Since then, three other production wells have been drilled, wells ÓS-2 in 2007, ÓS-3 in 2013 and ÓS-4 in 2019. The four production wells were all drilled to address the growing demand for more geothermal water for the municipality of Árborg.
- The Ósabotnar geothermal system is inside the South Iceland Seismic Zone and is highly permeable. The geothermal system is liquid-dominated reservoir and is fracture-controlled with the main upflow appearing to be associated with northeasterly trending faults or fractures.
- An extensive reservoir modelling was done in 2016 for the geothermal system in Ósabotnar. Both open and closed two-tank models were eventually used to predict changes in water level in the geothermal system during different production. Main results indicated that production from the system can be increased. It is likely the area can sustain up to 80 l/s annual average production. The water level lowers much faster according to the closed model than the open one.
- The drilling of the latest well ÓS-4 was completed in January 2019 at a depth of 2429 m and is one of the deepest low-temperature well in Iceland. The drilling of the well was very successful as the well intercepted permeable fractures down to the depth of 2300 m. Measure of temperature profiles in the well indicate that reservoir temperature of 105-110°C can be reached from 1700 m down to 2300 m depth. Results from a short-term pumping test show that the well is very productive. Pumping rates of 90-100 l/s resulted in a drawdown of water level in the well from 100 m to 180 m depth.

REFERENCES

Axelsson, G.: Simulation of pressure response data from a geothermal reservoir by lumped parameter models. Proceedings of the 14th Workshop on Geothermal Reservoir Engineering, Stanford University, California, (1989), 257-263

Axelsson, G., Björnsson, G., and Quijano, J.: Reliability of lumped parameter modelling of pressure changes in geothermal reservoirs. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey, (2005), 8 pp.

Axelsson, G., Gunnlaugsson, E., Jónasson, Th., and Ólafsson, M.: Low-temperature geothermal utilization in Iceland – Decades of experience. *Geothermics,* **39**, (2010a), 329-338.

Axelsson, G., Jónasson, Th., Ólafsson, M., Egilson, Th., and Ragnarsson, A.: Successful utilization of low-temperature geothermal resources in Iceland for district heating for 80 years. Proceedings of the World Geothermal Congress 2010, Bali, Indonesia, (2010), 6 pp.

Axelsson, G., and Halldórsdóttir, S.: *Staða orkuvinnslu Selfossveitna á jarðhitasvæðunum í Þorleifskoti og Ósabotnum í byrjun árs 2012.* ÍSOR-12001, (2012), 8p.

Flóvenz, Ó.G., Sæmundsson, K.: Heat flow and geothermal processes in Iceland. *Tectonophysics,* **225**, (1993), 123-138.

Hafstað, Th.H. and Gunnarsdóttir, S.H.: *Ósabotnar – Hola ÓS-3. Borun og afkastamat.* ÍSOR-2014/027, (2014), 8p + appendixes.

Hjaltardóttir, Á.R., Einarsson, P. and Björgvinsdóttir, S.G.: Fissure swarms and fracture systems within the Western Volcanic Zone, Iceland – Effects of spreading rates. *Journal of Structural Geology*, **91,** (2016), 39-53.

Ingimarsson, H., Hafstað, Th.H., and Erlendsson, Ö.: *Hola ÓS-4 í Ósabotnum. Tillaga að staðsetningu á norðausturhluta svæðsins.* ÍSOR-18050, (2018), 14p.

Ingimarsson, H., Hafstað, Th. H., and Sigurgeirsson, M.Á.: *Ósabotnar – Stóra-Ármót. Hola ÓS-4 – Borun, mælingar og jarðfræði.* ÍSOR-2019/XXX, (2019), unpublished.

Ólafsson, M., Hauksdóttir, S., Thórhallsson, S., and Snorrason, Th., 2005: Calcite Scaling at Selfossveitur hitaveita, S-Iceland when mixing waters of different chemical composition. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey, 6 pp.

Snæbjörnsdóttir, S.Ó.: *Jarðlög og ummyndun í holu ÓS-2 við Ósabotna norðan Selfoss. BS-verkefni við Háskóla Íslands*. ÍSOR-2009/015, (2009), 42p.

Tulinius, H., Halldórsdóttir, S. and Axelsson, G.: *Ósabotnar. Úttekt á forðafræði jarðhitasvæðisins og einföld líkangerð.* ÍSOR-2016/094, (2016), 29 p.

Xianghui, W.: Reservoir assessment of the Ósabotnar low-temperature geothermal field, SW-Iceland. *UNU Geothermal programme. Report 38,* Reykjavik, Iceland, (2012), 987-1008.