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

Numerical Modelling of the Hveragerði High-Temperature Field

Ragna Björk Bragadóttir[a,b*], Einar Jón Ásbjörnsson[b] and Gunnar Gunnarsson[a]

[a] Reykjavík Energy, Bæjarháls 1, 110 Reykjavík, Iceland

[b] Reykjavík University, Menntavegur 1, 101 Reykjavík, Iceland

* ragna.bjork.bragadottir@or.is

Keywords: high temperature fields, numerical modelling, geothermal utilisation, production history, district heating

ABSTRACT

The Hveragerði high-temperature geothermal field is located on the eastern margin of the Western Rift Zone and on the western end of the South Icelandic Seismic Zone. Located 40 km South-East of Reykjavík, Iceland and east of the Hengill Area, where the Hellisheidi and Nesjavellir geothermal power plants are located. The Hveragerði municipality district heating utility is one of the first district heating utility in Iceland, established in 1952. However, the geothermal field has been used for district heating since the early 1920s. Today the need for stable thermal power has increased due to the rapid population growth in and around the Hveragerði municipality. Reykjavík Energy and Veitur Utilities have high service standards set for district heating, in order to sustain that standard a better understanding on the Hveragerði geothermal field is needed. A better understanding can lead to a more economic and sustainable thermal power production.

A numerical model was developed using TOUGH2. Available data was collected, and formation temperatures of wells were estimated using well temperature measurements. The formation temperatures were used to calibrate the numerical model. Little data is available on the production from the field; thus, the production was estimated using the population growth and the building types and sizes. The calculated formation temperatures and the estimated formation temperatures show a good match. The production simulation shows that the production results in little drawdown in the field. These results indicate that more could be produced from the field, without compromising sustainability.

1. INTRODUCTION

The Hveragerði geothermal field is located about 40 km south east of Reykjavík, in southern Iceland. It is the easternmost geothermal field in the Hengill geothermal area, which is located on the eastern margin of the Western Volcanic Zone (WVZ) and on the Western end of the South Icelandic Seismic Zone (SISZ) (figure 1) (Geirsson & Arnórsson, 1995, Barja et al., 2015). The landscape surrounding Hveragerði is characterized by fumaroles in the northern part of the field, and hot springs in the southern part.

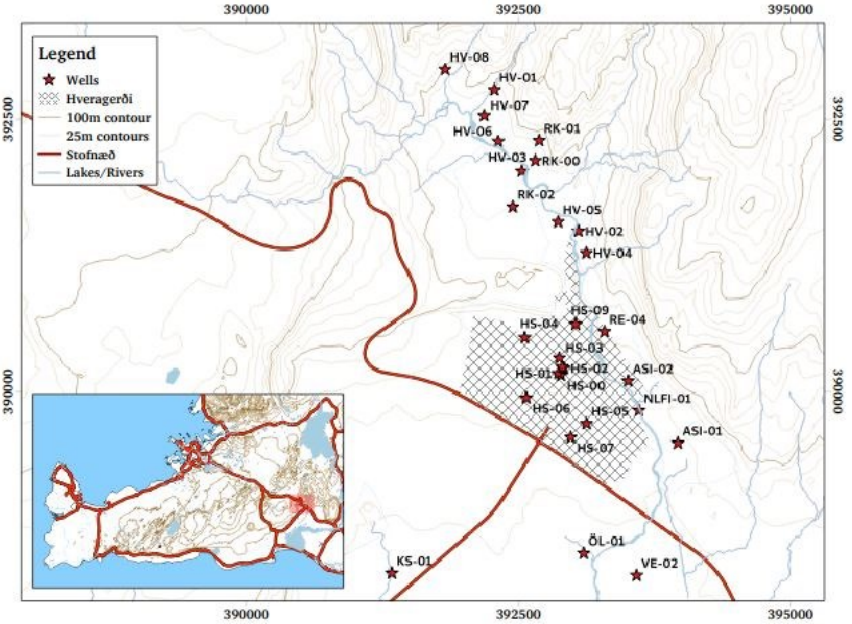

Figure 1: A map of the Hveragerði area showing well locations and names, elevation contours, the main highway as well as lakes and rivers. The inset show the location of the area in SW-Iceland

The first geothermal heated greenhouses were built in Hveragerði in 1929. Following that, experiments using geothermal energy to heat up residential homes began (Barja et al., 2015). Hot water was led from thermal pools and hot springs in primitive pipelines or wooden channels to a cistern that was located at each home. Inside the cistern was a radiator with fresh water that was heated up and circulated through the radiators in each home (Sæmundsson, 1969, Barja et al., 2015). As the population grew, demand for an effective district heating system arose and before 1944 more than 15 shallow wells had been drilled in the Hveragerði field (Sæmundsson, 1969, Jónasson, 2008). Hveragerði became a municipality on January 1st, 1946 (Jónasson, 2008). The first publicly owned well was drilled in 1946 and in 1952 the Hveragerði district heating utility was established, becoming the first district heating utility in Iceland to utilize high-temperature geothermal energy for district heating (Sæmundsson, 1969, Barja et al., 2015). The wells owned by the Hveragerði district heating utility are named HS-wells. HV-wells were drilled later by the State in order to construct a 15 - 35 MWe geothermal power plant, however, the plant was never built (Barja et al., 2015, Þórhallson, 2015). Figure 1 shows the location and the names of a few of the wells located in the Hveragerði geothermal field.

There are three different types of district heating systems in Hveragerði; a direct system, a double closed loop system and a steam system. Then there are privately owned wells that are also in use (Sæmundsson, 1969). In the simple direct system geothermal water is led in pipes directly to each user, which then has a small heat exchanger that heats up fresh water for use in the building. Wells HV-03 and HV-04 are a part of this system. Then there are those who use their privately-owned wells for their personal heating. Those are the NLFÍ Rehabilitation and Health Clinic (well NLFÍ-01), the Icelandic Confederation of Labour in Ölfusborgir (well ASÍ-02), the Vellir farm (well VE-02), the Öxnalækur farm (well ÖL-01) and the Kröggólfsstaðir farm (well KS-01) (Ívarsson, 2013, Sveinbjörnsson, 2016). The eastern side of the town gets its water from a separate geothermal system east of Hveragerði, Gljúfrárholt.

The double closed loop system consists of the wells connected to the thermal energy production unit in Hveragerði, which is a closed circulation system where a heat exchanger is used to heat up cold ground water. This heated water is then sent to the users in Hveragerði for use before returning to the thermal station where the water is heated up again (Sæmundsson, 1969, Barja et al., 2015, Ívarsson, 2013). This system utilizes production wells HS-08 and HS-09. Figure 2 shows a simplified diagram of the thermal energy production unit. Fluid from wells HS-08 and HS-09 is used to heat up cold ground water to 89 °C, which is then distributed to the users of space heating and the returned back to the heat exchanger at ~36 °C. There the water is heated up again and cold ground water or hot water from Gljúfrárholt is added if needed (Ívarsson, 2013). A small part of the returning water is re-injected into well HS-08 for dilution and cooling of the well.

Finally, the steam system reaches most greenhouses and industries in Hveragerði. The temperature of the steam ranges from 150-170 °C (Reykjavík Energy, n.d.).

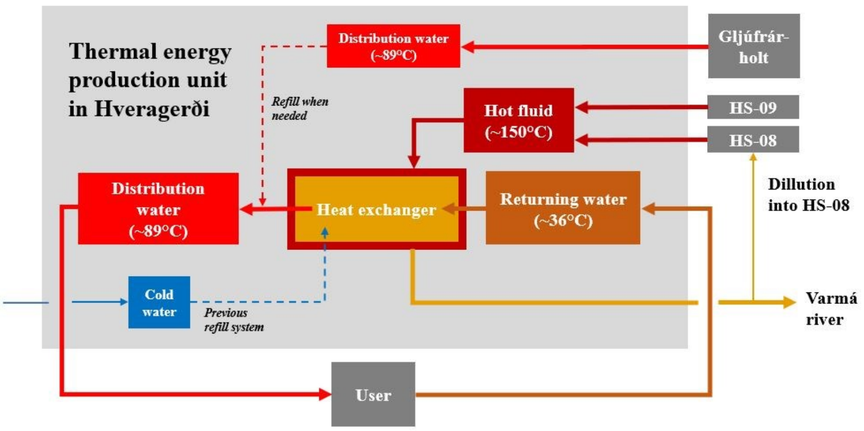

Figure 2: A simplified schematic of the thermal energy production unit in Hveragerði.

2. SITE DESCRIPTION

The Hveragerði geothermal field is widely considered as a high-temperature geothermal field, although the temperature ranges from 160-230 °C and does not quite fit the classic classification between high and low temperature fields (Arnórsson, 2015).

2.1 Geological and Tectonic setting

The geological configuration of the area is caused by the interaction between the active volcanism due to the plate boundary and over 20 periodically occurring glacial masses (Tómasson et al., 1975). Approximately 0.7 million years ago there was an active central volcano north of Hveragerði, called Grændalur volcano. It formed intrusions and dykes which resulted in the high temperature alteration in the area. Then during a glacial period, hundreds of meters of strata were removed from the top of the Grændalur volcano. This along with the shift of the volcanic activity to Hrómundatindur and then later to the Hengill area has resulted in diminishing geothermal activity in the Hveragerði field (Sæmundsson et al., 1972). The area is thus composed mostly of subglacial formed hyaloclastites, interglacial flows and surface deposits where the composition is mostly basaltic (Sæmundsson et al., 1972).

Three fracture trends have been measured in the area (Gonzalez-Garcia, 2011). Surface faults and fissures in NE-SW directions and inferred transform tectonics not visual from surface in NNE-SSW and ENE-WSW direction (Hersir et al., 2009). The largest earthquakes occur in structures associated with the SISZ, that is on the N-S lateral strike slip faults that are located roughly 2-5 km apart in the SISZ (Decriem, 2011). The most recent large earthquake was in 2008 where two earthquakes at an interval of 3 seconds with magnitudes of 5.8 and 5.9 on Richter scale were measured (Decriem, 2011). The impact of the 2008 earthquakes were thoroughly measured by the Icelandic GeoSurvey shortly after, and new faults and fractures were mapped in the Gufudalur valley. In Hveragerði, surface geothermal activity line up quite linearly in N-S direction which largely correlates with faults and fissures (Sæmundsson et al., 1972, Ívarsson et al., 2011). The location of surface manifestations could thus indicate the location of faults and fractures under the surface. Mapping of surface manifestations were conducted by Reykjavik Energy in 2007 to 2010 where the entire area was mapped and measured 2010-2013. In that report the calculated CO_2 and H_2S temperature indicates that the temperature in the field increases to the north (Ívarsson et al., 2011).

2.2 Geophysical and geochemical information

TEM resistivity measurements were performed in Ölfusdalur in 2000 by the National Energy Authority in Iceland. The resistivity structure indicates a high-temperature system, with a low resistivity cap and a resistive core. However, a middle layer that indicates chlorite demonstrates a temperature of 240 °C. Another possible explanation is that this middle layer is very permeable which would dominate in the resistivity measurements. These resistivity measurements also point out an epidote belt from 200-500 meters below sea level [mbsl.]. Well temperature measurements in that area show a temperature of 230 °C. Since an epidote belt indicates a temperature of over 250 °C it is clear the geothermal field in Ölfusdalur-Hveragerði is cooling down (Eysteinsson, 2000).

The Hveragerði geothermal field is characterized by hot springs rich of chlorine water. The water system indicates that the flow runs from the north (Geirsson and Arnórsson, 1995, Sæmundsson et al., 1972). The geothermal fluid in the system cools by mixing with cold groundwater of marine origin which has a high concentration chlorine and boron (Geirsson and Arnórsson, 1995, Sæmundsson et al., 1972). The geothermal steam in Hveragerði has low concentration of H_2 and H_2S and the gas geothermometry indicates that the temperature of the reservoir water increases to the north, where the estimated temperature is between 240-250 °C (Geirsson and Arnórsson, 1995). The higher dissolved solid content of the high-temperature resource causes clogging of wells and surface equipment (Sæmundsson, 1969, Barja et al., 2015).

3. CONCEPTUAL MODEL DEVELOPMENT

Previously, a conceptual model of Hveragerði was introduced by Geirsson and Arnórsson, 1995, focusing on geochemical data. Their research indicates that the reservoir water entering the geothermal field is between 240 °C and 250 °C. A cross section of Ölfusdalur was developed (figure 3) displaying the temperature distribution with depth for wells HV-01 to HV-07 (Geirsson and Arnórsson, 1995). In figure 3 the heat source is located in the northern part of the field resulting in the inverse shaped formation temperatures (Geirsson and Arnórsson, 1995). Apart from this figure, a conceptual model has not been developed for the study area.

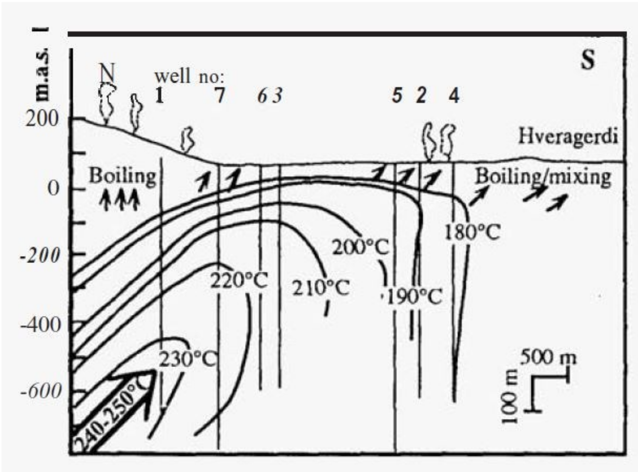

Figure 3: A conceptual model of Ölfusdalur and Hveragerði, showing a cross section of Ölfusdalur through wells HV-01 to HV-07 (Geirsson and Arnórsson, 1995).

3.1 Formation temperatures

Formation temperatures for wells HV-02, HV-06, HV-07 and HV-08 were available from the inhouse database of Reykjavík Energy (Reykjavík Energy, n.d.). Other formation temperatures in Hveragerði had not been estimated before. Using available downhole well temperature measurements, the following assumptions were made to estimate the formation temperatures (Björnsson & Steingrímsson, 1995):

- Surface temperature ranges from 5-15 °C, depending on the location of wells.
- Maximum temperature measured at the bottom of well is estimated as formation temperature.
- If temperature measurements are similar or the same during couple of measurements those temperatures are regarded as the formation temperature of that well.
- If only one temperature measurement is available, that measurement is considered as the formation temperature.

These assumptions as well as experience and instinct of the author were used to create formation temperatures for the remaining wells. The formation temperatures are always to be taken with caution and are open for review when new data is collected, or other assumptions can be made. Figure 4a shows estimated formation temperatures for all HV-wells. On the figure the inverse shape of the temperature curve is quite clear, where highest temperature is reached and then the well starts to cool down with dept. That indicates that there is a sideways flow rather than upward flow from the bottom.

4. NUMERICAL MODELLING

The structure setup of the numerical model is based on the information obtained about the reservoir as well as the formation temperatures. For this project a 2D grid using the AMESH Voronoi tessellation method is created. The shape of each element is defined by the closest points to the elements centre point, creating a honeycomb like structure (Haukwa, 1998). The grid refinement was split into five distances between centre points, doubling the distance with every step. The finest one is around the wells with 200 m intervals and the points on the edges are located 3200 m apart.

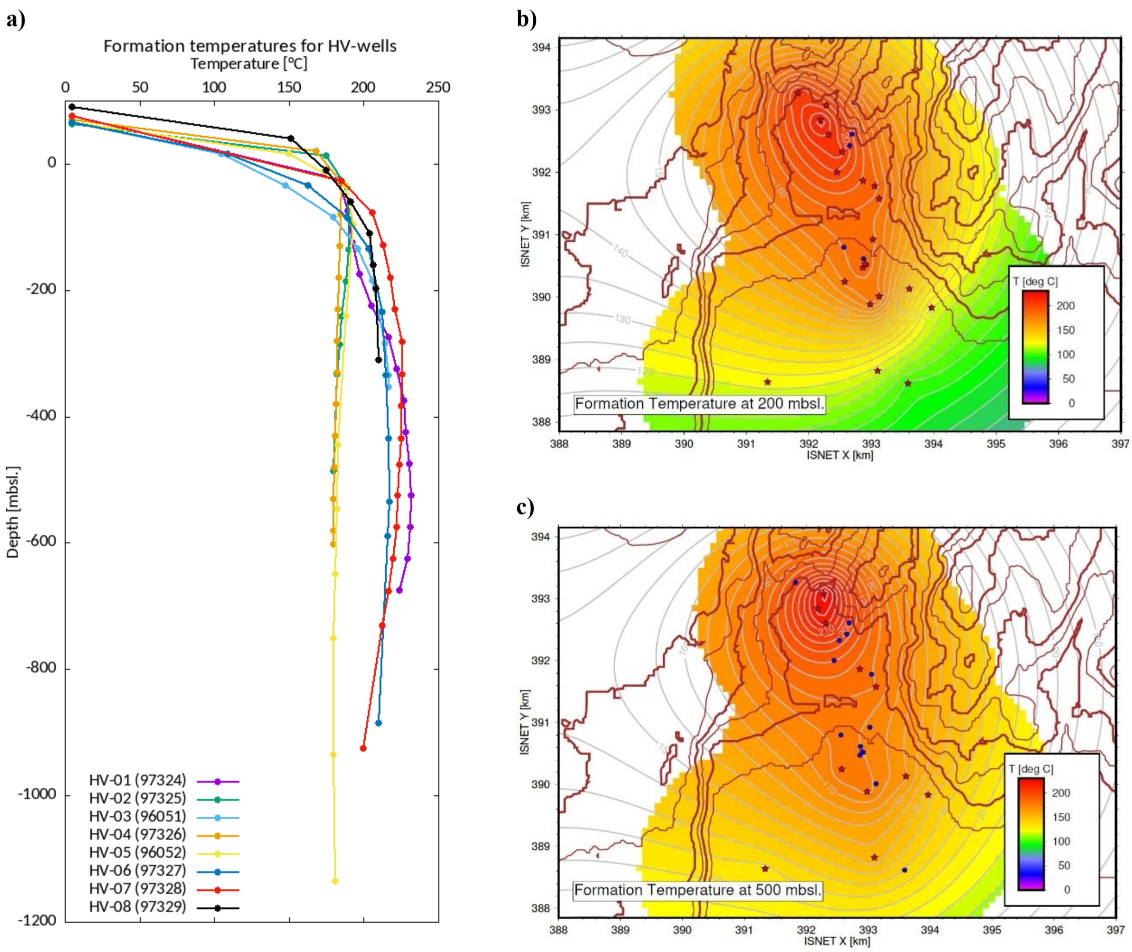

Figure 4: a) Estimated formation temperatures for all HV-wells. Estimated temperature distribution with depth b) 200 mbsl. and c) 500 mbsl.

The model has 11 layers, labelled from A to K and each layer consists of 2851 elements. Each element is named according to the TOUGH2 naming convention. The thickness of the layer varies where the layers near the surface are thinner than the layers near the bottom. All in all, the model has 31,361 elements and 121,614 connections. The detailed layer construction can be seen in table 1 where the layer name and depth measured in meters above sea level [masl.] to the top, midpoint and bottom of the layer is listed as well as the layer thickness [m] and its initial stratification. Layer A represents the atmosphere and is given a constant pressure of 1 bar and temperature of 5 °C, layer B represents the cap rock which is given lower permeability, layers C-J are the geothermal system and layer K represents the bottom of the model which is also given a lower permeability. A temperature gradient of 100 °C km^{-1} is used for the initial condition of the entire model. The initial pressure is the hydro-static pressure for that temperature gradient. The elements in the top and bottom layer of the model (layer A and K) are given a very large volume ($1 \cdot 10^{50}$) so that their pressure and temperature remain stable over the simulation time (Pruess et al., 2012). All rock types were given density of 2650 kg/m^3, porosity of 10%, thermal conductivity of 2.1 W/(mK) and heat capacity of 1000 J/(kgK) (Gunnarsson & Aradóttir, 2014).

Table 1: Detailed layer structure of the numerical model

Layer	Top [masl.]	Midpoint [masl.]	Bottom [masl.]	Thickness [masl.]	Stratification
A	150	125	100	50	Atmosphere
B	100	50	0	100	Cap Rock
C	0	-50	-100	100	Geothermal System
D	-100	-150	-200	100	Geothermal System
E	-200	-250	-300	100	Geothermal System
F	-300	-400	-500	200	Geothermal System
G	-500	-600	-700	200	Geothermal System
H	-700	-800	-900	200	Geothermal System
I	-900	-1000	-1100	200	Geothermal System
J	-1100	-1200	-1300	200	Geothermal System
K	-1300	-1400	-1500	200	Bottom Layer

5. PRODUCTION HISTORY OF THE FIELD

Very little is known about the production in the area. The data that is available is from a few mass flow measurements conducted in wells HS-08 and HS-09 by the Hveragerði district heating utility, with long intervals between measurements (figure 5). Measured production from other wells is unavailable.

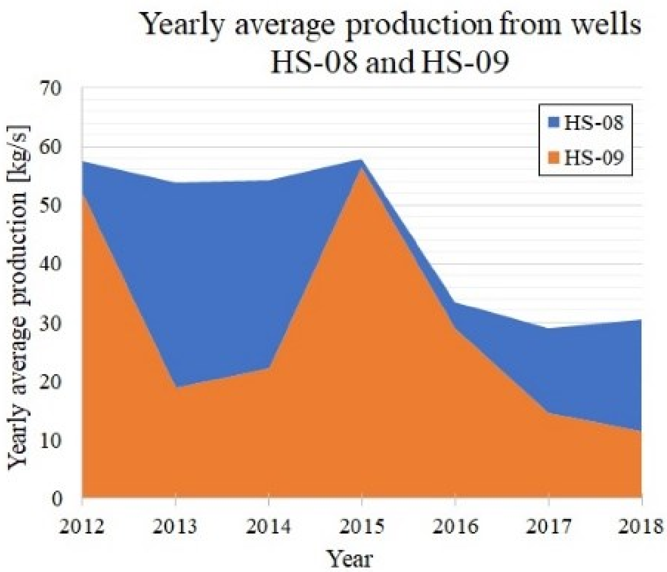

Figure 5: Estimated production from wells HS-08 and HS-09 based on mass flow measurements

Due to the shortage of direct flow measurements, other means were necessary to estimate the production history of the Hveragerði geothermal field. Two methods were used depending on available data; 1) Estimating energy use per person based on available mass flow measurements 2) Calculating the energy use per building and building type.

5.1 Estimating energy use per person based on available mass flow measurements

To estimate the average energy use per person, the average total production in wells HS-08 and HS-09 in 2012-2015 are divided with the average population in Hveragerði for the same period. Production from the years 2016-2018 are not used due to the connection to the Gljúfrárholt geothermal field during that period. These calculations give an average use of 0.03 kg/s per person, in which includes personal use and industrial use of hot water. The thermal energy production unit became operational in 1997. In the beginning wells HS-08 and HS-03 were connected to the unit. In 1999 HS-09 was drilled and then connected to the unit at the same time as HS-03 was disconnected and closed. Using this information along the calculated use of 0.03 kg/s per person it is possible to estimate the yearly average production for the thermal energy production unit. In order to estimate the production for the thermal energy production unit the following assumptions were made:

- The thermal energy production unit is and has been connected to 80% of the recorded population in Hveragerði since it became operational in 1997.
- From 1997-2000, 70% of the production came from HS-08 and 30% from HS-03.
- From 2000-2012, 65% of the production came from HS-09 and 35% from HS-08.
- Industry in Hveragerði increases at the same rate as population (Hveragerðisbær, 2015).

Figure 6a shows the results from the estimations listed above for the thermal energy production unit. Note that on the right side of the red line is figure 5 and on the left are the estimations based on that information. Production from wells HS-00, HS-01, HS-02, HS-03 and HV-02 was estimated based on the same average use of 0.03 kg/s per person. HS-00 was in operation from 1946-1959, HS-01 from 1958-1992, HS-02 from 1960-1996, HS-03 from 1964-1996 (and connected to the thermal energy production unit from 1997-2000) and HV-02 from 1973-2009. In order to estimate the production for the thermal energy production unit the following assumptions were made:

- If more than one of those wells was in operation at the same time, the production was divided equally between them.
- 20% is lost in production, transportation, and distribution.
- Combined, these wells were connected to all residents and industries in Hveragerði until 1997 when the thermal energy production unit became operational.
- From 1997-2000, HS-03 was connected to the thermal energy production unit.
- From 1997-2009, HV-02 was connected to 20% of the population in Hveragerði, during which the thermal energy production unit was connected to 80% of the population.

Figure 6b shows the results from the estimations listed above for the simple system. Note that the decline in production during 1997 is due to the opening of the thermal energy production unit that year.

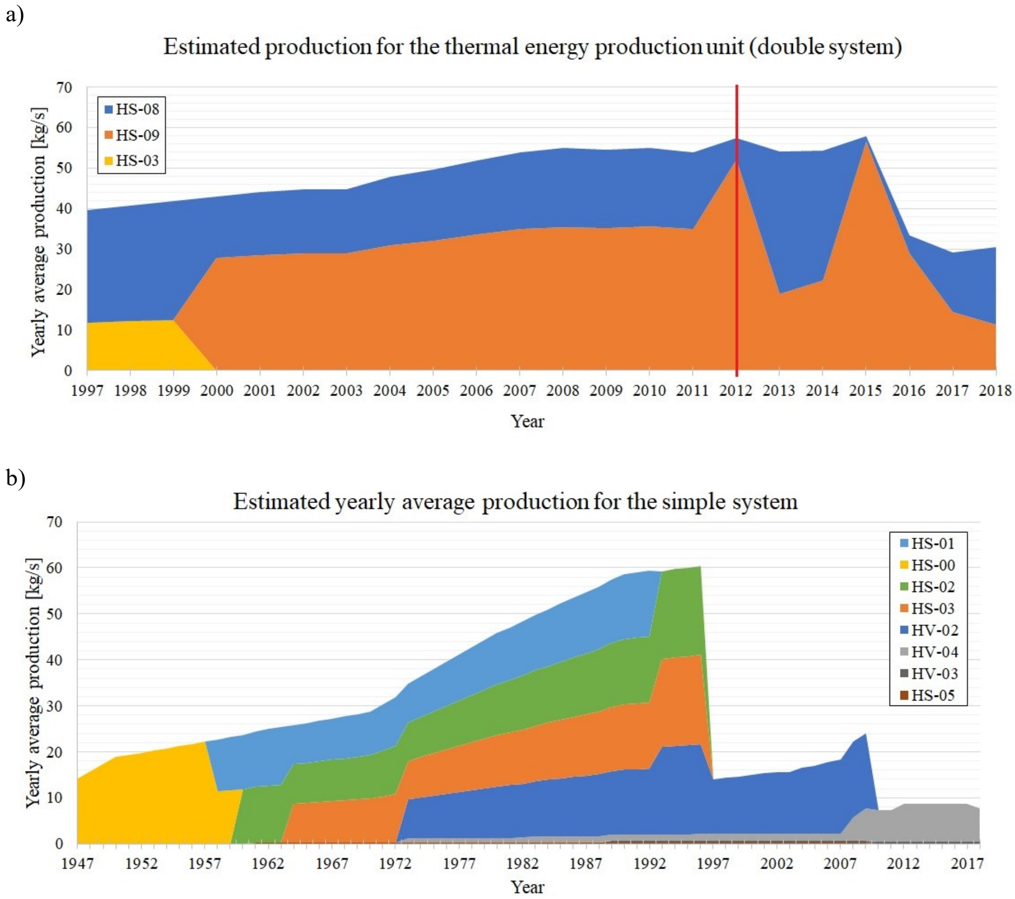

Figure 6: a) Production estimated for the thermal energy production unit, b) Estimated yearly average production for the simple system.

5.2 Estimating production data by calculating the energy use per building

The National Energy Authority of Iceland has estimated the energy utilization by different building types (Orkustofnun, 2018). A list of building types and their size in square meters [m^2] was provided by the Registers of Iceland (Þjóðskrá, n.d.). Production from wells HV-03, HV-04, HS-05, NLFÍ-01, ASÍ-02 and RE-04 was estimated using this method. In order to convert the information given by Orkustofnun, 2018 from kWh/m^3 (kWh/m^2 for swimming pools) to kg/s the following assumptions were made:

- 20% is lost in production and distribution and the power consumption is based on 4000 hours of utilization per year.
- The average ceiling height in residential homes garages, vacation homes, tool-sheds, stables and service and business premises is estimated at 3 m.
- The average ceiling height in greenhouses and churches is estimated at 6 m.
- The power consumption is based on 4000 hours of utilization per year.
- For wells HV-03, NLFÍ-01, ASÍ-02 and RE-04, the distribution water is estimated at 100 °C and ejected at 40 °C. The enthalpy of the fluid is calculated using these temperatures.
- For wells HV-04 and HS-05, the distribution water is estimated as the temperature measured at feed zones and ejected at 40 °C.

When these methods are joined together the total production for the field from 1947 to date has been estimated, as can be seen in figure 7. There the production is split between systems; double system, single system and private wells.

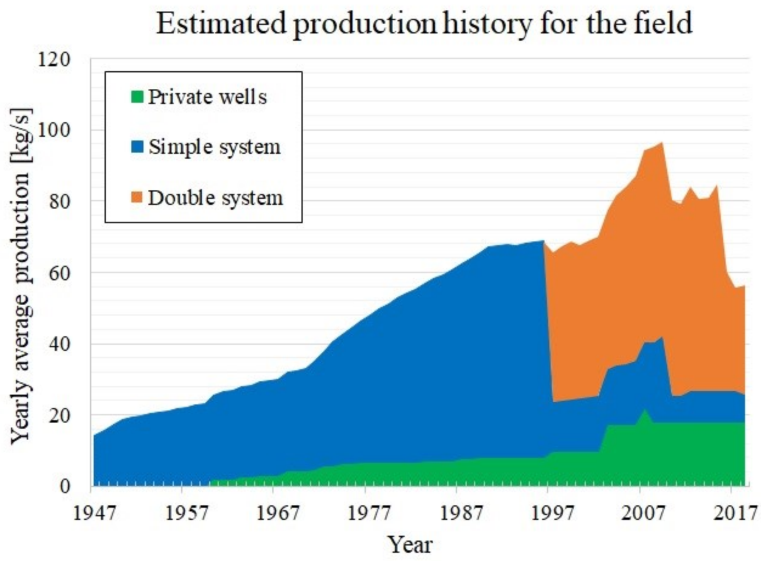

Figure 7: Estimated yearly average production in the Hveragerði geothermal field from 1947-2018.

6. RESULTS

The aim of a natural state model is to minimize the residual difference between the calculated and measured temperatures. That was achieved by using all relevant information found, by assigning a permeability to each rock type and by injecting a total of 120 kg/s of fluid with an enthalpy of 1060 kJ/kg in layer J (1200 mbsl.). That equals to a total energy flow of about 127 MW. The results of the calculated natural state show that the formation temperature is represented by the model quite well. This comparison can be seen in Figure 8 where wells HV-07, HS-06 and KS-01 are shown and compared to the formation temperatures.

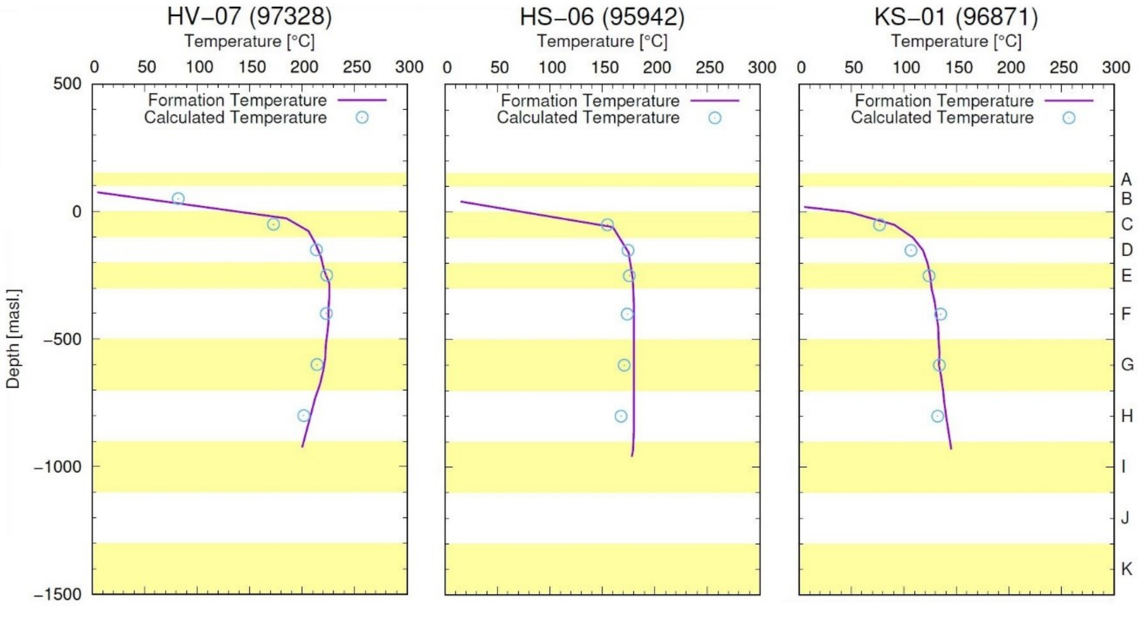

Figure 8: Formation temperatures compared to the calculated numerical model temperatures.

No pressure or temperature drawdown data is available for any of the production wells in the area. Thus, the results cannot be compared to actual data. In well HS-09 which is in the middle of the geothermal field (figure 1) there is clear pressure drawdown of 2.5 bars in layer F (400 mbsl.) and a 3 °C drawdown in temperature as well (figure 9a). The largest production fields are located close to well HS-09, with HS-09 being one of them which could explain this difference. Figure 9b shows the calculated total pressure drawdown in 2009. The pressure drawdown is plotted for layer I (1000 mbsl.). It should be noted that the year 2009 was the year where the highest amount of fluid was produced from the area. There it is shown that the pressure decrease in the system during the highest production is merely 2.5 bars, it can also be seen in figure 9a that the pressure recovers rather quickly as the production decreases.

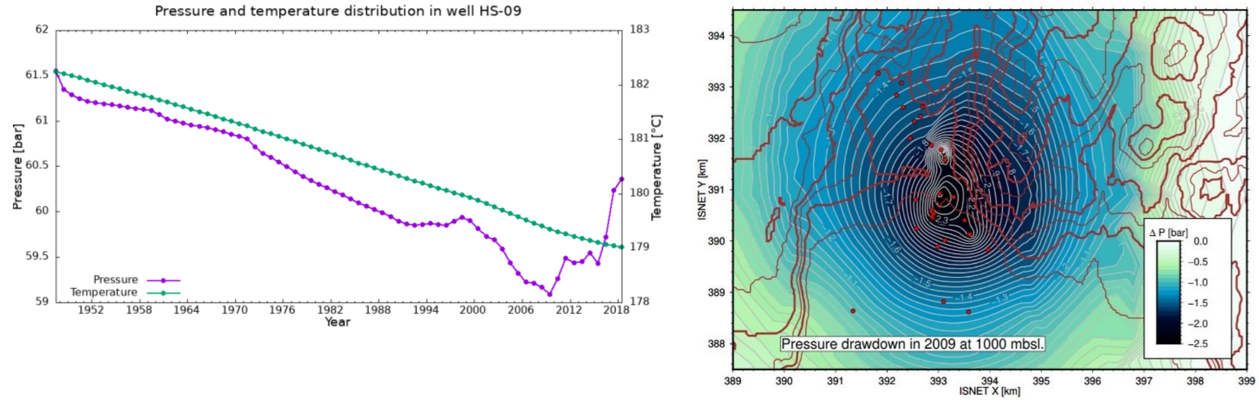

Figure 9: a) Pressure and temperature variance with time in well HS-09, b) Estimated pressure drawdown in 2009 at 1000 mbsl.

7. CONCLUSION

This study presents a natural state TOUGH2 model of the Hveragerði high temperature geothermal field. A broad search for information about the field was conducted and gathered to create a comprehensive overview of the Hveragerði geothermal field. The information found suggests that the heat and mass flow is flowing from north to south and that the area is highly fractured due to tectonic activity. This information led to the development of a numerical model for the Hveragerði geothermal field.

The study area is 400 km^2. The structural setup of the numerical model was based on the findings in the literature review, where the heat sources were located in the northern part of the field with highly permeable structures in the direction of faults, and surface manifestations. The grid used was of Voronoi method with five grid refinements, the most detailed one with centres 200 m apart and the coarsest one with centres 3200 m apart. The model is represented by 11 layers ranging from 150 masl. to 1500 mbsl. The number of elements in each layer is 2851, which brings a total of 31,361elements with 121,361 connections. The numerical model ran until stable for 10 000 years. Formation temperatures were created from well temperature measurements from 24 wells and used to calibrate the numerical model. There is a good match between the calculated formation temperatures and the formation temperatures estimated from the downhole temperature data.

Very little production data exists for the Hveragerði geothermal field, thus more unconventional methods were used to estimate the production during that time period. The two methods used were; a production estimation based on mass flow measurements and population and a production estimation based on building size and type. The production history of the field from 1947 to date was then simulated using the calibrated numerical model. Drawdown has not been measured in the area; therefore, calibration of the simulation model was not possible. The production simulation shows that there is relatively little drawdown in the field, however the field seems to be capable of much more production.

Numerical modelling and production simulations are important tools in the utilization of geothermal fields for district heating. Together they give valuable information about the geothermal field which in turn leads to more sustainable production. Numerical models are extremely dependent on the quality of the input data. In the Hveragerði geothermal field, monitoring of the resource and production has been inadequate. This fact resulted in many estimations and assumptions over the course of this modelling work. This project clearly pointed out the need for improved monitoring in Hveragerði and the importance of well owners to working together to support sustainable utilization. Once more data exist, this work could be carried on and further improved.

ACKNOWLEDGMENT

This work was carried out in cooperation with Veitur Utilities, a subsidiary of Reykjavík Energy.

REFERENCES

Arnórsson, S., *Jarðhiti og jarðarauðlindir [Geothermal heat and resources]*. Hið Íslenska bókmenntafélag, 2017, isbn: 978-9979-66-400-0.

Barja, A., Ásbjörnsson, E. J., and Harðardóttir V., “A Review of Scaling Mechanisms and Minerals in Hveragerði District Heating System”, in *Proc. Fortieth Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford. California, 2015, pp. 1–7.

Björnsson, G. and Steingrímsson, B., “Hitalíkan af Reykjasvæðunum í Mosfellsbæ [Temperature model of the Reykir area in Mosfellsbær]”, Orkuveita Reykjavíkur and Orkustofnun, Tech. Rep., 1995.

Decriem, J., “Crustal deformation from geodetic techniques: Earthquakes and plate movements in the South Iceland Seismic Zone”, PhD Thesis, Faculty of Earth Sciences, University of Iceland, Reykjavík, Iceland, 2011. [Online]. Available: http://hdl.handle.net/1946/7869.

Einarsson, P., “Earthquakes and present-day tectonism in Iceland”, *Tectonophysics*, vol. 189, no. 1, pp. 261–279, 1991, Imaging and understanding the lithosphere of Scandinavia and Iceland, issn: 0040-1951. doi: https://doi.org/10.1016/0040- 1951(91)90501-I.

Eysteinsson, H., “TEM-viðnámsmælingar í Grændal [TEM resistivity measurements in Grændalur]”, Orkustofnun, Tech. Rep. OS-2000/066, 2000.

Geirsson, K. and Arnórsson, S., "Conceptual model of the Hveragerdi geothermal reservoir based on geochemical data", in Proc. World Geothermal Congress 1995, Florence, Italy, 1995, pp. 1251–1256.

Gonzalez-Garcia, J., "Reservoir Assessment of the Ölfus-Bakki Low-Temperature Geothermal Area, SW Iceland", Master Thesis, Faculty of Earth Sciences – University of Iceland, Reykjavik, Iceland, 2011. [Online]. Available: http://hdl.handle.net/1946/7437.

Gunnarsson, G. and Aradóttir, E. S. P., "The Deep Roots of Geothermal Systems in Volcanic Areas: Boundary Conditions and Heat Sources in Reservoir Modeling", *Transport in Porous Media*, vol. 108, pp. 43–59, 2014. doi: 10.1007/s11242-014- 0328-1

Haukwa, C., "AMESH A mesh creating program for the integral finite difference method: A User's Manual", Lawrence Berkeley National Laboratory, Tech. Rep., 1998.

Hersir, G. P., Árnason, K., and Steingrímsson, B., "Exploration and development of the Hengill geothermal field", in *Short Course on Surface Exploration for Geothermal Resources*, Ahuachapan and Santa Tecla, El Salvador, 2009, pp. 1–12.

Hveragerðisbær, "Aðalskipulag Hveragerðis 2017-2029 - Skipulagslýsing [Hveragerði Municipal plan for 2017-2029 - Planning description]", Hveragerðisbær, Tech. Rep., 2015.

Ívarsson, G., "Ástandið í Hveragerði árið 2013 [The situation in Hveragerði 2013]", Orkuveita Reykjavíkur, Tech. Rep., 2013.

Ívarsson, G., Sigurðardóttir, Á., Kristinsdóttir, B., Þrastarson, E. Ö., Gretarsson, S., and Þorsteinsson, Þ., "Yfirborðsjarðhiti á Hengilssvæðinu IV [Surface geothermal heat in the Hengill area]", Orkuveita Reykjavíkur, Tech. Rep. 2011-34, 2011.

Jónasson, Þ., "Borholur í Hveragerði [Wells in Hveragerði]", Orkuveita Reykjavíkur, Nýjar virkjanir, Tech. Rep., 2008.

Orkustofnun, *Umsókn um nýtingarleyfi á jarðhita - áætluð orkuþörf, flæði og magn heits vatns [Application for a license of utilization of geothermal energy – estimated energy need, flow and volume of hot water]*, Last accessed 10 April 2019, 2019. [Online]. Available: https://orkustofnun.is/media/jardhiti/Umsokn-um-nytingarleyfi-jardhiti-jan2018.xlsx.

Pruess, K., Oldenburg C, Moridis, G., "TOUGH2 User's Guide, version 2", Earth Science Division, Lawrence Berkeley National Laboratory, Berkley, California, Tech. Rep. LBNL-43134, 2012.

Reykjavík Energy, *Reykjavík Energy internal data base*, Last accessed 28 April 2019, 2019.

Sæmundsson, K., "Jarðhiti á Suðurlandsundirlendi og nýting hans [Geothermal heat in southern Iceland and its utilization]", in *Suðri: Þættir úr framafarasögu Sunnlendingar frá Lómagnúpi til Hellisheiðar*, B. Bjarnason, Ed., vol. 2, Laugarvatn, 1969, pp. 101–160.

Sæmundsson, K., Arnórsson, S., and Benediktsson, S., "Greinagerð um borun í Sogni [A report on drilling in Sogn]", Orkustofnun, Tech. Rep., 1972.

Sveinbjörnsson, B. M., "Medium Enthalpy Geothermal Systems in Iceland – Thermal and Electric Potential", Icelandic Geosurvey, prepared for the National Energy Authority of Iceland, Tech. Rep. 15-0149, 2016.

Þjóðskrá, *Fasteignaskrá [Real estate registry]*, Last accessed 28 April 2019, 2019. [Online]. Available: https://www.skra.is/leit-i-fasteignaskra/.

Þórhallsson, S., "Notendur borholna ríkisins í Ölfusdal 2015 [Users of the state-owned wells in Ölfusdalur 2015]", ÍSOR, Tech. Rep., 2015.

Tómasson, J., Friðleifsson, I. B., and Stefánsson, V., "A hydrological model for the flow of thermal water in SW-Iceland with a special reference to the Reykir and Reykjavík thermal areas.", in *Proceedings of the Second United Nations Symposium on the Development and Use of Thermal Resources, San Francisco, USA*, 1975, pp. 643– 649.