SGP-TR-113-12

PROCEEDINGS
THIRTEENTH WORKSHOP
GEOTHERMAL RESERVOIR ENGINEERING

January 19-21, 1988

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Stanford Geothermal Program
Workshop Report SGP-TR-113*

*Sponsored by the Geothermal Technology Division of the U.S. Department of Energy, Stanford-DOE Contract No. DE-AS07-84ID12529

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PROCEEDINGS, Thirteenth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 19-21, 1988
SGP-TR-113

A SUMMARY OF MODELING STUDIES OF THE NESJAVELLIR GEOTHERMAL FIELD, ICELAND

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ABSTRACT

The Nesjavellir geothermal field in Iceland is being developed to provide the capital city of Reykjavik and surrounding areas with hot water for space heating. In the last few years, many wells have been drilled at the site and various geothermal studies have been conducted. The main upflow to the system is underneath the nearby Hengill volcano, and the natural recharge rate and enthalpy are estimated to be 65 kg/s and 1850 kJ/kg, respectively. An extensive vapor zone is believed to be present in the upflow region. Permeabilities and porosities of the system range between 1 and 50 md and 1 and 10 percent, respectively. In this paper, the characteristics of the Nesjavellir field are described and a three-dimensional numerical model of the resource is discussed.

INTRODUCTION

The Nesjavellir geothermal field in southwest Iceland is being developed for production of hot fluids for space heating purposes in the capital city of Reykjavik and surrounding areas. The hot geothermal fluids will be used to heat up fresh water to a temperature of about 90 °C using heat exchangers. The hot fresh water will then be piped about 30 km to the capital, and distributed. After use, most of the spent water is discharged into the sea at a disposal temperature of some 40 °C.

The Nesjavellir geothermal field has been under intermittent development for over 20 years, with the first well being drilled in the mid-1960s. At present, 18 wells have been drilled, identifying the presence of a high temperature (>300 °C) geothermal system. Most of these wells were drilled after 1982, as a result of the need for identifying a longterm solution to the approaching shortage of hot fluids from the geothermal fields in the vicinity of Reykjavik.

Concurrent with the drilling activities in recent years, various studies have been conducted in order to better understand the geothermal system. This includes a thorough geological and geophysical investigation (Arnason et al., 1986, 1987), extensive reservoir studies and flow testing of the wells, fluid sampling and analysis and the development of a three-dimensional numerical model of the system. All of these studies aim toward a proper assessment of the characteristics of each well and the overall generating capacity of the resource.

In this paper the available field data from Nesjavellir are briefly described and a conceptual model of the field presented. Then we describe the development of the three-dimensional reservoir model and the results obtained in terms of the characteristics and properties of the system.

THE NESJAVELLIR FIELD

The Nesjavellir geothermal field is a part of the Hengill geothermal area, which extends over some 70 to 100 km^2 (Bodvarsson, 1951).

The Hengill area is densely faulted, with the primary fault direction being SW-NE. Locations of extinct and active surface manifestations are controlled by the fault patterns, as is the flow of fluids and heat within the geothermal system. In general, the faults enhance N-S trending fluid flow, but probably retard E-W trending flow.

Drilling in the Nesjavellir area started in the mid-1960s; five wells were drilled during the period 1965 through 1972 (wells 1 through 5; Stefansson, 1985). These wells identified the presence of a high temperature resource, with higher temperatures at shallow depth found towards the south (Tomasson et al., 1974). Data from these wells also indicated that part of the system is two-phase, the remainder being a subcooled liquid system (Steingrimsson and Stefansson, 1979). Since the early 1980s 13 additional wells have been drilled at Nesjavellir (Fig. 1). All of these wells are commercial producers with the exception of well 8, which was abandoned at a depth of 400 m because of high shallow pressures (Franzson and Sigvaldason, 1985).

The Nesjavellir wells encounter vastly different thermodynamic conditions as evidenced by their pressure and temperature profiles and the enthalpy transients during production.

Figure 2 shows the estimated temperature distributions in a vertical cross sections extending W-E. The figure shows high temperatures near the Kyrdalshryggur fracture zone (wells 11 and 3), and rapidly declining temperatures away from it in both directions (east and west). Temperatures in excess of 380 °C were measured deep in well 11, perhaps related to a magmatic intrusion. In order to control the high pressure, high temperature feed near the bottom of this well, the well was filled with gravel at depths between 1700-1900 m (Steingrimsson et al., 1986).

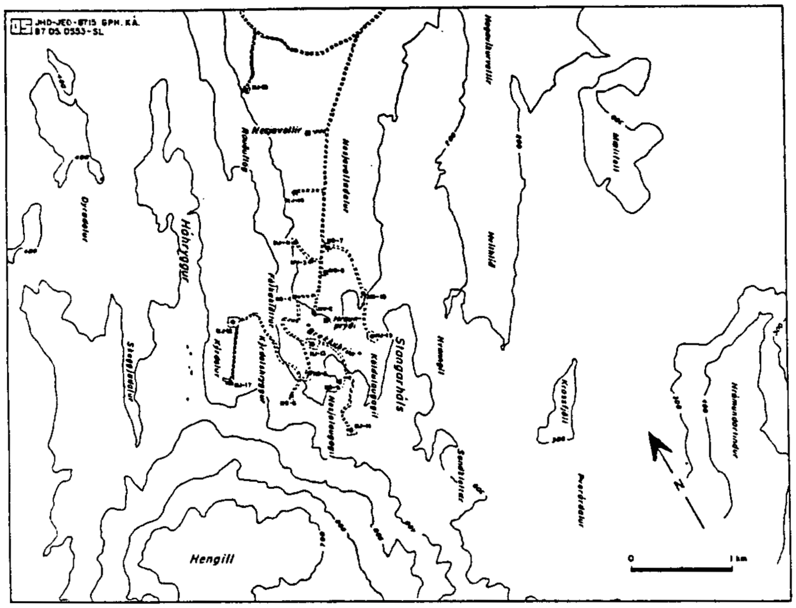

Figure 1. The Nesjavellir wellfield (after Arnasson et al., 1986).

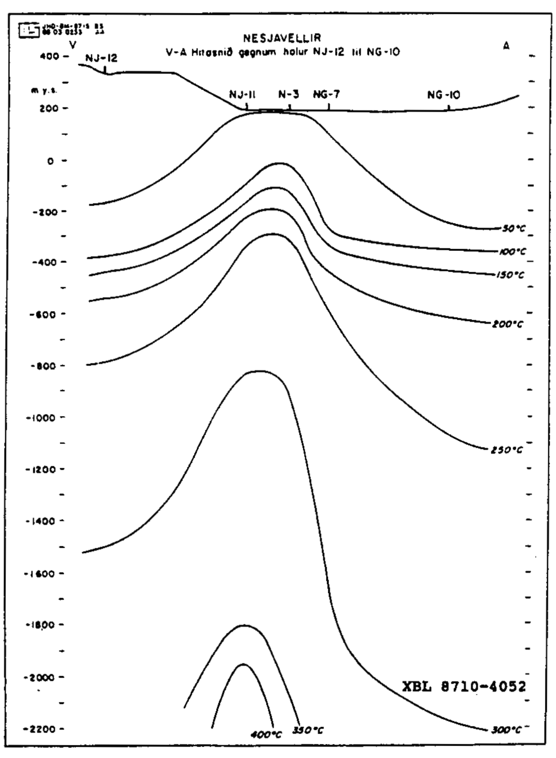

Figure 2. A W-E cross section through the northern wellfield showing the estimated temperature distribution.

The pressure conditions at feed zones in the various wells, shown in Figure 3, illustrate the complex thermodynamic state of the resource. The data suggest the presence of several aquifers with different pressure potential (Stefansson, 1985). Pressures are very high in shallow aquifers in the southern part of the reservoir system with two-phase conditions prevailing in the region around wells 6, 8 and 9. In the northern part of the wellfield the shallow aquifers do not contain high temperature fluids and the pressure potential is much lower. At intermediate depths high pressures prevail, but the temperatures are rather low, indicating subcooled liquid aquifers. Wells 12, 17 and 18 have anomalously high pressures at depth, about 5 bars higher than those in other wells at Nesjavellir.

The geological formations encountered at Nesjavellir consist primarily of hyaloclastites and basalt lavas. (Figure 4; Franzson et al., 1986). Basaltic hyaloclastite formations are dominant in the top 600 m, with basaltic lava series becoming more abundant below 600 m. Intrusions also increase drastically with depth and exceed 50% at depths below 1500 m (Franzson et al., 1986). The geological cross section shows two major fault structures delineating a central graben. The hydrothermal alteration indicates that in most of the reservoir system the mineral assemblages are in equilibrium with the prevailing temperatures (Franzson et al., 1986).

Franzson et al. (1986) discuss the fracture characteristics of the Nesjavellir system in light of fluid production. They believe that horizontal permeability is predominant in the upper 800 m of the system, perhaps due to contact permeability between layers. This agrees well with the observed pressure discontinuities between aquifers in the shallow parts of the field. For the main reservoir section below 800 m depth, Franzson and coworkers believe that vertical permeability becomes more dominant as fracture and fault permeability becomes important as well as contact permeability at the boundaries of the intrusions.

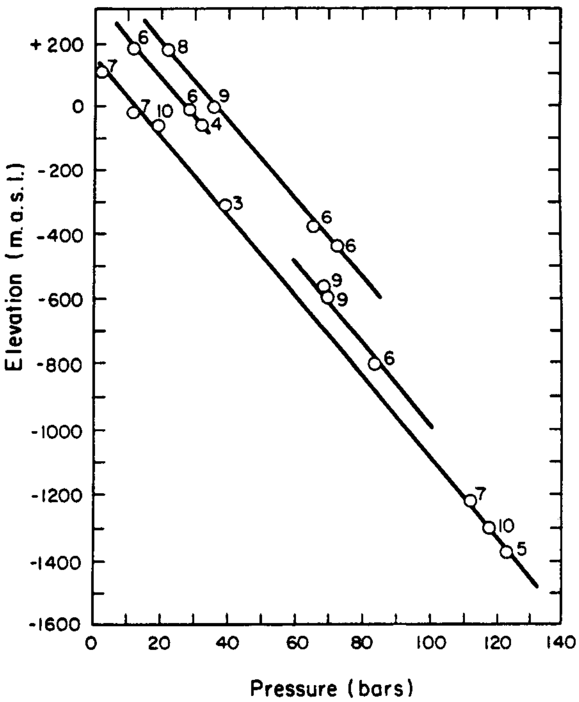

Figure 3. Pressures at feed zones in some of the wells (after Stefansson, 1985).

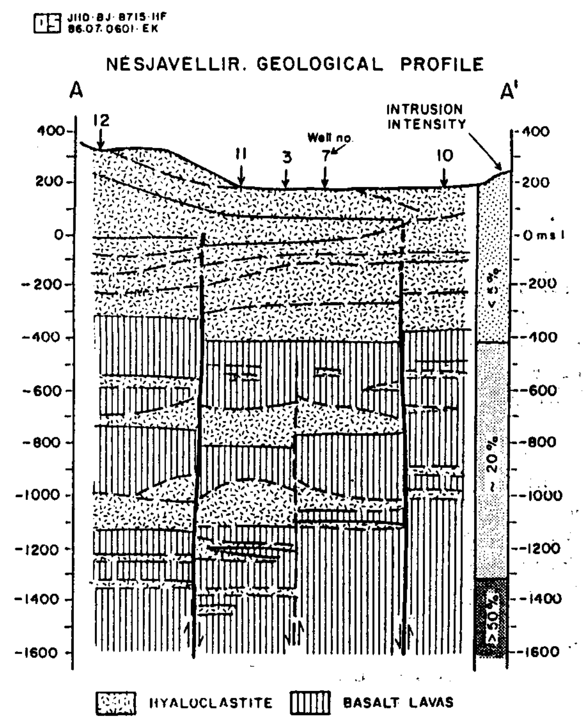

Figure 4. Geological cross section extending W-E through the Nesjavellir field (after Franzson et al., 1986).

Almost all of the Nesjavellir wells are good producers. Table 1 lists typical flow rates, enthalpies and energy outputs (in MW_t) for each of the commercial wells. The table shows that on the average the thermal output of the wells is about 60 MW_t. The average electrical generating capacity of the wells is about 8 MW_e.

The Nesjavellir wells vary greatly in the enthalpy of the produced fluids (see Table 1), which is mostly due to the different thermodynamic conditions in the vicinity of the wells. The two-phase wells produce fluids with enthalpy varying from 2000 to 2500 kJ/kg, whereas the wells completed in the subcooled part of the reservoir produce fluids with enthalpies below 1500 kJ/kg.

Monitoring of chemical concentrations of gases and dissolved solids in the produced fluids shows that concentrations of these chemicals are relatively low in comparison with other high temperature geothermal fields. In general, the chemical characteristics of the fluids from individual wells are so similar that it is difficult to infer fluid flow directions from the data. Recent isotope studies have shown that the fluids feeding well 12 have undergone less interaction with the rock than those feeding the other Nesjavellir wells.

CONCEPTUAL MODEL

A conceptual model of the field was proposed by Stefansson (1985) before the drilling of the last eight wells (wells 11 through 18). Most of the ideas proposed in the conceptual model developed by Stefansson are consistent with the results of wells drilled after the model was presented.

All evidence collected to date suggests that the main upflow zone to the system is located southwest of the wellfield under the Hengill volcano. In addition to the Nesjavellir anomaly, this upflow zone probably also

Table 1. Productivity of Nesjavellir wells.

Well	Flow rate (kg/s)	Enthalpy (kJ/kg)	Steam at 7 bars (kg/s)	Thermal output (MW_t)
5	10	1600	5.3	18
6	22	2500	19.0	55
7	36	1300	10.9	48
9	28	2200	20.4	62
10	52	1350	16.4	70
11	37	2500	32.7	93
12	57	1300	17.2	75
13	36	2500	31.4	90
14	28	1300	8.6	37
15	47	1450	16.5	67
16	27	2300	21.0	62
17	45	950	5.5	43
18	36	930	4.1	33

feeds fluids to other geothermal anomalies in the Hengill area (e.g., Kolvidarholl, Innstidalur, etc.). We believe that vapor-dominated conditions exist in the upper part of the upflow region, which helps to explain the high pressures in shallow aquifers in the southern part of Nesjavellir and the vastly different pressure potential at different depths in the wells. Well 8, in the southern part of the wellfield, identified a shallow two-phase aquifer ($\approx$ 120 m depth) with very high pressure (20-23 bars); this aquifer is also present in well 6, but has lower pressure (H. Franzson, personal communication, 1986). At depths between 400 and 800 m a single-phase aquifer with a high pressure potential can be found in many of the wells. The presence of an upflow zone with a small vertical pressure gradient (vapor-dominated zone), located beneath a high topography anomaly (i.e., the Hengill volcano) can explain the high shallow pressures and vastly different pressure potentials.

It is hypothesized that this vapor zone will have pressure on the order of 70 bars to be consistent with the large pressure potential of the aquifers between 400 and 800 m depth. The vapor zone would have to extend down to an elevation of about 600 mbsl to create the lower pressure potential in the deeper reservoir.

The temperature and pressure data obtained from the wells suggest that the fault zone near Kyrdalshryggur has higher permeability than the surrounding rocks. The extent of this high permeability zone (discharge channel) to the north is not well known, but it extends past well 16 and perhaps as far as well 18, which is located about 1 km north of well 12. Depths to the hot fluids become greater towards the north. The high temperature and pressure zone found deep in well 11 is located within the discharge channel, and perhaps some localized upflow occurs along it. The last eruption at Nesjavellir some 2000 years ago was a fissure eruption in the Kyrdalshryggur area (see Figure 1).

The anomalously high pressures deep in well 12 in Kyrdalur necessitate the presence of low permeability rocks between well 12 and the other wells to the east. Recent data from wells 17 and 18 also indicate high pressures in these wells, suggesting that they may be hydrologically connected to the aquifers feeding well 12. The impermeable barriers between well 12 (and perhaps wells 17 and 18) and the other wells can be readily explained because of the numerous eruptive fissures (dikes) extending NE-SW in the Kyrdalshryggur area.

The heat loss from the Nesjavellir system occurs through conductive heat transfer to the ground surface and laterally to the sides, and steam and hot water loss to surface manifestations. Most of the present active surface springs are located in the Koldulaugargil (see Figure 1) or in Nesjalaugargil between wells 6 and 9. Temperature data from the Nesjavellir wells generally show that the conductive shallow temperature gradient varies between 0.4 and 0.7 °C/m. There is a S-N flow of cooler fluids at depths of about 150-400 m over most of the northern parts of the wellfield. This fluid flow enhances the heat losses of the system.

THREE-DIMENSIONAL NUMERICAL MODEL

Because of the complex thermodynamic and geologic conditions of the Nesjavellir field it was decided to develop a fully three-dimensional model of the field. The model had to consider all relevant field data and be consistent with observed field conditions and behavior, including:

1. The pressure and temperature conditions;
2. The presence of two-phase zones;
3. The flow rates and enthalpies of wells;
4. The observed pressure interference effects.

After the model development was completed, performance predictions of the generating capacity of the field were made.

The Numerical Grid

The three-dimensional model consisted of four layers, three of which were 400 m in thickness, while the bottom layer was 800 m thick. The choice of the number of layers and their respective thicknesses was made based on the observed thermodynamic conditions in the field and the locations of major feed zones in the wells.

The grid used extends 12 km in all directions from the wellfield; constant pressure boundaries were used as external conditions to the model. In most of the simulations the outer boundary conditions did not affect the results.

The upflow zone was assumed to be located in grid block 53, which geographically represents a part of the Hengill volcano (Fig. 5). This location was chosen rather arbitrarily, but it places the upflow zone under the Hengill volcano, which we believe is necessary to explain the vast differences in pressure potential shallow in the wellfield.

Various reservoir parameters were adjusted during the natural state and history match simulations, including permeabilities and porosities, the production indices for the wells and the mass recharge rate and the enthalpy of the upflow zone. Most other parameters used are well known for geothermal systems or did not affect any of the simulation results significantly. The computer code MULKOM (Pruess, 1982) was used in this work.

Natural State Modeling

Over most of the Nesjavellir area the conductive heat losses amount to some 0.9 - 1.5 W/m^2, as indicated by the "static" temperature profiles in some of the wells. This conductive heat loss will decrease away from the main thermal plume. Convective heat losses to surface springs are estimated to be about 10 MW_t in Koldulaugargil and 5 MW_t Nesjalaugagili. In addition to these, we also include in our model mass flow to warm springs located close to Sandkletter on the eastern flanks of the Hengill volcano, where about 5 kg/s of 80 °C water are discharged in the area (S.P. Snorrason and K. Saemundsson, personal communication, 1986; see also Arnason et al., 1986).

As mentioned earlier, a basic four-layer model was used for all of the modeling work. The four layers will be referred to as layers U, M, L and R. Uppermost layer U averages 400 m in thickness, as do layers M and L beneath it. Bottom layer R is 800 m thick and resides at

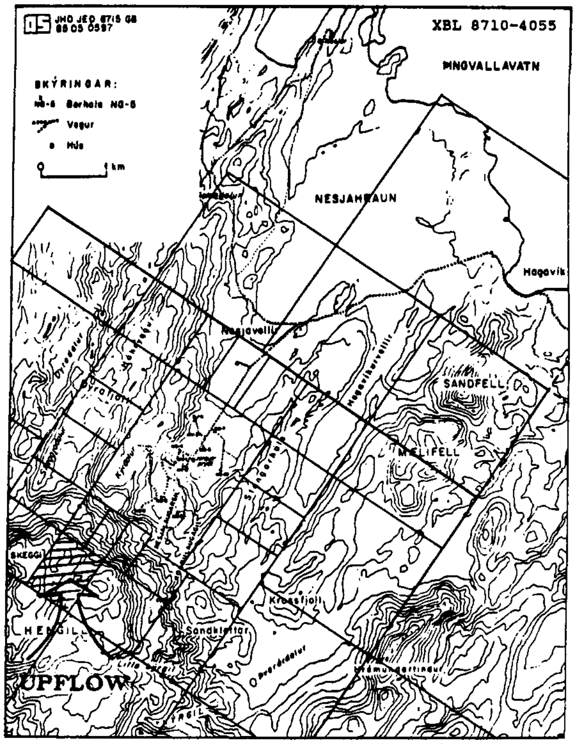

Figure 5. The basic grid superimposed on a topographic map of the Nesjavellir area.

elevations between 1000 and 1800 mbsl. Depending upon the specifics of the topography, layer U varies in thickness from about 300 m to about 550 m. Additional shallow layers are used in the vicinity of the upflow zone in the Hengill area to represent the topographic high of the central volcano.

The basic grid shown in Figure 5 was used for the main reservoir layers (layers L and R). Because of predominant conductive heat transfer to the ground surface for many regions in the two "shallow" layers (layers U and M), many of the elements (gridblocks) shown in Figure 5 were not needed in those layers. The conductive heat losses were computed by an algorithm developed by Vinsome and Westerfeld (1980).

In the "conductive" regions the conductive heat losses are computed for different areas based on the observed temperature data from the wells with proper interpolation and extrapolation where needed. Thus, the conductive heat losses vary areally to the degree the observed data demand. An average annual surface temperature of 5 °C was assumed in the simulations.

Many simulation runs were necessary until a coarse match with the observed thermodynamic conditions in the field was obtained. Each run simulated several hundred thousand years until near steady-state conditions were reached, after which temperatures would change by less than 1 °C anywhere in the system. As the model has about 300 gridblocks and 950 connections, the computations needed to reach steady state for each run were rather intensive.

History Match Simulations

For the history match simulations of the flow rate and enthalpy data from the wells, a finer grid than that used in the natural state simulations was required around each well.

A subgrid was placed in the well elements containing the major feed zones, using the approach developed in the Krafla (Pruess et al., 1984) and Olkaria (Bodvarsson et al., 1985) simulations. Concentric cylinders of radii 20 and 60 m were used as subgridblocks in the elements, which are typically equivalent in size to a cylinder 100 m in radius. The subgrid allowed for the simulation of the early time response of the wells.

In order to obtain a reasonable match with observed flow rates and enthalpies of the wells, numerous iterations were necessary. The main parameters controlling flow rate decline and enthalpy changes of the wells are productivity indices, permeabilities and porosities.

The method we used in the iterations was to determine the productivity indices of the wells based on the initial flow rate history, before well interference is seen. Then the enthalpy rise was matched by adjusting porosities, while the permeabilities were adjusted until the flow rate decline was approximately represented. It should be noted that any change made in porosity and permeability anywhere in the wellfield will have an affect on all nearby wells. Consequently, many iterations were required before a reasonable match was obtained. In addition to the flow rate and enthalpy data from the wells the model was also calibrated against pressure interference effects observed during the well production period.

As mentioned earlier, the calibration of the model against flow rates and enthalpies of wells and the observed pressure decline started after a coarse match was obtained with the natural thermodynamic conditions of the field. The calibration with the production history required many changes in the permeability distribution, especially in the production layers (layers L and R). This in turn required recalibration of the natural state calculations and vice versa.

Best Model

Natural State Results

In the best model 65 kg/s of steam-water mixture with an enthalpy of 1850 kJ/kg feed the Nesjavellir system through the upflow zone underneath the Hengill volcano. This energy input corresponds to about 120 MW_t, which is a similar value to that estimated from the two-dimensional natural state model (Bodvarsson and Pruess, 1986).

In the model some of this energy is lost through steam flow to surface springs in Koldulaugargil ($\approx$10 MW_t), Nesjalaugagil ($\approx$ 5 MW_t), and to warm springs near Sandklettar ($\approx$1.5 MW_t). However, most of the energy is lost through conductive heat transfer to the surface, or to shallow groundwater aquifers.

Figures 6 and 7 show the computed temperature distributions in the U and R layers, with observed temperatures of wells given in parentheses. The solid hatched lines indicate the presence of impermeable barriers retarding fluid flow and significantly reducing the

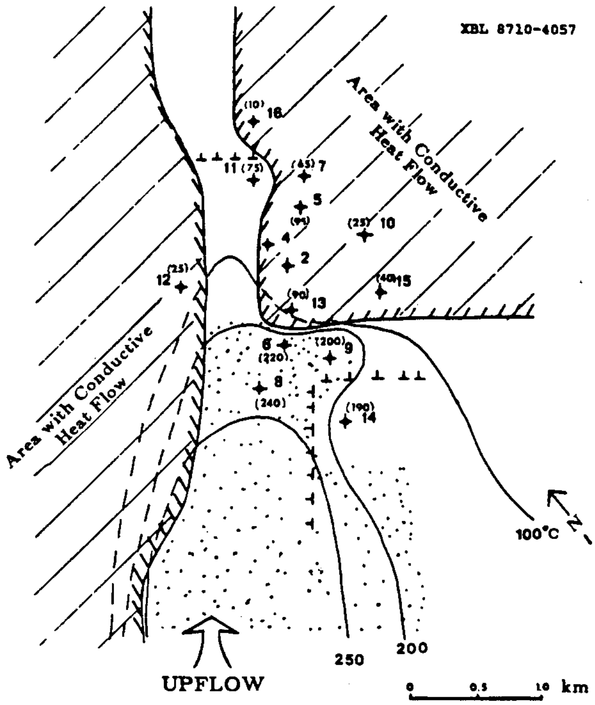

Figure 6. The computed temperature distribution for layer U. Observed values for each well are given in parentheses; dotted area represents two-phase zone.

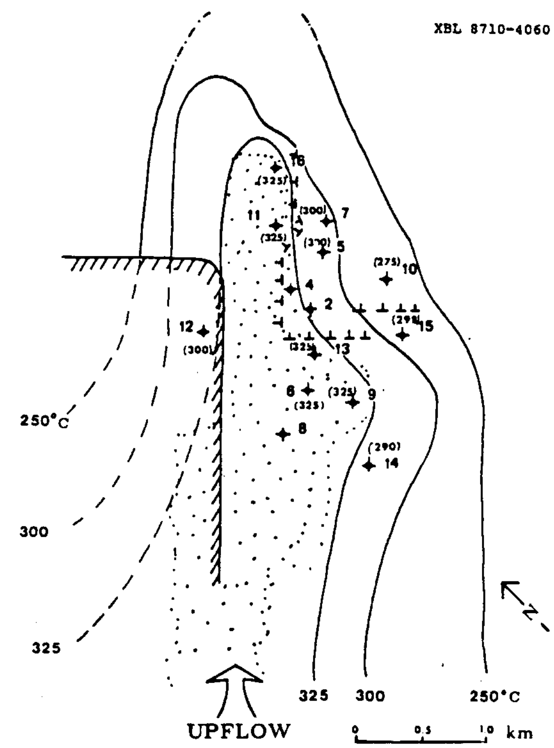

Figure 7. The computed temperature distribution for layer R. Observed values for each well are given in parentheses; dotted area represents two-phase zone.

total flow areas in layers U and M. The locations of these barriers are inferred from the shallow temperature distributions in the wells, indicating conductive heat flow for areas surrounding most of the low enthalpy wells. The impermeable barriers shown in layer R are inferred from the high pressure in well 12 in Kyrdalur in comparison with pressures in other wells. In the present model it is hypothesized that the high pressure in well 12 is due to separate high permeability flow paths from the upflow zone to the well. The broken lines shown in Figures 6 and 7 represent "imperfect" barriers, that is, lower permeability connections between various regions of the system. These are inferred from various observations during the calibration process with the temperature and pressure data, the production history and the observed pressure decline as will be described later. It should be emphasized that there is considerable uncertainty involved with these permeability barriers, and their locations and permeabilities are subject to various non-uniqueness problems.

As shown in Figures 6 and 7 the Nesjavellir model matches the temperature distributions in layers U and R reasonably well. In the U layer the match is good and the computed two-phase zone extends around wells 6, 8 and 9, which is in good agreement with observed data. The vapor saturation in this zone is fairly high and varies between 20 and 60%, which is consistent with the observation that mostly steam (and gas) was produced out of well 8 from the high pressure fracture zone at a depth of 120 m. Similar temperature matches were obtained for layers M and L, and also the computed three-dimensional pressure distribution agrees well with observed values. The high pressure potential in layer M and relatively low temperatures were not easy to simulate. This was finally achieved using a model with rather complex interaction between the various layers, as shown in Figure 8. As mentioned earlier we hypothesize that there is a vapor-dominated zone approximately 800 - 1000 m thick underneath the Hengill volcano. In the vapor-dominated zone steam is the pressure-controlling fluid with a near vaporstatic heat pipe transferring the energy upward towards the caprock. The average pressure in the vapor-dominated zone is grossly estimated to be about 70 bars. Below the vapor-dominated layer in the upflow zone there is a liquid-dominated two-phase zone that extends to unknown depths. The near-uniform pressure in the vapor-dominated zone causes the different pressure potential in the various aquifers in the drilled region of the geothermal field. According to this model, most of the fluids recharging the U layer consist of steam and gases ascending from the deeper M layer. The high vertical permeability needed for this mass exchange is provided by a series of faults cutting through the Hengill volcano just northeast of the proposed upflow zone, and then continuing towards the north near the Kyrdalshyggur area and providing high permeability for fluid flow towards the north. The vertical steam flow from the M layer to the U layer accomplishes two things consistent with the observed data. First, the steam loss cools down the fluids and rocks in the M layer, yielding single-phase liquid conditions with high pressure potential. Second, it produces a gas-rich, two-phase mixture in the U layer, without the excessively high pressures that would result if the U layer were in good lateral communication with the vapor-dominated upflow zone. It is possible that

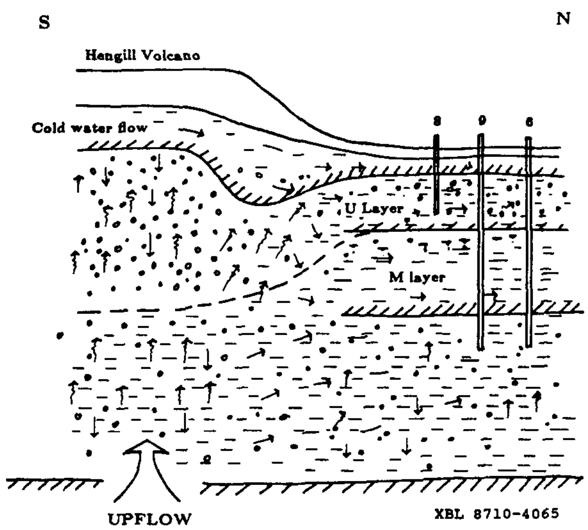

Figure 8. A model of the upflow zone and flow patterns for the various layers. Straight arrows indicate liquid flow and wriggled arrows vapor flow.

some of the degassed waters recharge certain regions of the L layer and provide fluids to well 14, which has anomalously low gas content and low fluid enthalpy.

History Match Results

All of the wells were modeled individually and their flow rate and enthalpy histories matched. The main parameters that were adjusted to obtain matches with the flow rate and enthalpy data of the wells were the productivity indices, permeabilities and porosities.

As an example, Figure 9 shows the match between observed and calculated flow rates and enthalpies for well 6. This well shows considerable variations in flow rate and enthalpy caused by mobility effects; i.e., when low enthalpy fluids recharge the well the flow rate increases and vice versa, but the thermal output of the well remains near constant. During the early flow period of the well the enthalpy decreases and the flow rate rises, which could be partly due to the large water losses during drilling (Stefansson et al., 1983). However, since the low enthalpy period lasts for more than a year it cannot be explained solely by the drilling fluid losses. It is probable that the low enthalpy fluids recharge the well from the region around well 9 and perhaps even further to the east. There is undoubtedly a very good permeability connection between wells 6 and 9, as evidenced by the rise in fluid enthalpy in well 6 in late 1984, when well 9 starts to flow. In our model, we find that very high permeabilities ($\approx$ 50 md) connect these wells, and that this high permeability zone extends considerably further to the east. The model results show good agreement with the flow rate history of well 6, especially the gradual decline that starts soon after well 9 starts producing. The rise in enthalpy due to the interference from well 9 is somewhat more gradual than what has been observed.

Some pressure decline has been observed at Nesjavellir due to fluid production. In June 1986 the low enthalpy wells were shut in and the pressure recovery was observed. The results suggest a 3 - 4 bar pressure decline in well 7, a 1 - 2 bar decline in well 10, and no decline in wells 12 and 14.

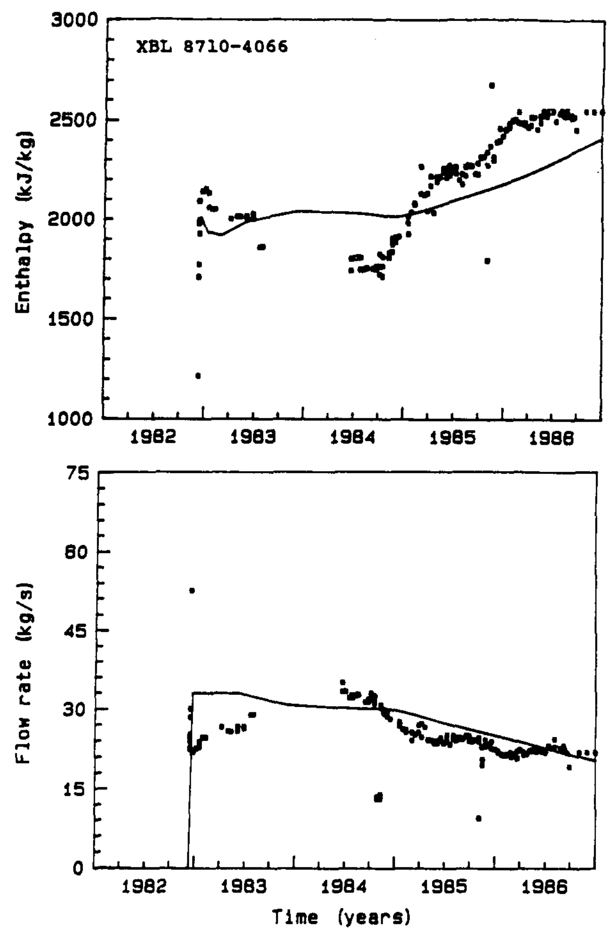

Figure 9. Comparison between computed and observed flow rates and enthalpies for well 6.

Figure 10 shows the computed downhole pressure versus time for well 7, and suggests that well 7 is in reasonable hydrologic communication with wells 10 and 15. Total pressure decline in well 7 is about 3 - 4 bars, which agrees very well with the observed data. As an example, the inferred permeability distribution in the main reservoir layer, layer R, is shown in Figure 11. The high permeabilities in the discharge channel are most pronounced. The permeability of this zone is estimated to be about 30 md. Other high permeability areas include the region north and east of wells 16 and 7 that enhance recharge from these directions and the high permeability zone extending from the upflow zone north towards well 12. The background permeability is estimated to be about 10 md, primarily from the matches with the pressure decline data. It should be noted that the area of influence from fluid production to date only extends a few kilometers in each direction, so that permeabilities outside this area are completely unknown.

The transmissivities deduced from this modeling work suggest that the overall average transmissivity of the Nesjavellir reservoir is about 10 Dm. This value is somewhat higher than those inferred from injection test

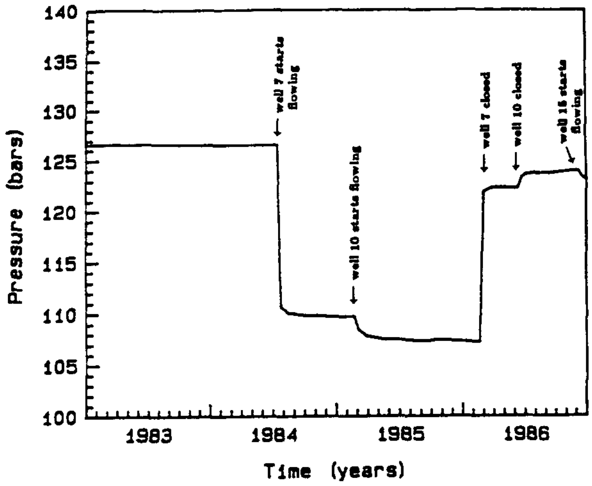

Figure 10. Computed downhole pressure changes in well 7.

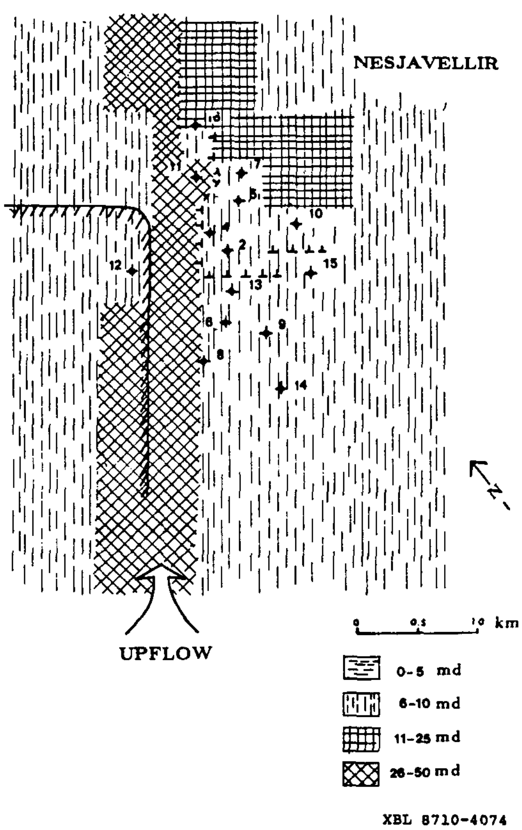

Figure 11. The permeability distribution in the R layer, inferred from the model.

data, which range from 2 - 8 Dm. The reservoir porosity values inferred from this model study were generally in the range of 3.5 to 5 percent, which is somewhat lower than those measured on cores.

CONCLUSIONS

A three-dimensional numerical model of the Nesjavellir field has been developed. The model is consistent with the observed thermodynamic conditions of the reservoir system and matches reasonably well the production histories of the wells and the observed pressure interference effects. The model has been used to study various exploitation cases for Nesjavellir in order to determine the generating capacity of the system, and the effects of reinjection and different well spacings. Many approximations and assumptions have been used in this work, including the use of a porous medium model for a fractured reservoir, and the assumption of constant bottomhole pressure in producing wells. The reader should evaluate the following conclusions in light of the approximations made:

1. It is hypothesized that the main upflow zone to the system is under the Hengill volcano. The recharge rate in the upflow zone is estimated to be 65 kg/s with an enthalpy of 1850 kJ/kg. An extensive vapor zone with high pressure ($\approx$ 70 bars) is hypothesized to reside underneath the Hengill volcano.
2. Most of the energy losses in the Nesjavellir area are due to conductive losses to the ground surface as well as lateral conductive and convective heat losses. Mass and heat losses to surface springs only amount to some 20 MW_t, compared to the total energy input of 120 MW_t.
3. The permeabilities of the system are very heterogeneous, and vary between 1 and 50 md. The permeabilty in shallow parts of the system are estimated to be in the range of 1 to 10 md. In the upper reservoir layer the average permeability is around 5 md, but about 10 md in the lower part of the reservoir. In the upper reservoir layer a high permeability fracture zone is believed to intersect wells 6 and 9; this fault zone is believed to extend a considerable distance east of well 9. In the lower reservoir layer the permeabilities are highest in the discharge channel extending to the north from the upflow zone. Various permeability barriers are believed to be present in the reservoir, isolating some of the wells from the others.
4. The "porous medium" porosities of the system vary between 1 and 10%. The "effective" porosity in the upper part of the reservoir is estimated to be 5% and 3.5% in the lower part. These values appear reasonable given the measured porosity of 8 - 15% in cores and the fact that only portions of the fluids may be recoverable from the tight matrix blocks.

ACKNOWLEDGMENTS

The authors acknowledge valuable work on this project by G. Bjornsson, M. Bodvarsson, K Pruess, M. Ripperda, and S. Suresh. The authors also appreciate technical discussions with K. Arnason, G. Bodvarsson, H.

Franzson, A. Gudmundsson, G. P. Hersir, S. P. Snorrason, and K. Saemundsson. Thanks are also due to the Reykjavik Municipal District Heating Service (RMDHS), for allowing publication of this paper. This work was supported by RMDHS and The Assistant Secretary for Conservation and Renewable Energy, Office of Renewable Technology, Division of Geothermal Technology through U.S. Department of Energy Contract No. DE-AC03-76SF00098.

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