A COUPLED WELLBORE-RESERVOIR SIMULATOR UTILIZING MEASURED WELLHEAD CONDITIONS

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ABSTRACT

Modeling a geothermal system requires simulating the behavior of a reservoir and the flow in production wells, which is usually done individually. The main objective in this study is to develop a coupled wellbore-reservoir simulator to allow for more integrated modeling and to use wellhead conditions to a greater extent than has been done so far by defining them as main inputs to the coupled model. The program TOUGH2 is used to simulate the behavior of a reservoir while a new model, FloWell, is used to simulate two phase flow in a wellbore. Furthermore, the model design in FloWell and in TOUGH2 is improved by calibration with the parameter estimation program iTOUGH2 during the coupling procedure. Emphasis is placed on adjusting the permeability distribution in a reservoir, productivity indices of wells and parameters in void fraction correlations for there are some great uncertainties involved in the assessment of these parameters, which have led to disagreement among investigators. This paper discusses in detail the methodology behind the coupling procedure and raises questions like: What can be accomplished with this coupled model? What are the limitations of the coupled model? The proposed coupling procedure in this paper is put to a test by examining the Reykjanes geothermal field located in the southwestern corner of Iceland and results analyzed.

NOMENCLATURE

g acceleration due to gravity [m/s^2]
G mass velocity [kg/m^{2}s]
h enthalpy [J/kg]
$\dot{m}$ mass flow [kg/s]
k permeability [mD]
P pressure [Pa]
PI productivity index
x steam quality

σ surface tension [N/m]
α void fraction
ρ density [kg/m^3]

Subscripts
l liquid phase
g gas or vapor phase

INTRODUCTION

With growing world population and increasing environmental concerns, the demand for renewable energy and sustainable use of resources is steadily rising. Excessive exploitation of geothermal resources sometimes occurs, resulting in cooling of rocks, reduced production capacity and finally depletion of geothermal reservoirs. Mathematical models are therefore one of the most fundamental tools in geothermal resource management for they can be used to extract information on conditions of geothermal systems, predict reservoir's behavior and estimate production potential (Axelsson, 2003).

Most reservoirs are monitored by descending equipment to measure pressures and temperatures in wells. From these measurements the drawdown in pressure in a reservoir can be estimated. This is a time consuming and expensive process which usually involves a production stop in producing geothermal wells. On the other hand, well conditions are observed constantly by measuring instruments accessible at the top of wells. From the information gathered at the wellheads much can be learned about the behavior of wells and consequently the reservoir behavior. Therefore, a method for simulating the response of geothermal systems to exploitation, such as the drawdown in pressure, by easily obtained wellhead parameters is very desirable.

The main objective in this study is to create a practical tool to evaluate the state of geothermal reservoirs and well performances using measured

wellhead conditions and inverse analysis. This is to be done by coupling a wellbore simulator to a reservoir simulator with the measured conditions as main inputs. For this purpose the program TOUGH2 is used to simulate the multi phase flow in a reservoir while a new wellbore simulator, FloWell, is used to simulate the behavior of wells. The inverse analysis, performed with the program iTOUGH2, enables continuous evaluation of chosen parameters in both FloWell and TOUGH2 and the measured wellhead conditions provide up to date data to model the current situation in the geothermal system.

In this paper the methodology behind the coupling procedure is discussed in detail, a numerical model of the Reykjanes geothermal field including the coupled FloWell-TOUGH2 model is introduced and results from several forecasting scenarios are examined.

THE WELLBORE SIMULATOR FLOWELL

For this study a wellbore model has been developed to simulate two phase flow in geothermal wells. This wellbore simulator is called FloWell and solves the conventional differential equations involved in flow calculations, namely the continuity, energy and momentum equations.

FloWell is intended to be a simple simulator that is able to produce reliable results with little effort. Despite the simplicity, FloWell has several useful features. The simulator is for example capable of simulating flow either up or down wells, accounting for single, two phase and superheated steam flows and providing numerical results at each depth increment.

Furthermore, FloWell offers users to choose between various empirical correlations. This is specifically useful when considering the void fraction in wells since its assessment involves great uncertainties. The model of Rouhani and Axelsson is an example of a void fraction correlation offered in FloWell. Their model can be seen here below.

$$\alpha = \left(\frac{x}{\rho_g}\right)\left(\left(1 + 0.12(1-x)\right)\left(\frac{x}{\rho_g} + \frac{1-x}{\rho_l}\right) + \frac{(1.18(1-x))\left(g\sigma(\rho_l - \rho_g)\right)^{0.25}}{G\rho_l^{0.5}}\right)^{-1} \tag{1}$$

FloWell can be used individually to simulate the behavior of producing geothermal wells. The model is also designed to be coupled to a reservoir simulator in a moderately simple way. Such a coupling procedure is described in the chapter *The Coupled FloWell-TOUGH2 Model*.

For more information about the structure of FloWell and the theory behind the model readers are referred to the paper *The Wellbore Simulator FloWell* by the same authors, presented at the Thirty-Eighth Workshop on Geothermal Reservoir Engineering at Stanford University.

THE RESERVOIR MODEL TOUGH2

TOUGH2 is a general numerical simulator for non-isothermal multi phase flow in porous and fractured media. TOUGH2 calculates the thermodynamic conditions present in a predefined geothermal reservoir by integrating basic mass and energy balance equations for a given domain. The mass and energy equations are discretized in space based on an integral finite difference method. To obtain numerical stability required for multi phase flow calculations the time is discretized as a first order finite difference in a fully implicit manner. This results in a set of coupled nonlinear equations which are solved by employing Newton-Raphson iteration. TOUGH2 accounts for sinks and sources in calculations and the generation rates can be time dependent or independent. Furthermore, it can be assumed that wells operate on deliverability against fixed bottomhole pressures and productivity indices (Pruess, 1999).

THE INVERSE MODEL iTOUGH2

Inverse problems often lead to difficult optimization routines with no straightforward solution. Therefore, no general method is at hand to solve all inverse problems. The most common formulation is based on system identification techniques and least-squares fitting of parameterized models to measured data. In brief, inverse modeling consists of estimating model parameters from measurements of system response at discrete points in time and space.

A number of mathematical models and data processing techniques can be used in solution of an inverse problem. A basic simulation package called iTOUGH2 is frequently used. iTOUGH2 is a computer program for parameter estimation and sensitivity and uncertainty analysis. The program contains various minimization algorithms to find the minimum of the objective function which is the difference between model results and measured data. The basic procedure in iTOUGH2 is to continuously compare the calculated output from TOUGH2 to measure data while changing the value of selected input parameters. If a change in an input parameter results in reduction of the objective function, the program has found a better estimation for the parameter. In this study the Levenberg-Marquardt

minimization algorithm is used to evaluate the objective function.

iTOUGH2 is usually run in combination with TOUGH2, a forward simulator for non-isothermal multiphase flow in porous and fractured media, but can also be linked to non-TOUGH2 models. In that way the iTOUGH2 can be used as an inverse analyzing tool for models such as the wellbore simulator FloWell (Finsterle, 2007).

To be able to link non-TOUGH2 models with iTOUGH2, a protocol called PEST has been implemented in iTOUGH2. The protocol enables interaction between the non-TOUGH2 model and iTOUGH2 through a clear and simple communication format (Finsterle, 2010).

THE COUPLED FLOWELL-TOUGH2 MODEL

In addition to designing a coupled wellbore-reservoir model, an inverse analysis with continually measured wellhead parameters as observations is applied to the coupled model to improve the model design and keep it up to date. For the model calibration the inverse analysis program iTOUGH2 is used. Usually, the emphasis is on calibrating the reservoir model TOUGH2, but the method suggested here is to apply an inverse analysis on the wellbore simulator as well. This is to be done in an iterative manner where measured wellhead conditions are used to calibrate the reservoir model to find estimates for the bottomhole pressures in wells. These bottomhole pressures are then used to calibrate the wellbore simulator. This iteration process is explained in detail in following paragraphs.

One of the main focuses in this study is to utilize the measured wellhead parameters to a greater extent than has been done so far, by using them as an input to the coupled model and to calibrate the model with an inverse analysis. As new wellhead parameters are measured they are imported into the coupled model and an iterative inverse analysis process is initiated. This results in continuous improvements being made to the model design in the reservoir simulator and in the wellbore simulator.

The basic methodology behind the coupled model is illustrated in Fig. 1. The parameters that are measured or estimated at the wellhead, the mass flow rate ($\dot{m}_t$), enthalpy (h) and pressure (P_t), are the input to the wellbore simulator FloWell. FloWell calculates the bottomhole pressures (P_b) in the wells using available empirical correlations. To couple FloWell to TOUGH2 the bottomhole pressures are inserted into the input file for TOUGH2. An inverse analysis by iTOUGH2 on the reservoir model returns new

values for the bottomhole pressures ($P_{b,new}$) in the wells. Lastly, these new values are used in a second inverse analysis performed on the wellbore simulator by iTOUGH2-PEST to obtain a new estimate on parameters in void fraction correlations (α_{new}). From this point, the whole process is repeated where FloWell calculates new bottomhole pressures with the improved void fraction correlation. This iteration is continued until a stopping criterion has been met.
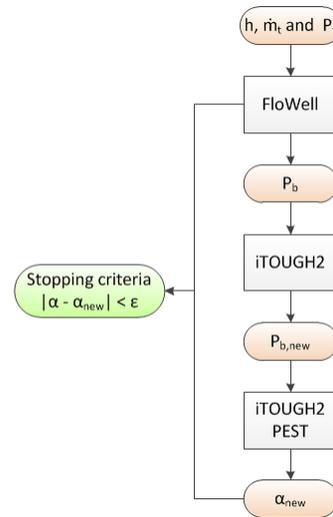

Figure 1: The basic ideology for the coupled FloWell-TOUGH2 model.

Although the basic ideology seems simple enough, the total coupling and calibration process is considerably more complicated as illustrated in Fig. 2. The coupling and calibration process can be done in several ways but the procedure depends mainly on what data is available for calibration and what parameters are to be evaluated.

The model design is best explained by taking a regular power plant with several producing wells that has been operated for i+1 years as an example. Historical data about the rate of production and the pressure drawdown in the reservoir is available, as well as continually measured data at the top of the wells.

In the first step a conceptual model is constructed for the reservoir in question. Before simulating the response of the reservoir to production the natural state of the reservoir is obtained by using a reasonable value for the permeability (k_{guess}) until a steady state has been reached. Supposing that historical data describing the pressure drawdown in the reservoir exists for year 1 to year i the data can be used to calibrate the model in order to obtain a fairly good estimate for permeability (k_{new}) of the rock structure in the reservoir.
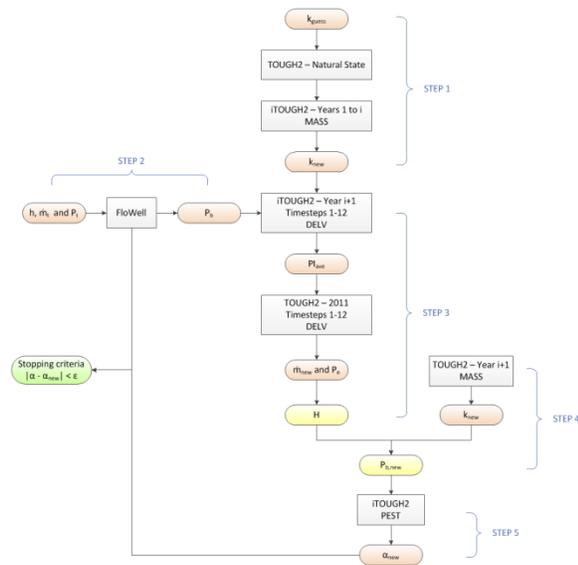
Figure 2: The detailed model design for the coupled FloWell-TOUGH2 model.

In step 2 it is assumed that measured wellhead conditions, mass flow rates ($\dot{m}_t$), enthalpies (h) and pressures (P_t), are available for every month of the year i+1. These parameters are used as inputs into FloWell, which calculates the bottomhole pressures (P_b) in producing wells in the reservoir.

Desirably, the next move would be to insert the calculated bottomhole pressures and the measured mass flow rates at the wellheads directly into the TOUGH2 model. However, TOUGH2 does not offer an option in which a mass flow rate and a bottomhole pressure for a well can both be used as inputs.

In the model design presented here, the DELV type is used to couple FloWell with TOUGH2. In step 3, the calculated bottomhole pressures from FloWell are entered to the reservoir model that has been arranged for year i+1 and guess values assigned to the productivity indices (PI) of the wells. By using mass flow rates as observations to calibrate the TOUGH2 model and to find new estimates for the productivity indices that suite the bottomhole pressure and mass flow rate for each well, the flow rates have now been linked to the coupled model. This calibration has to be performed in twelve time steps where each time step represents one month. In total the time steps add up to one year, year i+1 in production. The reason for this is that TOUGH2 does not allow the user to define time-dependant bottomhole pressures, the pressures have to be fixed throughout the simulation.

This procedure will result in twelve new estimates for the productivity index of each well to be produced. As it is custom to denote only one productivity index

for a well an average is taken of the twelve values obtained above (PI_{ave}). The average values of the productivity indices, one average value for each well, are now inserted into the TOUGH2 model instead of the guess values and a forward run in twelve time steps executed as before. After each run, pressures in the elements where wells are defined (P_e) are extracted from the output report from TOUGH2, along with mass flow rates ($\dot{m}_{new}$).

At this stage, the variable K (which is dependent on the density and viscosity of the fluid and the relative permeability) can be calculated with following equation as described by Pruess (1999);

$$\dot{m}_{new} = K \cdot PI_{ave} \cdot (P_e - P_b) \qquad (2)$$

In step 4 a new estimate for the permeability that describes year i+1 is found with iTOUGH2. Similarly to step 1, the MASS option in TOUGH2 is used and values for mass flow rates observed at the wellheads inserted into time-dependent tables. Since forward runs with MASS should not differ much from runs with DELV, the element pressures found in step 3 are used as observations for the inverse analysis in step 4. The inverse analysis results in permeability that yields element pressures that are close to the ones used as observations. These new element pressures can then be used along with correct mass flow rates ($\dot{m}_t$), the productivity indices and the variable K found in step 3 to achieve new bottomhole pressures ($P_{b,new}$) with Eq. (2).

The final step involves the calibration of FloWell with iTOUGH2-PEST. The new bottomhole pressures calculated in step 4 are used as observations in the inverse analysis and the parameters chosen for evaluation are variables in void fraction correlations. When the void fraction has been manipulated so bottomhole pressures match the ones from step 4 the first iteration has been completed. This new void fraction is inserted into FloWell and the procedure repeated until a stopping criterion has been reached.

A CASE STUDY OF REYKJANES GEOTHER-MAL FIELD

Reykjanes Conceptual Model

The Reykjanes peninsula, situated at the southwestern end of Iceland, is an onshore continuation of the Mid-Atlantic Ridge. The general topography of the Reykjanes peninsula has been shaped by sub- and postglacial fissure eruptions that created the northeast trending hyaloclastite ridges and crater rows. No central geothermal volcanoes have been developed in Reykjanes so the heat sources for the high

temperature fields in the peninsula are a dyke swarms (Friðleifsson et al., 2009).

From resistivity measurements reaching down to 1000 km it is believed that the geothermal system at Reykjanes covers an area of about 10 km^2. Interpretations of satellite pictures indicate however that the geothermal system becomes considerably more extensive with depth, where large parts of the system may lie beneath the ocean floor far south of the Reykjanes Peninsula (Friðleifsson et al., 2009).

The Reykjanes power plant began producing 100 MW$_e$ in May 2006 with two 50 MW$_e$ twin steam turbines with sea cooled condensers. HS Orka plans to expand the power production by 50 MW$_e$ in coming years as well as increase injection to support the pressure in the reservoir (HS Orka, 2009).

Little is known about the pressure change in the Reykjanes reservoir before power production started in the area but the data available indicates that the drawdown in pressure was hardly more than 2 to 3 bar prior to production (Hjartarson and Júlíusson, 2007). During the first months of production, steep decline in pressure was detected which continued until spring 2007. In total, from beginning of year 2006, the pressure drawdown in the center of the reservoir (RN-12) had reached the maximum of 36 bar while at the boundaries (RN-16) the drawdown is much less or 21 bar. This goes hand in hand with the magnitude of mass being extracted from the reservoir (HS Orka, 2011).

Numerical Model

The numerical model can be broken down into four main parts:

i.   A natural state model defining the Reykjanes geothermal reservoir prior to any production from the area.

ii. A reservoir model to simulate the production history ranging from the year 1977 to the year 2010 in Reykjanes along with calibration of the model against measured pressure drawdown in the reservoir over the production period.

iii. A coupled wellbore-reservoir model where wellhead measurements in 2011 are used to calibrate both the wellbore and the reservoir model.

iv. A forecasting model using the results from parts i-iii where different scenarios are simulated to predict the reservoir's response the next 15 years.

The mesh design is based on the conceptual model of Reykjanes geothermal field. Fig. 3 shows the overall

mesh used. The mesh covers 10x10 km area and consists of 2064 elements where 344 elements are defined as inactive. The numerical model of Reykjanes geothermal field consists of 12 layers, each with 172 elements and a thickness of 300 m. The horizontal mesh remains the same for each layer. Fig. 4 displays the innermost core of the mesh along with placements of wells at Reykjanes geothermal field. The rock types for the Reykjanes geothermal field can be seen in Fig 5. Layers A and L have the rock type names CAPR1 and BASE1 for the cap and base rock and the boundary of the Reykjanes geothermal field SIDE1. For the surroundings and the center of the reservoir rock type names ROCK1-5 have been assigned.
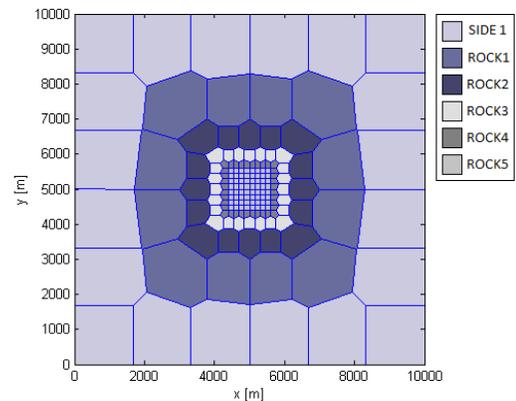

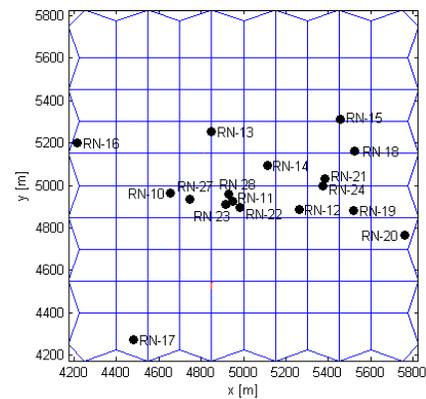*Figure 3: Horizontal mesh of Reykjanes numerical model.*

Figure 4: The innermost core of the numerical model and placements of wells at Reykjanes geothermal field.
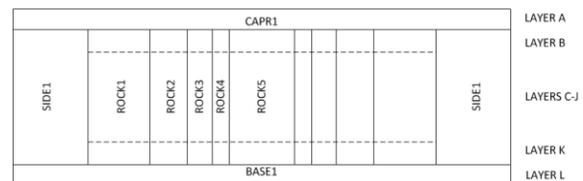

Figure 5: Vertical cross section of Reykjanes numerical model.

The initial conditions of the reservoir are set by a temperature gradient of 100°C/km with a corresponding hydrostatic pressure gradient. For simplicity and to facilitate calculations in the inverse program iTOUGH2 by reducing number of unknowns, the permeability in x and y direction in this model is assumed to be the same. Other main physical properties can be seen in Table 1.

Table 1: Physical properties of Reykjanes numerical model.

Physical properties	Values
Rock density	2650 kg/m^3
Thermal conductivity	2 W/m°C
Heat capacity	1000 kJ/kg
Porosity	10%

Numerical Results

For the natural state the change in thermodynamic variables becomes negligible after approximately 100.000 years and therefore it may be expected that a steady state has been reached in the reservoir. Heat entering the reservoir is equal to the one being discharged and the model is believed to describe the state of the Reykjanes reservoir in 1977, before exploitation started. The natural state model simulates the formation temperature and pressure reasonably well in some wells but inadequately in others.

The historical model describes the response of Reykjanes reservoir to exploitation from the year 1977 to 2010. This part mainly involves calibration of the historical model in order to use it in forecasting scenarios in the following section. The parameter estimation with iTOUGH2 is performed on the permeability distribution of the rock structure in Reykjanes reservoir with measured pressure drawdown in wells RN-12 and RN-16 as observations.

The parameter estimation results are shown in Table 2 along with initial values for the permeability distribution. After only four iteration with iTOUGH2 the objective function had decreased to 94% of the initial value. The simulated pressure drawdown for wells RN-12 and RN-16 with the new estimates for the permeability distribution is shown in Fig. 6 and 7. In both wells the historical model simulates the 3 bar pressure drawdown quite accurately. The model also produces acceptable simulations of the steep decline in pressure of 36 bar in the center of the reservoir and considerable lesser decline of 21 bar at the boundaries of the reservoir.

For the coupled model calculated bottomhole pressures are inserted to the reservoir model along

Table 2: Parameter estimation results and initial values for the permeability distribution in xy- and z-direction [mD].

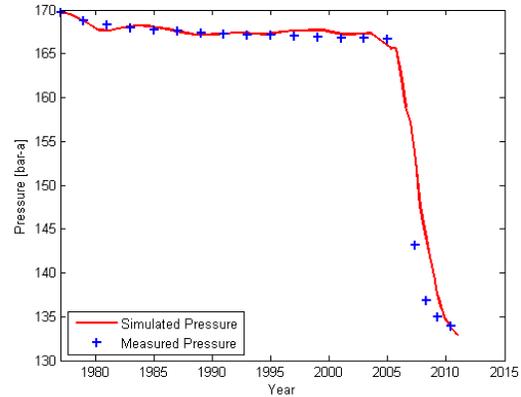|	SIDE 1	ROCK 1+2	ROCK 3+4	ROCK 5
xy (guess)	2.00	20.00	20.00	100.00
z (guess)	0.010	1.00	1.00	200.00
xy (estimate)	0.41	4.48	6.04	97.48
z (estimate)	0.0097	1.66	0.97	117.77

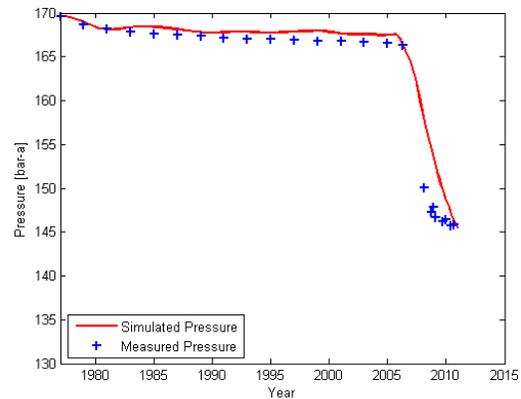*Figure 6: Simulated pressure drawdown vs. measured drawdown in well RN-12.*

Figure 7: Simulated pressure drawdown vs. measured drawdown in well RN-16.

with guess values $(3.0 \cdot 10^{-12}$ m^3) for the productivity indices of the wells. The reservoir model is then calibrated using observed mass flow rates and enthalpies at the wellheads, yielding new estimates of the productivity indices in all wells for the year 2011. Along with the productivity indices, the permeability of ROCK5 in xy- and z-direction is calibrated. Only the permeability of the center of the reservoir is considered in order to minimize the number of unknowns since the total process is very computationally expensive. The parameter, shown in red in Eq. (1) in the Rouhani-Axelsson void fraction correlation is chosen for the inverse estimation with

iTOUGH2-PEST to improve the model design in FloWell.

It takes approximately five iterations for the average of the productivity indices in the reservoir model and the void fraction in the wellbore model to reach equilibrium. The iteration process yields productivity indices in the range of $0.300\text{-}2.267\cdot10^{-12}$ m^3 for wells in consideration and an estimation of 0.111-0.122 for the parameter in the Rouhani-Axelsson void fraction correlation. For the permeability it takes around eight iterations to reach steady state. Minor changes are observed for the permeability of ROCK5, especially for the permeability in xy-direction. This is not unexpected since the simulation time only spans one year.

The purpose of designing a reservoir model is to use it to predict the future response of the reservoir to different production scenarios. In this study, four different production scenarios were modeled for the Reykjanes geothermal field. All scenarios involved simulations up to the year 2027.

- **Scenario 1**: Maintaining the same total production and injection rates as in the year 2011.
- **Scenario 2**: Maintaining the same total production rate as in the year 2011 and increasing the injection rate to 30% of the total extracted mass.
- **Scenario 3**: Increasing the production capacity of the power plant by 50 MW_e and maintaining the injection rate as in the year 2011.
- **Scenario 4**: Increasing the production capacity of the power plant by 50 MW_e and the injection rate to 30% of the total extracted mass.

In the forecasting model the forward simulator TOUGH2 is used. FloWell is excluded in this part but the permeability distribution found in the historical and the coupled FloWell-TOUGH2 models is used for the predictions.

Predictions of pressure drawdown in the center of the Reykjanes reservoir (well RN-12) and at the boundaries (well RN-16) are illustrated in Fig. 8 and 9. Scenarios are distinguished by colors where dotted lines represent cases with increased injection.

The figures show that in scenario 1 the pressure drawdown decelerates and the pressure in the reservoir is close to achieving equilibrium with just a total of 3-4 bar decline in pressure for the prediction period. By increasing the injection, the pressure in

the reservoir starts to rise again as displayed for scenario 2. In scenario 3 the power generation is boosted up to 150 MW_e with almost no injection taking place. Approaching five years of simulation a decline of 18 bar in the reservoir and 12 bar at the boundaries is observed. After five years of simulation a convergence failure is encountered in TOUGH2. This failure could indicate that the absolute pressure is dropping down to zero in one or more elements. If that happens the water recharge becomes insufficient and consequently it will be attempted to remove mass at a higher rate than physically possible. When adding considerably to the injection in scenario 3 less decline is detected and after 15 years of simulation the total drawdown in pressure is equal to the total drawdown after 5 years in scenario 3.
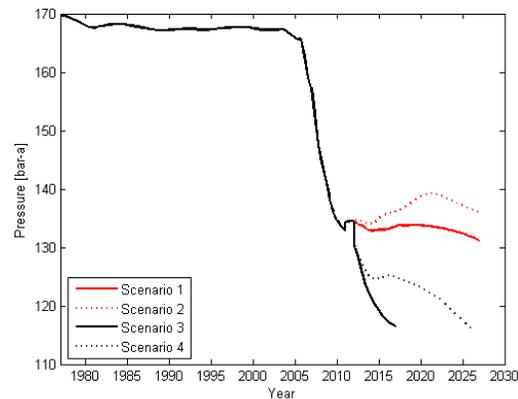
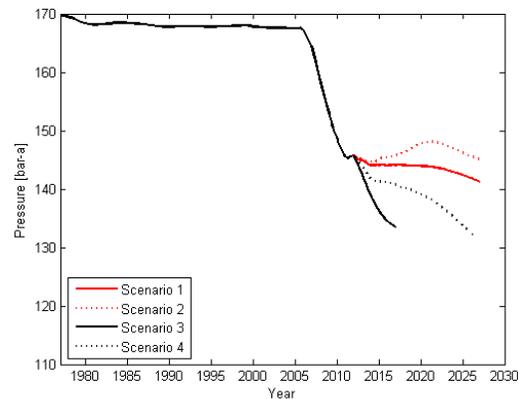*Figure 8: Pressure drawdown in well RN-12 in the forecasting scenarios.*

Figure 9: Pressure drawdown in well RN-16 in the forecasting scenarios.

Fig. 10 shows the development of the average enthalpy for the years 1977 to 2027. From the figure it can be concluded that the greater the production is from the reservoir, the greater the average enthalpy of the geothermal fluid becomes. Increasing the production causes the pressure to drop to a greater extent. As the pressure drops, boiling starts in

shallow feedzones in the wellbores and the enthalpy increases. However, the injection in scenarios 2 and 4 supports the pressure in the reservoir and hinders boiling to occur, which yields lower enthalpy.
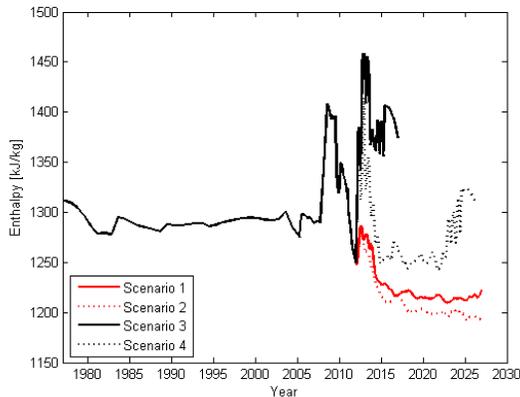

Figure 10: The average enthalpy development in wells in Reykjanes in the forecasting scenarios.

As noted above, scenario 3 causes convergence failure in TOUGH2. Increasing the production rates of the wells and keeping them constant throughout the simulation displays that the recharge to the reservoir cannot keep up with the rate of extraction. This also indicates that existing wells at Reykjanes may not support increased production from the reservoir and new wells covering larger area must be drilled. It should be mentioned that calculations of production rates needed for power generation of 150 MW_e are based on the state of the geothermal fluid observed in 2011. However, increased production causes the pressure to drop and boiling to start in the reservoir, yielding geothermal fluids with higher enthalpy. More steam can be obtained from fluids with higher enthalpy than the ones with lower enthalpy so the total mass of geothermal fluid needed for power production diminishes. Therefore, the pressure drop due to increased production will eventually result in less mass extraction from the reservoir. From this discussion it can be assumed that scenarios 3 and 4 display the worst-case scenario of increased production from the reservoir and that this increased production may even sustain greater power generation than 150 MW_e.

CONCLUSIONS AND FUTURE WORK

The focus of this work was to develop a model that can simulate the flow in a geothermal reservoir as well as the flow in a production well in a coupled manner using measured wellhead conditions as main inputs. The program TOUGH2 was used to simulate the behavior of a reservoir while a new model was used to simulate two phase flow in a wellbore.

A detailed numerical model of the Reykjanes geothermal field in Iceland including the coupled wellbore-reservoir model was constructed. An acceptable pressure distribution for the natural state was obtained in most wells. The exploitation and pressure drawdown history of the Reykjanes reservoir was used to find new estimates for the permeability in xy-direction and z-direction in the rock types SIDE1 and ROCK1-5. The new estimates yielded an excellent fit to the pressure data, but since the rock structure of Reykjanes was only roughly divided into sections it cannot be stated that these estimates reflect the actual permeability distribution.

Measured wellhead conditions for each month of the year 2011 were used to couple the numerical model to FloWell. The coupling procedure was carried out in an iterative manner where the model design in FloWell and in the numerical model was improved by calibration with iTOUGH2. The parameters improved were the productivity indices of the wells, a variable in the Rouhani-Axelsson void fraction correlation and the permeability in the center of the reservoir.

The calibrated numerical model was used in forecasting scenarios to predict the reservoir's response to future exploitation. Four scenarios were considered where the production rates of the wells were either kept constant as observed in 2011 or increased to maintain a 150 MW_e power production, with an increase in injection or not. Increasing the production the pressure dropped in the reservoir and the average enthalpy of the geothermal fluid in the reservoir increased. Seeing as the production rates were fixed throughout the simulations in the scenarios it can be assumed that they can sustain even greater power generation than 150 MW_e.

In the future, it would be advisable to increase the simulation time for the coupled FloWell-TOUGH2 model and the numerical model of Reykjanes when more measured wellhead data becomes available. Also, the modeling approach introduced in this study should be applied to other geothermal systems with as accurate data as possible to improve its performance and hopefully extend its application field.

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