The Wellbore Simulator FloWell – Model Enhancement and Verification

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ABSTRACT

Since the geothermal industry began developing, numerous geothermal models have been published. The simulator FloWell, developed at the University of Iceland in 2012, is one of the latest addition to the bundle of geothermal models. FloWell is a wellbore simulator designed to model liquid, two-phase and superheated steam flows in geothermal wells. FloWell is considered a very simple simulator, user-friendly and computationally inexpensive. It has been coupled with the reservoir simulator TOUGH2 with good results and is now being incorporated into iTOUGH2 to enable direct use of wellhead production data for model calibration.

In order to thrive in the fast developing industry and to stay up-to-date, it is vital that the development of FloWell is a continuous process. This paper discusses the enhancement and further verification of FloWell. During the initial development some general assumptions had to be made for simplification, such as simulations were restricted to wells with a single feedzone and for a single diameter value. In this paper the feasibility and implementation of adding these features to FloWell are discussed. Furthermore, a new interface of FloWell is introduced, improving the ease of use of the simulator. Lastly, an inverse analysis with iTOUGH2-PEST is performed for parameter estimation in FloWell in order to assess which factors have the most impact during wellbore simulations.

1. INTRODUCTION

Geothermal energy is classified as a renewable resource and has the potential of contributing greatly to sustainable energy use in many parts of the world. The energy is generated and stored in the Earth. The main source of the heat is the radioactive decay of unstable isotopes within the mantle and the crust and also some of the heat stored in the Earth is from the formation of the planet. Heat flows continuously from Earth's core to the surface, heating rocks and groundwater, and from the surface it is lost to the atmosphere. In terms of the human life time, the geothermal energy available is virtually inexhaustible, if used in a sensible manner (Carella, 2001).

Monitoring the behavior of a geothermal reservoir and wells over time leads to a greater understanding of the resource's nature and allows extensive databases of geophysical parameters to be created. Mathematical models are developed on the basis of these databases. These numerical models are one of the most important tools in geothermal resource management. They can be used to extract information on the condition of geothermal systems, predict reservoir behavior and estimate production potential (Axelsson, 2003).

With the growth of the geothermal industry, computer models of geothermal systems have become more sophisticated. The geothermal industry began accepting the concept of geothermal simulations in the 1980s. During that time, a great deal of pioneering work was published, but the lack of computer power forced the pioneers to simplify the geometry in their models so computational meshes could be created. As the computer power available increased more complex simulators emerged, producing more accurate results than their predecessors (O'Sullivan et al., 2001).

Even though there are various geothermal simulators available, many of them are limited in finding a good agreement between simulated and measured field data. FloWell is a new wellbore simulator developed at the University of Iceland in 2012. It is designed to model liquid, two-phase and superheated steam flows in geothermal wells. FloWell is considered a very simple simulator, user-friendly and computationally inexpensive. It has several built-in features, for example one that allows the user to identify which correlation for the void fraction should be use. FloWell has been coupled with the reservoir model TOUGH2 with good results and is now being incorporated into iTOUGH2 to enable direct use of wellhead production data for model calibration.

This paper discusses in detail the theoretical background of FloWell as well as describes the basic structure of the simulator, its features and limitations. In order to thrive in the fast developing industry and stay up-to-date, it is vital that the development of FloWell is a continuous process. In this paper, a further enhancement of FloWell is outlined and a new interface of the model introduced. During the initial development, simulations were restricted to wells with a single feedzone and a single diameter. In this paper the implementation of adding these features to FloWell are presented. Furthermore, an inverse analysis with iTOUGH2-PEST is performed for parameter estimation in FloWell in order to assess which factors have the most impact during wellbore simulations.

2. THE PHYSICAL MODEL OF FLOWELL

Two phase flow occurs frequently in nature and is most common in geothermal reservoirs, wellbores and surface pipelines. Whether the flow contains two immiscible liquids, a liquid and a solid, a liquid and a vapor, or a solid and a vapor, the internal topology of the flow constantly changes as the phases interact, exchanging energy, momentum and often mass. The following sections describe the mathematical approach behind the wellbore simulator FloWell, beginning with the most general principles governing the behavior of matter, namely, conservation of mass, momentum and energy.

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The expressions of the governing equations for single and two phase flow proposed by Pálsson (2011) are used in this study.

2.1 Single Phase Flow

The continuity equation derived from conservation of mass can be written as

$$u\left(\frac{\partial \rho}{\partial p}\frac{dp}{dz} + \frac{\partial \rho}{\partial h}\frac{dh}{dz}\right) + \rho\frac{du}{dz} = 0 \tag{1}$$

The energy equation containing a kinetic energy, gravitational potential energy and a thermal energy part. This equation can be written as

$$\dot{m}u\frac{du}{dz} + \dot{m}\frac{dh}{dz} + \dot{m}g + \dot{Q} = 0 \tag{2}$$

The momentum equation containing inertia, pressure changes, hydrostatic pressure and head loss part. The relation is written as follows

$$\rho u\frac{du}{dz} + \frac{dp}{dz} + \rho g + \frac{\rho f}{2d} + u^2 = 0 \tag{3}$$

where f is the friction factor and d is the pipe diameter. Possible relations for the friction factor are the Blasius equation for smooth pipes

$$f = \frac{0.316}{\text{Re}^{1/4}} \tag{4}$$

and the Swamee-Jain relation, where the effect of pipe roughness is included;

$$f = \frac{0.25}{\left(\log\left(\frac{\varepsilon}{3.7d} + \frac{5.74}{\text{Re}^{0.9}}\right)\right)^2} \tag{5}$$

The Reynolds number used for the evaluation of the friction factor is defined as

$$\text{Re} = \frac{\rho u d}{\mu} \tag{6}$$

2.2 Two Phase Flow

In two phase flow the flow consist of liquid and vapor states. Assuming constant pipe diameter, using the void fraction definition and introducing the uniform velocity u instead of the actual velocities, the continuity equation becomes

$$u\frac{\partial \rho_l}{\partial p}\frac{dp}{dz} + \rho_l\frac{du}{dz} = 0 \tag{7}$$

Similar to single phase flow, the energy equation can be written as

$$\frac{d}{dz}\left(\dot{m}_l\left(\frac{u_l^2}{2} + gz + h_l\right) + \dot{m}_g\left(\frac{u_g^2}{2} + gz + h_g\right)\right) + \dot{Q} = 0 \tag{8}$$

By using the mass fraction x, the uniform velocity u and the partial derivatives the energy equation can be expressed on the form

$$\gamma u\frac{du}{dz} + \frac{u^2}{2}\frac{\partial \gamma}{\partial p}\frac{dp}{dz} + \left(1 + \frac{u^2}{2}\frac{\partial \gamma}{\partial h}\right)\frac{dh}{dz} + g + \frac{\dot{Q}}{\dot{m}} = 0 \tag{9}$$

where γ is defined as

$$\gamma = \frac{(1-x)^3}{(1-\alpha)^2} + \frac{\rho_l^2 x^3}{\rho_g^2 \alpha^2} \tag{10}$$

The momentum equation for two phase flow can be written as

$$\eta \rho_l u \frac{du}{dz} + \left(1 + \rho_l u^2 \frac{\partial \eta}{\partial p} + \eta u^2 \frac{\partial \rho_l}{\partial p}\right)\frac{dp}{dz} + \rho_l u^2 \frac{\partial \eta}{\partial h}\frac{dh}{dz} + \left((1-\alpha)\rho_l + \alpha\rho_g\right)g + \frac{\Phi^2 \rho_l f}{2d} u^2 = 0 \tag{11}$$

where Φ^2 is the frictional correction factor for pressure loss in two phase flow and η is defined as

$$\eta = \frac{(1-x)^2}{1-\alpha} + \frac{\rho_l}{\rho_g}\frac{x^2}{\alpha} \tag{12}$$

Since u is based on a fluid with liquid properties, the friction factor is evaluated based on

$$\mathrm{Re}_l = \frac{\rho_l u d}{\mu_l} \tag{13}$$

2.1.1 Friction Correction Factor

Various relations exist for the friction correction factor Φ^2. Here, two relations will be presented, the Friedel and Beattie approximations. The Friedel (1979) correction factor is defined as

$$\Phi^2 = E + \frac{3.24FH}{Fr^{0.045}We^{0.035}} \tag{14}$$

where

$$E = \left(1 - x^2\right) + x^2 \frac{\rho_l}{\rho_g}\frac{f_g}{f_l} \tag{15}$$

$$F = x^{0.78}\left(1 - x^2\right)^{0.24} \tag{16}$$

$$H = \left(\frac{\rho_l}{\rho_g}\right)^{0.91}\left(\frac{\mu_g}{\mu_l}\right)^{0.19}\left(1 - \frac{\rho_g}{\rho_l}\right)^{0.7} \tag{17}$$

$$Fr = \frac{\rho_l^2 u^2}{g\rho_x^2 d} \tag{18}$$

$$We = \frac{\rho_l^2 u^2 d}{\sigma\rho_x^2} \tag{19}$$

$$\frac{1}{\rho_x} = \frac{x}{\rho_g} + \frac{1-x}{\rho_l} \tag{20}$$

Here ρ_x is the homogenous density based on steam quality. The Beattie (1973) correction factor is much simpler, and can be calculated by a single equation.

3

$$\Phi^2 = \left(1 + x\left(\frac{\rho_l}{\rho_g} - 1\right)\right)^{0.8} \left(1 + x\left(\frac{3.5\mu_g + 2\mu_l}{(\mu_g + \mu_l)\rho_g} - 1\right)\right)^{0.2}$$

2.1.1 Void Fraction Definition

One of the critical unknown parameter in predicting pressure behavior in a wellbore is the void fraction, which is the space occupied by gas or vapor. Countless void fraction correlations have been created and it can often turn out to be a difficult task choosing the appropriate correlation.

The homogeneous model is the most simplified. The two phases, liquid and vapor, are considered as homogeneous mixture, thereby traveling at the same velocity. Another approach is to assume that the phases are separated into two streams that flow with different velocities. The modified homogeneous model introduces the slip ratio, S, which is the ratio between the flow velocities at a given cross section. The model can be written as

$$\alpha = \frac{1}{1 + \left(\frac{1-x}{x}\right)\left(\frac{\rho_g}{\rho_l}\right)S} \tag{22}$$

In the homogenous model it is assumed that the slip ratio is equal to one. Other models extend the simple homogenous flow model by using other derived relations as the slip ratio. Zivi (1964) proposed that the slip ratio was only dependent on the density ratio of the phases;

$$S = \left(\frac{\rho_l}{\rho_g}\right)^{1/3} \tag{23}$$

Chisholm (1973) arrived at the following correlation for the slip ratio:

$$S = \left(\frac{\rho_l}{\rho_x}\right)^{1/2} \tag{24}$$

One of the more complex void fraction based on slip ratio is the one introduced by Premoli et al. (1970). Their slip ratio is defined as

$$S = 1 + F_1\left(\frac{y}{1 + yF_2} - yF_2\right) \tag{25}$$

where

$$F_1 = 1.578\text{Re}_l^{-0.19}\left(\frac{\rho_l}{\rho_g}\right)^{0.22} \tag{26}$$

$$F_2 = 0.0273We_l\,\text{Re}_l^{-0.51}\left(\frac{\rho_l}{\rho_g}\right)^{-0.08} \tag{27}$$

$$y = \frac{1}{\left(\frac{1-x}{x}\right)\left(\frac{\rho_g}{\rho_l}\right)} \tag{28}$$

$$We_l = \frac{G^2 d}{\sigma\rho_l} \tag{29}$$

$$\text{Re}_l = \frac{Gd}{\mu_l} \tag{30}$$

The Lockhart-Martinelli correlation (1949) is often chosen due to its simplicity. In this model, the relationship between void fraction, steam quality, density and viscosity is derived as

$$\alpha = \frac{1}{1 + 0.28\left(\frac{1-x}{x}\right)^{0.64}\left(\frac{\rho_g}{\rho_l}\right)^{0.36}\left(\frac{\mu_l}{\mu_g}\right)^{0.07}} \tag{31}$$

Rouhani and Axelsson (1970) proposed a void fraction computed by a semi-empirical equation given as

$$\alpha = \frac{x}{\rho_g}\left(\left(1 + 0.12(1-x)\right)\left(\frac{x}{\rho_g} + \frac{1-x}{\rho_l}\right) + \frac{\left(1.18(1-x)\right)\left(g\sigma\left(\rho_l - \rho_g\right)\right)^{0.25}}{G\rho_l^{0.5}}\right)^{-1} \tag{32}$$

This model is more extensive than previous model, as it takes into account the effects of cross sectional area of the pipe, mass flow rate of the mixture, surface tension and gravitation.

3. THE WELLBORE SIMULATOR FLOWELL

3.1 Basic Architecture of FloWell

For this study, a numerical wellbore simulator has been developed and named FloWell. The simulator is built around eq. (1)-(32) defined in the chapter The Physical Model of FloWell and MATLAB is used as a programming language.

To perform a simulation with FloWell the following input parameters are needed:

- Inner diameter and depth of a well
- Roughness of the walls in the well
- Total mass flow rate at the wellhead
- Enthalpy of the working fluid
- Bottomhole pressure or wellhead pressure

3.2 Features and Assumptions

The wellbore simulator is capable of:

- Modeling liquid, two phase and superheated steam flows
- Allowing users to choose between various friction, friction correction factor and void fraction correlations
- Accounting for multiple feedzones and diameters in the well
- Performing wellbore simulations from the bottom to wellhead section, or from the wellhead to the bottom of the well
- Providing simulated results, such as pressure and temperature distribution as well as steam quality, friction, velocity, enthalpy and void fraction at each dept increment
- Providing graphical plots of simulated pressure and temperature profiles

Some general assumptions have been made in the development of the simulator. It is assumed that:

- The flow is steady and one dimensional
- The fluid is pure water and IAPWS Industrial Formulation 1997 is used for the thermodynamic properties of liquid and vapor phases (IAPWS, 2007). The dynamic viscosity is obtained from the IAPWS Formulation 2008 for the viscosity of ordinary water substance (IAPWS, 2008)
- Phases are in thermodynamic equilibrium
- Fluid properties remain constant within a step
- The presence of non-condensable gases and dissolved solids is ignored

The simulator solves the continuity, energy and momentum equations up the well using numerical integration. The ode23 function built in MATLAB is used to evaluate the differential equations. The function uses second and third order Runge-Kutta methods simultaneously to obtain the solution (The MathWorks, 2011). The depth interval is adjusted by the integration function and at each depth node the function produces velocity, pressure and enthalpy values.

To validate the wellbore simulator FloWell, simulated output needs to be compared to measured data. Comparison is essential for the credibility of the simulator but many factors can affect the outcome of the simulation. The accuracy of the wellbore simulator depends mainly on:

- The amount and accuracy of measured data available
- The accuracy of any estimated data, such as well roughness and in some cases well diameter which may have been reduced by scaling

- The validity of correlations coded into the simulator, i.e. friction, void fraction and friction correction correlations
- Moreover, inaccurate prediction can be caused by the use of physical properties of water that do not represent actual thermodynamic behavior of geothermal fluid.

4. NEW VERSION OF FLOWELL

FloWell was designed at the University of Iceland in 2012. The development of FloWell was a part of a study to create a practical tool to evaluate the state of geothermal reservoirs and well performances using measured wellhead conditions and inverse analysis. In order to create this practical tool, FloWell was coupled to the reservoir simulator TOUGH2. Although, FloWell was originally designed to be coupled to a reservoir simulator it can also be used individually to simulate the behavior of producing geothermal wells.

In earlier versions of FloWell, the model was limited to wells with single feedzone. Furthermore, the model could not account for changes in wellbore geometry, such as diameters and roughness. In this new version of FloWell, these features have been implemented and the simulator is capable of simulating wells with multiple feedzones and changes in diameter.
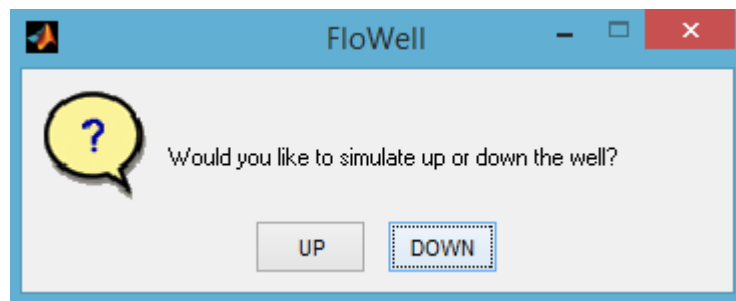
Although FloWell is considered relative simple and user-friendly model, it can be difficult to run the model if the user is not familiar with the program MATLAB or has no background in programming. Therefore, in this new version of FloWell, the user interface has been re-designed in order to facilitate the user to run the simulator and obtain both graphical results and numerical values of the simulated results.

4.1 The Interface of FloWell

The new interface of FloWell is user oriented and does not require the user to have programming knowledge other than being able to start the model. Once FloWell has been run the user is guided through series of steps in order to start a simulation of the geothermal well.

Step 1: Choosing between types of simulations

Since FloWell is capable of simulating both from bottom to the top of well (UP) and from top to the bottom of the well (DOWN) the user is asked to choose between these two types of simulations.

Figure 1: The interface of FloWell, the user is asked to choose between two types of simulations, up or down.

Step 2: Inserting input values

As listed above, FloWell needs several input values to be able to perform simulations of the flow in geothermal wells. These input values can be seen in Figure 2.

At the top of the input window the type of simulation is listed. The type of simulation is chosen in step 1. In this case the user has selected to simulate from the top of the well towards the bottom. Since this type of simulation has been selected, the user is asked to insert values measured at the top of the well; pressure, enthalpy, mass flow and diameter. If the user had selected to start from the bottom and simulate up, he would be asked to insert values measured at the bottom of the well. Other necessary input values are the depth of the well, that is how deep the user whishes to simulate, and the roughness of the well. One of the features of FloWell is to allow the user to choose between various friction factor, friction correction factor and void fraction correlations. These options can be seen in the lower half of the input window.

The newly implemented feature of multiple feedzones and diameters can be seen in table in Figure 2. There the user has the option of inserting varying values for the diameter and mass flow for different depth increments. In this case the user has inserted 315 mm diameter and 70 kg/s mass flow at the top of the well. At the depth of 845 m, the diameter decreases to 245 mm (this is the end of the production casing and where the liner starts). Moreover, the user specifies three feedzones at 985 m, 1100 m and 1325 m. The feedzone at 1325 m depth is the largest one with incoming fluid of 40 kg/s. The other feedzones are substantially smaller, with incoming fluid of 15 kg/s each.

Once the user is satisfied with the input values he has inserted, the "SIMULATE" button is clicked and FloWell starts to simulate the geothermal well. If the user whishes to cancel the simulation he can stop the simulation by clicking the "x" button in upper right corner.

Figure 2: The interface of FloWell, the user is asked to insert input values into the simulator and then to click the button "SIMULATE".

Step 3: Obtaining output values

The user can obtain both graphical and numerical results as can be seen in Figure 3. Once FloWell has finished simulating the wellbore a window appears allowing the user to interact with the model.

Figure 3: The interface of FloWell, the user can choose which results to view.

The user can choose to view several different graphical plots, such as pressure vs. depth, temperature vs. depth and steam quality vs. depth. When the user has selected the result to plot, the button "Update figure" is clicked and the plot appears below the popup menu. Furthermore, the user can click the "Obtain results as .txt file" and obtain the results as a text file. In the text file both input values and output values are listed. This is shown in Figure 4.


```
simulation_down_results - Notepad

File  Edit  Format  View  Help

INPUT
Type of simulation: From top of well to bottom
Depth of well (L): 1475 m
Roughness of well (e): 1 mm

Measure values at the top of well:
Pressure (p): 15 bar-a
Enthalpy (h): 1030 J/kg
Mass Flow (m): 70 kg/s
Diameter (d): 315 mm

Void Fraction: Rouhani-Axelsson
Friction Factor: Blasius
Friction Correction Factor: Friedel

Multiple dimensions and feedzones:
Depth (L)       Diameter (d)    Mass Flow (m)
0               315             70
854             245             70
985             245             70
1100            245             55
1325            245             40

OUTPUT
Depth (L)       Pressure(p)     Temperature(T)  Quality (x)  Enthalpy (h)  Velocity (u)
0               14.6578         197.2034        0.0975       1030.0        1.0330
140.0           17.5830         205.9651        0.0793       1031.4        1.0330
280.0           20.7785         214.3237        0.0612       1032.7        1.0330
420.0           24.5546         223.0024        0.0415       1034.1        1.0330
503.0           27.3584         228.8006        0.0277       1034.9        1.0330
562.1           29.8912         233.6570        0.0156       1035.5        1.0330
607.4           32.4966         238.3329        0.0036       1036.0        1.0330
622.7           33.6735         239.6807        0            1036.1        1.0330
638.0           34.8951         239.7099        0            1036.3        1.0329
714.5           41.0049         239.8558        0            1037.0        1.0323
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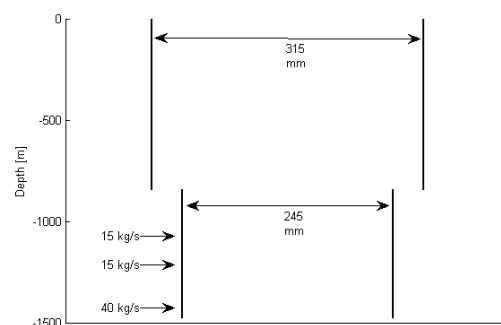
Figure 4: The interface of FloWell, input and output values in a text file.

4.2 New Features added to FloWell

The implementation of multiple feedzones and diameters in FloWell is quite simple. When the user has inserted input values into the input window (Figure 2) and clicked the "SIMULATE" button, the model constructs a matrix with three columns; depth, diameter and mass flow rates. FloWell evaluates the differential equations (continuity, energy and momentum equations) with the ode23 (second and third order Runge-Kutta formulas) built in MATLAB in steps. The steps are defined by the depth values in the first column of the matrix. If the user has chosen to simulator from the top to bottom, FloWell starts the simulation from the depth value defined in the first row and simulates down to the one in the next row. FloWell continues simulating down the well in this manner until it has reached the end of matrix. The depth interval within each step is defined by the integration function (ode23). After each step FloWell calculates new initial values for the pressure, enthalpy and velocity before starting the next step. Moreover, FloWell saves outputs after each step and at the end of simulation, the results are processed, output values organized and joined in one file.

After inserting input values the user has the option of inspecting visually the geometry of the well as well as the feedzones and magnitude of flow within the well. This is illustrated in Figure 5.

Figure 5: Graphical plot of the geometry and location of feedzones within the well.

4.3 Simulations with the new version of FloWell

Simulations with the new version of FloWell can be seen below. The wells used are from two geothermal fields, Reykjanes (RN-12) and Svartsengi (SV-21), in Iceland. RN-12 and SV-21 have similar characteristics (RN:Reykjanes, SV:Svartsengi). They are vertical wells with low enthalpy fluid and steam fraction between 9-13% at the wellhead. For these simulations the Blasius equation and the model by Friedel are used to calculate the friction factor and friction correction factor. For well RN-12 the Rouhani-Axelsson and the Chisholm void fraction correlations perform the best. For well SV-21 the Homogenous correlation shows simulations closest to the measured data. The Homogenous correlation usually yields adequate simulations for wells with a low steam fraction, for it assumes that the phases travel at the same velocity. This is the case in well SV-21, the steam fraction in the well is between 9-10%, while the steam fraction in well RN-12 is little over 13%.
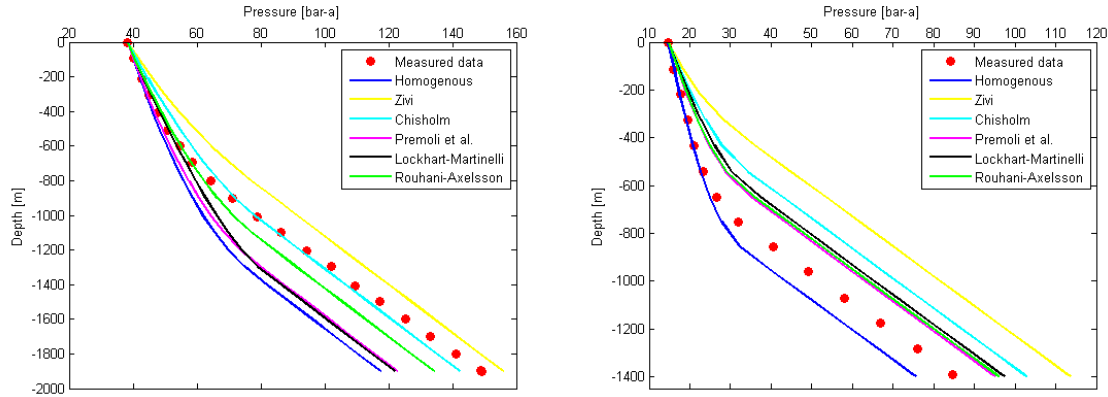

Figure 6: Simulations for well RN-12 (left) and SV-21 (right).

The new version of FloWell allows for changes in diameters and multiple feedzones. A typical well usually has a production casing with one diameter and a liner with another. Scaling can also cause changes in the diameter of the well as layers are added to the pipe wall resulting in reduction in the inner diameter of the well. Simulations with changing diameter, one for the upper half of the well (production casing) and another smaller one for the lower half of the well (liner), results in higher pressure at the bottom of the well as expected. Allowing the fluid to flow into the well at different depths also has some effect on the pressure distribution.

5. INVERSE ANALYSIS WITH FLOWELL

There are many uncertainties associated with wellbore modeling. In order to estimate the model's accuracy, results are compared to measured pressures at various depths. The measurements are performed at fixed mass rates and estimated enthalpy. In this paper, an inverse analysis with iTOUGH2-pest is used to correct the flow, enthalpy and correction factor in the homogeneous model of void fraction for two wells, i.e. well SV 21 and RN 12. The diameter of the production casing is the same for both wells, i.e. D = 0.3153 m. For the analysis, it is assumed that the inflow is at the bottom of the well. Figure 7 right shows results for well SV 21. According to measurements, the enthalpy is 1030 kJ/kg, the mass flow is 70 kg/s, and the red line in the figure shows the measured pressure. The cyan line shows model's results for the same enthalpy and mass flow with a correction factor equal to 1. The result of the inverse analysis is shown with a blue line. The mass flow is 65 kg/s, the enthalpy is 977 kJ/kg, and the correction factor is equal to 0.68.
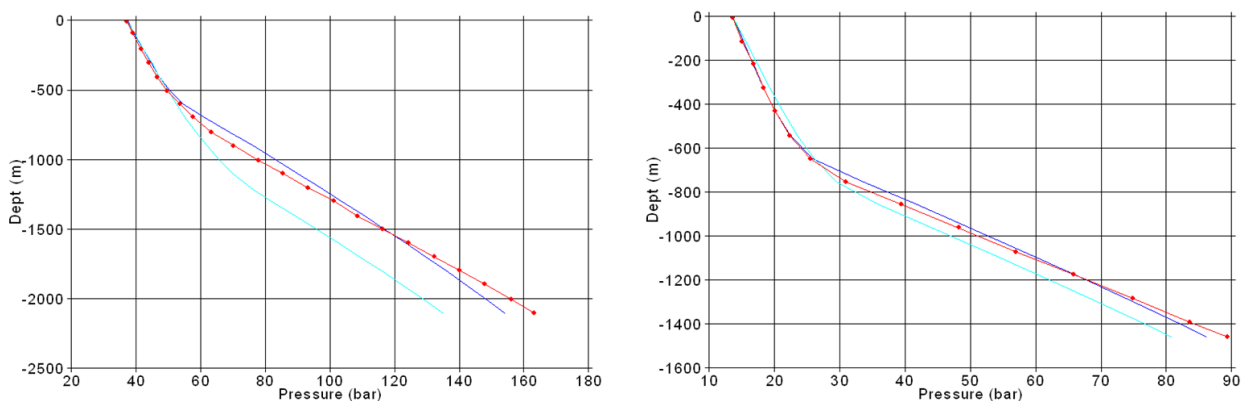

Figure 7: Inverse Analysis for well RN-12 (left) and SV-21 (right).

In Figure 7 right, the measured enthalpy is 1300 kJ/kg and the mass flow is 110 kg/s. The red line shows the pressure distribution and the blue line shows the model's results for the same conditions. The inverse analysis gives the best results, shown in blue, when the enthalpy is 1190 kJ/kg, the mass flow is 130 kg/s, and the correction factor is equal to 0.5. The inverse analysis also indicates that the enthalpy and the mass flow are correlated.

6. CONCLUSIONS AND FUTURE WORK

The wellbore simulator FloWell was designed at the University of Iceland in 2012 as a part of a study to create a practical tool to evaluate the state of geothermal reservoirs and wells by using measured wellhead conditions and inverse analysis. During the initial development, FloWell was a single feedzone and one dimensional simulator that used bottomhole or wellhead pressures, mass flow rates and well enthalpies to solve general equations for conservation of mass, momentum and energy.

The development of FloWell is a continuous process and with this new version of the simulator some improvements have been made. First, the user interface has been re-designed where the user is guided to series of steps in order to run a simulation of a geothermal well. Second, the code of the simulator has been enhanced allowing for simulations of wells with multiple feedzones and changing diameters within the well.

With the new interface of FloWell, the user can choose between simulating from top to bottom of well or from bottom to top of well. Moreover, the user is instructed which inputs are necessary for the simulation and is given the opportunity to insert different geometric values for the well as well as mass flows. Lastly, the user can obtain graphical results, such as pressure vs. depth or temperature vs. depth, in addition to obtaining the results as a text file, both input and output values. By adding the feature of multiple feedzones and diameters the accuracy of FloWell can be improved. However, it can prove difficult to evaluate how much the accuracy is enhanced since uncertainties are involved in measured data, such as the depth of feedzones and magnitude of fluid flowing into the well.

In order to improve the model's accuracy an inverse analysis is used to correct the flow, enthalpy and correction factor in the homogeneous model of void fraction for two wells, i.e well SV 21 and RN 12 with good results.

For future steps, further improvements could be made. The possibility of integrating curves for the well head valve could be analyzed. Such integration would allow for simulations with FloWell to be compared to pressure measurements taken before and after the valve. Moreover, this could be a step towards making a model that could simulate the total cycle of a geothermal power plant, from bottom of well to electricity production in the turbine. Furthermore, adding more options for the void fraction and friction correction factor correlations would allow the simulator to become even more user-friendly. Lastly, further verification of the new version of FloWell is necessary by simulating various types of wells with changing geometry and multiple feedzones and comparing to results from older versions of FloWell.

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