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SIMGWEL: EDC's New Geothermal Wellbore Modeling Software

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ABSTRACT

Simgwel is a new geothermal wellbore simulator intended as a tool for making resource management decisions and as well as a user-friendly alternative to existing DOS-based simulators. It is intended to model fluid flow in a geothermal well by solving steady-state conservation equations for liquid, vapor, and two-phase water with carbon dioxide gas present in both phases for testing against measured data from production or injection. Simgwel may be used to perform top-down and bottom-up simulations for vertical and deviated production and injection wells by defining the wellhead and/or feed parameters and well-geometry specifications. Its core is based on the research tool GWELL, rewritten in Fortran95 and improved to better handle effective viscosity at feeds, enable a graphical user interface, deliver output curve predictions using discharge test simulations and feed parameters and include various two-phase correlations as options for the user. Preliminary evaluation of the performance of the software using the Orkiszewski correlation was done using several discharge test cases.

1. INTRODUCTION

Simgwel is a wellbore simulation tool developed by Marsan Consulting Limited and Energy Development Corporation (EDC) that allows reservoir engineers to model the behavior of a discharging well, compare model data with actual flowing surveys and bore output measurements and predict the output of a well in response to changes in reservoir parameters or casing geometry. The primary purpose of developing Simgwel is to produce a reliable alternative to the latter company's existing DOS-based simulators which has either unresolved bugs or tedious and complicated work flow. The simulator was built on the foundations of GWELL, which solves coupled steady-state mass, momentum and energy conservation equations for liquid, vapor or two-phase fluids, with minimum to significant carbon dioxide mass fraction. The new simulator also includes several core enhancements to GWELL, among which are improvements to the treatment of effective viscosity at a feed, a portable and Windows-based graphical interface that enables a user-friendly simulation workflow, input handling functionalities, deliverability curve prediction using discharge test simulations and additional two-phase flow correlations.

2. SIMGWEL FEATURES

Simgwel solves one-dimensional coupled steady-state mass, momentum, and energy conservation equations for liquid, vapor, and two-phase water (McGuinness M. J., 2013). The conservation of momentum is generalized by the following relation:

$$\frac{\partial p}{\partial z} = -\frac{1}{A}\frac{\partial}{\partial z}(Qu^m) + p_z^f + p_z^g, \tag{1}$$

where A is the variable cross-sectional area of a wellbore section, u^m is a flowing average two-phase velocity, z is the distance along the well, Q is the total mass flow rate along the section, p_z^f and p_z^g are frictional and gravitational pressure drops, respectively. Energy conservation, on the other hand, is expressed in terms of a flowing two-phase enthalpy h_{flo}, a flowing two-phase kinetic energy KE, acceleration due to gravity g and the inclination angle θ from horizontal:

$$\frac{\partial}{\partial z}[\mathrm{h_{flo}} + \mathrm{KE}] + g\sin\theta = 0. \tag{2}$$

Various correlations are available to the user to determine the relative velocities of vapor and liquid phases such as Armand, Orkiszewski, Hadgu, Duns & Ros, and Hagedorn & Brown. Armand and Orkiszewski already exist in the base application, GWELL, while others were added to the final Simgwel module based on their acceptable performance in modeling specific geothermal well test conditions as shown in a related study (Probst, Gunn, & Andersen, 1992).

2.1 Simgwel Capabilities

The capabilities of this wellbore simulator include: a) modeling liquid, steam, and two-phase flow with CO_2 content, b) providing considerations to the effect of heat conduction between the reservoir and the well to the simulated parameters, c) giving options for using different well geometry parameters; i.e. roughness, inclination, and inner diameter, d) performing bottom-up and top-down runs for multiple and single feed production and injection (single-phase only) well models, e) producing simulated velocities and density for each phase, two-phase velocity, flash point, flow regime, CO_2 mass fraction, enthalpy, dryness, temperature, and pressure values across a well's depth, f) providing the output of the well for different wellhead pressures using estimated deliverability parameters (linear and quadratic drawdown coefficients, steam coefficient, and viscosity-independent productivity index) given other feed properties such as reservoir pressure and enthalpy, g) considering inputs for setting the bottom-hole pressure range of the simulated output curve and h) giving graphical plots of simulated temperatures, velocities, pressures, and bore output curves (McGuinness M. J., 2014). The Windows-based interface is easier to grasp, the time it consumes for calculation is significantly shorter, input parameters can be imported from source files, and output text files of simulation results are automatically generated in a designated directory.

2.2 Typical Workflow

There are four tabs in the main window of Simgwel (Figure 1): a) Input Setup, b) Data Input, c) Result, and d) Graphs. To perform a simulation, the following input parameters are necessitated in Input Setup: a) feed parameters (depth, feed type, pressure, enthalpy, productivity, CO_2 content), b) wellhead parameters (wellhead pressure, mass flow, enthalpy, CO_2 content), c) well geometry parameters (section length, diameter, and roughness), and d) simulation requirements (direction, flow correlation, conductive heat transfer inputs, and output test specifications). Discharge, output test simulations and plotting of results against actual data may be conveniently accomplished in one run if all the necessary inputs are given. The measured temperature, pressure, and well output data usually used in matching simulations are entered in Data Input while detailed in Results are the feed and wellhead input/output parameters. Temperature, velocity, and pressure profiles from discharge runs and bore output curves from output runs are summarized in the Graphs tab.

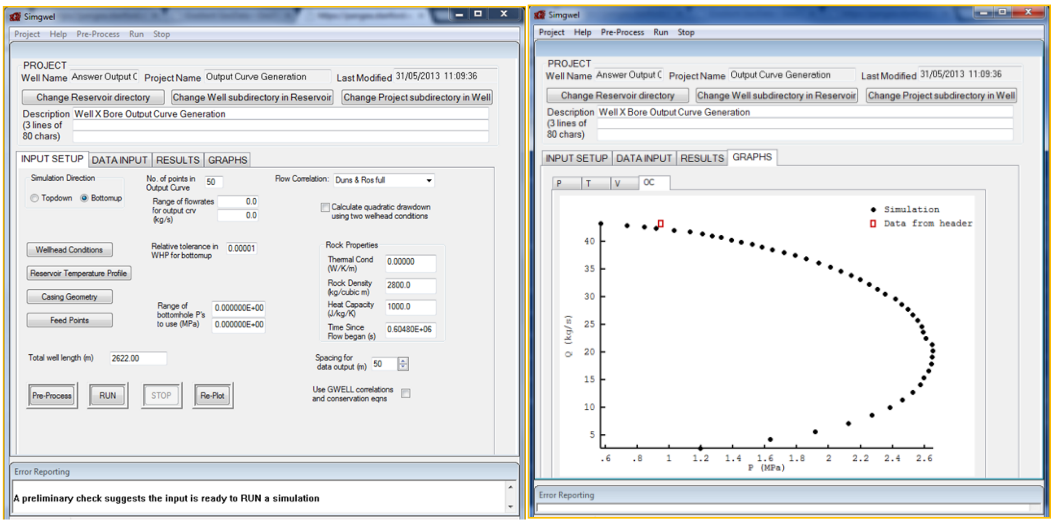

Figure 1. Snap shot of Simgwel input deck and graphical output display.

3. SIMGWEL EVALUATION

3.1. Wellbore Pressure and temperature at Depth Comparisons

Preliminary evaluation of the wellbore simulator involved wellbore pressures and temperatures at depth comparisons for Simgwel top-down simulation results, actual data and as well as results of existing DOS-based simulators, including GWELL. The Orkiszewski correlation was chosen for the comparison analysis since many earlier studies have confirmed the general applicability of the Orkiszewski correlation to geothermal wellbore flow (Ambastha & Gudmundsson, 1986). The fundamental aspects and limitations of the Orkiszewski correlation are adequately discussed in a previous study (Jasso & Pena, 1990). Six (6) discharge test simulation cases were chosen on the basis of wellhead dryness, mass flow, casing geometry and carbon dioxide content. Simulations only covered the length of the wellbore from the casing head flange (CHF) down to just above the shallowest feed to remove any bias that may result from user inputs of feed flow and enthalpy. They also ignored the effects of heat transfer from the formation to the wellbore. Discharge test parameters of the test cases were obtained using the James Lip Pressure Method of computing bore output while downhole surveys were taken using Kuster pressure and temperature gauge, except Well E for which a PTS tool was used. A table of categorized production test data used for the comparison is shown as follows:

Table 1. Categorized production test data of six (6) discharge test cases used for the evaluation of Simgwel. Mass flow types are High (>50 kg/s), Moderate (30-50 kg/s), and Low (<30 kg/s). Wellhead dryness categories are High (>2500 kJ/kg), Medium (1500 – 2500 kJ/kg) and Low (<1500 kJ/kg). Carbon dioxide mass fraction ranges are Very Low (0.001-0.01), Low (0.01-0.03) and None (<0.001).

Well	Shallowest Feed Depth (mMD)	Wellhead Diameter (in)	Liner Diameter (in)	Top of Liner (mMD)	Mass Flow (kg/s)	Wellhead Dryness	CO_2 Mass Fraction
A	1250	9-5/8"	7-5/8"	1224	Moderate	Low	Low
B	1950	9-5/8"	7-5/8"	1859	High	Low	Low
C	1300	9-5/8"	7-5/8"	1300	Moderate	Medium	Very Low
D	691 (perforated)	9-5/8"	7-5/8"	1309	Low	Low	None
E	1900	9-5/8"	7-5/8"	1738	Moderate	Low	Low
F	900	9-5/8"	7-5/8 "	887	Low	High	None

The plot of simulated versus actual data showed that Simgwel results are well within the critical limits of variations in the results of the DOS-based commercial simulator athough still beyond the individual accuracies of pressure and temperature measurements which are typically 0.05 MPa and 1^{o}C, respectively. Comparison of mean absolute percentage error (MAPE) showed that Simgwel temperature predictions results proved to be consistently comparable with those of Gwell and the commercial simulator while its pressure predictions are significantly more accurate than the commercial simulator for the test cases executed.

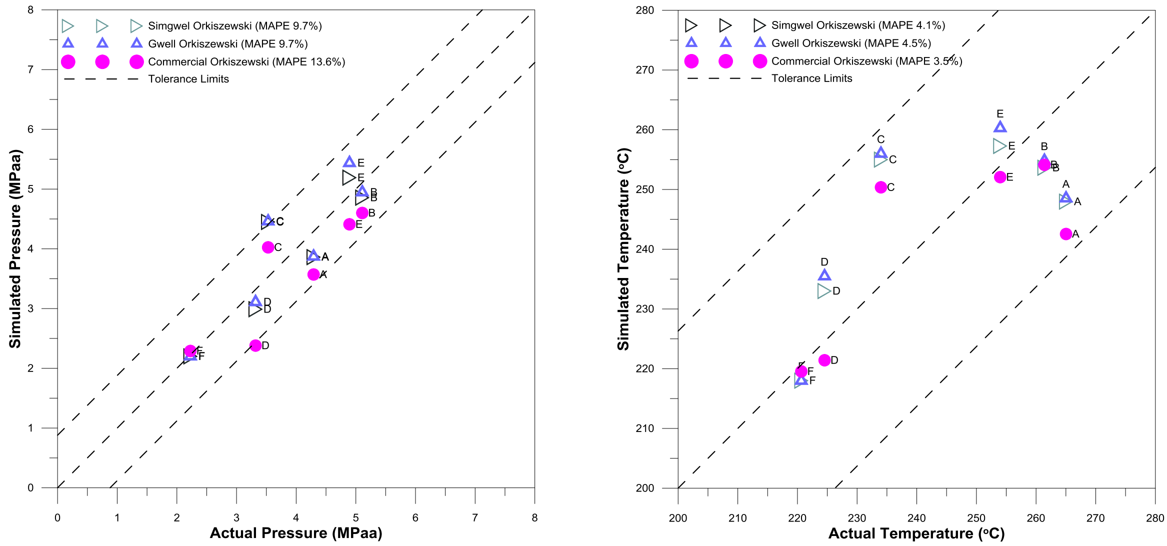

Figure 2. Plots of actual versus simulated pressure and temperature at depth of the welbore simulators. Dashed lines mark the critical limits of the models based on actual variations (3 standard deviations) of the simulated results of the commercial DOS-based simulator.

3.2 Pressure, Temperature, Spinner Survey and Output Curve Matching

Simgwel was also evaluated on its accuracy in jointly matching actual downhole pressure, temperature and spinner data obtained using a PTS tool for a discharging big-hole, deviated well with moderate mass flow, low enthalpy and negligible carbon dioxide content. The test well has seven feed points inferred at 1420, 1690, 1880 (primary), 2060, 2170, 2410, and 2592 mMD. Productivity indices in kg/s-MPa of the seven feed zones were varied from 0.8 to 6.5. The two-phase flow correlation used for the simulation was still Orkiszewski. The bottom-hole pressure in the discharge test simulation was automatically chosen by Simgwel to match the specified wellhead pressure in the Input Setup tab. Computed mean absolute percentage errors for the simulated downhole pressure and temperature were reasonable. The simulated spinner velocities reasonably matched the computed fluid velocities well in the lower section of the wellbore but with difficulty in the upper section (above 1690 mMD) where two-phase feed inflows were encountered. This issue could possibly be fixed with future improvements in the software.

4. CONCLUSIONS AND RECOMMENDATIONS

Preliminary evaluation of Simgwel using the Orkiszewski correlation for several discharge test cases with varied parameters and for a joint discharge and output test simulation showed reasonably consistent and accurate results relative to GWELL (the base code), the commercial DOS-based simulator and actual data. However, more effort is recognized to improve the performance of Simgwel in matching two-phase flow velocities, evaluate the performance of the software in applying other correlations and discharge test options for diverse discharge test conditions. Evaluation of the wellbore simulator also highlighted the application's ease of use, portability, flexibility in handling carbon dioxide inputs at feedzones, and ability to optimize reservoir parameters to match known wellhead parameters.

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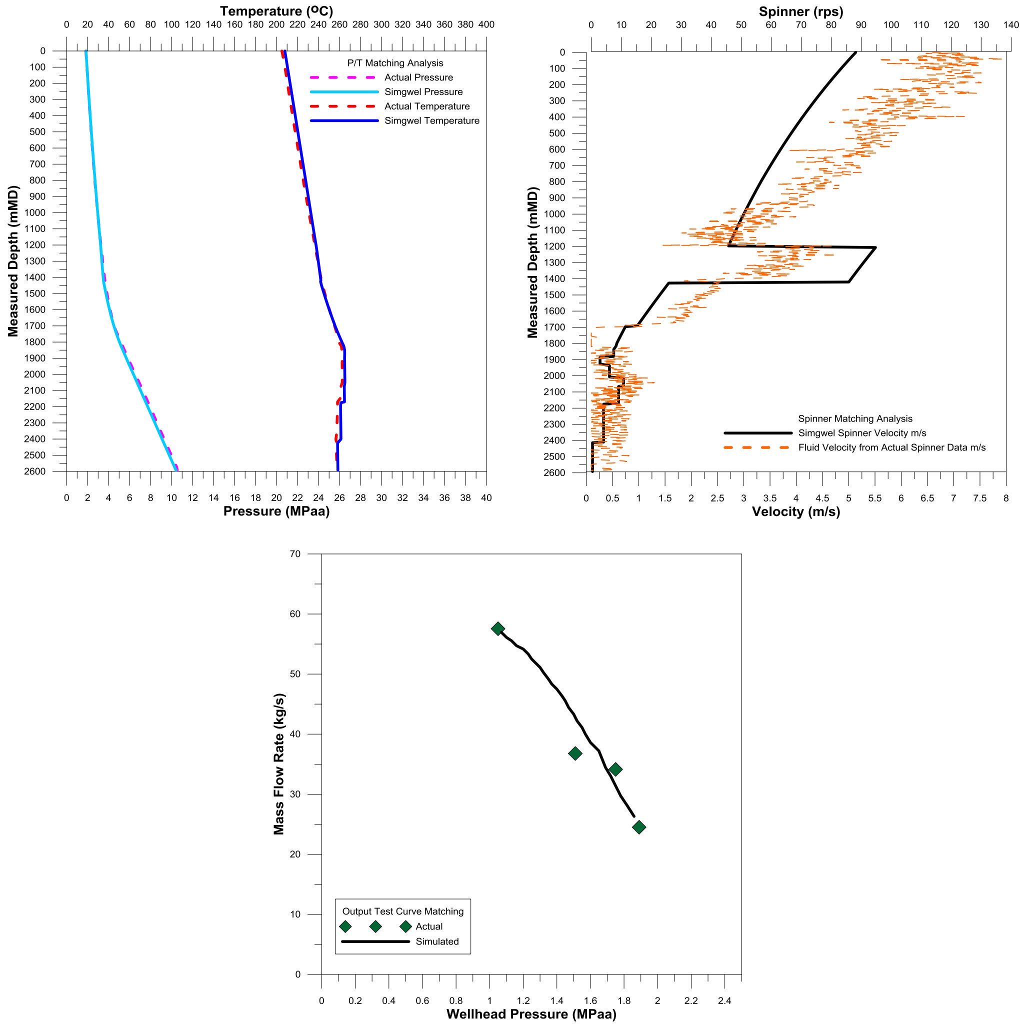

Figure 3. Pressure, temperature, spinner survey and output curve matching for a discharging well. MAPE of simulated pressures is 1.5% while that of simulated temperatures is 0.9%.