



Heat transfer in unconventional geothermal wells: a double numerical modelling approach

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1. INTRODUCTION

Geothermal energy aims at producing electricity or heat from underground resources. Worldwide geothermal energy extraction and use is still limited, despite its estimated high potential. To date, the efficiency and viability of Enhanced Geothermal Systems (EGS) and deep unconventional geothermal resources (e.g. superheated/supercritical systems) via conventional heat recovery techniques have led to limited success due to technology issues. Research on superheated/supercritical geothermal systems is highly active in Europe, notably triggered by the Iceland Deep Drilling project (IDDP) [1]. Supercritical resources could deliver more energy than conventional resources thanks to the increase of enthalpy and the sharp decrease of density around the critical point of water [2]. The first well from IDDP was drilled at a depth of 2072 m after unintentionally drilling into magma between 2092 m and 2104 m. The wellhead temperature reached 450°C, with a superheated steam at a pressure of 140 bars [3].

As geothermal fluid extraction and injection from very hot environment is still a technical challenge, unconventional well designs (e.g. closed-loop wells) can offer more reliable engineering solutions by lowering the risks and the costs compared to the conventional geothermal fields [4,5]. Deep Borehole Heat Exchangers (DBHE) [6] aim at circulating a fluid into a closed well without contact with the geothermal fluids. Forced convection needs to be described to assess the feasibility of the innovative closed-wellbore concept in very hot geothermal conditions.

2. METHODOLOGY

This study uses a double approach to understand the heat transfer taking place in the near-wellbore region of deep geothermal systems. While heat transfer processes in the well and in the reservoir have been investigated through several prior analytical and numerical approaches [5], this study makes a combined use of the 1D coupled wellbore-reservoir simulator T2Well [7] and a Computational Fluid Dynamics (CFD) code to calculate the fluid flow and heat transfer in a closed-well. T2Well describes a 1D transient two-phase non-isothermal flow based on a drift-flux model [8]. For a single component system such as water, it considers the following mass (1) and energy (2) conservations equations:

$$\frac{\partial}{\partial t}(\sum_{\theta} \rho_{\theta} S_{\theta} X_{\theta}) = q - \frac{1}{A} \frac{\partial}{\partial z} (A \sum_{\theta} \rho_{\theta} S_{\theta} u_{\theta}) \quad (1)$$

$$\frac{\partial}{\partial t}(\sum_{\theta} \rho_{\theta} S_{\theta} (U_{\theta} + \frac{1}{2} u_{\theta}^2)) = q - \lambda \frac{\partial T}{\partial t} - \frac{1}{A} \sum_{\theta} \frac{\partial}{\partial z} \left(A \rho_{\theta} X_{\theta} S_{\theta} u_{\theta} \left(h_{\theta} + \frac{u_{\theta}^2}{2} \right) \right) - \sum_{\theta} (\rho_{\theta} S_{\theta} u_{\theta} g) \quad (2)$$

where the subscript θ refers to the liquid and gas phases of water, z is the vertical axis [m]. The terms ρ [kg/m³] and X are the density and the local saturation of the phase considered, respectively. The latter is the ratio between the cross-section occupied by the phase and the total cross-section of the well A [m²]. In addition, q [W/m².K] represents the source or sink term, U [J] is the internal energy of the phase, u [m/s] is the velocity of the phase in the wellbore, λ [W/m.K] is the area-averaged thermal conductivity of the wellbore, h [kJ/kg] is the specific enthalpy, and g [m/s²] is the gravitational acceleration.

While the 1D flow formulation is based on an area-average value over the cross-section of the pipe, CFD can consider the radial system of the well. The CFD code ANSYS FLUENT 17.1.0 is used to solve the mass conservation, momentum and energy equations for water: the realizable k - ε turbulence model is selected, which takes into account the shear stress at the wellbore walls [9]. Due to the nature of the flow and to reduce the overall simulation time, a 2D axisymmetric model is applied. The mass conservation equation for this system can therefore be written as:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_z)}{\partial r} + \frac{\partial(\rho v_r)}{\partial z} + \frac{\rho v_r}{r} = 0 \quad (3)$$

Further details on the radial r - and axis z - momentum equations for an axisymmetric model can be found in [9]. The energy equation is:

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla \cdot (k_{eff} \nabla T - \sum_j \vec{h}_j \vec{J}_j + (\vec{\tau}_{eff} \cdot \vec{v})) \quad (4)$$

where k_{eff} is the effective thermal conductivity [W/m.K] and T is the temperature [K]. The two terms on the right-hand side of Equation 4 describe the diffusion and viscous dissipations. E is the energy calculated with the heat capacity [J/kg.K], detailed in [9].

T2well is based on the TOUGH2 formulation for porous media [10]. It calculates the water properties from the International Formulation Committee (1967). However, this code is currently limited to a maximum temperature of 350°C, which is lower than the temperatures expected for supercritical/superheated geothermal resources. The CFD code does not show such temperature limitations, but simulations require a longer time to run. Similarly to [11], constant water properties are applied in this work, and no phase change is considered in the CFD simulations. Both T2well and FLUENT are used to model a DBHE implemented in hot geothermal conditions, similarly to the IDDP-1 system, with bottom boundary conditions of 350°C at 2km for T2well and 650°C at 2100 m for FLUENT.

3. RESULTS

Figure 1 (Left) represents a DBHE where water is injected downward at a temperature of 10°C in an annular pipe and flowing upward in a central pipe. Figure 1 (Right) shows the CFD-based velocity distribution obtained in the well for an injected mass flow rate of 6 kg/s. As can be seen, water accelerates in the central pipe, from the bottom towards the surface, while no water circulation is present in the deeper region of the well system (navy blue zone).

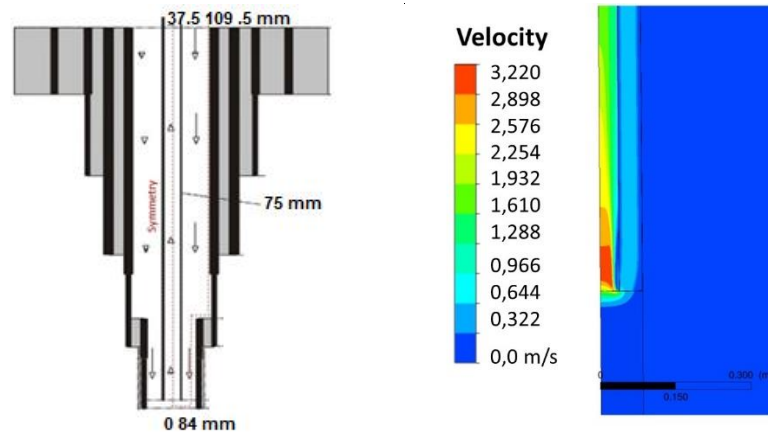


Fig. 1 (Left) DBHE geometry modelled for a depth of 1900 m with a 350°C boundary condition at 2000 m (T2Well), and a depth of 2070 m with a 650°C boundary condition at 2100 m (FLUENT). **(Right)** Velocity distribution in bottomhole region of DBHE for a mass flow rate injection of 6 kg/s.

Figure 2 (Left) shows the transient temperature production at the surface for one year, with the DBHE modelled with both T2Well and FLUENT. Water mass flow rates of 3 kg/s and 6kg/s are injected in the system. The gas saturation is presented on the right axis and is calculated with T2Well with an outlet pressure of 1 bar. steam appears only during few days (10 days for 3 kg/s). Conventionally, DBHEs use water kept in liquid state, but their application in a very hot geothermal context can produce vapour at the outlet. The temperature recovery calculated with FLUENT is higher than using T2Well as it is not limited to 350°C. The FLUENT model describes a different behaviour than T2Well on the first days of simulation until showing a similar slow decrease regime after 100 days. Despite the assumptions made for water in the CFD calculations, the model shows the energy recovery increase, notably the high peak above 350°C, by implementing a DBHE into superheated/supercritical geothermal context.

Figure 2 (Right) highlights the horizontal heat transfer flux computed with FLUENT on the vertical external wall of the DBHE after 10 years. The heat flux reaches nearly 4 kW.m⁻² at the bottom. The heat transfer is maximum at the bottom hole, mainly due to the temperature difference between the near-wellbore environment and the working fluid (around 100°C).

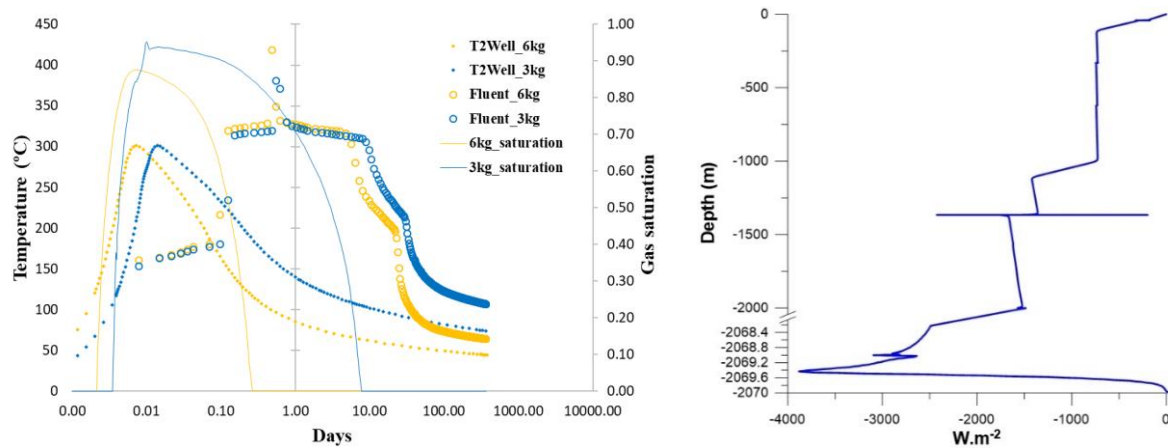


Fig. 2 (Left) One year transient surface temperature of the DBHE for a 350°C bottom temperature (T2WELL) and a 650°C bottom temperature (FLUENT). The gas saturation at the outlet is presented on the right axis. **(Right)** Horizontal heat flux on the external wellbore of the DBHE for a water injection mass flow rate of 3 kg/s.

4. CONCLUSIONS

Heat transfer and fluid flow in a closed-geothermal well in supercritical/superheated conditions have been discussed. T2Well provides a first assessment of the heat recovery from a hypothetical DBHE reaching a depth of 1900 m, when considering a constant temperature of 350°C at a depth of 2000 m. To better model the conditions encountered in the IDDP first well, 2D axisymmetric-based CFD simulations have been performed to describe the estimated radial velocity and heat transfer (DBHE completed at a depth of 2070 m and with a temperature of 650°C at a depth of 2100m). These two modelling tools have provided a complementary overview of the deliverability enhancement of DBHEs in superheated/supercritical conditions. T2Well shows that vapour can be produced during the preliminary time of the system. CFD identifies a non-circulation zone at the bottom of the well, where the heat flux from the surroundings is maximum. While the surrounding geothermal medium is considered as either a single- or a two-phase flow system, better physical formulations are needed to accurately model the increase of enthalpy in supercritical/superheated settings and the effects on the heat transfer process for novel closed-loop well designs.

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REFERENCES

- [1] G.O. Fridolfsson, B. Palsson, A. L. Albertsson, B.Stefansson, E. Gunnlaugsson, J. Ketilsson, P. Gislason, IDDP-1 Drilled Into Magma - World's First Magma-EGS System Created, *World Geothermal Congress 2015*, (2015), April.
- [2] M.-C. Suarez Arriaga, F. Samaniego, Deep Geothermal Reservoirs with Fluid at Supercritical Conditions, *Twenty-seventh workshop on geothermal reservoir engineering, Stanford University*. (2013).
- [3] B. Palsson, S. Holmgeirsson, A. Gudmundsson, H.A. Boasson, K. Ingason, H. Sverrisson, S. Thorhallsson, Drilling of the well IDDP-1, *Geothermics* 49 (2014), 23-30.
- [4] G. Falcone, X. Lui, R.R. Okech, F. Seyidov, T. Catalin, Assessment of Deep Geothermal Energy Exploitation Methods: the Need for Novel Single-Well Solutions, *Energy*, 160 (2018), 54-63.
- [5] C. Alimonti, E. Solo, D. Bocchetti, D. Berardi, The wellbore heat exchangers: A technical review, *Renewable Energy*, 123 (2018), 353-381.
- [6] T. Kohl, R. Brenni, W Eugester, System Performance of a Deep Borehole Heat Exchanger, *Geothermics* 31 (2002), 687-708.
- [7] L. Pan, C.M. Oldenburg, T2Well-An integrated wellbore-reservoir simulator, *Computers and Geosciences*, 65(2014), 46-55.
- [8] H. Shi, J. A. Holmes, L. J. Durlinsky, K. Aziz, L. Diaz, B. Alkaya, G. Oddie, Drift-Flux Modeling of Two-Phase Flow in Wellbores, *SPE-84228-PA* (2005), vol. 1.
- [9] ANSYS FLUENT Theory Guide, 17 (2016).
- [10] K. Pruess, C. Oldenburg, G. Moridis, TOUGH2 User's Guide Version 2.0, (1999).
- [11] Y. Noorollahi, M. Pourarshad, S. Jalilinasrabad, H. Yousefi, Numerical simulation of power production from abandoned oil wells in Ahwaz oil field in southern Iran, *Geothermics* 55 (2015), 16–23.



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