The HOCLOOP Project: Tools to model heat extraction from horizontal closed wells

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Summary

The HOCLOOP project ("A circular by design environmentally friendly geothermal energy solution based on a **HO**rizontal **C**losed **LOOP**") aims to verify a novel geothermal closed loop solution for the extraction of heat from deep or shallow formation rocks. The solution is based on new drilling technology and solves the challenges of conventional construction of geothermal wells. The project will develop the tools to enable the innovative geothermal solution and demonstrate the technology in a full-scale test operation. The work will cover the development and validation of models for the heat flow and investigate the possibility for improving the electricity production by using alternative to water fluids. The work will also cover the investigation of potential EU pilot sites, environmental assessment, and the social acceptance.

Introduction

Geothermal energy has a large potential as a clean renewable energy source. The conventional technology is mainly based on heat extraction from hot and permeable aquifers. However, such aquifers are not present everywhere. Indeed, the subsurface hydraulic properties (permeability, connectivity, etc.) are often limiting factors. This hinders the number of applications and implies high costs and risks. The proposed project aims to mitigate this challenge and the risk associated with subsurface by using an innovative horizontal closed loop solution for the extraction of heat from deep or shallow formations.

The solution is based on new drilling technology (developed by Reelwell) and solves the challenges of conventional construction of geothermal wells. The energy production will be enhanced thanks to extended reach horizontal drilling with a large hole diameter. Further improvement is expected to be achieved by use of alternative circulation fluids to water, such as CO_2 based fluids.

The solution is expected to significantly increase the deployment of geothermal resources for trigeneration with reduced environmental impact and economic attractiveness compared to conventional geothermal plants and avoiding several issues of Enhanced Geothermal Systems (EGS). It will also enable exploiting geothermal energy sources in new regions where conventional and EGS geothermal solutions are either not technically or economically feasible. For example, the innovative solution could reach regions where low-permeability, Hot Dry Rock or high content non-condensable gas reservoirs are present.

The target design is a geothermal heat exchanger that can deliver stable and cost-efficient energy for a time span of at least 50 years serving a surface district heating/cooling and power generation unit. The solution is foreseen to be integrated with other renewables to improve the reliability of the power supply and grid stability, the reliability of heat supply to district heating networks and that is applicable to any geological structural condition.

The project aims to develop the tools that will enable the proposed geothermal solution and demonstrate the technology in a full-scale test operation. The work will cover the development and validation of models for the heat flow and investigate the possibility for improving the electricity production by using alternative fluids to water. The work will also cover the investigation of potential EU pilot sites, environmental assessment, and the social acceptance. 9 partners from 6 European countries with complementary expertise join forces for this 42-month project.

Methods

One of the objectives of the project is to develop tools and models to predict the heat flow towards a closed-loop geothermal well and the associated temperature decrease of the surrounding rock, accounting rock properties, groundwater flow and the different layers elements of the walls of the well completion, such as casing and cement. Three different simulators are compared on the same well heat exchange benchmark cases: COMSOL (VITO), GWellFM (IFPEN) and GTW (IFE). All of them can model vertical and horizontal wells, for open- and closed-loop well completions. They can also account for vertical heterogeneous rocks (different properties and/or different geothermal gradient) and wells with multiple layers (i.e., casing, cement, insulation).

GWellFM (Geothermal Well Flow Model) is a steady-state, 1D non-isothermal axisymmetric, multicomponent, and two-phase flow simulator (Leontidis et al. 2023). The model considers the single-phase flows of liquids and gases, the hydrodynamics of the two-phase downward and upward flows, constitutive laws for mixtures and the heat exchange between the well completion and the surrounding formation. The modelling of the heat flow in the wellbore is considered under steady-state conditions, whereas the radial Fourier heat conduction equation under transient conditions is solved in the rock domain. In addition, the model is fully compositional and, to perform thermodynamic calculations, a thermodynamic engine has been integrated into the code. Calculations are performed in thermodynamic equilibrium and several Equation-of-States are available.

GTW (Geo-Thermal-Well) is a single-phase and semi-transient geothermal simulator in cylinder coordinates (Wangen 2022). The simulator solves the equation for transient heat conduction for cooling (or heating) of the rock, but it assumes stationary advective heat transport by the fluid in the well. The simulator obtains the numerical solution using an energy-conservative finite volume method. The energy transfer across cell boundaries is energy conservative in both the rock and the well. Local energy conservation for each cell implies global energy conservation for the combined system of well and rock.

COMSOL Multiphysics® is a general-purpose software developed to solve numerically in explicit and implicit fashion different physical phenomena, such as electromagnetic, solid mechanics, fluid and heat flow mechanics in open system and porous medias.

Models benchmarking

Analytical solutions exist either for single vertical wells (Ramey 1962) or for vertical (Al Saedi et al. 2018) and horizontal (Sharma et al. 2020) pipe-in-pipe wells. Those were used as references to benchmark the models and to predict the transient heat loss between the wellbore and the formation.

For cases that involves injection of a fluid without recirculation (Fig. 1, with 1 or more layers of rock properties), the simulators presented an error lower than 1.5% when compared to Ramey's analytical solution (Fig. 2), with GWellFM and GTW having the best accuracy for the tested cases. For the 2nd case, Ramey's solution had to be modified to consider the horizontal part.

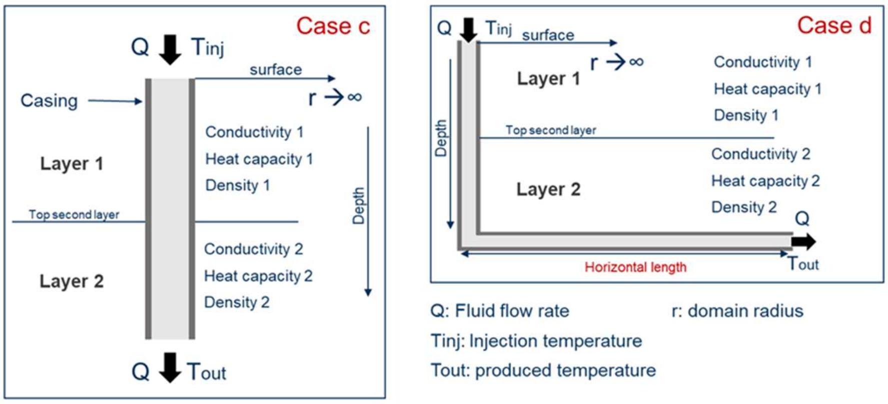

Figure 1 *Graphical representation of simple benchmark cases.*

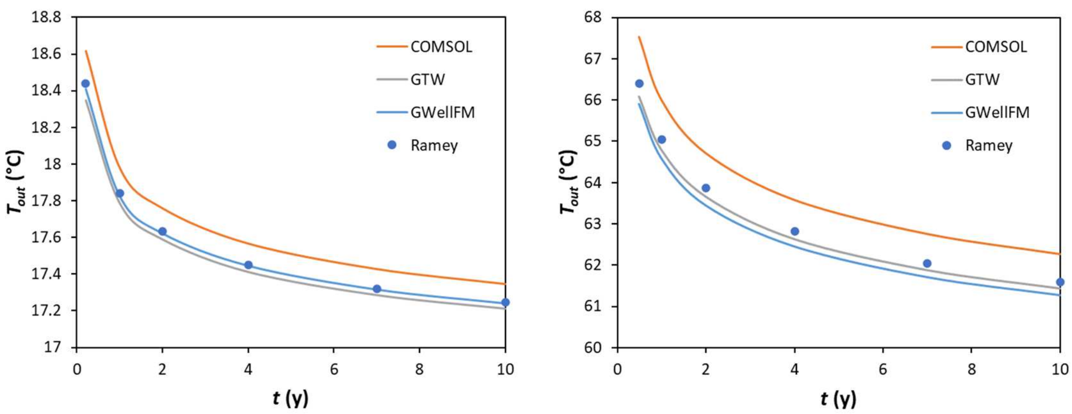

Figure 2 *Temporal evolution of the outlet temperature of a vertical (left) and a horizontal (right) well.*

The errors of the simulators when compared to the analytical solutions of Al Saedi et al. (2018) and Sharma et al. (2020) for closed-loops (Fig. 3) were equal or lower than 5% (Fig. 4 & 5). Again, GWellFM and GTW obtained the lowest error.

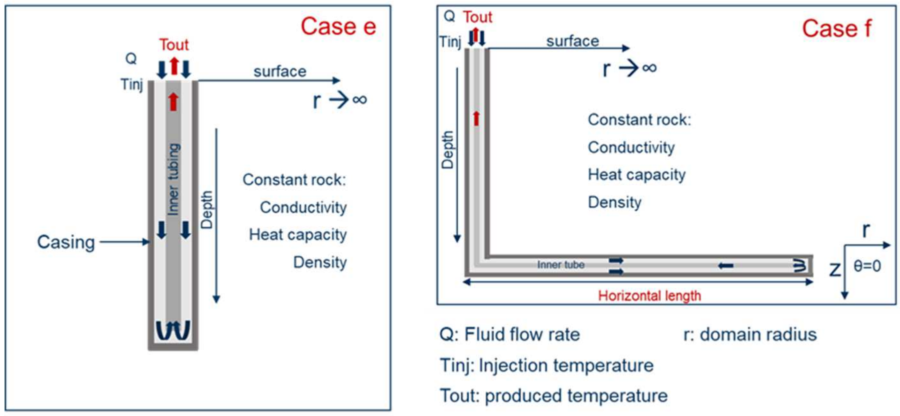

Figure 3 *Graphical representation of closed-loop benchmark cases.*

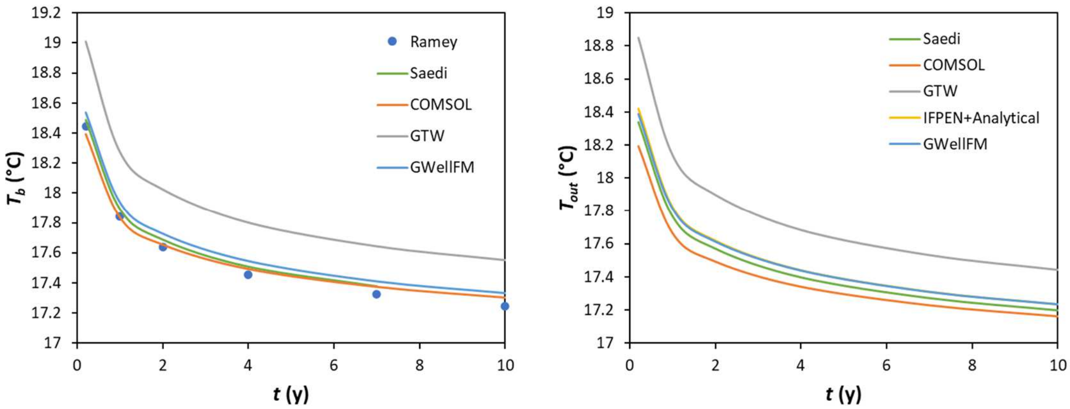

Figure 4 *Temporal evolution of the fluid temperature at the bottom of the annulus (left) and at the outlet (right) of a vertical closed well.*

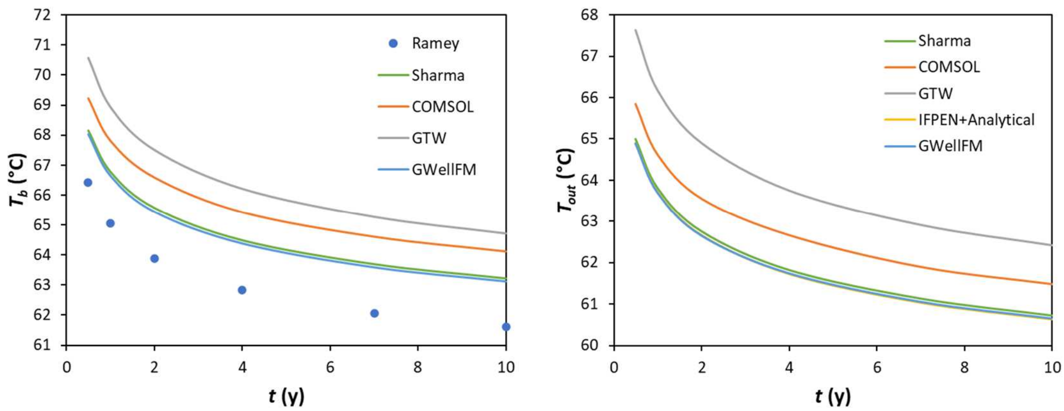

Figure 5 *Temporal evolution of the fluid temperature at the end of the annulus (left) and at the outlet (right) of a horizontal closed well.*

The error of the simulators is case dependent and the accuracy is affected by the flow conditions and the well completion properties when compared to the analytical solutions. However, in specific cases (such as complex geometries, low flow rates, strong pressure and temperature dependence of fluid's properties, highly heterogeneous rocks) the analytical solutions are not able to predict the temperature evolution of the fluid. Among the three simulators, the commercial COMSOL showed the lowest accuracy and GWellFM the highest. COMSOL simulations were always fully transient and performed in a 3D domain, whereas GWellFM and GTW are 1D axisymmetric codes considering steady-state fluid flow at every time step of the transient heat transfer process. GWellFM has no limitations in the construction of simple or pipe-in-pipe wells.

Pilot sites and full-scale tests

The pilot sites have been selected to cover a wide range of underground and surface conditions, but also development stages (from green field exploration to fully functional geothermal plants including district heating). For the two pilot sites, geothermal plants are in production test phase (Balmatt case in Belgium) or under the last phase of development (Darmstadt case in Germany), whereas for the Italian and French cases, no actual geothermal plants are considered.

The final objective of the project is to perform a representative full-scale validation of the solution in industrially relevant environment. There are several possible solutions for this. A solution that is considered appropriate and cost efficient is to perform the validation in an already existing horizontal test well at the Ullrigg drilling and well test centre at Norge in Stavanger Norway.

Conclusions

The validated in-house thermal models are used to simulate different pipe design scenarios with water as heat transfer medium, always in a closed loop configuration. Various scenarios are investigated through simulations, considering the thickness, the materials, the possibility of inserting some innovative geometries or even to create some small portion of vacuum. The simulations will also test different well-radii, bottomhole depths, rock heat conductivities and isolators between the inner pipe and the annulus to understand how the system can be optimized.

As groundwater flow can impact the subsurface heat transport, it is important to integrate the potential heat recharge from the aquifers in the models. In this aim, the models are under further improvement to consider the advective and convective heat transport in the rocks by adding convective heat flow and coupling them with available reservoir models. The heat extraction at the selected pilot sites will be then modelled using the complete simulation tools and a conceptual design for a closed system for each site will be proposed.

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