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Improvements to a previous numerical model, known as the Highly Conductive Material (HCM) model, are presented.

- The 'enhanced HCM model' implements uniform fluid temperature boundary condition at the borehole wall.
- The 'enhanced HCM model' is validated by comparing the g-function generated with reference solutions.
- The 'enhanced HCM model' is illustrated by simulating daily fluid temperatures of a monitored installation in Baiona (Spain). The simulated data is compared to around four years of measured data.
- A monthly simulation of 50 years of operation is performed to study the influence of the boundary condition defined at borehole wall: constant heat flux and uniform fluid temperature.

‘Enhanced Highly Conductive Material Model’: Uniform fluid temperature boundary condition

The Highly Conductive Material (HCM) model is a finite element model (FEM) that employs the concepts of a fictitious HCM embedded in the boreholes and connected to a HCM bar above the ground surface in order to represent a uniform temperature boundary condition at the borehole wall.

There is a borehole thermal resistance between the fluid and the borehole wall. The heat flux increases at the borehole ends and thus also the temperature changes between borehole wall and fluid. The borehole wall temperature deviates from the uniform assumption. This paper presents the improvements on the HCM model to overcome this error.

Improvements on the HCM model:

1. Introduction of a thin thermally resistive layer
The borehole resistance between the circulating fluid and the borehole wall is represented by a thin thermally resistive layer. The layer properties are set so that the thermal resistance is equal to the measured borehole resistance.

2. Hemi-spherical geometrical element
This is added at the bottom part of the borehole to have a evenly distributed heat dissipation.

Baiona’s GCHP Installation

- The Baiona’s GCHP satisfies the space heating and domestic hot water needs of an elementary school building located in Baiona, Spain.
- The system was monitored from February 2010 to December 2013.

Table: Geometrical aspect ratio of the bore field

<table>
<thead>
<tr>
<th>Geometrical Aspect Ratio</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>r/RiH</td>
<td>0.006</td>
</tr>
<tr>
<td>B/H</td>
<td>0.0678</td>
</tr>
<tr>
<td>D/H</td>
<td>0.0169</td>
</tr>
</tbody>
</table>

Figure 2: Bore field configuration

Table: Thermal properties of the ground

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undisturbed ground temperature (Tg)</td>
<td>16.5 °C</td>
</tr>
<tr>
<td>Ground thermal conductivity (k)</td>
<td>2.94 W/(m²K)</td>
</tr>
<tr>
<td>Volumetric heat capacity (C)</td>
<td>2.4MJ/(m³K)</td>
</tr>
<tr>
<td>Heat ground exchanger thermal resistance (Rg)</td>
<td>0.087 (m²K)/W</td>
</tr>
</tbody>
</table>

Figure 3: Comparison of g-functions from different models

Reference Solutions:

- FLS CQ: Finite line source model with constant heat flux boundary condition at the borehole wall.
- FLS UT: Finite line source model with uniform temperature boundary condition at the borehole wall.
- FEM CQ: Finite element model with constant heat flux boundary condition at the borehole wall.
- FEM-HCM UT-BHW: Finite element model with uniform temperature boundary condition at the borehole wall.
- FEM-EHCM UFT: Finite element model with uniform fluid temperature boundary condition.

Validation of the ‘enhanced HCM model’: g-function generation

Figure 4: Heat flux and temperature profiles at the boreholes of HCM and EHCM models

Prediction of daily fluid temperatures and comparison with measured data

- The simulated results are reasonably close to the measured data, with MBE of 0.94 K for the last simulated year. The error is higher in the first two years compared to the last two years. Tests performed on the bore field in January 2010 partially explains this. Maximum error in each year occurs in summer when high values are observed in measured data.
- Although ‘FEM-EHCM UFT’ has the least deviation from measured data, the difference is not significant enough to conclude that it is more accurate than other models.

Figure 5: Daily fluid temperature predictions and comparison with measured data

- ‘FEM CQ’ estimates the average fluid temperature to be 0.42 K lower than ‘FEM-EHCM UFT’.
- The results from ‘FEM CQ’ model presents an unexpectedly closer behavior compared to simulated values generated from a commercial software.
- The average fluid temperature decreases by 2.9K after 50 years of operation, this corresponds to 9% penalty on heat pump performance.

Monthly fluid temperatures simulation for 50 years

- ‘FEM CQ’ and ‘FEM-EHCM UFT’ are simulated with a high degree of accuracy.
- Although ‘FEM-EHCM UFT’ has the least deviation from measured data, the difference is not significant enough to conclude that it is more accurate than other models.

Figure 6: Monthly fluid temperatures predictions for 50 year of operation

Conclusions

- Uniform fluid temperature boundary condition was implemented in an ‘enhanced HCM model’. No relevant deviations are observed in the g-function in comparison with reference solutions obtained from a uniform temperature boundary. The ‘enhanced HCM model’ shows a realistic representation of the heat flux and temperature profiles at the borehole wall.
- The ‘enhanced HCM model’ is illustrated to predict daily fluid temperatures and compared to measured data (MBE of 0.94K last simulated year). However, the differences are not significant enough to conclude that ‘enhanced HCM model’ is more accurate than other models.
- Long term simulations (50 years) show more prominent differences between ‘FEM CQ’ model and ‘FEM-EHCM UFT’. ‘FEM CQ’ unexpectedly deviates less than ‘FEM-EHCM UFT’ in comparison to simulated values from a commercial solution.

Acknowledgement

& industrial partners