Hemispherical underground borehole heat exchanger field as a source of geothermal energy

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Finland is located between the 60th and 70th northern parallels and is characterized by continental subarctic climate. Due to climatic conditions, ground surface temperatures are low in Finland. The long-term average annual ground surface temperature ranges from 0.5 to 7.6 °C. Decommissioned mines offer a way to tap into larger geothermal resources by allowing access to deep underground where the temperature regime is more beneficial for heat extraction than in the shallow ground. The Energy Mine project was initiated to investigate how the Pyhäsalmi deep mine could be utilized to tap into the deeper geothermal resources of the Finnish bedrock.

The depth level of the deepest mine tunnel in the Pyhäsalmi mine is 1,440 m. We took this tunnel as the starting point for our study since it offers access to the largest geothermal resources that are accessible from the mine. We modelled the thermal performance of borehole heat exchanger (BHE) fields constructed by drilling the boreholes from a single site in different azimuth and tilt angles so that the resulting BHE fields took the form of a lower hemisphere. The borehole length was 300 m. The collector was coaxial open-loop with an insulated pipe. Bedrock temperatures within the depth range of the BHE fields ranged from 21 to 25 °C. Finite element models were constructed to simulate the operation of various configurations of hemispherical BHE fields. In all simulations, the temperature of the heat carrier fluid fed to the inlets of the BHEs was kept at 6 °C during the 100 simulated years.

The results indicate that it would require at least 145 BHEs for a hemispherical BHE field to sustain at least 1 MW of heating power from the bedrock for 25 years. Such a field would produce 300 GWh of heating energy during the first 25 years. This amount can be increased by adding boreholes to the field. However, at some point, adding BHEs no longer increases the amount of thermal energy that can be extracted from a hemispherical BHE field. The maximum amount of extractable energy is somewhere around 1.2 TWh which is the estimated heat content of a hemispherical volume of bedrock at the tunnel depth.

The hemispherical design is not the most optimal BHE field design with respect to thermal performance because the distances between BHEs become very small at the drilling site. However, the spatial restrictions imposed by mine tunnels do not allow much leeway in BHE field design. Another possibility is to construct a BHE field along a mine tunnel. But even in this case the BHEs would need to be drilled in a fan-like fashion at several drilling sites along the tunnel length. The hemispherical design is advantageous with respect to drilling and piping compared to a BHE field
that is constructed along the length of a mine tunnel.