Geothermal energy in Pyhäsalmi mine, Finland: performance evaluation of heat collector types

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Finland is a part of a low-temperature geothermal regime of Fennoscandian Shield. The need for heating energy is high and ground source heat pumps (GSHP) are common in heating of single houses. Shallow ground source heat can be effectively utilized using a closed collector loop with non-freezing heat carrier fluid operating at the temperature range of about -5 to +5°C. The system is economically feasible, because the average target temperature in heating of well-isolated houses is low. District heating requires high output temperatures (in Finland nowadays up to 110°C), implying that a heat pump must receive the ground temperatures of at least about 20°C. Heat collectors in porous, permeable sedimentary rocks may be based on an open circulation loop between two or more boreholes, whereas in Finland single deep boreholes equipped with a heat collector are mainly considered. A borehole heat exchanger (BHE) in deep and warm bedrock, like in decommissioned underground mines offers great temperature benefits in producing more energy than BHE placed on the ground surface.

The Pyhäsalmi mine in northern Ostrobothnia, Finland, is a 1 440 meter deep underground zinc and copper mine that will be decommissioned in a near future. In the Pyhäsalmi Energy Mine project funded by European Regional Development Fund (ERDF) we examined the heat transfer properties of heat collector types installed in the borehole at the bottom of the mine. The Precambrian crystalline bedrock, consisting of granitoids, migmatites, gneisses and schists typically has low geothermal gradient (10 – 20 K/km), but thermal conductivity is rather high (2.5 – 3.5 Wm\(^{-1}\)K\(^{-1}\)). Thus, the temperature at the depth of 1 440 m is about +20°C. We compared the performance of different collector types in the underground mine environment: coaxial open-loop collector with and without insulation and u-tube collector, as well as different borehole radii to optimize geothermal energy production. Also, we studied the effect of the bedrock temperature (5 – 50°C) on the performance of the BHE.

The heat exchange modelling was carried out with COMSOL Multiphysics®. The modelled physics included conductive heat transfer in bedrock and different collector types, and conductive-convective heat transfer in heat carrier fluid. The models were used to simulate heat transfer from bedrock to the heat circulation loop up to 100 years circulating water (feeding temperature +6°C) in the loop.

The results indicate that a single 300 meter deep energy well placed at the bottom of the mine can be dimensioned to produce water of approximately 12°C with twelve kilowatts power. Further
increase in output temperature requires deeper boreholes or serial coupling of two boreholes, allowing heat production at the temperature range of 70 - 90 °C by means of heat pumps. Compared with the conventional shallow geothermal energy solutions, the geothermal potential of the underground mine is several times higher due to higher bedrock temperature. An insulated open-loop coaxial collector is better than a coaxial collector without an insulation or a typical u-tube collector.