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GEOTHERMAL ENERGY IN PYHÄSALMI MINE, FINLAND: PERFORMANCE EVALUATION OF HEAT COLLECTOR TYPES

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Pyhäjärven
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Pyhäsalmi Mine

PYHÄSALMI MINE AS A SOURCE OF GEOTHERMAL ENERGY

- Shallow ground source heat can be effectively utilized by heat pumps using borehole heat exchangers (BHE) with non-freezing heat carrier fluid at a temperature range of about -5 to +5°C
- However, to produce district heating with heat pumps, higher source temperature would be advantageous
- Pyhäsalmi mine in northern Ostrobothnia, Finland is a 1440 meter deep underground Cu-Zn-S mine that will be decommissioned in a near future
- The temperature at the bottom of mine is ca. +20°C providing an optimal environment for geothermal energy utilization while the local annual mean temperature at the ground surface is ca. +3°C

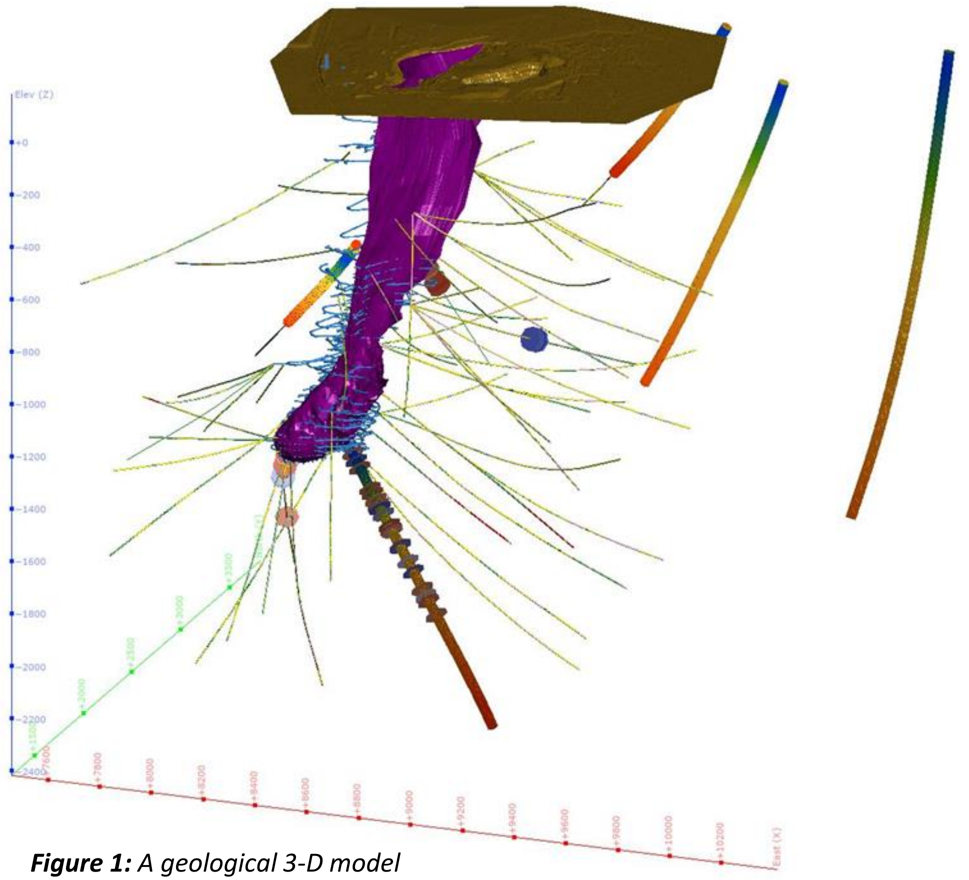

Figure 1: *A geological 3-D model representing drillholes rock species, the ore deposit and structures within Pyhäsalmi mine area. Jaakko Hietava, Geological Survey of Finland*

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OBJECTIVES AND METHODS

- To optimize geothermal energy production from a single 300 m borehole in underground environment, we evaluated the performance of plastic heat collectors comparing coaxial pipe with and without insulation and U-tube
- Numerical heat exchange modelling and the time-dependent simulation of the BHE's were based on the finite element method. Simulations were carried out using COMSOL Multiphysics®
- The underground mine environment and the temperature levels enabled to use water as circulation fluid, heat transfer from the bedrock to the fluid is purely conductive
- Optimizable parameters affecting the heat collector performance were:
  - *Borehole radius*
  - *Insulation levels for the coaxial pipe as well as flow direction (injection through annulus and injection through central pipe)*
  - *Flow rate*
- Insulated coaxial pipe had effective thermal conductivity of 0.1 W/(m·K) and non-insulated coaxial pipe had thermal conductivity of 0.42 W/(m·K)
- Also, we compared the conventional shallow and underground geothermal energy solutions and studied the effect of the bedrock temperature on the performance of the BHE

Parameter	
Initial bedrock temperature [degC]	21
Geothermal gradient [degC/m]	0.013
Thermal conductivity of bedrock [W/(m·K)]	2.92
Specific heat capacity of bedrock [J/(kg·K)]	682
Density of bedrock [kg/m^3]	2794
Specific heat capacity of circulation fluid [J/(kg·K)]	4184
Density of circulation fluid [kg/m^3]	1000
Thermal conductivity of pipe [W/(m·K)]	0.1 - 0.42
Specific heat capacity of pipe [J/(kg·K)]	1926
Density of pipe [kg/m^3]	950
Borehole depth [m]	300
Injection fluid temperature [degC]	6
Flow rate [l/s]	0.1 - 1.0
Simulation period [a]	100
Borehole diameter [m]	0.076* / 0.115 / 0.140 / 0.160
Pipe diameter [m]	0.040** / 0.050
Pipe thickness [m]	0.012* / 0.024 / 0.029

* Coaxial pipe
** U-tube

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HEAT COLLECTORS – GENERAL PERFORMANCE

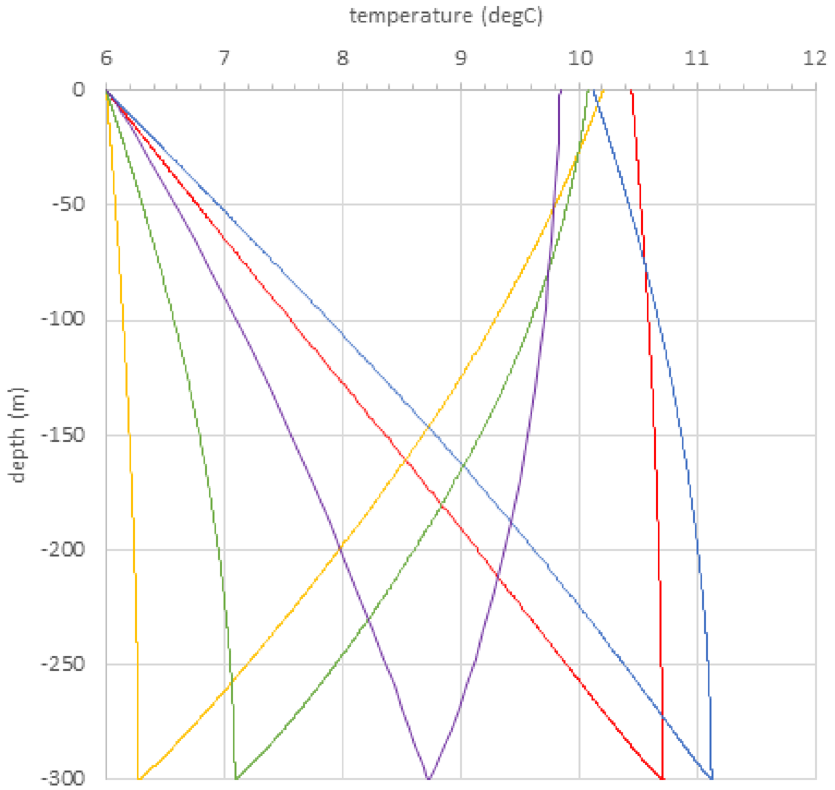
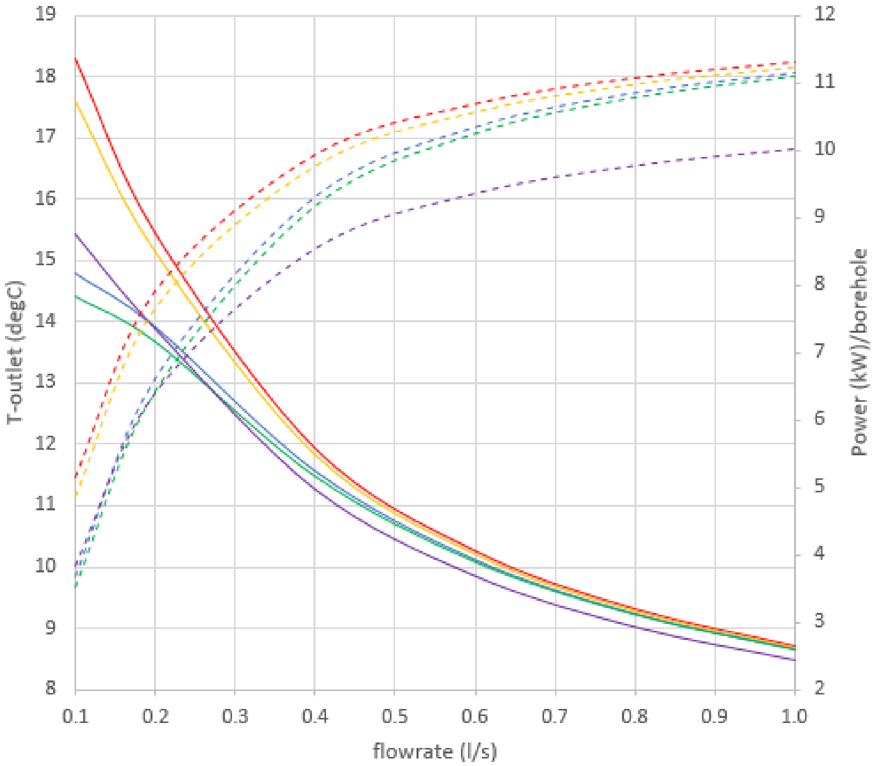


Figure 2: *The vertical profiles of down- and up-going circulation fluid temperatures. $Ø_{borehole}$ = 140 mm, flow rate = 0.6 l/s, time=100 a.*



- coax k_{eff} = 0.1 W/(m·K) in through annulus
- coax k_{eff} = 0.1 W/(m·K) in through central pipe
- coax k = 0.42 W/(m·K) in through annulus
- coax k = 0.42 W/(m·K) in through central pipe
- u-tube k = 0.42 W/(m·K)

Solid line = temperature
Dashed line = power

Figure 3: *The inverse relationship of the circulation fluid outlet temperature and borehole power as a function of flow rate. $Ø_{borehole}$ = 140 mm, time=100 a.*

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RESULTS

- The results show that insulated coaxial has the best performance:
  - *Injection through annulus is 2.5 % more effective than injection through central pipe*
- Increasing the insulation level in the coaxial pipe improves the performance:
  - *Insulated coaxial pipe achieves max. 3.3 % higher output temperature and max. 3.1 % higher power than non-insulated coaxial pipe*
- Borehole radius has low effect on the performances
- In overall, the performances between collector types, the effect of borehole radius and injection direction have low effect in a 300 m deep borehole in underground environment
- Compared with the conventional shallow geothermal energy solutions, the geothermal potential of the underground mine is several times higher due to higher bedrock temperature
- The results show that a single 300 m deep borehole placed at the bottom of mine gives approximately the circulation fluid temperature of + 10 degC with ten kilowatts power after 100 years of operation
- In comparison, a single 300 meter deep borehole placed on the ground surface in Pyhäsalmi gives approximately the circulation fluid temperature of +1.1 degC with 2.8 kilowatts power
- At the moment, practical testing of insulated coaxial is running in Pyhäsalmi mine

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