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Estimating the geothermal potential of the tunnel lining heat exchanger enhancement with thermally conductive matter

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[1] Introduction

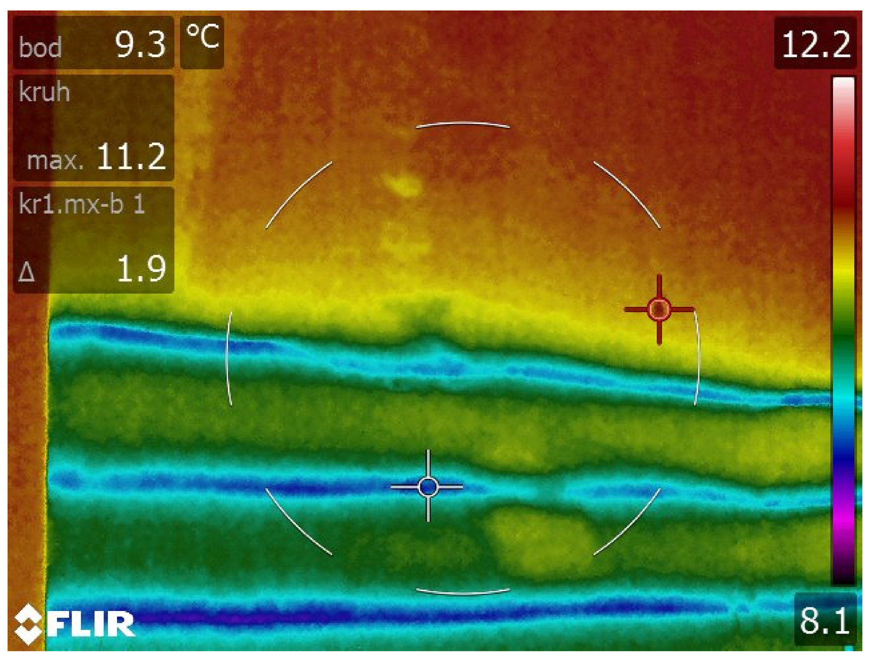
The rock massif represents an important energy resource for the heating and cooling of buildings. Utilization of tunnels and other ground embedded structures has many advantages. Our work is aimed at research of thermal energy extraction improvement from underground line constructions such as tunnels or utility corridors. The heat exchanger with novelty thermally conductive matter is placed between the primary and secondary lining of a tunnel constructed using the New Austrian Tunneling method (NATM).

[2] Experimental installation

Three experimental heat exchangers were constructed in abandoned mine. The exchanger consists of PEX-Al-PEX pipes, thermally conductive material and water insulation. Thermally conductive matter (TCM) is a mixture of flake graphite, cement and colloidal silica. Obtained data are used for numerical model calibration and verification.

Left: *PEX-Al-PEX tubes before TCM application;* ***right:*** *the heat exchanger with TCM and polyurea coating as water proofing .*

The photographed heat exchanger (above) has area of 5.5×2.5 meters. Current heat uptake is circa 190 W with 3.5°C temperature difference between rock massif and inlet heat transfer fluid.



Right: *Temperature distribution on the surface of the heat exchanger.*

[3] Estimation by mathematical model

The numerical model of the surrounding of the tunnel was created with the Heat Transfer Module in the COMSOL Multiphysics finite element software package. According to the experiment, the modelled process corresponds to unsteady heat conduction in a solid. The governing equation is:

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q$$

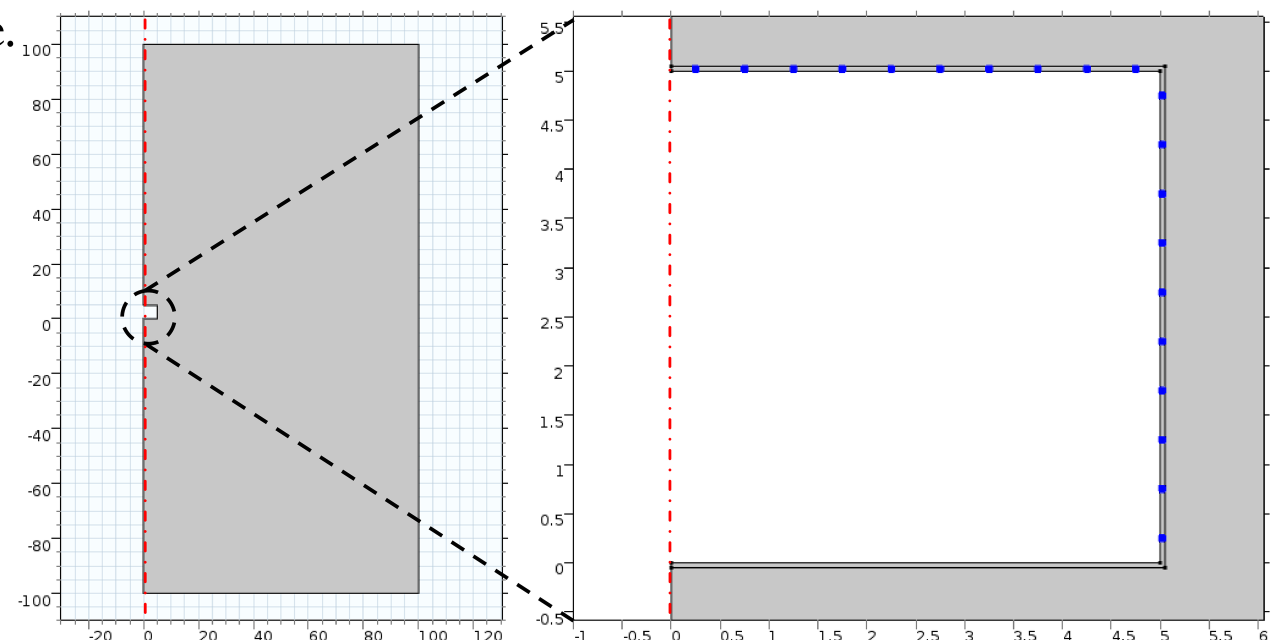
where T [K] is the temperature, t is time [s], Q [W] is the heat source, and the remaining coefficients are the material properties: the density ϱ [$kg \cdot m^{-3}$], heat capacity Cp [$J \cdot kg^{-1} K^{-1}$] and thermal conductivity k [$W \cdot m^{-1} K^{-1}$].

The rock massif was simulated as homogenous common rock with thermal conductivity $k = 2\ W \cdot m^{-1} K^{-1}$, heat capacity $C_p = 750\ J \cdot kg^{-1} K^{-1}$ and density $\varrho = 2300\ kg \cdot m^{-3}$.
TCM coefficients were set as representative values of measurements as follows: thermal conductivity $k = 7\ W \cdot m^{-1} K^{-1}$, heat capacity $C_p = 1324\ J \cdot kg^{-1} K^{-1}$ and density $\varrho = 1480\ kg \cdot m^{-3}$. Used parameters of the materials were temperature independent.

[4] Model description

- The numerical model was arranged on a 2D plane with the dimensions 100×200 m. The tunnel is 10 m wide and 5 m high.
- The pipes were simulated on the top and at the sides of the tunnel. The inner diameter of the pipes was 16 mm.
- The number of the heat exchanger pipes differed and was a subject of the evaluation. The number of pipes varied between 1 and 40. The pipes were equally distributed along the walls and the ceiling of the tunnel..
- TCM was simulated as a 5 cm layer on the surface of the tunnel.
- The temperature of the simulated heat transfer fluid was set 10 °C below massif temperature.

Left: *Model domain with detail of the tunnel with the heat exchanger with 40 pipes.*

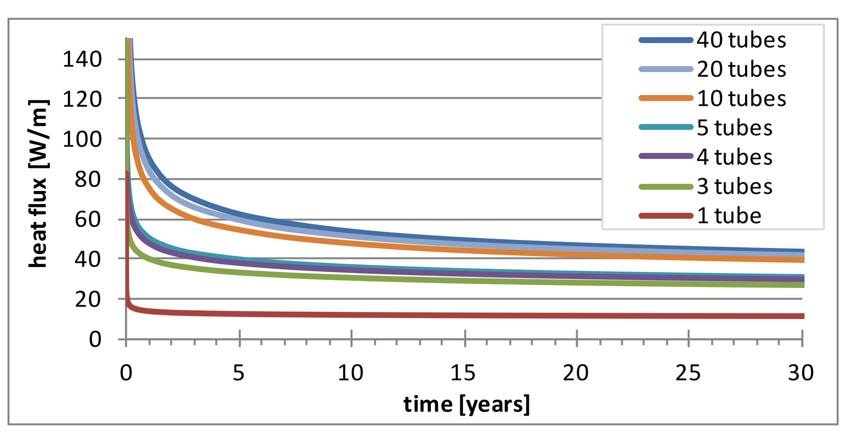


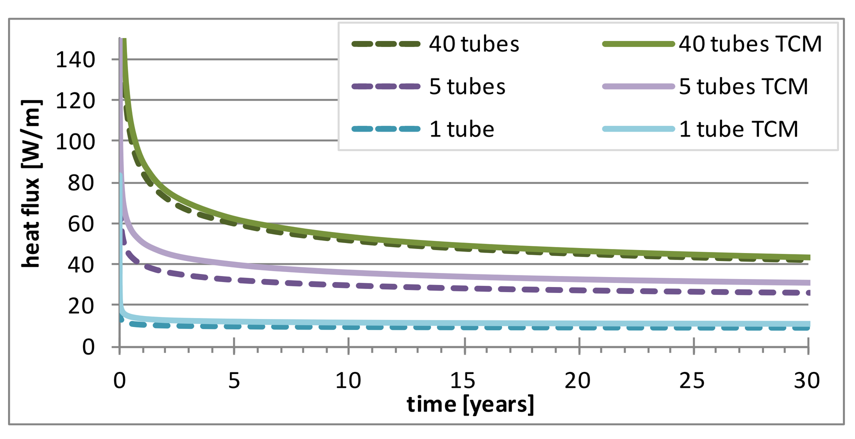
[5] Results

- The model evaluation was based on an integrated normal heat flux through pipe boundaries.
- The simulated initial heat flux quickly decreased in a few hours. The fast decrease occurred for the first five years. With an increasing number of the pipes, the decline of heat extraction more intensive.
- The benefit of TCM is evaluated in table below. It contains simulated heat flux gains after 1, 10, 20 and 30 years for models with and without the application of TCM. Evaluated heat flux is per 1 meter of tunnel length.

no. of tubes	heat flux without TCM [$W \cdot m^{-1}$]				heat flux with TCM [$W \cdot m^{-1}$]				TCM benefit			
	1 yr	10 yrs	20 yrs	30 yrs	1 yr	10 yrs	20 yrs	30 yrs	1 yr	10 yrs	20 yrs	30 yrs
1	10.1	9	8.8	8.6	13.7	11.8	11.5	11.1	36%	31%	31%	29%
3	29.9	24.2	22.7	21.9	40	30.4	28	26.7	34%	26%	23%	22%
4	40.1	28.4	26.2	24.9	48.1	34.5	31.5	29.9	20%	21%	20%	20%
5	40.2	30.1	27.9	26.6	55.6	36	32.6	31	38%	20%	17%	17%
10	64.9	43	38.4	36.1	75.6	47.6	42	39.4	16%	11%	9%	9%
20	77.2	48.4	42.6	39.9	84.9	51.7	45.2	42.2	10%	7%	6%	6%
40	85.4	51.9	45.4	42.3	91	53.8	47	44.2	7%	4%	4%	4%

- The benefit of TCM application decreases with an increasing number of tubes. For one tube, the benefit is over 30 % during the whole 30 years. In the case of 40 pipes (0.5 m spacing between pipes) the benefit is only 4 %. In absolute numbers, the greatest benefit 15 $W \cdot m^{-1}$ is for 5 tubes.
- When comparing the number of pipes in general, the collected heat does not increase linearly with an increase in the number of pipes. Three pipes collected twice the amount of one pipe, and 40 pipes collected approximately double the amount of three pipes.
- Although ground heat is considered as a renewable resource, the simulation showed that stationary heat reserves are utilized and the common geothermal heat flux (30 – 70 $mW \cdot m^{-2}$) is not sufficient to saturate the energy demand. For sustainable utilization of the ground as a heat source, it is suggested to inject heat during the summer.





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