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THE ACCUMULATION AND HEAT TRANSFER IN SOILS

Abstract
The paper is focused on the investigation of the 240 hours cycle of heat charging and spontaneous discharging in the soil/water environment with 12-hour charging and 12-hour non-charging (discharging) cycles. The temperature fields at different times of running the simulation have been presented. It can be consluded that generally defined semi-insulated soil environment has a potential for withholding substantial heat cumulatively over repeated heating cycles.

Keywords: heat accumulation, numerical analysis

1. Introduction

The ultimate target of this research is to find a low-cost way of covering all house heating needs using solar heat gains collected in the summer as the only heat source.

Storage of low potential heat has been widely studied for a long time, especially in connection to, and with prospect of utilization in house heating. We too would like to investigate properties of suitable materials, especially virgin ground, for the purpose of collection and trapping of summer solar heat gains (and also waste heat), holding it in time, and its transfer with minimum losses to the cold months of the winter for space heating.

To meet this goal, we need to focus on simulation on thermal and deformation properties of sub-surface ground environment with depth not more than 5 m, with respect to practical feasibility of the embracing works on the soil mass during real physical construction application later. Physically, we will have to measure mainly heat loss response to cyclic heating/cooling in typical ground types with focus on verification of cumulative incremental building effect of residual heat after each cycle which would cycle by cylce develop the substance of the warm mass needed. We would have to limit boundary conditions at first, such as granularity, proximity of the underground water table, capillarity effect and moisture content in general, outer temperature and humidity as well as climatic influences such as wind, rain and direct solar irradiation. In the first step all test programmes will be carried out in laboratory conditions and the boundary conditions would have to be simplified with gradual adding of variables. As part of the simulation, we will need to speed up the heating and cooling cycles with a correction reflecting the inertia of the soil mass and its resistance in reaching the stationary thermal status to simulate a typical season of the year in our latitude.

2. Heat transfer in soils

In analyzing thermal system in soils, it should be possible to identify the relevant heat transfer processes and only then the system behavior can be properly quantified. The heat transfer is divided into a number of simpler processes: heat conduction, convection and radiation. Conduction is the primary mode of heat transfer in soil. The thermal conductivity of soil is the rate at which heat energy flows across a unit area of soil due to unit temperature gradient. The governing parabolic partial differential equation for conductive heat flow is:

$$\nabla(\lambda\nabla T)=C\frac{\partial T}{\partial t}$$

where λ (W/mK) is the thermal conductivity, T is temperature, and $C = \rho c$ (J/Km^3) is the volumetric heat capacity. The symbol ∇ denotes the divergence operator.

Heat transfer in one dimension is obtained by the Fourier‘s law:

$$\vec{q}=-\lambda\frac{\partial T}{\partial n}$$

The dependent variable T is a scalar potential, while thermal conductivity and specific heat capacity are empirical parameters [1]. Soil is a three-phase material (water, air, solid) and conductivity of soil depends on the conductivity of each phase and their proportions.

Three main factors have influence on λ in soil:

– mineral composition of the solid phase
– proportion of voids and their spatial distribution
– proportion of water that fills the voids.

Numbers of analytical solutions for conduction heat transfer problems are available but in many practical situations, the material, geometry and the special boundary conditions are too complex for an analytical solution. In such situations, conduction heat transfer problems do need a numerical solution. Some commonly employed numerical methods are the Finite Difference, Finite Element and Boundary Elements techniques [2]. In the framework of our research activity we will use software based on Finite element method.

3. Future experimental investigation

Preparation of test programme aimed on real determination of heat accumulation effects in soils and heat transfer in this non-homogeneous material is the most important part of our current research. A test programme will be carried out in the testing laboratory in order to define all boundary conditions that can influence the experimental measurements like moisture, type of soil or ambient temperature. In the framework of this experimental research, four types of soils will be tested: gravel, sand, silt and clay, each with different moisture.

Simple test arrangement will consist of large-volume thermally insulated container with the tested ground material (1), heat source (2), system of thermocouples (3), decoding equipment (4) and computer (5). Test setup is schematically presented in Figure 1.

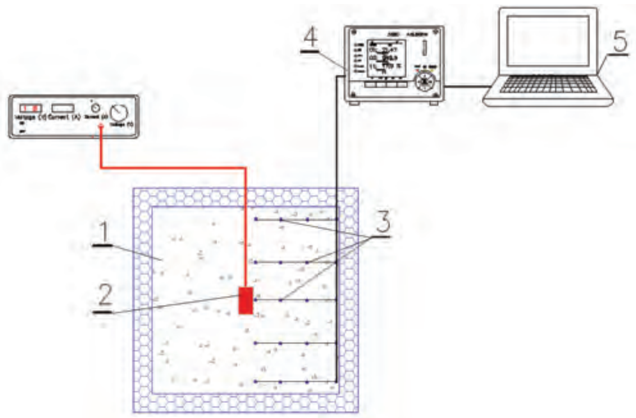


Fig. 1. Test arrangement

The heating of soil will be cyclic (Fig. 2). In this part of our work we try to adjust the heating cycles in such way to simulate the real conditions of external environment in short time. After each cycle (heating and cooling) we will observe and document the behaviour of temperature in soil (Fig. 2).

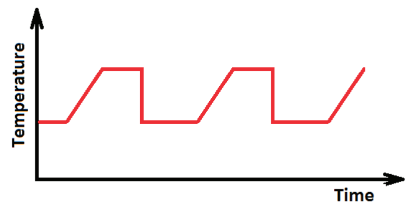


Fig. 2. Supposed cyclic heating of soil

Another problem is the moisture of soil because the change of water volume in soil has a great influence on thermal properties, so each type of soil will be tested in two or three moisture levels. During the test, we will have to prevent the natural reduction of moisture in the specimen. The results of experimental investigation should come in the form of time-temperature curves that can clarify the real thermal parameters for different types of soils.

4. Numerical analysis

The goal of the CFD is creating a calculation model for simulation of heat fluxes of heat accumulation into a mass of soil. In this text, we investigate a 10-day cycle of heat charging and spontaneous discharging (i.e. the soil/water heat exchanger was without thermal power) in 12-hour charging and 12-hour non-charging (spontaneous discharging) cycles. The calculation covered a time span of 240 hours or a ten-day cycle. The accumulator itself consists of a soil/water heat exchanger (A, Pic. 1) which is modelled as a conical earth screw 1.65 m long and 0.2 m in max diameter, the soil accumulator of dimensions 2 x 2 x 1.65 m (E, Pic. 1), horizontal thermal insulation

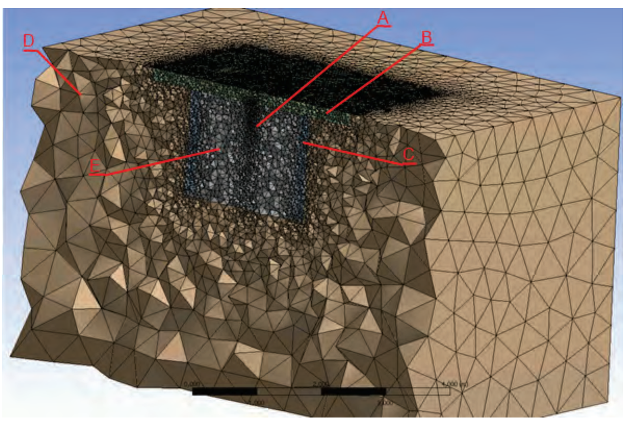
0.2 m thick (B, Pic. 1), vertical thermal insulation 0.2 m thick (C, Pic. 1), and of the surrounding mass (D, Pic. 1) which represents a semi-infinite soil volume. These simulations will be compared to experimental measurements in laboratory conditions.

The physical properties of the measured soil used in modelling were selected as follows:

- Thermal conductivity λ = 1.5 W/mK,
- Mass heat capacity c = 920 J/kgK,
- Soil specific weight ρ = 1900 kg/m^3.

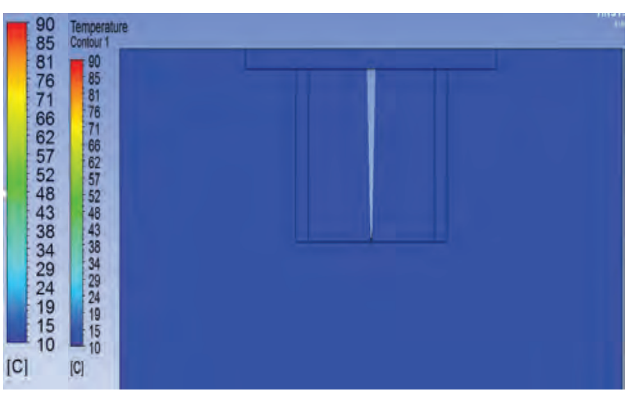
Boundary conditions for calculation were entered in software Fluent:

- unsteady model (12 hours charging/12 hours spontaneous discharging over 10 days),
- temperature of heat exchanger: 12 hours 90°C, 12 hours no heat power,
- temperature on top of horizontal thermal insulation 20°C
- temperature on top of surrounding ground 15°C,
- temperature of surrounding underground 10°C.

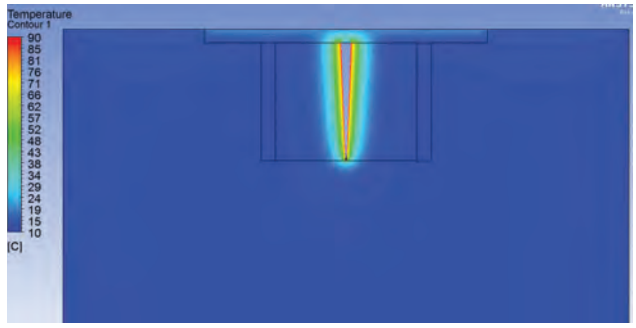


Pic. 1. The calculation mesh for the heating behaviour simulation of the soil heat accumulator

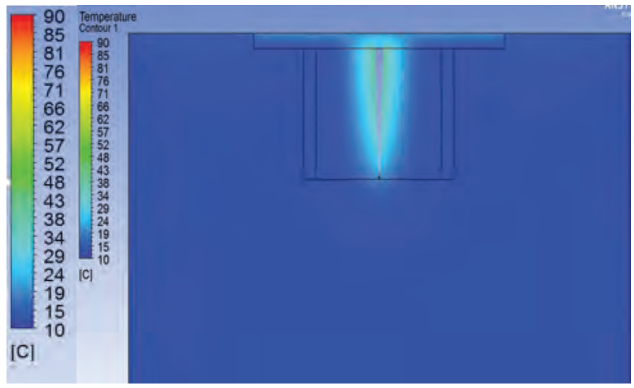
The following pictures show temperature fields in the vertical section through the heat exchanger axis at different times of the running simulation.



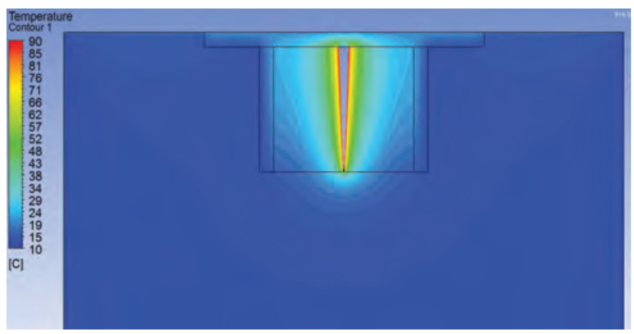
Pic. 2. Temperature field in vertical section through axis of the heat exchanger in time t = 0



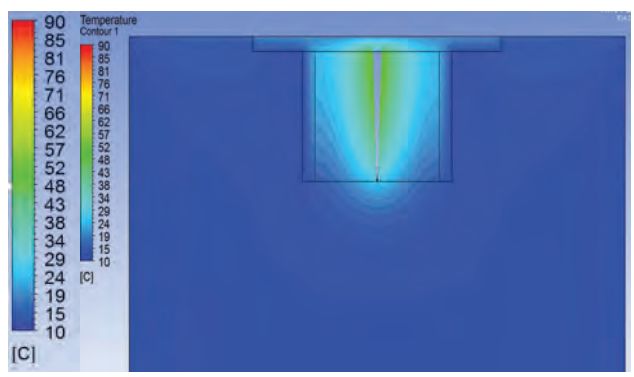
Pic. 3. Temperature field in vertical section through axis of the heat exchanger in time t = 0.5 day



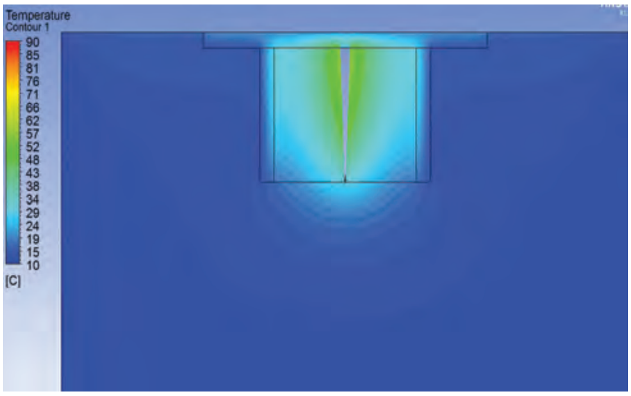
Pic. 4. Temperature field in vertical section through axis of the heat exchanger in time t = 1 day



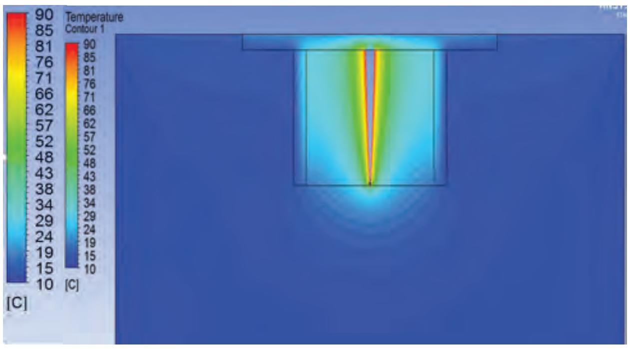
Pic. 5. Temperature field in vertical section through axis of the heat exchanger in time t = 5.5 days



Pic. 6. Temperature field in vertical section through axis of the heat exchanger in time t = 6 days



Pic. 7. Temperature field in vertical section through axis of the heat exchanger in time t = 10 days



Pic. 8. Temperature field in vertical section through axis of the heat exchanger in time t = 10.5 days

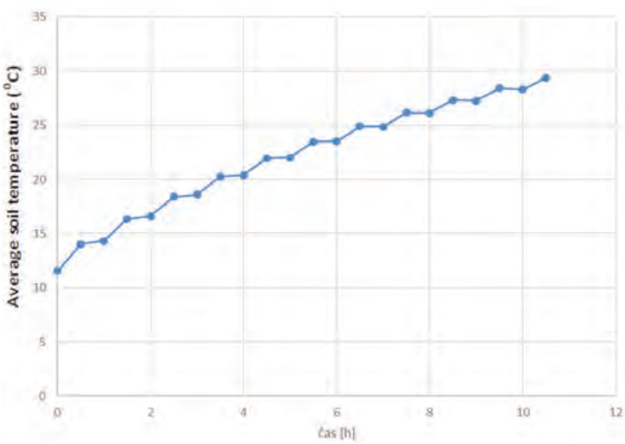


Fig. 3. Heat charging and spontaneous heat redistribution/leakage in soil heat accumulator

5. Conclusions

The model shows a clear trend in gradual temperature increase inside the heat accumulator. During the passive (non-charging) period, however, the average temperature measured volume-wise was raising as well, probably by spreading the heat from the warmer to colder parts of the enclosed volume body. Even though this positive heat redistribution effect was gradually weakening over time with drops getting more and more visible towards the end of the modelled period, the overall temperature uptrend is still close to linear and calls for further investigation of additional heating cycles to be done. Clearly, generally defined semi-insulated soil has a potential for withholding substantial heat cumulatively over repeated heating cycles.

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