KEB-45250 Numerical Techniques for Process Modeling 17.5.2018

Assignment 2 – REVISION 2

Kaj Lampio

Changes: Corrected the overall heat transfer coefficient (U) formula

Introduction

Securing the foundations of the house can be done using vertical piles, which are connected to the bedrock. An advanced form of a pile is so-called energy pile, which is basically a hollow cylinder containing piping, in which circulates a coolant (see Fig. 1). This fluid flow collects the heat stored in the ground by the Sun for use in home heating by heat pumps. The subject of this assignment is to study the amount of energy that can be collected from dry soil using a single energy pile.

The solution of an energy pile is considered in the case of a high volumetric flow, which gives the solution of the theoretical maximum yield. A semi-ready Python code is provided as part of the assignment material. As a student, you must modify this code, calculate the necessary results and produce a short written report.

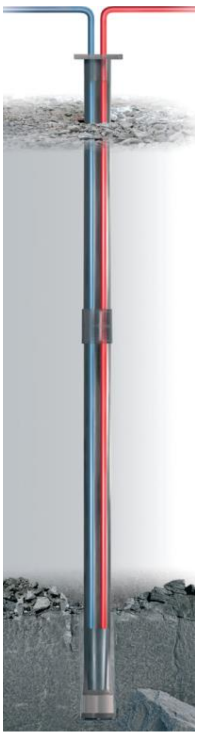


Figure 1. Energy pile (with the coolant flowing inside) in a soil, firmly attached to the bedrock.

About Python code

An incomplete Python code is provided as part of assignment material (solution is finite volume based, axial symmetric, and unsteady). The solution domain is illustrated in Fig. 2. The code is written for uniformly distributed mesh (different discretization length in directions r and z) with backward Euler integration in time. The average ambient temperature T_{air}, the average temperature of the sky T_{sky}, and the average daily irradiation of the Sun q_{sun} are given as ready functions. As seen in Fig. 2, only soil is meshed as a domain and no mesh for energy pile or its fluid region exists. You must define an appropriate boundary condition for the soil cells touching the energy pile. The domain is also simplified because it contains a "missing volume" under the energy pile. This simplification can be made because the total soil volume under the energy pile is minor, and it has no significant heat capacity relative to a large soil volume on the sides.

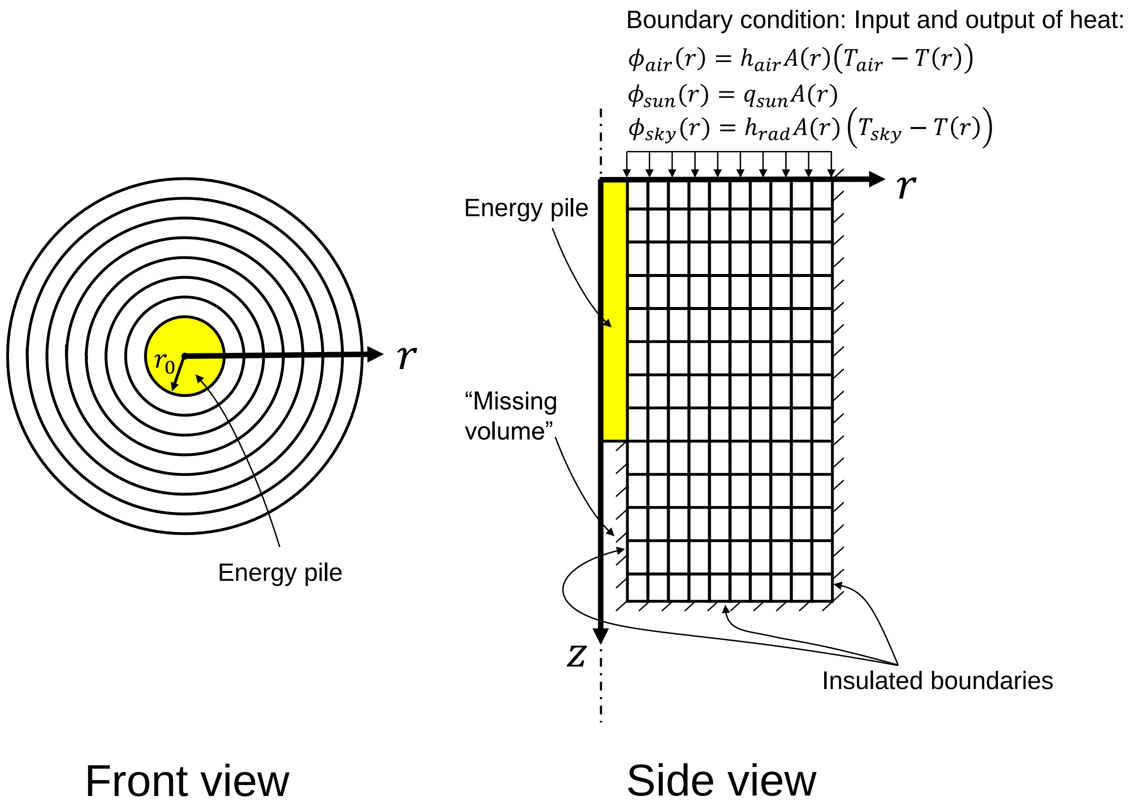


Figure 2. Schematic of calculation domain and boundary conditions.

Calculation details and boundary conditions

In this assignment, we are interested about the maximum theoretical yield from a single energy pile, which is in use from **<u>beginning of September to end of April</u>**. To make the comparison simple, we set the inlet temperature of a coolant as a constant value depending on your student number (ranging between -3 to -6 °C). We also assume that the volumetric flow of coolant is large, which results that the average outlet temperature is close to its inlet temperature $T_{out} \rightarrow T_{in}$. You can also assume that the heat transfer coefficient of fluid side is large.

A variable N is the last number of your student number (xxxxxN). Example: $123456 \rightarrow N = 6$

<u>Initial values and dimensions:</u>

To simplify radiation calculations, assume that the ground surface is a black surface: $\alpha = \varepsilon = 1{,}0$
In addition, sky is modeled as a black surface: $\alpha_{sky} = \varepsilon_{sky} = 1{,}0$

Assumed average convective heat transfer coefficient: $h_{air} = 10 \frac{W}{m^2K}$

Radiative heat transfer coefficient for sky: $h_{sky} = 4\sigma\varepsilon T_m^3 \ \frac{W}{m^2K}$, where T_m is average temperature between ground and sky

Inlet temperature of coolant: $T_{in} = \left(-6 + \frac{N}{3}\right)\ °C$

Initial temperature of the ground (whole domain): $T_0 = 5\ °C$

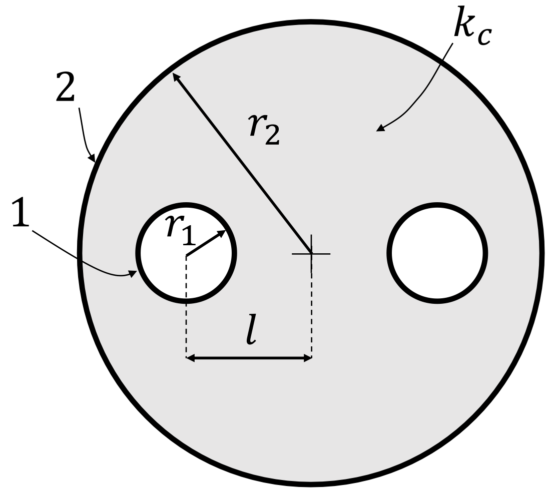
Height of the energy pile: $L = (15 + N)\ m$
Diameter of the energy pile: $D = 120\ mm$
Soil is assumed dry, and its properties are assumed to be following:

Thermal conductivity: $k_{soil} = 1{,}1 \frac{W}{mK}$

Density: $\rho_{soil} = 1750 \frac{kg}{m^3}$

Specific heat: $c_{soil} = 1380 \frac{J}{kgK}$

The Bedrock is calculated with the same thermal properties. Heat conduction inside energy pile is calculated analytically using shape factor (see Fig. 3). We assume, that coolant touches surface 1 (thin plastic pipe) and majority of conduction resistance is because of concrete (pictured as grey area in Fig. 3). An assumption is made that the energy pile is composed solely of concrete. In addition, calculate the heat transfer rate only for one plastic pipe and assume, as an engineering assumption, that for two plastic pipes (in Fig. 3), you can double the heat transfer rate.



Heat transfer rate between surfaces 1 and 2:

$$\phi = k_c S \Delta T$$

$$S = \frac{2\pi L}{\cosh^{-1}\left[\frac{r_1^2 + r_2^2 - l^2}{2 r_1 r_2}\right]}$$

Figure 3. How to calculate heat transfer rate inside energy pile (filled with concrete).

The overall heat transfer coefficient from coolant to first cell center is calculated using:

$$U = \frac{1}{R_1 + R_{1-2} + R_{2-cell}}$$

where R_1 is thermal resistance from flowing coolant to surface 1, $R_{1\text{-}2}$ is the conduction resistance within concrete, and $R_{2\text{-}cell}$ is the conduction resistance between surface 2 and first cell center in the calculation domain. Surfaces 1 and 2 are pictured in Fig. 3.

Ground temperature distribution

The calculations are started from January 1st with initial ground temperature at 5 °C. To get a somewhat realistic soil temperature distribution, calculate the first 1,5 years without energy pile, which means that the energy pile boundary condition starts from day 607.

Report

Report the findings as if you were finishing a working project as an engineer (max 7 pages including figures, tables and cover page). At minimum, the following subjects must be included in the final report:

- Brief introduction to the subject (energy piles, their use, etc.)
- Calculation methods, equations, etc.
- Calculate the total heat transfer of the energy piles per meter of their length. Plot this result as a function of time during the period of interest (at least a few years). Commercial advertisements

indicate that the maximum energy collection per meter of length is approximately 40 to 60 W/m, and average values somewhat less. Study, what values are obtained in this assignment.

- Check that overall heat balance holds for the volume and report its calculated values.
- Give a brief analysis of the possible sources of errors, the validity of the assumptions used, and the mesh and time step independence studies.
- Include important conclusions and summary of the work

Submitting the report

Report is submitted in PDF format to following email address by deadline:

kaj.lampio@tut.fi

Deadline: Wednesday 23rd May 2018 at 23:59.

Grading

This assignment is mandatory and it has to be passed (weight 15 % in total course grade).

- This report must be completed within deadline
  - Late, acceptable return results in grade 1
    - However, permission for late return must be asked before deadline
- Returned report may be
  - Accepted
    - Grade 1-5
  - If only minor errors, accepted with corrections after revision
    - Grade 0-5
  - Failed initially (with major errors), and accepted with full revising corrections
    - Grade 0-1
  - Failed with huge errors, or not submitted within deadline (no extra time asked)
    - Grade 0

Tips to complete the work

- First study carefully what the semi-ready code produces
  - Just play with the code for a few hours
- When checking the energy balance, use a low number of control volumes (to save time)
  - Use a pen and to figure out appropriate formulas to check the energy balance
- Study the mesh and the time step independence with some smaller sub problem
- Run full simulations with larger meshes only at the end (to save time)
- Use test prints to identify problems in your code