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INVESTIGATION OF HEAT TRANSPORT PROCESSES OF GROUND COUPLED HEAT EXCHANGER SYSTEMS USING NUMERICAL MODELING

Theses of Ph.D dissertation

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I. INTRODUCTION, AND RESEARCH OBJECTIVES

Nowadays, among the renewable energy sources the geothermal energy has also been gaining worldwide interest due to the ever increasing energy needs. This is particularly true in case of heat pump systems exploiting law enthalpy reservoirs. In Hungary, the number of implemented ground heat exchangers was a hundred times more in 2009 than in 2000.

Despite this fact, our country has still been lagging behind other european countries in utilization of energy produced by heatpumps. Taking the Swedish example, where 30 percent of housing estates are heated with heatpumps, which means 36000TJ/year energy production. Among the reasons we find the great investment costs and the long time of capital return. For this reason minimizing the investment and operational costs is of great importance.

To minimize the investment costs it’s needed to know the precise volume of heat gainable from the primer heat exchanging cycle. Since the determining this heat, except the vertical ground heat probes, primerily belongs to the scope of mechanical engineering, next I focus on vertical, closed systems in my paper. This decision is also motivated by the increasing number of the implemented high performance heat pump systems which belong to this type. On the other hand, calculating the primer side heat performance of these systems is rather difficult.

To minimize the operational costs the temperature step should be minimize, consequently it’s aimed to minimize the temperature difference between the condenser leaving and from the evaporator outcoming media. For this the pipeline system should be designed to reach the possibly highest returning temperature (outlet temp.) attainable in the conditions at hand.

In planning GCHP systems it’s essential to clarify the heat transfer processes occuring between the pipe of the heat exchangers and the surrounding soil mass, to calculate the returning temperatures in the operating conditions at the site. Nevertheless , this is rarely done in general practice. The main reason for this is that the analitical determination of heat transfer from the porous geological surround to the closed pipe can be done with introducing several simplifying hypothesis.

That’s why were my aims in this work to devise such a method that makes possible to calculate the heat energy gainable from the primer cycle, the temperature distribution of the GCHE-pipe and the geological surround, the inlet and outlet media temperatures in case of different hydrostratigraphical and geological conditions.

This method opened a way to take into account the impacts of special operational conditions, - strategies and the geological environment with such an emphasis which does not seem to be pronounced in the designing scheme of the Hungarian GCHE systems.

II. MATERIALS AND METHODS

During my work, using the measured data of the thermal response test carried out at an installation of Szeged University, I devised a method which makes possible, compared with the conventional interpretation of the TRT, a more precise defining of the inlet and outlet media temperatures, the heat gainable from the primer cycle, the temperature distribution of the whole tube and its geological surrounding for either a discrete GCHE or a GCHE system. The devised method is based on the geological information were at hand in advance and the measured data of theTRT.

I made calculations for the heat transport processes of a discrete GCHE and a GCHE system, which comprises 5 GCHE placed and connected different ways. The FEFLOW (Finite Element subsurface FLOW system) modeling program was used for the simulation of the GCHE-s. The FEFLOW utilizes Finite Element Method in 2D or 3D for the solution of the partial differential equations that describe the groundwater flow , mass and heat transport processes of the geological surroundings at a heat pump system's location. The heat exchanging pipe system placed in grout was represented by a one dimensional vertical element (DFE).

The description separates the processes taken place in the pipe system. On the one hand heat transport is taken place in vertical direction . To describe this process at first the velocity vector of the circulating fluid should be determined. This was done using the Hagen-Poiselle law. On the other hand the pipe system absorbs and delivers heat in horizontal direction. The transmitted heat is proportional to the pipe surface and the thermal conductivity coefficient which was calculated from the convective and conductive thermal resistance of the pipe.

The resulted one dimensional model of a GCHE or a GCHE system was next tested by a self devised FEFLOW plugin program module using different parameters in case of different operational strategies.

In the strategy one the following question was put forward: If the outdrawing performance is known and kept constant what will be the temperature step during the operation. For this the outlet temperature, which is defined only at the first moment, was decreased in the consecutive calculating steps by a given constant value. The calculated results showed the inlet and outlet absolute temperatures over time/ number of operating cycles.

In the strategy two the question was: what will be the temperature step curve if we draw out the maximum heat/temperature, by reducing the inlet temperature down the border that is allowed by the heat transfer media (phenomena supercooling down to -4°C). Here the only defined temperature is also the initial outlet temperature.

In the third strategy the problem is the following: Have to be taken into account that the temperature step difference limitates the economic operation of the heat pump, that's why the outlet temperature should not let be reduced down a given value. The difference between the previous and this case is that: this calculation does not allows the inlet temperature to drop down to such a value which is limited by the economic returning/outlet temp. Thus can be approached the maximum economically gainable groundheat at a given temperature step.

In case of a GHCE system I applied the program module with parameters apt for the above mentioned strategies, and beside I made the modelling for the serial and parallel connection of GHCEs and for their different placings.

The concluded relationships are comprised in my thesis.

III. THESIS POINTS HIGHLIGHTING THE MOST IMPORTANT RESULTS

1. The calculations using the Peclet number over 18 order of magnitude showed that it has effects on the heat output in its range of 1-10000. The output of a standalone, 100m long, U-shaped heat exchanger after 9h continuous work was obtained as 8,3 kW if Pe<=1 and 14 kW if Pe>=10000.

2. In case of low Peclet numbers the heat output shows a considerable decline over long operational periods in contrary of high Peclet numbers where the output reaches a constant value irrespectively of operational times. In the region of Pe<=1 the calculated output was 10,4KW, 8,7KW and 8,3KW for operational times of 3, 6, 9 hours respectively. If Pe>=10000 the output stays 15,4KW over operational times.

3. To define the length of the heat exchanger tubes, instead of the present practice when prevalent length is used, would be of outstanding inportance to consider the opened up strata. Since , taken the example of a 20 m long aquifer layer with a high Pe number, inserted into mainly aquitard layers of a 100 m long aquitard can increase the output even upto 22%.

4.If the output calculations of a heat exchanger placed in sedimentary strata being made as mere summary of the independently measured outputs of the differently behaving layers and their length ratio over the total disclose the result may underestimate the real output even by more KWs. It's based on that in a good aquifer layer with a Pe>10000 the heat exchanger collects surplus heat not only in that layer, but also in the layers above and beneath.

5. Applying a grout material of high thermal conductivity increases differently the output depending on the Pe numbers. The heat well conducting grout material gives an increase of 1KW in case of law (Pe <1) numbers and reaches a max. 2,8kW for the region of high Pe>10000 numbers. Amidst, 1<Pe<10000, the output difference (between the conventionally used grout material and that of higher thermal conductivity) is ever increasing.

6. If installing various exchanger tubes differing from the simple and lower cost U-tube the expected continual operation time and the geological environment should be taken into account. Short operation time and high Peclet numbers give the most advantage to the double U and W shaped heat exchangers. The use of a triple U shape in case of the heat exchanger diameter and geological environment utilized in the model is not suggested because the spacing of the tube legs are too small and reduce the possile heat output.

To the double U shape in Pe <1 region and at shorter operating time a small, 1,3KW output gain seams, but at longer time it is lost, more, at 40 hour operation time the gain is reversed to the U shape and reaches a steady 0,5KW after 140 hour. (higher Pe number reduces the 40 to 10 hours). To the W shape, in Pe <1 region, 1,5-2KW gain is calculated but after 40 hours comes a rapid fall in output. To the triple U shape a steady low output is calculated due to the thermal interference of the legs.

Concerning the U and double U shapes in the 1<Pe<10000 region considerable change seems in the output over operation time. Growing Peclet numbers helps them reach longer operation time without any drop of output and more, if Pe >=1000 the double U shape shows a better output at all operation time. The triple U and W shape shows a considerate output drop over operation time.

In Pe>=10000 region concerning the U shape and double U shapes we see a steady 15KW and 19KW output respectively. The triple U and W shape curves are featured as above.

7. In a GCHE sytem the heat exchangers' connecting pattern should be designed taking into account the fatures of the geological environment and the expected length of the operational periods. The different geological environments affect differently the output of the various connecting patterns and for a 5 membered system they can cause in case of parallel connecting upto 33% or in case of serial connecting upto 40% difference in the total performance.

8. In case of serial connecting the outlet media temperature attainable (at each heat exchanger or if taken the system as a whole) can exceed upto 14 °C the outlet temperature of the parallel connecting, but its total output is well below that of the parallel connecting. This comparison is valid at the same tube diameter and rate of flow at one tube, but evidently not at the same total massflow . The high outlet temperature has great advantage since this means a smaller temperature step which should be levelled off by the heatpump at the expense of the COP. Consequently a good combination of serial and prallel connecting of heat exchanging tubes is advantages. In exploiting serially connected members have to take care that the outlet temperature of the lastly connected member should be at the level needed for the economic operation of the heat pumping cycle.

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