# Modeling of Horizontal Ground Source Heat Pump System for Greenhouse Heating

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## Abstract

Greenhouses need heating supply most of the time of a year. Their heating demands are high and economical heating systems are very important for this kind of facilities. Horizontal ground source heat pump systems are getting more interest last years for being easy to apply and low initial cost. However, they need a wide area to apply. In this study, the heating system of a greenhouse is integrated with horizontal ground heat exchangers by using the floor of the greenhouse. Experimental result of a sample slinky type ground heat exchanger was imported to the model, then the model was validated with the results. The real ground heat exchanger (slinky type) is built in COMSOL® by using tools in geometry tab and heat transfer module and validation of the model is provided. To simplify the solutions a slinky type heat exchanger approximated with a long and thin rectangular block. The approximation is done based on to give the same results with 3D slinky solution. Furthermore more rectangular blocks allocated in the given field as different arrays to find the best performance. In 3D slinky and rectangular block temperature of pipes entered as an input. In the upper boundary of ground greenhouse's indoor set temperature is entered. After the solution is completed total heat flux magnitude is calculated. Benchmark of different allocation is this total heat flux magnitude. Then yearly analysis is done for this ground heat exchanger system for the greenhouses. It is showed that heating cost of the facility can be decreased considerably than the conventional heating system.

## Introduction

Horizontal Ground Heat Exchanger (GHE) is one of the simple solution to use as evaporator or condenser in a water-to-water heat pump. On the contrary of vertical boreholes, they are more affordable for last users. However, the most important problem in horizontal ground heat exchangers supported heat pump systems they need considerably wide area. This requirement an important barrier of these systems achieving wider usages. Therefore some technical solutions are represented for those of kind of systems like slinky™, helix etc. Applying of these geometrical types can be solution to lack of enough field.

Greenhouses are very common industrial places to grow plants in every condition of climate and they used worldwide. Depending on the plant growing, inside air has to be controlled continuously, therefore greenhouses need heating or cooling all of the year. Because of that the acclimating expenses (heating, cooling) is the one of the biggest consumption of greenhouses. Nevertheless, they laid on larger fields generally located out of city mostly without connection possibility to a gas network.

Advanced heating and cooling system for greenhouses are also investigated in literature. In the study of Fuji et al., [1] they studied on heating system in a greenhouse that located in a cold area of Japan. Their ground heat exchanger in the open field and they modeled the slinky heat exchanger using the ambient conditions. They show that double layered slinky is the best solution for limited areas. Also in the study of Dasare and Saha [2] it is explained that one layer piping is underperforming, multiple layers can provide high-energy heat transfer.

Performance comparison of horizontal ground heat exchangers is also investigated before [1-5]. In Aydin's study it is shown that vertical slinky heat exchanger give best performance in given area as compared others, spiral (snail) and horizontal slinky. Furthermore, new ground cutting technologies ease to open a narrow trench. Therefore, there is no need to remove all the soil from the field. That makes the application easy and more affordable prices.

Furthermore, in the study of Chong et.al. [6] it is shown that 1m slinky diameter and 0.25m pitch distance between to circles is the best type for slinky as shown their techno-economical analysis in their study. Actually helix type is the best solution [2,4] However based on previous experiences [7] applying helix type piping is not so easy and also drilling process needed, this increases the initial investment cost. Therefore, slinky type piping is the most common horizontal ground heat exchanger [8].

### Identification of the problem

In this study, a sample greenhouse has been considered. This greenhouse is located in north-west climate of Turkey, and in there four seasons can be seen. In the greenhouse different kind of flowers are planted. Furthermore, air temperature inside of greenhouse has to be kept at same temperature along the year.

In Fig.1. overview of the greenhouse is given. As it can be seen from Fig.1. there is no available space for horizontal ground heat exchangers except the under of the greenhouse itself.

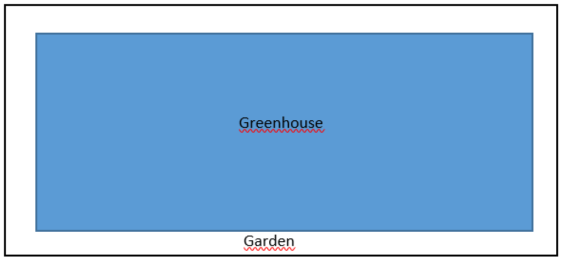


**Figure 1.** Location of greenhouse.

However, using underground as a heat exchanger has to be examined carefully, because of the sensitivity of products.

## Experimental Study

To see the effect of low temperature to the slinky heat exchanger, an experimental test is done based on similar conditions. Then a second test is done to check accuracy of results. Fig.2. shows the mobile test vehicle and its connection to a slinky GHE. To test the GHE in cooler temperatures, a heat pump is used. Outlet of cold side in the heat pump is connected to the mobile test vehicle, then the control system is adjusted the testing temperature.

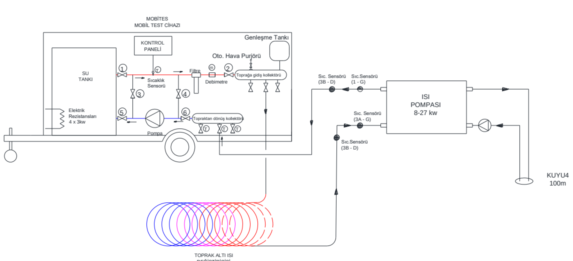

**Figure 2.** Mobile Test Vehicle and its connection to the slinky GHE.

In the Table 1, air and ground conditions of the test are given. The test system is given in Fig.2. and specifications of temperature sensors and flowmeters are in the range of ASHRAE standards.

To simulate non-stop working condition of GHE in heating mode, cooler constant temperature test method is applied. During the entire test, same flow temperature (5ºC) is sent to the GHE. Flow and return temperatures recorded each minute from the test system.

**Table 1.** Air and ground conditions.

| **Air & Ground Conditions** | |
|---|---|
| Test time | 04-06 May |
| Total duration | 57 h |
| Amb. temp. during the test | 12 - 22 ºC |
| Avg grou. temp. at 0.5m depth | 19 ºC |
| z =-2m temp. before the test | 11 ºC |
| **Test Data** | |
| Inlet fluid temp. to GHE | $T_g$= 5.6 ºC |
| Avg. return temp. from GHE | $T_d$ =7.0 ºC |
| Avg. fluid temp. in GHE | 6.3 ºC |
| Flowrate | $Q_v$ = 9.9 lt/min |
| Temp.diff. between slinky GHE and ground at z =-2m | 4.7 ºC |
| Average heat load | $\dot{q}$ = 999 W |
| Ave. heat load in unit trench | $\dot{q}'$ = 91 W/m |

In addition, two temperature sensors are located in underground on slinky pipes to see the changings during the test. One is located on flow pipe and one is on return pipe. Fig. 3 shows fluid flow and return temperatures and on pipe temperature changings taken from the sensors. T1 is located on the closer to flow side on PE pipe, similarly T2 is located on the closer to return side. From the fluctuations, it is seen that temperature sensors effected air temperature changings, however, the fluid inside the pipes does not effected.

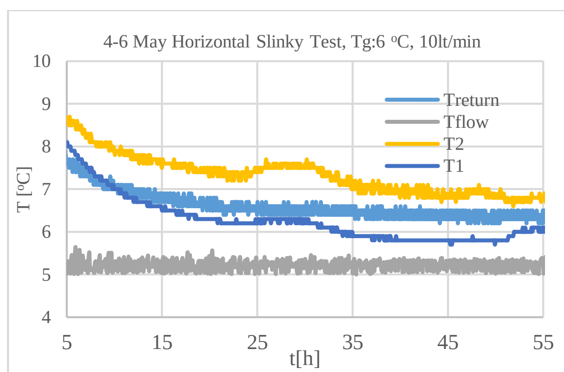


**Figure 3.** Changings in temperature sensors during the test.

By using the simple formula, we can obtain actual heat transfer rate in the entire GHE:

$$\dot{q}_{GHE-Slinky} = mc_p(T_{flow} - T_{return})$$

and obtained results are given in Fig.4.

## Modeling

As you can see from the Fig. 5 the slinky type piping has special geometrical property. That geometrical property enable to install more pipe in limited place.

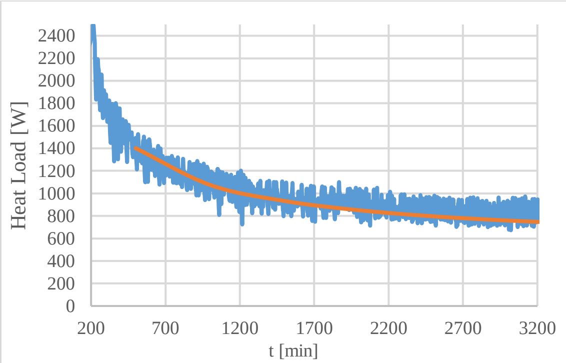


**Figure 4.** Heat load obtained from 100m slinky GHE.

However solution of this kind of geometry is little bit hard, therefore, an approximation based on rings in array can be used as shown in Fig.6 [9,10].

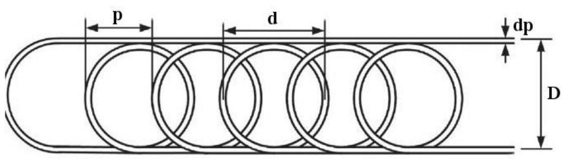


**Figure 5.** Slinky ground heat exchanger (GHE)[10]

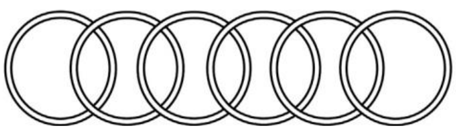

**Figure 6.** Ring Array approximation for slinky [10].

The same conditions are built in COMSOL[11]. Initially, the same geometry of slinky is built in the program (Fig.7). Dimensions of GHE are given in Table 2.

**Table 2.** Dimensions of Slinky GHE.

| | |
|---|---|
| Pinch (p) | 0.25m |
| Diameter (d) | 1m |
| Inlet diameter of pipe ($d_i$) | 0.026m |
| Outlet dia. of pipe ($d_o$ = dp) | 0.032m |
| Total length of pipe | 100m |
| Total trench length | 11m |

Then surrounding ground is added to the model as a box. Depth of slinky GHE is chosen as in the real conditions. Dimensions of box is chosen as big as that temperature changings in slinky GHE cannot effect considerably the borders of box.

It is seen that 6m x 10m x 25m box is adequate for one slinky GHE. Temperature changes in the borders can easily be seen from the results and can be checked after the solutions.

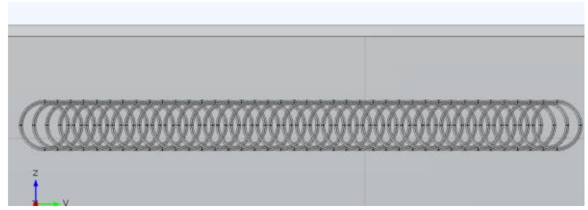

**Figure 7.** Comsol slinky model

Obtained temperature data from the experiment is entered in COMSOL by using the interpolation function. As it can be seen from the Fig.3 between the inlet and outlet of slinky there are just 1.5 - 2 ºC temperature difference. Therefore, for boundary condition, average GHE temperature is entered for entire GHE. In the box, for the upper plane boundary condition, heat flux boundary condition with 5W/(m$^2$K) and the ambient temperature is entered.

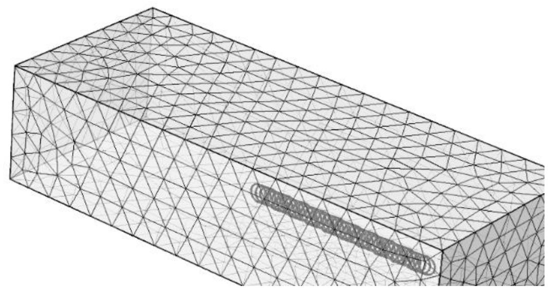

**Figure 8.** Slinky GHE and ground model in COMSOL.

Furthermore, for lateral walls symmetry condition is applied. In meshing process free tetrahedral geometry is used and it is seen that after "Finer" mesh the results do not change considerably. Then "Finer" mesh is used for following solutions.

***Governing Equations***

In ground heat exchangers, heat transfer mainly governed by conduction. Therefore, in COMSOL in Heat Transfer Module, "Heat Transfer in Solid" is used for solutions. Governing equations in the ground:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \nabla T + \nabla q = Q$$

Upper Boundary Condition

$$q_0 = h(T_{amb} - T)$$

GHE Boundary Condition

$T = T_{avg\text{-}exp}$

***Computations***

Computations are done Intel Core i7-4510U-2GHz, 8GB computer, solutions lasted about 3min. Solution time is chosen as the experimental duration 55hours and each hour one data is taken from the model. For the validation process, value of heat transfer from GHE is used. Amount of heat transfer is obtained from the results, surface integration of GHE. In fitting process, thermal conductivity of ground is changed until the best fitting achieved. The fitting of experimental results to numerical results is giving in Fig.4.

***Extending of results to field solution***

After fitting is achieved, the model is extended to field scale. In this process the best economical solution is tried to achieved for giving area by using COMSOL. It is seen from the previous studies that applying slinkies as vertical is better than applying them horizontal. In that case the view of the application field will be like in Figure 9.

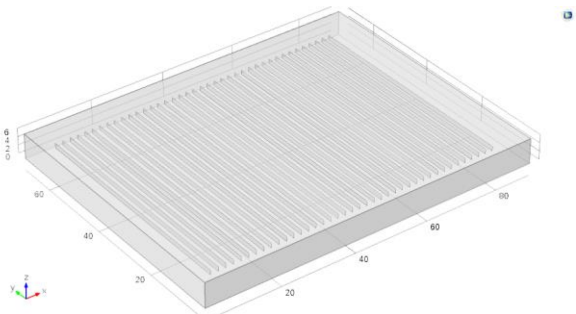

**Figure 9.** Field Application of Slinky GHE.

However installing slinky type GHE that as given in Figure 7 to all the field may cause unnecessary processing load for the computation. To faster the solutions in such a field, a simple approximation is required for the slinky geometry. A thin rectangular plate can be approximated to the slinky. However, length and depth of GHE is important for heat interaction, therefore in fitting process here thickness and height of the plate is changed. Approximated plate, slinky and experimental results are compared in Figure 10.

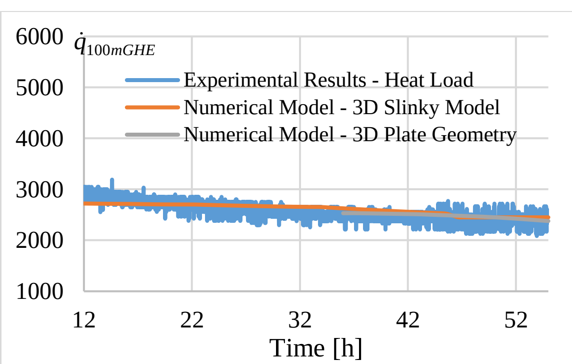


**Figure 10.** Experimental, Numerical Slinky and Plate comparison.

***Effect of Distance between GHE***

For this given limited space, locating of GHE as much as possible is found by COMSOL parametric solution. If the distance between two GHEs is chosen closer more pipes can be applied. However in that case thermal interaction will be higher, overall performance will decrease immediately, and the system may not support the heat pump. If the distance keep longer, in that case less piping can be applied, this will cause underperformance for heat pump.

To find the optimum value, yearly simulation is used for a part of field. In yearly solutions, 2400 h is chosen as like in VDI [12]. Solutions are given in Figure 11 and Figure 12.

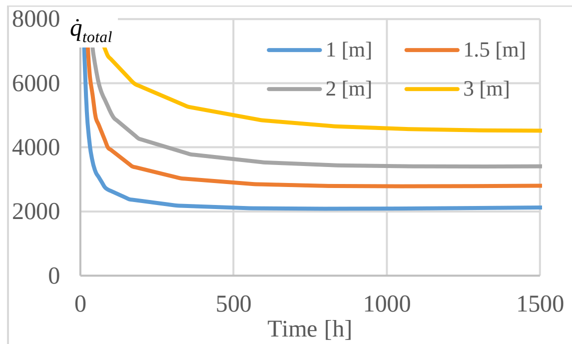


**Figure 11.** Heat load for one line, yearly working condition

Then beside this, depending on distance between slinkies and also for double layer obtainable instant minimum heat loads are given in Table 3.

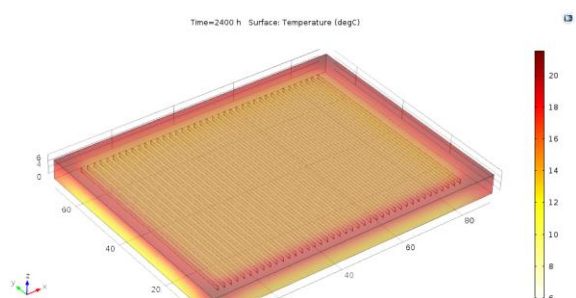

**Figure 12.** Simulation results.

All heat energies that can be taken from the given field for different scenarios are calculated and given in Table 3.
Values in Table 3 are that obtained with given thermal conductivity of the application field. As known from the previous studies [13,14], most important value in horizontal ground heat exchanger is thermal conductivity of ground. The obtainable values may be different based on thermal conductivity of the field.

**Table 3.** Heat value obtained from the 60m x 80m field at the end of the 2400h non-stop running condition.

| Distance between trenches [m] | Obtainable heat load from ground [kW] | | Given Heat to Greenhouse [kW] |
|---|---|---|---|
| | One Layer | Double Layers | Total Heat (COP:4) |
| 1 | 172 | 309 | 412 |
| 1.5 | 149 | 275 | 366 |
| 2 | 136 | 258 | 344 |
| 3 | 117 | 228 | 304 |

## Conclusion and Discussion

In this study, a horizontal ground heat exchanger system model is built for a greenhouse. For horizontal piping, slinky geometry is used as vertically that can be located in narrow trench easily. Experimental results of a sample vertical slinky is imported in COMSOL and using them in the model, the model is validated. After validation, underground of the greenhouse is used as the application field and the best allocation is examined. It is shown that double layer with 1.5m distance between each loop is given best performance.

However given values in Table 3 is one year obtainable heat energy values. In the solution here in the end of the year, it is assumed that no residual or lacking heat is left. Otherwise, allocation of the field has to changed to balance heat transfer between the ground and greenhouse. Required heat energy of greenhouse depends on the location of it. Therefore, the best allocation of this kind of field may be different.

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