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Investigation of the Effect of Mixture Type around Heat Transfer Tube on Extracting Geo-Thermal Energy

Leila Khanmohammadi[1], Naghmeh Jamshidi [2*]

1- Department of Civil Engineering, Payame Noor University (PNU), Tehran, Iran.
2- Department of Mechanical Engineering, Payame Noor University (PNU), Tehran, Iran
* P.O.B. 19395-4697 Tehran, Iran, N.jamshidi@pnu.ac.ir

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Abstract

The depletion of fossil energy resources and their limited resources on the one hand and the amount of pollution on the use of these fuels on the other hand, led different countries to use available and clean energies such as solar, geothermal, waves and wind. In the meantime, the use of geothermal energy is welcomed due to its simple equipment and especially its use in certain areas is very useful. The geothermal heat exchanger consists of a tube that is installed deep in the ground and mortars are used around this pipe to fix and increase performance. Since the type of this mixture is effective on the amount of geothermal energy received by heat exchangers, in this study, the effect of using different compounds in the structure of mortar around pipe is investigated. The evaluation was performed in different cities in Iran for a straight tube heat exchanger. Studies have shown that if the sand-bentonite combination is used, the energy extraction rate will increase by 10% compared to native soil and increasing water content up to a point will result in more energy exchange.

Keywords: Geothermal energy, Straight tube heat exchangers, Mortars' properties, Numerical simulations

1. INTRODUCTION

Renewable energies are clean and compatible with nature and there is no end to them. Iran has many sources of fossil fuels such as oil and gas as well as renewable energies such as solar, wind and geothermal energy. Due to the reduction of water resources in the country for use in hydropower plants, the use of clean and cheap energy such as wave, wind, solar and geothermal energies can be a way forward in the future. The use of geothermal pumps greatly contributes to the extraction of energy stored deep underground and its use in heating residential homes.

Meanwhile, the thermal conductivity of the working fluid in the heating cycle of the pump, the thermal conductivity of the pipe wall and the surrounding mortar will have a great effect on the amount of received energy from the ground by the working fluid. The higher the thermal conductivity of the pipe's fluid and mortar, the faster the earth will absorb energy. Therefore, many studies have been done on the material of the working fluid in the geothermal heating cycle, and the results indicated that if Nano-fluids are used, the extracted energy will increase intensively.

In recent years, researchers have conducted many researches on the type of mortars around the pipe and measuring their thermal conductivity. These researches include Lee et al. [1], Delaleux et al. [2], Lee et al. [3, 4], Liu et al. [5], Agrawal et al. [6, 7], Xu et al. [8] and Jobmann and Buntebarth [9].

The results of researches indicated that using special types of concrete mortar around the pipe in the ground can significantly increase the thermal efficiency of the heat pump. Therefore, in the present study, using mortars with different compositions and consequently different thermal conductivity, the thermal efficiency of a straight tube geothermal heat exchanger has been investigated in more detail.

2. The physical model under investigation

The geothermal heat exchangers studied in this research are of vertical and straight tube type. HDPE pipe with two different layers is assumed. The first layer will be the main wall of the pipe and the second layer is the cement mortar around the pipe. The heat exchanger has been investigated in Ansys-Fluent software. According to results of recent researches and purpose of the present research, the working fluid and the wall of the pipe and soil are assumed to be fixed and only the thermal conductivity of the cement mortar is changed. Consequently, the outlet fluid temperature from heat exchanger and extracted energy in each case are investigated and the results are compared with together.

2.1. Governing equations and Solving methods

According to the range of volume flow rate and Reynolds number, the flow is assumed to be turbulent. Numerical simulation is performed using Ansys-Fluent computational fluid dynamics software. The governing equations of fluid are given in Equations (1) to (3):

$$\vec{\nabla}.(\rho\vec{V}) = 0 \quad (1)$$

$$\rho(\vec{V}.\vec{\nabla})\vec{V} = -\vec{\nabla}p + \eta\vec{\nabla}^2\vec{V} \quad (2)$$

$$\rho(\vec{V}.\vec{\nabla})(c_pT_g) - \vec{\nabla}.(k\vec{\nabla}T_g) = \Phi \quad (3)$$

Where Φ is the heat source, which is mainly caused by friction losses in contact with the parts. Also in these relations, ρ, $\vec{V}$, p, k, c_p and η are density, velocity, static pressure, heat capacity and kinematic viscosity respectively. The k-ε RNG turbulent model is used to simulate the turbulent flow.

Using existing CFD simulation tools and Ansys-Workbench software, heat transfer in straight tube heat exchangers with different mortar materials is performed in different climatic conditions. The second order upstream method is used to discretize the equations and the simple algorithm is used to couple the pressure and velocity equations. There is good thermal contact between the soil and the pipe. The inlet air velocity to the heat exchangers is equal to 6 m / s. The boundary condition of the soil in the distance is constant temperature and the non-slip condition is applied to the walls. The pipe wall and the soil are coupled together to transfer heat along the joint wall. Since air is a compressible fluid, the outlet boundary condition is the outlet pressure.

Earth temperature varies at different soil depths, so it will be given to the software as a function of depth. The temperature of the earth depends on the temperature of the surrounding air, so by changing the studied city and using the relations related to the air of that city and converting the air-to-soil temperature information based on the defined functions, the study can be done in different regions of Iran.

Thermal properties of pipe and soil affect the thermal efficiency of geothermal heat exchangers. Table 1 shows the soil properties of Tehran and HDPE pipe.

Table 1. Properties of soil and HDPE pipe

	Thermal capacity $J/kg.K$	Thermal conductivity $W/m.K$	Density kg/m^3
Soil	2093	0.476	958
HDPE pipe	568.75	0.52	1600

How to obtain cities' and different depths of soil's temperature changes is described in reference [11]. According to Equation (4), soil temperature depends on soil depth, time studied and soil distribution:

$$T(z,t) = T_{mean} + A\cos\left[\omega(t-t_0) - \frac{z}{d}\right] \times \exp\left(-\frac{z}{d}\right) \quad (4)$$

Where T_{mean} is the average annual air temperature, t_0 is the time of occurrence of the hottest day since January 1st, A is the amplitude of the air temperature wave over 50 years, z is the height of the soil below the ground (meters) and ω is the frequency of the annual air temperature wave . The values of A and T_{mean} are obtained using the data available on the website of the Meteorological Organization of Iran for the city of Tehran.

The rate of geothermal energy extraction by the studied heat exchanger in each case will be obtained using simple equation (5) and the results will eventually be investigated together.

$$Q = \dot{m}\, c_p\, (T_{out} - T_{in}) \quad (5)$$

Where Q is the heat energy of exchanger, $\dot{m}$ is the mass rate of flow in the pipes, c_p is the heat capacity of air, and T_{in} and T_{out} are the inlet and outlet air temperatures of the geothermal heat exchanger, respectively.

2.2. Validation and Grid independency

The geometry of the straight model is made in SolidWorks and the grid is produced in Ansys-Meshing software. The number of grids is about 3.6 million cells and gridding is disorganized. The effect of k-w, k-ε standard and k-ε RNG turbulent models on temperature distribution has been investigated. In order to validate the solution method, modeling was performed unsteady with a time step of 5 minutes for one day and the inlet air temperature as variable, based on the results of Mathur et al. [10]. The results indicate that numerical solutions are appropriate approximation of laboratory conditions [10]. As a result, the geometry, grids and solution method can be used to simulate the heat exchanger in the climate of different cities in Iran.

The physical model of heat exchangers is divided into small components using three-dimensional gridding (polyhedral and pyramidal). The total number of computational grids in the solution area is about 2 million cells.

3. Numerical results and Discussion

3.1. Effect of ambient climate on geothermal energy extraction

In order to investigate the effect of the type of climate in the region on the rate of energy extraction from the straight tube geothermal heat exchanger, eight cities of Iran in different climatic regions have been selected and studied. Inlet air temperature and soil temperature at a depth of 6 meters in these cities are different. Tabriz and Hamedan have the lowest incoming air temperatures in the warm seasons and Ahvaz has the highest air and soil temperatures. Changes in air temperature in the heat exchanger and the rate of energy extraction in different cities of Iran in the warm seasons are shown in Table 2.

According to the obtained results, the best point in terms of the efficiency of the geothermal heat exchanger is the city of Tabriz and the lowest rate of energy extraction is related to the two cities of Rasht and Babolsar. Numerical values for the cold season of the year also show similar results to the hot seasons of the year.

Table 2. Changes in air temperature in the heat exchanger and the amount of energy extraction in different cities of Iran in the hot season of the year

City	Inlet air temperature	Outlet air temperature	Dissipated heat
Tehran	299.89	295.98	218.625
Rasht	296.072	293.174	162.227
Babolsar	297.004	294.1055	162.186
Ahwaz	308.43	304.59	214.86
Tabriz	294.8	290.79	224.78
Esfahan	298.41	294.69	208.014
Yazd	301.64	297.89	209.27
Hamedan	293.96	290.13	214.59

3.2. Effect of soil type around the pipe

According to the results of Section 3.1, in all simulations of this section, the inlet temperature is the same and considered to the air temperature of Tabriz in the cold season of the year and only the effect of the type of mixture around the pipe on the output results is evaluated. In order to perform this study, the pipe is covered with a layer of different mortars with thermal properties according to Table 3.

According to the obtained results, the sand-bentonite mixture has higher thermal conductivity and consequently higher energy extraction than ordinary sand or soil. The results also show that with increasing the percentage of water in the sand-bentonite mixture, the thermal conductivity and the amount of energy extraction increase. The slope of changes in low water percentages is high and decreases with increasing humidity percentage from 20%. This is due to the filling of the empty voids between the sand and bentonite in different percentages of moisture. At low percentages, with increasing humidity, the void between the sand and bentonite particles is filled with water, which has a higher thermal conductivity than air and consequently less heat resistance, and the energy extraction rate increases significantly. However, due to the limited capacity of filling the air cavities with water, the mortar is saturated and with increasing the amount of moisture in the sand-bentonite mortar, the thermal resistance increases and the thermal conductivity and the amount of energy extraction decreases. Table 3 also shows the temperature difference between the inlet and outlet air of the heat exchanger with different layers.

Table 3. Effect of soil and mixture around the pipe

Material of mixture	Thermal conductivity $(W/m.K)$	Difference of inlet and outlet air temperature (K)	Extracted energy (W)
native soil	0.5	1.4625	228.058
sand	0.8	1.6431	253.199
sand-bentonite	1.45	1.807	276.67
sand-bentonite-0%w	0.492	1.4553	226.417
sand-bentonite-10%w	1.174	1.751	270.703
sand-bentonite-20%w	1.515	1.8164	227.36
sand-bentonite-30%w	1.666	1.8377	280.15
Slit	0.52	1.4889	226.745
Clay	0.16	0.90872	141.63
sandy loam	2.1	1.822	287.026

4. Conclusions

In this study, the effect of the type of mixture around the pipe on the rate of energy extraction in a straight geothermal converter has been investigated. Initially, the study was conducted in different climatic conditions in the cities of Tehran, Rasht, Babolsar, Ahvaz, Tabriz, Isfahan, Yazd and Hamedan. According to meteorological data, the average air temperature of these cities in cold and hot seasons was calculated and extracted at different depths using the soil temperature function in these cities. Results show that Tabriz was the best city in terms of the highest amount of geothermal energy received in straight pipe heat exchanger. Other calculations were performed based on the air and soil temperature of Tabriz and the change of cement mortar around the geothermal pipe for mixtures with different water content. The results of numerical simulation indicated that in case of using mixtures with higher water content, the rate of energy extraction in the studied conditions has increased to a certain extent and after that the growth of changes is very slow.

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