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DESIGN AND FABRICATION OF A HEATING AND COOLING SYSTEM USING GEOTHERMAL ENERGY

Haris Rashid
Department of Mechanical and Aerospace Engineering
Air University
Islamabad, Pakistan
harris_rashid123@hotmail.com

Dr. Muhammad Afzaal Malik
Professor
Department of Mechanical and Aerospace Engineering
Air University
Islamabad, Pakistan

***Abstract*— Ground-source heat pump systems are one of the promising new energy technologies that can be a sustainable solution for on-going energy crisis in Pakistan. The purpose of this study is to build a working model of geothermal space cooling & heating system for energy savings and demand reduction for residential, school and commercial building applications. For analysis purposes ground heat exchanger is prepared for extracting energy from ground along with a heat pump and energy is delivered to the environment for space heating in winter and vice versa in summer.**

To make it a complete working model, temperatures of the soil, time required in changing the temperature of the air in specified area and heat exchange through pipe and radiator, considering losses in pipe are being calculated. The suitable material for pipe has been selected considering ground heat transfer and economics for different pipe materials. The length of the pipe has been determined depending on the heating and cooling load. The effect of flow rate on heat exchange and the length of the pipe have also been studied and a relationship between the pipe length and the heat exchange has been formulated and presented.

Keywords*— *Geothermal, Soil Temperature, Pipe Length, Flow rate

I. Introduction

Engineers around the world are facing challenges to cope up with the growing energy needs of the people. Some claim saving and using energy efficiently as more important that making new forms of energy and this is where the basis of alternate resources are set.

It is found that the temperature at the certain depth in the ground remains same throughout the year[1]. This can be efficient source of space cooling and heating. To exploit the heat energy of the ground a heat exchanger can be constructed inside the ground comprising of tubes buried in the ground. If air or water is circulated in this tubular heat exchanger, in winters this will extract heat from the ground and will be used for space heating and in summers the energy from the hot environment will be extracted and dumped into the ground thus providing space cooling. A heat pump can be connected to the underground heat exchanger to increase its efficiency and utilizing the maximum geothermal energy.

To exploit effectively the heat capacity of the ground, a heat-exchanger system has to be constructed. This is usually an array of buried pipes running along the length of a building, a nearby field or buried vertically into the ground. A circulating medium (water or air) is used in summer to extract heat from the hot environment of the building and dump it to the ground and vice versa in winter. A heat pump may also be coupled to the ground heat exchanger to increase its efficiency. In the literature, several calculation models are found for ground heat exchangers. The main input data are the geometrical characteristics of the system, the thermal characteristics of the ground, the thermal characteristics of the pipe and the undisturbed ground temperature during the operation of the system.

Measurements show that the ground temperature below a certain depth remains relatively constant throughout the year. This is due to the fact that the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia of the soil. Also, there is a time lag between the temperature fluctuations at the surface and in the ground. Therefore, at a sufficient depth, the ground temperature is always higher than that of the outside air in winter and is lower in summer.

The difference in temperature between the outside air and the ground can be utilized as a preheating means in winter and pre-cooling in summer by operating a ground heat exchanger. Also, because of the higher efficiency of a heat pump than conventional natural gas or oil heating systems, a heat pump may be used in winter to extract heat from the relatively warm ground and pump it into the conditioned space. In summer, the process may be reversed and the heat pump may extract heat from the conditioned space and send it out to a ground heat exchanger that warms the relatively cool ground.

II. Mechanism

The mechanism of this particular geothermal system is a simple demonstration of these systems that are being used throughout the world. In Pakistan this technology has not been incorporated so far. A lot of work has been done in Pakistan about geothermal potential but nothing so far has been done regarding geothermal systems. A traditional geothermal system is a two stage system. The first stage is the underground looping and the second stage is the assembly of heat pump which includes the refrigeration cycle also. A vapor compression cycle further increases the efficiency of this system but this is not used in this arrangement as the scope is restricted to the first stage only. This system has a pump that gets water from a water tank and circulates it in the pipe that is buried underground at a depth of 12 feet. The water flows in this pipe and then enters the radiator which is placed in the demonstration box. From radiator the water exchanges its heat with the ambient air by forced convection through a fan. The water then drains in the water tank again to be circulated further. The first critical selection is the organization of the heat exchanger.

Figure 1: Heat Exchanger (12x14 ft) of Galvanized Iron

A. *Geothermal Heat Exchanger*

Ground heat exchanger is the arrays of pipes buried inside the ground, through these pipes the heat is transferred from the circulation medium to ground and vice versa. There are two general types of ground heat exchangers; Open and Closed, however the open system is employed here[2].

In open systems, ambient air passes through tubes buried in the ground for preheating or pre-cooling and then the air is heated or cooled by a conventional air conditioning unit before entering the building may be reversed and the heat pump may extract heat from the conditioned space and send it out to a ground heat exchanger that warms the relatively cool ground.

B. *Horizontal Ground Heat Exchanger*

A horizontal loop field installation usually occurs in more rural areas or yards with lots of space. A horizontal loop field installation requires a great deal of land because a backhoe is used to dig up long trenches which are only a few feet deep (but below the frost line) in order to lay the necessary amount of piping. In some cases horizontal loop fields can be less costly to install than vertical because there is no drilling. Horizontal systems can be installed using an excavator or other ground moving machine and can be installed in 1-2 days.

For all horizontal systems in heating-only mode, the main thermal recharge is provided by the solar radiation falling on the earth surface. Therefore, it is important not to cover the surface above the ground heat collector.

The deeper the loop the more stable the ground temperatures and the higher the collection efficiency but the installation costs will go up. Horizontal loops are usually installed at a depth of approximately 3 m. Health and Safety Regulations do not allow personnel to enter unsupported trenches if they are more than 5 m deep. To reduce thermal interference multiple pipes laid in a single trench should be at least 0.3 m apart and to avoid interference between adjacent trenches there should be a minimum distance of 3 m between them [3].

III. Components

A. *Heat Exchanger Pipe*

Piping made from Galvanized Iron pipes, coated with zinc, is a cost effective solution for a broad range of piping problems in municipal, industrial, marine, mining, landfill, duct and agricultural applications. It has been tested and proven effective for above ground, surface, buried and slip lined applications. GI pipes can carry water, wastewater, slurries, chemicals, hazardous wastes, and compressed gases. In fact, GI pipes have a long and distinguished history of service to the gas, oil, mining and other industries. It has the lowest repair frequency per mile of pipe per year compared with all other pressure pipe materials used for urban gas distribution. Galvanized Iron is strong, extremely tough and very durable.

Comparison of different materials meeting the requirements is as follows:

	Pipe Material Comparison			
Pipe Material.	***Copper***	***PEX Pipe***	***HDPE Pipe***	***Galvanized Iron***
Life	20 Years	70 Years	70 Years	70 Years
Flexibility	Non - Flexible	Flexible	Non - Flexible	Non – Flexible
Conductivity	Very high conductivity (401 $W.m^{-1}.K^{-1}$)	Low Conductivity (0.4 $W.m^{-1}.K^{-1}$)	Low conductivity (0.5 $W.m^{-1}.K^{-1}$)	Medium Conductivity (55 $W.m^{-1}.K^{-1}$)
Plumbing	Require Fitting	Does not require fitting	Requires fitting	Requires fitting
Cost	Very Expensive	Cheap	Cheap	Moderate
Durability	Highly corrosive	Non - corrosive	Non - corrosive	Corrosive

Table 1: Properties of materials used for heat exchanger

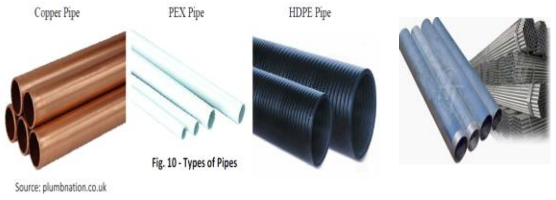

Figure 2: Types of pipe

B. Thermocouple

A thermocouple is a sensor that measures temperature. It consists of two different types of metals, joined together at one end. When the junction of the two metals is heated or cooled, a voltage is created that can be correlated back to the temperature. The most commonly used K – type thermocouple is used as Type K thermocouples generally work in most applications because they are nickel based and have good corrosion resistance.

C. Pump

Circulator pumps are designed to circulate liquids in open and closed heating systems, such as radiant floor heating, hydronic heating, hydro-air coils, water to air heat exchangers, and domestic hot water recirculation[4]. These pumps can be used in a variety of residential and light commercial systems, and are sized according to specific system requirements.

The pump used has a flow rate of 10 L/min. The RPM of the pump is 2900. The power of the pump is 0.5 HP.

Figure 3: Electric circular pump

D. Radiator

Radiator is used to exchange heat between air and a working fluid that flows in the vanes of the radiator. They are used for both cooling and heating purposes. The most common, and the one used is the radiator used in a car, with specifications as follows

Table 2: Properties of Radiator

R-SUZ030	1988/1994
Model:	Cultus/Swift 1.3L
Core Size:	324 x 324 x 30 mm^3
Header:	348 x 50 mm^2
Auto Assembly:	R-SUZ030
Bottom Tank:	T-SUZ450
Gaskets:	G-34849

Figure 4: Radiator

E. Demonstration Box

It is used to demonstrate the experiments conducted. The dimensions of the demonstration box are 2*2*2 feet. The radiator, fan and the heater is placed in this demonstration box. This box is highly insulated by the polyethylene sheets. A thermocouple is also placed inside the box to give the temperature reading.

Figure 5: Demonstration box

F. Water Tank

It is used to stock water that is delivered to the geothermal system. The pump is attached with it which sucks the water from this tank and circulates it through the pipe. The water drains back into this tank after moving from the whole system.

Figure 6: Water Tank used to distribute water

IV. Mathematical Relationships

A. Length of Pipe and Heat Transfer Relationship[5]

Length of the pipe for required heat transfer is given by relation:

$$L = \dot{Q}_W / U_L (T_{E,W} - T_{W,P}) \qquad (1)$$

Where L = Length of pipe

Q = Heat flow from earth through wall of pipe to air in pipe in W

U = Heat transfer coefficient between wall and water

TE,W = Earth temperature at wall of pipe

TW,P = Temperature of water in pipe

The heat transfer coefficient per length of wall of pipe UL for pipes typically used with earth heat exchangers is given by the following equation:

$$U_L = \pi D_o h_i \qquad (2)$$

Where hi = Heat transfer coefficient at inner surface of pipe in W/m^2K

Heat transfer coefficient at the inner surface of the pipe depends on the flow properties, dimensions of the pipe and material properties of the air in pipe, given by following equation:

$$h_i = \frac{Ka\ Nu}{D_o} \qquad (3)$$

Where Ka =Thermal conductivity of water in pipe W/mK

Nu = Nusselt number of water in pipe

D_o= Outer Diameter of pipe

The Nusselt number Nu of air in the pipe depends on Reynolds number Re and thus on flow rate. The following approximation is used for Nusselt number:

$$Nu = 0.0214\,(Re^{0.8} - 100)Pr^{0.4} \qquad (4)$$

Where Pr = Prandtl number of water (typically: P9 = 7)

Re = Reynolds number of water in pipe

Now for earth temperature at wall of pipe, $T_{E,W}$

$$T_{E,W} = \frac{UT_{E,O} + T_{A,O}}{U + 1} \qquad (5)$$

Where $T_{A,O}$ = Temperature of water inside the pipe

$T_{E,O}$ = Temperature of earth at depth d

U = Conductance ratio of heat transfer from earth surface to pipe and from airflow to pipe wall

The parameter, U (conductance ratio) is defined to measure the ratio of both effects taking in account thermal conductivity of the earth, heat transfer coefficient between the airflow and the earth at the pipe wall as well as the geometric configuration of pipe. The relation is given as:

$$U = \frac{K_s}{U_L} S \qquad (6)$$

Where S = Conduction Shape factor of the pipe

Ks= Thermal Conductivity of soil in W/(mK)

Conduction shape factor of the pipe is given by:[6]

$$S = \frac{2\pi}{\ln\left[\left(\frac{2d}{D_o}\right) + \sqrt{\left(\frac{2d}{D_o}\right)^2 - 1}\right]} \qquad (7)$$

Where d = Depth of pipe underground the surface

D_o = Outer Diameter of pipe in m

Now as;

$$Q = UA\Delta T \tag{8}$$

Where

$$U = K_p/L \tag{9}$$

$$\Delta T = T_2 - T_1 \tag{10}$$

Where T_2 = Water Temperature at inlet of pipe

T_1 = Water Temperature at outlet of pipe

B. Soil Temperature Calculations

The ground surface temperature satisfies the following conditions

$$T_{sur} = T(0,t) = T_m + A_s Re(e^{i\omega t}) \tag{11}$$

Where T(x,t) is the soil temperature profile as a function of depth x and time t. Tm and As are the annual mean value and the amplitude of the ground surface temperature variation, respectively, which should be calculated by considering the convective heat transfer between the air and ground, the solar radiation absorption by the ground, the long wavelength radiation emitted from the soil, and the latent heat loss due to the moisture evaporation at the ground surface.

The annual mean ground surface temperature, T_m, can be estimated as follows:

$$T_m = \frac{1}{h_e}[h_r T_{ma} - \varepsilon\Delta R + \beta S_m - 0.0168 h_s f b(1 - r_a)] \tag{12}$$

Where

$$h_e = h_s(1 + 0.0168af) \tag{13}$$

$$h_r = h_s(1 + 0.0168ar_a f) \tag{14}$$

Phase angle difference between the air and soil surface temperature (rad) can also be determined as follows:

$$A_s = \left\|\frac{h_r T_{va} - \beta S_v e^{i\varphi_I}}{h_e + \delta k_s}\right\| \tag{15}$$

$$t_o = t_{oa} + \frac{\varphi_s}{\omega} \tag{16}$$

$$\varphi_s = -Arg\left[\frac{h_r T_{va} - \beta S_v e^{i\emptyset_I}}{h_e + \delta k_s}\right] \tag{17}$$

The symbols ‖ ‖ and Arg are used to signify the modulus and the argument of a complex number, respectively.

The phase constant of the air is the time elapsed from the beginning of the year at which the air temperature reaches the minimum value in the year.

The value of delta is evaluated as follows

$$\delta = \frac{1 + i}{D} \tag{18}$$

Where the dampening depth (m), D, is calculated from the following equation:

$$D = \sqrt{\frac{2\alpha}{\omega}} \tag{19}$$

Assuming homogeneous soil of constant thermal diffusivity, the temperature at any depth z and time t can be finally estimated by the following expression:

$$T_{z,t} = T_m - A_s exp\left[-z\left(\frac{\pi}{365\alpha_s}\right)^{1/2}\right] cos\left\{\frac{2\pi}{365}\left[t - t_o - \frac{z}{2}\left(\frac{365}{\pi\alpha_s}\right)^{1/2}\right]\right\} U_L = \pi D_o h_i \tag{20}$$

C. Heat Transfer and Earth Tube Inlet AirTemperature Calculations

In order to calculate the heat transfer between the earth tube and the surrounding soil, the overall heat transfer coefficient should be determined using the following three thermal resistance values[7]:

$$R_c = \frac{1}{2\pi r_1 L h_c} \tag{21}$$

$$R_p = \frac{1}{2\pi L k_p} ln\frac{r_1 + r_2}{r_1} \tag{22}$$

$$R_s = \frac{1}{2\pi L k_s} ln\frac{r_1 + r_2 + r_3}{r_1 + r_2} \tag{23}$$

Where R_c is thermal resistance due to convection heat transfer between the air in the pipe and the pipe inner surface (°C/W), R_p the thermal resistance due to conduction heat transfer between the pipe inner and outer surface (°C/W) and R_s is the thermal resistance due to conduction heat transfer between the pipe outer surface and the undisturbed soil (°C/W).

The distance between the pipe outer surface and undisturbed soil, r^3 is assumed to be equal to the radius of the pipe.

The convective heat transfer coefficient at the inner pipe surface (W/m2 °C), h_c is a function of Nusselt number, Nu, and thermal conductivity of air (W/m °C), which can be expressed by the following expression:

$$h_c = \frac{Nu\, k_{air}}{2r_1} \quad (24)$$

Using the three thermal resistance values R_c, R_p and R_s, overall heat transfer coefficient of earth tube can be estimated as follows:

$$U_t = \frac{1}{R_t} \quad (25)$$

$$R_t = R_c + R_p + R_s \quad (26)$$

$$U_t dy\left[T_a(y) - T_{z,t}\right] = -\dot{m}_a C_a [dT_a(y)] \quad (27)$$

Now, the heat transfer between the soil and the air inside the pipe is equal to the amount of heat loss or gain as air flows along the pipe:

By solving for air temperature inside the pipe Ta(y), the following earth tube inlet air temperature (defined as the air leaving the earth tube and entering the space) can be finally obtained.

- In case $T_{am} > T_{z,t}$:

  $T_a(L) - T_{z,t} + e^A$
- In case $T_{am} = T_{z,t}$

  $T_a(L) = T_{z,t}$
- In case $T_{am} < T_{z,t}$

  $T_a(L) = T_{z,t} - e^A$

Where

$$A = \frac{\dot{m}_a C_a \ln\left|T_{am} - T_{z,t}\right| - U_t L}{\dot{m}_a C_a} \quad (28)$$

V. Experimental Results

In this section the results of the various experimental procedures are given along with the final actual result table which also shows the time and the respective temperature at which the research was conducted

The figure below shows how the water outlet temperature varies with the length of pipe

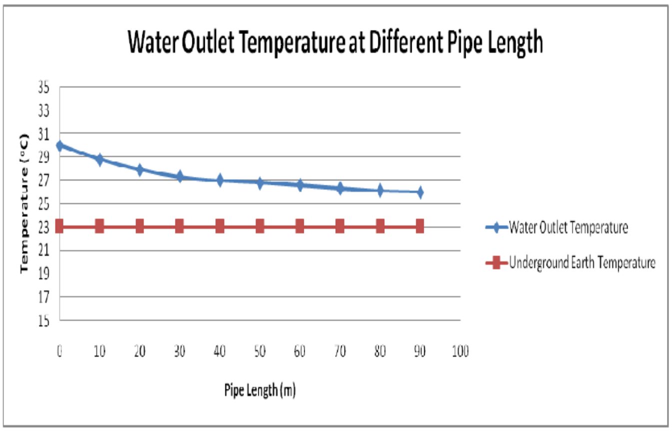

Figure 7: Variation of temperature with pipe length

The figure as under shows how the soil temperature varies with depth and it can be concluded that the temperature of the ground remains constant at the depth of around 3m and it would be useless to dig any further as it would increase the cost and not alter the results

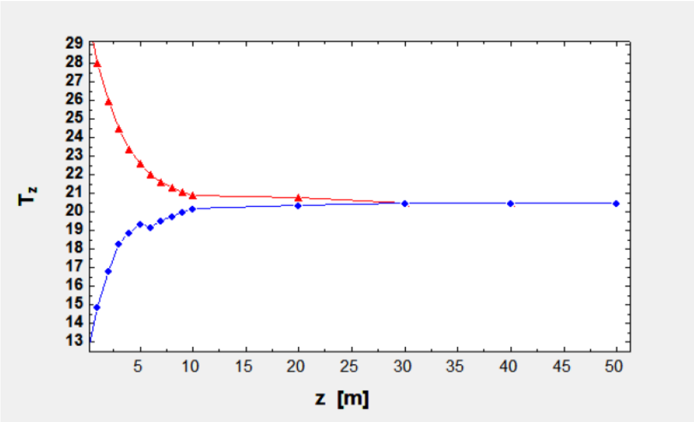

Figure 8: Variation of soil temperature with depth

The losses in the pipe were also calculated and the results on "MATLAB with Simulink" are as under

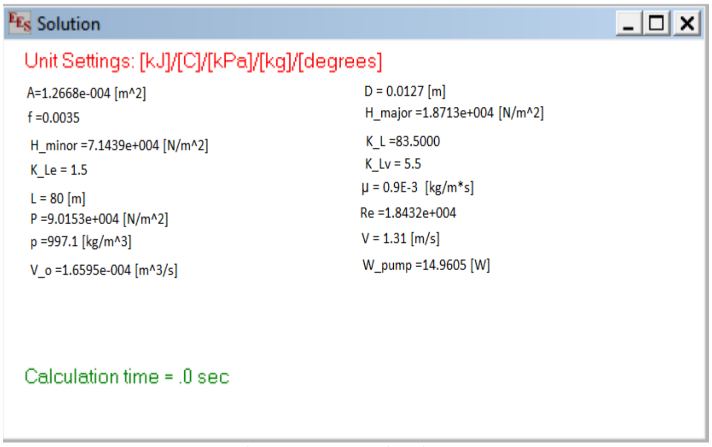

Figure 9: Losses in pipe

The experimental results obtained after three successive recording of temperature at different times is shown in the table below

Date: 24-04-2014	**Actual Results**					
Experiment No.	***Ambient Temp.***	***Inlet Water Temp.***	***Outlet Water Temp.***	***Box Temp. Before***	***Box. Temp. After***	***Time of Reading***
1	36.7°	30.0°	23.5°	39.0°	23.8°	1:30 pm
2	34.0°	29.0°	23.2°	37.0°	23.5°	3:00 pm
3	31.7°	28.6°	23.2°	36.5°	23.4°	4:30 pm

Table 3: Real time results

VI. Conclusion and Recommendations

The results of the experiments conducted were satisfactory. The basic working principle of the geothermal system was proved. The project showed that there is enough potential in Pakistan for geothermal space heating and cooling. It has been concluded that for areas like lower Punjab, where water level is at 25 m below ground level, vertical type geothermal systems are more feasible.

Keeping in view all the factors horizontal type geothermal system was selected. Grill type arrangement of horizontal geothermal system was incorporated. The pipe used is made up of Galvanized Iron and is known as GI pipe which is zinc coated. Pump selected is of 0.5 HP and it is a centrifugal pump. K-type thermocouples and a digital thermocouple was also sometimes used for temperature indication. Keeping all the things in mind we selected what best suited our requirements and by this we got the desired result of 10-14° gradient.

For better performance of the geothermal system flow rate should be minimized so that water gets maximum time to stay underground. For this reason:

- Variable frequency derived pumps are required.
- Vapor compression cycle should be used to get maximum gradient and to increase the efficiency of the system.

Acknowledgments

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