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COMPUTATIONAL APPROACH IN ANALYTICAL DESIGN OF HEAT EXCHANGER FOR A GROUND COUPLED AIR CONDITIONER

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Abstract —*Ground-source heat exchanger (GSHE) is used as an all inclusive term for a variety of systems that use the ground, ground water and surface water as a heat source and sink. In the present study, a simplified model is proposed to model the heat transfer from the underground buried heat exchanger pipes. In cooling system instead of air cooled condenser this ground heat exchanger can be used to cool down the refrigerant more effectively and economically. The model simulates the heat transfer between the water flowing inside the buried pipes to the surrounding soil of the ground taking into account the surface temperature of the ground, the thermal properties of the soil, the diameter of pipe, and the different plant capacity. The model is used to predict the diameter, length of pipe for different plant capacity and the possible different configurations. The Model also account for the pumping power required to circulate the water through pipe. The results indicate that the change of the ground temperature from one location to another has a significant effect on the overall pipe length and the pump power requirement*.

Keywords- *Geothermal cooling, refrigeration effect, mass flow rate, Nusselt number, Reynold number,*

I. INTRODUCTION

Geothermal means 'earth's heat" and it comes from the earth's interior or core which is having more than 5000^0 C temperature. This heat is a source of geothermal energy and power developed is cost effective, reliable, sustainable and environmentally friendly. Recent technological advances have expanded the range and size of viable resources, especially for applications such as home heating and cooling. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels. Working with underground loop system, a geothermal unit utilizes this constant temperature to exchange energy between the building and the earth as needed for heating and cooling. Geothermal resources vary in temperature from 30-350 °C, and can either be dry, mainly steam, a mixture of steam and water or just liquid water. In order to extract geothermal heat from the earth, water is the transfer medium. Naturally occurring groundwater is available for this task in most places but more recently technologies are being developed to even extract the energy from hot dry rock resources. The temperature of the resource is a major determinant of the type of technologies required to extract the heat and the uses to which it can be put. A heat exchanger technology employed in geothermal heating or cooling. The system consists of three parts: the ground heat exchanger, the heat pump unit, and the air delivery system (ductwork). The heat exchanger is a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground. Generally HDPE, CPVC, copper and galvanized materials are used in ground loop heat exchanger.

II. DESIGN CONSIDERATIONS FOR GROUND COUPLE HEAT EXCHANGER LOOP

The purpose of loop design is to estimate the required loop length. The cooling loads provide the designer with the energy transfer rates for sizing the loop. The design supply fluid temperatures must be estimated. The larger the loop for a known load, the cooler the supply fluid temperature will be. Lower fluid temperatures improve the heat pump performance and capacity. The designer must find a balance between cooling fluid (used in condenser) supply temperature and the capital cost of the ground loop. Also lengthier is the loop more will be the pumping power. The total heat load on the loop is given by the equation

$$Qc = L\,(tg - tw) / R$$

Where,

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Qc is the heat load (Btu/hr)
L is the pipe length (feet)
tg is the ground temperature
tw is the fluid temperature
R is the thermal resistance to heat transfer.
The challenge in loop design is that the ground temperature does not stay constant. For horizontal loops, where the pipe is near the surface, the ground temperature can change seasonally with the weather. In all cases, the loop itself affects the ground temperature. For loop design, it is common to break the effects into three parts:

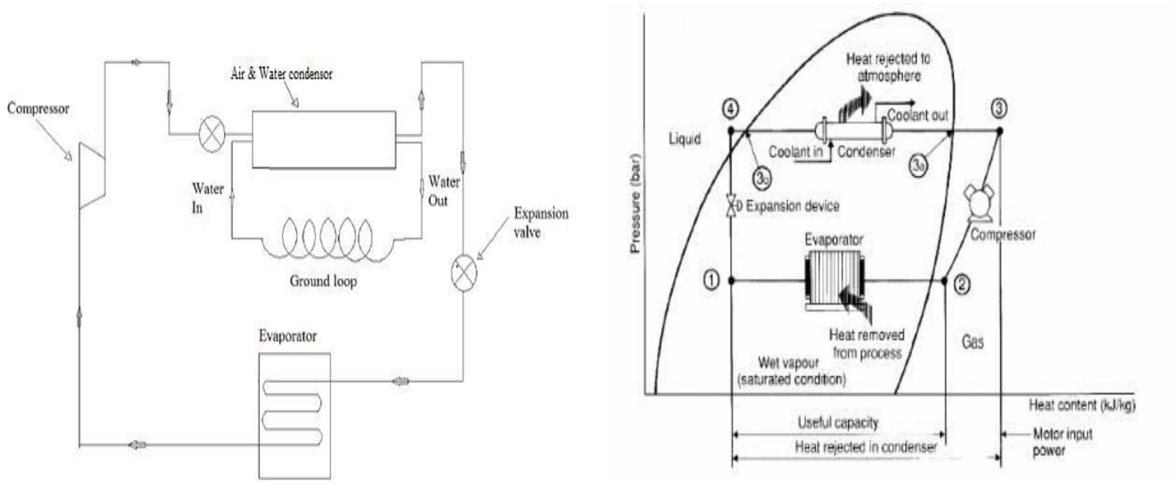

Figure 1. Model layout of refrigeration theory

(1) Carnot cop of the system $COP = T_e / (T_{cond} - T_e)$
Here Te= evaporator temperature,
T_{cond}=condenser temperature,

(2)Heat Rejected In Condenser $q_k = h_1 - h_3$
Here q_k = heat rejected in condenser, KJ/Kg
h_1 = enthalpy at point 2, KJ/Kg
h_3 = enthalpy at point 3, KJ/Kg

(3) Refrigeration Effect $q_0 = h_1 - h_4$
h_1 = Enthalpy at point 1, KJ/Kg
h_4 = Enthalpy at point 4, KJ/Kg

(4) Mass flow rate of refrigerant $m = (RE \times 3.51) / (h_1 - h_4)$
Here $\dot{m}$ = mass flow rate of refrigerant Kg/s
RE= refrigerant capacity TR

III. COMPRESSOR DESIGN

(1)Theoretical piston displacement of compressor $V = v_1$
Here V= Theoretical piston displacement of compressor m3/sec
v_1= Specific volume m^3/kg

(2) Power consumption of compressor $W = m\ (h_2 - h_4)$
W= Power consumption in KW

(3)Theoretical Horsepower of compressor $HP = W / 746$
Here H.P= horsepower

(4) Heat Rejected $Q_k = q_k$
Here Q_k = Heat Rejection of refrigerant in condenser, KW
Now, Taking Standard L/D=1.2 for piston design and N=1200 rpm

(5) Diameter of piston D (m)

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$D = [(4 \times v_1) / (n_v \times L \times N \times \pi)]^{1/2}$
n_v = Volumetric efficiency
v_1=Specific volume of refrigerant
L= Length of piston

(6) Mass flow of water (W)
$Q_k = W \times Cp \times \Delta t$
$W = Q_k / Cp \times \Delta t$

IV. DESIGN OF GROUND-SOURCE HEAT EXCHANGER

For small heat load applications, horizontal heat exchangers shallowly situated underground and vertical heat exchangers of rather small depth are used. Increasing the vertical heat exchanger depth makes it possible to exchange more heat. The depth setting highly influences the choice of a heat pump and its efficiency. In the horizontal mode of the earth coupled system, pipes are buried in trenches spaced a minimum of 5 feet (1.5m) apart and from 4 to 6 feet deep (1.2 –2m). This allows for minimum thermal interference between pipes; however, this system is affected by solar radiation. Solar radiation will affect the earth to a depth of about 30 feet, causing a cycling of soil temperatures, that lags in time and decreases with depth due to the insulating properties of the soil (Figure); however, the temperature is much more stable than for air-source units. Moist soil will have greater temperature swings than dry soil. The loops can be placed in a double layer as shown in
Figures. The ground temperature in the first approximate 100 m is well suited for supply and storage of thermal energy. The climatic temperature change over the seasons is reduced to a steady temperature at 10-20 m depth and with further depth the temperature increases according to the geothermal gradient (average 3 °C for each 100 m of depth).

Figure 2 Arrangement of heat exchanger in ground

The design of ground heat exchangers is complicated by the variety of geological formations and properties that affect thermal performance. Proper identification of materials, moisture content, and water movement is an involved process and cannot be economically justified for every project. Therefore, the necessary information for complex analysis is usually unavailable. A more prudent design approach is to apply empirical data to a simple solution of heated or cooled pipes place in the ground. It should be noted that design of horizontal loops, buried in trenches 4 to 6 feet (1.2 to 1.8 m) deep, are heavily influence by solar radiation and the number of loops in each trench. Since the solar radiation is difficult to quantify, no design methods are available for horizontal loops.

(1) Heat exchanger load (Q_H)
Knowing the heat pump capacity (QL), entering water temperature (EWT), water flow rate (GPM) and the Energy Efficiency Ratio (EER) or COP , the heat exchanger load (Q_H) and the water temperature difference (Tw-in , Tw-out) can be determined by : $COP = Q_L / (Q_H - Q_L)$

$$Q_H = m_W \times c_w \times (Tw_{out} - Tw_{in})$$

(2) Total resistance in pipe
Assuming a horizontal pipe of inside diameter Di and outside diameter Do buried at a depth d from the ground surface as shown in figure, The thermal resistances per pipe length of the water convection, pipe conduction and ground soil conduction are as follows,

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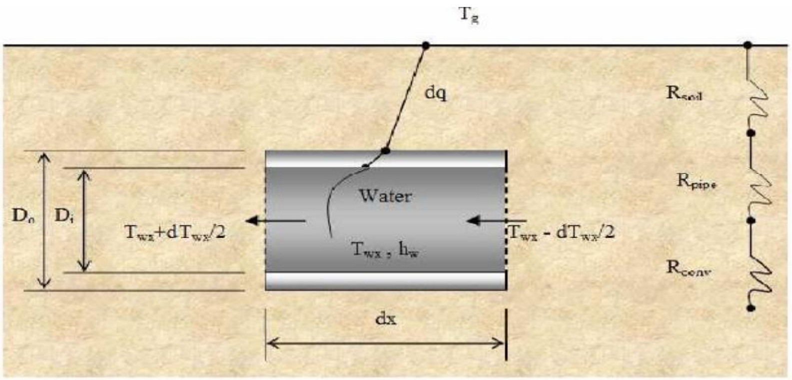

Figure 3. Pipe differential element

Rtotal = R conv + R pipe + Rsoil
Where,
Convection resistance Rconv = [1 / Di x hw x π]
Pipe resistance = Rpipe = ln (Do / Di) / 2 x π x k_{pipe}
Soil resistence = R_{soil} = 1 / S_{ksoil}

S is the conduction shape factor of pipe given as:

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

(3) Nusselt number:
The water properties are evaluated at the average water temperature because the variations are not significant. The heat transfer coefficient (hw) is evaluated by using the following Nusselt Number correlation:

Nu = (hw Di / k) = 0.023 (ρV Di / μ) $^{0.8}$(Pr) $^{0.3}$
Here Nu = Nusselt Number
Pr = Prandlt Number
Di = Inner diameter of pipe
Do= Outer diameter of pipe
K= Thermal conductivity, W/ mK
V= velocity of water, m/s
ρ = density of water, Kg/m^3

A computer program is developed to perform the calculations of the required tube length of a horizontal geothermal heat exchanger, based on the conduction model described above and the required circulating pump power. The software has the capability of considering different closed loop pipe configuration (series or parallel) as shown in figure as well as the required field area based on the recommended limited distances between pipes.

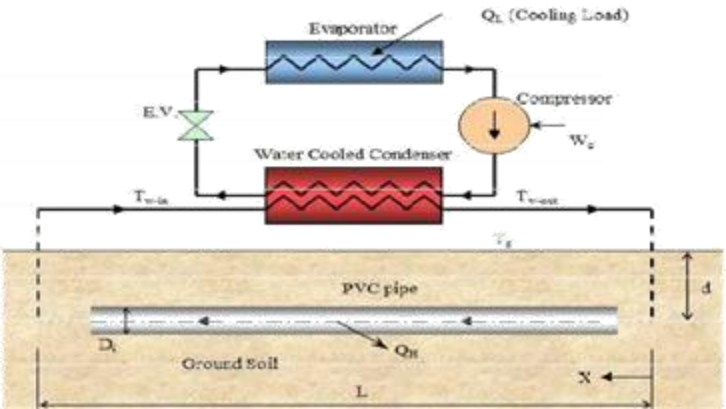

Figure 4 Co-ordinate system

(4) Length of groundloop pipe

$Q_{k=}$ (Tw-Tg)L / R_{total} L = (R_{total} x Q_k) / (Tw-Tg)

(5) Friction Head loss $H_f = 4flv^2 / 2dg$

f = friction factor which is function of Reynolds number

(6) Reynolds number $Re = \rho VD / \mu$

ρ = density of fluid

D = diameter of pipe

V = velocity of fliud

μ = viscosity of fluid

(7) Friction factor $f = 0.079 / Re^{1/4}$

For $4000 <= Re <= 10^6$

(8) Head loss due to friction $H_f = 4flv^2 / 2dg$

g = gravity

(9) Manometric head $Hm = Hs + Hd + hf + (Vd^2/ 2g)$

Hs= Suction Head

Hd= Delivery Head

Vd= Discharge velocity

(10) Required power for pump $P = W\ Hm / n_o$

W = weight of fluid = mg

V. MATLAB PROGRAMMING

```
//FOR VARIOUS LOAD CAPACITY//
close all clear
all clc
tec=input('Enter the value of evaparator temperature=');
te=tec+273;
copold=input('Enter the value of cop=');
cop=1/copold;
tcondenk=te*(cop+1); Tconden=tcondenk-
273 h1=input('Enter value of h1=');
h2=input('Enter value of h2=');
h3=input('Enter value of h3=');
h4=input('Enter value of h4='); qk=h2-h3
qo=h1-h4
v1=input('Enter the value of specific volume at tec=')
rpm=input('Enter the value of rpm=')
do=input('Enter value of outer diameter=')
di=input('Input diameter of pipe in meter=')
display('Mass flowrate of refrigerant')
%RE=input('Enter the value of Capacity=')
s=input('Starting value of capacity=') e=input('Ending
value of capacity=') d=input('Differnence of
interval=')
j=1
for i=s:d:e p(j)=i
    j=j+1;
end j=j-1; for
h=1:j
m(h)=(p(h)*3.51)/qo
display('Compressor design')
```

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```
display('Power consumption')
w(h)=m(h)*(h2-h1) display('Heat
rejected') Qk(h)=m(h)*qk
x=4.61;
y(h)=(m(h)*v1)/rpm;
D(h)=x*(y(h)^0.33)
l(h)=1.2*D(h)
display('Mass flowrate of water')
cp=4.184;
dt=10;
mw(h)=Qk(h)/(cp*dt)
den=1000;
A=0.785*di*di
v(h)=mw(h)/(A*den)
hw(h)=(((v(h)*di)^0.8)/di)*6.86203
Rconv(h)=1/(3.14*di*hw(h));
Rpipe=((log(do/di))/(2*3.14*0.1));
Rsoil=1/(1.14*2.07);
Rtotal(h)=Rconv(h)+Rpipe+Rsoil;
L(h)=((Qk(h)*Rtotal(h))/10) end
plot(p,L,'-o')
     xlabel('Capacity of load in Tones ')
     ylabel('Length of pipe(m)')
```

```
//FOR VARIOUS DIAMETER OF PIPE//
```

```
close all clear
all clc
tec=input('Enter the value of evaporator temperature=');
te=tec+273;
copold=input('Enter the value of cop=');
cop=1/copold;
tcondenk=te*(cop+1); Tconden=tcondenk-
273 h1=input('Enter value of h1=');
h2=input('Enter value of h2=');
h3=input('Enter value of h3=');
h4=input('Enter value of h4='); qk=h2-
h3;
qo=h1-h4;
v1=input('Enter the value of specific volume at tec=');
rpm=input('Enter the value of rpm=');
RE=input('Enter the value of Capacity=');
tw=input('Enter the temp. of water=')
tg=input('Enter the temp. of ground=')
display('Mass flowrate of refrigerant')
m=(RE*3.51)/qo
display ('Compressor design')
display('Power consumption') w=m*(h2-
h1)
display('Heat rejected'); Qk=m*qk
x=4.61;
y=(m*v1)/rpm;
D=x*(y^0.33)
l=1.2*D
display('Mass flowrate of water')
cp=4.184;
dt=10;
mw=Qk/(cp*dt)
%di=input('Input diameter of pipe in meter=')
s=input('Starting value of dia. in meter=')
```

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```
e=input('Ending value of dia.in meter=')
d=input('Differnence of dia. in meter=')
j=1
for i=s:d:e
     di(j)=i
     j=j+1;
end j=j-1; for
h=1:j
do(h)=di(h)+0.0035;
den=1000;
A(h)=(3.14/4)*di(h)*di(h);
v(h)=mw/(A(h)*den)
hw(h)=(((v(h)*di(h))^0.8)/di(h))*6.86203;
```

VI. RESULT AND DISSCUSION

Here in the design of ground heat exchanger which is coupled with air conditioner system and based on heat exchange between ground and water inside tube. A MATLAB program is used to get various parameter of ground heat exchanger i.e diameter of tube, capacity of plant, length of water tube in heat exchange, COP ,required power of pump ,by varying any parameter according to need. From above design equation and MATLAB programming we got graphs which are presented below.

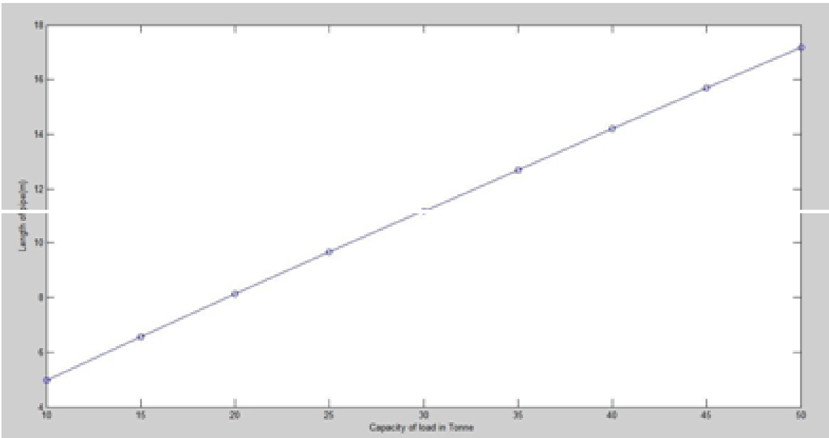

Figure 5 Length of pipe v/s Capacity of load

Here we have done calculation by taking capacity range 10 to 50 tone, evaporator temp.5°C,and diameter of pipe is 2.5cm. So we can get different length of pipe according to different capacity. By varying capacity of plant(tone) we can get different value of length of ground loop From above graph we can conclude that if capacity increases then length of pipe will be increased .Because if capacity increases then heat rejection needed is increases which increases the length of pipe.

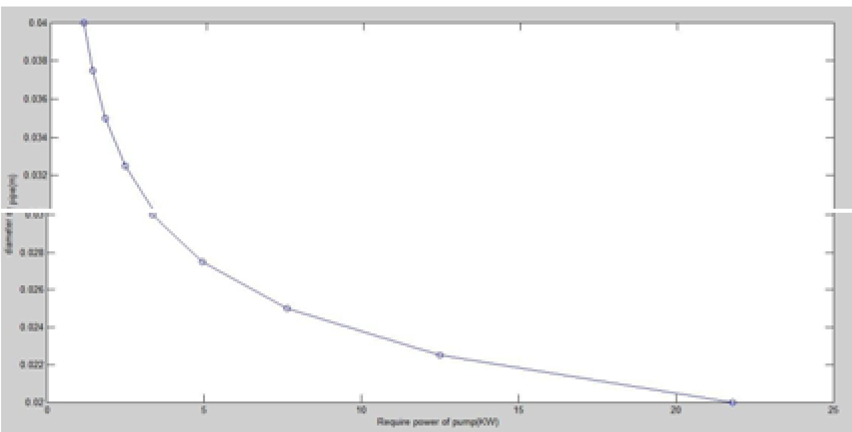

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Figure 6 Diameter of pipe v/s Require power of pump

Here we have taken a range of diameter of pipe from 2cm to 4 cm and for that the relation between diameter and power required for pump is as shown in figure. Here the capacity of plant is constant(50 tone) and ground temp. is 25°C.from graph we can say that as diameter increases then power required for pump is less because due to increase in diameter reduces the friction between water and pipe surface so water can easily circulate in pipe which results in lower power consumption.

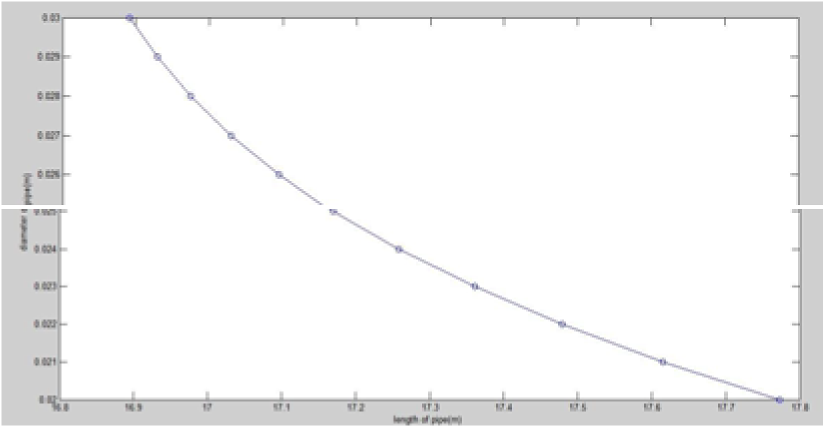

Figure 7 Diameter of pipe v/s Length of pipe

Here we have taken a range of diameter of pipe from 2cm to 3 cm and for that the relation between diameter and length of pipe is as shown in figure. Here the capacity of plant is constant(50 tone) and ground temp. is 25°C. Graph shows that as diameter decreases then length of pipe required will be increases because for same heat transfer required area is constant. So if area is constant then by reducing diameter we have to increase length of pipe to retain constant area.

Table-1: Temp of ground vs. power of pump and length of pipe.

Ground temp. (Tg)	Pump Power (Fp)	Length of pipe (L)
20	6.18	11.44
22	6.63	13.2
24	7.24	15.6
26	8.12	19.07
28	9.51	24.52
30	12.01	34.34
32	17.83	57.23

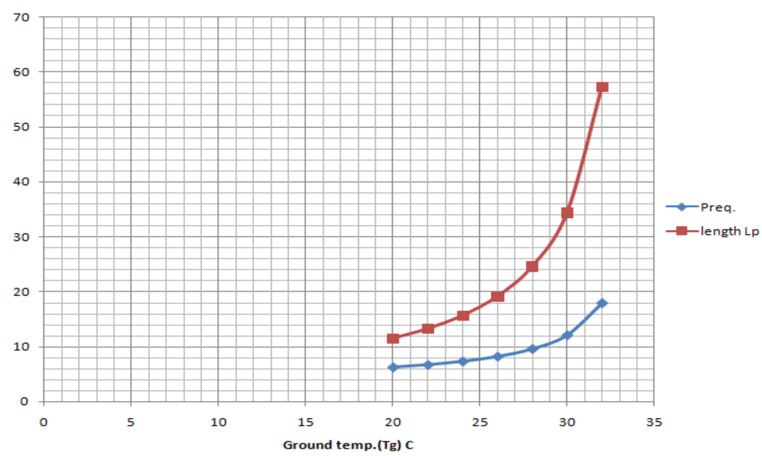

Figure 8 Length of pipe v/s Ground temperature

Temperature of ground up to 2.5 meter from surface remains between 20°C to 32°C throughout year. So for different temperature of ground between above range we got above graph for power required for pump and length of pipe. If temperature of ground increases then temperature difference between ground and circulating water will be less so heat transfer rate will be reduced .thus for same heat transfer rate we have to increase the surface area by increasing pipe length and further it will increases the power consumption of pump.

REFERENCES

[1].Girja Sharan and Ratan Jadhav, (1999), "Soil Temperatures Regime at Ahmadabad", Journal of Agricultural Engineering, 39:1,Jan-March 2002.

[2] S.A. M. Said, M .A. Habib, E.M.A. Mokheimer, N. Al-Shayea and M. Sharqawi "Horizontal Ground Heat Exchanger Design for Ground-Coupled Heat pump" , King Fahd University of Petroleum & Minerals, Dhahran Saudi Arabia.

[3] C P Arora, Referigeration and air conditioning, Tata McGraw Hill Education, 2001

[4]Eggen G., Vangsnes, G., 2005. "*Heat pump for district cooling and heating at Oslo" Gardermoen*.Proceedings from the 8th IEA Heat Pump Conference, May 2005. Las Vegas, USA.

[5]Georgios Florides, "Ground Heat Exchangers-A review of systems, models and applications in Renewable Energy", Nicosia, Cyprus: Higher Institute of Technology, 2006, 17.

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