HIGH FIDELITY COMPUTATIONAL ASSESSMENT OF EARTH TO WATER HEAT EXCHANGER FOR THE CLIMATE OF VADODARA

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Abstract : Earth-water heat exchanger is a heat exchanger which is utilized for cooling or heating a space with no or minimum consumption of electricity. The main objective of this project is to do a CFD analysis of a Earth Water Heat Exchanger (EWHE). The demand of cooling has been increased (to maintain the human comfort) due to the increase in temperature of environment due to various factor like global warming, geographical location and change in human life style. The demand has been increased mainly for the industries and for household purposes. The conventional cooling systems use quite a high amount of electricity and also emit chemical pollutants (CFC)s in the air. Here CFD analysis is to be done on EWHE which consumes less electricity and is eco-friendly. This system using the underground temperature maintains the thermal condition in room. The main advantage of this system is that it can provide heating during winter and cooling during summer as the temperature remains constant irrespective of the weather conditions. The analysis of this project is going to be done according to the weather conditions in Vadodara as the average temperature between March and July is around 40 °C and it is 30°C from November to February. The material of the pipe which will be used in our project is copper and the depth in the underground may be 3 metre. The analysis of this project will be done in ANSYS which is a simulation software for thermal and fluid analysis. The conclusion of this project will be done after the analysis in the software.

***IndexTerms* - Earth to water heat exchanger, Computational Fluid Dynamics, Cooling Demand, Underground Temperaure, ANSYS (Fluent).**

I. INTRODUCTION

As we all know that cooling systems are very much in demand nowadays for industries and household purposes. But the major drawback is their high electric consumption and releasing chemical pollutants such as CFC (Chloro Fluoro Carbon)s in the air. So due to the need of a renewable energy source, an alternative method was developed which is a low grade energy and environment friendly. Nowadays Ground Source Heat Pumps are gaining popularity because of its cheap availability and eco-friendly. The alternative method which is being discussed here is the Earth to Water Heat Exchanger. It uses the underground thermal conditions to get the required conditions in a room. The main highlight of this heat exchanger is that it can cool the room in summer as well as heat it in winter. The EWHE (Earth Water Heat Exchanger) uses the underground temperature which is almost constant throughout the year to cool the required space. As the name suggests, water is used as the refrigerant in the system. The system is usually an array of buried pipes running along the length of a building, a nearby field or buried vertically into the ground. 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. Earlier one dimensional models were prepared for the analysis of the geothermal systems and nowadays three dimensional models are prepared and further refined for finding the temperature variation in the pipes and in the ground. Ground source heat pumps are receiving increasing interest in North America and Europe and the technology is now well established with over 550,000 units installed worldwide and with more than 66,000 units installed annually. About 80% of the units installed worldwide are domestic [1](J, 2005).

The use of direct or indirect earth-coupling techniques for buildings and agricultural greenhouses requires knowledge of the ground temperature profile at the surface and at various depths[2]. The ambient climatic conditions affect the temperature profile below the ground surface and need to be considered when designing a heat exchanger[3]. Actually the ground temperature distribution is affected by the structure and physical properties of the ground, the ground surface cover (e.g., bare ground, lawn, snow, etc.) and the climate interaction (i.e., boundary conditions) determined by air temperature, wind, solar radiation, air humidity and rainfall. The temperature distribution at any depth below the earth surface remains unchanged throughout the year with the temperature increasing with depth with an average gradient of about 30 1C/km[4]. The geothermal gradient deviations from the average value are, in part, related to the type of rocks present in each section[5]. Heat flow, which is a gauge of the amount of thermal energy coming out of the earth, is calculated by multiplying the geothermal gradient by the thermal conductivity of the ground[6]. Each rock type has a different thermal conductivity, which is a measure of the ability of a material to conduct heat. Rocks that are rich in quartz, like sandstone, have a high thermal conductivity, indicating that heat readily passes through them[7]. Rocks that are rich in clay or organic material, like shale and coal, have low thermal conductivity, meaning that heat passes slower through these layers. If the heat flow is constant throughout a drill hole (i.e., water is not flowing up or down the hole), then it is obvious that low-conductivity shale layers will have a higher geothermal gradient compared to high-conductivity sandstone layers [8].

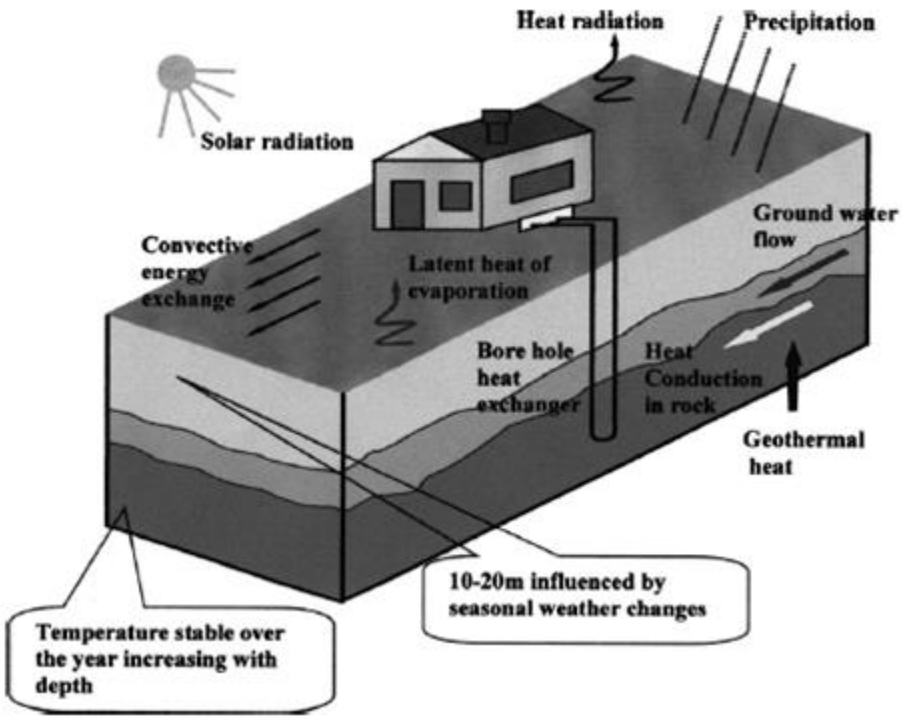


figure:

As we found that the soil temperature remains constant below a depth of 6-10 feet. Therefore we thought of using temperature difference between soil and water as a source of energy for preconditioning the air. So by conducting research on web, we came across many papers from which we found that this energy can be used for preconditioning the air. So many researchers have made use of earth tube heat exchangers for this process. Earth tube is a long underground metal pipe through which water is drawn. As water travels through the pipe, it gives up or receives some of its heat to/from the surrounding soil and enters the room as conditioned air during the cooling or heating period.

METHODOLOGY

As our objective is to see the relevance and the performance of earth-water heat exchanger with comparison to the commercial air conditioning unit, in Vadodara climatic condition. Detailed performance analysis is required and this we are going to do with both steady and transient conditions. Steady state analysis is going to be done for the cooling water, the U-tube, and the grout of time-independent temperatures under given heat flux in a 2-dimensional borehole cross-section. Thermal resistance between the borehole and the cooling water is uniform once the temperature difference is uniform, transient analysis will be done for finding the temperature variation inside the borehole until the steady state is reached. We have taken the base of (Choi *et al.*, 2018) [9] research paper to do our CFD analysis.

GOVERNING EQUATIONS OF FLUID FLOW

In this section, the equations that govern any fluid flow problem are introduced. These equations arise from the conservation laws of physics, from which it is possible to derive the most fundamental equations of motion for a fluid, the Navier-Stokes equations

CONSERVATION OF MASS

The increase in mass within a control volume must be equal to the mass inflow minus the mass outflow through the control volume's surface since mass can neither be created nor destroyed. This can be expressed mathematically for an incompressible fluid as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial x}+\frac{\partial w}{\partial x}=0 \qquad \text{......... (1)}$$

Where *u*, *v* and w are the three components of velocity corresponding to the *x*, *y* and *z* direction respectively.

NAVIER-STOKES EQUATIONS

The other fundamental set of equations that govern the flow of a fluid are derived from Newton's second law (the conservation of momentum). The equations are called the Navier-Stokes equations, and for an incompressible fluid the full instantaneous equations take the form

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho uu)}{\partial x}+\frac{\partial(\rho vu)}{\partial y}+\frac{\partial(\rho wu)}{\partial z}=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \quad \ldots\ldots\ldots[4.2]$$

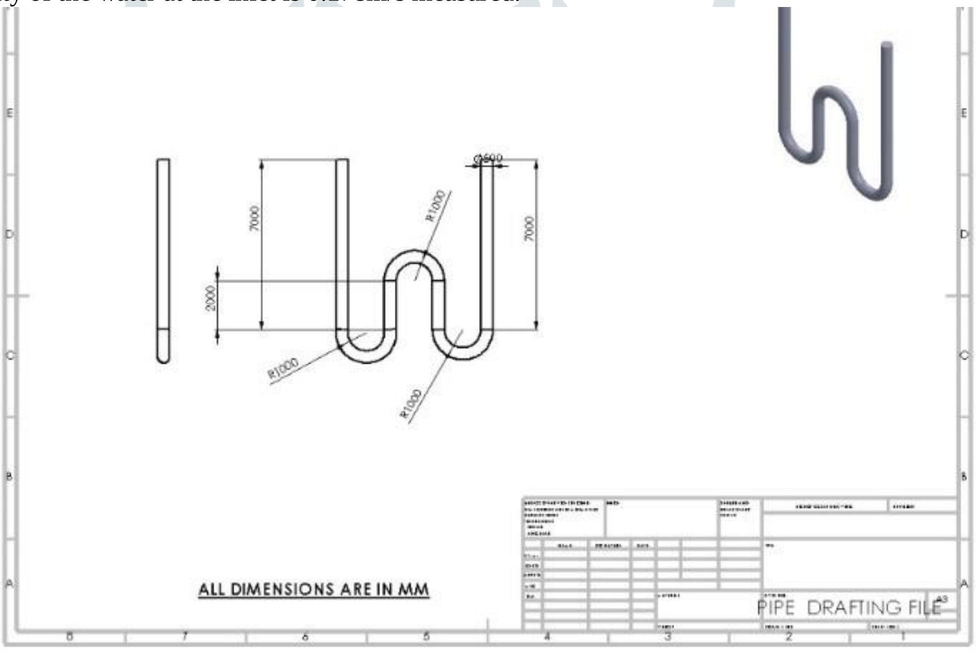
$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho vv)}{\partial y}+\frac{\partial(\rho wv)}{\partial z}=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad \ldots\ldots\ldots[4.3]$$

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+v\frac{\partial(\rho vw)}{\partial y}+w\frac{\partial(\rho ww)}{\partial z}=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \quad \ldots\ldots\ldots[4.4]$$

Where u, v and w are the stream wise, lateral and vertical velocity components respectively, x, y and z are the corresponding directions to the velocity components, μ is the fluid viscosity, ρ is the fluid density and p is the pressure.

CFD analysis of earth water heat exchanger was performed using Fluent 18.1 software.

The experimental setup is an open loop flow system has been designed and fabricated to conduct experimental investigation on the temperature difference for inlet and outlet section, heat transfer, coefficient of performance and fluid flow characteristics of a pipe in parallel connection. The experimental data are to be used to find the increase of cooling rate for the summer condition , and heating rate of winter condition heat transfer coefficient. The Earth Tube Heat Exchanger taken is a pipe having passes with inner diameter 27mm and outer diameter 30mm , made up of high density polyethylene pipes and buried at a depth of 7m in a flat land with dry soil. Velocity of the water at the inlet is 0.178m/s measured.



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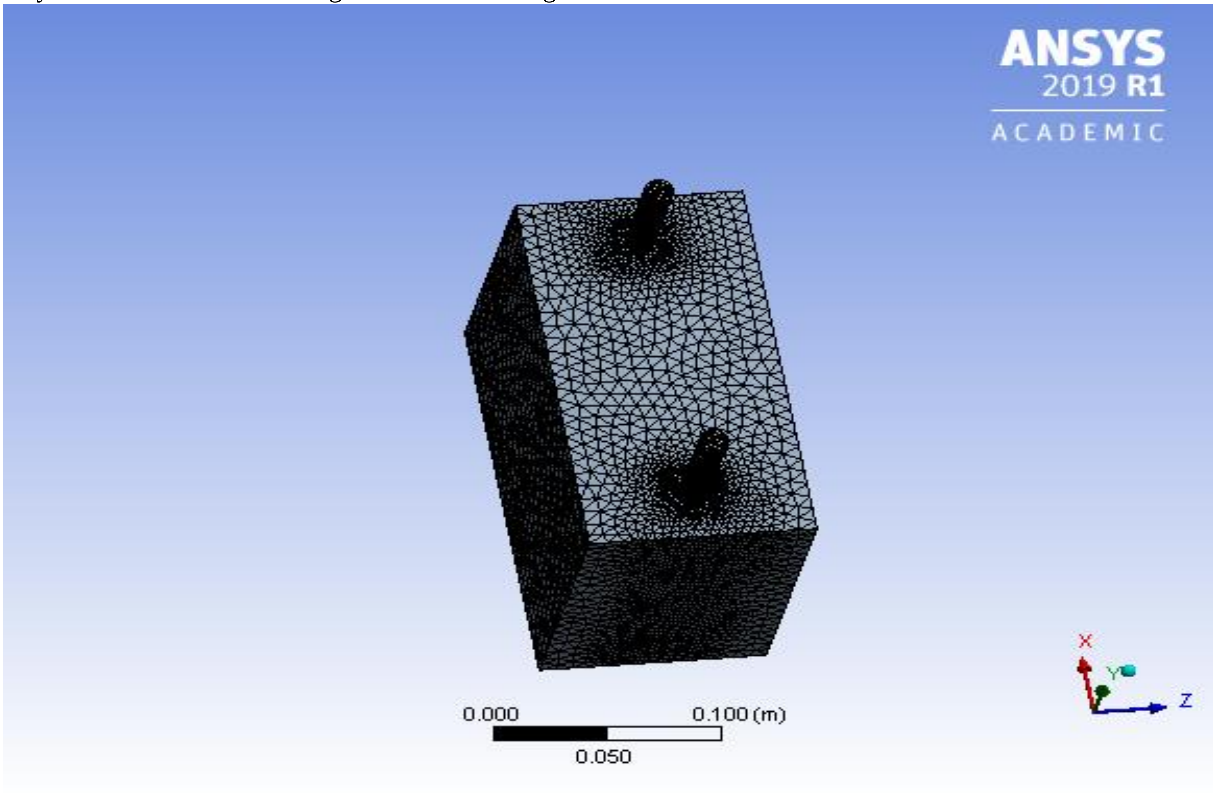
material	(λ)thermal conductivity w/mk	Specific heat J/KgK	density
soil	1.5	850	2350
HDPE	0.4		
Water	0.582	4180	1000

OBSERVATIONS

We are doing this performance on ansys fluent software. In the proposed vertical closed branch tube type GHE, hot fluid enters through inlet as shown in figure. Circulating cooling fluid flow out through the outlet. Thus the analysis domain includes primary u tube and the surrounding soil as shown in figure.



This assumption are taken to simplify the calculation.

1) The ground is regarded as a homogeneous medium with the mean thermal physical properties.
2) The initial soil temperature is assumed as a function of depth.
3) Heat transfer in the solid region is regarded as pure heat conduction and the effect of groundwater flow is negligible.
4) A profile of velocity in U-tube pipe is uniform.

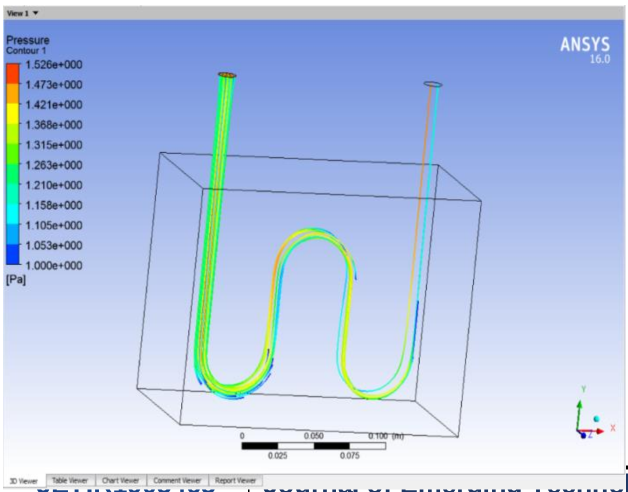
In the earth–water heat exchanger, the medium used for transportation of heat is water only. The heat is released or absorbed by the water flows through the pipe walls by conduction and from pipe walls to the surrounding soil and vice versa by conduction. If the contact of the pipe wall with the earth is assumed to be perfect and the conductivity of the soils taken to be very high compared to the surface resistance, then the wall temperature at the inside of the pipe can be assumed to be constant. The total heat transferred to the air when flowing through a buried pipe is given by:

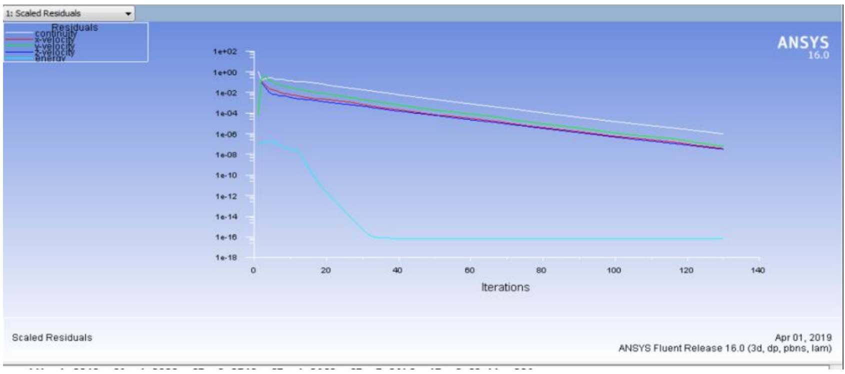
Q= ṁCp (T(out)-T(in)) ….(6.1)

where ṁ is the mass flow rate of water (kg/s), Cpis the specific heat of water (J/kg-K), T(out) is the temperature of air at outlet of EWHE pipe (°C), and T(in) is the temperature of air at inlet of EWHE pipe (°C).

Inlet conditions are set to constant flow rate (velocity) & three different temperatures. The outlet conditions for u-tube are set to pressure outlet conditions. The no slip conditions is apply to all walls of u-tube.

Position	Boundary condition
Tube inlet velocity	0.178m/s
Primary tube inlet temperature	1) 40℃ 2)28℃ 3)05℃





Here the velocity contour graph of 40°C is shown in the above picture. In this analysis too the velocity increases from inlet to outlet. Because as stated above the temperature of the water is decreasing from inlet to outlet as it is passing through the pipe which is inside the ground. The temperature inside the ground is always constant. As pressure decreases from inlet to outlet the velocity increases.

RESULT

Season	**Inlet Tempera ture(K)**	**Outlet Tempera ture(K)**	**Tempera ture Differenc e(K)**	**Heat Dissipati on(W)**
Summer	313	297	16	12
Winter	278	288	10	7.24
Spring/M onsoon	301	295	6	4.34

From running the analysis we had find that the more the temperature difference more will be the effectiveness of the heat exchanger. In summer the most heat is dissipated. The effectiveness of the heat exchanger is .80 in summer and .49 in winter and .30 in monsoon season.

CONCLUSION

After doing the analysis for 250 iterations it is found that when the inlet temperature in degree Celsius is 40, 28 and 5 the outlet temperature obtained are in degree Celsius are 24, 22 and 15 respectively. From this analysis we came to know that when the temperature difference is more than the efficiency of the system is more as it can be seen that there is a temperature difference of 16, 6 and 10 in degree Celsius for temperatures in degree Celsius 40, 28 and 5 respectively. The theoretical and analytical data match to a certain extent which states that the proposed model is feasible and ready for experimentation.

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