EVALUATION OF ENVIRONMENTAL PARAMETERS ON THE PERFORMANCE OF EARTH TO AIR HEAT EXCHANGERS

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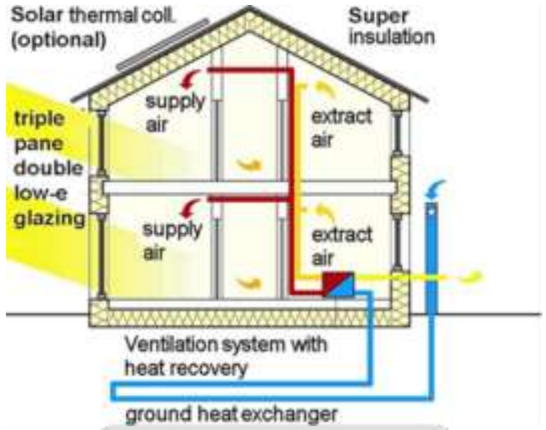
Abstract

The earth to air heat exchangers (EAHE) is effective passive cooling and heating techniques for buildings. This paper studies numerically the effect of some design and environmental parameters (moist content of soil, pipe material and thickness of pipe wall) on the overall performance of EAHE system. Three types of soil were selected (dry soil, moist soil and saturated soil) with two pipe materials PVC and steel and three thicknesses of pipe wall (2, 3 and 6 mm). This numerical study has been done for summer and winter seasons according to the weather conditions. First the built numerical model was validated against experimental model and the results of comparison showed good agreement. After the validation the overall performance of EAHE system with selected parameters was analysed with ranges of air velocity, inlet temperature and pipe length of 30 m. The simulated results showed that the very moist or saturated soil gives the best overall performance of EAHE system compare with other soils, Furthermore there is no significant effect of pipe material and wall thickness on the overall performance. The geometry of the problem and meshing of it have been made in and the models have been solved by ANSYS Workbench. CFD models or packages provides the contours and data which predict the performance of the heat exchanger design and are effectively used because it has ability to obtain optimal solutions and has work in difficult and hazardous conditions.

Key words: *EAHE system, numerical investigation, CFD, thermal performance, geothermal energy.*

Introduction: Geothermal energy is a huge renewable source of energy which can be used to reduce energy consumption in wide range of applications such as generation of electricity, spaces heating and cooling, heating and cooling of water. For cooling and heating of buildings it can be dependent on the earth as a heat source in winter and heat sink in summer, where the soil temperature at certain depth from ground surface is relatively stable during the year and it is lower than outside air temperature in summer and higher in winter. The benefits of geothermal energy in cooling and heating spaces can be accomplished by using Earth – Air Heat Exchanger (EAHE) or also called ground heat exchanger. Earth – air heat exchanger usually consists of pipe or multi-pipes buried in the ground horizontally or vertically. One end of the pipe is connected to the delivery end of blower and the other end is open to atmosphere. When air flows through buried pipes, the heat is transfer from air to the surrounding soil during summer season and vice versa in winter. A ground-coupled heat exchanger is an underground heat exchanger that can capture heat from and/or dissipate heat to the ground. Some consider that it is more efficient to pull air through a long tube than to push it with a fan. A solar chimney can use natural convection (warm air rising) to create a vacuum to draw filtered passive cooling tube air through the largest diameter cooling tubes. Natural convection may be slower than using a solar-powered fan. Earth-air heat exchangers, also called ground tube heat exchangers, are an interesting technique to reduce energy consumption in a building. They can cool or heat the ventilation air, using cold or heat accumulated in the soil.



The consumption of high-grade energy has increased considerably with growing needs to achieve thermal comfort conditions inside buildings, residential, greenhouses, livestock buildings, etc. It is desirable to minimize the use of high-grade energy consumption and to promote the use of renewable energy in order to save the earth from hazardous effects of global warming and ozone layer depletion. Numerous alternative techniques are being currently explored to achieve thermal comfort conditions inside buildings. The earth–air heat exchanger is one of these promising techniques which can effectively be used to preheat the air in winter and vice versa in summer. The temperature of earth at a depth of 1.5 to 2 m remains fairly constant throughout the year. This constant temperature is called earth's undisturbed temperature (EUT). The EUT remains higher than ambient air temperature in winter and lower than ambient air temperature in summer. The concept of earth–air heat exchanger (EAHE) is very simple as shown in Fig. The ambient air is drawn through the pipes of the EAHE buried at a particular depth, moderated to EUT, and gets heated in winter and vice versa in summer. In this way, the heating and cooling load of building can be reduced passively.

II. Computational Fluid Dynamics

CFD is useful for studying fluid flow, heat transfer; chemical reactions etc by solving mathematical equations with the help of numerical analysis. CFD resolve the entire system in small cells and apply governing equations on these discrete elements to find numerical solutions regarding pressure distribution, temperature gradients. This software can also build a virtual prototype of the system or device before can be apply to real-world physics to the model, and the software will provide with images and data, which predict the performance of that design. More recently the methods have been applied to the design of internal combustion engine, combustion chambers of gas turbine and furnaces, also fluid flows and heat transfer in heat exchanger. The development in the CFD field provides a capability comparable to other Computer Aided Engineering (CAE) tools such as stress analysis codes.

Basic Approach to using CFD :-

a) Pre-processor:

- Establishing the model
- Identify the process or equipment to be evaluated.
- Represent the geometry of interest using CAD tools.
- Use the CAD representation to create a volume flow domain around the equipment containing the critical flow phenomena.
- Create a computational mesh in the flow domain.

b) Solver:

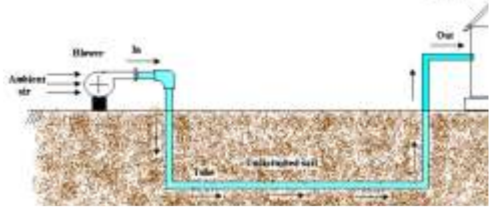
- Identify and apply conditions at the domain boundary.
- Solve the governing equations on the computational mesh using analysis software.

c) Post processor:

- Interpreting the results.
- Post-process the completed solutions to highlight findings.
- Interpret the prediction to determine design iterations or possible solutions, if needed.

Theoretical Calculation

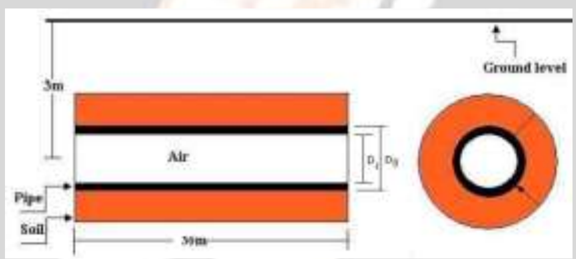
In a investigation 3D EAHE system buried at depth of 3 m underground surface with inner pipe diameter of 0.150 m and length of 30 m. Figure shows the pipe of EAHE with thickness of disturbed soil.



Layout of EAHE

The soil layer near surface of EAHE channel is affected by heat transfer and this soil called thermally disturbed soil. There is no rule to calculate the thickness of disturbed soil, some researchers proposed that the thickness of disturbed soil equalled to the pipe radius , twice of pipe diameter, four times of pipe radius, and 10 times of pipe diameter , furthermore some studies found out that the effect of disturbed soil on performance of EAHE system can be decreased by running the system in summer and winter seasons. In this paper the thickness of disturbed soil is equal to four times of pipe radius.

The previously studies and tests for Nasiriya's soil which are carried out by the engineering consultation bureau of Thi-Qar university showed that the moist content of soil increased with increasing the depth from the ground surface and soil in Nasiriyah city is saturated. The pipe materials selected for study are steel and PVC which are available in the local market.



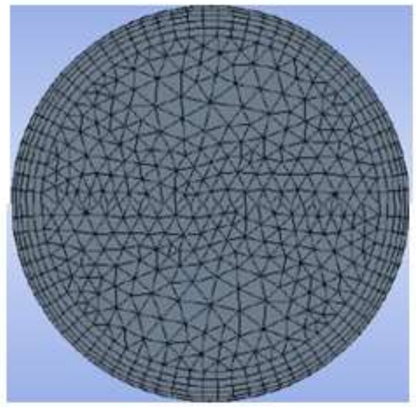
Pipe Arrangement

III. RESULTS AND DISCUSSION

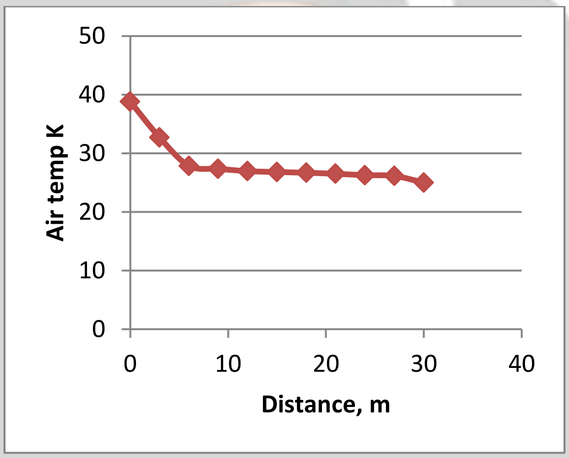
To check the validity of the built numerical model, verification was made by solving the experimental and theoretical model presented. The same experimental and theoretical models which are presented in and represent a EAHE system consists of a pipe with 0.150 m diameter, 30 m length and 3 m depth.

The comparison between the simulation results of present model with the experimental and simulation results of and respectively for temperature distribution along length of EAHE pipe. From figure it can be seen that, the agreement between the simulation results of the present model with the experimental and simulation results of and respectively is acceptable with the average error between the simulation result of present model and the experimental model of and simulation result of respectively.

To assess the quality of developed CFD model with high accurate solution the grid independent test was conducted. The solution is grid independent, if the mesh is refined (i.e. the cells are made smaller in size hence larger in number) and the results of solution were unchanged. "Fig. 3", shows that the solution is grid independent and there is no or minimum effect on the air temperature when grid size changed from mesh 1 to mesh 2 to mesh 3, therefore and for more accuracy the mesh is used for all calculations.



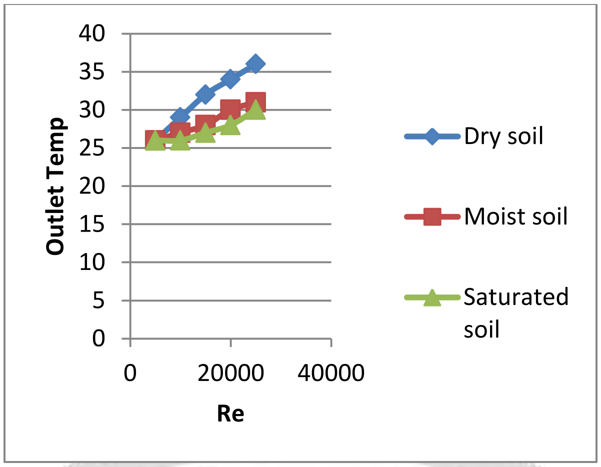
Mesh distribution of the tube



Air temp Vs Distance

Illustrates the variation of pressure drop (Δp) with Reynolds number at inlet air temperature of 40˚C. From this figure it is easy to see that the pressure drop increased with increasing Reynolds number due to increasing the pressure losses with increasing Reynold Number.

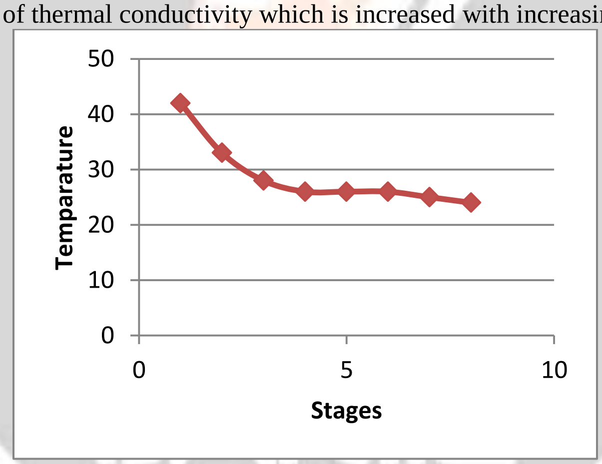
The variation of performance factor with Reynolds number for all studied soils at inlet air temperature of 40˚C. From this figure it can be found that the performance factor declined with increasing Reynolds number due to increasing the pressure drop with increasing Reynolds number and the performance factor is proportional inversely with the pressure drop. Also this figure illustrates that the performance factor grown slightly with increasing moist content of soil, so the maximum performance factor can be obtained from the very moist or saturated soil compare with the moist and dry soil.



Reynold Number Vs Outlet Temperature

From this figure it can be seen that the air temperature decreased and the soil temperature increased toward undisturbed soil layer, where the heat is transferred from air to the soil.

This amount of heat transfer is higher at first meters from inlet section and decreased with increasing distance from inlet.It can be seen that the difference in the amount of heat transfer between studied soils increased with increasing moist of soil due to the effect of thermal conductivity which is increased with increasing moisture.



Outlet & Inlet layout of EAHE

It can be noted the effect of soil on the outlet air temperature, where the outlet temperature decreased with increasing moisture content of soil.The saturated soil gives the minimum outlet air temperature then moist soil and finally dry soil.The cause of this is that with increasing moisture the thermal conductivity of soil increased and this leads to increase the heat transfer rate.

Conclusion :-

In this the three dimensional model is investigated for the shell and tube heat exchanger and CFD analysis is carried out for the Heat exchanger unit with different designs of cross sections.

This research investigated to show the effect of moisture content of soil, pipe material and thickness of pipe wall on the overall performance of EAHE system under the climatic conditions. From the simulation results, the following remarks can be concluded:

1- The outlet air temperature enhanced with decreased Reynold Number.

2- With increasing Reynold number the flow rate increased, so the amount of heat transfer increased and this leads to increased and improved Nusselt number..

3- The overall performance of EAHE system is better when it is operating as a cooling system under high inlet air temperature and heating system under low inlet air temperature.

4- With increase in length of pipe, the outlet air temperature from EAHE decreases. The decrement in air temperature was sharp for the first 15 meters length of pipe and it became moderate afterwards.

5- With increasing moisture content of soil, the process of thermal exchange enhanced and increased.

6- The required length can be reduced when operating in moist soil.
7- The overall performance of EAHE system improved with increasing moisture content of soil, and since the soil of Nasiriyah city considers saturated soil, so the EAHE system is more suitable for use in this city.
8- In spite of there is a priority in the performance of EAHE system for steel pipe but this priority is little and can be neglected compared with the prices of materials and problems of corrosion and this lead us to believe that the PVC pipe is more suitable.
9- There is no significant effect of wall thickness on the overall performance.

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