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A Computational Study on the Performance of Earth Air Heat Exchanger (EAHE) Using Different Duct Geometries and Material Combinations

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Abstract- The study explores the thermal performance of Earth air Heat Exchanger (EAHE) for warming and cooling modes under Indian climatic conditions. A 3-dimensional, computational fluid dynamics (CFD) model is produced in ANSYS FLUENT v15.0 under relentless conditions for various pipe materials and pipe geometries. The pipe geometries considered for the investigation are round; square; triangular and circular-corrugated and the pipe materials considered are Aluminium and Steel. This paper expects to locate the optimal geometry and pipe material to acquire ideal temperature variation for thermal comfort. The effect of ambient temperature, mass stream rate, Reynolds Number, Prandtl number and Nussult number were considered. Results demonstrated that if the length of the pipe increases, the temperature at the outlet diminishes in cooling mode and vice versa. The greatest temperature drop watched is 12.05K and 16.65K during cooling and warming mode respectively for the triangular-corrugated pipe. Moreover, most extreme temperature variation was watched for aluminium pipe material at 2m/s. It can be presumed that corrugated aluminium pipes can be utilized to get ideal temperature drop for better thermal comfort. In addition, as the mass stream rate increases, the temperature variation also increases regardless of the pipe materials and pipe cross-segments.

Keywords - EAHE, CFD Simulations, Corrugated Geometry, Pipe Materials, Heat Transfer, Temperature Variation.

I. INTRODUCTION

Energy is one of the major inputs to the economic growth of a country but energy saving is one of the major challenges in today's world. Our concern is to minimize the use of high-grade energy and to promote the use of renewable energy. Out of the world's total energy demand, RES supply up to 14% [1], [2]. Renewable energy includes biomass, geothermal energy, hydropower etc.[1]. In developing countries the energy sector is considered as a crucial sector, the demand for consumption is increasing than its production. India consumes more energy in residential, commercial and agricultural sectors than China, Japan, and Russia etc. [3]

The consumption of energy in buildings has significantly increased in the last decade. In order to improve the energy conservation in building it has been recommended to use energy audit in buildings while construction. According to the research conducted by the United States Department of energy, RES can be a good alternative to the non-renewable sources. Sources like solar energy, wind energy, geothermal energy and Ocean energy can be envisaged in the years. These sources have enormous potential to replace the prevailing sources if used in a correct way.

The energy usage depends on temperature, humidity as its changes affect the demand for space heating or cooling. In summers, generally in commercial buildings, air conditioningsystem is used. These systems improve the efficiency by using a heat sink and are cooler than the standard air. Heating/cooling of air with Earth-Air Heat Exchanger (EAHE) is a passive way to reduce the heat losses due to ventilation and thermal comfort in buildings. This system uses geothermal energy by burying a network of pipes of different combination installed in open spaces or beneath the building at a certain depth [7]. Although the technology is suffering from the critical concerns like high installation cost and the superior pipe designs that can provide uniform temperature distribution.

EAHE technology is an emerging technology and has many advantages over conventional systems. EAHE technology finds its application especially in space heating/cooling, greenhouses, snow melting etc. This technology can also be adapted for energy saving as it saves around 50% more energy than a conventional system. Nowadays, hybrid EAHE is also used for increasing the efficiency of these systems.

It has been already noted that the effectiveness of EAHE depends on the depth of the pipe installed, thermal diffusivity of the soil, length and diameter of the pipe, ambient temperature of a certain location, thermal conductivity of the pipe and air flow velocity. Adequate studies have already been conducted on EAHE considering the above-mentioned parameters. But least studies have been conducted considering the pipe geometry and materials. This research work focuses on the variation of temperature for different duct geometries and different pipe material. The rest of the paper is organised as follows, section II contains the Research Methodology, which describes the various methods required in the research, section III shows the results and discussions and finally in the section IV, conclusions are made.

II. RESEARCH METHODOLOGY

The study intends to computationally find the best pipe geometry and material for Indian climatic conditions. For the study, four different pipe geometries such as circular, square and triangular-corrugated and circular-corrugated and four different pipe materials such as Aluminium(Al), Steel(St), Copper(Cu) and Polyvinylchloride (PVC) were considered as shown in fig.1. The Computational Fluid Dynamics analysis was run using Ansys FLUENT v15.0. Ansys FLUENT is computational fluid dynamics software used to solve turbulence, flow models, heat transfer etc.

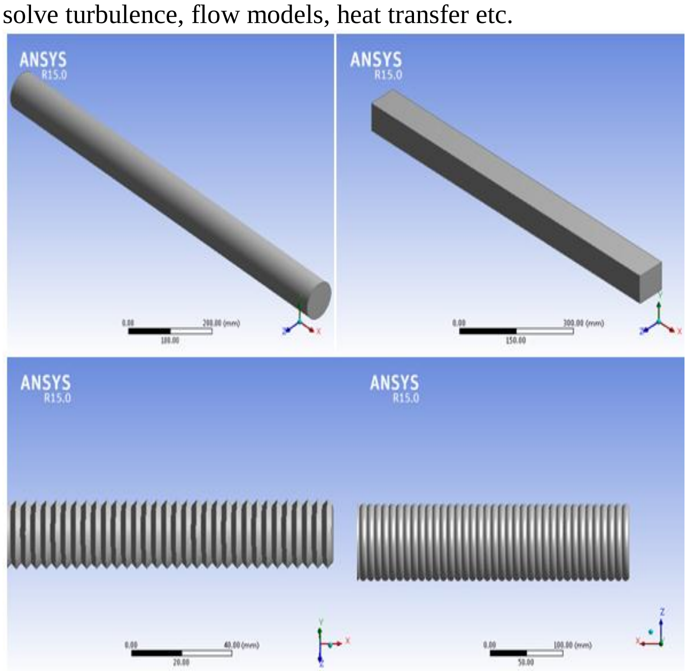


Figure 1.*Different pipe geometries considered for simulation(a)Circular; (b) Square; (c) Triangular-corrugated; (d) Circular-corrugated*

The study considers four different pipe materials to evaluate the effect of the temperature variations. Thermal conductivity is an important property in heat transfer which may be defined as the ability of a material to conduct heat. Thus, selection of material was done on the basis of the thermal conductivity. In the CFD simulations air is used as the operating fluid. The thermo-physical properties of the materials used in simulations are stated in table 1.

Table 1.Thermo-physical properties of materials considered for simulation

Material	***Density (Kg/m3)***	***Heat Capacity (J/KgK)***	***Thermal Conductivity (W/m K)***
PVC	1380	900	0.161
Copper	8978	381	387.6
Aluminium	2719	871	202.4
Steel	7833	465	54
Air	1.225	1006	0.024

Assumptions

In the present study, the following assumptions are considered:

- The air is incompressible.
- The soil properties are homogenous in nature.
- The soil temperature /wall surface temperature of the pipe is 300K.
- The soil temperature is constant throughout the length.
- Hydraulic diameter and length of the pipes are equal for all geometries.
- The wall thickness on consideration of pipe material is 0.001m for all the pipe geometries.

Design Parameters

Table 2: Design parameters considered for simulation

Design Information				
Geometry	**Circular**		**Square**	
Mode	Summer	Winter	Summer	Winter
Inlet temperature	318K	278 K	318K	278K
Hydraulic Diameter	0.08m		0.08m	
Length of pipe	1m		1m	
Geometry	**Triangular-Corrugated**		**Circular-Corrugated**	
Mode	Summer	Winter	Summer	Winter
Inlet temperature	318K	278 K	318K	278 K
Hydraulic Diameter	0.08m		0.08m	
Length of pipe	1m		1m	

Creation of Geometry and Meshing

A 3-dimensional model of all four geometries is created in ANSYS design modeller and meshing is done using Ansys ICEM CFD. The aim behind creating these geometries is to maintain a constant hydraulic diameter of 80mm for all four geometries. The pipe length considered for the study is 1000 mm. The CFD model is generally connected together with a large number of points in the form of numerical grid or mesh.

Post-processing

For the post-processing of the simulation, the results were executed considering steady state, pressure based and turbulence model enabling the energy equation. The most commonly used model for turbulence is Spalart–Allmaras, k–ε and k–ω model. Generally, K-epsilon model includes three models Standard, RNG and realizable model is used for viscous heating, buoyancy effect etc. The RNG models can be used for differential viscosity model where low Reynolds number is included under turbulence viscosity. The turbulence model is selected for thermal modelling of flow having Reynolds number greater than 4000. In the present study, K-epsilon model with standard wall treatment is considered.

Boundary Conditions

<u>Inlet Condition:</u>

Velocity magnitude: 2-5m/s

Inlet Temperature: 318K (summer), 278K (winter)

<u>Wall Condition</u>:

Wall Thickness: 0.001m

Extraction of Results

The results of the CFD simulation were extracted for two seasons (summer and winter) by varying the velocities from 2-5m/s for all the considered geometries and materials. The results were in the form of temperature reduction. The variables considered were:

i. The variation of temperature along the length.
ii. The behaviour of Pressure drop and Reynolds number.
iii. Variation of Nussult number over Prandtl number.

III. RESULTS AND DISCUSSSIONS

In this paper, the simulations results were carried out for two seasons (summer and winter). For the study of temperature reduction, the parameters such as velocity, length, Pressure drop, Reynolds number and Nussult number were examined for the all four geometries by taking the pipe material into account. The slope of each graph presented in this paper indicates different pipe geometries such as orange indicates round geometry, blue indicates the square geometry, grey indicates triangular-corrugated geometry and yellow indicates circular-corrugated geometry.

The temperature variation for the four pipe geometries was investigated at different velocities ranging between 2-5m/s for both the seasons. The velocity range chosen was quite low keeping in mind the design dimensions as well as suggested in the literature. Based on Indian climatic conditions, during the summer season, the inlet temperature considered was 318K. In order to study the temperature reduction for the four pipe geometries, the temperature variation from the inlet to the outlet along the length was considered. The simulation results indicate that there was a decrease in temperature at the outlet in reference to the inlet temperature at 2m/s as shown in figure 2. For the same pipe material, the triangular-corrugated pipe resulted in a drop of 13.24K in comparison to the other three geometries. Also, by comparing both the corrugated geometry pipe, triangular-corrugated pipe geometry resulted in a maximum drop. While varying the velocities from 2-5m/s a similar trend was observed for all the pipe geometries. It was observed that on varying the velocities from 2-5m/s the outlet temperature increases with an increase in the inlet velocities. Thus, the inlet velocities are a direct function of outlet temperature during the summer season.

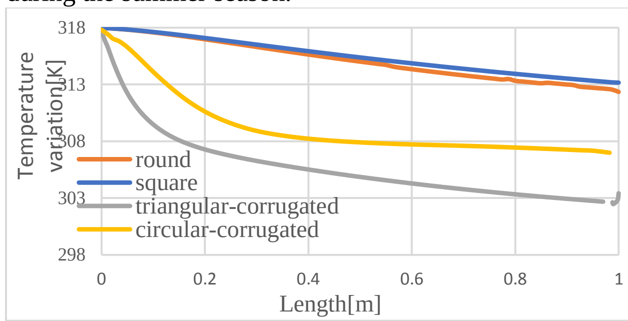


Figure 2.*Temperature variation along the length for all pipe geometries at 2m/s*

Generally, the pressure drop may be defined as the variation between the inlet and outlet section of a pipe flow. Pressure drop is developed in a pipe considering the frictional forces acting on the fluid. Liquids and gases flow in the direction of low pressure. The pressure drop in a pipe is affected by various factors such as surface roughness, tube convergence, pipe fittings, pipes materials etc. Low velocities result in a low-pressure drop. Ordinarily, the pressure drop is calculated using Reynolds number and relative roughness of the pipe. However, Reynold number provides the information about the flow [laminar or turbulent]. Reynolds number may be defined as the ratio of the inertial forces and viscous forces. In this study, the flow results in low Reynolds number where the viscous forces are dominated.

The variation of Pressure drop over Reynolds number on varying the inlet velocity from 2-5m/s is shown in figure 3 and 4. The figure clearly indicates that as the Reynolds number increases the pressure also increase irrespective of the seasons. Thus, the pressure drop and Reynold number of a pipe are in direct variation with the inlet velocity.

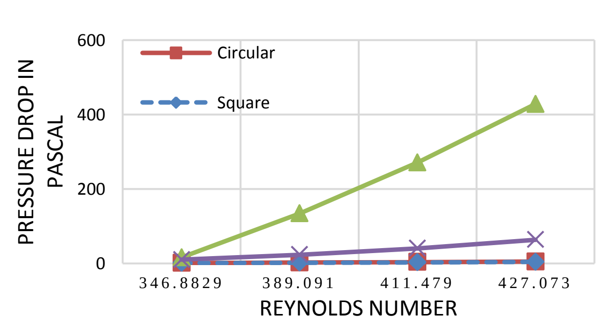


Figure 3.*Variation of Pressure drop and Reynolds number for Summer*

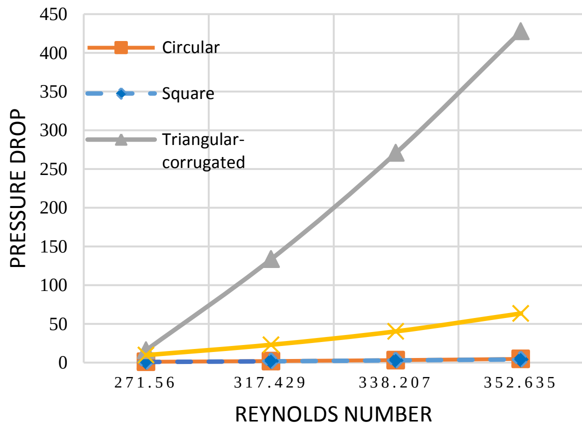
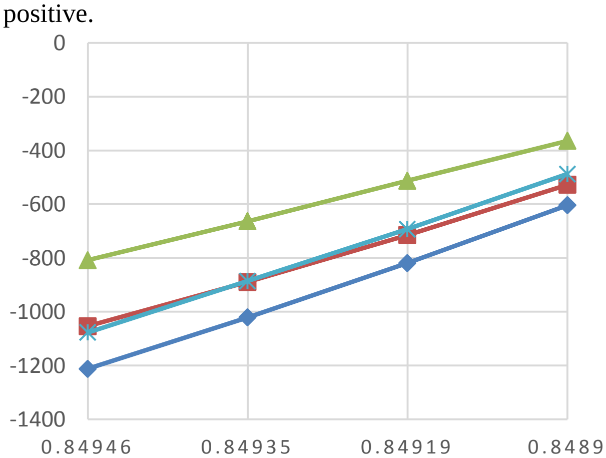
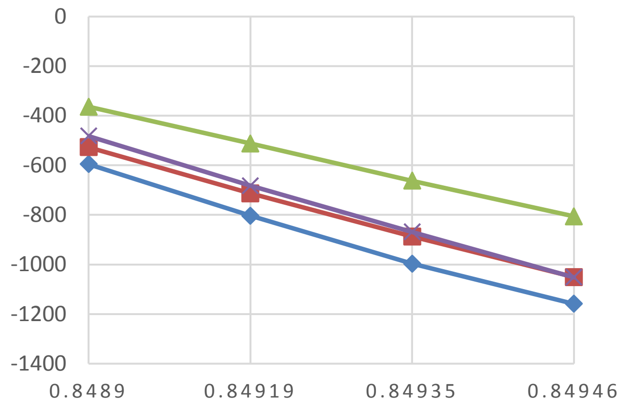


Figure 4.*Variation of Pressure drop and Reynolds number for Winter*

In heat transfer studies, the dimensionless quantities such as Prandtl number and Nussult number are generally considered. The Nussult number is a function of Prandtl number and Reynolds number. The Nussult number is considered to make a comparison between the conductive heat transfer and convective heat transfer whereas Prandtl number is considered to study about the type of fluid [information about thermal thickness and hydrodynamic boundary layer]. In this study, the variation of Nussult number over Prandtl number at different inlet velocities for all four-pipe geometry and four-pipe material are investigated.

The variation of Nussult number over the Prandtl number for velocities ranging between 2-5 m/s are shown in figure 5 and 6. From the figures, it can be clearly stated that the Nussult number value increases with the increase in Prandtl number during the summer season and vice verse during winter seasons thus confirming that Nussult number is a function of Prandtl number. It can be observed from the figure that during the summer season the Nussult number value is negative whereas during the winter season the value is positive.





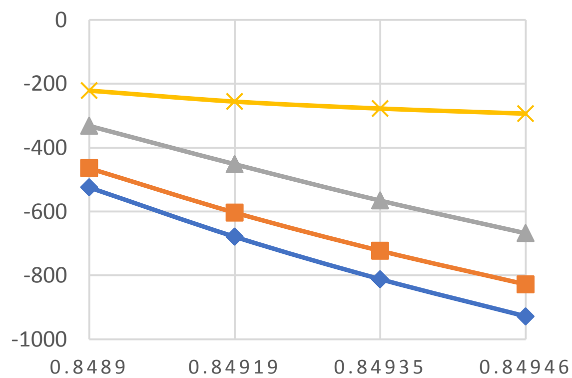


Figure 5.*Variation of Nussult number over Prandtl Number for different pipe materials during summer season(a) Aluminium; (b) Steel; (c) PVC*

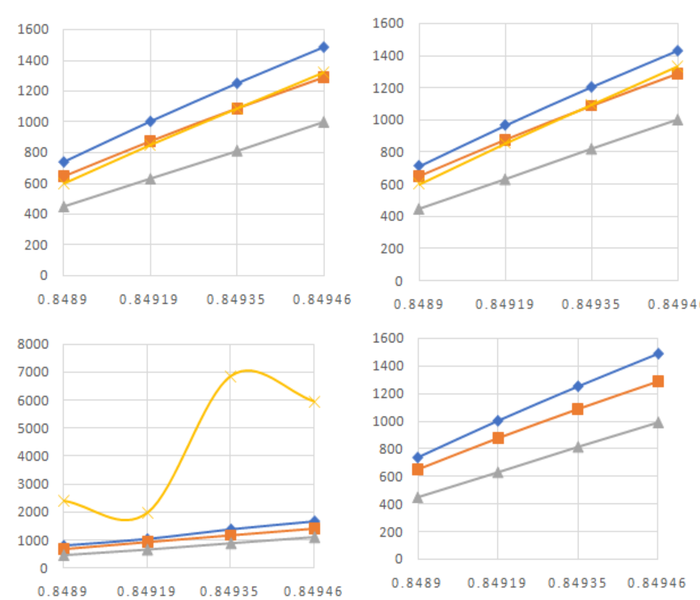


Figure 6. *Variation of Nussult number over Prandtl Number for different pipe materials during winter season (a) Aluminium; (b) Steel; (c) PVC; (d) Copper*

IV. CONCLUSION

Energy consumption in building for thermal comfort a quite high thus numerous passive heating and cooling techniques and strategies are introduced to save energy. One such passive technique is EAHE that uses geothermal energy. This paper aims in studying the cooling and heating potential of EAHE system. Also, approaches to find the appropriate pipe geometry to obtain optimum temperature drop using CFD that will help the occupants for thermal comfort. The CFD simulations were carried out using Ansys FLUENT. In the study, four different pipe geometries such as circular, square and triangular-corrugated, circular-corrugated geometry and four- pipe materials such as Aluminium, Steel, PVC and Copper of 0.001m thickness was considered. The simulations were carried out for two seasons (summer and winter). The results reveal that there was appreciable temperature variation while comparing the four geometries. As suggested in the literature the pipe material was not taken into much importance.

Based on the result of the CFD simulations it can be established that the pipe geometries can have a large impact on the performance of EAHE system. During the summer season, the maximum drop in temperature was 13.24 K and 16.18 K during the winter season at 2m/s. Thus, EAHE system is beneficial for Indian climatic conditions. Again, in case of pressure drop and Reynolds number, both the variables are the direct function of inlet velocity for all the three-pipe geometry. Also, for both the seasons there was a similar trend of variation was observed irrespective of the pipe material. In the variation of Nussult number over Prandtl number, the results indicate that the Nussult number is a function of Prandtl number. But during the summer season, there was a negative variation of the Nussult number was observed and vice versa during the winter season. This kind of variation was observed for inlet velocities ranging between 2-5 m/s. Thus, the inlet velocity and pipe geometries play an important role in estimating the performance of EAHE system. This study confirms the objective that the appropriate pipe geometry is the corrugated pipe geometry for optimum temperature variation. Also, reasserts that the EAHE system can be used for space heating as well as cooling in Indian climatic conditions. In order to obtain maximum temperature reduction, corrugated pipes can be laid underground for further experimentation in this field.

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