

CHAPTER 1

THERMAL ANALYSIS AND TEMPERATURE DISTRIBUTION IN EARTH PIPE AIR HEAT EXCHANGER

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ABSTRACT

Temperature of air that flows into underground tunnel can be cooled down, which can be utilized for reducing the cooling load of buildings. The present chapter aims to analyse the outlet air temperature of an earth pipe air heat exchanger (EPAHE) system. A transient and implicit model based on computational fluid dynamics was developed to predict the thermal performance of the EPAHE. Computational fluid dynamics (CFD) simulation is employed to determine the temperature distribution across the EPAHE system for different types of soil and with different range of air velocities. The transient study of temperature profile, velocity profile of the piping model has been conducted by using Renormalized Group (RNG) $k-\varepsilon$ turbulent model. Effects of the operating parameters such as the type of soil and air velocity on the thermal performance of EPAHE systems are discussed. The 23.42 m long and 2.75 m depth inside the soil of EPAHE system discussed in this paper gives cooling in the range of 10.0 to 13.0°C for the flow velocities 1 to 5 m/s in four different types of soils. We found the type of soil buried, and the flow of air velocity contributed to the major effect of the performance of EPAHE system.

Keywords: earth pipe air heat exchanger, CFD, thermal analysis

1.1 INTRODUCTION

Air conditioning is to provide thermal comfort for building occupants. Cooling is conventionally achieved by vapor compression machines. However, due to the depletion of the ozone layer, global warming by chlorofluorocarbons (CFCs) and the need to reduce high grade energy consumption with the rising electricity, numerous alternative techniques are currently being explored.

There is a growing interest in heating and cooling systems based on renewable energy. Using the earth to cool was available since ancient times. Wind towers as well and underground air tunnels were used by Iranian architects for passive cooling (Bansal et al., 2010; Dubey et al., 2016). One of the efficient methods is earth pipe air heat exchanger (EPAHE) system. Another name for EPAHE is underground air tunnels (UAT) systems. The system aids in reducing the high energy usage compared to conventional systems in cooling. The cooling applications of this system can be used in offices, residential houses, buildings, as well as industrial setups.

The temperature of earth ground (of about 2.5 to 3 m underground) remains nearly constant throughout the year. This constant temperature is called undisturbed temperature of earth. The EPAHE system works by supplying hot outdoor air into pipes that are buried in the ground by using blower with specified air speed. When air flows in the earth air pipe, heat is transferred from air into earth. As a result, the air temperature at the outlet of the earth air pipes is much lower than that of the ambient due to the cooler underground temperature.

Several researchers have studied how to further improve the EPAHE system. One of them is Darkwa et al., 2011 who found that a longer earth tube and deeply placed with smaller diameter and lower inlet air velocity lead to reducing the outlet air temperature. In another study, Busby, 2015 proposed the thermal properties for horizontal ground collector loop. In his proposal, horizontal closed loop ground collectors for ground source heat pumps are located within the soil and the top of the underlying, unconsolidated geology. Estimating thermal properties for this zone is difficult as it is heterogeneous and is subject to seasonal water content variations.

Main concern in this area of research is that the lack of previous actual research on the velocity of air flow and type of soil plays important role in EPAHE system. The purpose of this study is to evaluate the change in outlet air temperature across the pipe buried (EPAHE) in different soil types. Computational fluid dynamics (CFD) is used to simulate air flow within the EPAHE system with different velocities in different soil medium.

1.2 METHODOLOGY

1.2.1 Geometry

In design the geometry, SolidWorks software was used to build the model of EPAHE system. The EPAHE model is designed in simpler form as the piping system modelled as U-shaped pipe to take advantage of symmetric computational domain. Using ANSYS Design Modeler enables editing of some other features. Before proceeding to mesh the model, all domains have been justified to its respective type (see Fig. 1.1).

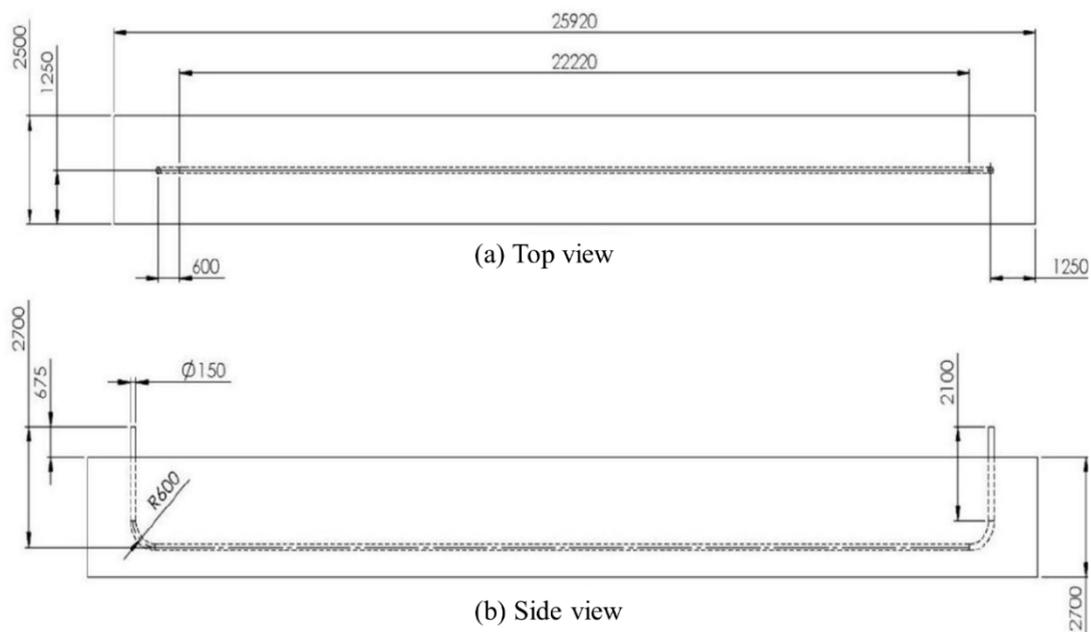


Fig. 1.1: Computational domain with dimension in unit mm; (a) top view, (b) side view

Fig. 1.2 shows mesh generated for the pipe and soil domain in this study with cutcell method with added inflation layers near the wall. For comparison, the study also investigate the impact of unstructured mesh, which is considered a conventional method of discretization. The setup is shown in Fig. 1.3. Several steps to determine the grid independent results were done and finalized. In this study, the final mesh had been considered. For example, for mesh discretized using cutcell method, the maximum element size is 2.6 m, minimum element size of 0.013 m, and the total element is 700,000 having a maximum skewness of 0.85.

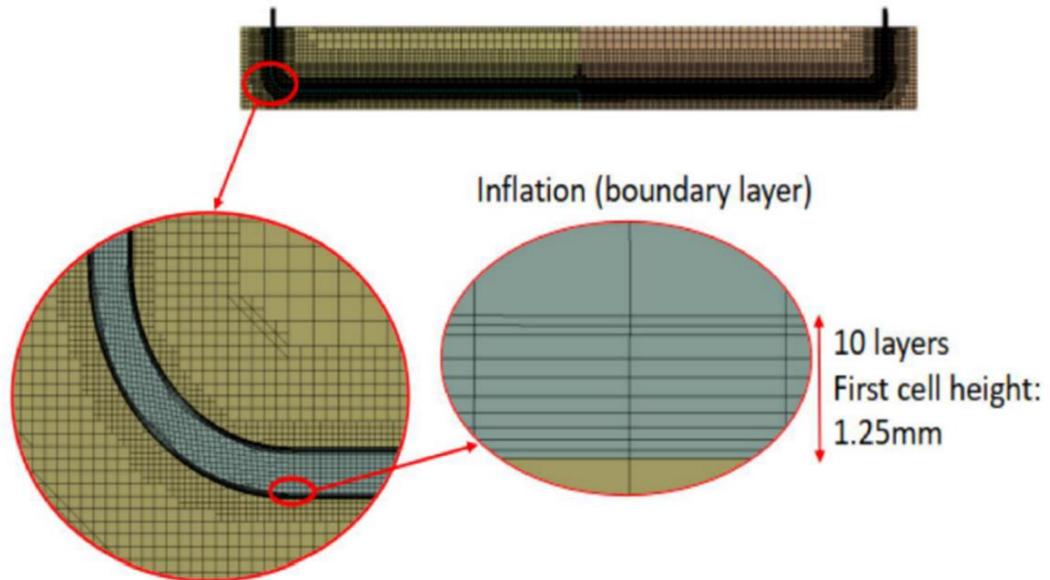


Fig. 1.2: Discretization using cutcell method

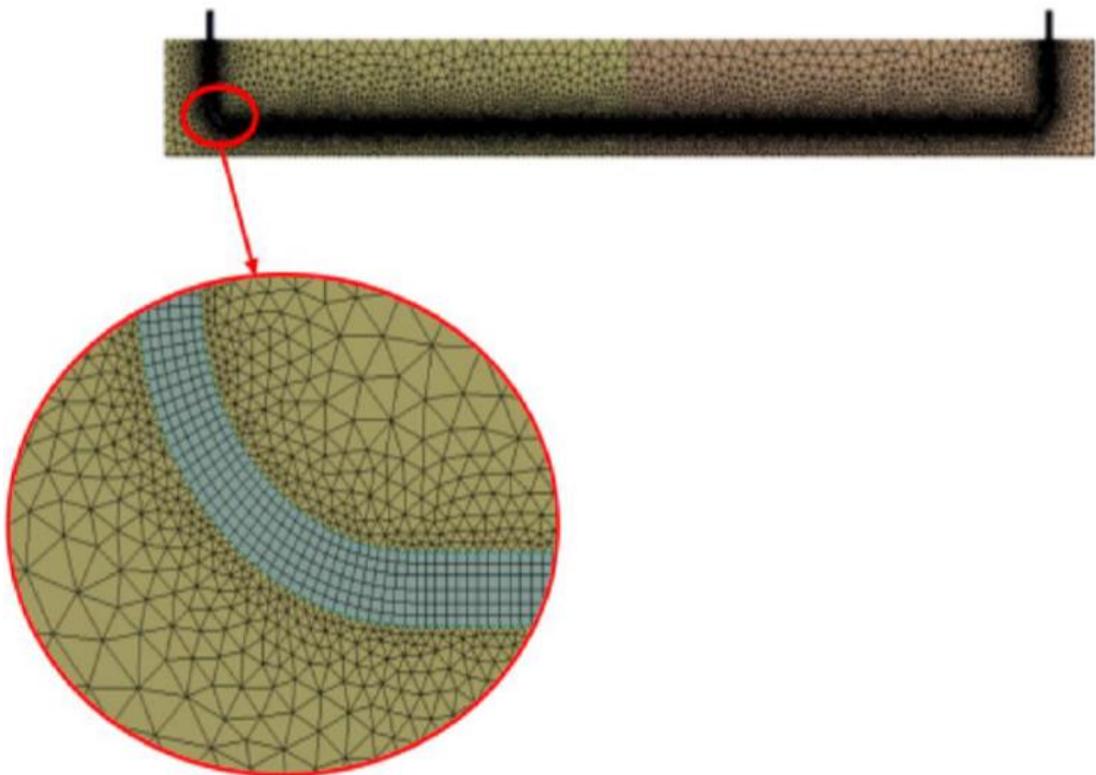


Fig. 1.3: Discretization using unstructured mesh

Fig. 1.4 shows the boundary conditions for this analysis, air will enter from inlet of the pipe, the thickness of pipe used in this simulation is 3mm (Dubey et al., 2016) which was defined as polyvinyl chloride (PVC) and the soil type used in this analysis is dry-soil. Temperature of top soil and air at pipe inlet was taken as 43.4°C, which is similar to ambient temperature. The temperature of side and

bottom soil was defined as 23°C and 29°C, respectively, which are based on data from study by Singh and Singh (2015). The physical and temperature properties of fluid and solid used in this study are presented in Table 1.1. The analysis was conducted using RNG k- ϵ turbulence model with energy equation to solve the heat transfer problem.

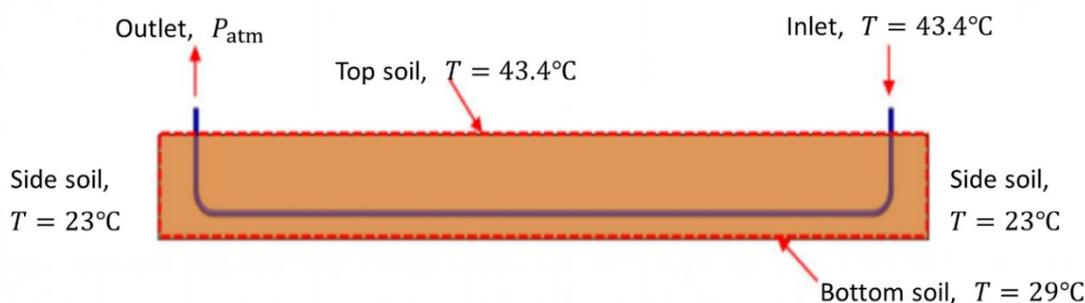


Fig. 1.4: Boundary condition used in the simulation

Table 1.1: Thermophysical properties used in simulations

Material	Density (kg/m^3)	Specific heat capacity ($\text{J}/\text{kg}\cdot\text{K}$)	Thermal conductivity ($\text{W}/\text{m}\cdot\text{K}$)
Air	1.25	1006	0.0242
PVC	1380	900	0.16
Clay soil	1760	1381	1.10
Dry soil	2050	1840	0.52
Loamy soil	1430	1102	1.42
Peat soil	1038	1900	0.08

In order to validate the CFD simulation with the experiment done by Singh and Singh (2015), a validation study has been carried out to get the least variation percentage with the real experimental value. Based on the comparison graph in Fig.1.5, it was found the CFD results are in agreement and achieved a maximum error of 4.2% compared to unstructured mesh method for all points along the length of EPAHE pipe. The location of the section is illustrated in Fig. 1.6.

Additionally, four types of turbulence models were also compared to validate the CFD result. Based on the result shown in Fig. 1.7, k- ϵ standard and RNG k- ϵ turbulence models produced lower errors to other turbulence model used for all points along the length of EPAHE. The RNG k- ϵ turbulence model was considered the best as it show more accurate result.

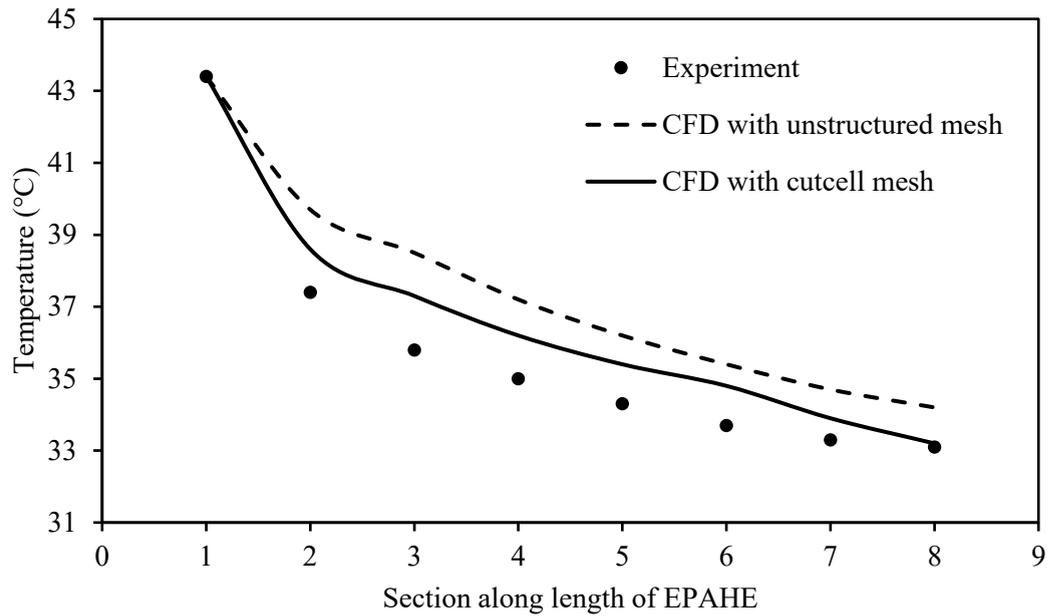


Fig. 1.5: Comparison of temperature distribution between CFD and experimental data

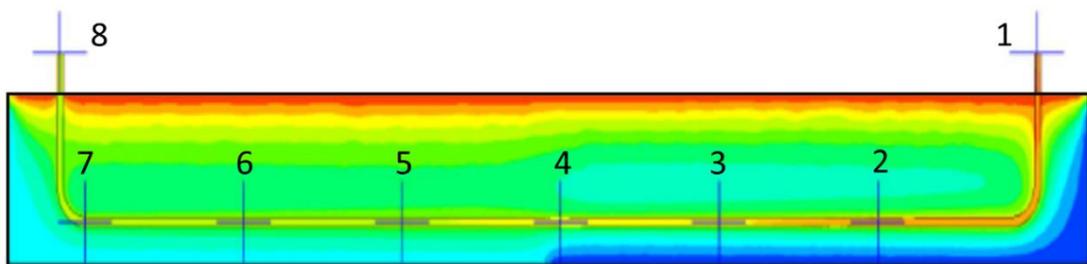


Fig. 1.6: Sections of data extraction along the length of EPAHE pipe

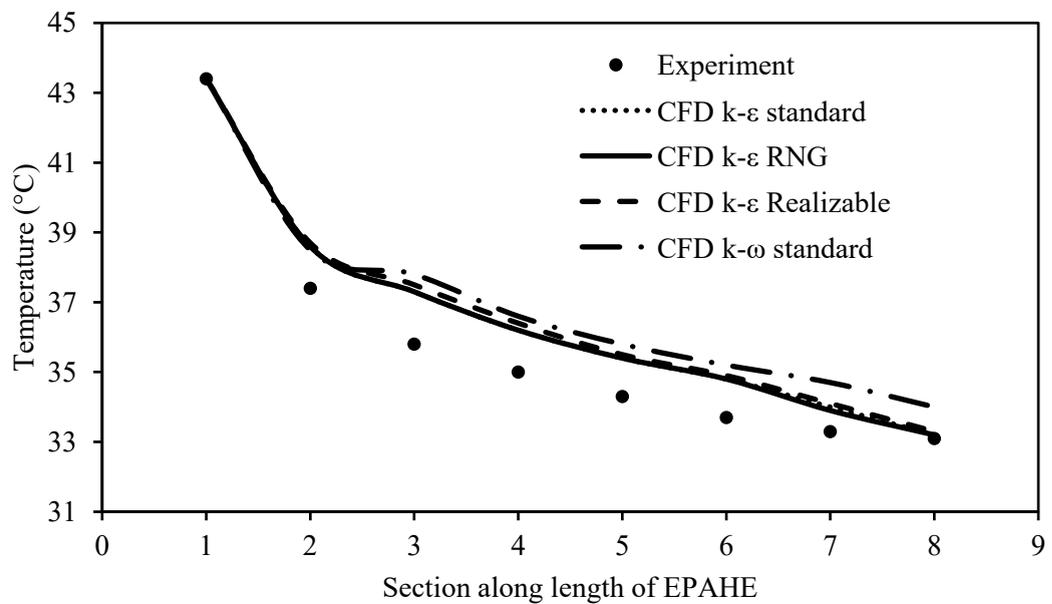


Fig. 1.7: Comparison of temperature distribution between CFD and experimental

data

1.3 RESULTS AND DISCUSSION

Fig. 1.8, 1.9, 1.10 and 1.11 shows temperature distribution at five different inlet velocities for for dry soil, clay, peat and loamy soil, respectively. Comparing all figures, it was found that loamy and clay types of soil have lowest air temperature at pipe outlet (point 8) compared to dry-soil and peat for all inlet velocity cases. Loamy reached lowest outlet temperature of 29.9°C from 43°C for inlet velocity of 1m/s (see Fig. 1.11), which indicates temperature drop around 30.5% and highest temperature drop compared to other cases. It was followed by clay soil, dry soil and peat soil with temperature drop around 30.5%, 28.5% and 15.6% respectively.

The CFD simulation results continue to show the same trend in temperature drop for different inlet velocities of 2, 3, 4 and 5m/s, with the highest temperature drop for loamy soil, followed by clay and dry soil and the lowest temperature drop is the peat soil. These results of temperature drop could be related to thermal conductivity of the soil itself, loamy soil has the highest thermal conductivity, followed by clay, dry soil and the lowest thermal conductivity is the peat soil. Because thermal conductivity indicated how efficient soil type to dissipate heat in its body, as soil with the higher thermal conductivity can easily drop the temperature compared to the soil with lower thermal conductivity.

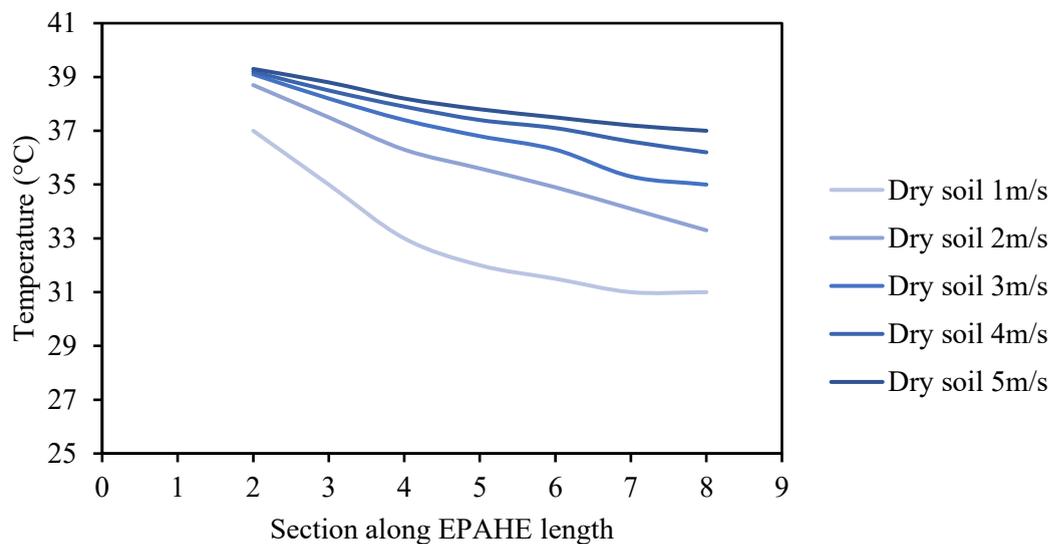


Fig. 1.8: Temperature distribution along the length of the pipe for different inlet velocity for dry soil

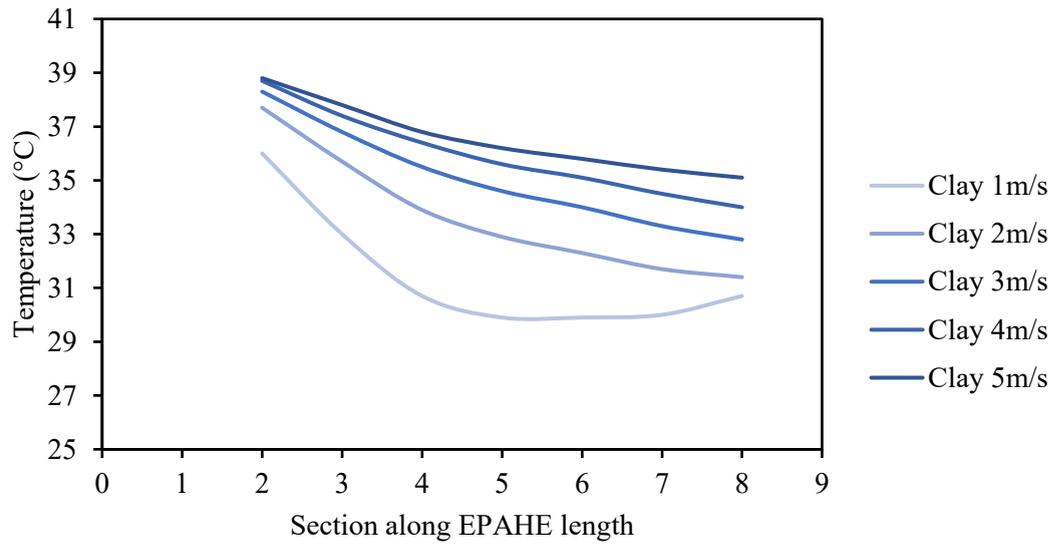


Fig. 1.9: Temperature distribution along the length of the pipe for different inlet velocity for clay soil

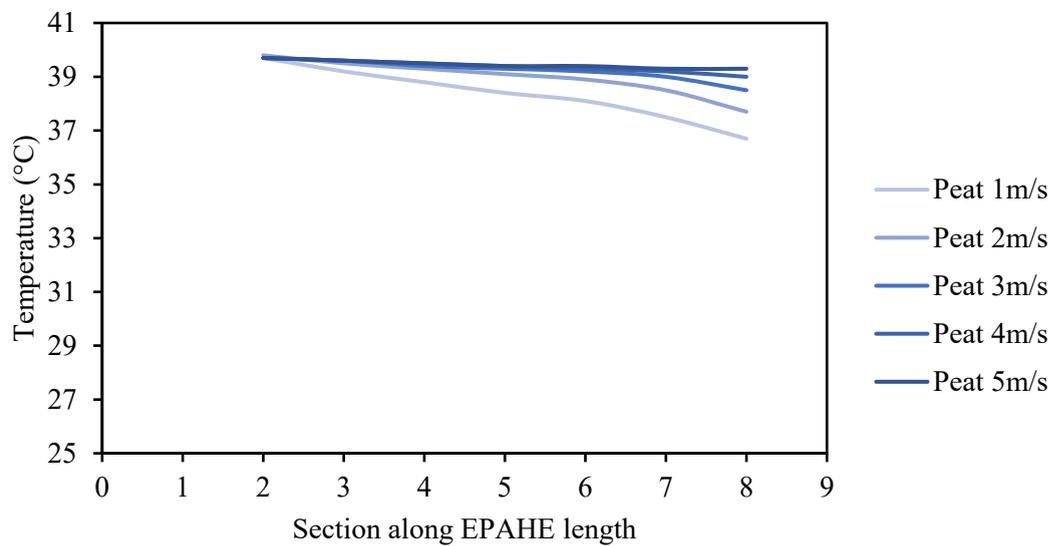


Fig. 1.10: Temperature distribution along the length of the pipe for different inlet velocity for peat soil

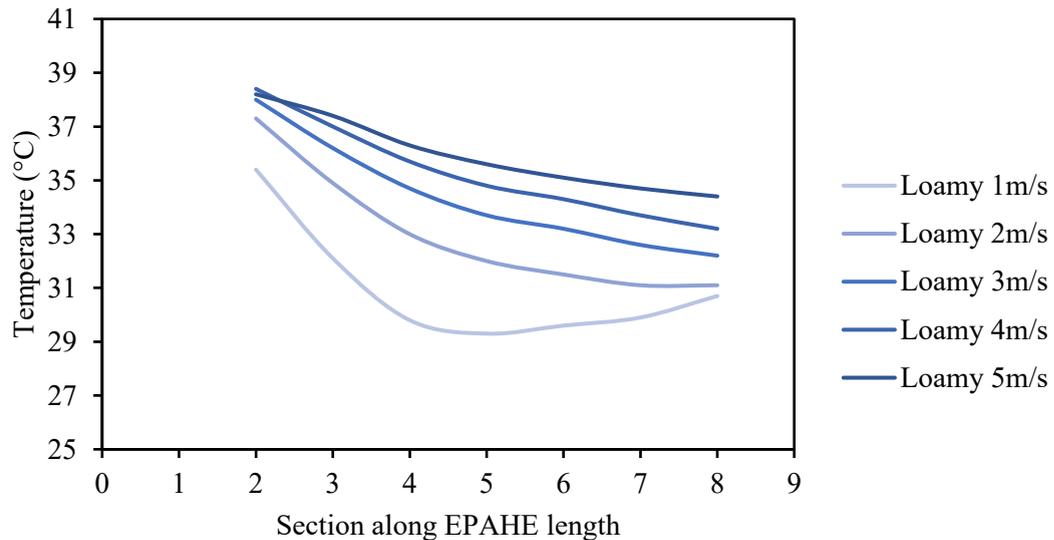


Fig. 1.11: Temperature distribution along the length of the pipe for different inlet velocity for loamy soil

Comparing all the soil types, the loamy soil provided the lowest temperature distribution along the pipe. Fig. 1.12 shows the contour plot of temperature at varying air speeds, from 1 m/s to 5 m/s obtained from the simulation study run inside loamy soil to elucidate the temperature distribution. The simulation clearly indicates the air temperature reduces along pipe section. In addition, the highest air speed is optimum to use and able to provide the largest temperature drop.

Loamy is a type of soil with higher moisture content compared to dry soil. In addition, loamy soil has higher thermal conductivity than dry soil. This is because moisture or water content in the loamy soil has increased its thermal conductivity compared to dry soil which has more air in its pore due to the higher thermal conductivity in water compared to air. Because dry soil has more air in between its grain that acts like insulator which lowers heat dissipation compared to loamy soil that has less air between its grain which is replaced by water. Because of this fact, loamy soil has lower temperature around pipe from point 2 until point 4 compared to dry soil because heat from this area in loamy soil has been dissipated to the boundary faster compared to dry and peat soil.

Another factor that contributes to higher thermal conductivity in loamy soil is that it has lower organic matter content in it compared to peat soil. Organic matter like plant foliage, cereal straw, root of crops, deciduous tree litter and many more, trapping the heat from escape to the boundary and acting like insulator around the pipe. Peat soil has the lowest thermal conductivity compared to three other soil types. Moreover, temperature drop for peat soil only drop around 5.8°C compared to loamy soil with temperature drop of 12.4°C and the temperature

almost stable from inlet to outlet for peat soil which indicate it acting as insulator that trap heat in the pipe from escaping to its surrounding.

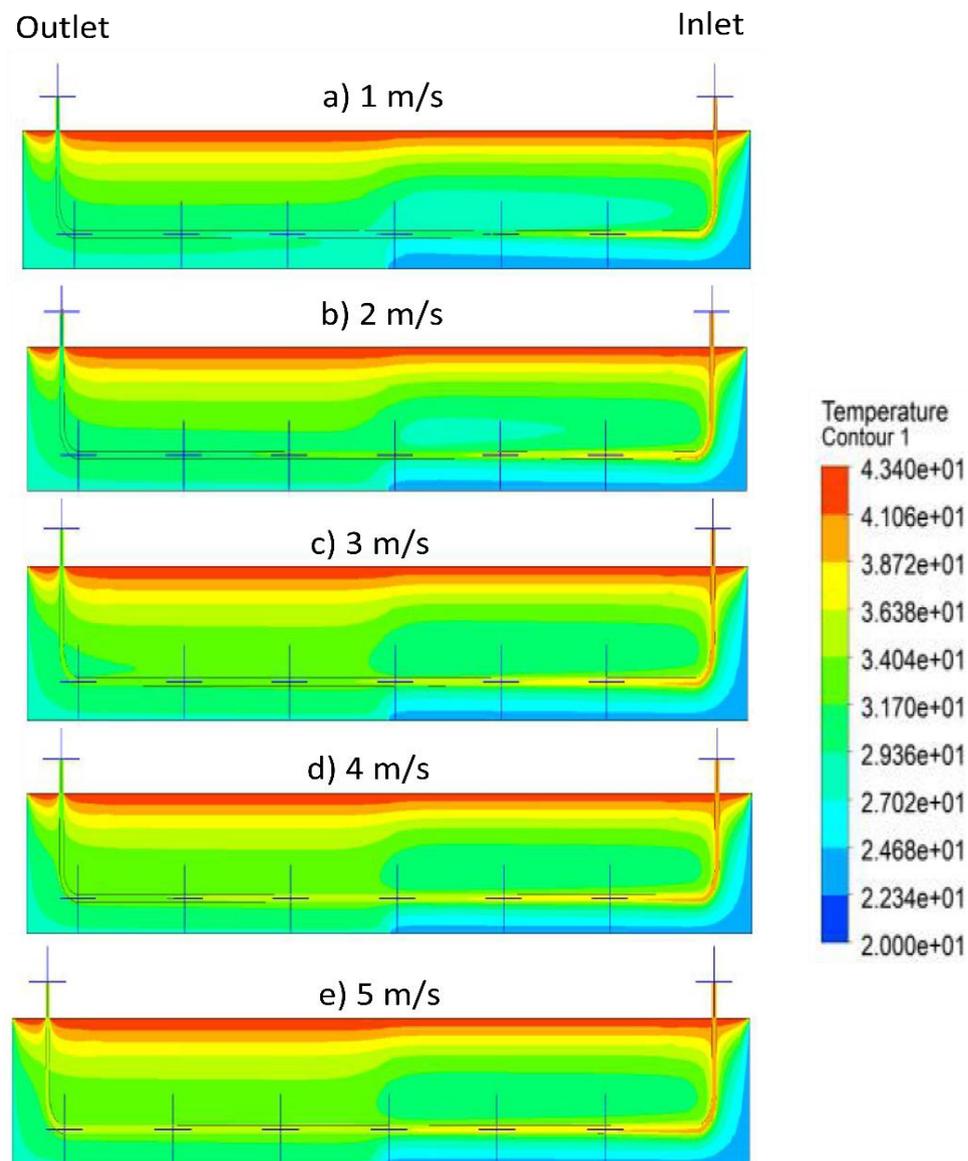


Fig. 1.12: Temperature contour for loamy soil at various air speeds

1.4 CONCLUSION

It was found that loamy and clay type of soil has lowest air temperature at pipe outlet (section 8) compared to dry-soil and peat for all inlet velocity cases. Loamy reached lowest outlet temperature of 29.9°C from 43°C for inlet velocity of 1m/s, which indicate temperature drop around 30.5% and highest temperature drop compared to other cases. It was followed by clay soil, dry soil and peat soil with temperature drop around 30.5%, 28.5% and 15.6%, respectively.

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