Comparative CFD Analysis of Helical Shaped Earth Air Pipe Heat Exchanger Using Water Tube as a Thermal Reservoir Using Different Pipe Materials

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Abstract- Thermal performance of the earth air pipe heat exchanger (EAPHE) has been evaluated under transient condition using helical geometry of air pipe. Helical shaped air pipe reduces the installation area up to 60% compared to commonly used straight or U shaped geometry. Performance of the EAPHE system deteriorates after a long run of use due to thermal saturation of nearby sub-soil; the thermal saturation of sub-soil is attempted by installing a water pipe of different pipe material at the center of the helical pipe layout. The water pipe acts as a thermal reservoir to absorb heat from surrounded soil and maintains constant heat transfer after 24 hours of the long run. CFD model was developed and simulated in FLUENT 19.0. Thermal performance of proposed models has been investigated, and comparisons were made in terms of outlet air temperature, sub-soil temperature at 0.05m and 0.25 m from pipe surface, change in water temperature, COP, and effectiveness of the system for the continuous 72hours of the run. In the first hour, 61.5%, 83.5%, and 94.5% heat is removed in 10m, 20m, and 30m pipe length, respectively. Maximum temperature drops of 14.55^{0}C were recorded using an aluminum water pipe after 72 hours of continuous run. The model with aluminum water pipe shows constant effectiveness as 0.76 after 36 hours run.

Keywords Earth air pipe heat exchanger, renewable energy, COP, thermal saturation, thermal reservoir.

1. Introduction

The demand for energy is increasing rapidly as the population grows exponentially. Around 35% of total energy is utilized for space cooling and heating purposes [1]. The study shows that the number of A.C. systems is expected to increase by 250 % by 2050, which will lead to a 300 %–400 % increase in energy demand [2]. Presently the energy demand is fulfilled by fossil fuel, which is the main concern of environmental pollution and ozone depletion. The cost of electricity is becoming costlier day by day due to the limited sources of fossil fuels. The conventional HVAC system demands high electric cost to run the system and is the main concern of global warming and environmental pollution. Hence, the demand for renewable energy sources is increasing rapidly to minimize the demand for conventional fuel [3]. Gerneral awareness toward the use renewable energy sources and to implement the green building concept is essential for public to fulfill the energy demand [4] [5]. Most of the countries are making renewable energy polily to meet the rising demand of energy [6] [5]. Study shows that integeration of renewable energy sources can be used to reduce the energy demand singnificantly [7] [8].

In the present, contest utilization of passive energy sources has the greatest importance as a renewable energy source. Geothermal energy is one of the passive energy sources, which has received increasing attention to reducing heating and cooling load of the residential and commercial space.

Literature shows that earth sub-soil temperature remains constant at a depth of 2-4m and can be used as a heat sink for the space cooling and heating purposes in summer and winter seasons respectively [9] [10].

Earth air pipe heat exchanger uses geothermal energy to reduce the cooling or heating load of the building space. It consists of a long underground pipe through which air is drawn by using a blower fan. Air gives up or receive some heat from the surrounding soil and enters the room as conditioned air [11].

Over the last decade, many researchers have done the performance analysis of the EAPHE system either by simulation or by experimental methods to assess the main parameters affecting the performance [12][13][14]. Researcher shows that the length of the pipe, diameter of the pipe, thermal conductivity of the nearaby soil and air velocity are the main parameters which affects the performance of the system [9]. Researchers have carried the thermal performance analysis and optimized the different parameters to improve the performance of the EAPHE system and concluded that the EAPHE system has the potential to provide cooling effect or to reduce the cooling load of the building [15] [16]. Bansal et al. [17] developed a CFD model to predict the effect of pipe material and air velocity on the performance of the EAPHE system. The result shows that a low air velocity of 2m/s maximum heat transfer rate can be achieved. The researcher performed a parametric analysis in the poultry form of Morocco and reduced electric consumption at the rate of 250.6MWh with an optimum pipe length of 30m and an air velocity of 2m/s [18]. Belatrache et al. [19] proposed a numerical study to optimize the operating parameter of the EAHE system assisted by the green wall, and it shows that shorter pipe length can be used to achieve the same temperature difference. A parametric study of the system was performed in the Adrar region, and the air is used for air-conditioning the room. The daily maximum cooling capacity of 1.755KWh was achieved [20]. Pressure drop in pipe flow is important parameter to reduce the blower power. Pressure loss in pipe flow can be regulated by using conical diffusers using different cone angles [21]. The numerical study was also carried out to reduce the relative humidity of the outlet air, and it reduced by 50% compared to the earlier research [22]. The effect of soil diffusivity on the heat transfer rate was studied by Mathur et al. study shows that maximum heat penetration takes place at 0.25m from the outer surface of the air pipe [23].

Researchers have coupled the EAPHE system to improve the performance of the earth heat exchanger. The system was coupled with a solar heater to improve the performance of EAPHE in winter application, and an increase in outlet temperature of 1.1-3.5^{0}C was observed [24]. The performance of EAPHE was improved significantly after integrated with evaporative cooler in the hot summer season [25].

The thermal performance of EAPHE systems starts deteriorated due to the thermal saturation of surrounding soil in the long run. Researches show that with the help of different techniques i.e., ground irrigation, shading, ground management contribution of plants, small rocks, and stones, soil temperature could be improved as per the conditions of hot climate or elevated temperature [26]. Effect of soil moisture was studied and compared with dry and wet soil of 15% moisture content. The effectiveness of the system increased by 26% with wet soil of 15% moisture content [27].

The result of previous research shows that heat dissipation is largely affected by the thermal conductivity of sub-soil layers [14]. Mathur et al. [28] conducted CFD analysis with three different soils, and results show that soil, which has high thermal conductivity, can be used for the long run compare to the soil having low thermal conductivity. Another term that has emerged as the defining factor for the losses measured in the EATHE system is known as 'derating factor' and is used for estimating the decrease in thermal performance of EATHE. Dearating factor is greatly affected by the thermal conductivity of soil, length of pipe, and duration of continuous operation of EATHE [29]. The problem of thermal saturation of nearby soil was attempted by several researchers by using different techniques under different operating conditions and soil compaction levels. [30] [31].

Experimental analysis conducted by the researcher using dry and wet soil and the results obtained from the experiment shows that, for dry soil, the temperature of 11.2 ^{0}C was achieved with 60 m of the length of pipe whereas, for wet soil, the same temperature is achieved in 28 m of pipe length [32]. Further, the researcher attempt to recover the soil thermal saturation by using the intermittent operation mode, and they found 1.81% performance improvement using intermittent operation [33] [34].

Effectiveness of the EAPHE can be improved by increasing the length of the buried pipe, which requires a large installation area. The initial installation cost of the system is very high due to the long pipe and digging cost of land. Researcher attempted to reduce the pipe length without affecting the performance by using wet soil. Wet soil EAPHE reduces 12-14m of pipe length compare to the earlier research [35]. Mathur et al. [36] also attempted to reduce the longitudinal space by using spiral geometry of the EAPHE system and found COP of 4.23 and 4.48 in summer; 5.0 and 5.16 in winter for straight and spiral respectively. Benrachia et al. [37] also used a spiral-shaped air pipe to optimize the installation area and performed a parametric analysis of the EAHE system. The result shows that pitch distance has a significant effect on the outlet temperature. Outlet temperature varies by 6^{0}C when pitch distance varies from 0.2 to 2m.

In spite of the earlier research done to optimize the performance of the system, the EAPHE system is not widely used in small homes and office applications. There are two important factors due to which the EAPHE system is not used widely, i.e., large installation area and thermal saturation of nearby soil. In the present study, the author proposed a model using helically shaped air pipe and water tube as a thermal reservoir to address both the issues. Study shows that helically shaped geometry significantly reduces installation area up to 60% compared to the widely used straight or U shaped air pipe. Water can be used as a thermal reservoir due to its high specific heat. Proposed model also studied the effect of water pipe material on the performance of system by using different pipe materials. The simulation result shows that the water tube maintains the constant heat transfer rate of the nearby soil without significant change in its temperature, and it maintains almost the same soil temperature near to the air pipe after 24 hours run time. The effect of pressure drop is also considered to calculate the COP of the system. The COP of the system is compared with the installation area and represented as space utilization factor (SUF). The SUF was also compared with earlier research done and found major performance improvement.

2. System Description and Simulation Setup

2.1. Physical Model

The geometrical configuration of the EAPHE system is presented in Table 1. The geometrical diagram is shown in Fig. 1(a) and 1(b). CFD analysis was conducted for two different models, with the water pipe, and without water pipe, keeping other parameters same for both model. Three different water pipe materials selected for the analysis on the basis of different thermal properties. PVC and pipes are most commonly used for the fluid flow due to low cost and easily available, and it was also used in most of the research papers. Fire clay pipe and the aluminum pipe are also used for the study due to its robust design and high thermal conductivity, respectively. In spite of the high initial cost of aluminum pipe, it has an advantage over other pipes due to its high thermal conductivity.

The thickness of the clay from the outer surface of the Water is considered 0.25m as earlier research shows that maximum heat penetration takes place at 0.25m from the outer surface of the air pipe [23]. The control volume of the soil cylinder is considered as 1.1 m for the analysis. Table 2 shows the details of the four models used in the present paper.

Length of the water pipe calculated taking pitch of the helical pipe as 1m. The length of the helix and the total number of turn for 40m long pipe is calculated as per the design calculation shown below. A 20m water pipe is taken for the analysis, which can hold 157 liters of water, and the Water can be recharged from the inlet of the pipe whenever it is necessary.

2.2. Design Calculation

Length of Helix in one complete rotation:

Length of pipe in one turn = $\sqrt{Circumference^2 + Pitch^2}$

$= \sqrt{C^2 + P^2}$ (1)

For 100 mm water pipe

Length in one turn = $\sqrt{C^2 + P^2}$

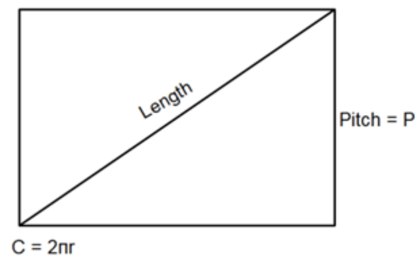
where, C = 2π x 0.3 = 1.88 m

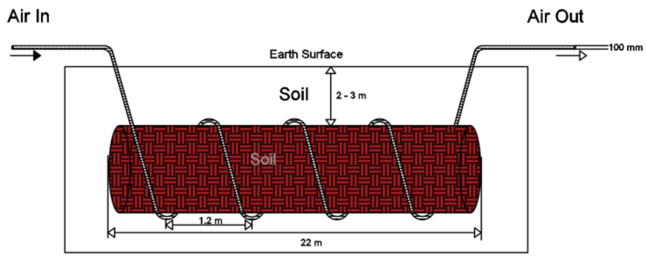
L = $\sqrt{1.88^2 + 1.2^2}$ = 2.23 m

Number of turns for 40 m pipe = $40/2.23$ = 17.9≈ 18

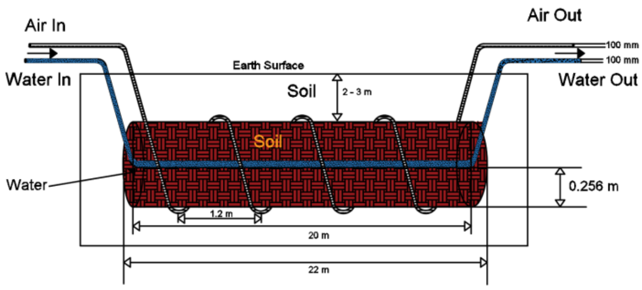
Volume of water pipe = π x $(0.05)^2$ x 20 = 0.157 m^3

Water required= 157 Liters.





(a)



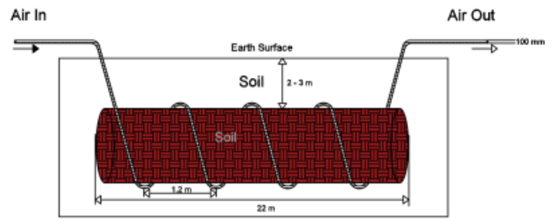
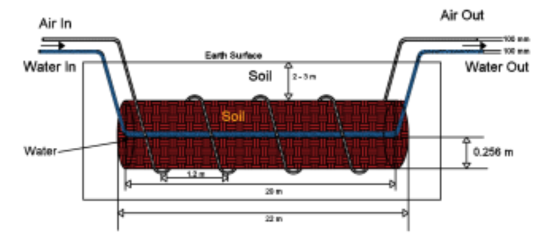
(b)

Fig. 1. The different layout of EAPHE system, (a) without water pipe (b) with water pipe

Table 1. Geometric configurations of EAPHE pipe

Parameter	Air pipe	Water Pipe
Diameter (mm)	100	100
Thickness (mm)	3	3
Length (mm)	40000	20000
Material	HDPE	PVC Clay Aluminum
Clay Pipe Thickness	-	25mm (According to Standard of RCC Pipe)
Soil Diameter (mm)	-	1000 mm from Outer diameter of water pipe

Table 2. Models used in the present study

Model	Nomenclature	Water pipe material	Design
Model 1	M-1	No water pipe	
Model 2	M 2	PVC water pipe	
Model 3	M 3	Clay water pipe	
Model 4	M 4	Aluminum water pipe	

2.3. Simulation Model

ANSYS FLUENT 19.0 was used in the study that uses a finite volume method to convert governing equations into numerically solvable algebraic equations. The simulation parameter shown in Table 3 was used for the analysis. The finer grain size is incorporated to mesh the model for better results. After meshing, necessary boundary conditions are incorporated that are important to initiate the calculation and solution of the CFD model. Simple k-ε turbulent models and techniques with standard wall treatment are chosen in order to determine and predict turbulence inside the tubes. The energy equation model has been developed as the thermal transfer, included within the data processing or observation; [33]. The far outer boundaries in the soil were treated as an adiabatic surface to ensure that it would not have any effect in the process of simulation. Initial boundary conditions are used as soil temperature of 27^0C and air velocity 5m/s, as shown in Table 4.

The study was a transient based study carried out for 72 hours for each case on the CFD ANSYS. Hourly air temperature variations, soil temperature, and change in water temperature were recorded at a different interval, as shown in Fig. 2. The radial distance of 0.05 m and 0.25 m were taken for the measurement of soil temperature as presented by green lines and yellow points.

The investigation was based on the following assumptions.

- Solid and liquid thermal physical characteristics and their property remain consistent all through operating conditions over the soil and average temperature range.
- Air velocity remains constant throughout the analysis.
- Perfect thermal contact between the grounds, Water buried, and air tubes.
- The temperature of the soil and the HDPE pipe is first seen as equal and uninterrupted.

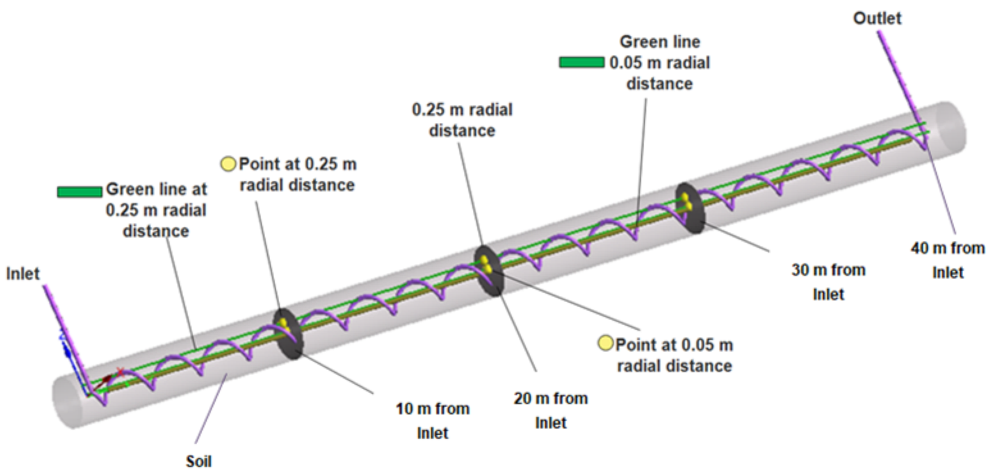


Fig. 2. Schematic diagram of the simulation model

2.4. Governing Equation

The following set of governing equations is used to perform simulation in FLUENT software to describe the heat and mass transfer and flow of fluid within any systems [34],[38].

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \quad (2)$$

Momentum Equation in x direction

$$\frac{\partial(\rho u)}{\partial t} + \nabla.\ (\rho u \vec{v}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau xx}{\partial x} + \frac{\partial \tau yx}{\partial y} + \frac{\partial \tau zx}{\partial z} + \rho f x \quad (3)$$

Momentum Equation in y direction

$$\frac{\partial(\rho v)}{\partial t} + \nabla.\ (\rho v \vec{v}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau xy}{\partial x} + \frac{\partial \tau yy}{\partial y} + \frac{\partial \tau zy}{\partial z} + \rho f y \quad (4)$$

Momentum Equation in z direction

$$\frac{\partial(\rho w)}{\partial t} + \nabla.\ (\rho w \vec{v}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau xz}{\partial x} + \frac{\partial \tau yz}{\partial y} + \frac{\partial \tau zz}{\partial z} + \rho f z \quad (5)$$

Energy Equation

$$\frac{\partial}{\partial t}[\rho(e + \frac{v2}{2})] + \nabla.\ [\rho(e + \frac{v2}{2}\ \vec{v})] = \rho\dot{q} + \frac{\partial}{\partial x}(k\frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(k\frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(k\frac{\partial T}{\partial z}) - \frac{\partial(uP)}{\partial x} - \frac{\partial(vP)}{\partial y} - \frac{\partial(wP)}{\partial z} + \frac{\partial(u\tau xx)}{\partial x} + \frac{\partial(u\tau yx)}{\partial y} + \frac{\partial(u\tau zx)}{\partial z} + \frac{\partial(v\tau xy)}{\partial x} + \frac{\partial(v\tau yy)}{\partial y} + \frac{\partial(v\tau zy)}{\partial z} + \frac{\partial(w\tau xz)}{\partial x} + \frac{\partial(w\tau yz)}{\partial y} + \frac{\partial(w\tau zz)}{\partial z} + \rho \dot{f}\ \vec{v} \quad (6)$$

Table 3. Properties of material used in the simulation

Material	Density (Kg/m^3)	Specific Heat (J/Kg K)	Thermal conductivity (W/mK)	References
PVC	1380	900	1.16	[39]
Clay	2083	835	0.72	[40]
Soil	2050	1840	0.52	[28]
HDPE	1600	568.75	0.57	[36]
Aluminum	2719	871	202.4	ANSYS
Air	1.225	1006.43	0.0242	[25]
Water	998.2	4182	0.6	ANSYS

Table 4. Boundary conditions

Air Inlet Velocity	5 (m/s)
Air Temperature	46.2^{0}C
Soil Temperature	27^{0}C
Pipe Temperature	27^{0}C
Water Temperature	27^{0}C
Water	Non-flow condition
Turbulence Model	k- ε

3. Grid Independence Test

The model is created by using tetrahedron meshing, as shown in Fig. 3. The number of nodes and element counts are 1176277 and 4303779 respectively.

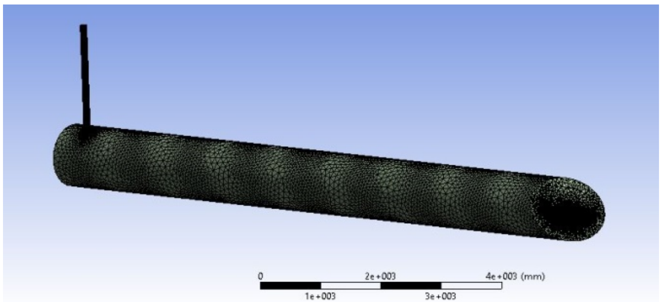


Fig. 3. Meshing of model

The simulation was run for different grid sizes; the output temperature should remain constant to be grid-independent. Three different grid sizes i.e., 0.02m, 0.01m, and 0.005m were considered for the simulations considering the same operating parameter for both grid sizes. It is observed from Fig. 4 that there is no or minimal change in air temperature is observed when grid size changes from 0.01m to 0.005m. Therefore 0.01m grid size is taken to have better accuracy and less computational size.

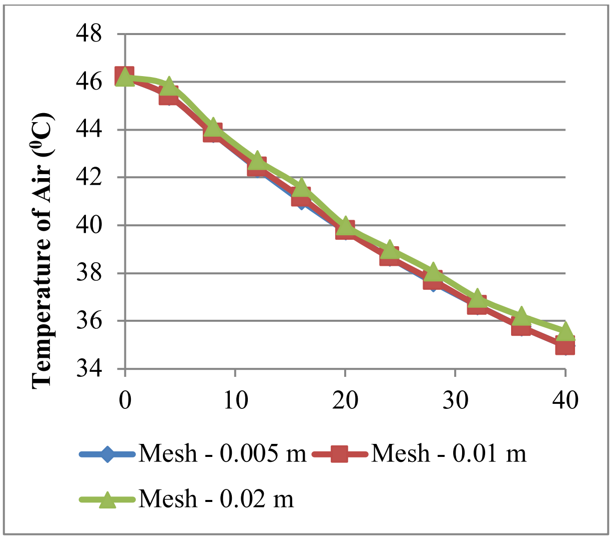


Fig.4. Grid Independent Test

4. Validation CFD Model

The present CFD model was validated against the results of the numerical and CFD analysis done by Mishra et al. [41] and Mathur et al. [23]. Figure 5 shows the air outlet temperature at different time intervals; the results of the two studies show that temperatures were almost the same at most of the points. Table 5 shows the percentage error between present model and the result of Mishra et al. Maximum error of 5.87% with mean and standard deviation was found as 2.91 and 1.58 respectively. It shows very good agreements between the two studies, hence the present CFD model is validated.

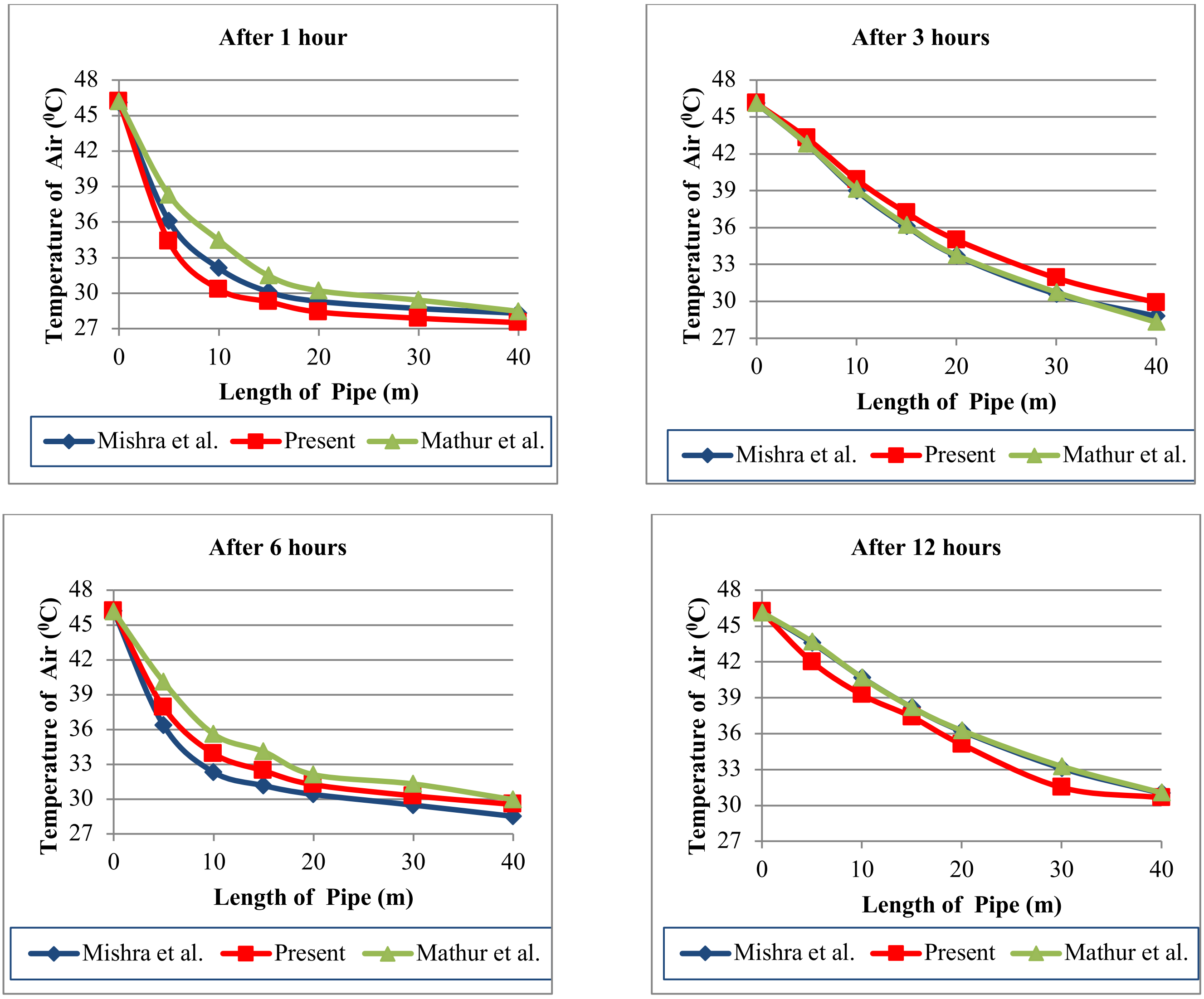


Fig. 5. Air outlet temperature comparisons from earlier research

Table 5. Air outlet temperature comparison and percentage error.

Length of air pipe (m)	1 Hr		% Error	3 Hr		% Error
	Mishra et. Al	Present model		Mishra et. Al	Present model	
0	46.1	46.20	0.22	46.1	46.1	0.00
5	36.1	34.35	5.08	42.8	43.3	1.15
10	32.1	30.32	5.87	39	39.9	2.26
15	30.1	29.26	2.86	36.1	37.2	2.96
20	29.3	28.40	3.17	33.7	35	3.71
30	28.7	27.88	2.96	30.6	31.9	4.08
40	28.3	27.51	2.88	28.8	29.9	3.68
	6 Hr			12 Hr		
0	46.2	46.2	0.00	46.1	46.2	0.22
5	36.35	37.91	4.12	43.6	42.01	3.78
10	32.32	33.92	4.72	40.7	39.25	3.69
15	31.16	32.44	3.95	38.2	37.4	2.14
20	30.4	31.24	2.69	36.2	35.1	3.13
30	29.48	30.28	2.64	33.1	31.49	5.11
40	28.51	29.54	3.49	31	30.64	1.17

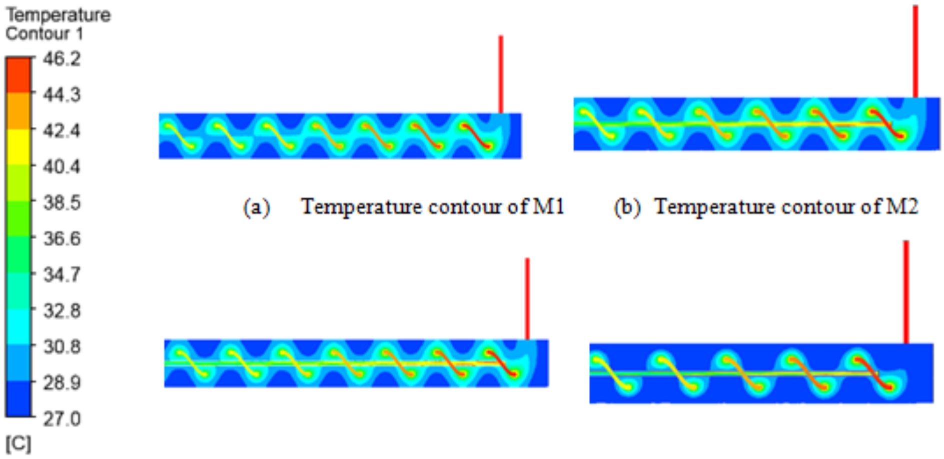


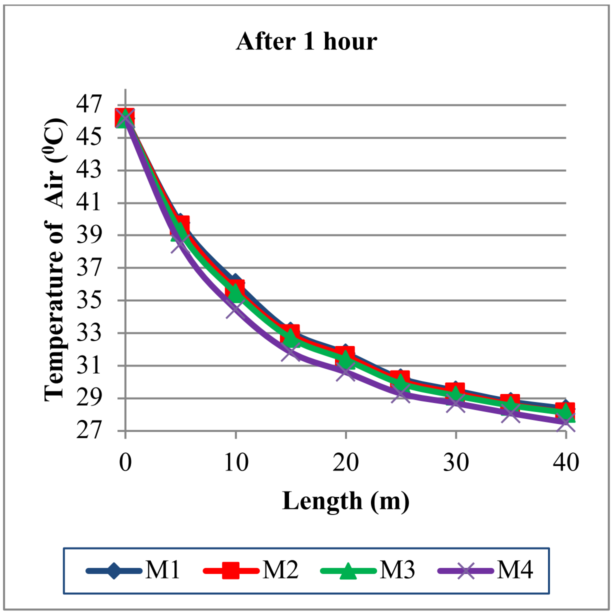
Fig. 6. Temperature distribution contour of all the models used in the analysis

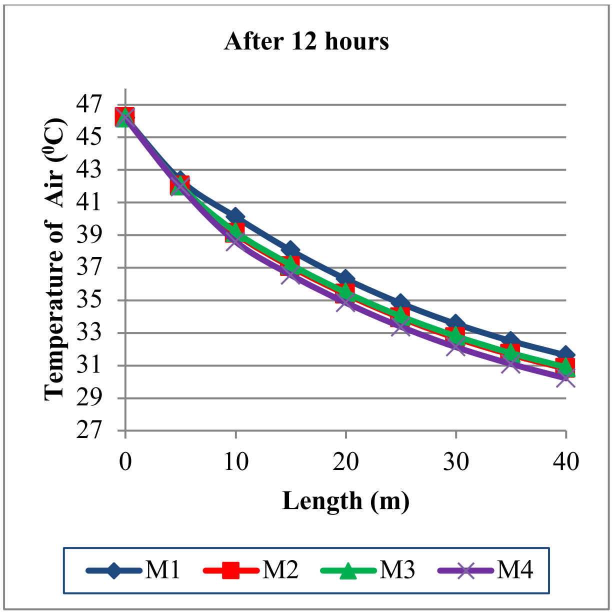
5. Result and Discussion

Four different models of EAPHE system have been considered for the CFD simulation analysis. Effect of different water pipe material on the performance of system was studied and compared with the model, without water pipe. The system was operated continously for 72 hours to observed the effectiveness of the water pipe reservoir. COP and effectiveness of all the models was compared on the basis of air outlet temperature. Hourly change in soil layer temperature and water temperature variation is also considered in the present study. Figure 6 shows the temperature contour of all the models used in the analysis i.e., M1, M2, M3, and M4.

5.1. The Hourly Temperature of Air Along the Pipe Length

Outlet air temperature of all the models were recorded at 5m interval along the length of pipe. Outlet temperature was recorded after 1 hour, 12 hours, 24 hours, 48 hours and 72 hours of continuous operation as shown in Fig. 7. After first hours of operation outlet temperature of the air is almost the same of all the models and it follows the same trend. The significant effect of the water reservoir on the thermal performance of the EAPHE was observed after 12 hours of operation. After 12 hours of operation, heat penetration approaches to the water pipe surface, and heat intraction started between water pipe and surrounded sub soil. Significant difference in air temperature can be observed after 24 hours. With inlet temperature of 46.2^{0}C, maximum temperature drop after 72 hours of operation is obtained as 11.73^{0}C, 12.18^{0}C, 12.26^{0}C and 14.55^{0}C for M1, M2, M3 and M4 respectively. The lowest air temperature was recorded for M4, which uses aluminum water pipe since the thermal conductivity of aluminum is very high compare to the PVC and clay pipe. However in all the models outlet temperature increase continously with respect to the time. Heat from the air transfer to the sub-soil layers and heat started accumulating with time, hence increase the temperature of near by soil layers. Air temperature in the case of model M4 remains almost constant after 24 hours of run time.





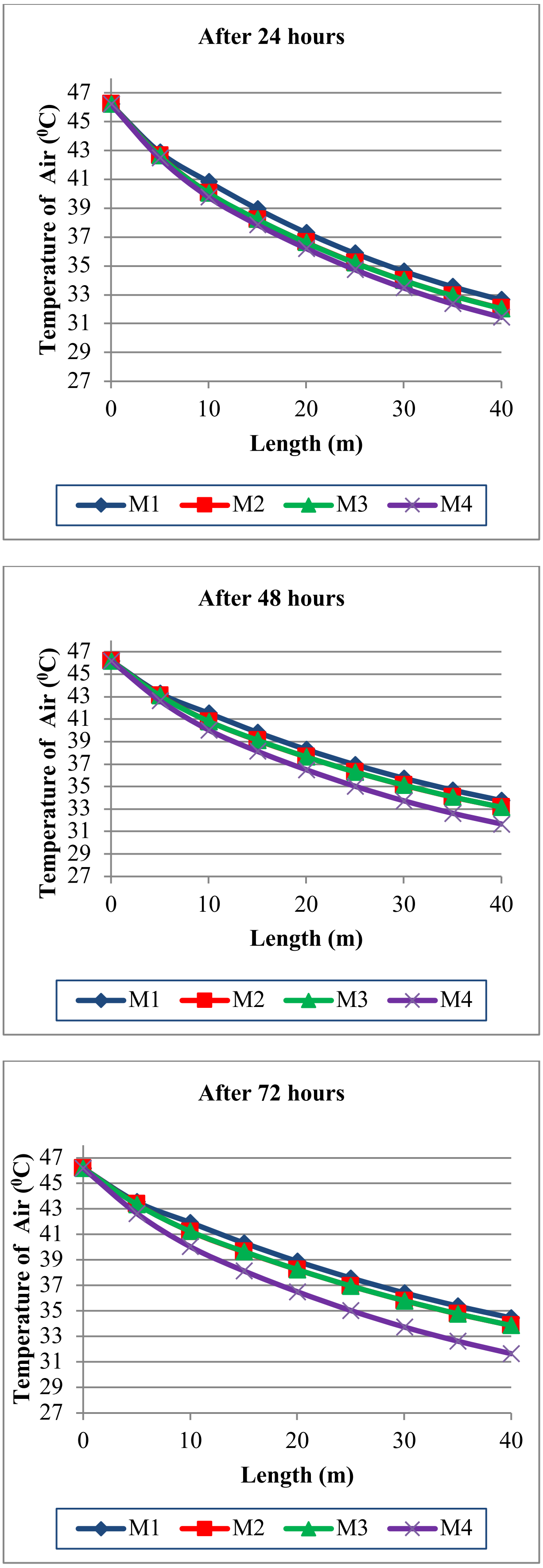


Fig. 7. Air outlet temperature variation along the length of the pipe at a different time interval

5.2. Hourly Variation in Air Temperature

Hourly variation in outlet temperature was also recorded for 72 hours operation. Table 6 shows hourly temperature variations at different time intervals considered. After first hour of operation no or minimum change in air temperature can be observed. Lower air temperatures were recorded in M4 as compared to M1, M2, and M4. Air temperature drop per unit length is almost same after first hour of operation. However air temperature drop after 72 hours of operation was obtained as 0.29^{0}C, 0.30^{0}C, 0.31^{0}C and 0.36^{0}C for M1, M2, M3 and M4 respectively. Figure 8 shows that the temperature variation of air is high till 20 hours of operation and it started decreasing after 20 hours run time for M4. A maximum temperature difference of 2.82^{0}C can be observed from model M1 after 72 hours of operation. The water tube worked as a thermal reservoir and maintains constant heat transfer after 20 hours of the run time. Almost constant air temperatures were recorded after 24 hours in the case of aluminum water tube.

Table 6. Hourly temperature variation of air flowing through a pipe at the outlet

Hours	Air Temperatures (°C)			
	M1	M2	M3	M4
1	28.66	28.31	28.12	27.5
6	30.48	30.11	29.98	29.51
12	31.53	31.00	30.89	30.21
18	32.18	31.76	31.64	31.12
24	32.64	32.22	32.04	31.4
36	33.3	32.87	32.68	31.61
48	33.77	33.34	33.24	31.64
60	34.15	33.72	33.62	31.65
72	34.47	34.04	33.94	31.65

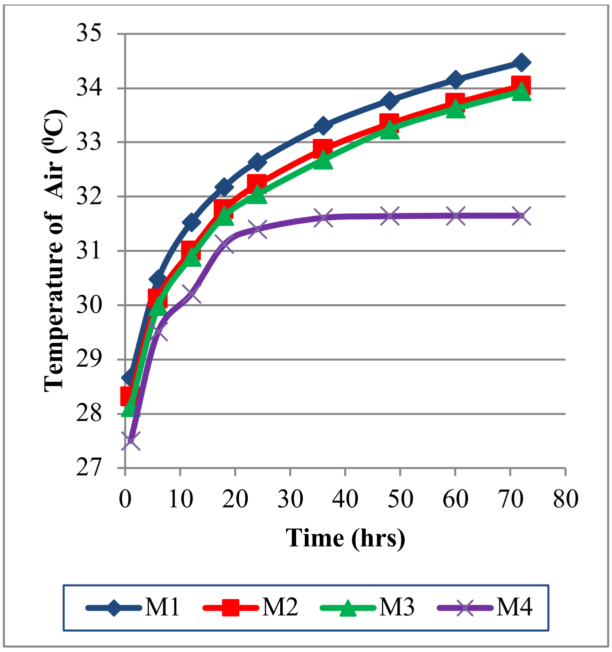


Fig. 8. Hourly outlet air temperature variation

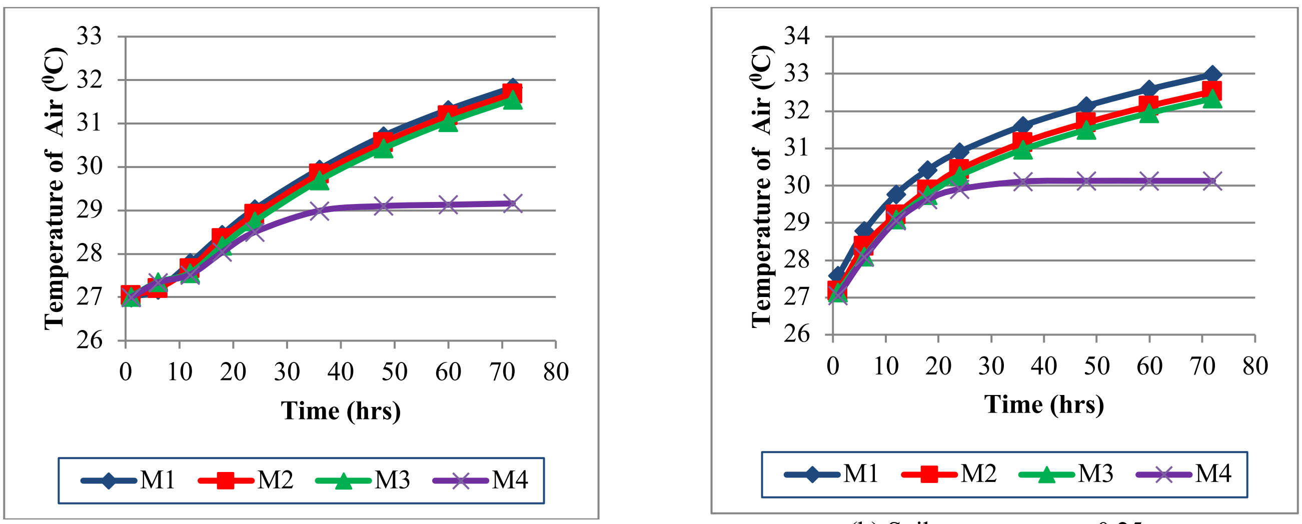
5.3. The Hourly Temperature of Soil Layers

It is observed from the simulation result that soil temperature near to the air pipe started increasing due to temperature interaction between air and surrounded soil. Maximum heat transfer takes place at the start of the air pipe due to the maximum temperature difference. Soil thermal saturation of the nearby soil is the major reason of deterioration of the EAPHE system. Heat must dissipate from the nearby soil as quickly as possible for the effective performance of the system in the long run.

Radial soil temperature was recorded at two locations, at 0.05 m and 0.25 m, from the water tube surface at 10 m from the inlet of pipe. Hourly temperature variation was recorded for 72 hours of continuous operation. Table 7 and Figure 9 shows that soil temperate is high at 0.25m, compared to the soil near to the water tube at 0.05m. A significant difference in subsoil temperature at 0.25m can be observed from Fig. 9 after 24 hours of run time. The maximum difference in soil layer temperature at 0.25m was 2.84^{0}C between model M1 and M4. Model M2 and M3 show almost the same soil temperature, but model M4 shows almost constant soil temperature after 24 hours run time, which is required for the continuous operation of the EAPHE system.

Table 7. Hourly temperature variation of soil layers at section 10 m length from inlet

Time (hour)	**Soil temperatures (°C) at various radial distances from pipe surface**							
	0.05 m				**0.25 m**			
	M1	**M2**	**M3**	**M4**	**M1**	**M2**	**M3**	**M4**
1	27	27.05	27.02	27.00	27.58	27.18	27.15	27.05
6	27.18	27.20	27.35	27.34	28.79	28.38	28.11	28.08
12	27.79	27.66	27.56	27.52	29.77	29.22	29.1	29.06
18	28.45	28.36	28.19	28.04	30.43	29.89	29.76	29.63
24	29.03	28.91	28.75	28.50	30.91	30.44	30.27	29.91
36	29.95	29.84	29.69	28.99	31.61	31.16	30.97	30.11
48	30.72	30.57	30.43	29.10	32.14	31.69	31.5	30.13
60	31.32	31.18	31.04	29.13	32.59	32.14	31.95	30.13
72	31.83	31.69	31.55	29.16	32.98	32.53	32.34	30.13



(a) Soil temperature at 0.05m (b) Soil temperature at 0.25m

Fig. 9. Hourly Soil Temperature variation at 10 m length at 0.05 m and 0.25 m radial distance respectively

5.4. Hourly Water Temperature Variation

A previous study shows that the performance of the system deteriorated after a long run because of the thermal saturation in the soil near to the pipe surface. In this study, the water pipe is used as a thermal reservoir to absorb heat from surrounded soil, which helps to run the system for the long term. Water can act as a heat reservoir because it can absorb more heat than other materials while having its temperature change by a small amount due to the highest specific heat. The effect of water pipe material was also studied by using three different water pipe materials i.e., PVC, Clay, and Aluminum in the CFD model. Results show that a small change in water temperature can be observed after 12 hours of the run. Water temperature in aluminum pipe remains almost constant after 30 hours of the run due to the highest thermal conductivity of pipe material. Table 8 shows the hourly variation of water temperature of three pipes, i.e., PVC, clay, and aluminum.Water temperature after 72 hours operation was obtained as 29.92^{0}C, 29.66^{0}C and 27.87^{0}C for M2, M3 and M4 respectively. Figure 10 shows that with the increases in time, the temperature rises for all the pipes, but M4 shows a very low rise in temperature as compared to M2 and M3.

Table 8. Average hourly temperature variation of water

Time (Hours)	**M2**	**M3**	**M4**
1	27.08	27.083	27.08
6	27.088	27.088	27.09
12	27.05	27.09	27.06
18	27.4	27.42	27.24
24	27.74	27.7	27.46
36	28.39	28.22	27.75
48	28.97	28.76	27.83
60	29.47	29.24	27.86
72	29.92	29.66	27.87

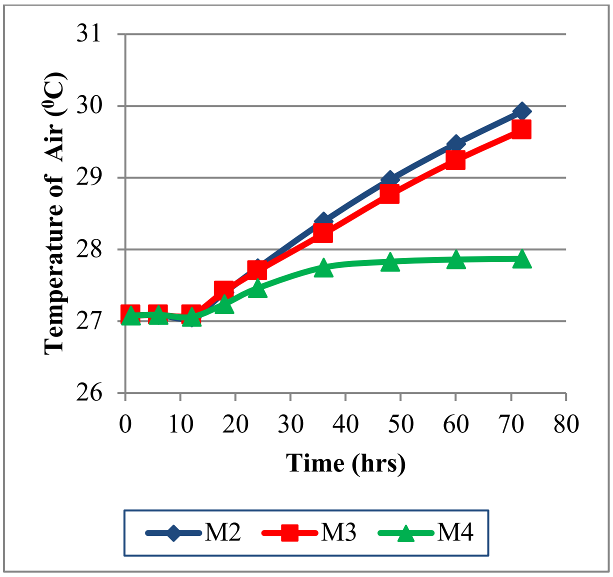


Fig. 10. Average hourly temperature variation of Water

5.5. Average Hourly Variation of COP of EAPHE System

5.5.1 Effect of Pressure Drop on Blower Power

Pressure drop was recorded during CFD analysis, and the pressure drop will be more due to the helical geometry of the pipe. Drop-in pressure is considered in this paper while calculating the blower power, taking straight 40m pipe is as a reference to calculate the extra blower power required. Table 9 shows the blower power required in a different geometry.

Table 9. Blower power required for different geometry

Pipe layout used of 40 m length	Pressure drop(Pa)	Blower power required
Straight pipe	139	120W (Mathur et al., 2016)
Helical pipe (present study)	379	130W

Extra blower input power required = A.V. (Difference in pressure drop with respect to straight pipe)

Where A = Cross-sectional are of air pipe in m^2 and V= Velocity of air in m/s

$$Heat\ Transfer\ Rate\ (Q) = \dot{m}C_p(T_{inlet} - T_{outlet}) \quad (7)$$

$$COP = \frac{Q}{W} \quad [33] \quad (8)$$

$$COP = \frac{\dot{m}C_p(T_{inlet} - T_{outlet})}{W} \quad (9)$$

Where $\dot{m}$, mass flow rate of air through the pipe = 0.048 kg/s; cp =specific heat of air = 1005 J kg^{-1} K^{-1}; T_{inlet}, T_{Outlet}, is inlet & outlet temperature of the air, W is theoretical blower input power = 130W.

Table 10. Comparative performance analysis of previous research.

S. No	Readings	References
1	COP's were recorded as 5.94 and 6.24 in summer; and 1.92 and 2.11 in winter for straight and spiral respectively	[36]
2	3.78	[27]
3	4.57	[42]
4	3.2	[43]
5	3.35.	[44]
6	4.23	[45]
7	4.20	[23]

Table 10 shows the comparative COP of published work by researcher. In present model COP was calculated at different time intervals, which has been presented in Table 11 for all the proposed model. Figure 11 shows the variation of COP is high initially and after 20 hours of continuous operation the M4 shows higher COP because the outlet temperature is low as compared to other cases. Table 11 also shows the percentage change in COP compare to the model M1. Chnage in COP was calculated as 19.36% of M4.

Table 11. Hourly COP variation of air flowing through a pipe at outlet

Hours	Hourly COP variation				% Change in COP w.r.t M1		
	M1	M2	M3	M4	M2	M3	M4
1	6.42	6.54	6.61	6.84	1.83%	2.87%	6.14%
6	5.75	5.89	5.93	6.11	2.38%	3.04%	5.89%
12	5.37	5.56	5.60	5.85	3.42%	4.11%	8.21%
18	5.13	5.28	5.33	5.52	2.84%	3.75%	7.07%
24	4.96	5.11	5.18	5.41	2.94%	4.25%	8.32%
36	4.72	4.88	4.95	5.34	3.28%	4.65%	11.61%
48	4.55	4.70	4.74	5.33	3.19%	4.01%	14.63%
60	4.41	4.57	4.60	5.32	3.50%	4.13%	17.11%
72	4.29	4.45	4.48	5.32	3.60%	4.24%	19.36%

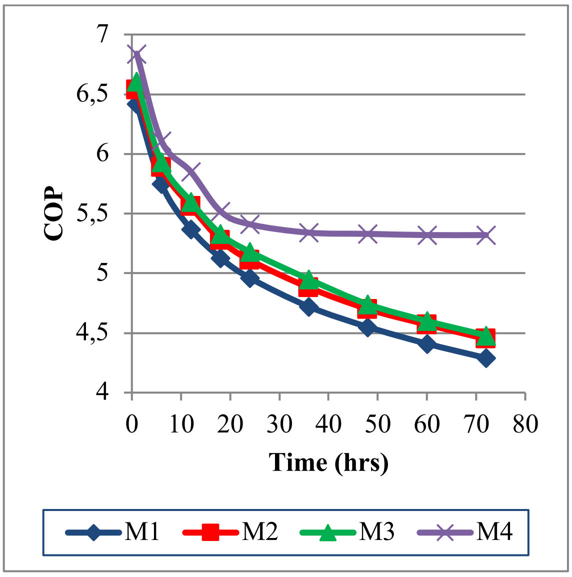


Fig. 11. Hourly COP variation

5.6. Comparison of SUF of Various EAPHE System with Previous Research

A common configuration of EAPHE usually considers single or U shaped configuration, which requires a large installation area and is not suitable under a small home or office setup, this major drawback can be overcome by using a helically shaped air pipe, which reduces the installation area up to 60%. Usually, in such systems, the COP of the system reduces due to extra blower power required because of more pressure loss in the case of helical pipe. Loss of COP can be neglected as compared to the saving in the installation area. COP of the system is directly proportional to the length of the air pipe. Greater length of the air pipe requires large installation area. To understand the relation between the COP of the system and the installation area, this paper introduces a space utilization factor (SUF). SUF is the ratio of COP of the system to the minimum installation area required. The SUF is also calculated and compared with the previous model used by the researcher, further describing the difference in major performance. Table 12 also shows that SUF of the present model is very high because of the significant reduction in the installation area. The installation area is calculated by multiplying the pipe length to the minimum digging width required. The minimum digging width is assumed 1m and 2m for the straight pipe and U-shaped pipe, respectively, as shown in Fig. 12.

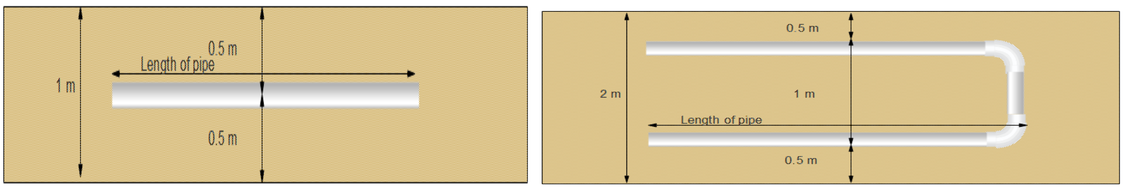


Fig. 12. A common configuration of straight and U shaped pipe

Table 12. Average hourly temperature variation of Water

		Minimum installation area required in m^2.	SUF=Average COP of the system per unit space occupied. (COP/Minimum Installation Area)					
			12 hrs	24 hrs	36 hrs	48 hrs	60 hrs	72 hrs
Present Model	Normal	22	0.27	0.26	0.26	0.25	0.25	0.25
	PVC	22	0.27	0.26	0.26	0.26	0.25	0.25
	Clay	22	0.27	0.26	0.26	0.25	0.25	0.25
	Aluminum	22	0.28	0.27	0.27	0.27	0.26	0.26
Previous Models	[23]	40	0.07	-	-	-	-	-
	[27]	60	0.0945	-	-	-	-	-
	[36]	53	0.118	-	-	-	-	-
	[26]	60	0.062	-	-	-	-	-
	[46]	46.84	0.062	-	-	-	-	-
	[47]	37	0.173	-	-	-	-	-

5.7. Effectiveness Variation of System

The effectiveness of the EAPHE system can be defined as the ratio of actual heat transfer to the maximum possible heat transfer of the system. According to equation 10.

$$\varepsilon = (Ti - T2)/(Ti - Tmin), \qquad (10)$$

where ε is the effectiveness of the EAPHE system, Ti is the inlet temperature of air (46.2^{0}C), T_2 is the temperature of outlet air, and T_{min} is the minimum air outlet temperature can be recorded (27^{0}C). The effectiveness of the system is calculated on an hourly basis for different pipe material. Table 13 represents the hourly effectiveness of all the models; model M4 shows constant effectiveness as 0.757 after 18 hours run.

Table 13. Hourly Effectiveness variation of the system

Hours	**Effectiveness in different Pipe material**			
	M1	**M2**	**M3**	**M4**
1	0.91	0.93	0.94	0.97
6	0.82	0.84	0.84	0.87
12	0.76	0.79	0.80	0.83
18	0.73	0.75	0.76	0.79
24	0.71	0.73	0.74	0.77
36	0.67	0.69	0.70	0.76
48	0.65	0.67	0.68	0.76
60	0.63	0.65	0.66	0.76
72	0.61	0.63	0.64	0.76

6. Conclusion

Present paper investigates helical shaped EAPHE system for the optimum use of installation area. Four models were developed, namely M1, M2, M3, and M4 using water pipe and without water pipe. The proposed model has been validated by the previously published numerical solution. In the present paper to study the effect of water pipe material on the performance of system, three commonly used pipe materials has been considered. Different water pipe material having different thermal properties have chosen for the comparative study. A significant effect of pipe material on the performance of the system is observed. Due to the high thermal conductivity of aluminum pipe, it exchanges the heat at a fast rate between water and nearby soil and constant outlet temperature can be observed after 24 hours of operation. The proposed model can be used in common household and small office setup. In the future, the effect of different operating parameters like the pitch of the helical pipe, water pipe diameter, air pipe diameter, and air velocity must be considered to further minimize the installation area required. The following main conclusion was observed.

- Performance of EAPHE of model M2, M3, and M4 was very close to each other up to 12hrs of continuous operation. After 12 hrs of operation, model M4 shows better results because of the high thermal conductivity of pipe material. Maximum heat transfer takes place in the initial 30m air pipe. In the first hour, 61.5%, 83.5%, and

94.5% heat is removed in 10m, 20m, and 30m pipe length, respectively.

- A temperature drop of 0.43^0C, 0.53^0C, and 2.82^0C were recorded after 72hours of a run of the models M2, M3, and M4 respectively, compared to the M1.

- Soil temperature was recorded at 0.05 m and 0.25 m from the water pipe surface. The maximum temperature is found near the air pipe at 0.25m, which is near to the air pipe. A temperature difference of 1.5-2^0C has been observed between two layers at 0.05m and 0.25m. A soil temperature of model M4 remains constant after 24 hours run time.

- Water works as a thermal reservoir after 12 hours of the run when the heat approaches near to the pipe surface. Change in water temperature recorded after 12 hours and model M4 shows constant thermal performance even after 24 hrs run. Water temperature increases by 1.87^0C after 72hours continuous run, it shows constant value after 48 hours run time.

- A helically shaped air pipe was studied to minimize the installation area. The space utilization factor is calculated for all the models and compared to the previous model. SUF is found constant as 0.25-0.26 after 72hrs run, whereas SUF for the previous model is calculated as 0.15 for the same 40m long pipe.
- COP and effectiveness of the system are very high in initial hours of run time; after that, it starts deteriorated due to the rise in temperature of the surrounding soil. Constant COP of the system i.e., 5.33, can be observed after 36hours of run time for M4. The model with aluminum water pipe shows constant effectiveness as 0.76 after 36 hrs run.

It is worth to note that, the CFD simulation is based upon assumption before analysis. In practical approach it is not possible to bring the system as per the assumption made, since there will be error in the result. We can minimise the error by bringing the system close to the assumtion made. Researcher can use shading to minimize the effect of sun heat, use of blower heater to maintain constant inlet temperature, soil should be packed perfectly to be in close contact.

It is imprtant to mention that fabrication and installation of helical pipe is difficult compare to horizontal layout, also initial cost of model M4 is high due to aluminium pipe.

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