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EVALUATING THE INFLUENCE OF SOME DESIGN AND ENVIRONMENTAL PARAMETERS ON THE PERFORMANCE OF EARTH TO AIR HEAT EXCHANGER

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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 for Nasiriyah city in southern of Iraq. 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 analyzed with ranges of air velocity, inlet temperature and pipe length of 50 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.

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

تقييم تأثير بعض العوامل التصميمية والمحيطية على ألاداء العام للمبادل الحراري الارضي

الخلاصة: المبادل الحراري الارضي تقنية فعالة لتبريد وتدفئة المباني الصناعية والسكنية من خلال الاعتماد على طاقة باطن الارض. هذه الدراسة توضح عدديا تأثير بعض العوامل التصميمية واالمحيطية (المحتوى الرطوبي للتربة، مادة صنع الانبوب وسمك جدار الانبوب) على ألأداء العام للمبادل ألحراري ألارضي. تمت الدراسة بأستخدام ثلاثة أنواع من التربة (تربة جافة ، تربة رطبة وتربة مشبعة) اضافة الى مادتين من مادة صنع الانبوب البلاستيك والحديد وثلاث اسماك مختلفة لجدار الانبوب (2, 3 and 6 mm) هذه الدراسة تمت لموسمي الصيف والشتاء تحت تأثير الظروف المناخية لمدينة الناصرية في جنوب العراق. قبل بدء الدراسة تم التأكد من صحة بناء النموذج من خلال المقارنة مع دراسة عملية سابقة وقد اظهرت النتائج توافق كبير. بعد ذلك تمت دراسة الاداء العام للمبادل الحراري الارضي باستخدام انبوب بطول 50 m مع سرع مختلفة لجريان الهواء ودرجات حرارة مختلفة لدخول الهواء وقد اظهرت النتائج النظرية التي تم الحصول عليها باستخدام ميكانيكية الموائع الحسابية ان التربة المشبعة تعطي أفضل اداء شامل للمبادل الحراري الارضي.

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1. 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.

Several researchers have described the earth to air heat exchangers (EAHE) coupled with buildings as an effective passive energy source for cooling and heating spaces such as:

Clara et al (2013) [1] presented a study to discusses the affected of comprehensive performance of EAHE system by the soil, climate and soil consumption. They noted from their results that the wet surface for cooling purpose is suitable for the cooling, also they found that the performance of EAHE system enhanced with increasing the moisture content of soil. Ramírez-Dávila et al (2014) [2] showed a numerical analysis of conjugate heat transfer between the soil and pipe for three regions in México. They concluded that the use of EAHE system is suitable for heating and cooling of buildings in regions where the thermal inertia effect in soil is higher. Ahmed et al (2016) [3] presented an experimental and numerical investigation about the thermal performance of EAHE system under Egyptian weather conditions with different parameters (pipe diameter, pipe length pipe space and pipe material). The results obtained by using CFD showed that the outlet air temperature enhances with decreasing diameter, decreasing flow rate and increasing pipe length. Furthermore they found that the change in outlet air temperature for various pipe materials is less and can be neglected compared with their prices. Anuj Mathur et al (2016) [4] discussed numerically the problem of accumulation of heat near the pipe throw summer season with soil having high specific heat and low moisture content. They showed that the saturation of soil by heat impedes the performance of EAHE system and it can be enhanced by running the system in winter days. Mohamed Khabbaz et al (2016) [5] presented a numerical and experimental study of an EAHE connected to residential building in Morocco. Their experimental results showed that EAHE is a good semi-passive system for air refreshment, as the recorded blown air temperature into the building is constant at 25◦C 40% air humidity, even though the outside temperature reaches more than 40◦C.

In this paper the effect of moist content of soil, pipe material and wall thickness of pipe on the overall performance of EAHE system will be studied numerically under the climatic conditions of Nasiriyah city in south of Iraq, which considered one of most hot spots around the world.

2. Problem Description

The model studied in this paper is 3D EAHE system buried at depth of 3 m underground surface with inner pipe diameter of 4in (0.1016 m) and length of 50 m.

Figure (1) shows the pipe of EAHE with thickness of disturbed soil.

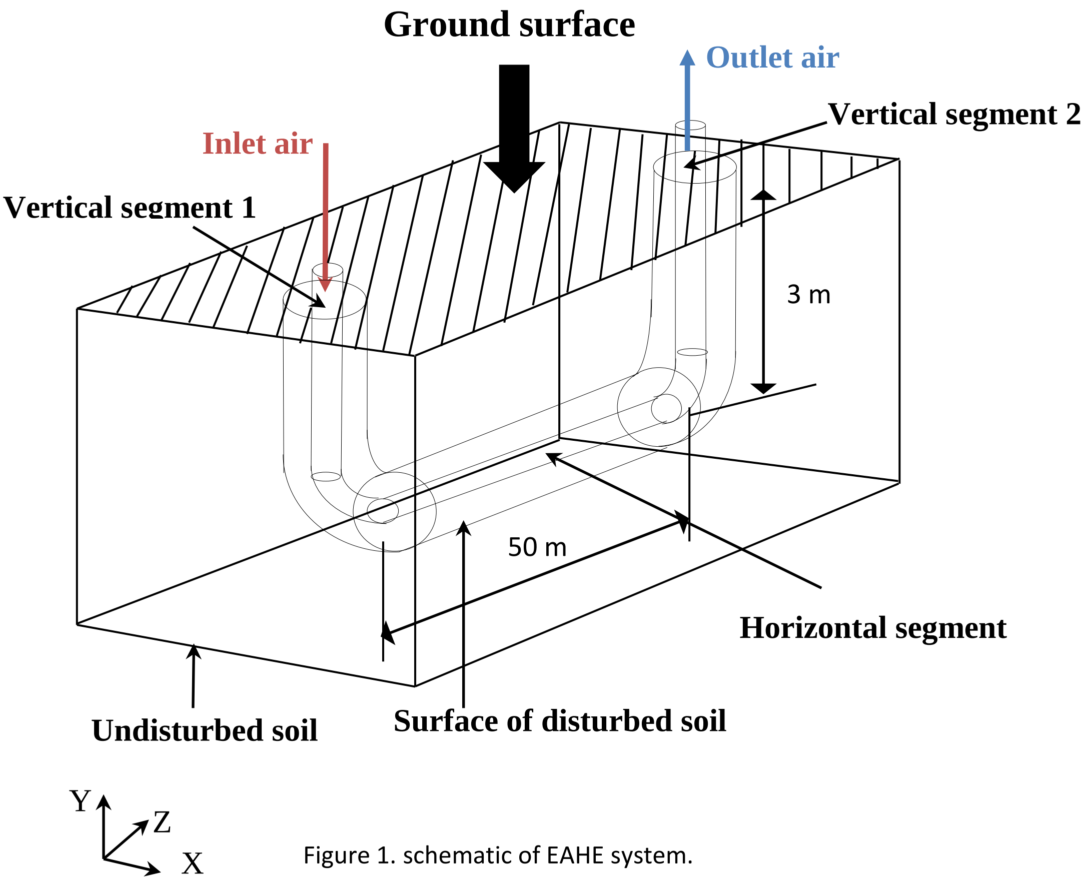


Figure 1. schematic of EAHE system.

2.1. Disturbed Soil

The soil layer near surface of EAHE channel is affeced by heat transfer and this soil called thermally disturbed soil. There is no rule to calculate the thickness of disturbred soil, some researchers propesed that the thickness of disturbed soil equaled to the pipe radius [6], twice of pipe diameter [7], four times of pipe radius [8], and 10 times of pipe diameter [9], furthermore some studies found out that the effect of disturbed soil on performance of EAHE system can be deccreased by running the system in summer and winter seasons [4]. In this paper the thickness of disturbed soil is equale to four times of pipe radiuse as used by [8].

The previously studies and testes for Nasiriya's soil which carred out by the engineering consultation bearue 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 [10]. The pipe materials were selected for study are steel and PVC which are available in the local market. The wall thicnesses studied were (2, 3 and 6 mm) which are selected according to the standard thickness of 4 in pipe diameter.

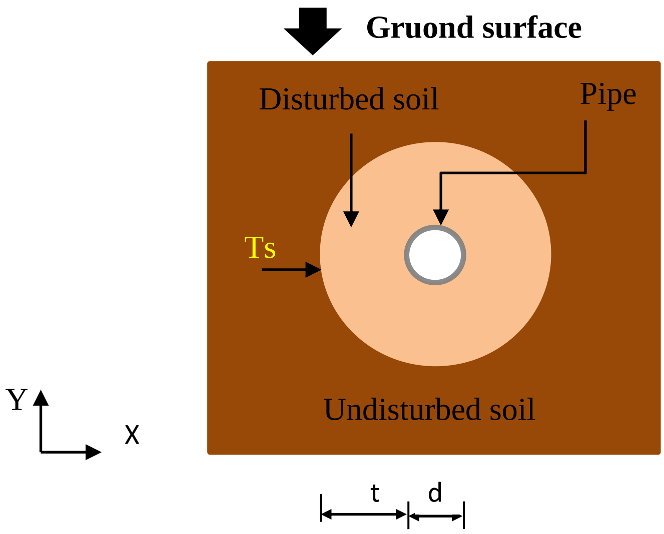


Figure 2. Cross sections of EAHE pipe with thickness of disturbed soil

3. Mathematical Model

The following assumptions were made during the development of mathematical model [9]:

1- Steady state.
2- The velocity of flow is constant and uniform.
3- The soil is homogeneous and physical properties are constant.
4- The fluid is incompressible with constant specific heat, density and thermal conductivity.
5- There exists a perfect contact between the tube and the soil.

3.1 Governing Equations

The following equations of fluid flow and heat transfer are used in this analysis [11].

Continuity equation:

$$\text{div}\,\overline{V} = 0 \qquad (1)$$

Momentum equations:

x.....dir.

$$\frac{\partial \overline{u}}{\partial t} + \mathrm{div}\left(\overline{u}\,\overline{V}\right) + \mathrm{div}\left(\overline{u'\,V'}\right) = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{x}} + \nu\,\mathrm{div}\left(\mathrm{grad}\left(\overline{u}\right)\right) \quad (2)$$

y......dir.

$$\frac{\partial \overline{v}}{\partial t} + \mathrm{div}\left(\overline{v}\,\overline{V}\right) + \mathrm{div}\left(\overline{v'\,V'}\right) = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{y}} + \nu\,\mathrm{div}\left(\mathrm{grad}\left(\overline{v}\right)\right) \quad (3)$$

z.....dir.

$$\frac{\partial \overline{w}}{\partial t} + \mathrm{div}\left(\overline{w}\,\overline{V}\right) + \mathrm{div}\left(\overline{w'\,V'}\right) = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{w}} + \nu\,\mathrm{div}\left(\mathrm{grad}\left(\overline{w}\right)\right) \quad (4)$$

Energy equation:

$$\frac{\partial U\tilde{T}}{\partial x} + \frac{\partial V\tilde{T}}{\partial y} + \frac{\partial W\tilde{T}}{\partial z} = \frac{k}{\rho\,cp}\left(\frac{\partial}{\partial x}\left(\frac{\partial \tilde{T}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial \tilde{T}}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial \tilde{T}}{\partial z}\right)\right) \quad (5)$$

For determining the overall performance of EAHE system the performance factor (η*) is used which represents the ratio of heat transfer rate between air and soil to the pumping power required [12], [13], [14].

$$\eta* = \frac{Q}{P.P} \quad (6)$$

Where:

$$Q = \dot{m}Cp\Delta T \quad (7)$$

$$Q = h\,A\,(Tb - T_{w}) \quad (8)$$

$$P.P = \dot{v}\Delta P \quad (9)$$

Pressure drop: is the total difference in pressure between inlet section and outlet section of the channel of EAHE.

$$\Delta P = Pi - Po \quad (10)$$

$$Re = \frac{\rho\,w\,D}{\mu} \quad (11)$$

$$Nu = \frac{h\,D}{k} \quad (12)$$

3.2. Boundary Conditions

The following boundary conditions were used to complete the model:

At inlet section of EAHE pipe the constant air velocity and constant inlet dry-bulb temperature (Tin) were used with subsonic and turbulent flow. The values of (Tin) which used as B.C were selected a according to the Nasiriya city in south of Iraq for summer and winter seasons [15].

At outlet the relative pressure was taken equal to the atmospheric pressure.

At walls: the horizontal segment of EAHE pipe is in thermal contact with thickness of disturbed soil as in fig (1), therefore its boundary condition used as conjugate heat transfer. At the outer surface of disturbed soil with distance (t = 0.2032 m) from pipe wall, the temperature is constant and equal to (Ts = 26.3˚C) which correspond to the temperature of undisturbed soil which was measured experimentally at depth of 3 m in south of Iraq [16].

The two vertical segments were assumed thermally insulated because the gradients in temperature of air for both of them (inlet and outlet) are equal and cancel each other so its assumed insulated to simplify the numerical solution [4].

4. Numerical Solution

The above system of governing equations and boundary conditions are numerically solved using finite volume method. The flow is developing and the 3D continuity and 3D Navier stock equations are solved by using computational fluid dynamics modeling.

4.1. CFD Modeling

Presently, computational fluid dynamics (CFD) is very popular for modeling and performance analysis of EAHE systems [16]. The purpose of using CFD is to find out the behavers of air in EAHE pipe for a given set of boundary conditions. To predict the turbulence inside the pipe, simple k–ε model with standard wall treatment is selected as turbulent model and energy equation is also solved since the computations included heat transfer. From CFD modeling the values of air flow characteristics can be obtained at large number of points in the EAHE system. These points are generally connected together in the form of numerical grid or mesh. $1 *10^{-6}$ is used as the value for convergence criteria for momentum and energy equations.

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 3 is used for all calculations.

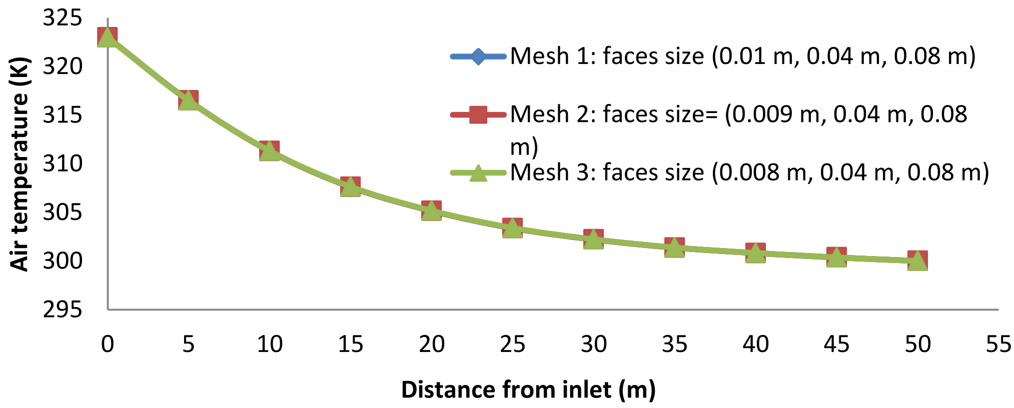


Figure 3. Grid independent test.

5. Results and Discussions

To check the validity of the built numerical model, a verification was made by solving the experimental and theoretical model presented in [17] and [18] respectively. The same experimental and theoretical models which are presented in [17] and [18] represent a EAHE system consists of a pipe with 0.1016 m diameter, 19.228 m length and 2 m depth of burial.

"Fig. 4", shows the comparison between the simulation results of present model with the experimental and simulation results of [17] and [18] 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 [17] and [18] respectively is acceptable with the average error of 5.1% and 2.75% between the simulation result of present model and the experimental model of [17] and simulation result of [18] respectively. Therefore the present numerical model is reliable and can be used with adequate accuracy.

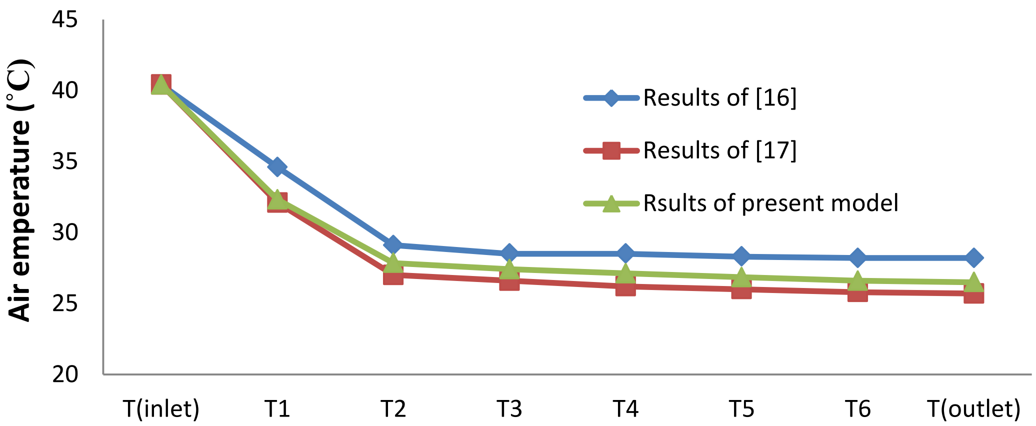


Figure 4. Distribution air temperature along length of EAHE pipe as a comparison between present model with experimental results of [28] and simulation results of [29] at air velocity of 3.5 m/s.

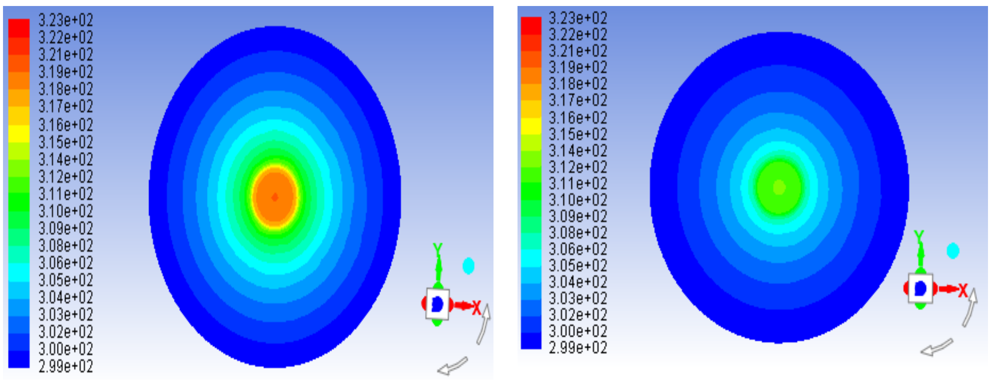
The thermal and physical properties of air and soil are assumed constant and their values are given in table (2).

All simulation results which showed the effect of soil were carried out with PVC as a pipe material and 2 mm wall thickness. The simulation results of EAHE system when it is operating as a cooling system for summer seasons are presented in figures (5-15) and the results of heating are illustrated in figures (16-18).

The air temperature distribution through a temperature contours on longitudinal (x-y) plane at two distances from inlet pipe (z=5 m and z =15 m) with Reynold number of 20866.212 and inlet air temperature of 50 ˚C illustrated in "Fig. 5",. 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 and this amount of heat transfer is higher at first meters from inlet section and decreased with increasing distance from inlet. Also 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.

Table 2. The thermal and physical properties of the materials [11] [16].

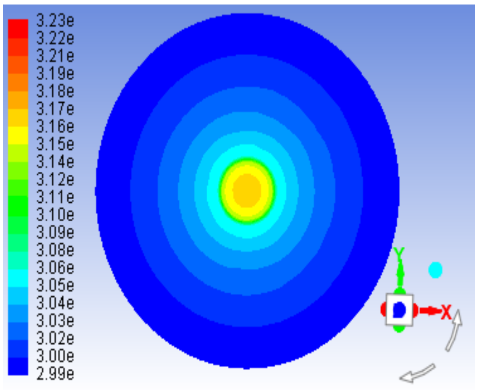
Material	Density (kg/m^3)	Specific heat (J/kg.˚C)	Thermal conductivity (W/m.˚C)
Air	1.225	1006.5	0.0242
Dry soil	2050	1840	0.52
Moist soil	1470	1553	1
Saturated soil	1500	880	1.4
PVC	1380	900	0.16
Steel	7833	465	54



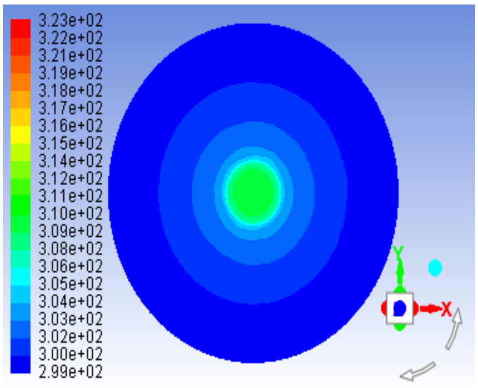
a. Dry soil (5 m from inlet)

b. Dry soil (15 m from inlet)

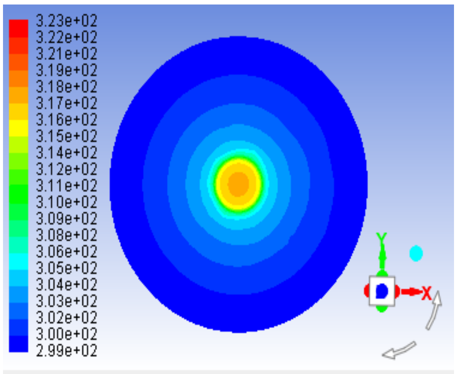
Figure 5. Cross section of temperature contour (K) of EAHE pipe and disturbed soil for all studied soil at distance 5 and 15 m from inlet.



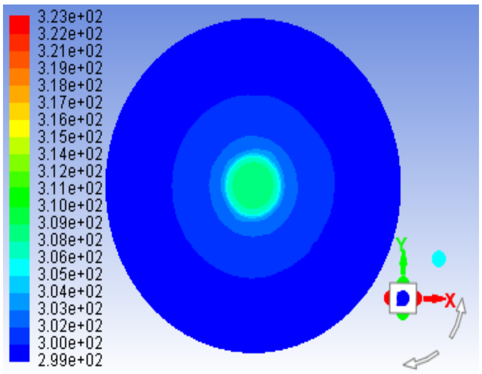
c. Moist soil (5 m from inlet)



d. Moist soil (15 m from inlet)



e. Saturated soil (5 m from inlet)



f. Saturated soil (15 m from inlet)

Figure 5. Continuous.

The variation of outlet air temperature (To) with Reynolds number for all studied soil at inlet air temperature of 50 ˚C is presented in "Fig. 6",. First from this figure it can be seen that for all studied soils the outlet air temperature increased with increasing Reynolds number due to increasing velocity of air flow and this lead to decrease residence time of heat transfer rate between air and soil. Also it can be noted the effect of soil on the outlet air temperature, where the outlet temperature decreased with increasing moisture content of soil, so the saturated soil gives the minimum outlet air temperature then moist soil and finally dry soil and the cause of this is that with increasing moisture the thermal conductivity of soil increased and this leads to increase the heat transfer rate.

"Fig. 7", illustrates the variation of pressure drop (Δp) with Reynolds number at inlet air temperature of 50˚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.

"Fig. 8", indicates the variation of performance factor with Reynolds number for all studied soils at inlet air temperature of 50˚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.

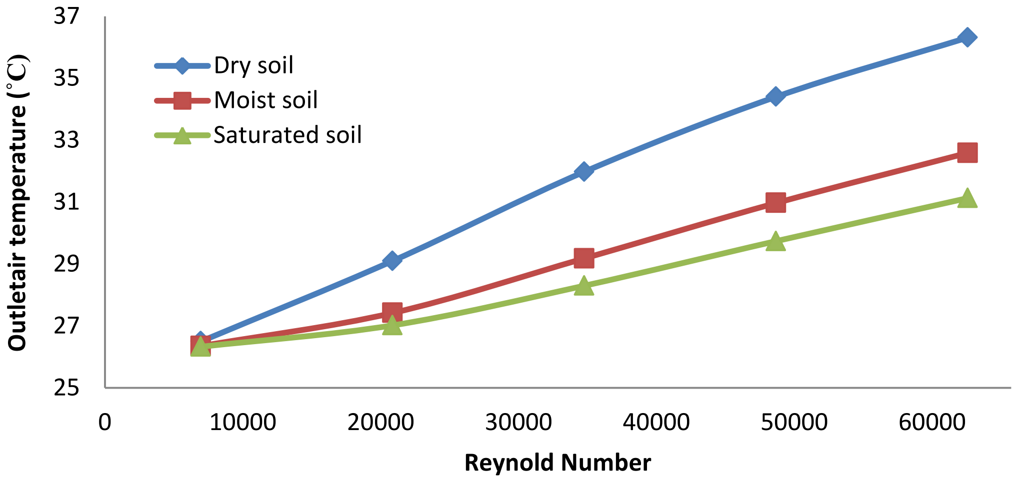


Fig. 6 variation of the outlet air temperature of EAHE system with Reynold number for all studied soils at inlet temperature of 50˚C.

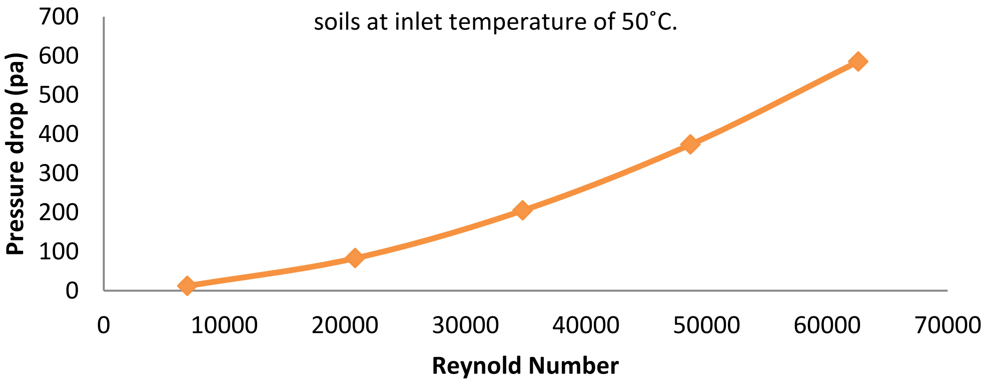


Figure 7. The variation of the pressure drop of EAHE system with Reynold. nomber.

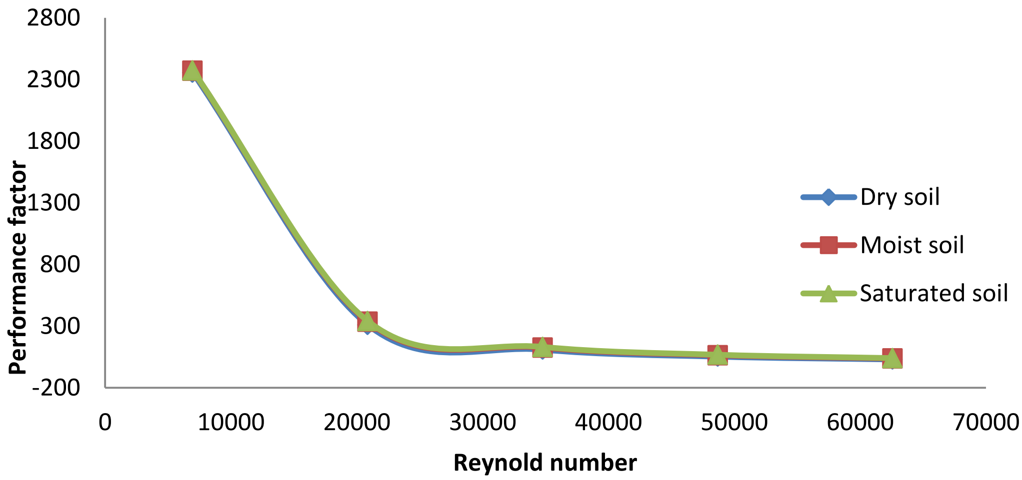


Figure 8. The variation of performance factor with Reynold number for all studied soils at inlet temperature of 50˚C.

The variation of outlet air temperature with inlet air temperature for all studied soils with Reynold number of 20866.212 is illustrated in "Fig. 9",. From this figure it is easy to see that the outlet air temperature grown with increasing inlet air temperature. Also it seems from this figure that the outlet air temperature enhanced and declined with increasing moist of soil, so the saturated soil has the minimum outlet air temperature then the moist soil and finally the dry soil due to increasing of the amount of heat transfer from air to the soil, where the saturated soil has the lower thermal resistance because it has higher thermal conductivity compare with the moist and dry soil.

"Fig. 10", shows the variation of performance factor with inlet air temperature for all studied soils at Reynold number of 20866.212. First it is observed that the performance factor increased with increasing inlet temperature due to increasing rate of heat transfer with increasing inlet temperature. Also it can be noted that the saturated soil gives the huge performance factor of EAHE system then the moist soil and finally the dry soil, where the thermal conductivity increased with increasing moisture of soil therefore the thermal resistance decrease and the amount of heat transfer from air to soil increased. This indicate that, the efficiency of using increased when inlet temperature increased.

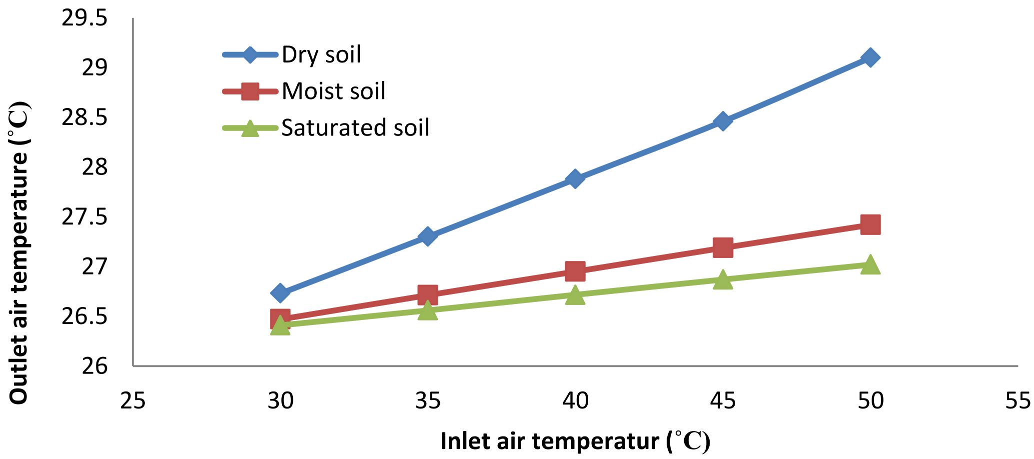


Figure 9. Outlet air temperature of EAHE system under different inlet air temperature conditions for all studied soils at Reynold Number of 20866.212.

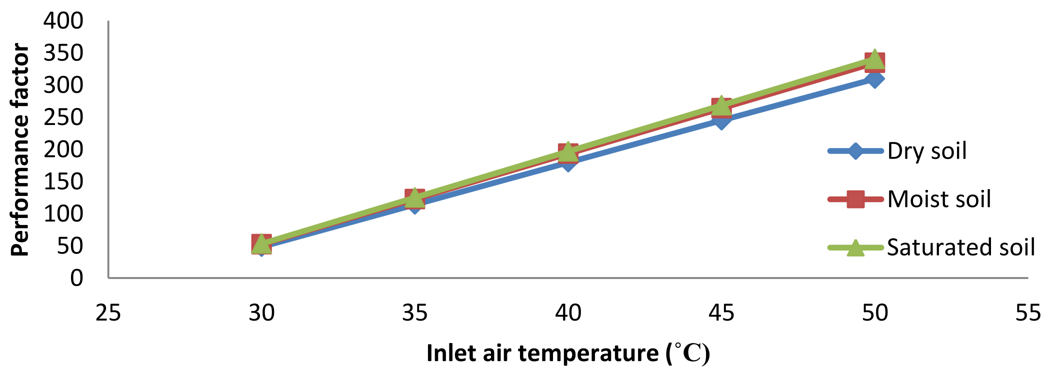


Figure 10. Performance factor of EAHE system under different inlet air temperature conditions for all studied soils at Reynold Number of 20866.212.

The variation of local air temperature along the length of EAHE at Reynold number of 20866.212 and DBT 50˚C for all studied soils is shown in "Fig. 11",. From this figure it can be seen that for all studied soils that the local air temperature decreases along flow direction, where with increasing the pipe length, the air takes enough time to exchange thermal energy with surrounding soil. Also it can be seen that the local air temperature declined with increasing moist of soil, where the saturated soil gives the lower air temperature along pipe compared with moist and dry soil, and the cause of this that the saturated soil has low thermal resistance, so it is more suitable for using compare with the other soils.

"Fig. 12", shows the variation of the pressure drop with respect to inlet ($\Delta P=P_L-P_{in}$) along EAHE pipe at Reynold number of 20866.212 and constant inlet temperature of 50 ˚C. It can be noted that the pressure drop increased along flow direction due to increasing the losses and the pressure drop is proportional with pipe length.

"Fig. 13", illustrates the variation of heat transfer rate along EAHE pipe for studied soils at constant Reynold number of 20866.212 and inlet air temperature of 50˚C where heat transfer rate is calculated up to specified section [$Q=\dot{m}\ cp\ (T_{in}-T_L)$] to focous on EAHE pipe length. It seems from this figure that the amount of heat transfer grown along flow direction due to increasing the temperature drop (ΔT). Also this figure reveal that the amount of heat transfers with using saturated soil is higher than that for moist and dry soil due to increasing the ability of soil to absorb heat with increasing the moisture due to increasing of the thermal conductivity. Also the differce in the value of heat transfer between different soils decreased with length.

"Fig. 14", presents the variation of performance along length of EAHE at Reynold number of 20866.212 and inlet air temperature of 50˚C. From this figure it can be seen that for all studied soils the performance factor increased along flow direction until reach the maximum value at certain length then begins to decrease for the remaining length and this occurs due to the large increased in pressure drop with mild increasing in temperature difference after the specified value of pipe length. Also this figure show the difference in performance factor from soil to another, where the maximum value of performance factor can be obtained from saturated soil then moist soil and finally dry soil, from this it can be concluded that, the overall performance of EAHE system improved with increasing the moisture of soil.

To investigate the ability of reduction in the EAHE length, a specified value of heat transfer rate (Q = 617.804 W) has been selected and different soils have been tried with this heat rate and the required length which gives tis heat amount corresponding to the selected soil calculated. The length of 50 m correspond to the pipe with dry soil has been selected as a base value for calculation.

The reduction in length of EAHE pipe $L.R = ((L_o - L / L_o)*100\%)$ for all studied soils with 617.804 W, as an amount of heat transfer is shown in "Fig. 15",. From this figure it can be observed that the reduction in length to obtain (617.804 W) as an amount of heat transfer rate from air to the surrounding soil decreased with increasing moisture of soil, for the same amount of heat transfer for all studied soils the reduction in length is about 38.33%, 28.82% for saturated, moist and dry respectively compared with dry soil of length 50 m which indicates increasing in reduction of length with increasing in the moisture of soil, so this amount of heat transfer rate can be obtained with 30.835 m, 35.6 m and 50 m length of pipe for saturated, moist and dry soils respectively, so the saturated soil is suitable since it requires minimum length and this occurs due to the effect of thermal conductivity, where the saturated soil has higher thermal conductivity.

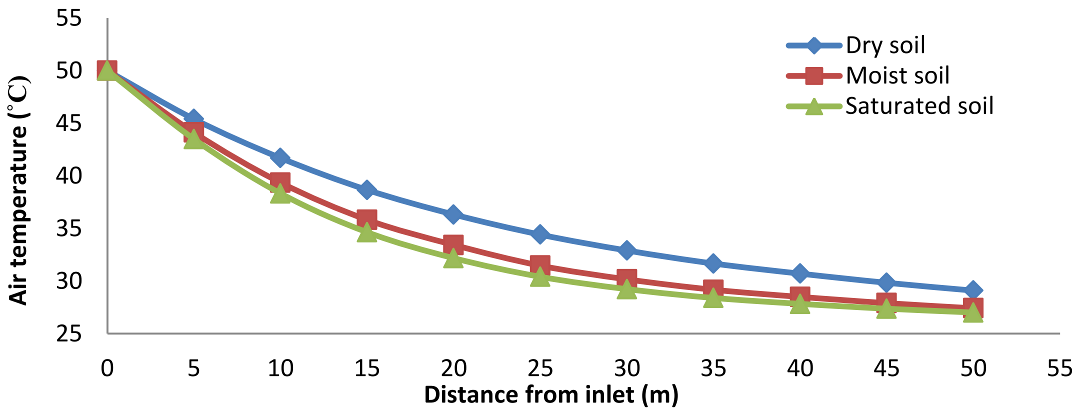


Figure 11. Distribution of air temperature along length of EAHE pipe for all studied soils at Reynold Number of 20866.212 and inlet air temperature of 50˚C.

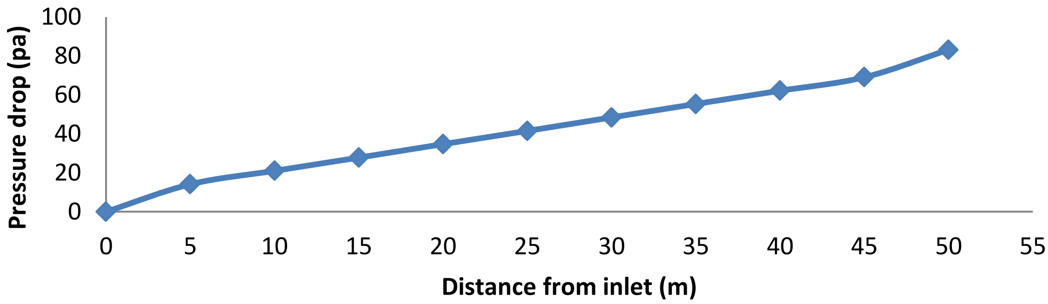


Figure 12. Pressure drop along length of EAHE pipe for all studied soils at Reynold Number of 20866.212 and inlet air temperature of 50˚C.

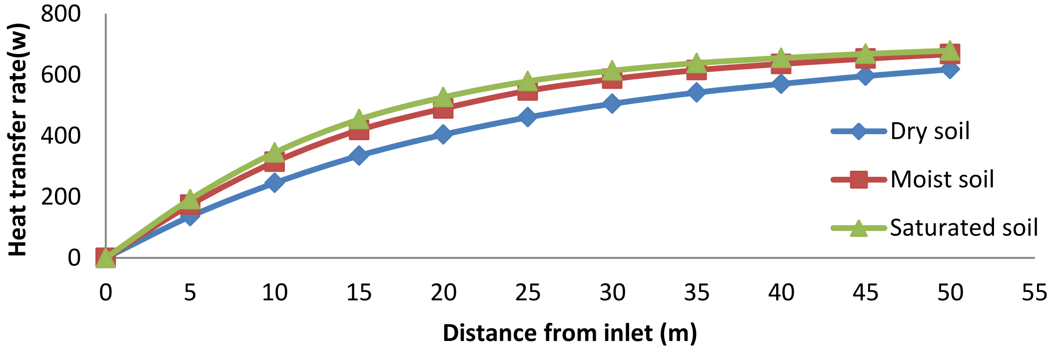


Figure 13. Distribution of heat transfer rate along length of EAHE pipe for all studied diameters at Reynold Number of 20866.212 and inlet air temperature of 50˚C.

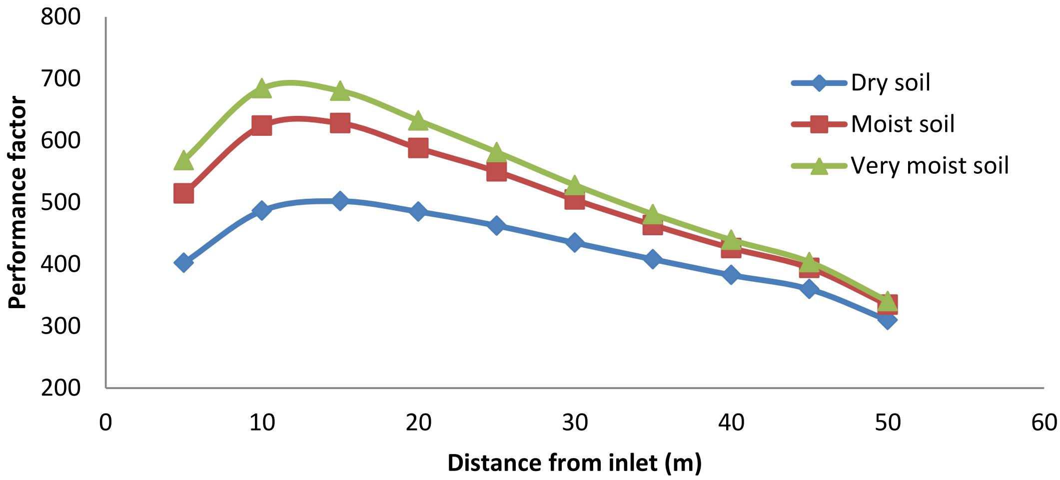


Figure 14. Performance factor of EAHE system at different distance from inlet of EAHE pipe for all studied soils at Reynold Number of 20866.212 and inlet air temperature of 50˚

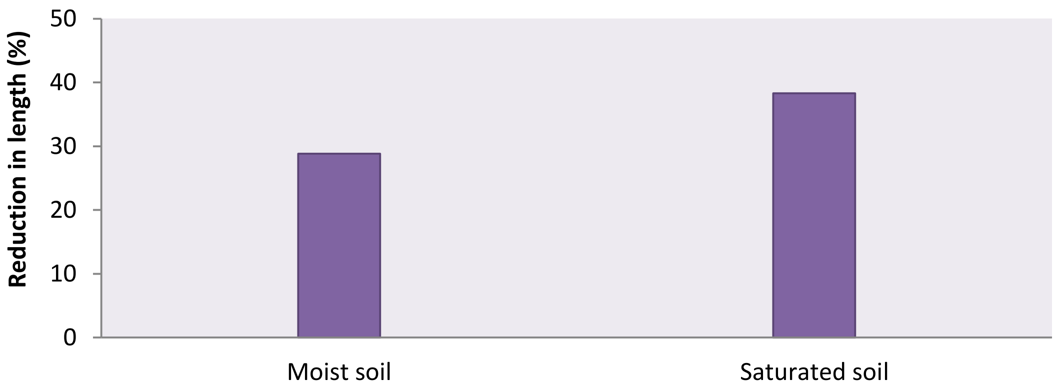


Figure 15. Reduction in length for all studied soils to gives (617.804 W) as a heat transfer rate in percentage form at Reynold Number of 20866.212 and inlet air temperature of 50˚C.

The variation of outlet air temperature with inlet air temperature during winter season for all studied soils of with constant Reynolds number of 20866.212 is illustrated in "Fig. 16",. From this figure it is easy to see that the outlet air temperature increased with increasing inlet air temperature. Also it can be noted that the outlet air temperature increased with increasing the moisture of soil due to increasing of the thermal conductivity with increasing the moisture of soil, so the maximum outlet air temperature during the winter season obtained from the saturated soil then the moist and finally the dry soil.

"Fig. 17", indicates the variation of performance factor with inlet air temperature for all studied soils at Reynold number of 20866.212. It is observed that the performance factor increased with increasing inlet temperature due to increasing rate of heat transfer with increasing inlet temperature. From this figure it is found that the maximum value of performance factor was saturated soil and the minimum in the dry soil due to the large amount of heat transfer at larger saturated soil compared with the other soils.

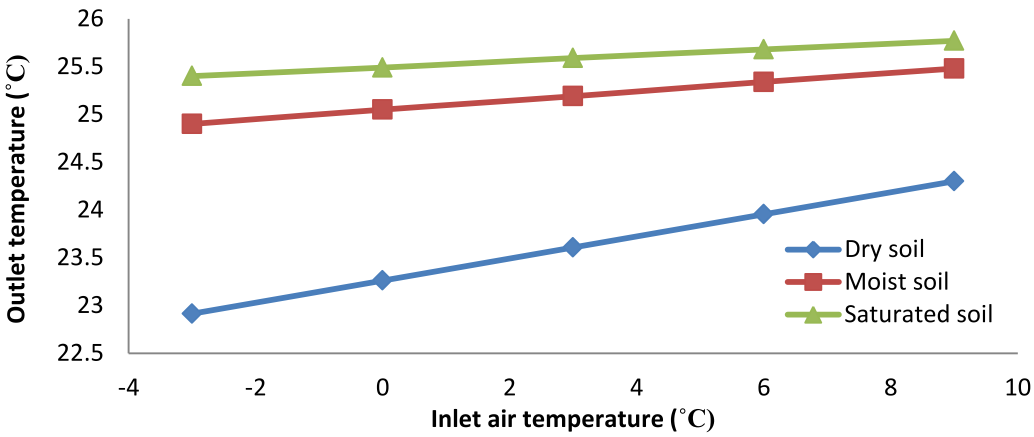


Figure 16 Outlet air temperature under different inlet air temperature for all studied soils of during winter season at Reynold Number of 20866.212.

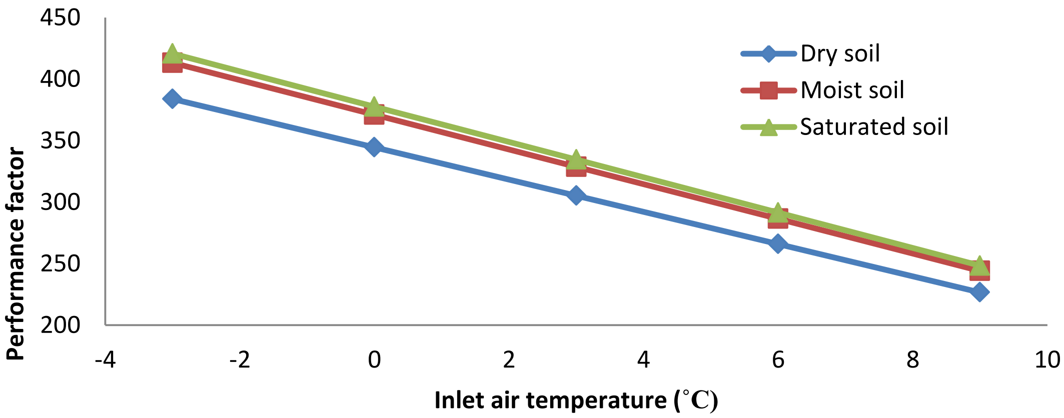


Figure 17 performance factor of EAHE system under different inlet air temperature for all studied soils during winter season at Reynold Number of 20866.212.

The variation of local air temperature along the length of EAHE pipe at Reynold number of 20866.212 and inlet air temperature of 3˚C during winter season for all studied soils is shown in "Fig. 18",. It can be seen from this figure that the local air temperature increased along flow direction and this increase is sharp at first meters of length because of the higher difference between air temperature and constant soil temperature of 26.3˚C in the first meters which is decreasing along flow direction. Also it can be noted that during the winter season the air temperature increased with increasing the moisture of soil due to increasing the thermal conductivity of soil with increasing the moisture and this leads to increasing the ability of soil to exchange thermal, therefore the saturated soil gives the maximum outlet air temperature.

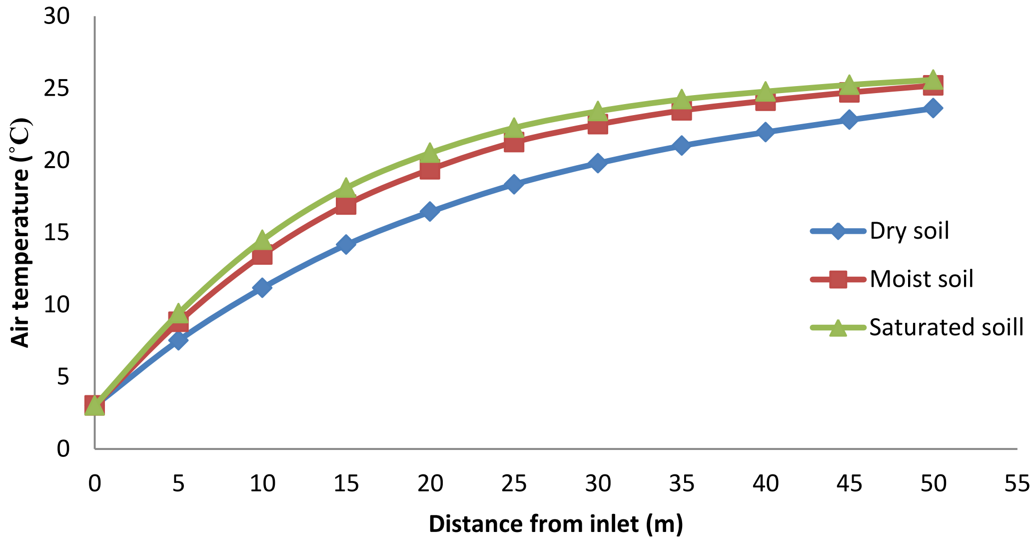


Figure 18. Distribution of air temperature along length of EAHE pipe for all studied soils at Reynold Number of 20866.212 and inlet air temperature of 3 ˚C.

The variations of local air temperature and performance factor along length of EAHE pipe for both studied materials during summer season with saturated soil, Reynold number of 20866.212 and inlet air temperature of 50 ˚C is presented in "Fig. 19", & "Fig. 20", respectively. From figure 26 it can be concluded that the air flows in PVC pipe has less temperature compared with steel pipe and this occurs due to high thermal resistance of PVC pipes compared with less thermal resistance for steel pipe. Also it can be seen in figure 20 that there is a little preference for steel in overall performance but this preference can be neglected compared with the prices and corrosion problems of materials.

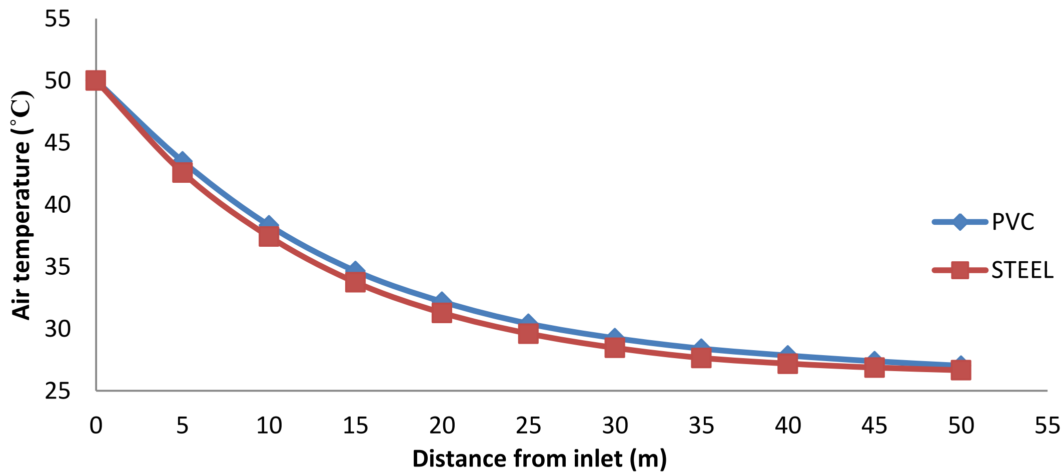


Figure 19. Distribution of air temperature along length of EAHE pipe for both studied materials at Reynold Number of 20866.212 and inlet air temperature of 50˚C.

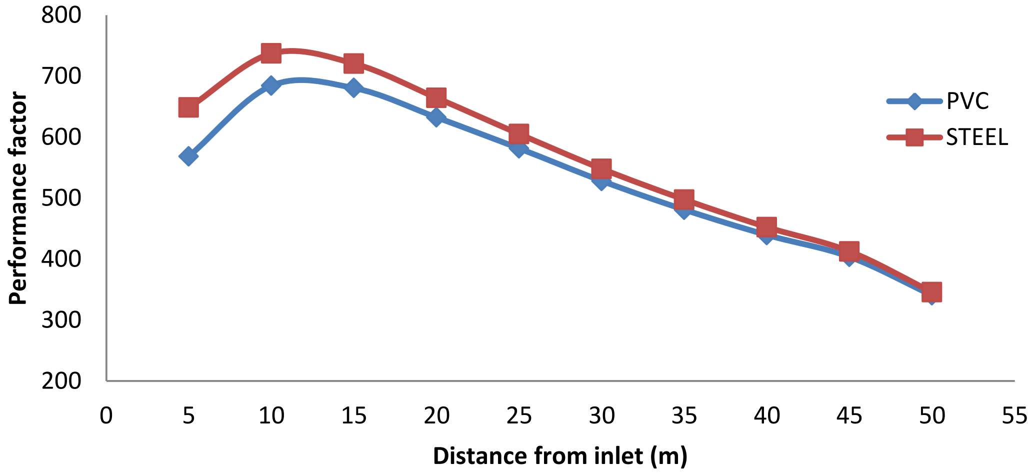


Figure 20. Performance factor of EAHE system along length of EAHE pipe for both studied materials at Reynold Number of 20866.212 and inlet air temperature of 50˚

The variations of local air temperature and performance factor along length of EAHE pipe during summer season at Reynold number of 20866.212 and inlet air temperature of 50˚C is illustrated in "Fig. 21",. From this figure it can be observed that with increasing wall thickness the local air temperature and decreased due to increasing thermal resistance with increasing thickness but this decrement is mild, therefore can be neglected.

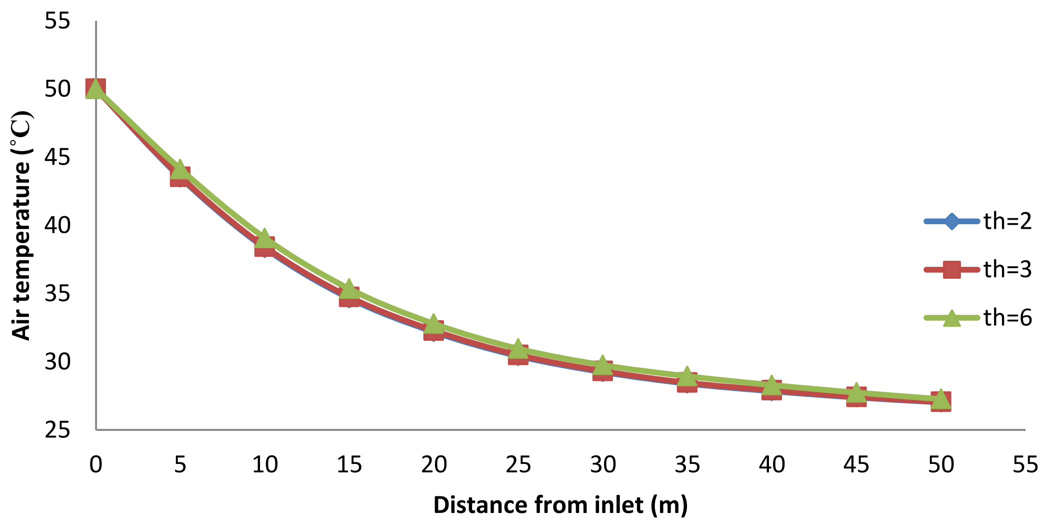


Figure 21. Distribution of air temperature along length of PVC pipe of EAHE at Reynold Number of 20866.212 and inlet air temperature of 50 ˚C.

6. Conclusions

This paper presented a numerical study 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 of Nasiriyah city in south of Iraq. 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.

Nomenclature

Cp specific heat (J\kg.K)
k thermal conductivity (W/m.K)
$\dot{v}$ volumetric flow rate (m^3/s)
$\dot{m}$ mass flow rate (kg/s)
T temperature (K)
P total pressure (Pa)
Q heat transfer rate (W)
P.P pumping power
η^* Performance factor
ΔP total pressure drop across EAHE pipe (Pa)

Greek Symbols:

ρ density (kg/m^3)
μ dynamic viscosity (m^2/s)
Subscripts:
i inlet
o outlet
s surface of soil disturbed

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