ABSTRACT
The world researches are continuing to make use of renewable energy to meet the challenge facing the human race. All of these renewable energies are clean. The G.S.HP system which use the earth as a heat exchanger have been reviewed, the study is focusing on the U-tube type of ground coupled heat exchanger, which is used in air-conditioning applications to improve the COP as external heat exchanger. This technique is wildly used in the last decades, and it is attracting the increasing research interest for such application. This study presents the simulation of U-tube heat exchanger. The U-tube ground heat exchanger is modeled, constructed and grid generated using Gambit and Fluent software is used to simulate the model to solve diffusion energy equations at unsteady state. Temperature distributions against different shank space (50, 70 and 90 mm) are plotted at different radial point and vary with time for each mode.

1. INTRODUCTION
Utilizing the ground source as heat exchanger systems have been gaining an increasing popularity for space air conditioning in the residential as well as commercial buildings, this will contribute to the reduction of the global energy consumption. This system is environment friendly, causing less gas emission than the conventional energy sources. Heat transfer between a ground source system and surrounding soil is somehow difficult energy system to analyze. The system thermal response is very important for simulating and designing the ground energy source. In analyzing the heat transfer of the ground energy system one needs to understand the enter dependence of varies parameters such as the structure of the system, geometrical configuration of pipes, the thermal and hydraulic properties of the fluid carrier, surrounding system, and time response of the simulation. All these parameters and properties are used in analytical and numerical solution. These solution are the most significant to design ground loop heat exchanger. In the next sections the review of the previous work in both solutions are considered.

2. ANALYTICAL SOLUTION OF GROUND LOOP HEATXCHANGERS

2.1. LINE SOURCE MODEL (KELVIN THEORY)
The Kelvin heat source theory is based on an infinitely long permanent line source of heat, with a constant rate of heat rejection on an infinite medium at an initial uniform temperature of $T_0$. Kelvin Theory is assuming the following:
• Soil properties are a constant and homogeneous.
• Ground water movement is neglected.
• It does not consider the end effects of the borehole.

The temperature at any point in the medium is given by the following equation:

$$T - T_o = \frac{Q}{2\pi k} \int_0^\infty \frac{e^{-\frac{\beta}{2}}}{\beta} \, d\beta$$  \hspace{1cm} (1)$$

Equation (1) is applicable to both single and multiple horizontal and vertical heat exchangers and can be used to determine the thermal interference between boreholes in close proximity. This solution as given in equation (1) can be used for small pipes in the range of 2 inches or less and a dimensionless term $\alpha \frac{t}{r^2}$ which must be greater than 20 to maintain an error that is small enough for practical applications.

2.2. Cylindrical Source Model

Borehole has a finite diameter in the cylindrical source model. The U-shaped pipes diameter $D_{in}$ is approximated by an equivalent diameter $D_{meq} = \sqrt{2L \cdot D_{in}}$. The cylindrical source solution is the exact solution to a buried cylindrical pipe in an infinite medium. It can produce results for either a constant pipe surface temperature or a constant heat transfer rate. This method produces similar results if longer time intervals are used. The cylindrical solution for a constant heat flux is as follows:

$$\Delta T^\rho = T^\rho - T_{ro} = \frac{Q}{k} \int L G(F_o, \rho)$$  \hspace{1cm} (2)$$

Equation (2) is further modified account for the fact that the heat flux is not constant. The solution may be divided into time intervals for the different heat rates. Then the solutions are superimposed, by adding the resulting temperature difference for each interval.

3. STATEMENT OF THE PROBLEM

The objective of this study is to discuss the analysis of the conduction heat transfer of borehole of a vertical ground heat exchanger type U-tube. The geometry of the borehole, the two legs (inlet, outlet) and interior diameter of, the grout material around the two legs of the borehole, and the soil around borehole as shown in Figure (1).

![Figure 1: Cross view of a vertical ground heat exchanger type U.](image-url)
Where the following assumptions are selected in this study: two dimensions \( r - \theta \), transient state, constant property and homogenous, and neglect the effect of ground water movement.

The governing equation of the transient heat conduction in polar coordinates around the borehole is:

\[
\frac{1}{\alpha} \frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} + \frac{1}{r^2} \frac{\partial^2 T}{\partial \theta^2}
\]

(3)

Fluent Software is used to simulate the heat transfer by conduction in and around borehole of single U-tube

4. Problem Analysis

The field of CFD has a board range of applicability, however specific application of CFD, here is considers in this study, generally the sequence of steps must be followed in order to obtain a satisfactory solution in the following order: [2]

1. Problem specification, geometry preparation, problem conditions, and the requirements of the simulation, (Pre-processing) is considered as a first step.
2. Governing equations and boundary conditions of the problem is selected as second step (solver).
3. Simulation results and discussion (post-process).

5. Energy Equation

The energy equation is expressed from first law of thermodynamic, where the rate of change of energy of a control volume equal to the rate of heat addition to the control volume plus the rate of work done on the particle [3].

\[
\frac{\partial (E)}{\partial t} = Q + W
\]

(4)

Without work (in or out)

\[
\frac{\partial (\rho h)}{\partial t} = \nabla \cdot (k \nabla T) + S_h
\]

(5)

\[
dh = C_p \, dT
\]

(6)

\[
\frac{\partial (T)}{\partial t} = \nabla \cdot (\Gamma \nabla T) + S_c
\]

(7)

The equation (7) is used as the starting point of computational procedures in numerical solution in this study.

6. Finite Volume Method (FVM):

In this study, a Finite Volume Method (FVM) is used in simulation to solve the diffusion equation. The key step in the solution of the diffusion equation by FVM is to integrate the overall control volume CV as shown in the following equation [4].

\[
\int \nabla \cdot \frac{\partial T}{\partial t} \, dV = \int \nabla \cdot (\Gamma \nabla T) \, dV + \int S_c \, dV
\]

(8)

To integrate the above equation (8) the Gauss Divergence Theorem is applied to replace the volume integrals into the entire bounding surface as shown in equation (10). [3]
\[
\int \nabla \cdot \mathbf{a} \, dV = \int_{d} n \cdot \mathbf{a} \, dA \quad \quad (9)
\]
\[
\int \frac{\partial(T)}{\partial t} \, dV = \int_{d} n \nabla \cdot (\Gamma \nabla T) \, dA + \int_{\partial} S_{v} \, dV \quad \quad (10)
\]

In transient state, it is also necessary to integrate the above equation (10) with respect to time; this yields the most general integrated form of the diffusion equation as follows:
\[
\int \frac{\partial}{\partial t} \left( \int_{\rho} \frac{T}{\rho} \, dV \right) \, dt = \int_{\rho} \int_{d} n \nabla \cdot (\Gamma \nabla T) \, dA \, dt + \int_{\partial} \int_{\rho} S_{v} \, dV \, dt \quad \quad (11)
\]

The integral boundary in the domain of this problem is shown in the Figure (2).

7. Boundary Conditions and initial condition
To determine the simulated heat transfer in a medium, it is necessary to solve the appropriate form of the heat equation, a solution depend on the physical condition existing at the boundaries of the medium, if the situation is time dependent on conditions existing in the medium at some initial time. The three kinds of boundaries that are commonly in heat transfer are summarized:

- Constant surface temperature \( T(0,t) = T_s \)
- Constant surface heat flux
  - Finite heat flux, \( -k \frac{\partial T}{\partial x} = q_s \)
  - Adiabatic or insulated surface \( \frac{\partial T}{\partial x} = 0 \)
- Convective surface condition \( -k \frac{\partial T}{\partial x} = h[T_s - T_s(t)] \)

From the physical meaning of the problem, the heat transfer from the fluid is treated by a heat flux boundary condition at the pipe walls. When the distribution is varied between the 0% - 100% case and the 50% - 50%, case as a assumption in this study.

8. Simulation cases by Fluent
Fluent v5.2 (commercial software) is used in this study to predict the simulation of the conduction heat transfer in and around the heat exchanger (U tube), for steady state and transient condition. In this study, segregated method implicit solution for steady and unsteady case is selected.

9. Validate Simulation
The real geometry in this study somehow is complicated and it has no analytical solution. The validation of the problem in this study is simulated by using a selected case from a previous
work in the literature. The solution of the problem is considered here into two steps. The first step is to consider an existing case such as concentric cylinder (equivalent diameter) could be simulated by Fluent and compared with the analytical solution of a diffusion heat transfer in and around U-tube borehole (Vertical heat exchanger). A second step in this study is to utilize Fluent software for the concentric cylinder (using equivalent diameter) compared with the real geometry of the problem. More details for the first and the second step are outlined in the following figure (3), figure (4).

![Figure 3: Comparison of the numerical solution with analytical solution at outer borehole surface using approximated equivalent diameter](image)

Figure 3: Comparison of the numerical solution with analytical solution at outer borehole surface using approximated equivalent diameter

![Figure 4: Comparison of the numerical solution between a real geometry and approximated equivalent diameter at outer borehole wall](image)

Figure 4: Comparison of the numerical solution between a real geometry and approximated equivalent diameter at outer borehole wall

10. **Analytical Solution**

The model transient conduction through an infinitely long hollow cylinder (the inside and outside cylindrical surface co-axial) in this study is compared with the numerical solution of concentric tube. The boundary conditions are a constant heat flux at the inside surface of the hollow cylinder at \( r_{in} \) and a constant far-field temperature at the outside surface at \( r_{out} \). This implementation of these boundary conditions yields the following analytical solution for the temperature as a function of time and the radial coordinate (Cars laws and Jaeger 1947) \(^5\).
\[ T(r, t) = \frac{r \eta}{k} \log \left( \frac{r_{\text{out}}}{r} \right) + \frac{m}{k} \sum_{n=0}^{\infty} e^{-\beta_n t} J_1(r \beta_n) Y_1(r \beta_n) - Y_1(r \beta_n) J_1(r \beta_n) \]  

(15)

Where: \( \beta \) \( n \)'s are the positive roots of

\[ J_1(r \beta_n) Y_1(r \beta_n) - Y_1(r \beta_n) J_1(r \beta_n) \]

(16)

11. Results and Discussion

As it has been mentioned before numerical solutions is used to simulate the heat transfer from a vertical closed ground heat exchanger type U tube well using a Fluent software for the objective outlined above and the results are as follows.

11.1 Simulation results of heat transfer in and around borehole of a single U tube.

The simulation result of temperature distribution from a single U tube is constructed in different shank space of Model A (50 mm), Model B (70 mm), and Model C (90 mm), for 7 hours simulation time, the results have plotted as contours. These curves as a function of time will be obtained at difference points against the radius of borehole, these points are shown in Figure (5).

![Figure 5: Position points at different radius of borehole.](image)

The result of simulation of model A (50 mm) shank space is shown by contour in the figure below. The time frame considered here to simulate the model A (50 mm) is vary between 30 minutes to 7 hours. According to the existing temperature located at different points on the axis as shown in Figure (5) with respect to time, the temperature distribution have been plotted against time for different radius as shown in Figure (9). In addition figure (10), Model B, and figure (11), Model C.

![Figure 6: Temperature distribution around U tube after 30 min (1800 sec).](image)

![Figure 7: Temperature distribution around U tube after 2 hour (7200 sec).](image)
Figure 8: Temperature distribution around U tube after 7 hour (25200 sec).

Figure 9: Temperature distribution of different points at different radius of Borehole, 50 mm shank space (time = 600 minutes).

Figure 10: Temperature distribution of different points at different radius of Borehole, 70 mm shank space (time = 600 minutes).
Simulation results have obtained by changing time from 30 minutes until reach steady state condition, which nearly start after 5 hours. It has also obtained that temperature reaches its maximum value (32.6 °C) at the distance between two legs (shank space). Figure (9) shows that most of points that temperature distribution located at, have the same limit of time when temperature change from unsteady to steady state condition (reach ton heat capacity of materials (grout), which roughly occur after 5 hours. One can notice that temperature difference decrease as shank space increase at the same heat flux and the same period of time, this give a suitable diffusion around every tube. This difference decrease from 32.5 °C (50 mm shank space) to 28.5 °C (70 mm shank space), at the center of borehole which is 4 °C, also the difference is less than 2 °C between (70 mm) and (90 mm) at the same centre point, so the optimum point of U tube position on the bore hole should be searched.

12. Conclusion and Recommendation

Conclusions: The objective of this study is to obtain the temperature distribution in and around the borehole. The temperature distribution is affected by a different value of shank space (50, 70 and 90 mm). However, the increase in the shank space distance is decreasing the mean temperature at the center of the borehole. Four degrees lower is recorded in the amount of the mean temperature in the two Models 50, 70 mm shank space and a decrease of two degrees is found in the two Models 70, 90 mm shank space.

Recommendation: Future research could be carried out on a farm of wells to understand the effect of the distance between these wells and the critical distance between them, as well as the effect of moved ground water movement. This field of study needs more attention by the authorities, the research centre, and the universities in the aired regions due to its improvements in the energy efficiency of the heating and cooling systems.

References: