Islamic University of Technology

Department of Mechanical and Production Engineering

NUMERICAL SIMULATION ON THERMAL ANALYSIS OF SINGLE BOREHOLE U-TUBE

A Thesis by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Bachelor of Science in Mechanical Engineering

May (2022)

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CERTIFICATE OF RESEARCH

*This thesis titled “*NUMERICAL SIMULATION ON THERMAL ANALYSIS OF SINGLE BOREHOLE U-TUBE*” submitted by AHMAD TIJJANI AHMAD(170011074)and MOHAMED ALIE KAMARA(170011075) has been acknowledged as adequate as part of the requirements for a Bachelor of Science in Mechanical Engineering degree..*

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DECLARATION

I henceforth certify that the work, titled "Numerical Simulation on Thermal Analysis of Single Borehole U Tube," is a genuine document of our research conducted as part of the requirements for the certificate of a B.Sc. (Mechanical Engineering) degree at Islamic University of Technology, Gazipur, Dhaka, in the year 2022, under the supervision of Md. Abul Kalam Azad, Assistant Professor, Mathematics, *MPE, IUT.*

This thesis has not been submitted in part or in its entirety to any other university for the academic award.

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ABSTRACT

The most vital element in evaluating the thermal efficiency of a geothermal coupled heat pump system is the thermal layout of a borehole. It necessitates an understanding of the borehole's U-tube configuration and design. For the ground-coupled heat pump's thermal equipment designer, the heat transfer rate and borehole design provide significant obstacles. The current model is a mathematical numerical technique that has been used to solve such a problem. For a heat pump used for cooling reasons in the summer, a thermal evaluation was devised to quantify the total energy wasted to the ground zone. The thermal performance of a single U-tube borehole that circulates water as a thermal transfer medium was assessed using the COMSOL Multiphysics 5.6 software. For this investigation, the (Heat Transfer) module was used with the (Stationary) study option. The model incorporates both heat conduction in solids, such as tube metal, grout, and soil, as well as thermal medium fluid flow within the U-tubes. Numerical solutions for heat exchangers with set borehole shape, diameter, and depth, as well as constant operating parameters in a steady-state configuration, were compared. The effects of drilling depth and time on mean fluid temperature, overall borehole wall, grout, and surrounding temperature of the soil, in addition with borehole loads, were explored. A dynamic simulation was used too to evaluate the impact of key data. The effect of two data, fluid mass flow rate and grout heat conductivity, over mean fluid temperature, borehole wall, grout, and soil temperature, in addition with borehole loading and heat efficiency, was studied. The findings will allow researchers to save time by immediately determining the effect of different data on the working effectiveness of a vertical single U-tube borehole heat exchanger. Moreover, this acquired finding may be used as guide for designing as well as optimizing a heating and cooling system that incorporates a ground coupled heat pump configuration.

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Nomenclature

Parameter	**Definition**
cp	Heat capacity at constant
d	Diameter, (mm)
g	Gravitational acceleration, (m/s2)
H	Depth, (m)
k	Thermal conductivity, (W/m.K)
m	Mass flow rate, (kg/s)
n	Number of tubes, for a single U-tube
p	Pressure, (Pa) or (bar)
Q	Specific heat transfer rate, (W/m)
Q	Heat transfer rate, (kW)
R	Specific thermal resistance, (m.K/W)
Sp	Tube or pipe spacing, (mm)
t	Time, (sec)
tp	Pipe thickness, (mm)
T	Temperature, (K)
ΔT	Temperature difference, (K)
v	Water flow velocity, (m/s)

Subscripts	**Definition**
b	Borehole
c	Cooling
DW	Downward flow direction
e	Equivalent
g	Grout
H-E	Heat exchanger
i	Inside
in	Inlet
leg	U-tube leg
m	mean
o	Outside
out	Outlet
p	Pipe
s	Soil or ground
S-D	Single to double U-tube
Single	Single U-tube value
t	Total
UW	Upward flow direction
w	Water

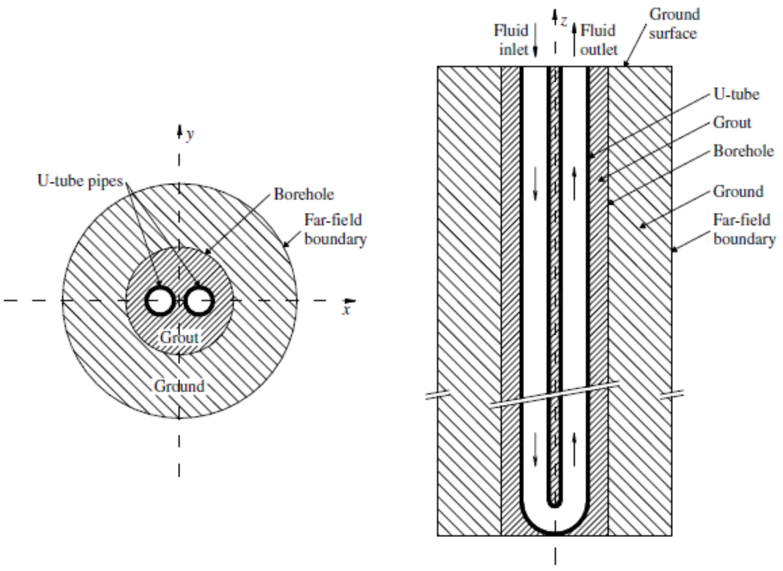
Chapter 1

INTRODUCTION

Ground source heat is currently being emphasized thermal methods for the home and cooling (GSHP) in buildings because of their benefits in terms of providing more energy. In comparison to traditional air source heat pumps, they are more efficient and environmentally benign [1]. This is as a result of the fact that the soil used as a producer or drain of warmth in the GSHP system in comparison to the variable ambient air temperature.

[1] As a supply of warmth for air source heat exchanger. Simulated findings were compared to Scientific data from two test ponds was obtained to validate the model. Drawings of a ground loop heat exchanger and a liquid heat pump were provided by Daniel and Rees [2] in a building annual energy simulation software (Energy Plus). Ground source heat pumps (GSHP) are frequently combined with a bore hole heat exchanger (BHE) array in projects exceeding 61 30 kW to recover a substantial amount of heat from the shallow subsurface [3]. When heat pumps (HPs) are combined, they achieve increased efficiency. GHEs (ground heat converters) are a type of warm transfer that is used to transfer warm from the This is because the soil is constantly cooler inside the warmer in the heat and colder in the winter than the ambient air conventional Heat is exchanged through heat pumps. The variation in degree from cool and warm reservoirs determines the efficiency of an HP (TH). The bigger the HP's effectiveness factor, the lower the temperature differential. The two most common Horizontal and vertical (and occasionally diagonal) GHE setups are available oblique). Heat exchangers in the series kind are subsurface, as well as a heat transport channel circulates throughout the heat transfer, transporting Heat can be transferred from the earth to a heat pump or the other way around. Several tubes are connected in series or parallel in this configuration. When enough There is lawn space available, and ditches are simple to build. it is usually the most cost-effective option, especially when the structure is under construction.

A critical component of geothermal energy systems such as GSHPs. It is usually made of polyethylene with a high density (HDPE). A Pipe U-tubes are placed drilling into boreholes that are 30–90 meters deep. The boreholes are typically 76–127 mm in diameter, while the pipe sizes are in the range of the sizes range between 17 and 30 millimeters. Typically, a grout mixture consists of injected to the borehole in order to fill it space from bottom and U-tube of the borehole side of the borehole. The grout's goal has to increase the hotness. Transmission between the soil and pipes made of plastic, as well as to protect preventing pollutant entrance into the groundwater structure modeling. Numerical Due of the large number of approaches used in this sector, it is frequently used. The benefit of resolving difficult heat transfer problems. There are now several entrance into the. They tried different strategies to deal with the heat process in the borehole. One of the GHE's major research areas can be loosely divided into 3 stages: The grout is treated as one main There are no variations in thermophysical properties between the two halves of the soil. For transient analysis, a local procedure with a semi phase is considered, and quantitative approaches built on square structures are utilized, however this method requires a rough representation of real world. borehole structural geometrical.



(a) Horizontal cross section (b) Vertical physical symmetry plane

Fig 1.1: Diagram of a vertical U-tube ground heat exchanger

An influence of depth and ground geological nature on the performance of the heat exchange were studied numerically under steady-state conditions in a 3-dimensional model. Objective is that it analyzed compressively from aspect of depth, porosity, permeability and heterogeneity. Limitation and scope Heat exchangers have two potential drawbacks: leakage and pressure drop in the system. It is difficult to prevent and correct leakage in the heat transfer process. In fact, many heat exchangers must be completely dismantled to repair a leak.

- Excessive fluid velocity on the casing or tube sides of a heat exchanger might cause problems. damage to Metal piping wears out wears away. Erosion eliminates the pipes guardian layers subjecting new metal to more assault, speeding up any existing corrosion Future scope Can Increase efficiency of heat exchangers.
- Reduce the size of heat exchangers in order to use less material and make it compact for same efficiency.
- Further research can be done for the simplification of the solution to the problem given.

Apart. from the standard procedure of design, one can design Heat Exchanger by using nonstandard procedure and can come to same results. Methodology after we for water velocity, a ground heat exchanger was evaluated between (1.0) and (1.5) m/s. Drilling depth of 56 m, they recommended a value of (1.3) m/s. The In this study, the following operational parameters for a steady-state condition were studied study:

1- Table 2 shows the all zones of the system's actual size, including the Caulking, U-tubes, and earth section.

2- Table 1 shows the temperature of the water inflow at (334.15) K. The energy and flow characteristic equations were solved using the (k-) turbulence model because the flow region was within the turbulent zone. The flow velocity at the U-inlet tube's foot was variable, ranging from (.3) to (.6) m/s. The mass flow rate produced by this velocity range was (0.133 (0.34) kg/s and kg/s, correspondingly). GSHP systems are the subject of various basic scientific research and design factors. Y. Shang et al.[14] developed a three-dimensional approach based on the porosity concept to examine geo-temperature change during the operation and recovery of GSHPs. In comparison to typical heat pumps, GSHPs are more cost-effective and environmentally beneficial. The vertical U-tube GHEs' key advantage is that they are vertical is its greater performance coefficients (COPs). Because the seasonal swing in the ground mean temperature is lower, it needs less earth surface and provides higher performance [15]. To evaluate heat transfer in a single U-tube subsurface heat exchanger, a number of analytical [16] and numerical models [21&22] have been created. The initial attempt to calculating the thermal efficiency of GHEs was Kelvin line source theory, which is now the theoretical basis for the design of most GCHP systems [14]. The vertical GHE, which is inserted into such a borehole with a diameter of 100–200 mm and a depth of 20–200 m, usually provides higher thermal performance.

in comparison to the horizontal one [17]. The addition of certain geometric assumptions therefore makes it increasingly challenging to apply the system. For instance, consider the writers in reference [18]. Hell storm [19] created a model for vertical ground heat exchanger banks and used the conjunction of a local, steady flux, and global solution to estimate customer satisfaction. Kavanaugh [23] studied the potential of a circumferential borehole using a multiple relatively limited approach.

Pasquier and Marcotte [24] modified the TRCMs previously created by Bauer et al. [25] by increasing the system to also include the thermodynamic capabilities of the heat carrier fluid and the pipe, as well as tubing separation, which is also not examined in the prior TRCMs. To predict the brief reactions of underground heat exchangers, Li and Lai [26] devised a composite-medium modeling. Yang and Li [27] also created a numerical solution and an analytical composite-medium model to examine the quick heat exchange mechanisms in the underground heat exchanger, which these simulations were confirmed by comparing research observations.

Furthermore, the lateral heat flux in borehole heat exchangers was not taken into account in these simulations. Furthermore, the dynamics of the circulating fluid in these systems. Maestro et al. [28] created a composite heat dissipation and capability theory (with discrete time heat transfer equations). Short and long time-step functions were used to describe the heat transfer rate to the neighboring earth (just within the borehole).

However, the scientists did not account for heat resistance between the U-tube legs in their research. As a result, the fluid temperature drops as it descends raising the depth of the borehole first from inflow The temperature with upward fluid flowing, on the other contrary, gradually falls as the fluid flows upward from the borehole's bottom to its outlet.

1.1 SOME DEFINITIONS

1.1.1 Ground sources heat pump

A geothermal heat pump is a type of renewable energy of residential A heating/cooling system that uses a heat pump to transport heat to or from the earths relatively constant temperatures throughout the season

1.1.2 Borehole

An investigative well is a hole bored or drilled in the earth. A small-diameter well drilled specifically for the purpose of extracting water.

1.1.3 Grout

Grout is a mixture of water, concrete, and dirt that is used in the stress grouting process.

1.1.4 Water Velocity

The velocity of water refers to the rate during which water flows. The volume of water passing per minute is commonly used to calculate flow rates.

1.1.5 Heat Exchanger

A heat exchanger is an instrument that releases energy from one stream to another. Both cooling and heating operations employ heat exchangers. A massive wall may split the elements to avoid combining, or they may be in direct touch.

1.2 Application

GSHPs are most commonly used in cooling towers. GSHPs are made up of a heat pump unit on the generator side and a geothermal energy exchange system and load system on the building side, with minimal heat sources such as rock soil, ground soil, and groundwater or waterways. Ground source heat pumps, often characterized as geothermal heat pumps, are a type of high-efficiency heat pump. way to generate electricity that is gaining popularity in both residential and commercial structures. Space heating and cooling, as well as water heating, are all possible with geothermal heat pumps.

Chapter 2

2.0 MATHEMATICAL MODELLING

Two heat exchangers were numerically studied in a parallel flow arrangement for simultaneous U-tube design. The functionality of these configurations was also contrasted to that of a singular U-tube heat exchanger operating in the same conditions and with the same geometry dimensions. Water was used as the fluid medium, having flow rates ranging from (0.14-0.34) kg/s and a velocity of (0.2-0.5) m/s. In flow rate circuits, the flowrate was split evenly between U- tubes. As detailed in [29], the low Reynolds () turbulence module was developed in the flow

mechanics realm.

Calculated Region of an exceptional surface Heat Exchanger A 3D figure of the exceptional 20 m in depth U-tube surface heat exchanger was created using COMSOL. In contrast to two-dimensional(2D) numeric approaches, 3D models entail simulating the patch and ground heat pipe [39]. In this scenario, the 3D U-tube underground thermostat was constructed as can be seen in Figure 2, with the U-shaped junction at the lower part of the U-tube removed.

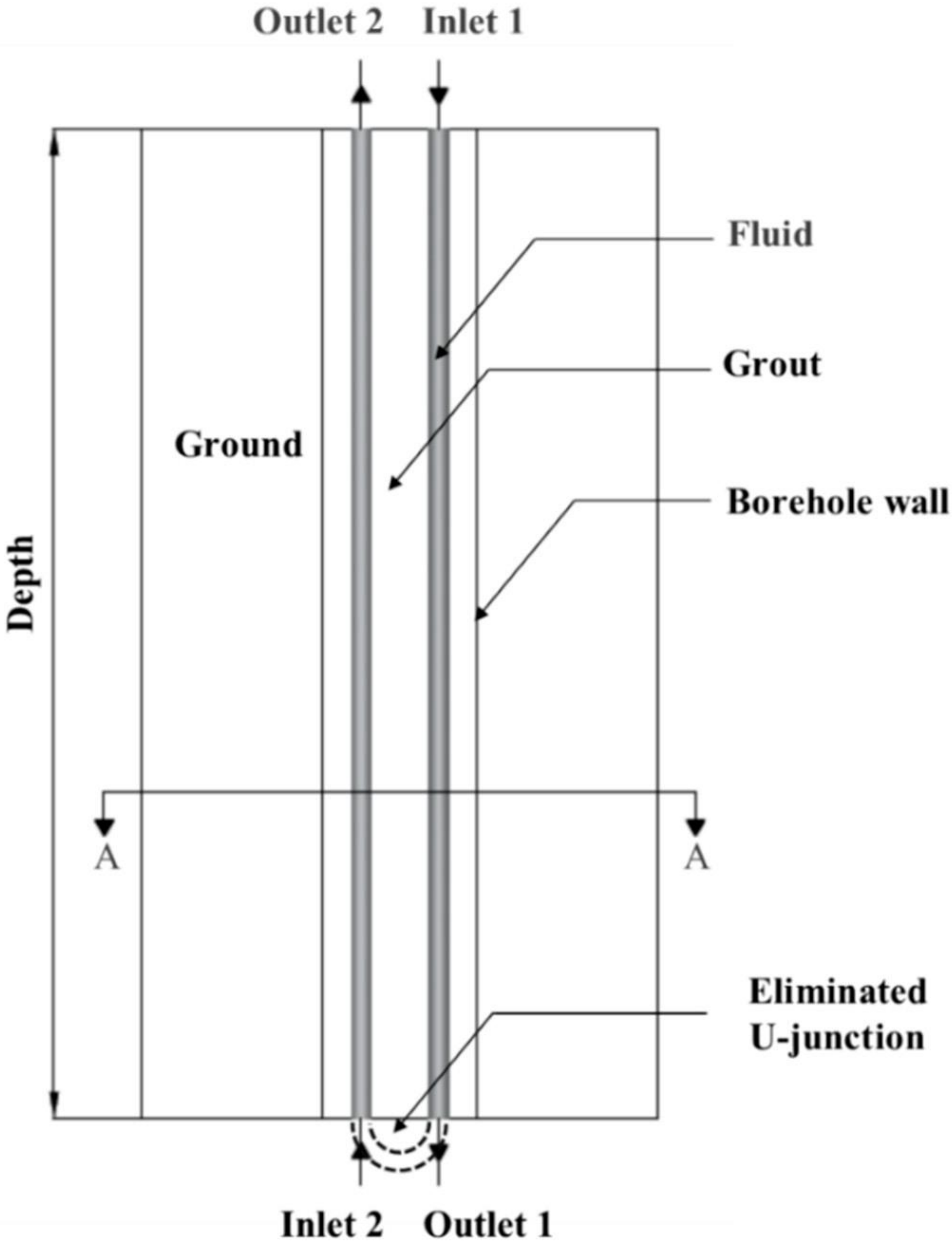


Fig. 2.11 A straight passage of the separated GHE mathematical computation.

The goal of this change was to simplify the model, resulting in a considerable reduction in designing time. The stream was changed when the U-junction was removed which would have normally formed an uninterrupted pipe loop and introduced an intermediate as indicated in Figure 2, there is an exit (Outlet 1) and an input (Inlet 2), the suggested model was evaluated using experimental data to guarantee its reliability. Borg's work on a 20-meter-deep surface heat converter, as well as the following (numerical). To show that the selected design without the U-tube was workable, a number of experiments were done. The connection was accurate, involving indicating that the liquid approaching Inlet 2 had become completely turbulent across the whole distance of the tube and exact matching to Sciberras; [8] model results. In the first case, the hydrodynamic entrance length was roughly ten periods the pipe The stream was instability during the first 2% of the pipe size, or 0.36 m (the tube; s inner diameter was 0.036 m), suggesting that the flow was turbulence in the first two percent of the pipe height. A direct indifference with the second test Sciberras&; temps from [8]. In the model described in this research, the temperatures at exit as a result of the same. Both were found to be somewhat about 0.0007% off from Sciberras&; projected temps. According to this discovery, removing the U-junction had no important impact on the carrier liquid&; s simulated temperature profile. Due to the small shank-spaces examined in this research (and typical of U-tubes), it was reasonable to assume that omitting the U-junction from the model has no significant effect on the total temperature between intake 1 and exit 2, and that this expectation would hold true for all subsequent experiments with dissimilar shank-spaces. The isolated ground heat exchangers numerical model is shown in Figure 3, which was divided into the recommended volume had been in the configuration of a muti box (cuboid) spanning 60 to 60 m, with two fluid sub-domains representing the carrier water moving through the sub parts of the U-tube and two straight sub- domains depicting the refill sidewalls caulk and boundary ground.

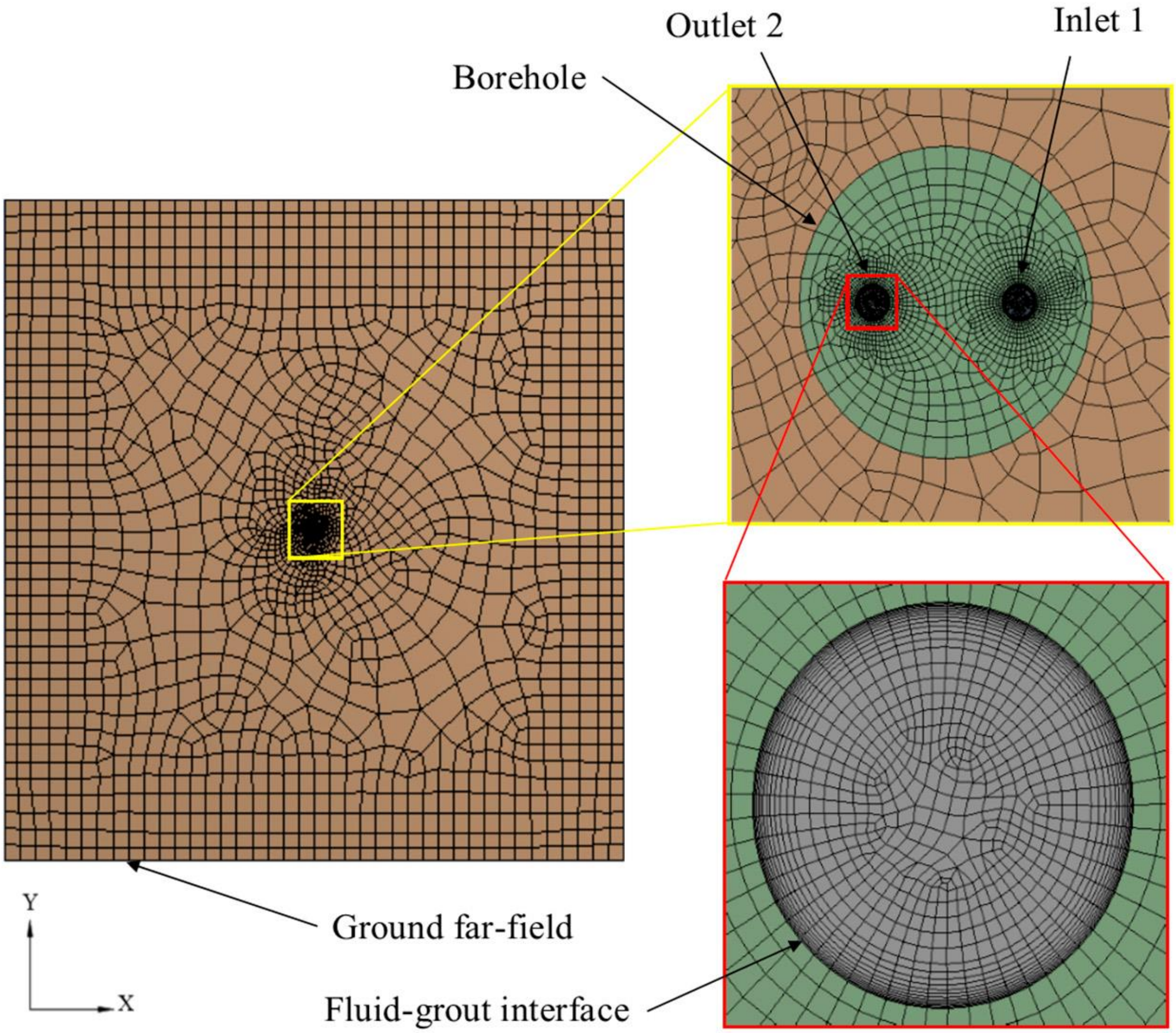


Fig. 2.12: Enlarged top view of three-dimensional (3D) m

2.1 Model description

The geometrical parameters are show in table 2 for the numerical model additionally the mixture of distinct zones. A depth of the grout the (110) mm layer beneath the U-tube was fixed. This area of calculation contained the ground layer under the U-tube heat exchanger is 2.5 m thick., as well as the environment in general with a diameter of (5) m. To analyze the created model, the COMSOL Multiphysics program was used to Multiphysics is used to handle heat transfer in solids and fluids connection.

Table 1. Measurements of different parts

Zone Materials	Parameter	Value
(HDPE) High density polyethylene pipe	(d_o),(millimeter) (di), (millimeter) (tp), (millimeter) (WF), (nondimensional) (S_p), (millimeter) ($H_{u\text{-tube}}$), (Meter)	33.40 29.50 2.00 17.00 66.80 50.00
Borehole (Grout)	(d_b),(millimeter) (H_b), (Meter)	120 50.1
Ground	(d_s),(millimeter) (H_s), (Meter)	5.00 52.50

Fig 1 shows the heat exchanger, borehole, and ground zone arrangement. Geometric directions and individual heat transfer were studied.

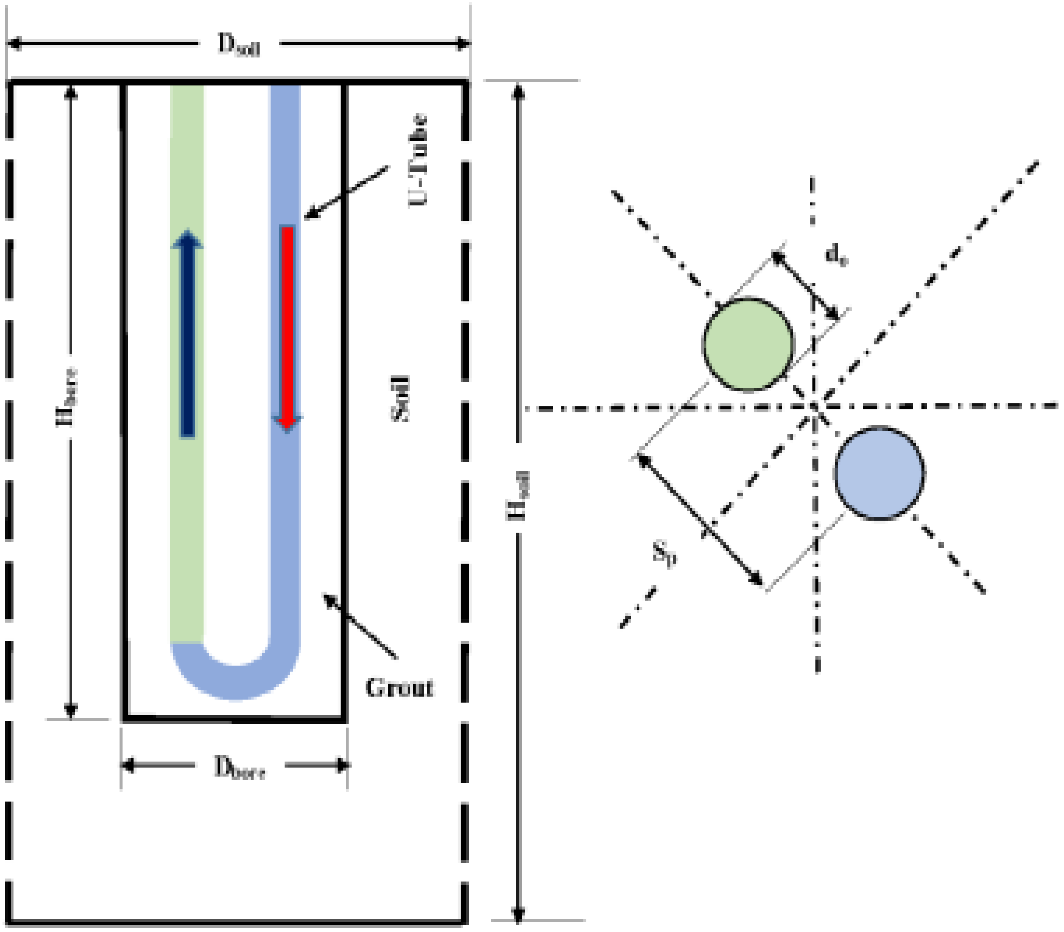


Figure 2.13: Exchangers with a simple U-tube

Topic design: According to the early design for the EUBHE network in the Chinese city of Xi'an [4]. The vertical borehole depth is 2505m, while the horizontally space between multiple boreholes on the ground surface is 205m. At 2355m, the diverted hole begins with a 45 ° angle deviation and connects to the vertical borehole at the bottom. The complete off set is around 5200m. A second numerical model with two 2600m deep boreholes is developed and connected in parallel to build an analogous 2-DBHE matrix in order to sustain a fair assessment to the EUBHE device.

2.2.2 Governing Equations

The general forms of the equations of energy and fluid flow which control the process in the borehole is stated below These relations represent the cylindrical forms of heat transfer and fluid flow as known by Fourier’s law for the solid domains and the Navier-Stokes, energy, and continuity equations in the fluid domain. The following boundary conditions were implemented in the present work:

Fluid Domain

According to [7], the governing equation for the flow domain, continuity, Navier-Stokes, and energy in an incompressible flow are defined by the following formulae.

Continuity Equation.

$$\frac{1}{r}\frac{\partial(rUr)}{\partial r}+\frac{1}{r}\frac{\partial u\theta}{\partial \theta}+\frac{\partial uz}{\partial z}=0 \qquad (2.1)$$

Navier-Stokes Equation

$$\rho\left(\frac{\partial ur}{\partial t}+ur\frac{\partial ur}{\partial r}+\frac{u\theta}{r}\frac{\partial ur}{\partial \theta}+uz\frac{\partial ur}{\partial z}-\frac{U\theta^2}{r}\right)=\rho gr-\frac{\partial p}{\partial r}+\mu[\frac{\partial}{\partial r}\left(r\frac{\partial ur}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 ur}{\partial \theta 2}+\frac{\partial 2ur}{\partial z2}-\frac{2}{r^2}\frac{\partial u\theta}{\partial \theta}-\frac{ur}{r^2}] \qquad \mathbf{(2.2)}$$

$$\rho\left(\frac{\partial u\theta}{\partial t}+ur\frac{\partial ur}{\partial r}+\frac{u\theta}{r}\frac{\partial u\theta}{\partial \theta}+uz\frac{\partial u\theta}{\partial z}+\frac{uru\theta}{r}\right)$$
$$=\rho g\theta-\frac{1}{r}\frac{\partial}{\partial \theta}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u\theta}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 u\theta}{\partial \theta^2}+\frac{\partial^2 u\theta}{\partial z2}+\frac{2}{r^2}\frac{\partial u\theta}{\partial \theta}-\frac{u\theta}{r^2}\right] \qquad (2.3)$$

$$\rho\left(\frac{\partial uz}{\partial t}+ur\frac{\partial uz}{\partial r}+\frac{u\theta}{r}\frac{\partial uz}{\partial \theta}+uz\frac{\partial uz}{\partial z}\right)=\rho gz-\frac{\partial p}{\partial \theta}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial uz}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 uz}{\partial \theta^2}+\frac{\partial^2 uz}{\partial z^2}\right] \quad (2.4)$$

Energy Equation

$$\frac{\partial T}{\partial t}+ur\frac{\partial uz}{\partial r}+\frac{u\theta}{r}\frac{\partial T}{\partial \theta}+\frac{u\theta}{r}\frac{\partial T}{\partial \theta}+uz\frac{\partial T}{\partial z}=\frac{q}{cp}+a\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial 2T}{\partial \theta^2}+\frac{\partial^2 T}{\partial \partial^2}\right]+\frac{\varphi}{\rho cp} \qquad (2.5)$$

Where the viscous dissipation rate is:

$$\varphi=2\mu\left[\left(\left(\frac{\partial ur}{\partial u}\right)^2\right)+\left(\frac{1}{r}\frac{\partial u\theta}{\partial \theta}+\frac{ur}{r}\right)^2+\left(\left(\frac{\partial uz}{\partial z}\right)^2\right)\right]+\mu[\left(\left(\frac{1}{r}\frac{\partial ur}{\partial \theta}+\frac{\partial u\theta}{\partial r}-\frac{u\theta}{r}\right)^2\right)$$
$$+\left(\frac{\partial u\theta}{\partial z}+\frac{1}{r}\frac{\partial uz}{\partial z}\right)^2+\left(\left(\frac{\partial uz}{\partial r}+\frac{\partial ur}{\partial r}\right)^2\right) \qquad (2.6)$$

For the types of intervention, these formulae capture the current forms of the processed variables in the viscous sublayer. The time-dependent variables, as well as the heat generation (and gravity terms (g), was removed from the standard paradigm

Solid Domains

In the solid domains of the model, the following general Fourier’s law is applicable:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial \theta}\right)+\frac{1}{r^2}\frac{\partial}{\partial \theta}\left(r\frac{\partial T}{\partial \theta}\right)+\frac{\partial}{\partial z}\left(\frac{\partial T}{\partial Z}\right)+q=\frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (2.7)$$

For a stable scenario, the power production per given volume (and the temperature fluctuations over period assumed to be zero inside this expression.

1- The An isolated barrier was postulated for such borehole's upper ground surface.

.

2- The far-field and bottom boundaries were set as undisturbed temperature boundaries. The plant's border was set at a certain heat of (16) °C. It is extended from the top ground face to a great extent of (37.6) m.

3- The entering water temperature to the heat exchangers were assigned as (33) °C.

4- The water flow velocity fell in the variety of (1.2-1.5) m/s for the single and series flow in the double U-tube configurations. The velocity was fixed at (0.1-0.25) m/s for the parallel flow U-tube circuiting to keep a fixed mass flow rate in the examined heat exchangers.

5- The U-tubes outlet valves were used as outflow boundaries for the river flow.

COMSOL Multiphysics 5.4 software (Placeholder4). In which T is the temperature, t is the period, q is indeed the intensity, c is the heat capacity, k is the heat capacity, V is a locational geographic area surrounded by sealed ground A, and n is the upwards and unit normal quaternion on exterior d A, earth and grouting heat transfer is recognized the procedure of clean conduction of heat and the resulting sustainable energy formula can be published as

$$\rho c \frac{\partial}{\partial \in} \int_v \; T dv = \int_A \quad \boldsymbol{\lambda V \nabla T . n d A} \text{ ----------------- } \mathbf{(1)}$$

to were

T is indeed the heat,

t is the period,

q is the intensity,

The energy conservation equation of the fluid in the pipes is if resistive temperature distribution along the liquid routes is ignored.

$$\boldsymbol{\rho 1 C 1 A t \frac{\partial}{\partial t} \int_l \quad T t d L + \alpha U \int_L \quad (T t - T i) d L = m c t (T t, i n - T t, o u t)}$$

where an is really the fluid's radiative heat flux, m_ is its flow rate, If is its pass flow area, and U is its volume is the conduit interior L is the fluid cell's perimeter diameter. The subscript I signifies the pipe interior surface, while f specifies the fluid. The input and outlet are indicated by the subscripts in and out simultaneously. Conservation of energy is demonstrated in Eq. (2). the GHE's on-time performance No fluid would be delivered during the off-season o the pipe (U-tube) On the correct, there is a word (RHS) is used here. Equation (2) equals zero. As a result, forced convective heat in the opposite flank, the transfer coefficient in the second phrase (LHS) of Eq. (2) becomes the rate of heat exchange via convection. Because the thermal capacity of the pipe wall is so low, it is often overlooked. As a result, in the tube's circular path, the heat cycle can be modeled as a quasi-continuous action.

2.2.3 Boundary Condition

For the calculations, the borehole's upper ground wall was supposed to be an isolated barrier. For entire borehole depth and the lower half of the hollow at (42.5) m deep, the far side of the hollow far surface border of the earth was set at a stable degree at a (5) m in diameter. The pipe outlet ports were used as the flow of liquid property's discharge borders, which has a predetermined entry warmth and flowrate.

2.2.4 Materials

Besides the liquid area, which used the built-in collection, the thermal decomposition of other domain resources was provided according the consumer class, table 1.

Table 1 shows the geothermal state's parameters and working circumstances.

TABLE 2. DIFFERENT MATERIALS AND THERE PHYSICAL PROPERTIES USED

Zone Materials	Physical Parameter	Value
Water	(T_{in}), (℃) (T_{out}), (℃) (P_{in}), (bar) (Vin), (m/s) (m_w), (kg/s)	33.00 --- 1.00 0.20-0.50 0.14-0.34
(HDPE) High density polyethylene pipe	(K_{HDPE}), (W/m K) ($\rho HDPE$), (kg/m^3) (cp_{HDPE}), (J/kg K)	0.40 940 2300
Grout	(K_g), (W/m K) (ρg), (kg/m^3) (cp_g), (J/kg K)	0.78 1000 1600
Ground	(K_s), (W/m K) (ρs), (kg/m^3) (cp_s), (J/kg K) Ground (T_s), (℃)	2.42 2800 840 16

Data were taken from reference [9].

Many researchers [11, 12, and 13] have defined the working parameters and suggested a variation in heat between the two downhill and a borehole heat exchanger's uphill flow as a suitable driving force. The least permitted temperature differential and in heat transfer between the two flow streams to guarantee appropriate functioning is (3) degrees, whereas larger temperature differences are desired. In heat source the heat carrier water moving across the soil heat exchanger should be between (5-11) ^{o}C below ambient temperature in the heating cycle and (11-17) ^{o}C over ambient temperature in the cooling process according to Kavanaugh & Rafferty [7].

2.3 Grid Study

2.3.1 Geometry Meshing

The meshing process of the model Figure 2 shows how the tetrahedral element type was used to run the model. The fluid dynamic prescribed finer element size was used to mesh the liquid area. The predefined coarser element size meshes with the earth or soil area. The matching up of the other two domains was done with bespoke generate value, which were done with defined generate value.

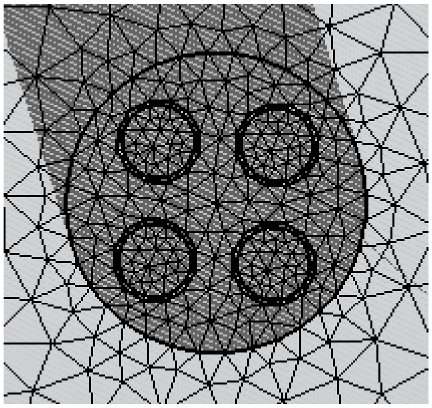


Fig. 2.31a. Grout and U-tube Meshing

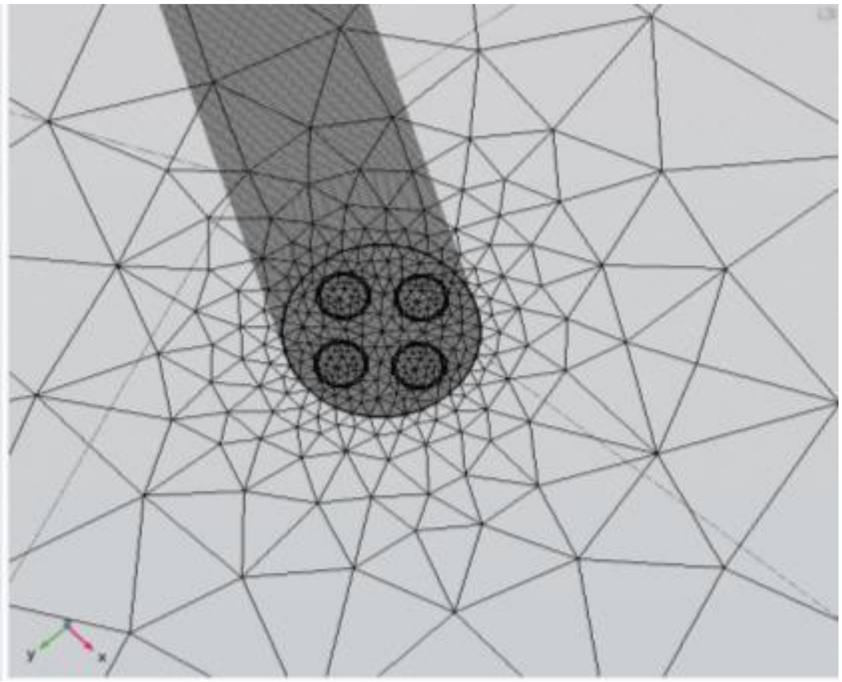


Fig.2.31b. Soil Meshing

To reduce computation time, the size of particles was chosen based on the area type fine for tube, soil, and liquid, and big for the soil area (fig.3).

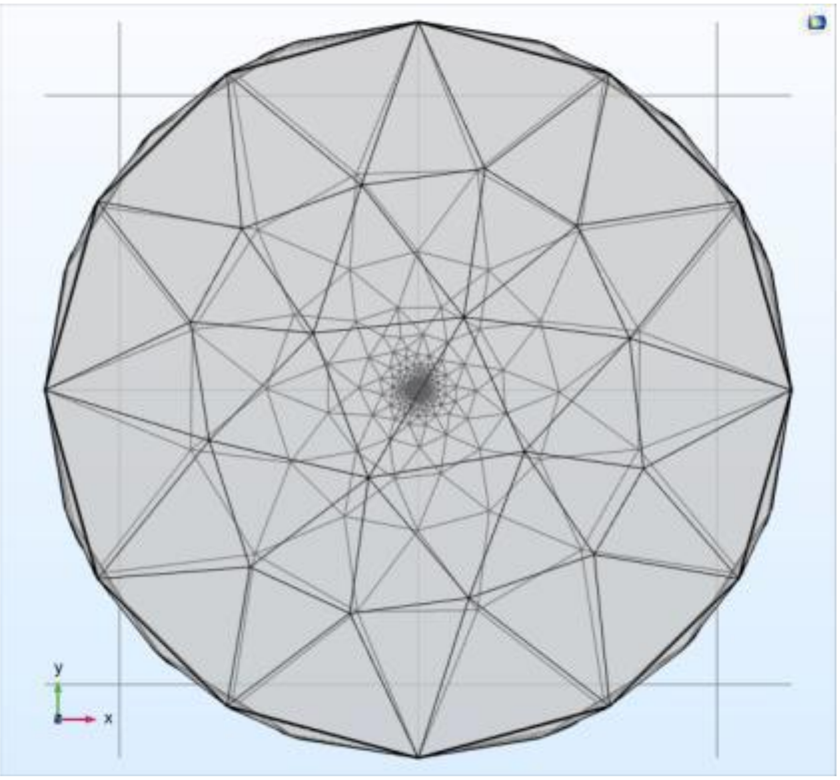
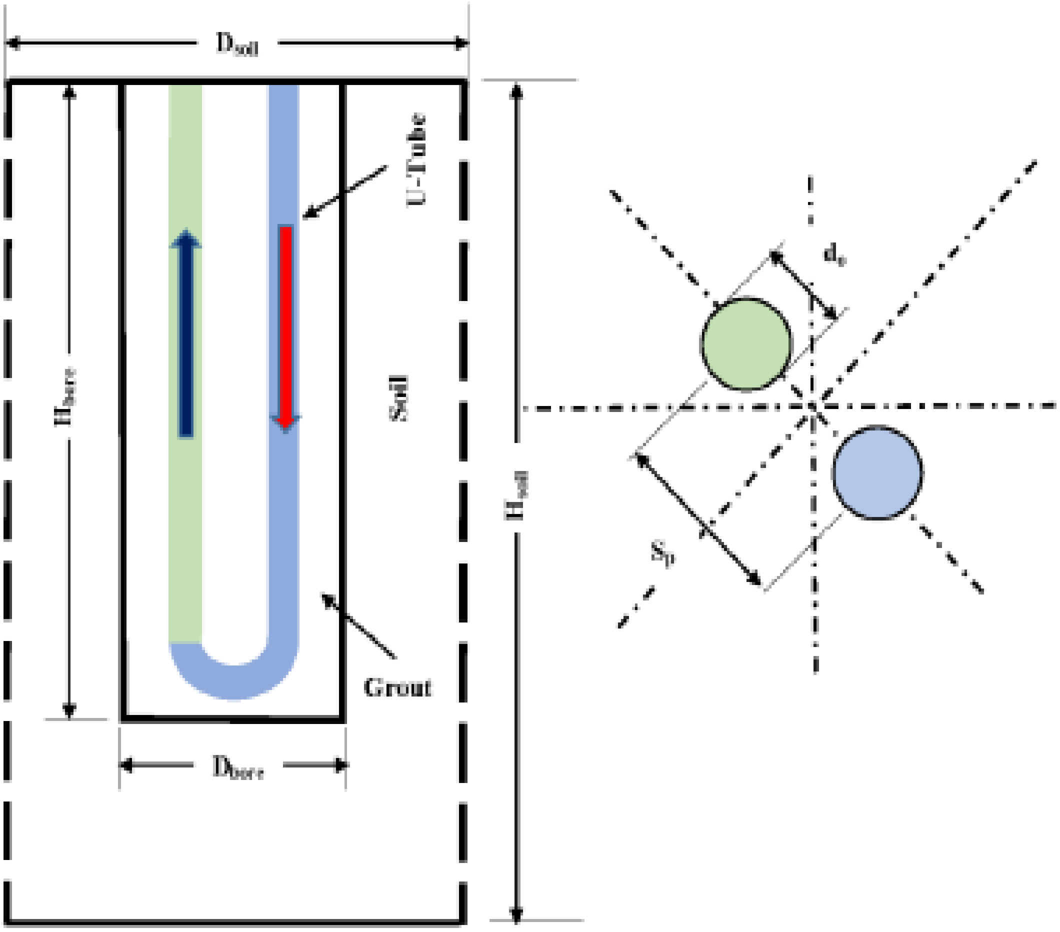


Fig. 2.31c. Element Size for meshing

This figure illustrates the construction of the examined U-tube ground heat exchanges. Parallel and series flow circuiting for the single U-tube were studied at a diagonal position in the borehole. A fixed velocity of mass flow as that of the single U-tube borehole was passed through the heat exchangers. For the parallel flow in the double U-tube (PFCD) and (PFPD) arrangements, the amount of mass rate was split evenly among the U-tubes of the heat

exchanger.

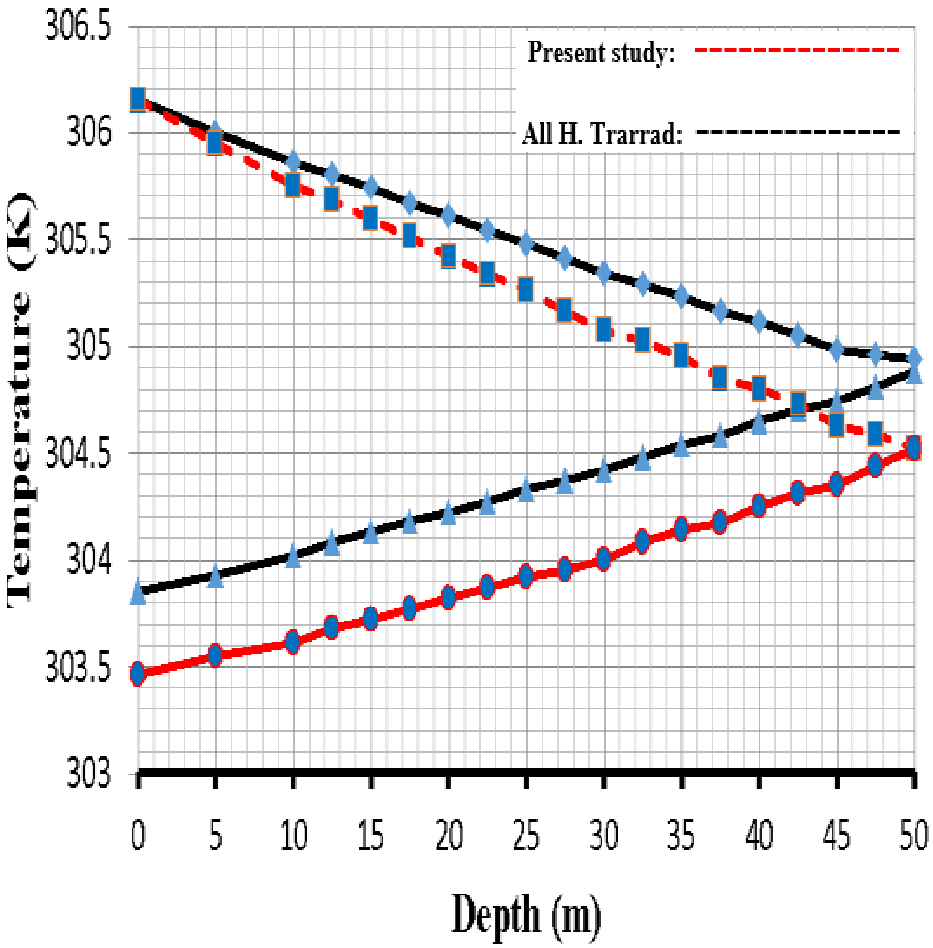


The thickness of the caulking one below the U-tube at the bottom portion was maintained at (110) mm. The area of calculation of the earth was extended to a diameter of (5) m in the r-direction, as well as a (2.5) m thick ground layer under the bottom portion of the U-tube heat exchanger in the z-direction of the geometry. **Fig. 3** shows the meshing characteristics of the borehole as implemented in the present work; a free tetrahedral element type was used.

2.3.3 Code Validation

Comparisons with previous reports are necessary to check the accuracy of the findings results and the validity of the numerical method obtained throughout the current investigation. Nevertheless, confirmation of the predictions against trial was not hundred percent perfect due to a lack of some experimental data on the specific difficulties and associated boundary conditions studied in this study, but it was very identical and close. Below are the results of the present study and the All H. Tarrad study for validation.

2.3.4 Results


Present study:
All H. Trarrad:
Temperature (K)
Depth (m)
306.5
306
305.5
305
304.5
304
303.5
303
0
5
10
15
20
25
30
35
40
45
50

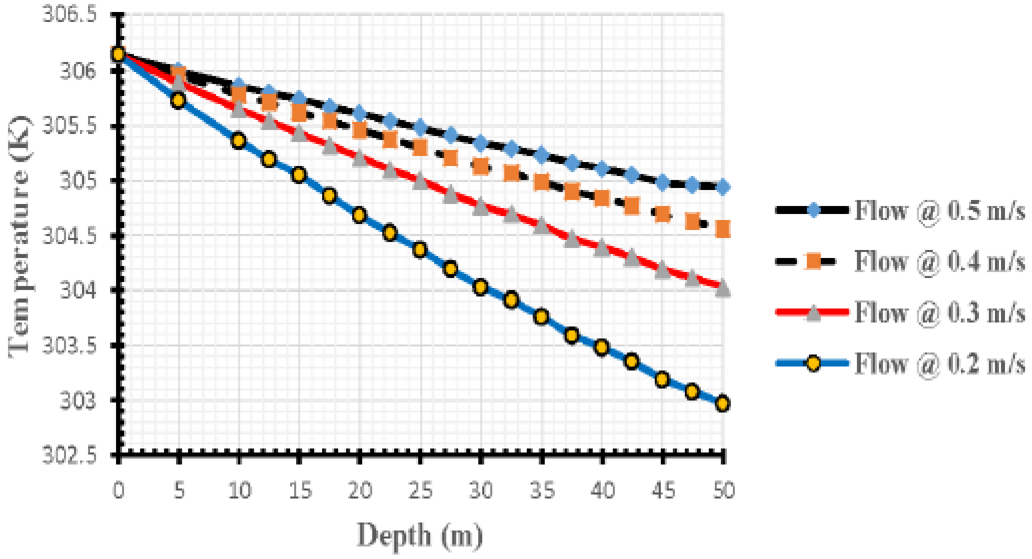
Chapter 3

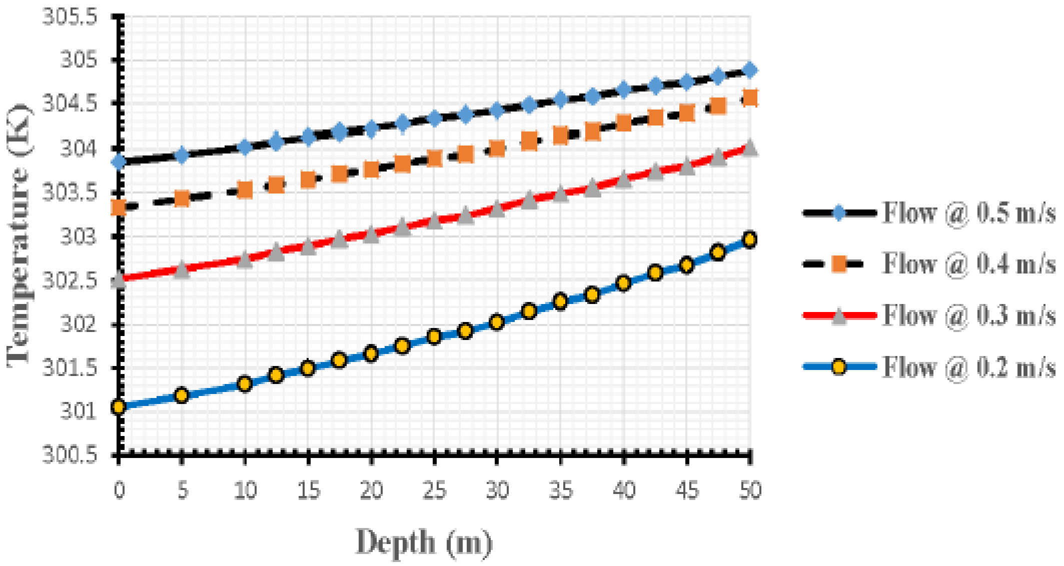
3.1 RESULTS AND DISCUSSION

The previous figures depict the fluctuation in mean fluid temperature, average grout temperature, and borehole wall temperature along the drilling depth. This really is the situation when heat is injected into the borehole. When a fluid with a greater intake temperature than the earth is injected into a borehole, the fluid loses heat towards the ground as it goes below. As a result, as seen in the previous figure, the fluid temperature drops as it descends raising the depth of the borehole first from inflow The temperature with upward fluid flowing, on the other contrary, gradually falls as the fluid flows upward from the borehole's bottom to its outlet.

Furthermore, the temperature of the grout reduces from 29.5 to 25.8 C as heat flows through the back-fill material anywhere along borehole depth. Similarly, the numerically calculated borehole surface temperature drops from roughly 25 degrees Celsius at the entrance to 22.4 degrees Celsius at the bottom. Overall, as indicated by the variance in heat transmission with depth, the fluid temperature varies along the flow channels due to heat interaction with the underlying soil.

Results





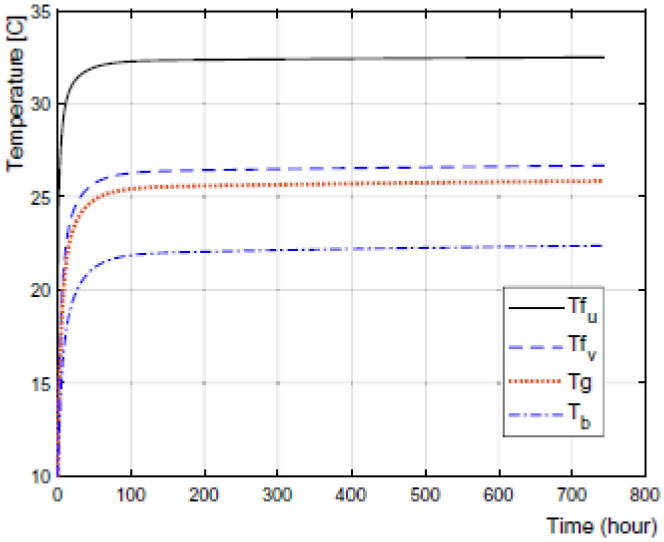


Fig 3.11: Average upward and downward flow fluid temperature, grout and borehole wall temperature variation with time.

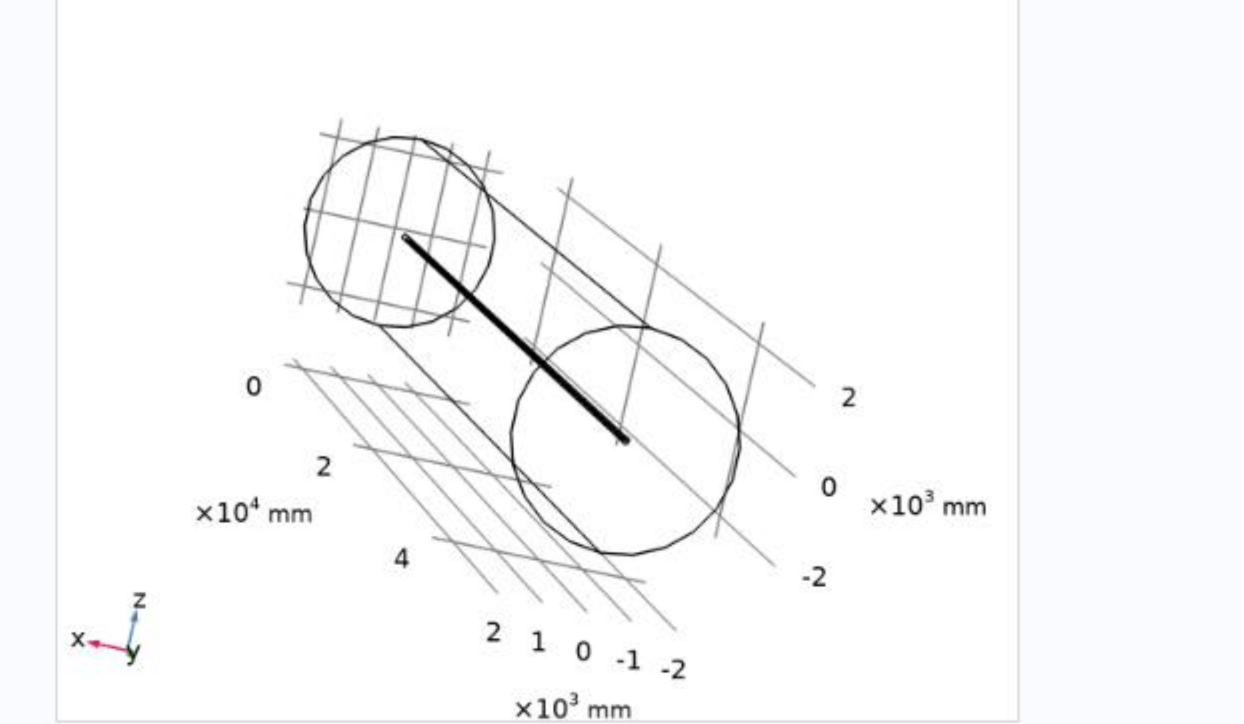
TABLE 3. RESULTS TABLE

BASIC

Description	Value
Thermal conductivity	{{2.42,0,0},{0,2,42,0},{0,0,2,42}}
Thermal conductivity symmetry	0
Heat Capacity at constant pressure	840
Heat capacity symmetry	0
TD	TD(T[1/K])[M^2/s]
TD-symmetry	0
Density	2800
Density-symmetry	0

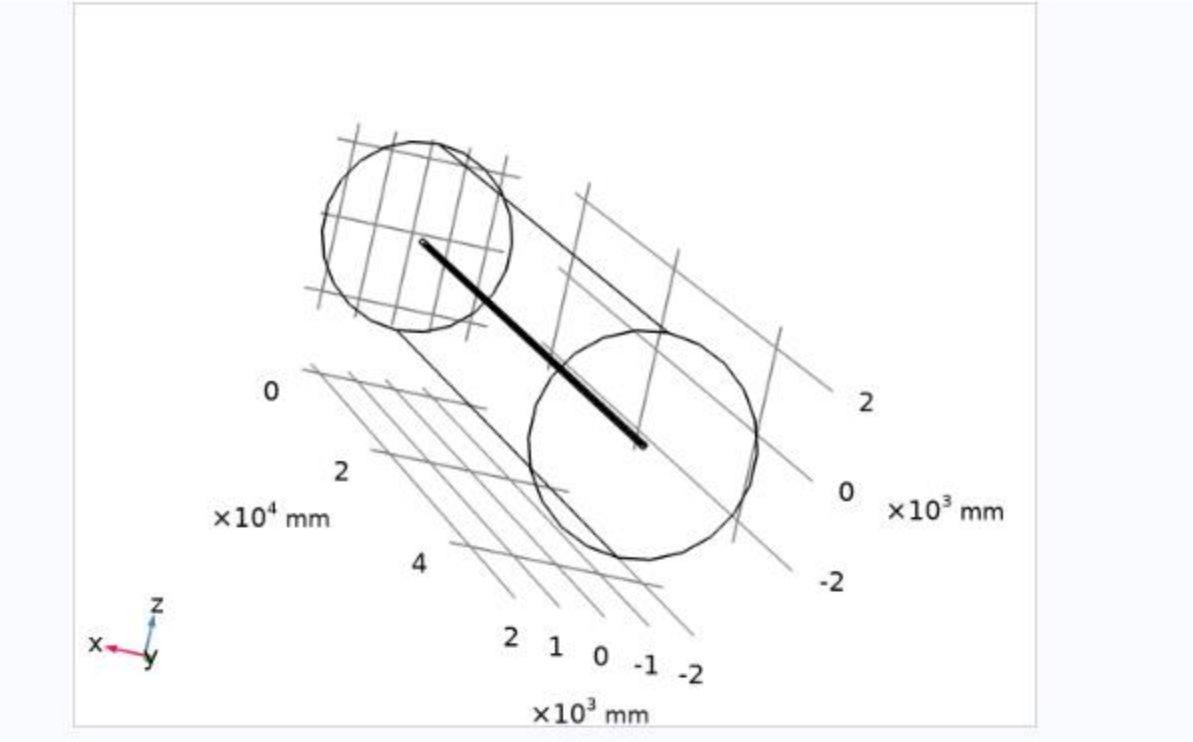
Material

Limestone(Brazil)[solid, bounded under argon]



This is simply the type of soil used in the ground surface as it has better heat conductivity and can stand certain unforeseen weather circumstances. However, our soil is totally different compared to the previous papers we followed as we wanted to make the efficiency of the heat exchanger better.

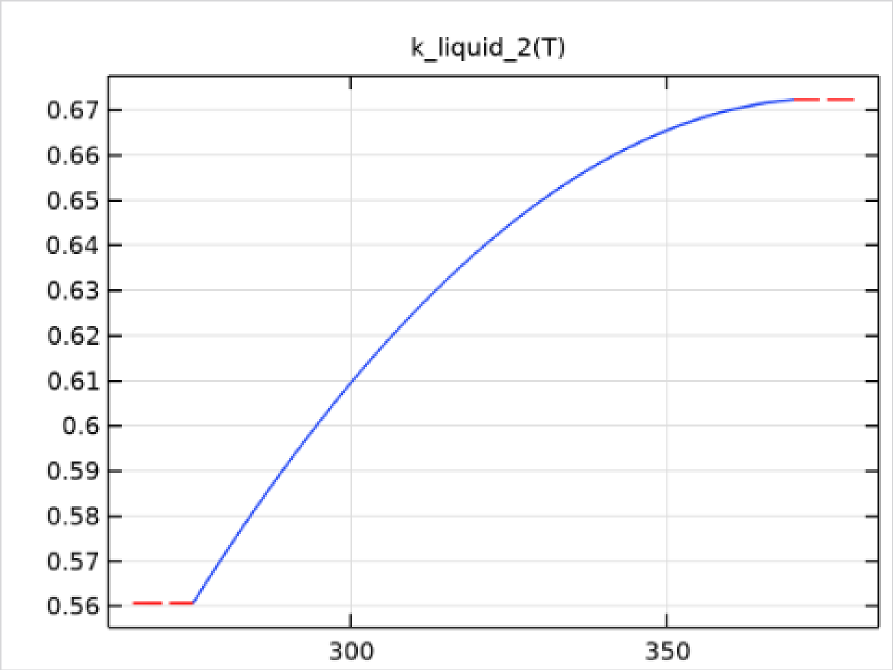
H20(water) [Liquid]



H20(Water)[Liquid]

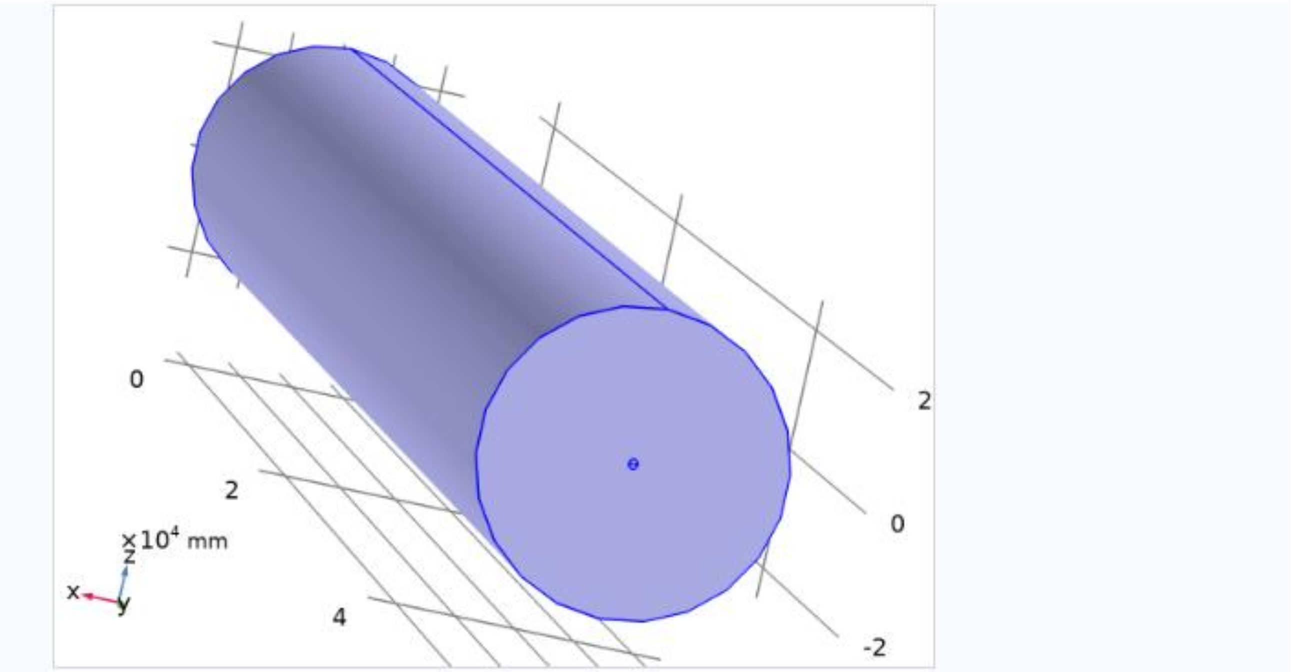
Water was used as the heat transfer medium as it has a very high heat transfer effectiveness, however it doesn’t contain high heat transfer conduction as it may evaporate easily at any temperature above 100 degrees Celsius. Moreover, for this experiment, water was found to be the most perfect heat transfer medium to be used.

Piecewise



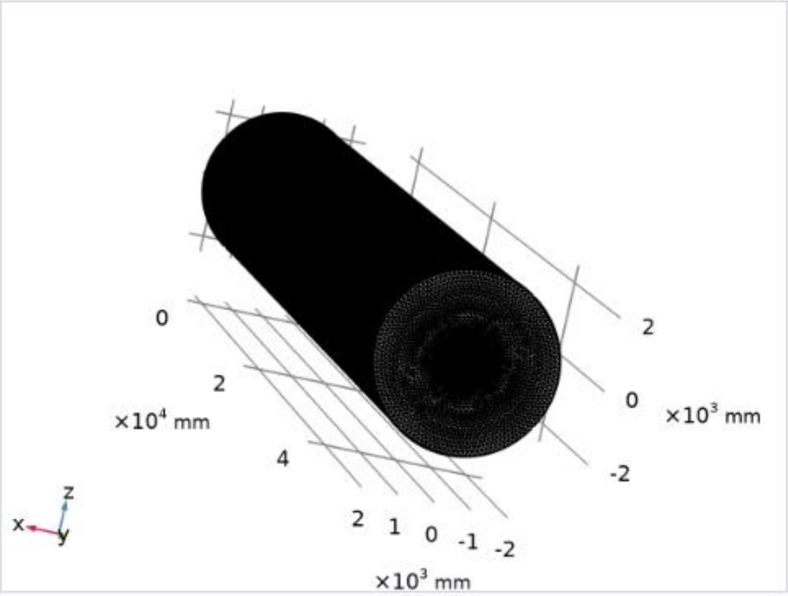
k_liquid_2

Laminar flow



Turbulence is reduced by laminar fluid flow, but it is encouraged by turbulent fluid flow, which creates unplanned swirls of air that scatter objects on walls inside an area. Turbulent flow could cause pollution and hinder work that requires a debris area.

Mesh



In comparison to coarser meshes, finer meshes suggest improved load distribution inside the unit. This idea is particularly interesting and necessary for the mesh within the loading region, and even a coarser mesh is sufficient away from the loading.

TABLE 4. MESH STATISTICS

Description	**Value**
Minimum element quality	0.0
Average element quality	0.6644
Tetrahedron	4187344
Pyramid	56
Prism	235764
Triangle	181256
Quad	176
Edge element	10102
vertex	32

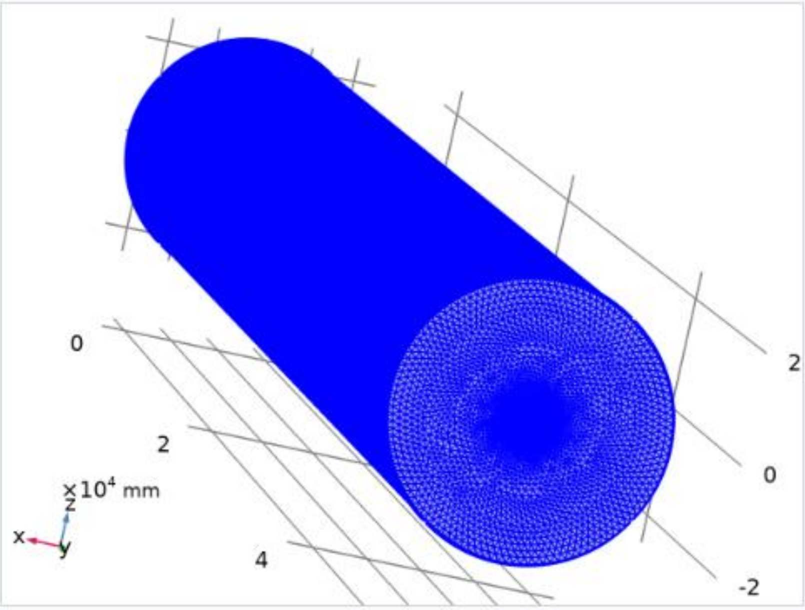
TABLE 5. SIZE

Description	**Value**
Calibrate for	Fluid dynamics
Maximum elements size	308
Minimum element size	58.2
Curvature factor	0.5
Resolution of narrow regions	0.8
Maximum elements growth	1.13
Predefined size	Fine

TABLE 6. SETTING

Description	Value
Calibrate for	Fluid dynamics
Maximum element size	134
Minimum element size	8.73
Curvature factor	0.3
Resolution of narrow regions	0.95
Maximum element growth rate	1.08
Pre-defined size	Extra fine

Boundary Layer 1



Boundary value issues are crucial because they mimic a wide range of processes and uses, including solid mechanics, heat transfer.

Water temperature distribution comparison at different flow velocities for the single U-tube

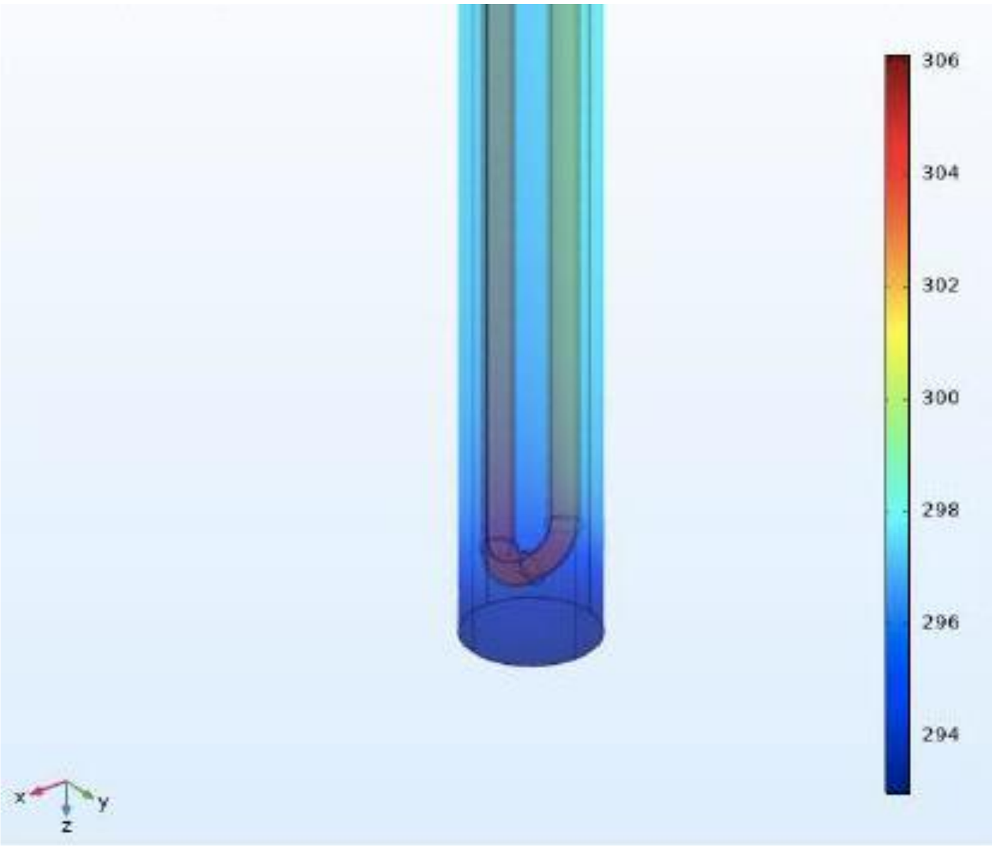


Fig 3.12a: Water Velocity of (0.2) m/s

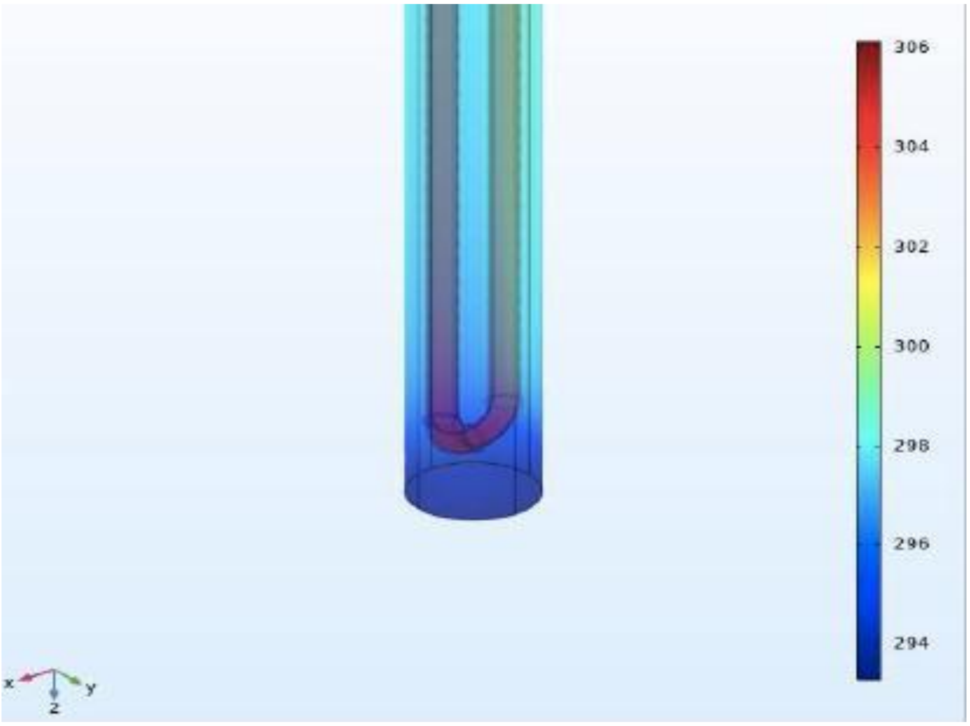


Fig 3.12b: Water Velocity of (0.3) m/s

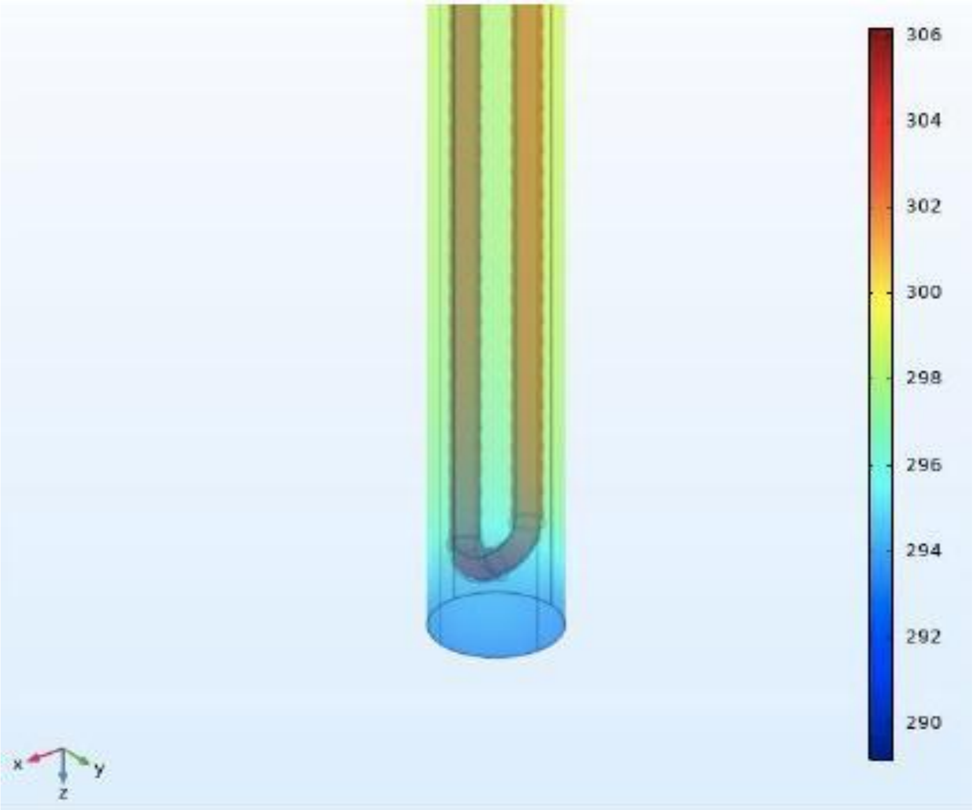


Fig 3.12c: Water Velocity of (0.4) m/s

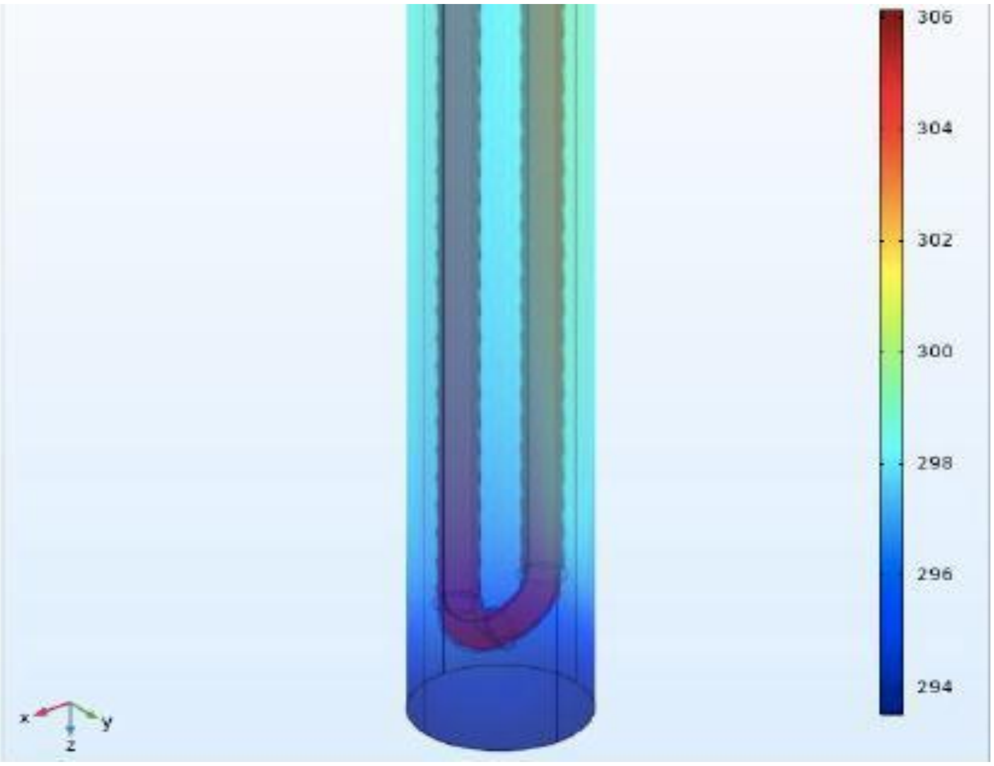


Fig 3.12d: Water Velocity of (0.5) m/s

The temperatures of the U-tube/grout system varies with drilling depth, as shown in these graphs. For both configurations, the lowest observed temperature is found near the bottom of the borehole. There was no concentric difference in the results for both studied configurations. As a result, the temperature at the borehole's wall is mostly unaffected by the concentric angle. This is because the water in both U-tube legs is at a cold temperature.

Chapter 4

4.1 CONCLUSION AND RECOMMENDATION

A three-dimensional steady-state methodology was built for single U-tube borehole heating systems in a ground-heat pumping organized network. For the heat exchanger, the downstream flow of water undergoes a significant temperature loss than the upward flow of water. Its range was between (53-66) and (60-76%) of the overall drop in temperature (Tt) for the given day. There was no substantial concentric change in the temperature gradient at the borehole surface. As a result, it is mostly unaffected by the concentric angle. A single U-tube borehole heat exchanger was subjected to heat transfer studies and simulation. The boundary integral numerical method was used to analyze unsteady heat transport formulas derived from energy balance and thermal resistance-capacitance. Change of mean fluid temperature, grout temperature, borehole wall surface temperature, ground temperature, and heat transfer to the ground with borehole depth are among the study' outcomes. Temperature, heat transfer rate, and BHE effectiveness all varied over time, according to the simulation and study. A contingency study was also carried out to look into the effects of heat carrier fluid mass flow rate and grout heat capacity on temperature reaction, borehole strain, and BHE thermal performance. Because heat transfer into the borehole changes with depth, the temperature of the fluid, grout, borehole wall, and ground fluctuate in the longitudinal axis. This demonstrated that in the heat exchange study of BHE, the fluctuation of heat transfer throughout the borehole depth should be included. Some suggestions for better efficiency and easy usage in the future are as follows:

Recommendations

- Can Increase efficiency of heat exchangers.
- Reduce the size of heat exchangers in order to use less material and make it compact for same efficiency.

- Further research can be done for the simplification of the solution to the problem given.
- Apart. from the standard procedure of design, one can design Heat Exchanger by using nonstandard procedure and can come to same results.

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