

Experimental study of Horizontal Ground Heat Exchanger

A Thesis

submitted in partial fulfillment of the requirements for the award of degree of

Masters in Thermal Engineering

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DECLARATION

I hereby declare that the thesis entitled *Experimental study of "Horizontal Ground Heat Exchanger"* submitted in the partial fulfillment of Master of Engineering in Mechanical (Thermal) Engineering to Thapar University, Patiala, is a record of candidate's own work carried out by him under our supervision and guidance. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.



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ABSTRACT

Ground heat exchanger are one of the most important part of geothermal utilization system. Factors like rising electricity prices and the environmental factors have forced us to look for cheaper and cleaner alternatives to various applications. Air conditioning, water heating and cooling is one such device that heavily consumes electricity and its emissions are detrimental to the environment. Ground heat exchangers uses underground soil as a heat sink or source. When water flows through pipes, heat is transferred from the water to the earth or from earth-to-water depending upon the temperature of water relative to temperature of earth.

In the present experimental work, water flow through the heat exchanger and exchange heat to or from the ground. The performance of horizontal ground heat exchanger investigated under different conditions of discharge of water and length of the pipe. The temperature of the inlet and outlet of the circulated water were also measured to calculate the heat exchanger rate.

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NOMENCLATURE

Q	Heat Exchange Rate (kw)
C_p	Specific Heat of the fluid at constant pressure (KJ/KgK)
ΔT	Temperature Difference ($^{\circ}$ C)
m	Mass flow rate (Kg/sec)
T_{in}	Temperature at the inlet ($^{\circ}$ C)
T_{out}	Temperature at the outlet ($^{\circ}$ C)
A	Cross sectional area of pipe (m^2)
h	Convective heat transfer coefficient (kW/ m^2 -deg)
Re	Reynolds Number
ρ	Density of water (Kg/ m^3)
Temp	Temperature of the fluid ($^{\circ}$ C)
S	Conduction shape factor
D_o	Outer diameter of the pipe (m)
D_i	Inner diameter of the pipe (m)
d	Buried depth (m)
Nu	Nusselt number
Pr	Prandtl number
u_w	Water velocity (m/sec)
μ_w	Water viscosity (kg/m sec)
K_w	Water thermal conductivity (kW/m-deg)
K_{pipe}	Pipe thermal conductivity (W/m-deg)
K_{soil}	Soil Thermal conductivity (W/m-deg)

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CHAPTER 1

INTRODUCTION

1.1 Ground Heat Exchanger:

Ground heat exchangers use underground soil as a heat sink or source. When water flows through pipes, heat is transferred from the water to the earth or from earth-to-water depending upon the temperature of water relative to temperature of earth that remains nearly constant at the annual mean temperature of that place. In some cases, the thermal condition of water coming out from the pipes is such that it can be directly supplied to the space where it is to be used, whereas in extreme weather conditions, it needs another stage of processing before becoming acceptable for supplying to the connected space. Ground temperature below a certain depth remains relatively constant throughout the year because temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia of the soil. Therefore ground temperature is always higher than that of the outside environment in winter and is lower in summer at a sufficient depth. The difference in temperature between the outside environment and the ground can be utilized as a preheating means in winter and pre-cooling in summer by operating a ground heat exchanger. Efficiency of a heat pump is higher than conventional natural gas or oil heating systems, a heat pump may be used in winter to extract heat from the ground and pump it into the conditioned space. In summer, the process may be reversed and the heat pump may extract heat from the conditioned space and send it out to a ground heat exchanger that warms the relatively cool ground. A ground source heat pump extracts heat from the ground – whose temperature will be warmer than the air in winter (and cooler than the air in summer). Therefore ground heat exchangers are more efficient than air source heat pumps, especially in the coldest weather when they are most needed. Ground heat exchangers generate very little noise and should last for many years with minimal servicing. Ground heat exchangers are the system that is simple to use and easy to maintain. In addition, since the system takes care of both heating and cooling. Geothermal energy is a form of clean energy because using it doesn't emit any type of pollution.

1.2 History

The ground heat exchanger was described by Lord Kelvin in 1853 and developed by Peter Ritter von Rittinger in 1855 [1]. After experimenting with a freezer and Robert Webber built the first direct exchange ground heat exchanger in the late 1940s. The first successful project was installed in the Commonwealth Building (Portland) in 1946 and has been designated a national historic mechanical engineering landmark by ASME. This technology became popular in Sweden in the 1970, and has been growing slowly. Open loop systems controlled the market until the development of polybutylene pipe in 1979 made closed loop systems economical. Since 2004, there are over a million units installed worldwide providing 12 GW of thermal capacity. 80,000 units are installed in the US every year and 27,000 in Sweden every year [2].

1.3 Need of Ground Heat exchanger

Factors like rising electricity prices and the environmental factors have forced us to look for cheaper and cleaner alternatives to various applications. Water heating and cooling is one such device that heavily consumes electricity and its emissions are detrimental to the environment. The high current requirements of the water heating and cooling require the installation of the high capacity electric cables. Also, because of the intermittent starting and stopping of the air-conditioners the installed capacity of the electricity has to be much higher than required for the actual running. Moreover, the gap in the demand and supply of the electricity in our country limits the suitability of the water heating and cooling. One of the alternatives that can address the above mentioned concerns and the most promising energy resources available to man is geothermal energy. It is a form of clean energy because using it doesn't emit any type of pollutions, and renewable energy because the heat within the ground goes around in a cycle so we are assured that there will always be heat available to us. Geothermal energy is mainly used in electricity production. Geothermal energy power plants are becoming a popular alternative to plants that run on fossil fuel. Geothermal energy is also used for heating, especially in many localities in Iceland, Turkey, and the United States. On a smaller scale, geothermal energy is using ground heat exchanger for heating and cooling purpose.

1.4 Mechanism of Heat Transfer

Ground heat exchangers use underground soil as a heat sink or source. Ground temperature below a certain depth remains relatively constant throughout the year because temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia of the soil. When water flows through pipes, heat is transferred from the earth to the water or from the water to the earth depending upon the temperature of water relative to temperature of earth that remains nearly constant at the annual mean temperature of that place [3].

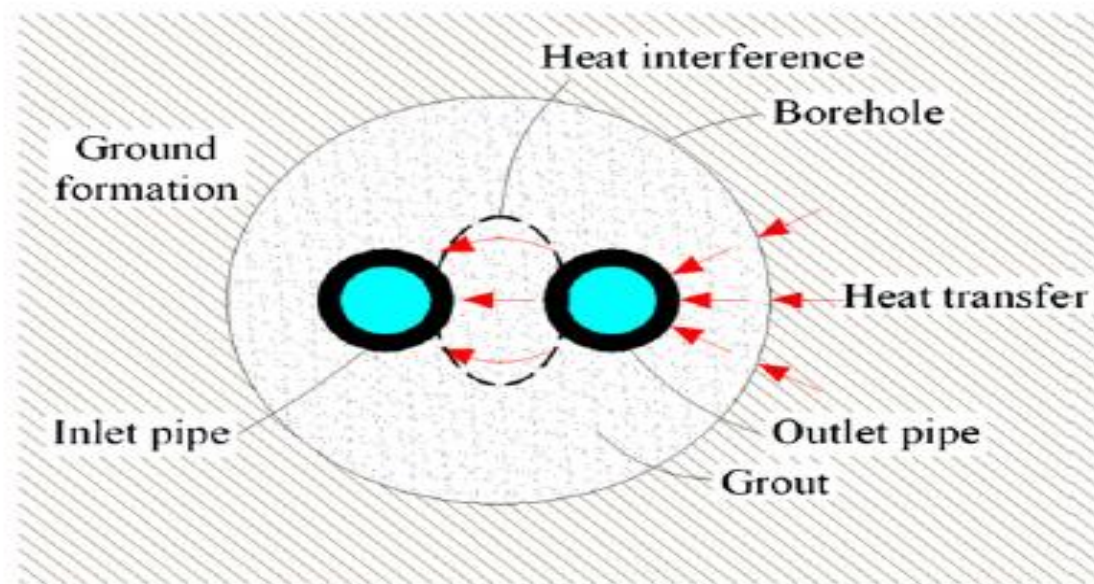


Figure 1.1: Mechanism of heat transfer (heating mode) [2]

1.5 Types of Ground Heat exchangers

There are two general types of ground heat exchangers: open system and closed system.

1. Open systems

In open systems, ambient air passes through pipes buried in the ground for preheating or precooling and then the air is heated or cooled by a conventional air conditioning unit before entering the building.

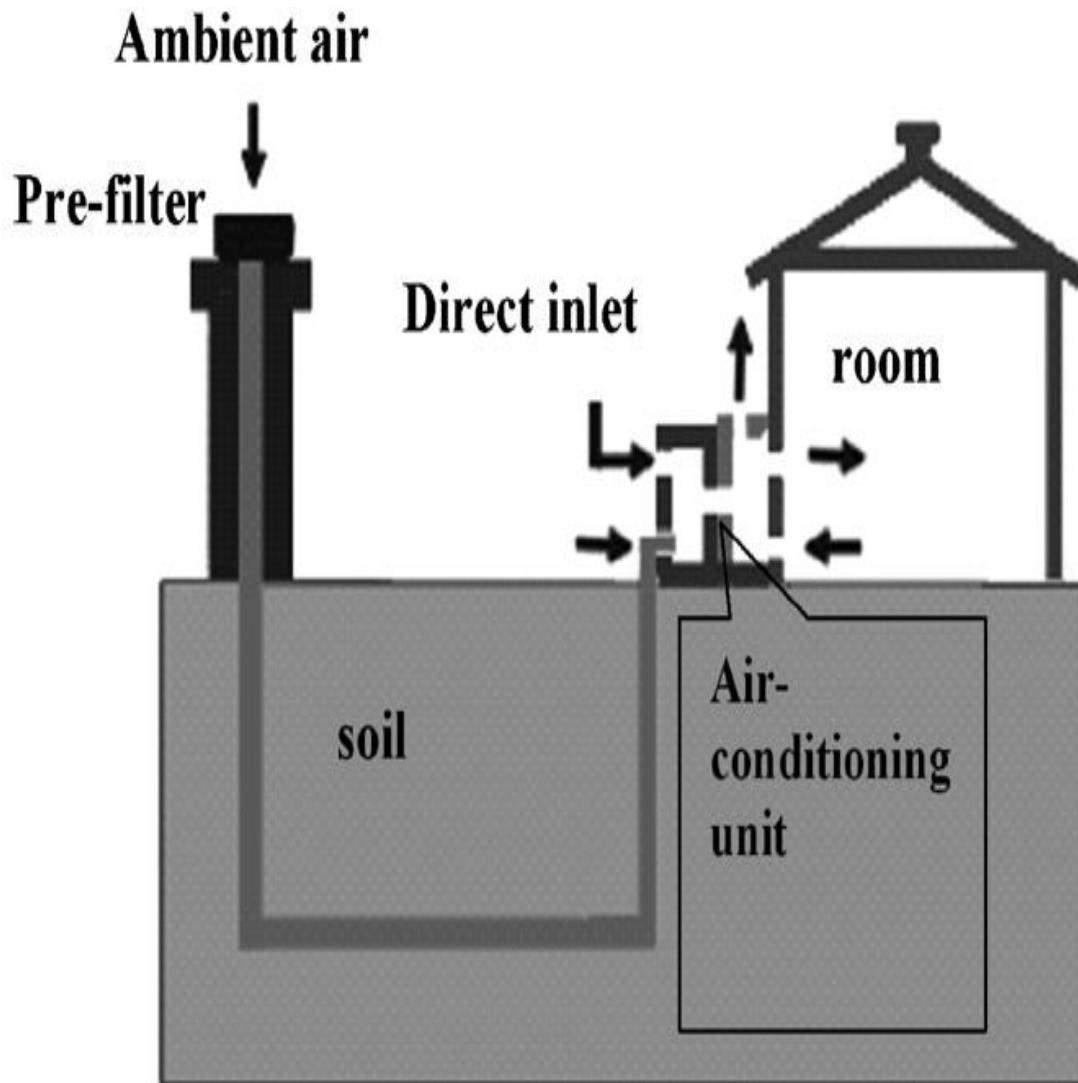


Figure 1.2: Open loop heat exchanger [3]

2. Closed Systems

In closed system ground heat exchangers are located underground, either in horizontal position or vertical position and a heat carried medium (water or air) is circulated within

the heat exchanger, transferring the heat from the ground to heat carried medium or vice versa. Closed system can be further classified into three types:

- **Horizontal type ground heat exchanger**

Figure 1.3 indicates the horizontal type ground heat exchanger which has a number of pipes connected together either in parallel or in series. This type of system is generally most cost-effective for residential installations, particularly for new constructing building where sufficient space is available. It requires trenches at least four to five feet deep. Horizontal ground loops are the easiest to install while a building is under construction.

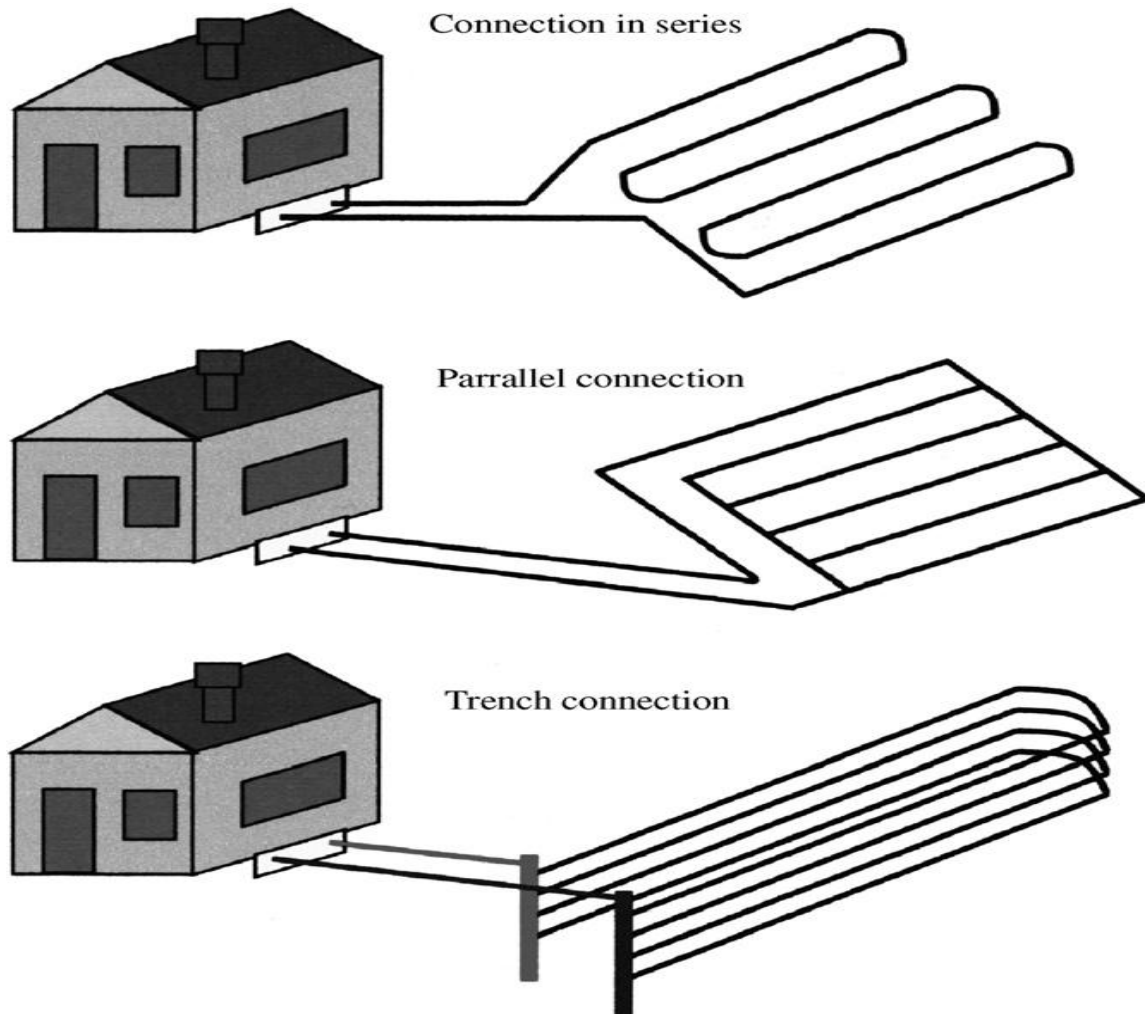


Figure 1.3: Horizontal-type ground heat exchanger [3]

- **Slinky type ground heat exchanger**

The Slinky type ground heat exchanger allows more pipe in a shorter trench, which reduced the installation costs and makes horizontal installation possible in areas it would not be with conventional horizontal applications. This configuration is usually the most cost-effective when adequate yard space is available and trenches are easy to dig. The trenchers have a depth of 1–2m in the ground and usually a series of parallel plastic pipes is used. Fluid runs through the pipes in a closed system. In USA, some special ground heat exchangers have been developed for heat pump systems, in which the pipe is curled into a slinky shape (Figure 1.4). In this way, it is possible to place more pipes into shorter trenches in order to reduce the amount of land space needed.

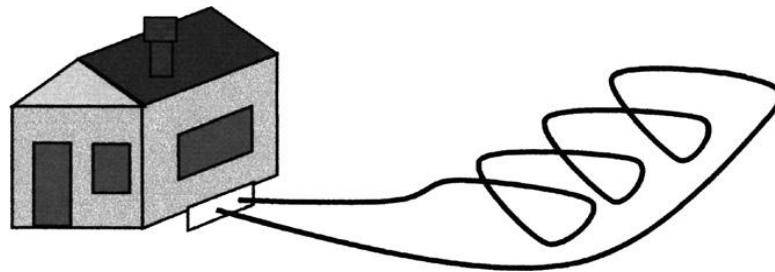


Figure 1.4: “Slinky”-type ground heat exchanger [3]

- **Vertical type ground heat exchanger**

Vertical ground heat exchangers or borehole heat exchangers are widely used when there is a need to install sufficient heat exchange capacity under a confined surface area such as when the earth is rocky close to the surface, or where minimum disruption of the landscape is desired. This is possible because the temperature below a certain depth remains constant over the year. In a standard borehole, which in typical applications is 50–150m deep, plastic pipes are installed, and the space between the pipe and the hole is filled with an appropriate material to ensure good contact between the pipe and the undisturbed ground and reduce the thermal resistance .

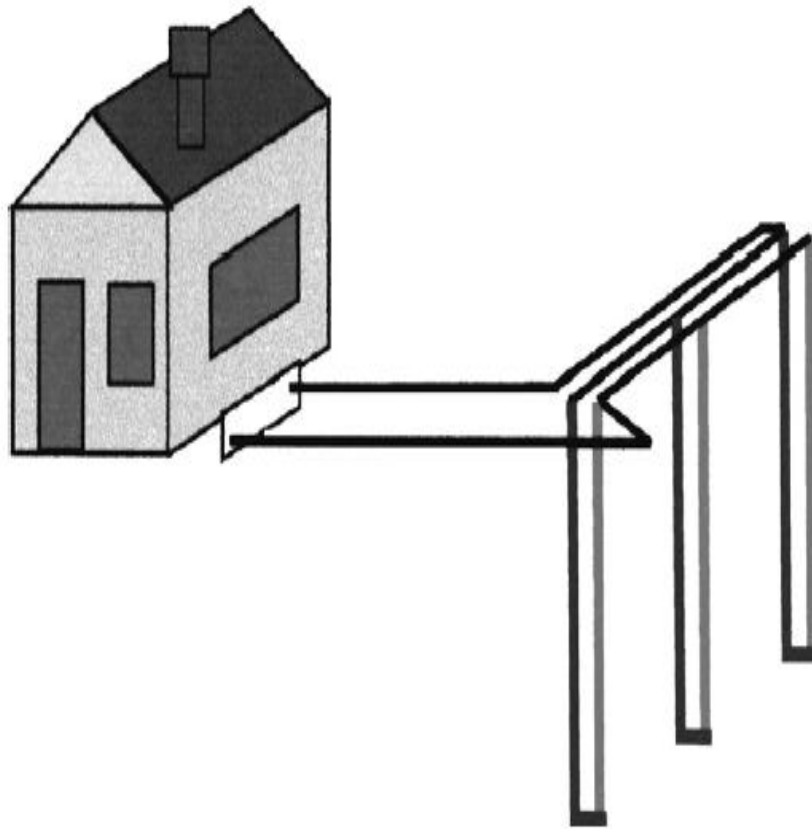


Figure 1.5 : Vertical ground heat exchangers [3]

1.6 Ground-source heat pumps

Ground-source heat pumps, often referred to as geothermal heat pumps, are recognized to be heating, cooling, and water-heating systems. They provide high levels of comfort, offer significant reductions of electrical energy use and demand, have very low, levels of maintenance requirements, and are environment friendly. A ground source heat pump is a heating and cooling system that transfers heat to or from the ground, using the ground as a heat sink in the summer and heat source in the winter. A ground source heat pump can be significantly more energy efficient than conventional air source heat pump.

Ground source heat pumps have several advantages over conventional air source heat pumps as:

- a) They consume less energy to operate.
- b) They are more stable energy source than air.
- c) They do not require supplemental heat during extreme low outside temperature
- d) They have a simpler design and consequently less maintenance.
- e) They do not require the unit to be located where it is exposed to weathering.

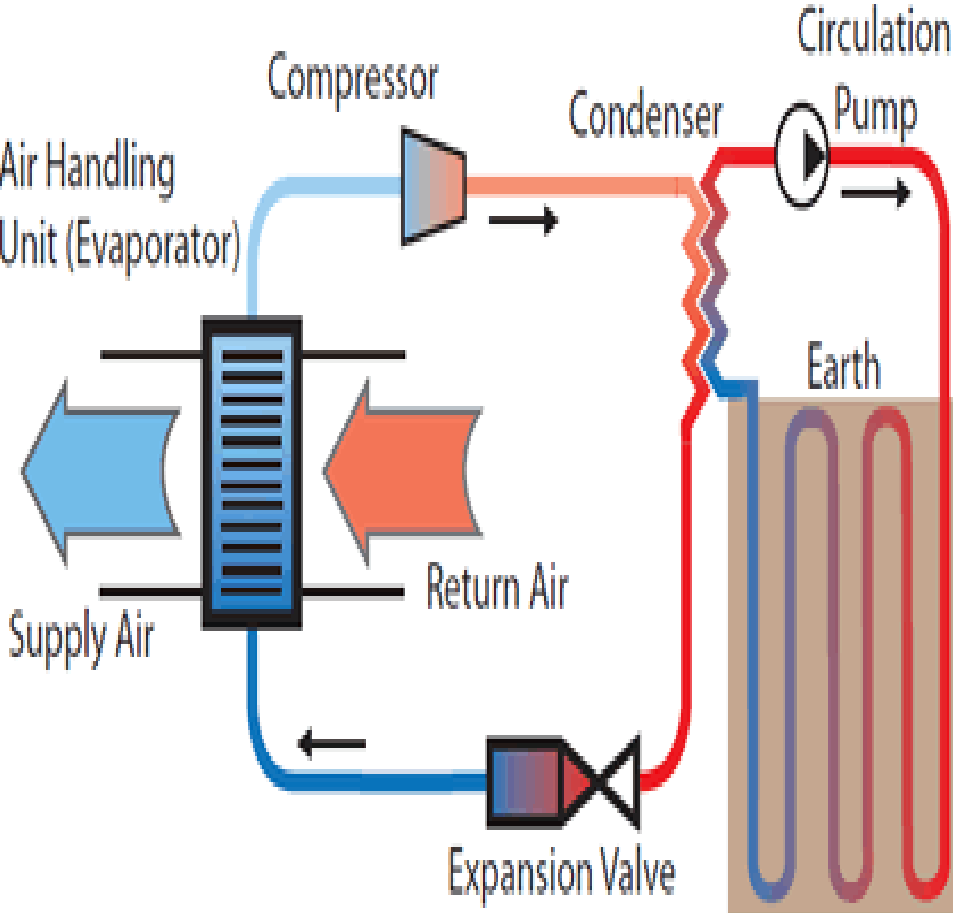


Figure 1.6: Heat Pump [4]

1.7 Convective Heat Transfer

Convection is the transfer of heat from one place to another by the movement of fluids (liquid and gas). Convection is a dominant form of heat transfer in fluids. The term convection can refer to transfer of heat by fluid movement. The process of transfer of heat from a solid to a fluid or from fluid to surface requires not only transfer of heat by bulk motion of the fluid, but also by conduction of heat through the still boundary layer next to the solid. Thus, convection is a process with a moving fluid requires both advection and diffusion of heat. The convection heat transfer depends upon the type of fluid, the area of contact and the temperature gradient. This is mainly classified as natural or free convection and forced convection. Natural convection mainly due to the variations of the density due to the temperature gradient in the fluid, On the other hand, forced convection is artificially induced by means of some external source like fan or blower.

Free Convection

When fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid. In the absence of any type of external source, when the fluid comes in contact with a hot surface, its molecules separated and scattered, causing reduction in density of the fluid .

Forced Convection

When a fluid is forced to flow over the surface by an external source such as fans, by stirring, and pumps, creating an artificially induced convection current. The heat transfer in forced convection, for the purpose of analysis is considered under separate heads namely laminar heat transfer and turbulent heat transfer. The heat transfer depends upon the Nusselt number which in turn is proportional to the Reynolds number, hence heat transfer rate in laminar flow heat transfer is lower than the heat transfer rate in turbulent flow. To best utilise the given length of the pipe, we will use turbulent flow to achieve higher heat transfer rates.

1.8 Methods for the determination of thermal conductivity of ground formation

Thermal conductivity of a soil/ground formation is defined as the amount of heat passing per unit time through a unit cross-sectional area of soil/ground formation under a unit temperature

gradient applied in the direction of this heat flow. The soils and ground formations are made up of different compositions and layers; thus, the definition of the thermal conductivity is understood to suggest an effective thermal conductivity. Additional complications arise by considering other factors that effect the conductivity such as the moisture content of the formation since the effective conductivity of the same unit element will vary for different moisture contents. Thermal conductivity of soil can be measured by two methods:

- **Steady State Methods**

The most important steady state method for measuring the effective thermal conductivity of soils/ground formations is the guarded hot plate test, which has been standardized by the American Society for Testing and Materials. In this test, two identical test specimens are placed above and below a flat-plate main heater unit that is surrounded by an outer guard heater. The guard eliminates the horizontal heat losses and causes heat from the main heater to flow vertically up or down the test specimen. Liquid cooled heat sinks are placed adjacent to the outer surfaces of the specimen. A certain temperature drop is obtained across each specimen of known thickness. Since the amount of heat transferred per unit time and the test area of the specimen is known, the thermal conductivity can be calculated using Fourier's law of heat conduction. The method is quite time-consuming and suitable only for laboratory use.

- **Transient Methods**

The transient method is the thermal probe or thermal "needle" method, which is a rapid and convenient way of measuring the effective thermal conductivity of soils and/or ground formations in the laboratory or in situ. The thermal "needle" consists of a heater producing thermal energy at a constant rate and a temperature-sensing element (a thermocouple or a thermistor). The "needle" is inserted into the ground/test specimen and the rate of rise in the temperature of the "needle" depends on the thermal conductivity of the surrounding formation. The theory of the thermal probe is based on the theory of the line heat source placed in a semi-infinite, homogeneous and isotropic medium. Variations of the general Fourier equation of one-dimensional heat conduction in cylindrical coordinates that can be used to explicitly solve the thermal conductivity of the surrounding medium.

1.9 Ground Thermal Behavior

The use of direct or indirect earth-coupling techniques for buildings and agricultural greenhouses requires knowledge of the ground temperature profile at the surface and at various depths. The temperature profile below the ground surface affected by ambient conditions of the climate and need to be considered when designing a ground heat exchanger. Ground temperature distribution is affected by the structure and physical properties of the ground, the ground surface cover (e.g., bare ground, lawn, snow, etc.) and the climate interaction (i.e., boundary conditions) determined by air temperature, solar radiation, wind, rainfall and air humidity..

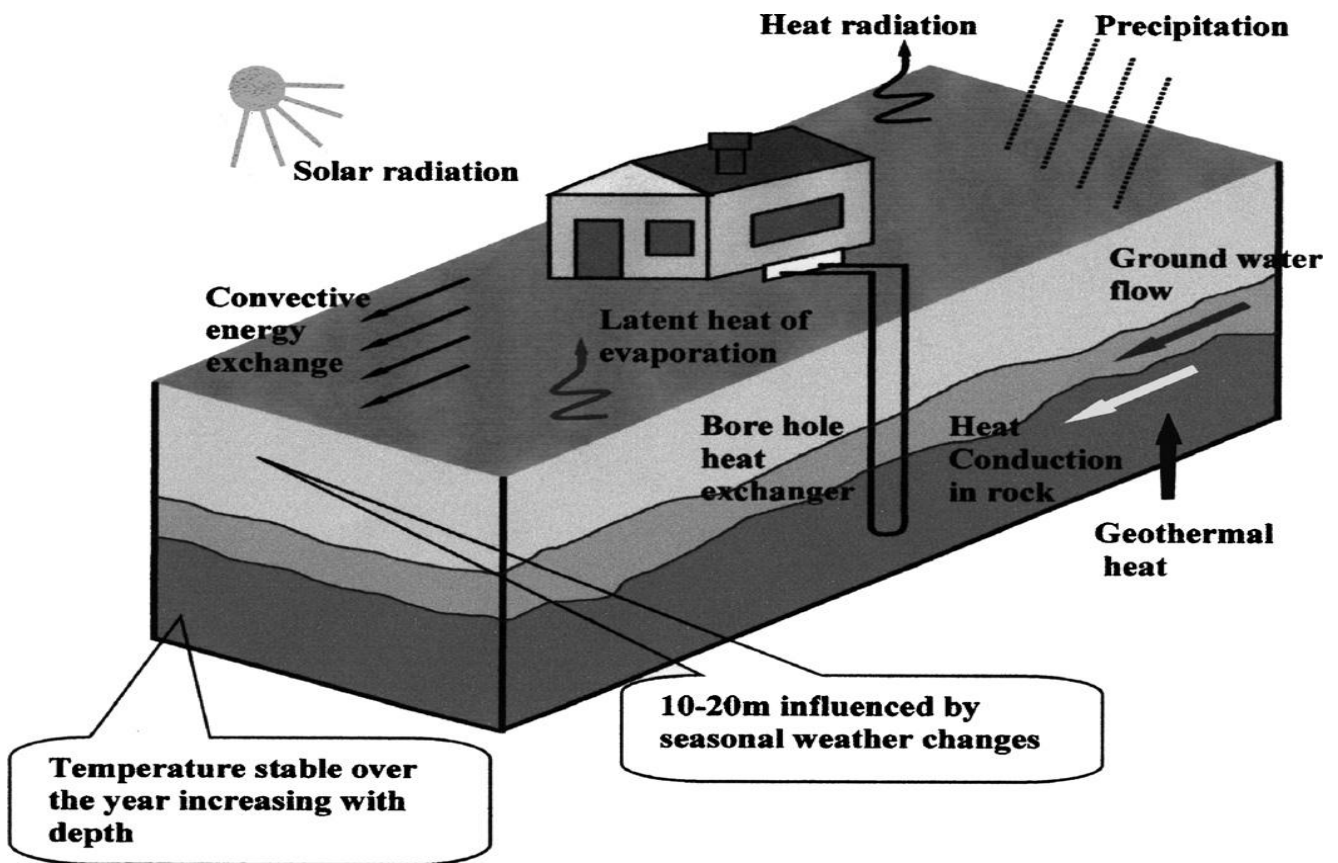


Figure 1.7: Energy flows in ground [3]

From the point of view of the temperature distribution, there are three different ground zones [2]:

1. **Surface zone** at a depth of about 1m, in which the ground temperature variation depend on the weather conditions.
2. **Shallow zone** extending from the depth of about 1–8 m (dry light soils) or 20 m (moist heavy sandy soils), where the ground temperature is almost constant and close to the average annual temperature. In this zone the ground temperature distributions depend mainly on the seasonal cycle weather conditions.
3. **Deep zone** (below about 8–20 m), where the ground temperature is almost constant (and very slowly rising with depth according to the geothermal gradient).

1.10 Environmental impact

The US Environmental Protection Agency (EPA) has called ground heat exchanger the most energy efficient, cost effective and environment friendly space conditioning systems available. Ground heat exchangers have unsurpassed thermal efficiencies and produce zero emissions, but electricity supply includes components with high greenhouse gas emissions, unless the owner has opted for a 100% renewable energy source [1]. Their environmental affect therefore depends on the characteristics of the electricity supply source and the available alternatives.

1.11 Advantages and Disadvantage of Ground Heat Exchanger

1.11.1 Advantages:

1. Ground heat exchanger always produce less greenhouse gases
2. Ground heat exchanger system is very simple to use, easy to operate and work quietly.
3. Low maintenance cost and the high reliability of the system
4. Ground heat exchanger work in both winter and summer.

1.11.2 Disadvantages:

1. Ground heat exchanger is expensive to install
2. A ground heat exchanger will typically costs twice that of a conventional system.
3. Another potential disadvantage of a geothermal heating and cooling system can be finding an installer in your area.
4. Ground heat exchanger is only usually recommended and best used in new houses which meet the latest building regulations of excellent insulation and air-tightness.

CHAPTER 2

LITERATURE REVIEW

Review of literature has been carried out indepth understanding of problem definition and its solution. The literature consist research papers mainly from the ground heat exchanger .

Firstly the literatures based on ground heat exchanger are reviewed and the variations of efficiency to some parameters e.g. length of the pipe, diameter of the pipe, mass flow rate etc is observed. Some papers and books are followed for the knowledge of ground heat exchanger.

Literature of ground heat exchanger is studied profoundly. The main points of my literature review are:

Soteres et al [3] discussed various types of ground heat exchanger and stated that temperature at a certain depth in the ground remains nearly constant throughout the year. The ground capacitance can be regarded as a passive means of heating and cooling of buildings. A vertical borehole heat exchanger was drilled to a depth of 20–300 m with a diameter of 10–15 cm. It was found that performance of ground heat exchanger was effected by length of bore hole, U-tube shank spacing, thermal conductivity of the grout and diameter of the pipe.

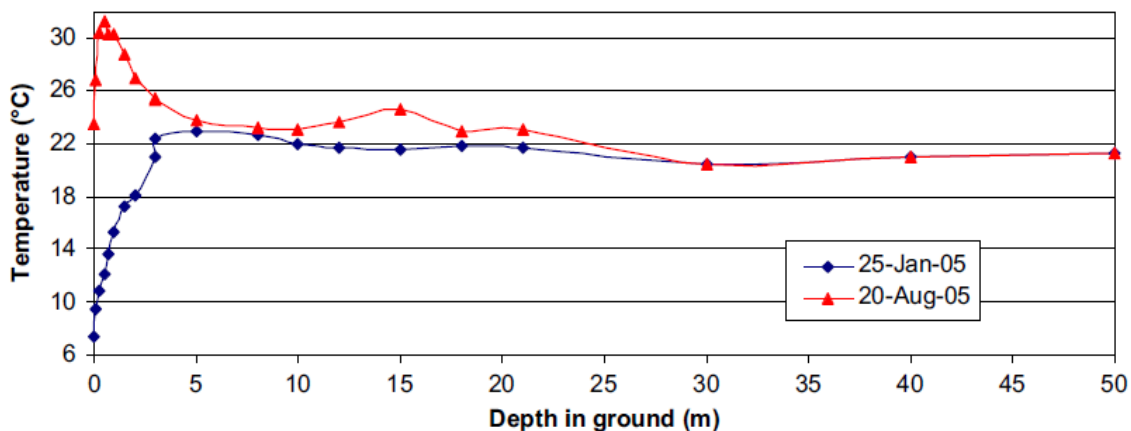


Figure 2.1: Temperature variation with depth [3]

Ascione et al [4] investigated the energy performances of an earth-to-air heat exchanger for an air conditioned building for both winter and summer conditions. The performance of the systems have been analyzed for different boundary conditions such as the type of soil, pipe material, pipe length, depth, velocity of the air crossing the pipe, ventilation air flow rates. Normally, the soil temperature at a depth of 5 to 8 m under the ground level remains almost constant throughout the year.

The following conclusions were drawn as for summer conditions:

- The influence of the tube material (usually, PVC, metal or concrete) on the energy performance is negligible
- Low speeds (about 8 m/s) of the air flow inside the tubes are preferable, as the pressure drops and fan electric energy requirements decrease; the higher energy costs due to the use of intake fans instead of exhaust ones are negligible
- The performances of the system is best for wet/humid soil

Vahid Khalajzadeh et al [5] discussed a variable undisturbed ground temperature profile of a vertical ground heat exchanger and the presence of underground water flow is not considered. A full three dimensional computational fluid dynamics simulation with 3.5 % error was performed using the CFD software. The objective of this paper was to quantify the total heat transfer efficiency and heat exchanger efficiency of vertical ground heat exchanger. As the depth of borehole is increased, the heat exchanger efficiency is increased but the total heat transfer efficiency is decreased. Optimization was performed with the conditions which are heat exchanger efficiency and total heat transfer efficiency.

Hikmet Esen et al [6] presented a model to find out the temperature distribution of U tube borehole for ground coupled heat exchanger system according to borehole depth. In this study vertical drilling of bore was carried for three different depth as 30, 60 and 90 meter. The best performance of the system was obtained at a depth of 90 meter but optimum depth is about 60 meter. In this study experimental result compared with simulation result which was performed by

commercial code ANSYS . Design length and performance of heat exchanger strongly depend on the thermal conductivity of the backfill material

Zonghe zheng et al [7] investigated effect of thermal conductivity of soil on the performance of vertical U tube ground heat exchanger and effect of center distance of the U tube legs. In this study center distance of the U tube legs at a distance of 60 mm, 80 mm and 100 mm was considered. The heat transfer was more prominent between the two tubes at a center distance of 60 mm but there was a considerable decrease in the heat transfer when distance between two legs was increased from 80 mm to 100 mm.

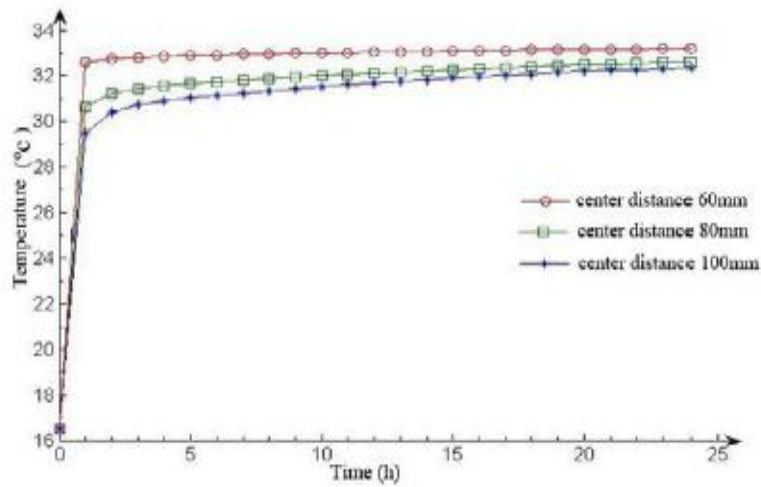


Figure 2.2: Temperature curve for different center distance [7]

Bansal et al [8] investigated the performance of horizontal earth pipe air heat exchanger and effect of flow velocity and material of the pipe on the performance of the system. In this study it is concluded that convective heat transfer is more important than conductive heat transfer and therefore performance of the system does not depend on the type of material. With increase in flow velocity, rise in air temperature decreased.

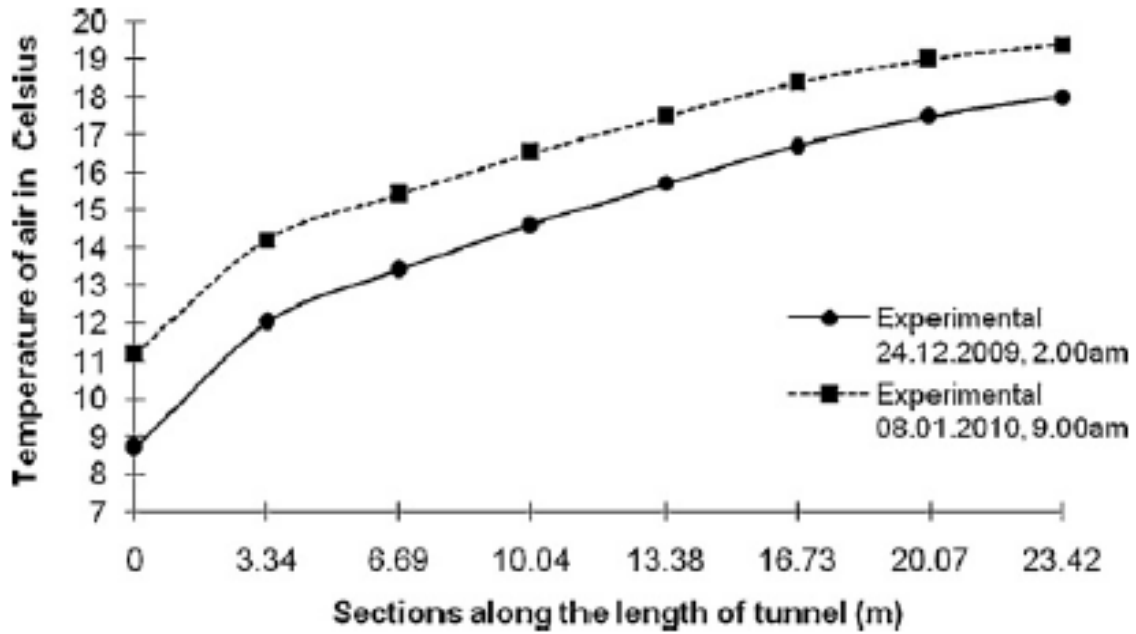


Figure 2.3: Temperature variation along the length of the tunnel in winter conditions for air velocity of 5 m s^{-1} [8]

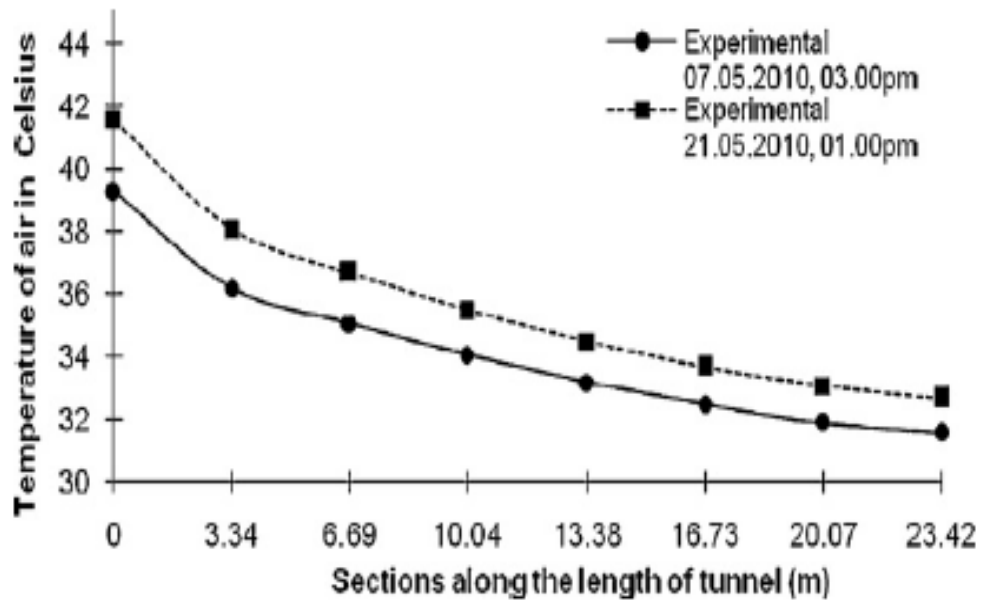


Figure 2.4: Temperature variation along the length of the tunnel in summer conditions for air velocity of 5 m s^{-1} [8]

Popiel et al [9] investigated that there are three different ground zones according to temperature distribution:

- Surface zone reaching at a depth of about 1 m, in which the ground temperature is very sensitive to weather conditions.
- Shallow zone extending from the depth of about 1–8 m (for dry light soils) or 20 m (for moist heavy sandy soils), where the ground temperature is almost constant and close to the average annual air temperature; in this zone the ground temperature distributions depend mainly on the seasonal cycle weather conditions.
- Deep zone (below about 8–20 m), where the ground temperature is practically constant (and very slowly rising with depth according to the geothermal gradient

Wang et al [10] investigated that due to ground water flow performance of borehole heat exchanger increased and based on the measurement of the natural ground temperature profile, a theoretical model was presented to estimate the affect of groundwater flow.

Mihalakakou et al [11] presented a complete model for the prediction of the daily and annual variation of ground surface temperature. With the help transient heat conduction, differential equations and an energy balance equation at the ground surface to predict the ground surface temperature. The energy balance equation included the convective energy exchange between soil and air, the solar radiation absorbed by the ground surface.

Kyriakis et al [12] presented a new analytical model, capable to determine the required ground heat exchanger length. Heat flow does not remains constant over time because it depends on the thermal load of the building and on the coefficient of performance of the heat pump. Heat pump electricity consumption reduced with increase of the overall heat exchanger length. Instalation cost increase with increase of overall heat exchanger lengh therefore final decision regarding the length must be based on the combination of the installation and operation cost.

G. Colangelo et al [13] investigated the efficiency and energy behavior of horizontal ground heat exchanger for different configurations (Linear and helical). The calculations were made

with the Fluent and the simulations covered one year of system operation for climate conditions of the South of Italy. In this work, a comparative analysis of two types of horizontal ground heat exchangers, to be coupled with water to water heat pumps, had been performed. For each type ground heat exchanger water velocity and ground thermal conductivity is varied in order to investigate the performance of ground heat exchanger. The heat exchangers were simulated under different operating conditions. Water mass flow rate was set at 3 different levels (0.25 kg/s, 0.50 kg/s, 1.00 kg/s). The most important parameter that affect the performance of the system was the thermal conductivity of the ground around the heat exchanger. The velocity of the heat transfer fluid inside the pipe was another key factor. The depth of installation of the horizontal ground heat exchangers did not affect the performance. The helical heat exchanger arrangement show the best performance.

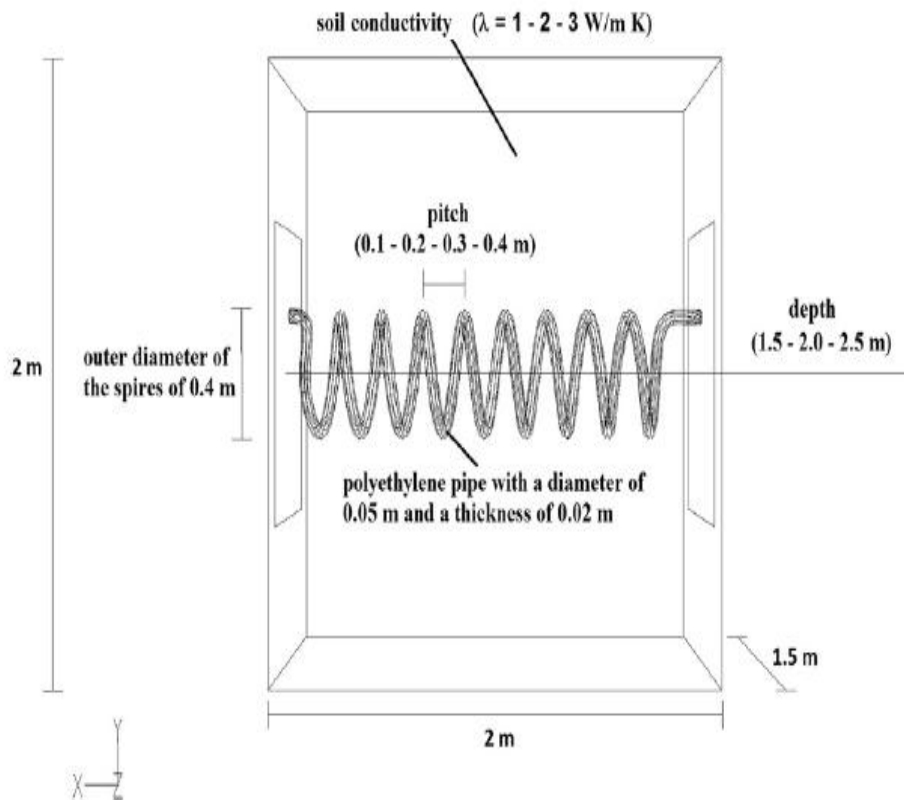


Figure 2.5: Helical horizontal ground heat exchanger configuration considered in the simulations[13]

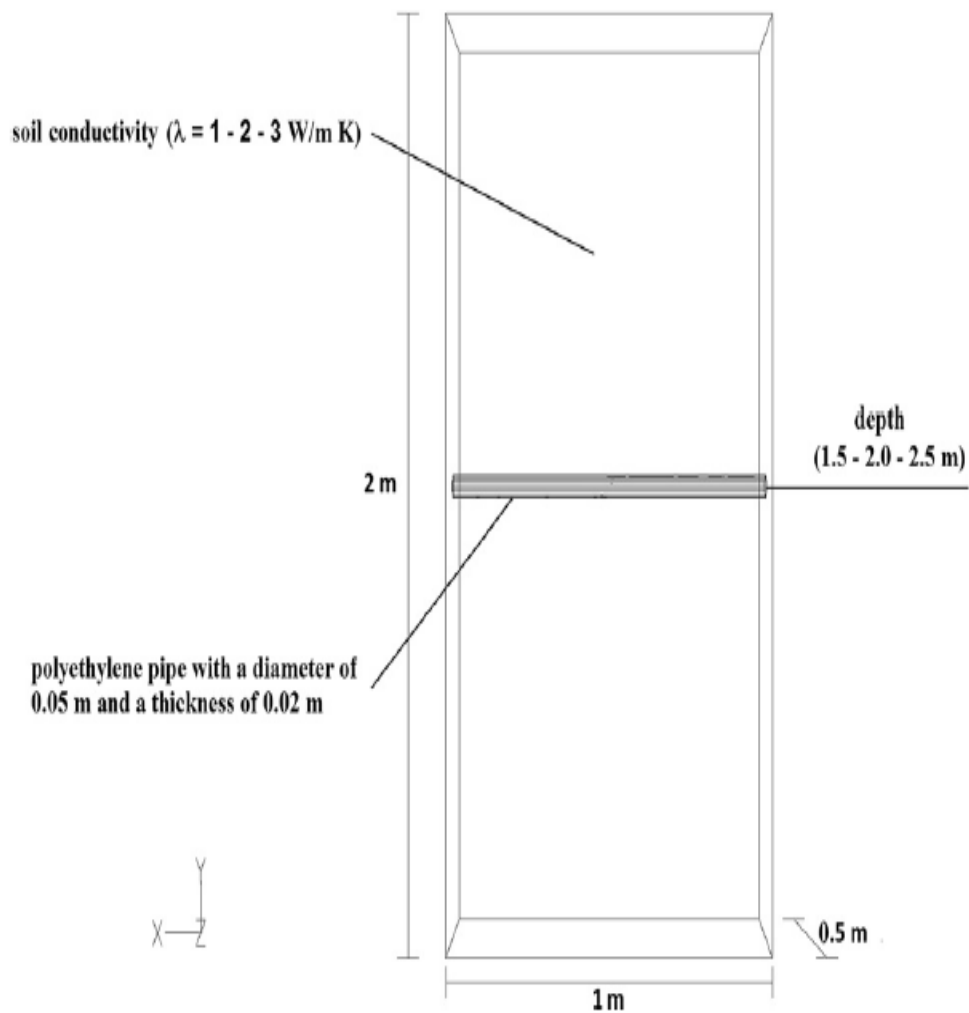


Figure 2.6: Linear horizontal ground heat exchanger configuration considered in the simulations [13]

Leong et al [14] studied the effect of soil type and moisture content on ground heat pump performance and found that the performance of a ground heat pump system was found to depend strongly on the moisture content and the soil type (mineralogical composition). Alteration of soil moisture content from 12.5% of saturation to complete dryness strongly decreases the ground heat pump performance, and any reduction of soil moisture within this range has a devastating effect.

Yavuzturk et al [15] studied both U-tube and coaxial ground heat exchanger. Coaxial geometry may have some advantages in reducing the bore hole thermal resistance, which represents the resistance between the circulating fluid and the bore hole wall. Decreasing bore hole thermal resistance increases the heat transfer between the fluid and the ground.

Zoi Sagia et al [16] studied that bore hole thermal resistance in ground heat exchanger (GHE) is affected by parameters such as geometrical attributes of heat exchanger in the bore hole, pipe properties and grout thermal conductivity. Borehole thermal resistance decreased as shank spacing between GHE pipes increased, a rise in grout's thermal conductivity leads to a fall of bore hole resistance and the slighter wall pipe enabled a bigger heat transfer rate between the heat carrier fluid and the ground [17]. A small value of borehole thermal resistance is desirable in order to achieve a high performance of ground heat exchanger.

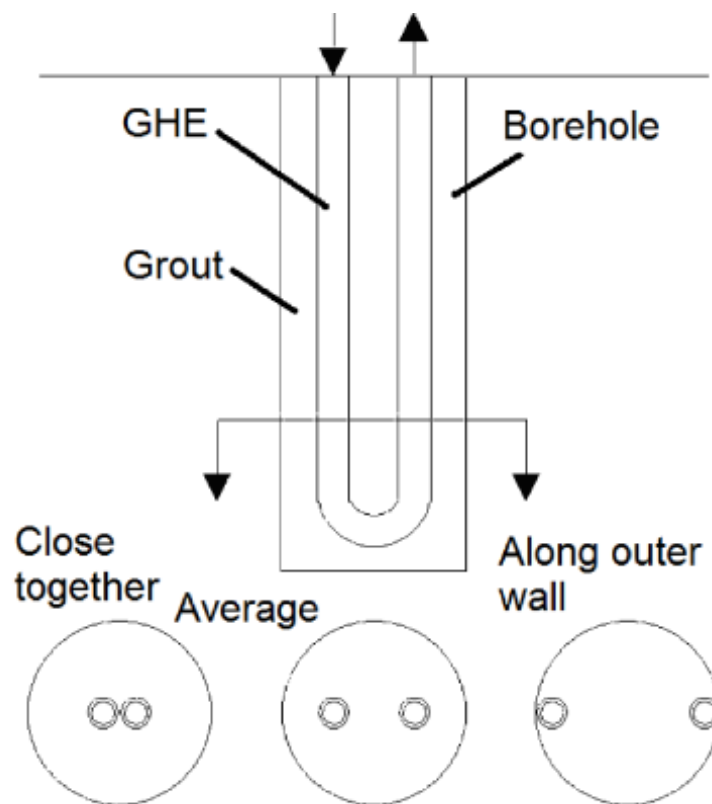


Figure 2.7: Vertical Ground Heat Exchanger and Configurations [16]

Hangseok Choi et al [18] investigated that cement grout has higher effective thermal conductivity than the bentonite grout by 7.4-10.1%, and the graphite outperforms the silica sand by 6.7-9.1%. In addition, the new 3-pipe type heat exchange pipe that yields less thermal interference between the inlet and outlet pipes shows better thermal performance over the conventional U-loop type heat exchange pipe by 14.1-14.5%.

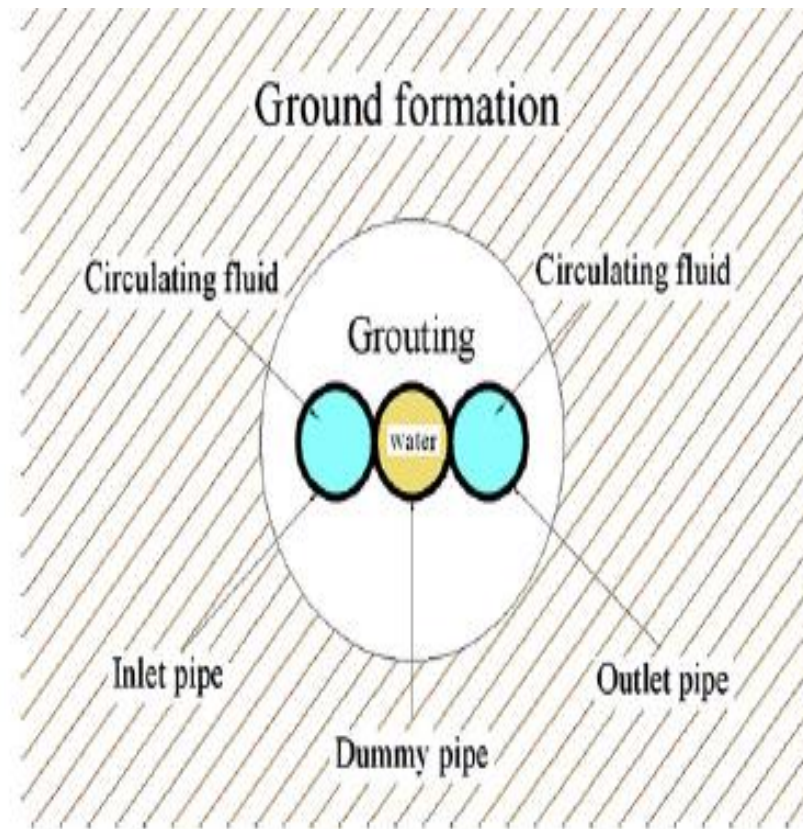


Figure 2.8: Schematic diagram of 3-pipe type [18]

Akio Miyara et al [19] studied several types of ground heat exchangers (GHEs) installed in a steel pile foundation around the bore hole, including double-tube, U-tube, and multi-tube GHEs. The performance of GHEs was investigated in the cooling mode with flow rates of 2, 4, and 8 lt/min. The temperatures of the inlet and outlet of circulated water were also measured to calculate the heat exchange rate. The double-tube had the highest heat exchange rate than multi-tube and U-tube GHEs.

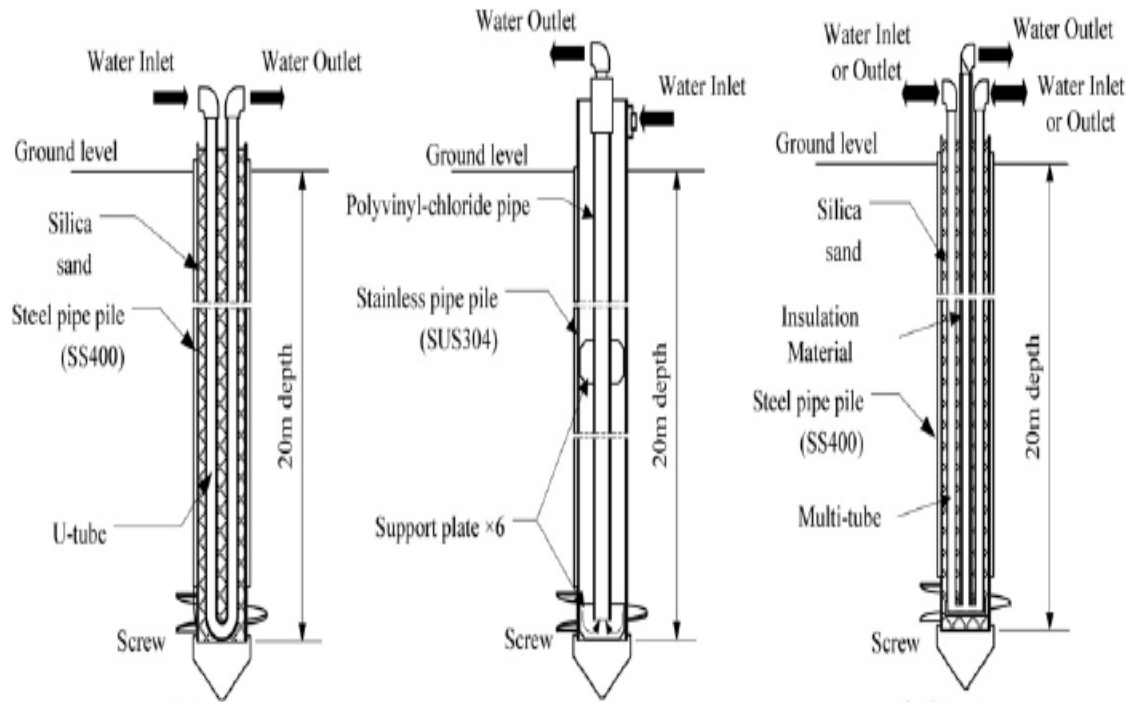


Figure 2.9: The schematic diagrams and photographs of the geothermal heat exchangers.
 (a) U-tube (b) Double-tube. (c) Multi-tube [19]

Jindal et al [20] presented a system for space cooling and heating using solar energy.

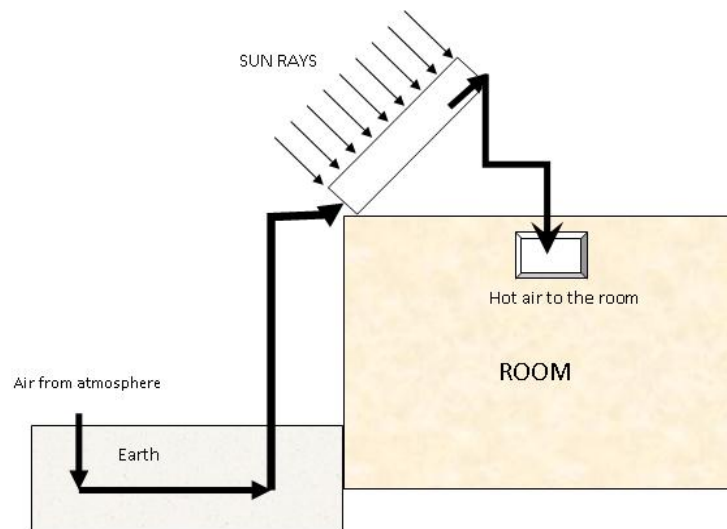


Figure 2.10: The arrangement for winters

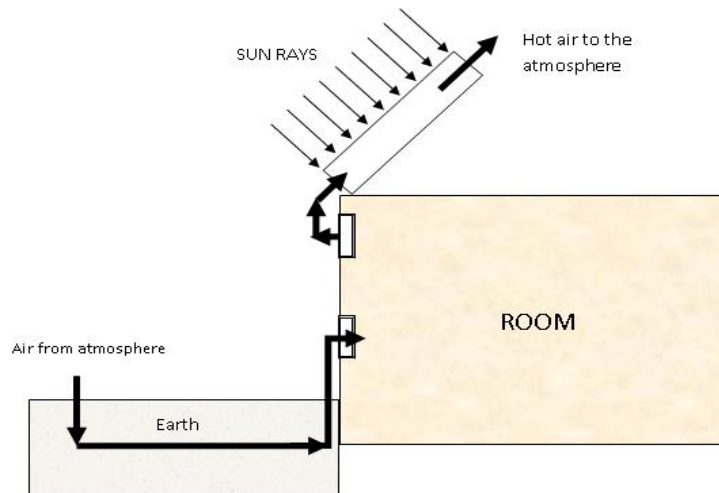


Figure 2.11: The arrangement for summer

The system consumes only a fraction power as compared to conventional devices used for the purpose because the system works on first law of thermodynamics instead of second law of thermodynamics. Theoretical analysis has been done to calculate the cooling/heating power of the system. There was a temperature gradient in the earth up to a depth of the 3m and further below, the temperature is seen to be fairly constant

CHAPTER 3

EXPERIMENTAL SET-UP

3.1 Experimental Set – Up

The Horizontal Ground Heat Exchanger consisted of pipe, made up of galvanized iron and buried at a depth of 3.3 meter. At the inlet, the open end of the pipe was connected to the supply of water. A water tank of 500 litre capacity was placed at a height of 8 meter from the inlet of the pipe. The water from the tank entered the horizontal ground heat exchanger. Discharge of the flow can be varied by ball valve. Thermistor used to measure the temperature of the water along the length of the pipe. Two thermistors were located at a length of 7m and 9m from the inlet. Insulation was provided at the outlet pipes.

Components used

- a) GI pipe (0.0127m)
- b) Water tank (500 Litre)
- c) Float valve
- d) Ball valve
- e) Different types of joint (Elbow, Tee, Union, Socket)

Instrument used

- a) Thermistor
- b) Temperature Auto Scanner
- c) Stop watch

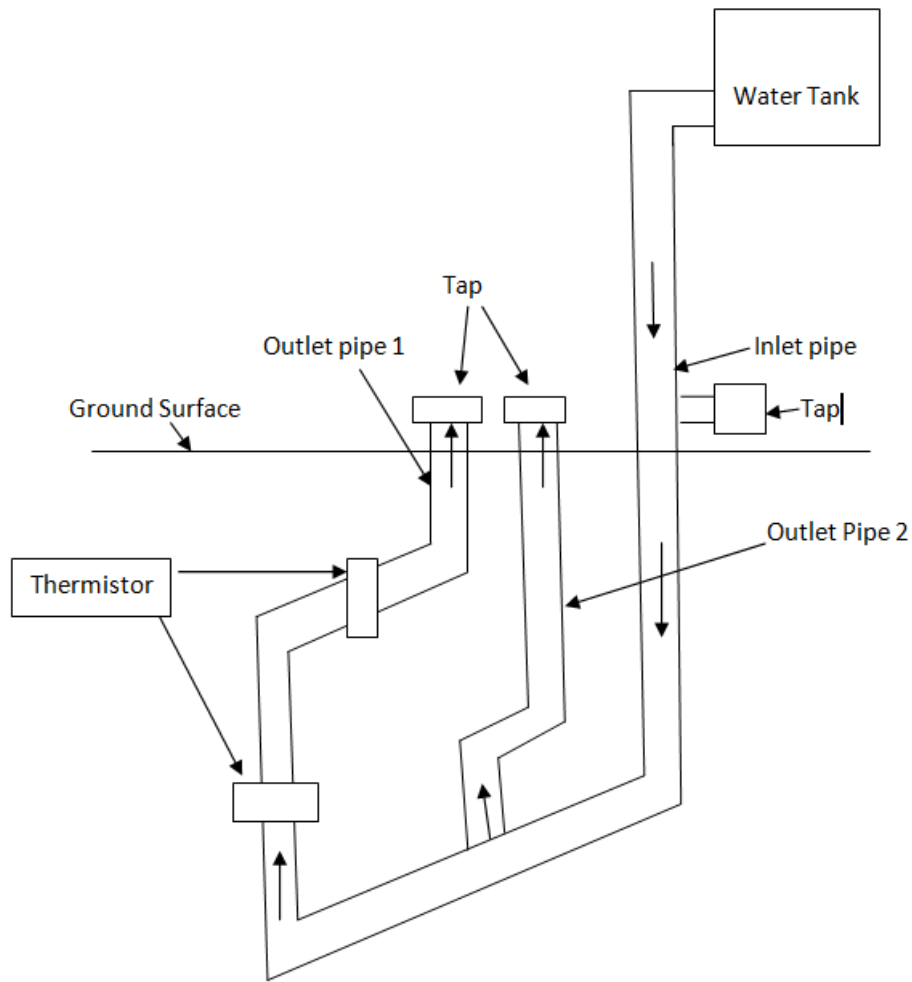


Figure 3.1: Schematic Representation of the Experimental Set-Up

DEPTH	3.3
OUTER DIAMETER OF PIPE	0.0127
INNER DIAMETER OF PIPE	0.0112
AVAILABLE HEAD AT INLET	8
SPACING BETWEEN INLET PIPE AND OUTLET PIPE1	3
SPACING BETWEEN INLET PIPE AND OUTLET PIPE2	1.5

Table 3.1: Dimensions of Horizontal Ground Heat Exchanger (in meter)

As we can see in the Figure above the system consist of 0.0127m diameter GI pipe buried below the ground level at a depth of 3.3m. The pipe is spread horizontally for an approximate length of 7m. Elbow is used to connect the two pipe perpendicular to each other. Tee joint is used to attached the thermistor. Thermistor is placed at a length of 7m and 9m from the inlet of the pipe. Inlet of the pipe is connected to supply of water through ball valve.



Figure 3.2(a): Photograph of Experimental Set-Up



Figure 3.2(b) :Photograph of Experimental Set-Up

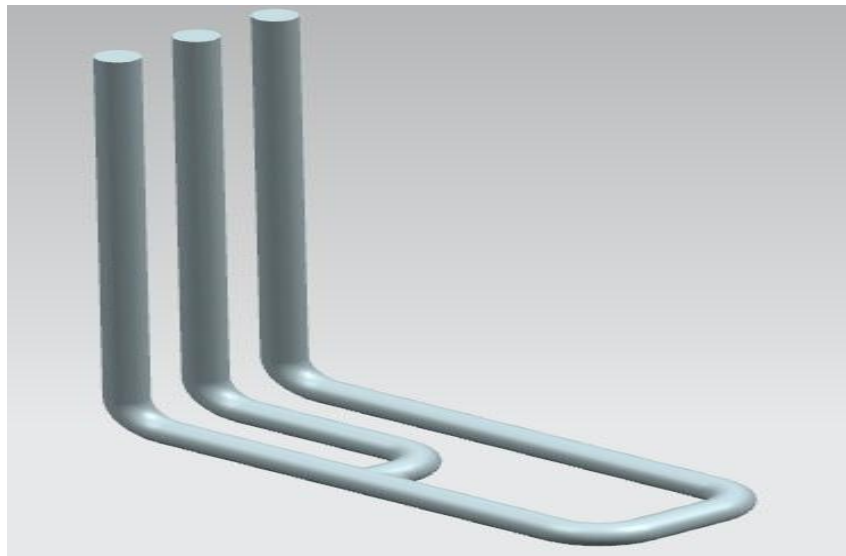


Figure 3.3: Schematic Representation of the Experimental Set-Up in 3 Dimensional

3.2 Components Used For Experimental Set-Up

1. Ball Valve

A ball valve have a spherical disc. Spherical disc controls the flow through it. The sphere has a hole through the middle so that when the hole is in line with both ends of the valve, flow will start. When the valve is closed, the hole is perpendicular to the position of the ends of the valve and flow is blocked. The lever will be inline with the hole position letting you "see" the valve's position. Ball valves are durable and used to achieve perfect shutoff even after years of operation.



Figure3.4: Cut-away view of a ball-valve mechanism [2]

2. Float Valve

A float valve (ballcock) is a mechanism or machine for filling water tanks, while avoiding overflow. A valve is connected to a hollow sealed float by means of a lever, mounted near the top of the tank. The valve is connected to the incoming water supply, and is opened and closed with the help of a lever which has the float mounted on the end. When the water level rises, the float valve rises with it as the water rise after a certain pre-set limit, the mechanism forces the lever to close the valve and shut off the water flow.



Figure 3.5: Float Valve

3. Water Tank

A water tank of 500 liter capacity is installed at height of 8m from the ground surface and it is used to store the water.

3.3 Instrument Used For Experimental Work

1. Thermistors

A thermistor is a temperature-sensing element composed of sintered semiconductor material which exhibits a large change in resistance proportional to a small change in temperature. Thermistors mostly have negative temperature coefficients which means the resistance of the thermistor decreases with increase in temperature. Thermistors are one of the most accurate types of temperature sensors. Thermistors have an accuracy of $\pm 0.2^{\circ}\text{C}$. Thermistors are chemically stable and not affected by aging.



Figure3.6:Thermistor Symbol



Figure 3.7: Thermistor

Assuming, as a first-order approximation, that the relationship between resistance and temperature directly proportional, then:

$$\Delta R = k \Delta T$$

Where,

ΔR = change in resistance

ΔT = change in temperature

k = First-order temperature coefficient of resistance

Parameter	Value
Resistance Value At 25 °C	2.2 Kw To 470 Kw
Tolerance	±5%
Thermal Time Constant	7.5 S
Dissipation Factor	23 Mw/K
Operating Temperature Range At: Zero Dissipation	-25 To +100 °C 0 To +55 °C
Maximum Dissipation	
Mass	1.5 gm

Table 3.2: Specification of Thermistor

2. Temperature Auto Scanner

A temperature auto scanner was used to display the thermistor readings.



Figure 3.8: Temperature Auto Scanner

Parameter	Value
Sensor Input	Thermistor
Display	4-½ Digit, 7 Segment; .56" Height; Red L.E.D.
Accuracy	1% Of Full Scale Or $\pm 10\%$ 2°C.
Resolution	0.01°C Up To 200°C 1°C Above 200°C
Sensor Break Protection	Display Starts Blinking
No. of Input Channel	10
Cold Junction	Automatic From 0 To 70°C
Dimensions	96 X 96 X 130mm / 192 X 96 X 140mm
Channel Selection	Both Manually & Automatic By Means Of Timer

Table 3.3: Specification of Temperature Auto Scanner

CHAPTER 4

EXPERIMENTAL WORK

4.1 Introduction-

The main aim of work is carried out to study the horizontal ground heat exchanger and effect of different boundary conditions on the performance of the system.

Different boundary conditions are given below:

- a) Length of the system.
- b) Mass flow rate of circulating water.
- c) Duration of time.
- d) Heat transfer coefficient
- e) Thermal resistance
- f) Inlet temperature

4.2 Experimental procedure-

The experiment was conducted for various boundary conditions. To start the experimentation, inlet ball valve is opened. The water is let to pass through the pipe for some time till the steady state is achieved. This was noted through the thermistor readings. Then the thermistor is placed at the four points, 0 m, 7 m, 9 m and 14 m. Thermistor was connected to temperature auto scanner unit which display the reading of temperature of water which was circulated in the pipe. Discharge was control with the help of ball valve. Discharge is measured with the help of a stop watch and a container.

The above procedure is repeated with different ambient conditions, this is achieved by conducting the experiment over a span over of several weeks, All the data thus obtained is compiled into a table. The graphs were plotted for various set of observations obtained from experiment.

4.3 Experimental calculations-

1.Heat Exchange rate

Heat Exchange rate is measured by using following equation:

$$Q = m \times C_p \times (T_{in} - T_{out})$$

Where,

Q : Heat Exchange Rate (KW)

m : Mass flow rate (Lt/sec)

C_p : Specific heat of the fluid at constant pressure (kJ/kgK)

T_{in} : Temperature of water at the inlet ($^{\circ}$ C)

T_{out} : Temperature of water at the outlet ($^{\circ}$ C)

2. Thermal Resistance

Thermal resistance is a heat property and a measurement of a temperature difference by which an object or material resists a heat flow.

Various assumptions have been made which are listed below

- a) The variation of properties of fluid are neglected
- b) No heat generation
- c) Constant convection coefficient
- d) The soil is homogeneous and the soil thermal properties are constant
- e) Steady state is assumed

Assuming a horizontal pipe of inside diameter D_i and outside diameter D_o buried at a depth d from the ground surface. The total thermal resistances per pipe length are as follows:

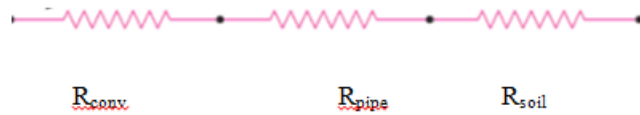


Figure 4.1: Thermal Resistance Model

$$R_{total} = R_{conv} + R_{pipe} + R_{soil}$$

Where

$$R_{conv} = \frac{1}{\pi D i h}$$

$$R_{pipe} = \frac{\ln \frac{D_o}{D_i}}{2\pi K_{pipe}}$$

$$R_{soil} = \frac{1}{S K_{soil}}$$

S is the conduction shape factor of the pipe given as (Incropera and DeWitt-2002)

$$S = \frac{2\pi}{\ln \left(\frac{2d}{D_o} + \sqrt{\left(\frac{2d}{D_o} \right)^2 - 1} \right)}$$

Where,

R_{total} = Total thermal resistance

R_{conv} = Convective thermal resistance

R_{soil} = Thermal resistance due to ground soil conduction

h = Convective heat transfer coefficient

K_{soil} = Soil Thermal conductivity

K_{pipe} = Pipe thermal conductivity

2.1. Physical properties from heat transfer data base

Water density, ρ	1000 Kg/m ³
Water specific heat, C_p	4.18KJ/K
Water thermal conductivity, K_w	643×10^{-6} kW/m-deg
Water Prandtl number, Pr	3.54
Water viscosity, μ_w	544×10^{-6} kg/ms
Pipe thermal conductivity, K_{pipe}	16 W/m-deg
Soil Thermal conductivity, K_{soil}	1.16 W/m-deg

Table 4.1: Physical properties assumed for calculation of thermal resistance

2.2 Convective heat transfer coefficient

We now proceed to estimate the heat transfer coefficient of the pipe using the following empirical correlations:

$$Nu = 0.023 (Re)^{0.8} (Pr)^{0.4}$$

Where,

Nu : Nusselt number (dimensionless)

Re : Reynolds number (dimensionless)

Pr : Prandtl number (dimensionless)

If the water flow is passed through a single pipe, the water velocity will be:

$$\text{Water velocity, } u_w = Q_w / A_p$$

Where,

Q_w : mass flow rate (Kg/sec)

A_p : Area of the pipe (m^2)

Using the following relation, Reynolds number is calculated

$$Re = (\rho_w \times u_w \times D_i / \mu_w)$$

Where

ρ_w : Density of water (Kg/m^3)

u_w : Velocity of the water (m/sec)

μ_w : viscosity of water (kg/msec)

Then, from the value of Nu obtained from the above relations, we calculate the convective heat transfer coefficient, which can be calculated using the relation below

$$h = Nu \times K_w / D_i$$

Having calculated the heat transfer coefficient h we can now utilise the relation derived earlier for finding the thermal resistance due to convection heat transfer.

CHAPTER 5

RESULTS AND DISCUSSION

The experiment was conducted for various boundary conditions. In this chapter we discuss all the results which we got from the experiments like heat exchange rate, temperature difference, heat transfer coefficient, thermal resistance.

1. Ground Temperature Distribution

Ground temperature below a certain depth remains relatively constant throughout the year because temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia of the soil. Therefore ground temperature is always higher than that of the outside environment in winter and is lower in summer at a sufficient depth. Figure 4.1 shows that ground temperature after a depth of 3 meter remains nearly constant.

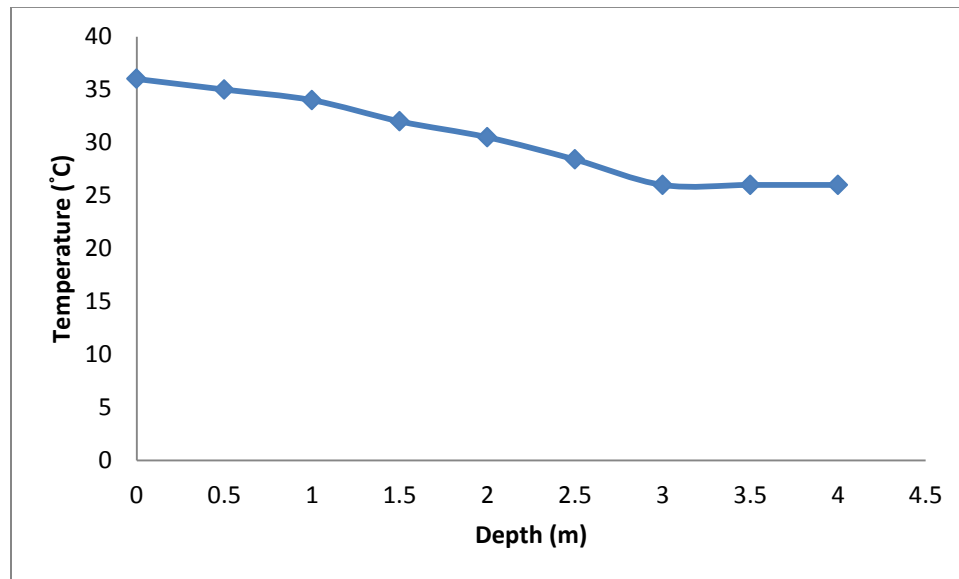


Figure 5.1: Variation of ground temperature with depth

2. Variation of Temperature along the length of ground heat exchanger

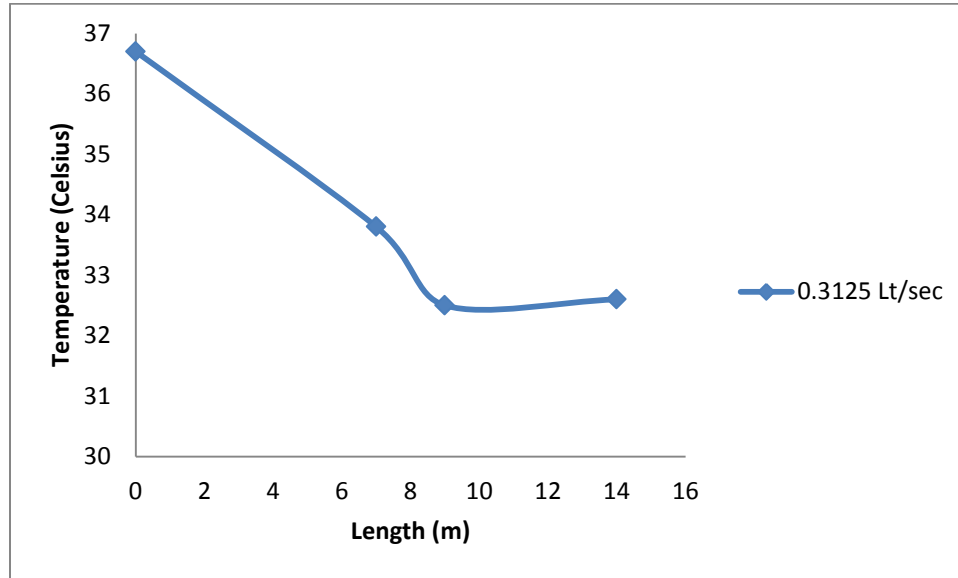


Figure 5.2: Variation of temperature with 36.7⁰ C inlet temperature

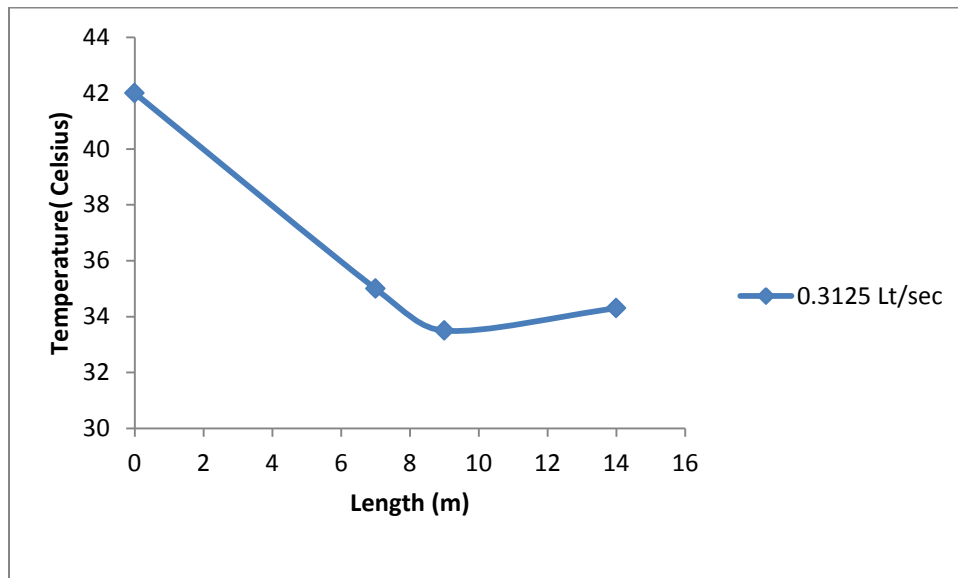


Figure 5.3: Variation of temperature with 42⁰ C inlet temperature

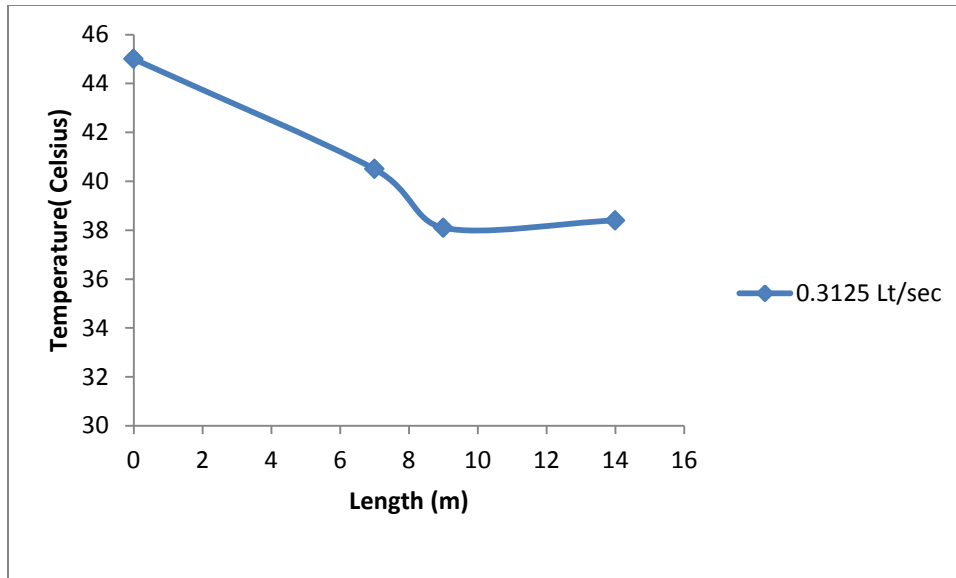


Figure 5.4: Variation of temperature with 45⁰ C inlet temperature

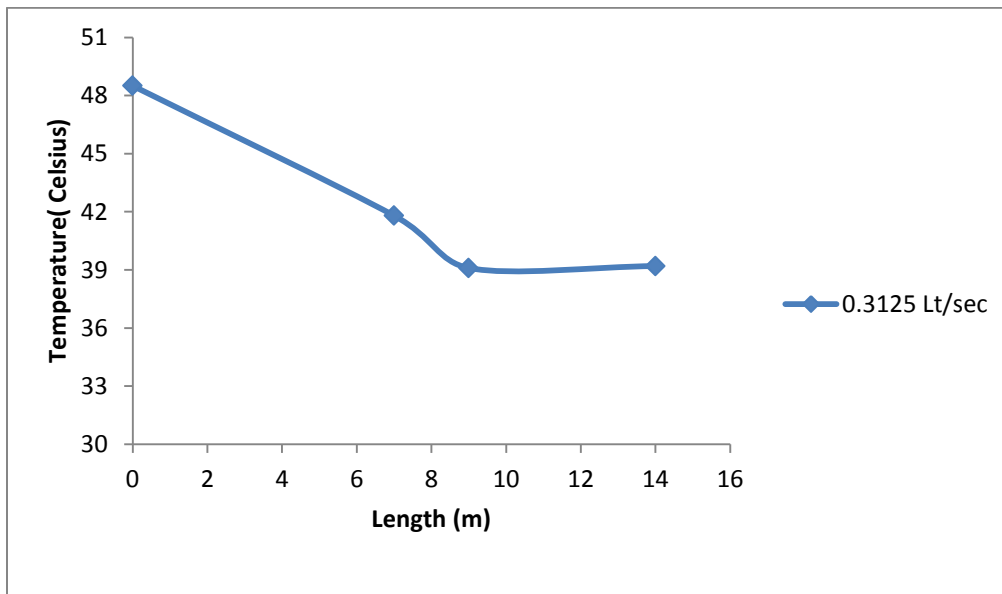


Figure 5.5: Variation of temperature with 48.5⁰ C inlet temperature

Temperature of horizontal ground heat exchanger is measured at different length with the help of thermistors after 30 second. From figure it can be concluded that temperature decrease almost linearly up to 9m. After 9m temperature remains almost constant because insulation is provided at outlet pipe.

3. Effect of discharge on temperature variations

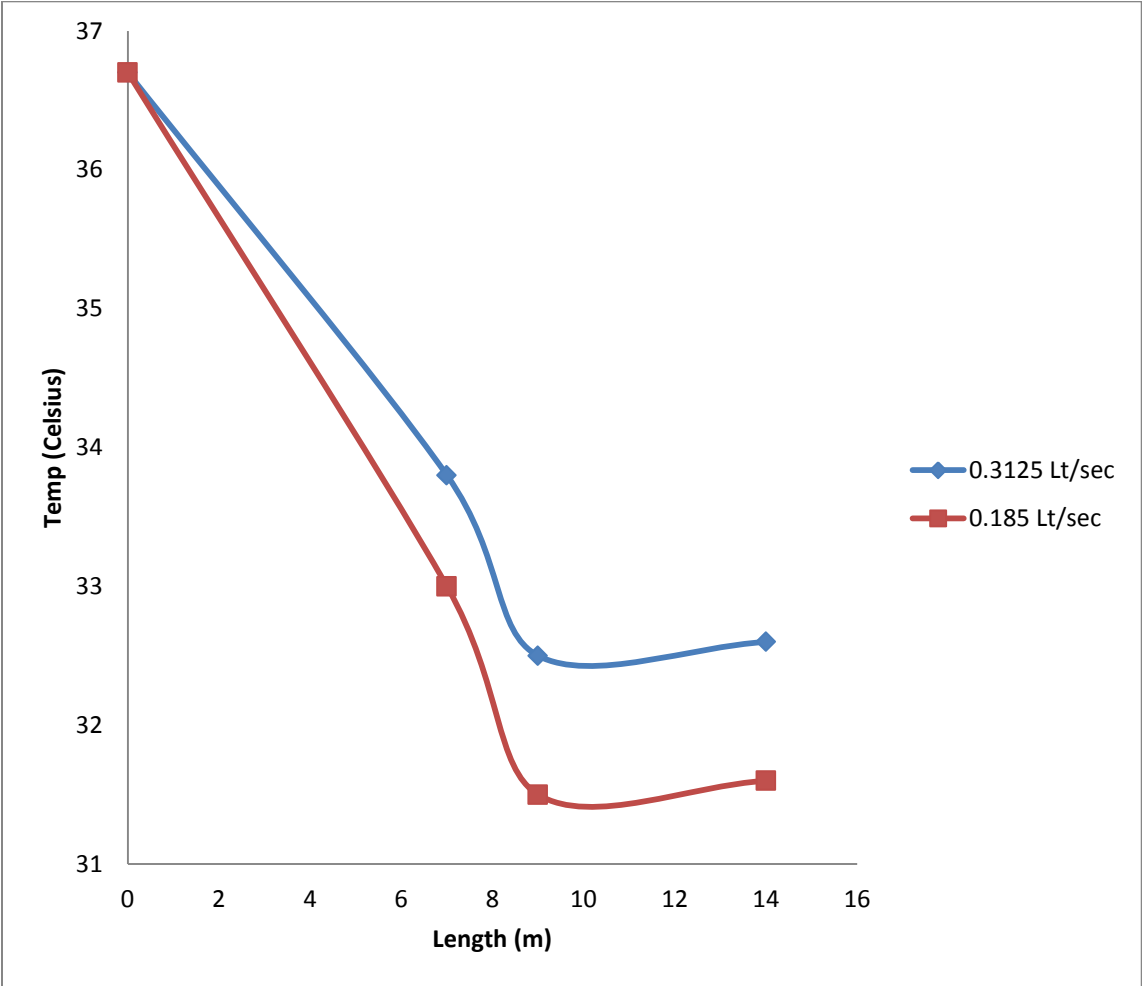


Figure 5.6: Variation of temperature with different discharge at 36.7⁰ C inlet temperature

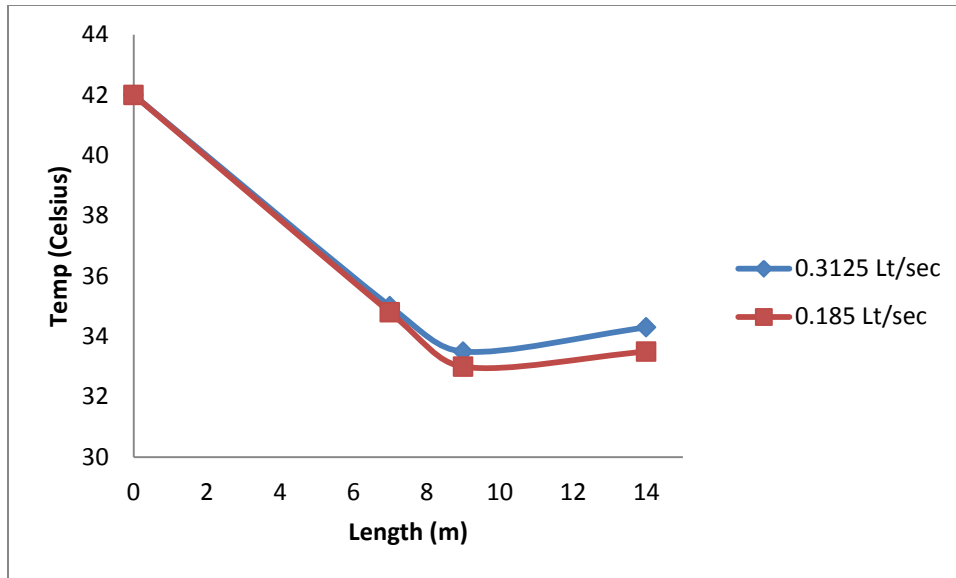


Figure 5.7: Variation of temperature with different discharge at 42⁰ C inlet temperature

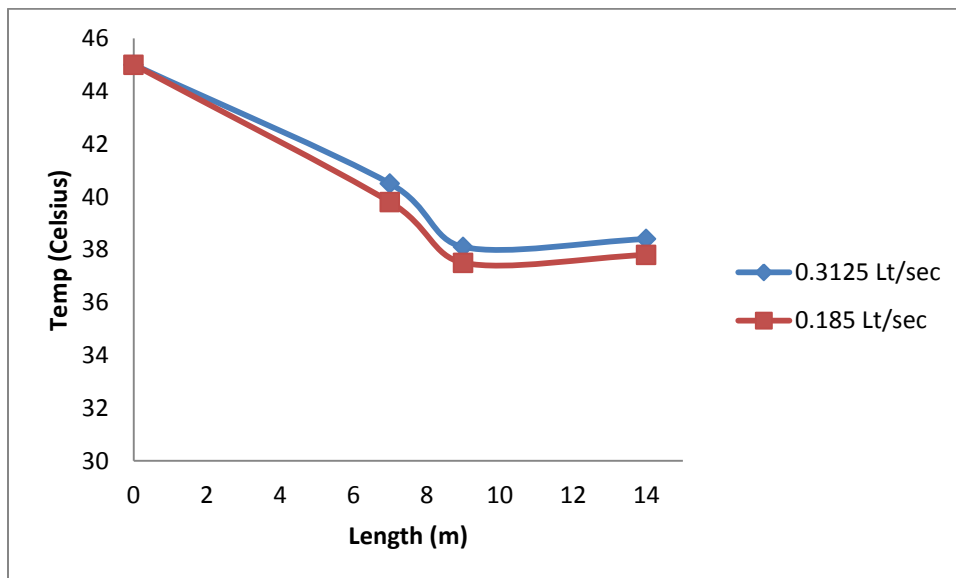


Figure 5.8: Variation of temperature with different discharge at 45⁰ C inlet temperature

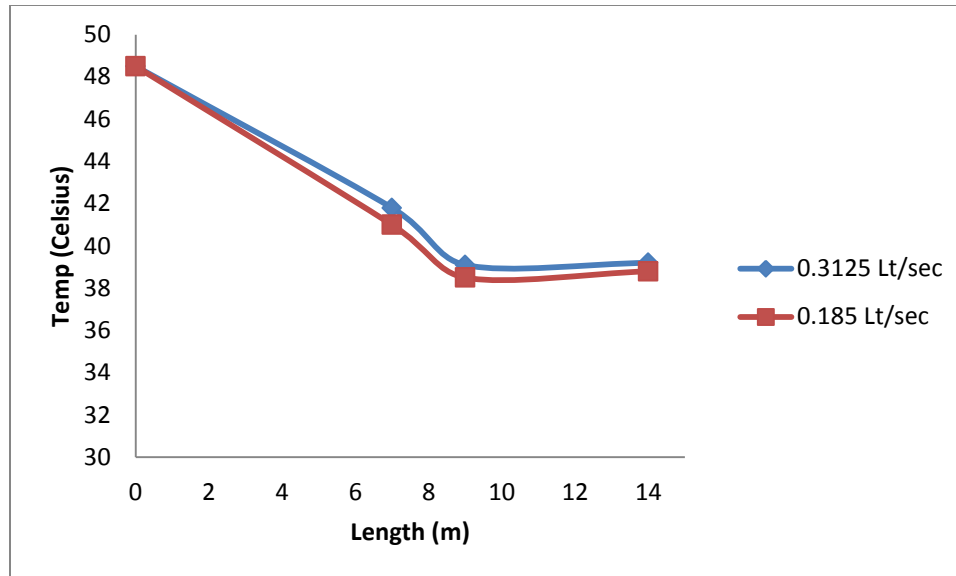


Figure 5.9: Variation of temperature with different discharge at 48.5⁰ C inlet temperature

Discharge is measured with the help of a stop watch and a container. From figure it is concluded that temperature difference between inlet and outlet decrease with increase in discharge.

4. Variation of temperature with time

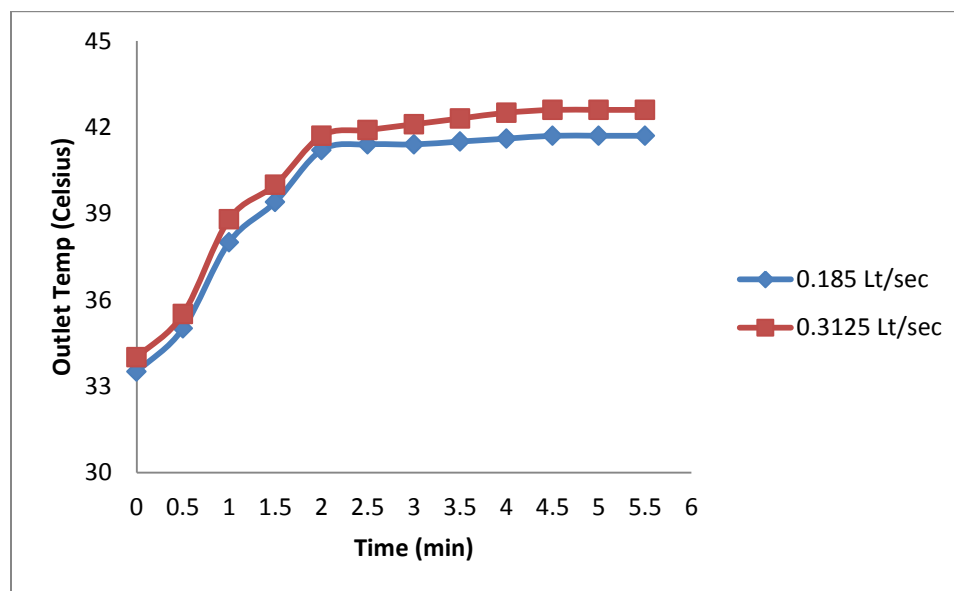


Figure 5.10: Variation of Temperature with time when inlet temperature is 44.2⁰ C

From figure 4.10 it is concluded that temperature difference between inlet and outlet decrease with increase in time but after 4 minutes temperature difference remains constant and a steady state condition is achieved.

5. Effect of inlet temperature and discharge on heat exchange rate

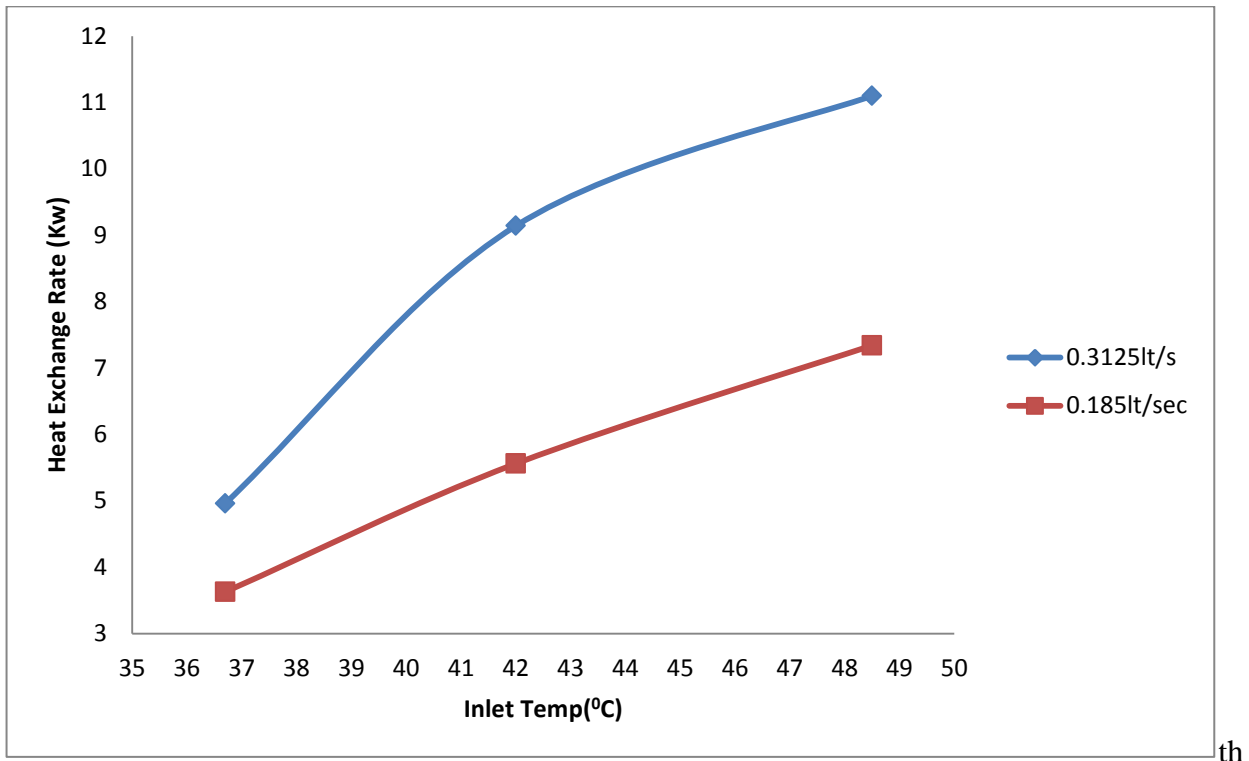


Figure 4.11: Variation of Heat Exchange Rate with inlet temperature after 30 seconds

From figure 4.11 it is concluded that heat exchange rate increase almost linearly with increase in inlet temperature and heat exchange rate increase with increase in discharge.

6. Effect of mass flow rate on convective heat transfer coefficient (h)

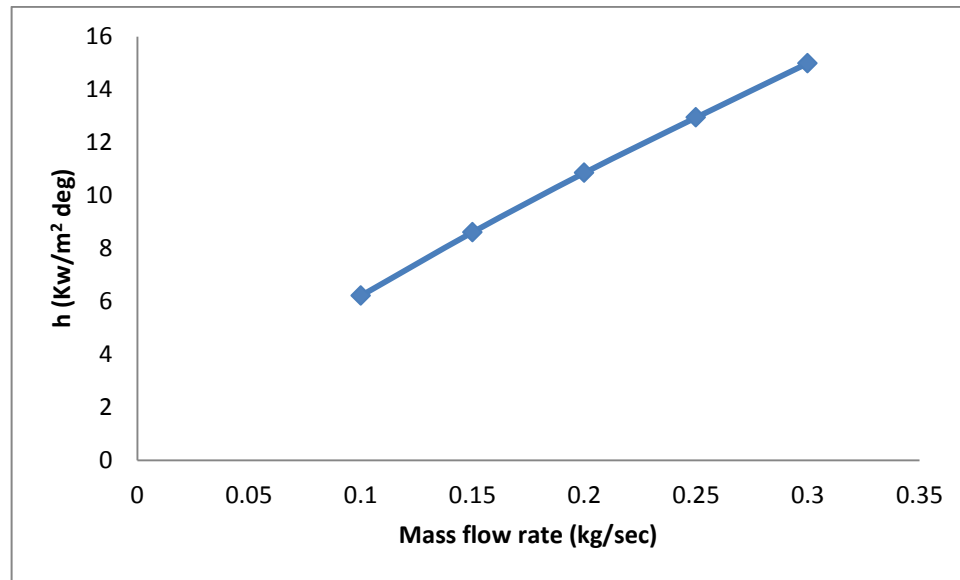


Figure 4.12: Variation of convective heat transfer coefficient with mass flow rate

Figure 4.12 shows the behaviour of convective heat transfer coefficient with different mass flow rate and it is concluded that convective heat transfer coefficient increase linearly with increase in mass flow rate.

7. Effect of mass flow rate on thermal resistance

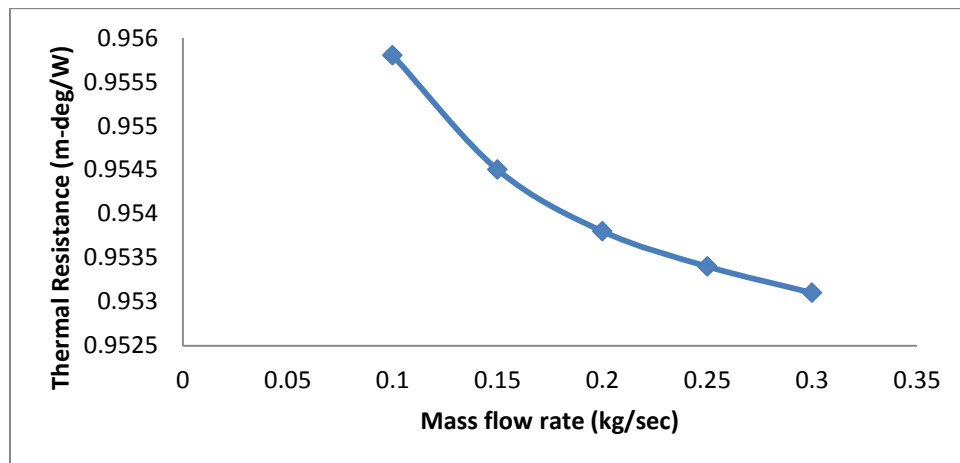


Figure 4.13: Variation of thermal resistance with mass flow rate

Figure 4.12 shows the behavior of thermal resistance with change in mass flow rate and it is concluded that variation of thermal resistance with mass flow rate is negligible.

8. Effect of discharge on heat exchange rate

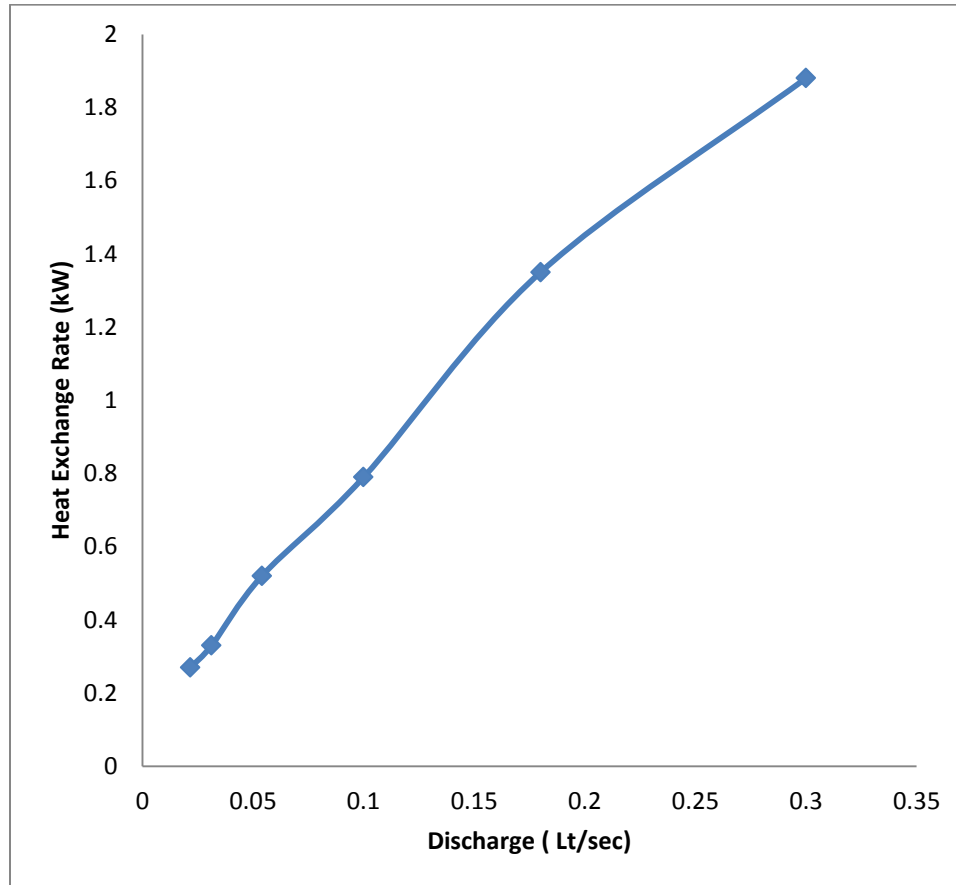


Figure 4.14: Variation of Heat Exchange rate with Discharge

Figure 4.11 shows the behavior of heat exchange rate with change in discharge. It is concluded that heat exchange rate increases with increase in discharge almost linearly. The reason is that heat exchange rate is directly proportional to mass flow rate.

9. Effect of Horizontal Length of the system on temperature

S.No	Inlet Temp (⁰ C) (0 M)	Outlet Temp (⁰ C) (3.5 m)	Outlet Temp (⁰ C) (7 m)
1	48.5	40	39.2
3	36.7	32.9	32
5	42	35	34.3
7	45	39	38.4

Table 5.1: Variation of temperature with horizontal length

From the table data it is concluded that if horizontal length of ground heat exchanger is reduced to half, then outlet temperature is reduced by 1 ⁰C approximately. The reason is that if horizontal length is reduced then heat exchange rate also reduced.

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION

The experimental study expanded the understanding of heat exchange rate and temperature variation with length, time and discharge. The heat exchange rate of horizontal ground heat exchanger was calculated based on the parameter such as mass flow rate and temperature difference of inlet and outlet of circulated water. Temperature distribution of ground heat exchanger according to the length and mass flow rate provide good understanding of heat exchange process.

From the result of this study, the following conclusion is drawn:

1. Ground temperature remains nearly constant below a depth of 3 meter.
2. Heat exchange rate increase with increase in mass flow rate.
3. Difference between inlet and outlet temperature of water increase with decrease in mass flow rate
4. Difference between inlet and outlet temperature of water increase with increase in time but after 4 minutes it remain constant
5. Difference between inlet and outlet temperature of water increase with increase in horizontal length of ground heat exchanger.
6. Reynold number is directly proportional with mass flow rate of the fluid.
7. Mass flow rate has negligible effect on thermal resistance
8. Convective heat transfer coefficient increase linearly with increase in mass flow rate.

6.2 SCOPE FOR FUTURE WORK

Due to time constraints, we were unable to complete all the testing proposed at the beginning of the semester. Because of this, there are many areas of further research that can be done to

improve the performance of the system. Listed below are few ideas that we thought would be interesting for further research.

The following additions may be made in future in the horizontal ground heat exchanger

1. Effect of different material can be studied on the performance of the horizontal ground heat exchanger
2. Effect of different type of configuration on the performance of ground heat exchanger.
3. A mathematical model can be developed to find the temperature at the outlet and required length to achieve this temperature.
5. Comparison of horizontal and vertical ground heat exchanger can be performed.
4. Effect of different type of soil and moisture in soil on the performance of ground heat exchanger.

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ANNEXURE

Table A.1 Experimental data of ground temperature at different depths.

S.No	Depth (m)	Ground Temperature (°C)
1	0	36
2	0.5	35
3	1	34
4	1.5	32
5	2	30.5
6	2.5	28.4
7	3	26
8	3.5	26
9.	4	26

Table A.2 corresponds to the data obtained from the physical observations made from the experimental set-up installed after 30 seconds

S.No	Inlet Temp (0 m)	Temp at Point 1 (7 m)	Temp at Point 1 (9 m)	Exit Temp (14 m)	Discharge (Lt/sec)	Heat Exchange rate $Q=mcp\Delta T(kW)$
1	48.5	41.8	39.1	39.2	0.3125	12.1
2	48.5	41	38.5	38.8	0.185	7.73
3	36.7	33.8	32.5	32.6	0.3125	6.13
4	36.7	33	31.5	31.6	0.185	4.02
5	42	35	33.5	34.3	0.3125	10.05
6	42	34.8	33	33.5	0.185	6.57
7	45	40.5	38.1	38.4	0.3125	8.62
8	45	39.8	37.5	37.8	0.185	5.56

Table A.3 corresponds to the data obtained from the physical observations made from the experimental set-up installed when the overall all length is 10m and after 30 seconds .

S.No	Inlet Temp (0 M)	Outlet Temp (10 m)	Discharge (Lt/sec)	Heat Exchange Rate $Q=mc_p\Delta T(kW)$
1	48.5	40	0.3125	11.10
2	48.5	39	0.185	7.34
3	36.7	32.9	0.3125	4.96
4	36.7	32	0.185	3.63
5	42	35	0.3125	9.14
6	42	34.8	0.185	5.56
7	45	39	0.3125	7.83
8	45	38.2	0.185	5.17

Table A.4 Experimental data of thermal resistance at different mass flow rate.

S.No	Mass flow rate (Kg/sec)	Reynolds Number Re	Heat transfer Coefficient $h(Kw/m^2)$ deg)	Thermal Resistance $R_{total}(m-deg/W)$
1	0.3	62588.23	14.99	0.9531
2	0.25	52088.22	12.94	0.9534
3	0.2	41794.10	10.85	0.9538

S.No	Mass flow rate (Kg/sec)	Reynolds Number Re	Heat transfer Coefficient h(Kw/m ² deg)	Thermal Resistance R _{total} (m-deg/W)
4	0.15	31294.10	8.61	0.9545
5	0.1	20794.11	6.21	0.9558

Table A.5 Experimental data of temperature variation with time

S.No	Time(min)	Temp at 0.3125 Lt/sec	Temp at 0.185Lt/sec
1	0	34	33.5
2	0.5	35.5	35
3	1	38.8	38
4	1.5	40	39.4
5	2	41.7	41.2
6	2.5	41.9	41.4
7	3	42.1	41.4
8	3.5	42.3	41.5
9	4	42.5	41.6
10	4.5	42.6	41.7
11	5	42.6	41.7
12	5.5	42.6	41.7

Table A.6 Experimental data of heat exchange after steady state

S.No	Discharge (Lt/sec)	Inlet Temp	Outlet Temp	Heat Exchange Rate $Q=\dot{m}c_p\Delta T$ [kw]
1	0.0217	39.6	36.6	0.27
2	0.03125	42	39.5	0.33
3	0.0540	42.6	40.3	0.52
4	0.1	44.2	42.3	0.79
5	0.18	45	43.2	1.35
6	0.3	45.3	43.8	1.88

