To study impact of various pipe geometries on performance parameters of Ground Source Heat Pump: An experimental investigation

Dissertation-II

Submitted in partial fulfillment of the requirement for the award of degree

Of

Master of Technology

IN

THERMAL ENGINEERING

By

Shankar Dutt Bijalwan

Regd. No-**11617129**

Under the guidance of

Aashish Sharma

U.ID-**16420**

DEPARTMENT OF MECHANICAL ENGINEERING
LOVELY PROFESSIONAL UNIVERSITY
PUNJAB
2017-2018

CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled **"To study impact of various pipe geometries on performance parameters of Ground Source Heat Pump: An experimental investigation"** in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **Mr**. **Aashish Sharma**, **Assistant Professor** Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

Date:

Shankar Dutt Bijalwan

Regd. No.-11617129

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date:

Name:-Mr. Aashish Sharma

UID-16420

COD (ME)

The external viva-voce examination of the student was held on successfully ________________

Signature of Examiner

Acknowledgement

With deep sense of gratitude I express my sincere thanks to my esteemed and worthy supervisor, **Mr. Aashish Sharma**, Assistant Professor, Department of Mechanical Engineering, of Lovely Professional University, Phagwara for his valuable guidance in carrying out work under his effective supervision, encouragement, enlightenment and cooperation. His feedback and editorial comments were also invaluable for writing of this dissertation.

I shall be failing in my duties if I do not express my deep sense of gratitude towards **Dr. Manohar Singh Saini** (HoS) and **Mr. Sudhanshu Dogra** (HoD) of Mechanical Engineering, Lovely Professional University, Phagwara.

I would like to thankful towards my university Lovely Professional University, Phagwara, Punjab for giving a change to prove myself in this challenging world.

I am greatly indebted to friends who constantly encouraged me and also would like to also thankful to the authors whose work have been consulted and quoted in this work.

At last but not the least my gratitude towards my parents, who always supported me in doing the things my way and whose everlasting desires, selfless sacrifice, encouragement, affectionate blessings and help made it possible for me to complete my degree. I would also like to render my gratitude to the Almighty God who bestowed self-confidence, ability and strength in time to complete this task and for not letting me down at the time of crisis and showing me the silver lining in the dark clouds.

Place**: LPU, Phagwara** **Shankar Dutt Bijalwan**

Date**:** **(11617129)**

Table of Contents

List of figures

1 Introduction

The way towards energy consumption around the world is increasing, renewable energy technologies like solar, wind, geothermal etc. are attracting the attention of renewable energy sources to meet the energy demand. Limited availability of conventional energy resources fossil fuels (coal, oil, natural gas) on the earth and the high carbon emission for energy production by them are the main reasons for focusing on the renewable non-conventional energy sources. Researchers are developing new renewable energy technologies, which are environment friendly emitting low or no carbon to the environment and further doing advancement to improve their system efficiency.

Ground source heat pump (GSHP) is one of the renewable energy technology, which is widely used for space heating and cooling. Lord Kelvin introduced the concept of GSHP system in 1852 and then it is modified by Robert Webber in the 1940s. GSHP system uses the ground as a heat source in cooling mode by absorbing heat from the ground and as a heat sink in heating mode by releasing the heat to the ground.

1.1 Energy

Energy can be defined as the ability to do work or the capacity of doing work. Any physical activity which happens in nature or done by human beings caused by the mean of energy. According to the law energy conservation "Energy neither can be created nor destroyed, it only can changes its form from one to another". Energy plays an important key role in the economic development of any country across the world. Energy can be classified into following two major groups.

1.1.1 Primary energy

The energy either found or stored in the nature like coal, oil, natural gas, biomass etc. and can be extracted or captured directly from the environment is known as primary energy and sources are known as primary energy sources.

1.1.2 Secondary energy

The energy sources (electricity, fuel or steam etc.), which are the converted form of primary energy sources (oil, gas or coal etc.) are known as secondary energy sources.

1.2 Non-renewable energy

The energy sources or conventional fossil fuels that are formed from remaining dead animals and plants inside the earth's crust for millions of year, under the exposure of high pressure and heat are known as non-renewable energy sources. These sources are going to deplete with time. Coal, crude oil or petroleum, natural gas and nuclear energy are the non-renewable energy sources.

1.3 Renewable energy

The non-conventional energy sources like wind, solar, tidal, geothermal and biomass, which are found in the nature with the abounded quantity and not going to deplete with time are known as renewable energy sources. These type of energy sources are attending the attention of researchers due to their environmental friendliness.

1.4 Geothermal energy

Geothermal energy is one of the potential option wellsprings of energy which has been effectively taking into account both modern and residential energy necessities in many parts of the world in the course of the most recent couple of decades. Geothermal is made of two Greek words – geo which signifies 'earth', and thermal, which signifies 'heat'. Subsequently, geothermal energy is the heat from the earth. Geothermal energy is known as a sustainable power source on the grounds that the water is renewed by precipitation, and the heat is constantly delivered by the earth.

Utilizing geothermal energy to deliver power is a generally new industry. It was started by a gathering of Italians who fabricated an electric generator at Lardarello in 1904. Their generator was controlled by the common steam ejecting from the earth. The principal endeavor to create geothermal power in the United States came in 1922 at The Geysers steam field in northern California. The undertaking fizzled in light of the fact that the channels and turbines of the day couldn't face the scraped area and consumption of the particles and contaminations that were in the steam. Afterward, a little yet effective aqueous plant opened at the Geysers in 1960. Today 28 plants are working there.

The most dynamic geothermal assets are generally found along significant plate limits where tremors and volcanoes are concentrated. The vast majority of the geothermal action on the planet happens in a territory known as the "Ring of Fire." The Ring of Fire edges the Pacific Ocean and is limited by Japan, the Philippines, the Aleutian Islands, North America, Central America, and South America.

Applications

There are major three types of geothermal applications

- Power generation
- Direct use
- Heat pumps

1.4.1 Power generation

There are basically following three types of geothermal power plants used for electricity generation.

Dry steam plants

Dry steam reservoirs are rare but highly efficient at producing electricity. The Geysers in California is the largest and best known dry steam reservoir. Here, steam is obtained by drilling wells from 7,000 to 10,000 feet deep. In a dry steam reservoir, the natural steam is piped directly from a geothermal well to power a turbine generator. The spent steam (condensed water) can be used in the plant's cooling system and injected back into the reservoir to maintain water and pressure levels.

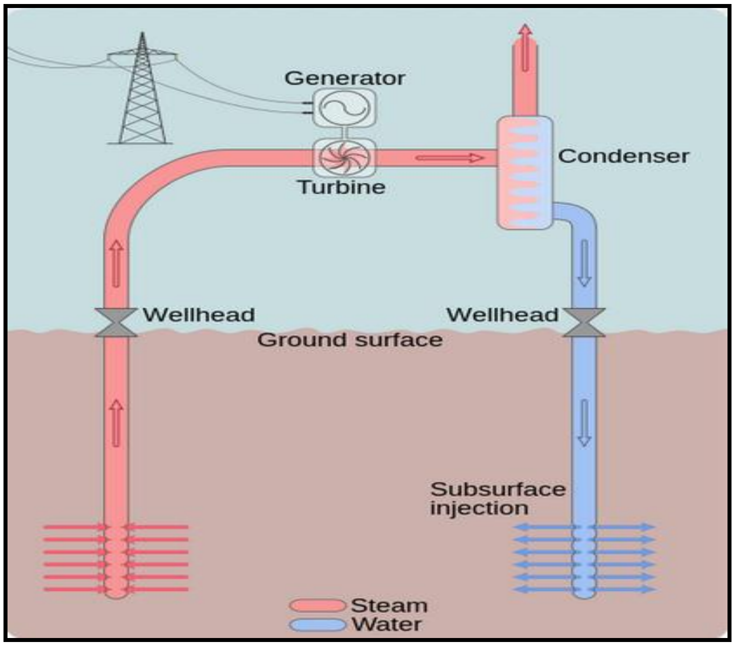

Figure 1 Dry steam plants

Flash cycle steam plants

These types are the most common due to the lack of naturally occurring high-quality steam. In this method, water must be over 180°C, and under its own pressure, it flows upwards through the well. This is a lower temperature than dry steam plants have. As its pressure decreases, some of the water "flashes" to steam, which is passed through the turbine section. The remaining water that did not become steam is cycled back down into the well, and can also be used for heating purposes. The cost of these systems is increased due to more complex parts, however, they can still compete with conventional power sources.

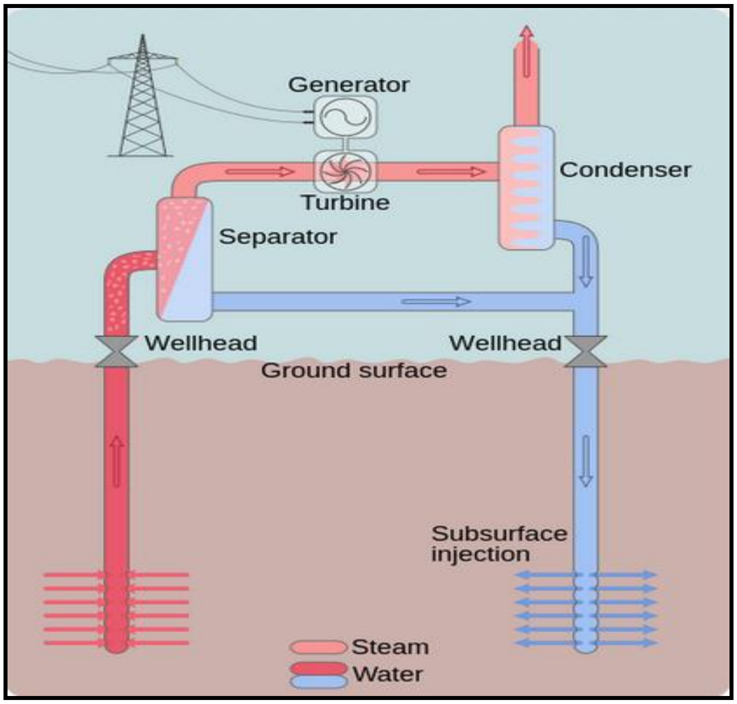

Figure 2 Flash steam plants

Binary cycle plants

Binary power plants are expected to be the most commonly used type of geothermal power plant in the future, as locations outside of the known hot spots begin to use geothermal energy. This is because binary cycle plants can make use of lower temperature water than the other two types of plants. They use a secondary loop (hence the name "binary") which contains a fluid with a low boiling point, such as pentane or butane. The water from the well flows through a heat exchanger which transfers its heat to this fluid, which vaporizes due to its low boiling point. It is then passed through a turbine, accomplishing the same task as steam.

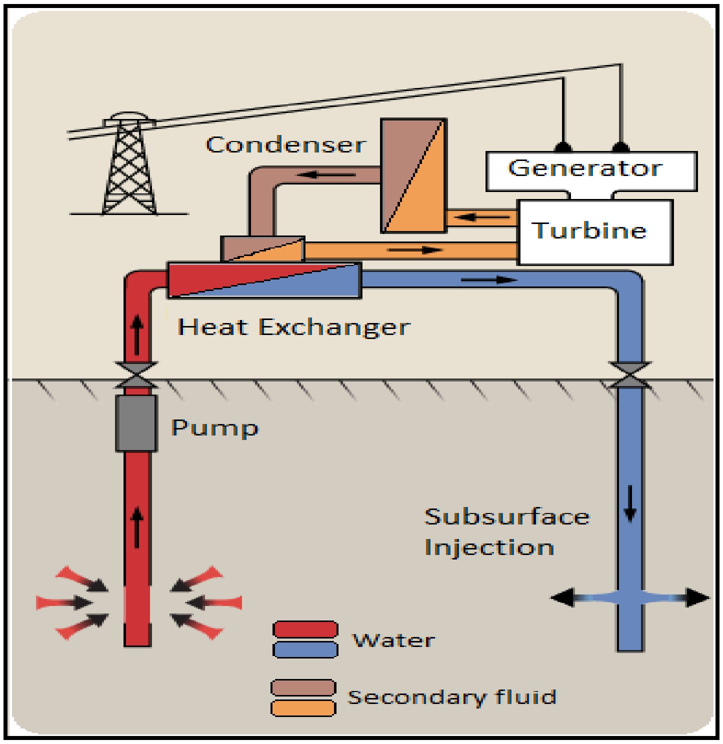

Figure 3 Binary cycle plants

1.4.2 Direct Use

Direct use, as the name implies, involves using the heat in the water directly (without a heat pump or power plant) for such things as heating of buildings, industrial processes, greenhouses, aquaculture (fish farming) and resorts. Direct use projects generally use resource temperatures between 38°C (100°F) to 149°C (300°F). Current U.S. installed capacity of direct use systems totals 470 MW or enough to heat 40,000 average-sized houses.

1.4.3 Heat Pumps

Geothermal heat pumps use the natural insulating properties of the earth from just a few feet underground to as much as several hundred feet deep, offering a unique and highly efficient renewable energy technology for heating and cooling. Most work by circulating water in a closed system through a “loop field” installed horizontally or vertically in the ground adjacent to or even beneath a building. Heat is taken from the building and transferred to the ground in the summer. The system is reversible, and heat is taken from the ground and used in the building in the winter. The system only moves heat, which is much more efficient than using a fuel or electricity to create heat.

Advantages

- Geothermal energy does not produce any pollution and does not contribute to the greenhouse effect.
- The power stations do not take up much room, so there is not much impact on the environment.
- No fuel is needed.
- Once you've built a geothermal power station, the energy is almost free.
- It may need a little energy to run a pump, but this can be taken from the energy being generated.

Disadvantages

- The big problem is that there are not many places where you can build a geothermal power station. You need hot rocks of a suitable type, at a depth where we can drill down to them.
- The type of rock above is also important, it must be of a type that we can easily drill through.
- Sometimes a geothermal site may "run out of steam", perhaps for decades.
- Hazardous gases and minerals may come up from underground and can be difficult to safely dispose of them.

1.4.4 Ground source heat pump

Ground source heat pump (GSHP) is one of the renewable energy technology, which is widely used for space heating and cooling. Lord Kelvin introduced the concept of GSHP system in 1852 and then it is modified by Robert Webber in the 1940s. GSHP system uses the ground as a heat source in cooling mode by absorbing heat from the ground and as a heat sink in heating mode by releasing the heat to the ground.

The GSHP system is of two types: 1- Open loop system

2- Closed loop system

In open loop system, groundwater is most widely used as a heat source or sink in the system. Whereas closed-loop system is classified into possible two ways-

1- Direct expansion, where the refrigerant is circulated directly through the ground loop.

2- Indirect expansion, where a water/antifreeze solution circulates through the ground loop and energy is transferred to or from the heat pump refrigerant circuit via a heat exchanger.

A closed-loop system is preferable in GSHP due to their high efficiency and low power consumption as compared to the open loop system. Performance of direct expansion GSHP system is better than indirect expansion or any other GSHP system but there is a high risk of refrigerant leakage. A ground heat exchanger (GHX) either can be vertical or horizontal loop system. In a vertical system, pipes are buried inside the boreholes drilled at a depth of 30-300m whereas in horizontal loop system high-density polyethylene (HDP) pipes are buried at a depth of 2-5m under the ground. The vertical system needs less land surface area as compared to the horizontal loop system and the system efficiency is also high due to greater temperature variation as the depth increases from ambient temperature.

GSHP system mainly consists of three major elements:-

1- A ground heat exchanger.

2- A heat pump unit.

3- A air delivery system.

Ground heat exchanger

A ground heat exchanger (GHX) plays a vital role in the system efficiency of GSHP because of more the heat transfer takes place, more efficiently the system works. GHX either can be placed vertically or horizontally depending on the land availability. Installation cost of a vertical system is more than the horizontal one but the efficiency is high and also the material of pipe is less required.

Types of ground heat exchanger

Indirect heat exchanger - This type of system consists high-density polyethylene pipe in a closed loop inside which working fluid circulates and the heat transfer takes place indirectly between GHX and heat pump.

Direct heat exchanger - In this type of system copper pipe is used inside which fluid circulates, which increases the efficiency of the system due to their high thermal conductivity. Heat transfer in the direct expansion is high as compared to indirect expansion due to good thermal contact of fluid circulating pipe and the ground. More refrigerant requirement for the system and risk of refrigerant leakage are the main drawbacks of the system.

Heat pump unit

The performance of heat pump can vary widely according to the varying load condition so the selection of efficient heat pump unit is essential. The coefficient of performance (COP) of the heat pump (which is heat output divided by the electrical input of the heat pump) should be high in order to increase the system efficiency. Working of a heat pump unit is similar to a simple refrigeration cycle. The working fluid takes heat to raise his temperature, which is given through the ground heat exchanger to the evaporator and the phase change occurs. The vapor phased fluid then goes to the compressor where its pressure and temperature rises and then passes through the condenser, where the heat exchanges take place to another loop used for heating the space. The condensed fluid is then allowed to expand in the expansion valve and send back to the evaporator with low pressure and temperature. This cycle works for space heating and the reverse of this can be used for space cooling.

2 Scope of the study

The GSHP is much popular in USA and many European countries such as Germany, Italy, Switzerland etc., mainly for space heating and air conditioning of the buildings as compare to the Asian region, where its market is increasing day by day. In developing countries like India, it has a wide scope due to the renewable energy technique, which can fulfill the energy demand needed for air conditioning and space heating for new buildings.

3 Objectives of the study

- To investigate the effects of different pipe geometries on the performance parameters of GSHP system.
- Calculate the COP of the system for different configurations.
- Overall performance of the GSHP system for different pipe geometries.
- Power consumption of the heat pump.

4 Literature review

P.C. Zhao et al., [1] **(2002)** conducted an experimental study on geothermal heat pump system, using different non-azeotropic mixtures as working fluids. They found that R123/R290 (50/50 by mass %) and R123/R290/R600a (40/50/10 by mass %) are two working fluids suitable for single stage vapor compression heat pump system under the operating conditions of the site due to their high performance. Adoption of a larger condenser and a larger evaporator in the system to make greater heat transfer and optimal temperature matching, are two proposed improvements for the better performance of the system.

Mustafa Inalli et al., [2] **(2004)** had investigated the effects of parameters such as mass-flow rate of water-anti-freezing solution and buried depth of ground-coupled heat exchanger (GCHE) on the performance of a horizontal ground source heat pump system used for space heating. Two horizontal ground heat exchanger (HGHE) buried at 1m (HGHE-1) and 2m (HGHE-2) depths are used in this experimental study. R-22 was used as a working fluid for the system with non-toxic propylene glycol solution (25% by weight) as an anti-freezing agent. 2.66 and 2.81 are the average value of COPs (Coefficient of performances) for HGHE-1 and HGHE-2 obtained from the results, which are low due to poor system design when compared with the other heat pump systems operating under similar conditions.

Arvind Chel et al., [3] **(2008)** has done the performance evaluation and life-cycle cost (LCC) analysis of earth air heat exchanger (EAHE) with adobe building in New Delhi for the composite climate. To predict room air temperature and energy saving potential of an adobe house having six interconnected rooms with vault roof structure, a computer-based thermal model was developed. Experimentally he concluded that the room air temperature of the adobe house has a higher value than ambient temperature in winter and lower in summer by 5-15 degree Celsius. The average seasonal efficiency ratio of the EAHE was determined as 1.8 and 2.9 for heating and cooling mode respectively, which shows EAHE is more efficient for the heating as compared to the cooling. The annual savings of EAHE was estimated as 5376 kWh/year by LCC analysis which also shows the substantial benefits of adobe house integrated with EAHE with payback period less than 2 years.

Vikas Bansal et al., [4] **(2012)** has done the performance analysis of EATHE integrated with an evaporative cooling system, by using multiphase CFD modeling. Inlet air condition (humidity and temperature) was considered as of the ambient air and air velocity for observation was taken as 5m/s. The analysis was done for the hot and dry climate of the city of Ajmer(India), for 8760h of the year individually. EATHE delivers total 7609MJ cooling effect, out of which 3109MJ is enhanced by the integrated evaporative cooling. This result clearly shows that EATHE with evaporative cooler has better performance as compared to the simple EATHE.

Mohammad Hossein Abbaspour-Fard et al., [5] **(2011)** had studied the effect of different parameters on the performance of an earth to air heat exchanger in the north-east of Iran. On the basis of 72- experimental trials, it was found that all other parameters except that the pipe material had the significant effect on the system performance. PVC (Polyvinyl Chloride) and galvanized mild steel pipes are used in the experiment, galvanized pipe shows the higher differential temperature over PVC pipe in the system. It was also observed that COP of the system for cooling mode was higher than of the heating mode, which was 5.51 and 3.57 respectively with a moderate air velocity of 7m/s.

Vikas Bansal et al., [6] **(2012)** has done the economic and energy savings analysis of EATHE integrated with an evaporative cooling system. The analysis was done for 4 different retrofitting cases having the different combination of four, three, one and three-star rated air conditioner with varying COP heat pump in CFD. Results reveal that performance of the blower is an important parameter and should be considered for efficient system design of EATHE. It also found from the result that in case of retrofitting, an EATHE system is a viable option only in the case where the existing system is inefficient.

T. Sivasakthivel et al., [7] **(2014)** studied the CO2 and energy-saving potential of GSHP in India, considering 10 northern part states by assuming that only 10% families use GSHP system and electric heater for space cooling and heating in these states. From the analysis, it was concluded that the power consumption by an air conditioner and by electric heater ranges from (5506 to 27532)GW and (1416 to 7085)GW for space cooling and heating respectively. Whereas, GSHP were consuming power ranges from (4811 to 14440)GW and (471 to 1416)GW for space cooling and heating, which could save (67 to 80)% and (13 to 48)% energy savings for same load demand in a year. It also concluded from the study that use of GSHP system reduces CO_2 emission about (24 to 54)% in a year.

T. Sivasakthivel et al., [8] **(2014)** applied Taguchi and Utility methods for the optimization of their study objective functions, which are length, the thermal resistance of GHX and COP of the system. From the results of the study, it was concluded that the length of GHX does not only depends on the heating load. Inlet water temperature, the mass flow rate of fluid per kW of load, the thermal conductivity of HX pipe material and heating load are the main affecting parameters of COP. Optimum values for COP, thermal resistance, and GHX pipe length were 3.84, 0.068 m.K/W and 56.5m respectively computed from Taguchi analysis. 1.18% and 13.23% decrease in COP and thermal resistance respectively, whereas 3.2% increase in the length of GHX pipe were computed values from the application of utility concept.

Md. Hasan Ali et al., [9] **(2016)** experimentally investigated the performance of horizontal GHX's for two different orientations, standing and reclined. LDPE coated copper tubes were taken for GHX's pipes, which were buried 1.5m deep inside the ground and ground temperature distribution was also monitored by placing thermocouples (T-type) at different depths up to 10m deep. From the results, it was concluded that the increase in flow rate from 1l/m to 2l/m, increases heat transfer rate by 17.5% and 21.7% for reclined and standing GHX. Standing GHX has higher heat transfer rate as compare to reclined one due to the higher thermal conductivity of backfilled sand.

Nui et al., [10] **(2016)** has done an experimental study on the performance of GSHP system for R-410A refrigerant. The result reveals that increase in condensation temperature from 30 degree C to 60 degree C keeping evaporator temperature constant at 5 degree C, decreases cooling capacity and COP by 33% and 66%, whereas increases the input power by 97.8% respectively. It was also observed that increased evaporation temperature from 0 to 12.5 degree C, increases both input power and refrigeration effect by 20% and 55% respectively. The refrigerating capacity was affected by temperature drop of chilled water and cooling water flow rate.

Zoi Sagia et al., [11] **(2016)** had done a search to find the most suitable environment-friendly replacement of R-22, most widely used refrigerant as working fluid of heat pump in a GSHP system. 7 different alternative refrigerants (5-binary mixtures and 2-ternary blend) was examined for a given GSHP system to meet the required energy demands. MATLAB and REFPROP 8.0, two computer software's were used to studying the performance of refrigerants in the heat pump system. The ternary mixture R-152a/R-125/R-32 had shown the highest COP (4.608) value among all other proposed alternatives, closest to the COP (4.61) of R-22 and it also can be taken into account for the effective operation of the heat pump due to a high glide at a relatively small pressure.

Monika Ignatawicz et al., [12] **(2017)** had studied the performance of different ethyl alcohol based secondary fluids (commercial products in European countries) in GSHP. The performance evaluation is done on the basis of heat transfer and pressure drop in the BHE, taking EA20 as a reference fluid. (EA18+PA1.6+BA0.4), most commonly used a commercial product in Sweden had shown the best performance in terms of lower pressure drop and higher heat transfer up to 2.7% and up to 10% respectively. Further with the lower pressure drop (up to 2%) and higher heat transfer (up to 5%), (EA20+MEK2+MIBK0.5) had shown the second best performance. (EA17.5+PA2+BA0.5) and (EA20+MEK1.8+MIBK2.7) had shown the worst performance both in terms of pressure drop and heat transfer than EA20.

5 Equipment and material

Pipe - 50m long pipe made of high density polyethylene (HDPE) material, having 18mm outer diameter of 3mm thickness.

Flow controller - To control the flow rate of working fluid inside the loop of ground heat exchanger.

Capillary tube - Capillary tube made of copper used as a throttling device in the system. Inner diameter of the tube is 1.6mm and the length is 1.2m.

Compressor - Scroll type compressor having volumetric flow rate about 6.9 cubic meter/h.

Thermocouple - T-type thermocouple is used for temperature measurement of the R-22 at the outlet of compressor, condenser and evaporator. Also the temperature variation inside the ground can be measured with the help of T-type thermocouples.

Working fluid - R-22 refrigerant is used as a working fluid in the system. Solution of water and propylene glycol (by 25% weight) is used as an anti-freezing agent.

Blower - It is used to blow the heat to the room gained by the heat pump.

Manometer - It is used to measure the pressure of compressor and evaporator in the GSHP system.

6 Research methodology

Geographical survey- Need of geographical survey for the site selection is an important task, in which different properties of soil such as moisture content, thermal conductivity are find out. Temperature variation profile of the site gives an idea for the depth needed for an experimental setup installation, where GHX is going to be installed. Surrounding ambient temperature profile of the site also helps at the time of suitable system design of GSHP.

Experimental setup- A closed-loop horizontal ground source heat has been considered for the experimental study. Different types of pipe geometries such as circular, coagulated and rectangle are taken for the GSHP system. Thermocouples are used to measure the ground temperature at different depths.

Reading and calculation- Inlet temperature of working fluid with constant mass flow rate, outlet temperature, electricity consumption by the system will be measured in the month of January, February and March. COP of the system with its overall performance and pumping power required for the working fluid circulation would be calculated from the readings.

Simulation- Calculated results would be compare with simulation of the GSHP system in fluent.

7 Proposed work plan with timeline

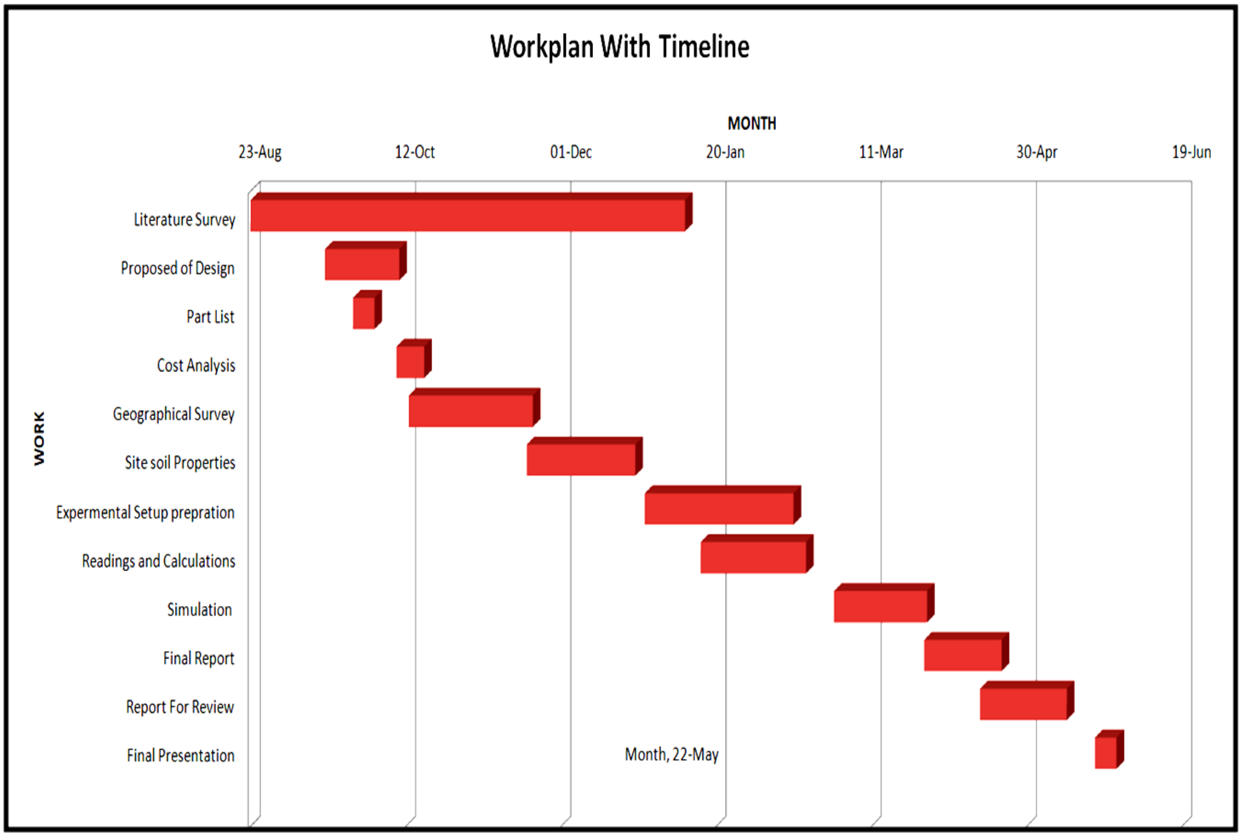

Figure 4 Work plan with timeline

8 Expected outcomes

In this experimental study the effects on the performance of GSHP by using different pipe geometries COP of the system and power required to derive the pump will be observed. From the final result, a suitable pipe geometry can be found for the GSHP system, by use of which overall performance of GSHP system can be improved.

9 Summary and conclusion

In this experimental study of GSHP system, the effects of different pipe geometries on the system performance parameters such as COP and power consumption of the system will be investigated. A suitable pipe geometry can be found for the system from the obtained results on the basis of overall performance of the GSHP system.

10 References

[1] P. C. Zhao, L. Zhao, G. L. Ding, and C. L. Zhang, "Experimental research on geothermal heat pump system with non-azeotropic working fluids," *Appl. Therm. Eng.*, vol. 22, no. 15, pp. 1749–1761, 2002.

[2] M. Inalli and H. Esen, "Experimental thermal performance evaluation of a horizontal ground-source heat pump system," *Appl. Therm. Eng.*, vol. 24, no. 14–15, pp. 2219–2232, 2004.

[3] A. Chel and G. N. Tiwari, "Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate," *Energy Build.*, vol. 41, no. 1, pp. 56–66, 2009.

[4] V. Bansal, R. Mishra, G. Das Agarwal, and J. Mathur, "Performance analysis of integrated earth-air-tunnel-evaporative cooling system in hot and dry climate," *Energy Build.*, vol. 47, pp. 525–532, 2012.

[5] M. H. Abbaspour-Fard, A. Gholami, and M. Khojastehpour, "Evaluation of an earth-to-air heat exchanger for the north-east of Iran with semi-arid climate," *Int. J. Green Energy*, vol. 8, no. 4, pp. 499–510, 2011.

[6] V. Bansal, R. Misra, G. Das Agrawal, and J. Mathur, "Performance evaluation and economic analysis of integrated earth-air-tunnel heat exchanger-evaporative cooling system," *Energy Build.*, vol. 55, pp. 102–108, 2012.

[7] T. Sivasakthivel, K. Murugesan, and P. K. Sahoo, "A study on energy and CO2 saving potential of ground source heat pump system in India," *Renew. Sustain. Energy Rev.*, vol. 32, pp. 278–293, 2014.

[8] T. Sivasakthivel, K. Murugesan, and P. K. Sahoo, "Optimization of ground heat exchanger parameters of ground source heat pump system for space heating applications," *Energy*, vol. 78, pp. 573–586, 2014.

[9] M. Hasan Ali, S. Bin Selamat, K. Kariya, A. Miyara, M. Hasan ALI, and S. Bin SELAMAT, "Purdue e-Pubs Experimental Performance Estimations of Horizontal

Ground Heat Exchangers for GSHP System Experimental Performance Estimations of Horizontal Ground Heat Exchangers for GSHP System," 2016.

[10] J. Niu, H. Wu, and Y. Dong, "Experimental Investigation on the Performance of Ground-source Heat Pump with the Refrigerant R410A," *Int. Compress. Eng. Refrig. Air Cond. High Perform. Build. Conf.*, pp. 1–8, 2016.

[11] Z. Sagia and C. Rakopoulos, "Alternative refrigerants for the heat pump of a ground source heat pump system," *Appl. Therm. Eng.*, vol. 100, pp. 768–774, 2016.

[12] M. Ignatowicz, W. Mazzotti, Å. Melinder, and B. Palm, "Different ethyl alcohol secondary fluids used for GSHP in Europe," *12 IEA Heat Pump Conf.*, p. 12, 2017.