ENERGY AND EXERGY ANALYSIS OF GROUND SOURCE HEAT EXTRACTION TECHNOLOGY IN INDIA

A DISSERTATION

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IN
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Submitted by:

MAHENDRA KUMAR ARYA
2K20/THE/25

Under the supervision of

Prof. RAJESH KUMAR
PROFESSOR

MECHANICAL DEPARTMENT
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi 110042

MAY, 20222

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Mahendra Kumar Arya, Roll No. 2K20/THE/25, student of M. Tech (Thermal Engineering), hereby declare that the project Dissertation titled "ENERGY AND EXERGY ANALYSIS OF GROUND SOURCE HEAT EXTRACTION TECHNOLOGY IN INDIA" which is submitted by me to Department of Mechanical engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and is not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi

Date: MAHENDRA KUMAR ARYA

DEPARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the project dissertation titled "ENERGY AND EXERGY ANALYSIS OF GROUND SOURCE HEAT EXTRACTION TECHNOLOGY IN INDIA", which is submitted by Mahendra Kumar Arya, 2K20/THE/25, Mechanical Department, Delhi Technological University, Delhi, in partial fulfilment of the requirement for the award of the degree of Masters of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part of full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date:

Prof. RAJESH KUMAR
SUPERVISOR

Professor
Department of Mechanical Engineering
Delhi Technological University
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

ABSTRACT

A geothermal heat pump (GHP) or ground source heat pump (GSHP) is the heart of the geothermal technology which in fact pumps the heat from the ground to the dwellings. This design takes advantage of the moderate temperatures of the ground to boost efficiency and reduce the operational costs of heating and cooling systems. Primarily, there are two independent loops working in heat extraction process i.e., ground loop and refrigeration loop. A mixture solution of antifreeze & water absorbs heat from ground and supplies to the refrigerant loop through heat exchanger. The refrigerant loop transmits this heat to a desuperheater that is interfacing the user load where accumulation of heat occurs. It also may be combined with a thermal or solar heating system with even greater efficiency. GHPs use the relatively constant temperature of the earth to provide heating and a small amount of electricity input is required to run a compressor; however, the energy output is of the order of many times of this input.

Earlier in this project a vertical U-tube design of 'geothermal heat exchange system' has been used to provide a regulated preheated water supply to the existing central heating plant used for space heating to the dwellings. The outcomes of this project have been translated into 'Geothermal Technology' towards energy savings in the space heating in the Himalayan region as well as to the armed forces and also for futuristic energy plans of the country. Now, in this study the main focus is on increasing the overall efficiency of the system and for attaining this objective two approaches were taken. First, to evaluate the performance of the existing facility at Defense Geoinformatics Research

Establishment (DGRE), Manali, in order to get the optimum parameters for further studies; Second, to do the energy and exergy analysis of the complete geothermal heating system to find out the COP, or first law efficiency, and exergetic efficiency, or second law efficiency. This analysis is performed in Engineering equation solver (EES) software. Parameters obtained in performance evaluation study like Pressure (P_o), Dead state temperature (T_o) etc. has been utilized for the energy and exergy analysis. The refrigerant used for the analysis is R-134a.The COP calculated for the system is 5.851 and the exergetic efficiency obtained was 77%. Maximum destruction or Irreversibility obtained in compressor as compared to condenser and expansion valve.

Keywords: Exergetic efficiency, EES Software, Geothermal heat pump (GHP), Irreversibility or destruction

ACKNOWLEDGEMENT

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Mahendra Kumar Arya

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LIST OF ABBREVIATIONS

DGRE - Snow and Avalanche Study Establishment

DRDO - Defence Research and Development Organization

GHP - Geothermal Heat Pump

COP - Coefficient of performance

GSHP - Ground Source Heat Pump

HDPE - High Density Poly Ethylene

MDPE - Medium Density Poly Ethylene

HVAC - Heating Ventilation and Air Conditioning

EAHE - Earth Air Heat Exchanger

EGS - Enhanced Geothermal Systems

PVC - Polyvinyl Cloride

CHAPTER 1

INTRODUCTION

In the Himalayan region of India our troops are deployed for safeguarding the country boarders but because of snow avalanches many soldiers and civilian's loss their lives and property. Therefore, advance warning of avalanche occurrence is very essential which DGRE is doing by carrying out field research work, snow-met data collection and by generating the avalanche reports. For smooth execution of these works heating is one of the major needs of the technical/scientific staff not only for comfort but also for their survival. In the NW-Himalaya, DGRE is having scattered observatory setups and various manned and unmanned field stations where climatic conditions are extremely cold. DGRE has been using conventional methods of heating like bukharis, kerosine-heaters, electric heat pillars, bio-fuel, fire woods, etc, since long time. Recently few of stations are facilitated by diesel run central heating plants. Every year DGRE consumes lacs of litre of diesel to meet its heating needs.

Keeping in minds the upcoming oil crisis in the globe this is very essential to explore the alternates of oil fuels today, otherwise coming generations may face great troubles. Also, for the setups like DGRE there is dire need of some alternate of sustainable and reliable source of renewable energy which either can replace the oil-based heating or at least can provide an energy saving system to reduce the oil consumption. Replacement of conventional heating system is the need of time. As far as sources of renewable energy is concerned, there are various energy sources like solar energy, wind energy, micro-hydro-electric energy, tidal energy, wave energy, geothermal energy, etc. For space heating geothermal systems are one of the most prominent alternate if we see its thermal efficiency, cost effectiveness, long life and maintenance as compared to other sources. Because of high geothermal flux and supporting local geology of Himalaya, geothermal system is suitable for remote snow bound locations of DGRE for space heating. The oil-burnt heating is increasing pollution level in Himalaya causing global warming and at the same time it is also not good for human health. Geothermal heat is a form of renewable emanating from interiors of the earth, resulting as a combination of residual heat from the planetary accretion and heat produced through radioactive decay within the earth's cores. The major heat-producing isotopes within the Earth are considered as 40K (Potassium), 238U (Uranium), 235U (Uranium) and 232Th (Thorium). It has been observed that the temperature within the earth increases with depth and at its center it may go up to 7,000 K. Highly viscous or partially molten rocks at temperatures between 650 to 1,200°C are postulated to exist everywhere beneath the earth's surface at depths of 80 to 100 kilometers. Estimated heat content within the earth is of the order of 1031 Joules and an estimated total heat loss from the earth is approximately 4.2 × 1013 Watts. An average geothermal temperature gradient in the outer crust of the earth is 25-30°C/Km which can be higher near the tectonic boundaries. If the heat trapped within the earth interiors can be utilized for energy generation purposes it can lasts for next lakhs of years. In this context, this is only the energy source which can provide our coming generations a reliable and secure energy alternate. Geothermal heating works by catching steam and hot water directly and piping it into heat exchangers or radiators. Many of the sun's energy can be absorbed as heat through geothermal heat exchangers. A geothermal heat pump (GHP) is a simple device that transfers heat from the earth to the building's heating system. Although geothermal heat can be transformed into geothermal electricity if needed, no energy conversion is required. A geothermal heating system works by pumping water through subterranean pipes and allowing the water to be heated by the soil temperature. The heat pump is installed within the house, similar to a furnace. The heat pump functions similarly to a central air conditioner, but it also delivers heat.

A geothermal heat pump (GHP) is the heart of geothermal technology that forces the heat to flow from ground to the user building. The basics of a GHP system work by pumping a mixture solution of water & antifreeze or any other liquid through underground pipe circuits and letting the soil temperature to warm the water moderately. The heat pump can be located inside the house and connected to the ground loop by a heat exchanger. In a complete cycle of refrigeration, heat is extracted from ground loop to the desuperheater system (an interface between refrigerant loop and the user heating device). A refrigerant circuit comprising evaporator, compressor, condenser and expansion valve units serve the heat extraction in GHP and a particular refrigerant like

R134a is primarily used at high pressures. Also, there is ground source heat pump that provides warmer and more stable heat as the soil below the frost level stores most of the geothermal and solar energy and is generally at a constant temperature at a depth of 4-5 m. While geothermal can deal with average ambient temperatures around the same as a conventional heat pump, it will need to be able to provide a backup source if temperatures drop below freezing. As a result, this alternative energy source can be very useful for space heating in DGRE's remote stations in the Himalayan cold. Geothermal heat exchangers can also absorb much of the sun's heat energy. In GHP a ground loop is a heat exchanger that either extracts or adds heat to the ground. The ground itself is not a perfect heat source because the energy added to the ground by the loop can change its temperature over time. The principles of this interaction are common in all loop types. Geothermal systems come in several different configurations, each with its own strengths and weaknesses, i.e., open loop, closed loop, horizontal loop, vertical loop, surface water loop, etc. The GHP closed loop system maintains a clean environment and the savings in CO_2 emissions is also a major benefit. The technology is highly adaptive – it can use the earth mass or water bodies (lakes, rivers, ground water) as a heat source.

1.1 SPIN-OFF BENEFITS

As illustrated in Figure 1.1, the sun is the primary source of energy, and its energy is absorbed by the ground. This energy can be used for geothermal heating or cooling. This geothermal technology can be utilized at snow bound regions where geothermal energy available in abundance at higher altitude from mean sea level. The utilization can be for space heating or some other application DRDO and Armed forces. Apart from the research point of view this technology can Hot water needs of the local residents can be achieved significantly which presently is met by consuming large amount of electricity by the geysers. In addition to it, the fishing and agriculture sector of the state governments can be benefitted.

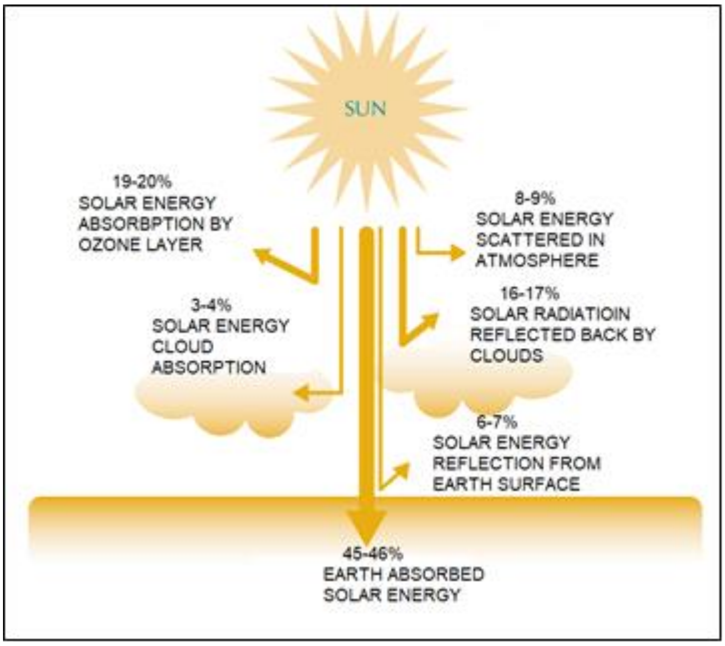


Figure 1.1**:** Distribution of Solar Energy

1.2 RESEARCH OBJECTIVES

The objective of this work is mainly to evaluate the energy saving performance of Geothermal Heat Pumps (GHP) unit at DGRE (Manali) in the cold climatic environment. This objective is achieved by dividing the work into three parts as discussed below:

1. Performance evaluation of Geothermal based Space Heating system with existing central heating plant connected to the dwellings.
2. Energy and exergy analysis of geothermal based space heating system.
3. Computational fluid dynamics analysis of horizontal pipe in group loop of the geothermal heating system plant to get an optimum water velocity to obtain the maximum outlet temperature of water circulated through ground loop.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In Geothermal space heating system, a pipe filled or circulated with water buried under the earth to exchange heat, it will gain heat in winters. About 4-6 meters below the Earth's surface the temperature remains relatively constant throughout the year irrespective of the place. In addition, there is always a usable temperature difference between the ground temperature and the ambient temperature. If higher input temperature is there it definitely would enhance the efficiency of the geothermal system. GHP capitalizes on these two phenomena and heat transfer takes place from ground to the user load /building to reduce energy consumption. In geothermal system earth adds heat in the circulated water in winters and that heated water when interact with the air in the dwelling through a blowing fan placed inside the room, exchanges heat and the air temperature increase than the ambient temperature and hence it helps in keeping the room warm in winters. Ground Energy consisting of two major sources, one produced within the earth interior and other is solar energy absorbed by earth surface (46% of total solar energy). So total ground energy consisting of 94% due to geothermal energy and 6 % due to Solar energy. A geothermal heat pump (GHP) or ground source heat pump (GSHP) is the heart of the geothermal technology which in fact pumps the heat from the ground to the dwellings. This design takes advantage of the moderate temperatures of the ground to boost efficiency and reduce the operational costs of heating and cooling systems. Primarily, there are two independent loops working in heat extraction process i.e., ground loop and refrigeration loop. A mixture solution of antifreeze & water absorbs heat from ground and supplies to the refrigerant loop through heat exchanger. The refrigerant loop transmits this heat to a desuperheater that is interfacing the user load where accumulation of heat occurs.

It also may be combined with a thermal or solar heating system with even greater efficiency. GHPs use the relatively constant temperature of the earth to provide heating and a small amount of electricity input is required to run a compressor; however, the energy output is of the order of many times of this input. The source of geothermal energy is within the deep interior (outer core) of the Earth and as a result of thermal conduction and intrusion into the crust of hot molten magma this energy is brought to the cooler earth surface. Geothermal energy is clean, very environment friendly, abundant and reliable in nature. Geothermal energy can be categorized under grade-I and grade-II energy classes. The grade-I class is purely the geothermal energy coming from hot magma of the Earth to the surface in the form of volcanoes/hot water springs/Geysers, which are having very high temperatures. This form of energy is mainly harnessed in the power generation technology, where water temperature should be more than 100^0C (steam point). However, the grade-II energy is a low heat content energy lying within the top earth crust. This type of energy comprises both the geothermal energy coming from earth interiors as well as the solar energy as shown in Figure 2.1 (nearly 47% of total solar energy is absorbed by the earth that contributes into the grade-II energy). Geothermal technology capitalizes this energy for direct space heating by using the principle of refrigeration in extraction of heat from a heat source. At any moderate temperature of $10\text{-}120^0$C or more is enough to extract heat and as such no hot water spring or geyser is required for space heating purposes. But if there is a hot water sources like geyser it definitely would enhance the efficiency of the geothermal heat pump. Irrespective of any tectonic faults, such moderate temperatures can be found almost everywhere in the world including the Himalayan region.

Geo Exchange system produces an average of about one pound less Carbon Dioxide (CO2) per hour of use than a conventional system. To put that in perspective, over an average 20-year lifespan, 100,000 units of nominally sized residential Geo Exchange systems will reduce greenhouse gas emissions by almost 1.1 million metric tons of carbon equivalents.

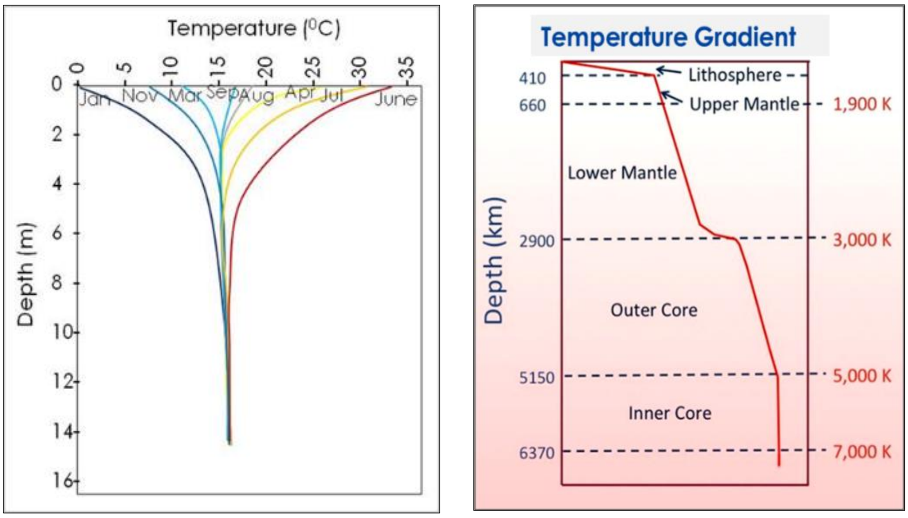


Figure 2.1: Temperature variation along the depth inside the ground.

2.2 LITERATURE REVIEW

Stober and Bucher (2013) The thermal energy stored beneath the surface of the Earth is known as geothermal energy or geothermal heat. Geothermal heat recovered from various depths beneath the surface offers a variety of unique and diverse applications. One of the benefits of geothermal energy is that it is weather independent and available throughout the year. When used sustainably, consumed geothermal energy is restored and refilled from the internal planetary reservoir, making it infinite from a human perspective. To use renewable energy resources responsibly, the rate of consumption must be equal to or less than the rate of renewal.

Self et al. (2012) The three main uses of geothermal energy are electricity generation, direct heating, and indirect heating systems using geothermal heat pumps (GHPs). These three processes employ high, medium, and low temperature resources in that order. High and medium temperature resources are usually derived from thermal fluxes formed by the earth's core, which concentrate in areas of water or rock. Low-temperature resources are those that are close to ambient temperature and are primarily powered by solar energy and ambient air. Drilling and other extraction costs can increase at extreme depths, therefore medium and high temperature thermal resources are typically discovered deep beneath the ground. Their depth has an impact on whether or not they can be economically exploited.

Liu (2010) GHP indirect heating systems is not the same as geothermal power generation, also known as enhanced geothermal systems (EGS), which employs the extreme heat of underlying geological processes to generate steam and, eventually, electricity. It's also not the same as direct geothermal heat, which includes heating greenhouses, farming ponds, and other agricultural facilities with moderate-temperature geothermal sources like hot springs. GHP systems use the only renewable energy source that is (a) available at the point of use in most buildings, (b) available on demand, (c) not generally exhausted (assuming excellent design), and (d) potentially cost-effective.

Liu (2010) Instead of rejecting heat from building structures to the surrounding atmosphere (in the cooling cycle) and attempting to extract heat from fossil fuel combustion, electricity, or possibly the lower atmosphere (in space and/or heating water methods), a GHP rejects heat to or extracts heat from a variety of ground resources, such as earth, surface water and sewage treatment plant effluent.

Kavanaugh (2006) As the price of energy and maintenance services rises, GHPs are more common. Because GHPs have no exposed exterior equipment, they not only save energy but also minimize maintenance costs and lengthen equipment life when correctly built and installed. They're fairly basic machines that only differ slightly from standard heat pumps.

Rybach (2012) Finances are, of course, a major concern. Although GHPs need a significant upfront expenditure (more than standard HVAC systems), their overall performance is theoretically superior. The extra ground and site work (typically drilling operations activities) and components contribute to the higher installation cost (heat pump, connections, and distributors). GHPs, on the other hand, have minimal operating expenses because the heat pumps and circulatory pumps are mostly powered by electricity.

S.H. Hammadi (2018) The stored water tank temperature is above 50°C, this water was exposed to direct sunlight and also to warm breeze in summer. The approach to tackle this problem was time-based analysis of a cylindrical tank of hot water which is exposed to high. The analysis of this problem includes the energy balance of water tank and ground water heat. This problem was also solved numerically by fourth order Runge-Kutta method. The usage of underground heat exchangers was found to reduce the temperature of water by approximately16 degree Celsius. Result of both experimental and numerical method was found comparable.

Namrata at el. (2018) The current situation requires energy efficiency. EAHE heat exchangers are a technique for reducing energy consumption. EAHE is a novel method of heating and cooling that makes use of geothermal energy from the earth. The different EAHE combinations are discussed in this article. The overview provides a comprehensive overview of prior EAHE operations. Various approached were adopted to study EAHE combination in details. It also considers the environmental impact of energy conservation. Their study also mention that design parameters have major impact on outlet temperature. The outcome also demonstrates that the pipe material has no impact.

Sayeh Menhoudj et al. (2018) The energy efficiency of an air-to-ground heat exchanger (EAHE) for buildings in Algeria is investigated in this paper. One air duct of galvanized plate and the other of PVC) studied under the same geometric conditions. Separately, they are used to air two adjacent rooms that make up a test cell. The temperature has been measured at several places (air inlet / exit) using an experimental equipment. In August of 2015, the measurements were taken.

Lazaros, & Georgios Florides (2018) Renewable energy systems and its derived technologies' have developed significantly over a period of time. Use of geothermal energy was initially used in Italy in 1904, and its efficiency has enhanced since then. One of the most common types if geothermal heat pumps (GSHP), which are used in conjunction with geothermal heat exchangers (GHE) to heating and cooling of a space.

Geothermal energy uses a network of pipes to extract heat from the earth. The most frequent configuration is a closed-circuit system (vertical or horizontal). In an open circuit, pipes can also utilize natural subsurface wells. Traditional air-to-air heat exchanger systems do not compare to GHEs in terms of performance. It is critical for research to reduce costs and increase overall efficiency through design.

Stuart J. Self, & Bale V. Reddy (2013) Geothermal heat pumps are energy-efficient heating systems that can reduce CO_2 emissions, prevent the use of fossil fuels, and provide financial benefits. Heat pumps use substantially less energy than other heating technologies to heat a building. There are many distinct types of geothermal heating systems, each with varied configurations that are ideal for diverse conditions and most regions around the world. When picking between heating solutions, it's critical to weigh the advantages of various ground heat pump choices, which are often measured in terms of efficiency, emissions, and cost.

CHAPTER 3

SYSTEM DESCRIPTION AND INSTALLATION

3.1 DESIGN OF GEOTHERMAL HEAT EXCHANGE SYSTEM

Heat pumps provides heating in winter time by extracting heat from the ground and transferring it to the user side. A ground source heat pump uses the shallow ground as a source of heat, thus taking advantage of its seasonally moderate temperatures. About 4-6 meters below the Earth's surface the temperature remains relatively constant throughout the year irrespective of the place. In addition, there is always a usable temperature difference between the ground temperature and the ambient temperature. If higher input temperature is there it definitely would enhance the efficiency of the geothermal system. GHP capitalizes on these two phenomena and heat transfer takes place from ground to the user load /building to reduce energy consumption. Because of limited land space available at the proposed site a closed U-tube design of GHP system is proposed in this project with nearly a 100kW of GHP system. How heat is extracted from earth at a moderate temperature 10^0C to 25^0C and converted in to nearly 80^0C at the desuperheater can be understood by the complete geothermal heating cycle which is described in detail below:

SPACE HEATING CYCLE:

1. A mixture solution of water and antifreeze flow in the ground loop and passing through it may attain temperature of $10–25^0$C, depending on the specific site.
2. Cold liquid refrigerant passes through the evaporator (heat exchanger, HX) and get vaporized after absorbing heat through heat exchanger combining ground loop & evaporator in a spiral arrangement.
3. The cold gas refrigerant passes to the compressor and is compressed at very pressure of 45-55 bar, converting in to high temperature & high-pressure refrigerant gas.

4. The hot refrigerant from the compressor is cooled to sufficiently usable temperatures at the condenser (in the contact of De-superheater).
5. Through the reversed valve warm refrigerant gas is sent directly to the User Interface (Room side heat exchanger).
6. The refrigerant heats the room and cools down sufficiently for liquefaction.
7. Expansion valve liquefies the refrigerant and temperature drops.
8. “Hot in” from the Ground Loop then vaporizes the refrigerant for entry to compressor.
9. The De-superheater serves to heat User Side water supply if required. If hotter refrigerant is required at Air Coil (due to more heating load or longer distances of supply) then the De-superheater section may not be implemented.
10. A sustained flow of heat takes place from ground to the residential dwellings by consuming small amount of electricity to run the compressor and pumps.

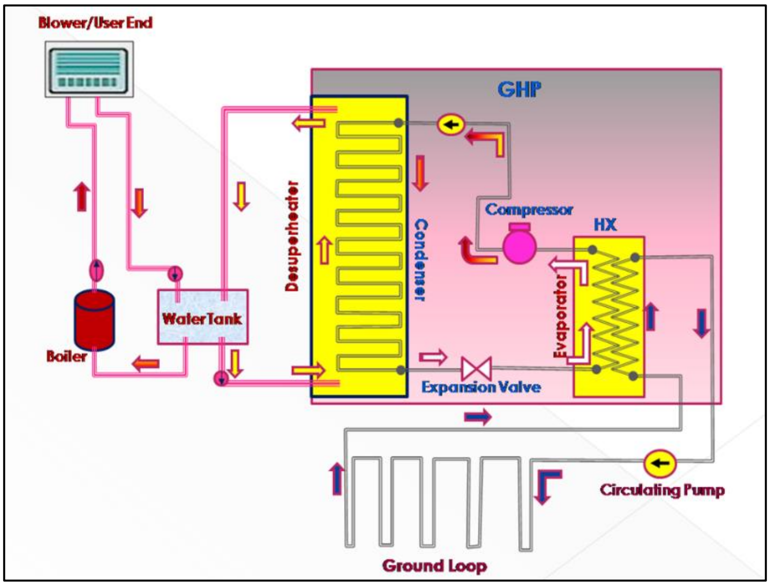


Figure 3.1: Schematic design of 100 kW geothermal space heating system.

3.2 GHP TECHNOLOGY

A geothermal heat pump (GHP) is the heart of geothermal technology that forces the heat to flow from ground to the user building. The basics of a GHP system work by pumping a mixture solution of water & antifreeze or any other liquid through underground pipe circuits and let the temperature of soil warm the water moderately. The pump can be placed inside the house and connected to the ground loop by a heat exchanger. In a complete cycle of refrigeration, heat is extracted from ground loop to the desuperheater system (an interface between refrigerant loop and the user heating device). A refrigerant circuit comprising evaporator, compressor, condenser and expansion valve units serve the heat extraction in GHP and a particular refrigerant like R134a is primarily used at high pressures. Also, there is ground source heat pump provides more stable heat as the soil stores most of the geothermal and solar energy and is generally at a constant temperature at a depth of 4-5 m. While geothermal can work with average ambient temperatures, it will be able to provide a supplemental source if temperatures dip below freezing, therefore, this alternate of energy can be very useful for space heating in various remote stations of DGRE located in the cold regions of Himalaya. A geothermal heat exchanger can also absorb much of the sun’s heat energy.

A ground loop in GHP refers to a heat exchanger that extracts or adds heat to the earth. Because the energy delivered to the earth by the loop might change its temperature over time, the ground is not a perfect heat source. In all loop types, the basics of this interaction are the same. Open loop, closed loop, horizontal loop, vertical loop, surface water loop, and other configurations of geothermal systems exist, each with its own strengths and drawbacks, such as open loop, closed loop, horizontal loop, vertical loop, surface water loop, and so on. The GHP closed loop system keeps the environment clean, and the reduction in CO_2 emissions is a significant benefit. The technology is extremely adaptable, as it can employ the earth's bulk or water bodies (lakes, rivers, and ground water) as a source of heat..

3.3 INSTALLATION OF GROUND HEAT EXCHANGER SYSTEM

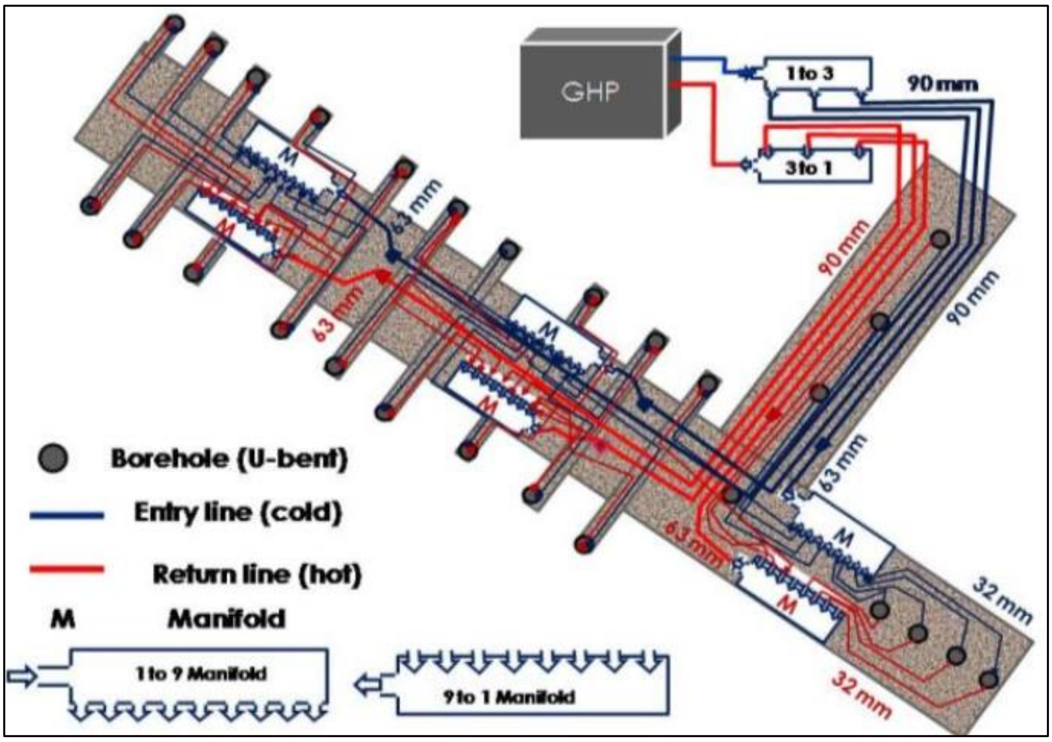


Figure 3.2: Schematic diagram of ground loop heat exchanger and manifolds.

The ground loop heat exchanger is in fact the heart of the entire geothermal heat extraction technology; by and large it would determine the successfulness of the project and stability of output heat load. The schematic of ground loop heat exchanger is shown in Figure 3.2. In this figure the dark rectangular strip is the horizontal trench in which the vertical loop, horizontal loop and manifolds would be erected. In the present case the total trench length is 115 m (first major section 95 m and second smaller portion with bifurcation is 20 m). The width of the trench is 1.5 m and depth 1.0 m. In the entire loop there are three manifolds (1x9) for entry cold water (blue) and three for return (9x1) mild hot water (red). Each manifold connects to 9 different U-bent in the boreholes, as shown by red spots encircled by violet color. The vertical U-bent of HDPE pipe is having OD 32 mm however, the MDPE horizontal loop is with OD 90 mm 63 mm and 32 mm, respectively. In order to maintain required uniform pressure within the horizontal and vertical loops, reducers are used between 90 mm and 63 mm line and between 63 mm and 32 mm line. Also, pressure can be controlled manually through the valves connected at each inlet/exit of the manifold line. In the horizontal loop more or less laminar flow is maintained (Reynolds Number, R_e<100), however, within vertical U-tube turbulent flow is maintained (R_e>3000) in order to have better heat transfer from ground to the U-tube. Therefore, the pressure in horizontal loop is kept between 1 to 1.5 bar, however, in vertical U-tube it can be between 2 to 4 bar, which is one of the important criteria to design a ground loop heat exchanger.

3.3.1 BOREHOLE DRILLING AND U-BENT INSTALLATION

(a) **(b)**

Figure 3.3: (a) The drilled boreholes as shown by uncut top portion of MS-casing in trench, (b) the top cut view of covered borehole and trench after cutting top portion of the MS-casing (ready for installation of U-bent).

There were 27 boreholes sunk for the installation of the whole geothermal space heating system, with a total running length of 2500 m and a bore diameter of 127 mm (5 inch). Temporary MS-casing of 7 inch is provided first top depths 70 to 90 feet, as discussed in the previous part. Permanent MS-casing (5 inch) is delivered up to full depth as discussed in the previous section. The bore-to-bore separation was restricted to a maximum of 5 to

6 metres. Figure 3.3(a) depicts the uncut top portions of the 5-inch MS-casing representing the drilled boreholes, whereas Figure 3.3(b) depicts the trench with cut top portions of MS-casing. Cello tape and trench tape were used to cover the top portions of the MS-casings after they were cut.

3.3.2 INSTALLATION OF VERTICAL LOOP OF U-BENT HDPE PIPES

Figure 3.4: HDPE U-bent for vertical boreholes installation, top view is the roll of HDPE pipes (U-bent) and bottom view id the end of U-bent.

The vertical U-bents were carefully put into the boreholes after passing pressure and leak tests. Figure 3.4 depicts a roll of HDPE U-bent pipe and an unrolled HDPE U-bent pipe ready for installation. The U-terminus bent's may be seen on the right side (bottom). Because the cased boreholes were partially full of water from soggy earth, they had to be drained. To keep the U-tube from floating, two 20 mm MS-rods, each with a length of three metres, were fastened to the U-bent. This U-bend (which is already filled with water) could easily reach a depth of 100 metres. The total of 27 U-bents were placed into all 27 boreholes drilled, resulting in a total of U-bent running.

3.3.3 INSTALLATION HORIZONTAL LOOP OF MDPE PIPES

After complete installation of vertical U-bents into the boreholes, the horizontal loop was laid on the trench. First 90 mm MDPE pipes (SDR 11) were installed 10 feet away from respective manifold. Thereafter the 63 mm line was laid connected to respective manifold, similar to the design as discussed in previous section. Finally, the exit distribution (1 to 9) / entry collection (9 to 1) line was connected by 32 mm MDPE pipe to the respective U-bent inserted into boreholes. The three 90 mm lines each for entry and return then converts into 3 to 1 or 1 to 3 lines for connection to the GSHP. All U-bents are connected in parallel fashion, rather than series. The joints/fittings were connected using electro-fusion and thermo-fusion methods. Since joints are the weakest links determining the life of a loop, therefore, the jointing work was done carefully. Figure 3.5(a) depicts how horizontal and vertical loops are erected. Further during laying of horizontal loops, a sand bed was provided beneath the pipes in order to provide more safety and life to the ground loop. Figure 3.5(b) shows the distribution of lines at the exit or entry of a manifold and Fig 3.5(c) the header connection to the GSHP. In Manifolds, each line has a valve to control the pressure in U-bent. The electro-fusion onsite is shown by Figure 3.5(d) along with the electro-fusion fitting on right lower side.

The electrical terminals as seen in this figure are used to connect the joint to the electro-fusion controller, as shown in right upper side of this figure. But for connection at manifolds, the thermo-fusion was used, in which the jointing part is melted over a thermo-fusion plate (hot plate) and joints/parts are connected straightway, this method is rather a simple method. Each U-loop should be pressure tested before insertion into the borehole and again after manifolding. Testing should be by air and water at least for half an hour under recommended pressure limit.

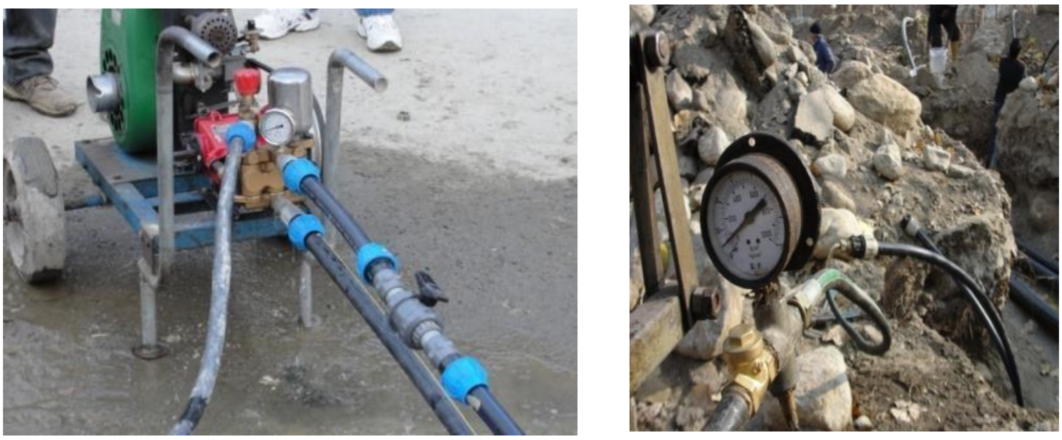
(a) **(b)**

(c) **(d)**

Figure 3.5: (a) Erected horizontal and vertical loop, (b) connection to manifolds, (c) the header connections (1X3 and 3x1) to GSHP, (d) ongoing onsite electro fusion work of the pipe joints/fittings.

3.3.4 GROUND LOOP LEAK AND PRESSURE TESTING'S

After completion of the ground loop installation work, the pressure and leak testing of the entire loop (vertical and horizontal) was carried out. For pressure testing the motorized (Fig 3.6(a)) and manual pumps (Figure 3.6(b)) were used. The pressure testing was carried out at a pressure of 10 bar and observed the pressure stability up to 30 minutes consecutively three times. It was found that there was no leakage or pressure drop in the entire ground loop.



(a) (b)

Figure 3.6: Pressure and leak testing of the ground loop, using (a) motorized pressure pump (150 bar), (b) manual Pressure pump (50 bar).

3.3.5 GROUTING OF GROUND LOOP

Grouting is one of the important tasks of the project making perfect thermal contact of U-bent to the adjoin ground. In this work we have used the paste of Bentonite mixed with E-Z mud. In this work, a special grout pump was used to mix both the components and then allowing to pass inside the borehole with high pressure. The grout pipe starts filling the borehole from bottom to top. In the present case stopper was provided to the U-bent at a depth of 50 m therefore lower portion of borehole was filled by natural water and top portion by bentonite paste. The grouting was completed in steps of 2 m.

(a) (b)

Figure 3.7: Grouting work going on at the project site (a) grout pump, grout paste entering into borehole through a 32 mm pipe.

3.3.6 INSTALLATION OF GROUND SOURCE HEAT PUMP

In the next phase the installation of ground source heat pump and its other accessories were completed. Figure 3.8 shows the GSHP (model NKW130R7PE8NNSSC, supplied by WFI, USA) installed at the project site which is housed inside a hut. The right top side of this figure shows the electric control panel and right-side bottom figure shows the circulating pump for ground loop. The headers as shown in Figure 3.5(c) are connected to the GSHP through the circulating pump. The actual load capacity of the GSHP, in this case is 130 kW so as to meet the high-altitude efficiency factors and other losses during heat transmission to the user's dwellings and ensuring 10kW load capacity to the user side. In the present case the capacity of the circulating pump is kept 5HP and connected to flows witch towards entry side of the ground loop. The electrical control unit provide a 3-phase electric power supply (370 - 415 VAC, 50 Hz), which is compatible to the requirement of GSHP load capacity. The flow-switch can be used to regulate the flow rate in the ground loop.

Figure 3.8: The Ground Source Heat Pump installed at the project site along with its control panel (right side top) and circulating pump (right side bottom).

CHAPTER 4

PERFORMANCE EVALUATION AND EXERGY ANLYSIS

4.1 EVALUATION OF SYSTEM PERFORMANCE

The performance of the GSHP based space heating system was measured in terms of output heating load while running the GHP and ground loop circulating pump, electric power consumed and temperature achieved along with temperature stability. Figure 4.1 depicts the water reservoir tank of capacity 2000 litre which supplies water to the boiler of existing central heating plant and then store cum supply the return hot water from dwellings to the boiler. In the existing heating plant, the two 5HP circulating pumps supply water to the dwellings at a flow rate of 30Litre/second and 14 dwellings are supplied heating. Two cascaded diesel run boilers (make - Alfa Therm, capacity 105 K calorie) are used in the heating plant to heat up the cold water. In the present arrangement the output of the GSHP is connected to this tank providing preheated water supply and it get further heated to reach the required temperature of entry water to the dwellings. The right top side of this figure is the insulated heat line to the dwelling and right bottom figure is the heat ventilator cum blower inside the dwelling. The output load performance of the GSHP system was measured in a separate tank of capacity 512 litre. The inlet temperature of water entering into GSHP was 9^0C-13^0C- and return water from GSHP was re-circulated into it until the peak temperature is achieved. In this study the maximum temperature of the output water that this system could provide was 53^0C and once temperature reached at this point GSHP automatically cuts down. While to heat up the initial 9-13^0C of water to the peak temperature of 53^0C, GSHP took 14 minutes of time.

With this information we calculated the output load as 102.4 kW, which is more than the desired load of 10 kW. The flow rate of the GSHP can be varied from 0.5 litre/second to 1.5 litre/ second. At minimum flow rate (0.5 litre / second) we could achieve the desired output load of 10 kW. This test was repeated many times to check the deterioration in its output load as well as peak temperature stability. It was found that output loads and peak temperatures were stabilized. Simultaneously the electric power consumption was measured while running the entire setup. It was observed that 33 kW was the electric consumption while GSHP was running, in this way we could estimate the Coefficient of Performance (COP) of the system was estimated near about 3.1, which could yield the energy saving up to 67% at its peak loading. Further, the GSHP was connected to the user load side through tank of central heating plant. It was observed that additional heating was provided by burning diesel to further increase the water temperature up to 70^0C, in existing setup of heat line to the users. The return water temperature in this case is 40^0C. Effectively the GHP could save up to 60% of the diesel consumed. Because there is still need of improving the quality of heat transmission lines to dwellings and their insulation.

Figure 4.1: Performance evaluation of GSHP based space heating system with existing central heating plant connected to the dwellings.

In this work it was also observed that the emission of carbon and other greenhouse gases and as a rough estimate it was find that the significant decrease in the carbon emission up to 5%. This is due to the fact that initial burning of diesel is high resulting into more carbon emission because the temperature of 2000 litre of tank has to brought up to 70^0C from water temperature of close to 0^0C. Thus, GSHP based heating system is providing the preheated water to the existing central heating plant at temperature 53^0C and heating the return temperature of 40^0C to 53^0C. The GSHP is providing heat through initial heating of cold-water of 2000 litre capacity and the further heating of return water. Since the user requires a comfortable temperature of 25^0C to 30^0C, however, GSHP is providing a 53^0C of temperature, therefore by providing good quality of heat insulation, quality of heat transmission line and dwelling door/window arrangement the GSHP system alone is capable to supply sufficient heating to the dwellings. Also, by utilizing the full capacity of the ground loop heat exchanger and upgrading the GSHP capacity, the other dwellings can be benefitted with this geothermal based space heating system. Further, this system works in the reversible mode, hence cooling cycle can also be run during summer season. The cooling tests were done on same tank of 512 litre capacity to bring down the water temperature of 53^0C to 13^0C, and it took nearly 17 minutes to achieve this temperature which is relatively more than the heating cycle.

4.2 COST-BENEFIT ANALYSIS

The GHP system is proposed to be used for space heating to the DGRE setup at Manali based on its specific requirements because DGRE presently has diesel run boilers to support the heating to its dwellings which is too costly but by introduction of such units the preheated water supply from GHP system will save enormous amounts of money or may replace this heating system in totality. After successful demonstration of this technology DRDO will be able to translate the same benefits to their large number of locations and Indian army. The expected benefits to the end users are:

1. Reduced operating cost & Reduction in electricity bills.
2. Reduced pollution with carbon credits by promoting an environment friendly heating set up.
3. Minimizing the fuel/oil consumption that is mostly imported by the country.
5. Reduced problem of logistics for collecting and storing fuel on site.
6. Reduced fire hazard.

4.3 CALCULATION OF POWER CONSUMPTION IN DIESEL HEATING PLANT BOILER AND NEWLY PLANTED GEOTHERMAL HEAT PUMP

DIESEL HEATING PLANT

Boiler water tank dimension: - 124 cm x 124cm x 100cm = 1537600 cm3= 1537.6 Ltr.

The mass of water in the tank, m= 1537.6 Kg

Time taken by system to rise the temp of this water from 16deg to 49deg= 41min.

Diesel consumed by the system = 10 Ltrs

Power of the system = 1537.6 x 4200x 33/ 41x 60 = 86.63kW

GEOTHERMAL HEAT PUMP

Boiler water tank dimension = 124 cm x 124cm x 100cm = 1537600 cm3 = 1537.6 Ltr

The mass of water in the tank, m= 1537.6 Kg

Time taken by heat pump to rise the temp of water from 16 deg to 49deg = 35min.

Rise in temp =33 deg.

Power of the heat pump= 1537.6 x 4200 x33 / 35x60 watt = 101.4 kW

DIESEL SAVING BY GEOTHERMAL HEAT PUMP

Average consumption of Diesel Unit = 24 Lt. /Hr.

Total hour during Morning=2.5 Hour

Oil consumed at Morning=2.5 x 24 Lt. = 60Lt.

Total hour during Night=5.5 Hour.

Oil consumed at Night=5.5 x 24 Lt. =132Lt.

Total Oil consumed in a day=192 Lt.

Total Diesel Saving per Day =192Lt.

Total day Running in a Year=165 Days (1Nov.-15Apr.)

Annual Diesel Saving in Lt. =165days x 192 Lt. = 31,680 Lt.

Annual saving in Rs. = 31,680Lt. X 92 Rs. =29, 14,560/-

Total Repay time = ~8 Year

4.4 TEMPERATURE VARIATION IN 4 DIFFERENT ROOMS

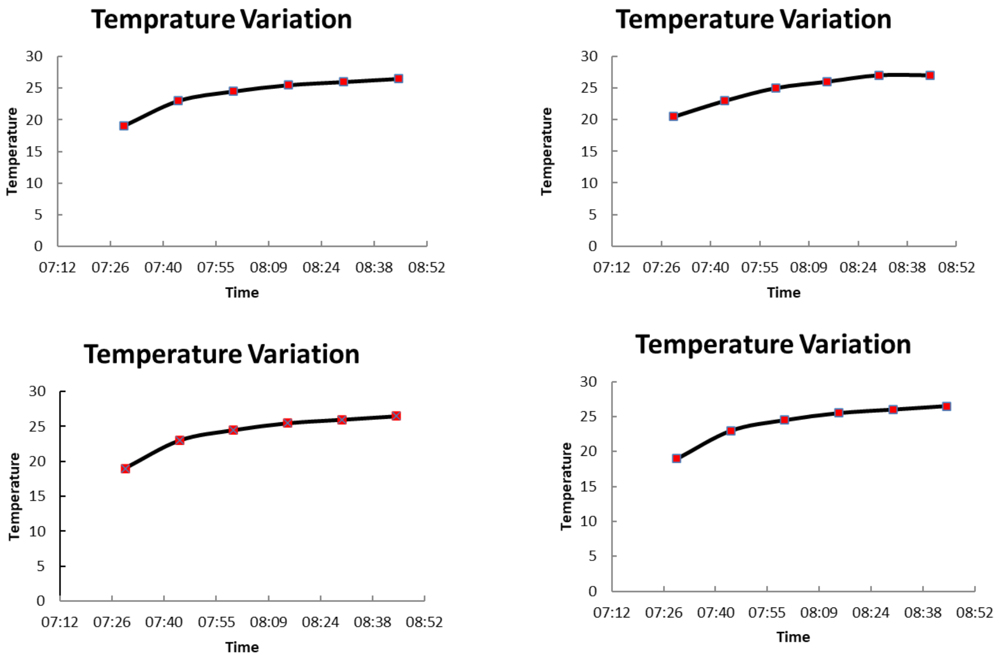
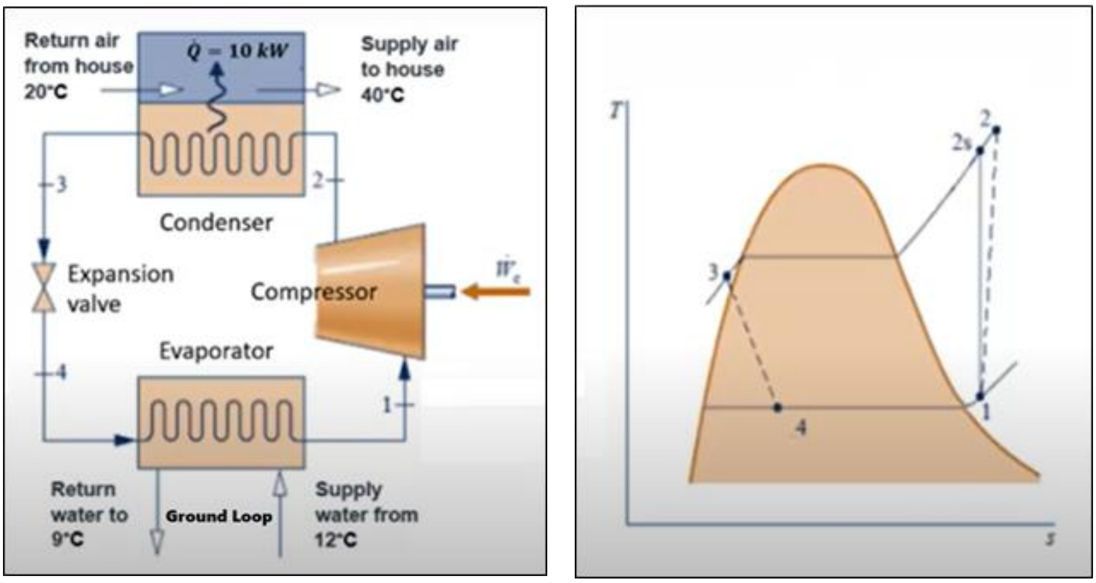


Figure 4.2: Represents variation of temperature in 4 different room GHSP is operational.

4.5 ENERGY AND EXERGY ANALYSIS OF A GROUND SOURCE (GEOTHERMAL) HEATING SYSTEM

In evaluating the efficiency of geothermal heating system, we commonly measure or calculate coefficient of performance (COP) of the system which also called energy efficiency or First law efficiency. However, it has been observed that there is thermodynamic improvement in the performance of the system by doing Exergy analysis in addition to Energy analysis of the system. This study focused in exergetic assessment of a ground-source (or geothermal) Heating System (GSHP). The concept of this system has been designed, constructed and tested in the Defense Geoinformatics Research Establishment (DGRE), Manali. The exergy destructions in each of the components of the overall system are determined for average values of experimentally measured parameters. Exergy efficiencies of the system components are determined to assess their performances and to elucidate potentials for improvement. COP values for the GSHP unit is found 5.381 by calculating numerically where COP value in EES software is found 5.851, while second order exergy efficiency for the system is found 71% numerically and 77% in EES Software at a dead state temperature of -10^{o}C.



(a) (b)

Figure 4.3: (a) Schematic design of geothermal space heating system. (b) T-S Diagram.

In this Analysis the main focus is kept at optimizing the working parameters on the existing geothermal heating system plant and to increase it thermodynamic efficiency in order to get maximum results. It is considered that the complete system is working at steady state with Refrigerant R-134a as the working fluid. The heat pump uses water that is circulated in ground loop where it gains heat from ground. The ground act as thermal source for heat pump. Following are the assumptions taken in energy and exergy analysis if the system:

a) All processes are steady state and steady flow with negligible potential and kinetic energy effects and no chemical or nuclear reactions.

b) The directions of heat transfer to the system and work transfer from the system are positive.

c) Exergy loss rate by the pump is neglected for the complete analysis of the system.

d) The compressor operation has an adiabatic efficiency of 80%.

e) Air is an ideal gas with a constant specific heat, and its humidity content is negligible.

f) The dead state of the refrigerant is taken at ambient temperature, T_0= 263.15 K and at a pressure, P_0=101.3 kPa equal to the saturation pressure of the refrigerant at T_0.

4.5.1 THERMODYNAMIC PROPERTIES OF THE REFRIGERANT USED

R134a is also called Tetrafluoroethane (CF3CH2F) from HFC refrigerant family. As it is found that the CFCs and HCFCs refrigerants are contributing in ozone layer depletion, hence the HFC family of refrigerant are taken as alternative worldwide. The boiling temperature of R134a is -14.9°F or -26.1°C. Refrigerant properties are tabulated in Table 4.1 and Table 4.2.

Table 4.1. Refrigerant thermodynamic properties

Refrigerant	**Molecular Weight**	t_s **(N.B.P) °C**	t_c **(Critical-Temperature) °C**	P_c **(Critical-Pressure) bar**	t_f **(Freezing point) °C**
R134a	102.03	-26.15	101.06	40.56	-96.6

Table 4.2. Physical and environmental properties

Refrigerant	**Type**	**GWP**	**ODP**	**Safety class**	**Flammability**
R134a	HFC	1430	0	A1	Non-flammable

4.5.2 MODELLING AND ANALYSIS

Following equations were used to determine rate of exergy destructions, first law efficiency and second law efficiency:

Mass balance $$\sum \dot{m}_{in} - \dot{m}_{out} = 0 \qquad (1)$$

Energy balance $$\sum Q - \sum \mathrm{W} - \sum \dot{\mathrm{m}}\mathrm{h} = 0 \qquad (2)$$

Exergy balance $$\sum_{X_{mass\ in}} - \sum_{X_{mass\ out}} - \sum_{X_{heat}} - \sum_{X_{work}} - \sum X_{destroyed} = 0 \qquad (3)$$

Here, X_{MASS}, X_{heat} X_{work} $and\ X_{Destroyed}$ stands for Exergy due to mass transfer, heat transfer, work transfer and exergy destruction or known as irreversibility, respectively.

EES software helps to calculate the thermodynamic properties of refrigerants such as enthalpy, entropy, thermal conductivity, saturation temperature, etc. It consists of pure and mixed substances, making EES convenient for carrying out energy/exergy analysis and optimization of any refrigerant available in its database. Therefore, the system is modelled to investigate the influence of thermodynamic laws. Energy equations used in system modelling is given in Table 4.3.

4.5.2.1 ENERGY ANALYSIS

Table 4.3. Energy equations used in system modelling

Component/Parameter	Energy balance	
Evaporator	$\dot{m}_{evap} = \dfrac{\dot{Q}_{evap}}{(h_{out} - h_{in})_{evap}}$	(4)
Compressor	$\eta_{Comp} = \dfrac{W_{Comp,isen}}{W_{comp,actual}}$	(5)
	$\eta_{comp} = 0.85 - 0.046667 PR_{comp}$	(6)
Condenser	$\dot{Q}_{cond} = \dot{m}_{cond}(h_{out} - h_{in})$	(7)
Expansion Valve	$h_{in,ev} - h_{out,ev}$	(8)
COP	$COP = \dfrac{\dot{Q}_{Evap}}{W_{Comp,actual}}$	(9)

Finally, the performance of the system is measured using the equation No. 9 which help us to calculate COP of Geothermal heating system plant (GHSP).

4.5.2.2 EXERGY ANALYSIS

1. Exergy Flowing into the system are as follow:

(a) Exergy flowing through compressor work

$$\dot{E}_{X,Comp} = \dot{W}_{comp,actual} \quad (10)$$

(b) Exergy flowing through ground water

$$\dot{E}_{X,Water} = \dot{m}_{w}((h_{in} - h_{out}) - T_{o}(S_{in} - S_{out}) \quad (11)$$

Total Exergy flowing in sum of Exergy flowing through compressor work and Exergy flowing through ground water.

2. **Exergy Flowing out of the system is as follow:**

(a) Exergy transfer rate into the air

$$\dot{E}_{X,air} = \dot{m}_a((h_{out} - h_{in}) - T_o(S_{out} - S_{in})) \quad (12)$$

Where T_o is the dead state temperature, $\dot{m}_w$ is the mass flow rate of water in the ground loop and $\dot{m}_a$ is mass flow rate of air into the room.

Exergy flowing out is observed less than Exergy flowing in, so there is destruction of exergy at various components. To evaluate exergy destruction at various components following equations has been taken in consideration:

Total exergy destruction rate of compressor:

$$X_{des,comp} = \dot{E}_{X,Comp} - \dot{m}_r(((h_2 - h_0) - T_o(S_2 - S_0)) - ((h_1 - h_0) - T_o(S_1 - S_0))) \quad (13)$$

here $\dot{m}_r$ is the mass flow rate of refrigerant, h_0 is dead state enthalpy and S_0 is dead state entropy.

Total exergy destruction rate of condenser:

$$X_{des,cond} = \dot{E}_{X,air} - \dot{m}_r(((h_2 - h_0) - T_o(S_2 - S_0)) - ((h_3 - h_0) - T_o(S_3 - S_0))) \quad (14)$$

Total exergy destruction rate of expansion valve:

$$X_{des,exp\ valve} = (((h_3 - h_0) - T_o(S_3 - S_0)) - ((h_4 - h_0) - T_o(S_4 - S_0))) \quad (15)$$

Total exergy destruction rate of evaporator:

$$X_{des,\text{evap}} = \dot{E}_{X,\text{water}} - \dot{m}_r(((h_1 - h_0) - T_o(S_1 - S_0)) - ((h_4 - h_0) - T_o(S_4 - S_0))) \quad (16)$$

Exergy efficiency can be calculated using the equation:

$$\eta_{II} = \frac{Exergy\ recovered}{Exergy\ supplied} = \frac{\dot{E}_{X,air}}{\dot{E}_{X,W}} \quad (17)$$

is the second law efficiency for Geothermal heating system plant (GHSP).

The result obtained through EES software has been shown in Table 4.4. The parameters for the analysis have been observed manually and based on those values calculations has been done to find out the first law efficiency, second law efficiency and exergy destruction and different component of the system. Exergy loss rate by the pump is neglected for the complete analysis of the system and compressor is considered adiabatic. The exergy flowing in and out calculated through exergy balance equation and remaining exergy called as destruction is also calculated for each component separately. The exergy flowing out of the system i.e., exergy flow of air is significant in our calculation as it is desired maximum to get more heating affect in winters. This Geothermal heating plant system is installed and operational at one of the laboratories of DRDO in Manali. The parameters measured for the analysis in EES software are shown in Table 4.5 and Table 4.6.

Table 4.4. Results Obtained through EES Software

Refrigerant	Present work (EES)					
	$\boldsymbol{COP}$	$\boldsymbol{\eta_{II}}$ (%)	$\mathbf{E\dot{x}_{air}}$	$\mathbf{Xdes_{Comp}}$	$\mathbf{Xdes_{Cond}}$	$\mathbf{Xdes_{Evap}}$
R134a	5.851	77	1.317	0.412	0.1925	0.2617

Table 4.5. Measured parameters of System

Parameters	**Value**
Evaporation Temperature, T_{evap} (℃)	1
Condensation Temperature, T_{cond} (℃)	36.3
Dead state Temperature, T_o (℃)	-10.0
Compressor Efficiency, (%)	80
Cooling Load, (kW)	10
Evaporation pressure, P_e (kPa)	230
Condensation pressure, P_c (kPa)	920
Supply water from ground loop, T_{ig} (℃)	12
Return water to ground loop, T_{og} (℃)	9
Supply of air to the house, T_{oa} (℃)	40
Return of air from the house, T_{ia} (℃)	20

Table 4.6. Property data for the GSHP system

State	P (kPa)	T (℃)	x	h kJ/Kg	s kJ/kg k
0	101.3	-10		244.7	0.9918
1	230	1		250.08	0.9477
2S	920	48		279.96	0.9477
2	920	54		286.28	0.9672
3	920	30		91.49	0.3396
4	230	-6.55	0.248	91.49	0.3531

4.6 RESULTS AND DISCUSSION

Temperature, pressure and mass flow rate data for the working fluid (R-134a), water and air are given in Table 4.5 and thermodynamical properties for the various state numbers specified in Table 4.6. Exergy rates are also calculated for each state and presented in this table. In this study, the reference state is taken to be the state of environment at which the temperature and the atmospheric pressure were -10°C and 101.325 kPa, respectively. The thermodynamic properties of water, air and R-134a are found using the Engineering Equation Solver (EES) software package (F-chart, 2009).

Table 4.4 presents some energetic and exegetic data for one representative unit of the GSHP system. As seen from this table, the exergy efficiency value for the GSHP unit is estimated as 77%. The COP value is found to be 5.851 for the GSHP unit using Equation 9. Irreversibility's in the evaporator and the condenser occur due to the temperature differences between the two heat exchanger fluids, pressure losses, flow imbalances and heat transfer with the environment. The high value of irreversibility in compressor is fluid friction pressure drop occur and due to finite temperature difference heat transfer also occurs. A program has been made in EES software considering evaporative temperature as 1°C and condenser temperature as 36.3°C. Subsequently, properties like enthalpy and entropy calculated at every state as shown in Figure 13 (a) & (b) TS diagram. The load considered in Condenser unit is 10kW. The exergy analysis is done by aiming to balance the rate of exergy flowing in to rate of exergy flowing out.

4.6.1 Effect of evaporator temperature and condenser temperature on COP & exergetic or second law efficiency

The effect of evaporator temperature and condenser temperature on COP and exergetic or second law efficiency has been studied and it has been observed that as we increase the evaporative temperature both COP and exergetic efficiency increases. The result was very much expected as we have studied, as the load on the evaporator increase and compressor running at constant rpm, the pressure of evaporator increases which subsequently increases the evaporator temperature. As the evaporative pressure increases, it has been seen from the P-h diagram that desired effect increases which ultimately leads to increase in COP and exergetic efficiency. But opposite is the case when the affect of condenser has been studied as it leads to decrease of desired effect in the p-h diagram and hence COP and exergetic efficiency decreases with increase of Condenser temperature. This result can be seen from the graph shown in Figure 4.4 and Figure 4.5.

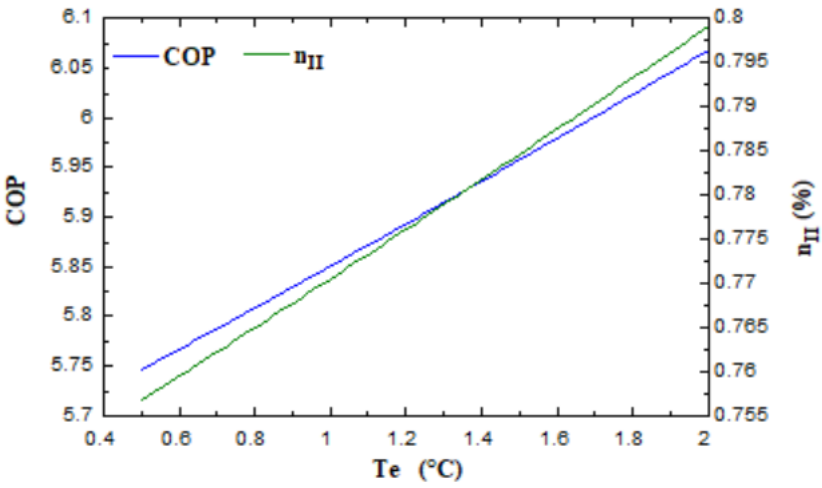


Figure 4.4: COP and second law efficiency variation with Evaporator temperature.

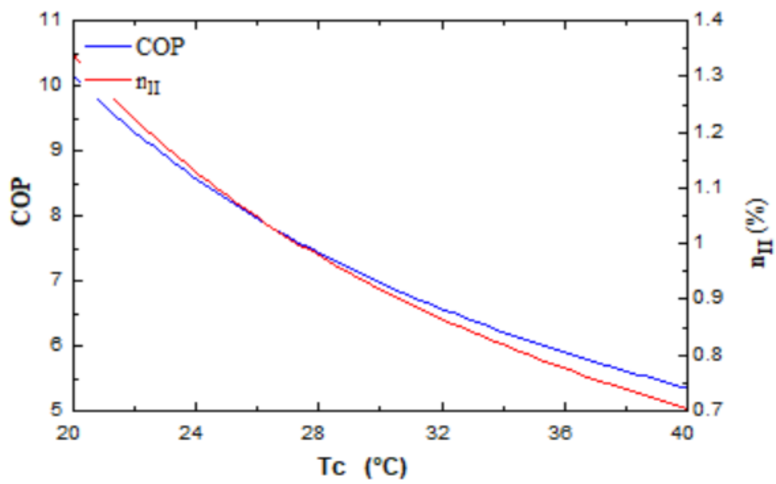


Figure 4.5: COP and second law efficiency variation with Condenser temperature.

4.6.2 Effect of mass flow rate of water on rate of exergy flowing into the system and exergy destruction in evaporator

In Geothermal heat plant exchange of heat between inlet water from ground loop and refrigerant (R134a) in evaporator takes place, so the flow of water and refrigerant plays an important role in functioning of the system efficiently. As shown in figure 4.6, the increase in mass flow rate of water will increase the exergy flowing into the system but that will also lead in increasing the exergetic destruction or irreversibility. The relation between mass flow rate of water and exergy flowing into the system can be seen for the below equation.

$E_{x,w} = \dot{m}_w(Cp(T_i - T_e) - T_0\left(C_p \times \frac{T_i}{Te}\right)$ T_i& T_e is water temperature at inlet and exit.

For the smooth and efficient performance of the geothermal heating system an optimum mass flow rate has to be chosen. In this analysis the mass flow rate of water is taken 0.6Kg/sec.

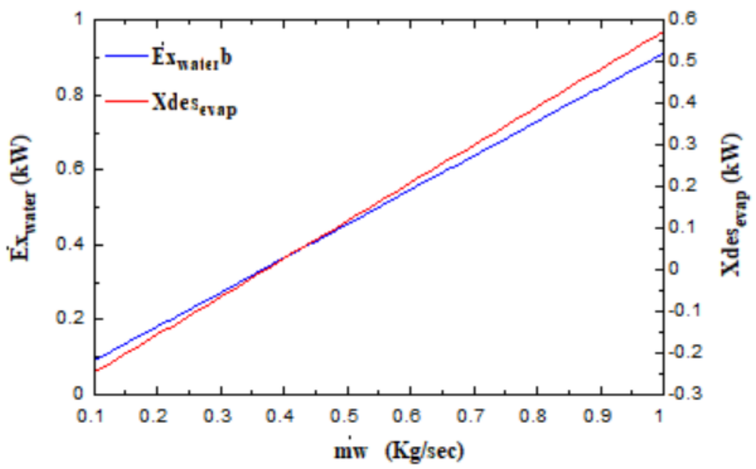


Figure 4.6: Effect of mass flow rate of water on rate of exergy flowing into the system and exergy destruction in evaporator.

4.6.3 Effect of mass flow rate of air on rate of exergy flowing out of the system and exergy destruction in condenser

In this system it is desired to have higher temperature than ambient temperature in winters inside the room, this can only be achieved by reducing the exergy destruction or irreversibility in the condenser unit at the load side. As shown in figure 4.7, the increase in mass flow rate of air will increase the exergy flowing out of the system but that will also lead in increasing the exergetic destruction or irreversibility. The relation between mass flow rate of air and exergy flowing out of the system can be seen for the below equation.

$$E_{x,a} = \dot{m_a}(Cp(T_{ai} - T_{ae}) - T_0\left(C_p \times \frac{T_{ai}}{Tae}\right)$$

Tai & Tae is air temperature at inlet and exit.

For the smooth and efficient performance of the geothermal heating system an optimum mass flow rate has to be chosen. In this analysis the mass flow rate of air is taken 0.0513 Kg/sec.

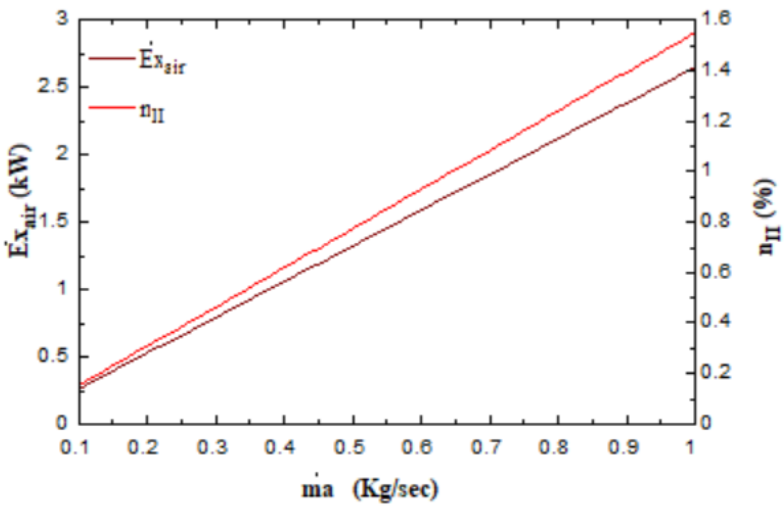


Figure 4.7: Effect of mass flow rate of air on rate of exergy flowing out the system and exergy destruction in condenser.

4.6.4 Effect of Compressor work on rate of exergy flowing into the system and exergy destruction in compressor

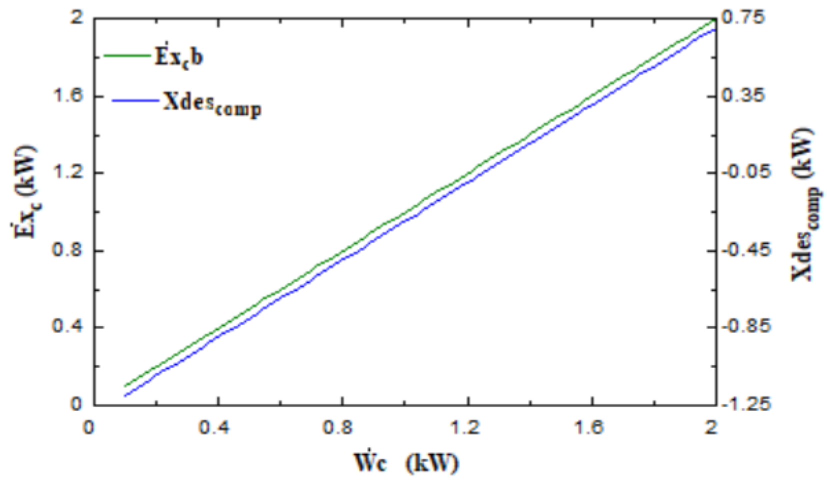


Figure 4.8: Effect of Compressor work on rate of exergy flowing into the system and exergy destruction in compressor.

As shown in figure 4.8, the increase in the compressor work will increase the exergy flowing out of the system but that will also lead in increasing the exergetic destruction or irreversibility. The high value of irreversibility in compressor is fluid friction pressure drop occur and due to finite temperature difference heat transfer also occurs.

4.6.5 Effect of inlet air temperature on rate of exergy flowing out of the system and exergy destruction in condenser

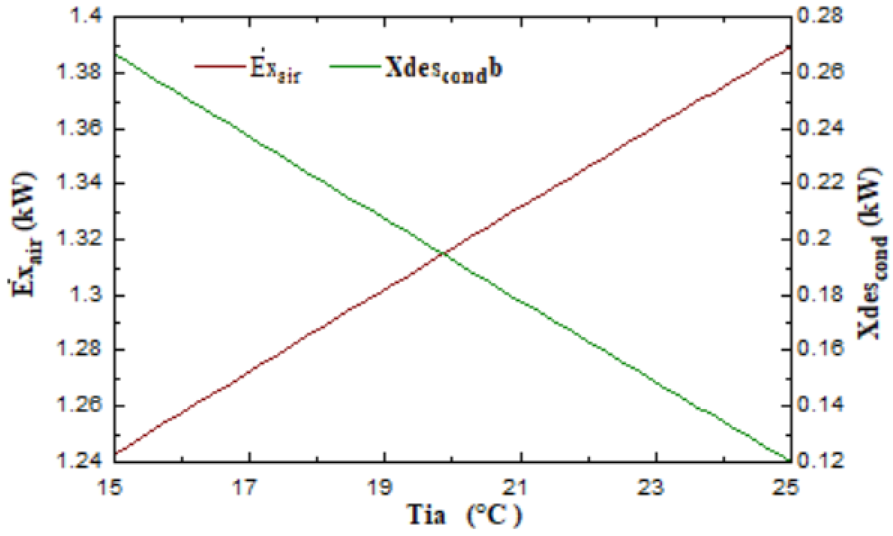


Figure 4.9: Effect of inlet air temperature on rate of exergy flowing out the system and exergy destruction in condenser.

In figure 4.9, the effect of inlet air temperature was studied on rate of exergy flowing out of the system and the exergy destruction or irreversibility in the condenser unit at the load side. It was observed that as inlet air temperature increases, the exergy flowing out of the system will also increase but the exergetic destruction or irreversibility will decrease because the inlet temperature of air keeps on increasing as the experiment progress. It can be extracted from this study that the at the beginning we can expect higher irreversibility which lowers the efficiency. So, proper measure shall be taken in account while designing this system initially.

CHAPTER 5

CFD ANALYSIS OF GEOTHERMAL HEATING SYSTEM PUMP

5.1 INTRODUCTION

The Geothermal heating system plant has been analyzed by two methods, firstly by doing energy and exergy analysis of refrigeration system consisting Compressor, condenser, evaporator and expansion valve. Secondly by computational fluid dynamics analysis of horizontal pipe. The computational fluid dynamics analysis of the geothermal heating system plant is required to get an optimum water velocity to obtain the maximum outlet temperature of water circulated through ground loop. Prior to the simulation study, energy and exergy analysis of the system has been done to calculate the exergetic efficiency and Irreversibility or destruction in various component of the system. This system consisting of pipeline buried under the earth in horizontal and vertical direction. In this CFD analysis the water flow through horizontal pipe is taken into consideration. To achieve the best results following assumptions were made:

1. Soil is considered homogenous around the ground loop.
2. Isotropic soil properties and soil is intact to the pipe.
3. Water flow is uniform throughout the length of pipe.
4. Soil conductivity is constant in all direction.

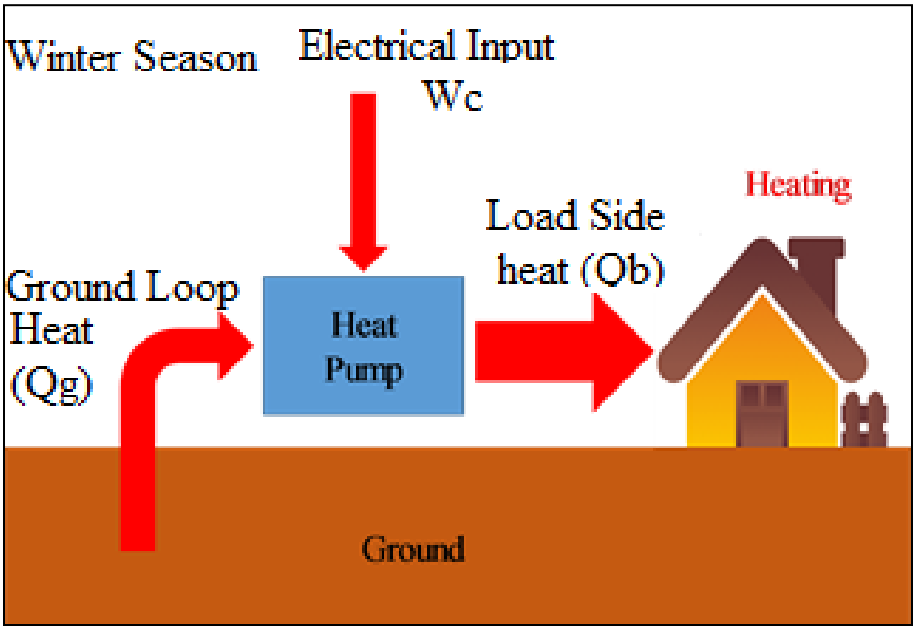


Figure 5.1: Schematic design of geothermal space heating system.

5.2 Mathematical Analysis

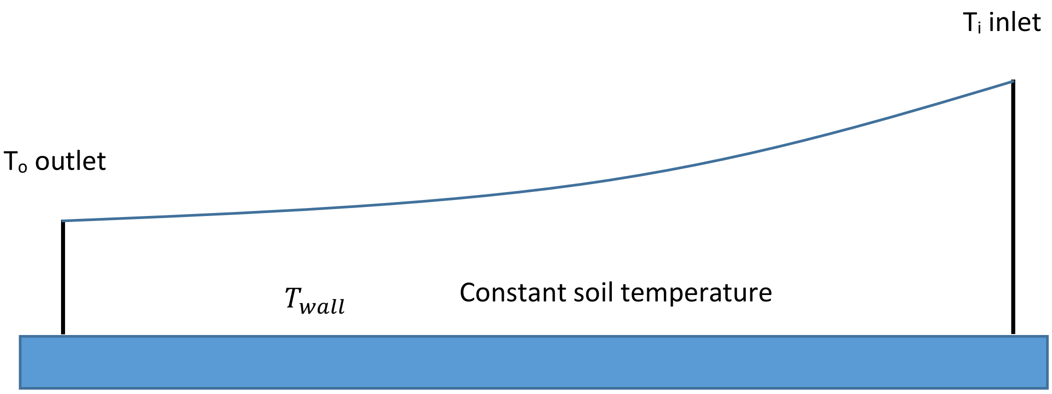


Figure 5.2: Temperature variation diagram at inlet and outlet.

Heat transfer along the pipe can be calculated as

$$q_{conv} = h * (Area) * (T_i - T_o)$$

h=convective heat transfer coefficient, W/m^2 °C,

T_o *is the outlet temperature and* T_i *is outlet temperature*

$$q_{conv} = \dot{m} * c_p(T_i - T_o)$$

$$h=\frac{u_{m*D}}{\mu} = 4* \frac{4*\dot{m}}{\pi*D*\mu}$$

The Dittus-Bolter equation is: - Nu (Nusselt No.) = 0.023 × $(Re)^{4/5}$× Pr^n n=0.4 for heating.

Re=Reynolds Number, Pr= Pandtl Number

Also, Nu (Nusselt No= $\frac{Convective\ heat\ transfer}{Conductive\ heat\ transfer} = \frac{hD}{K}$)

Overall heat transfer Coefficient (Ui) is also considered as the hear flow from outside to
inside.

$$\frac{1}{UiAi} = \frac{1}{hiAi} + \frac{ln(\frac{ro}{ri})}{2\pi kl} + \frac{1}{hoAo}$$

Ai=area inside pipe & Ao=area outside pipe.

Conservation of mass or continuity equation:

$$\frac{\partial\rho}{\partial t} + \nabla.(\rho\ \vec{v}) = A_m$$

Where A_m= mass added any user defined sources.

5.3 CFD Simulation of Horizontal Ground Loop Pipe

Computational fluid dynamics (CFD) is a branch of fluid mechanics that involves finding the numerical solution to the governing equations in order to forecast fluid flow behavior.

The horizontal ground loop pipe simulation is carried out in ANSYS® FLUENT® v1. CFD analysis is broken down into three parts, which are detailed as below:

5.3.1 PRE-PROCESSING

The motive of the simulation of horizontal ground loop pipe is to measure the water velocity inside the horizontal tube to obtain the optimum velocity in which maximum outlet temperature can be achieved. First, the simple geometry of the horizontal was made using Design modeler in Ansys R 19.2. The geometric model of horizontal ground loop pipe is shown in the Figure 5.3. Parameters used for CFD analysis are tabulated in Table 5.1, these parameters were recorded when the set-up mage functional during winters.

After creation of the geometry, the entire domain is discretized into small control volumes which helps to convert the quadratic form of equation to linear and hence increase the ease of solving equation like the various form of Navier stroke equations, these equations are solved by the help of iteration method.

Table 5.1 Parameters used for CFD analysis.

Parameters	Reference Value
Pipe length (m)	50
Inside Diameter (mm)	32
Outside Diameter (mm)	60
Water Velocity(m/sec)	0.6-1.5
Soil Temperature(K)	290
Water Temperature(K)	286

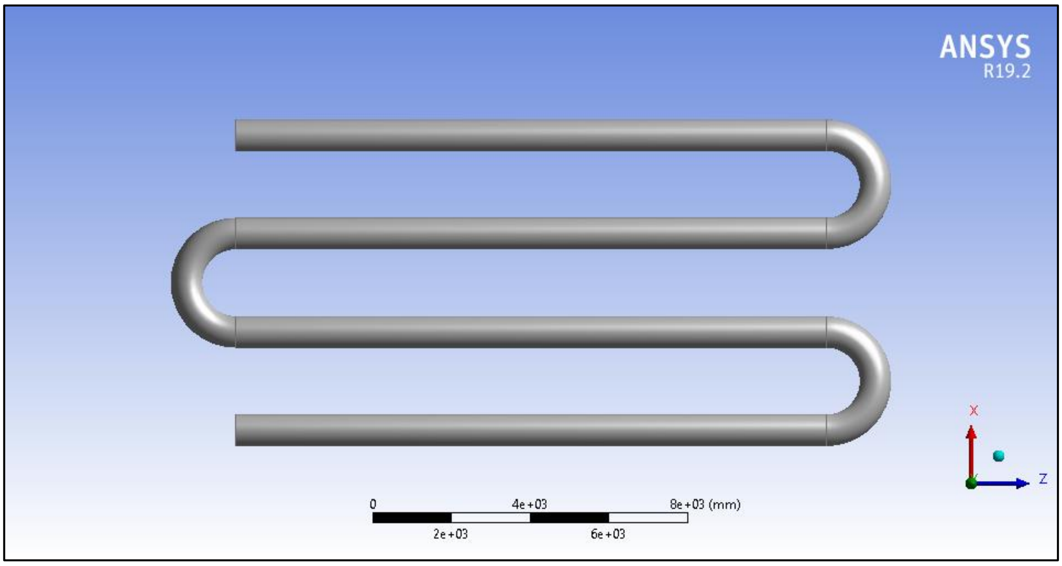


Figure 5.3: Geometric model of horizontal ground loop pipe.

The meshing of the horizontal ground loop pipe is presented in Figure 5.4. In this meshing, cells taken are tetrahedrons. The statistics (maximum value) which are obtained after meshing is as follow.

Aspect ratio	1.2
orthogonal quality	0.99361
skewness	0.84225

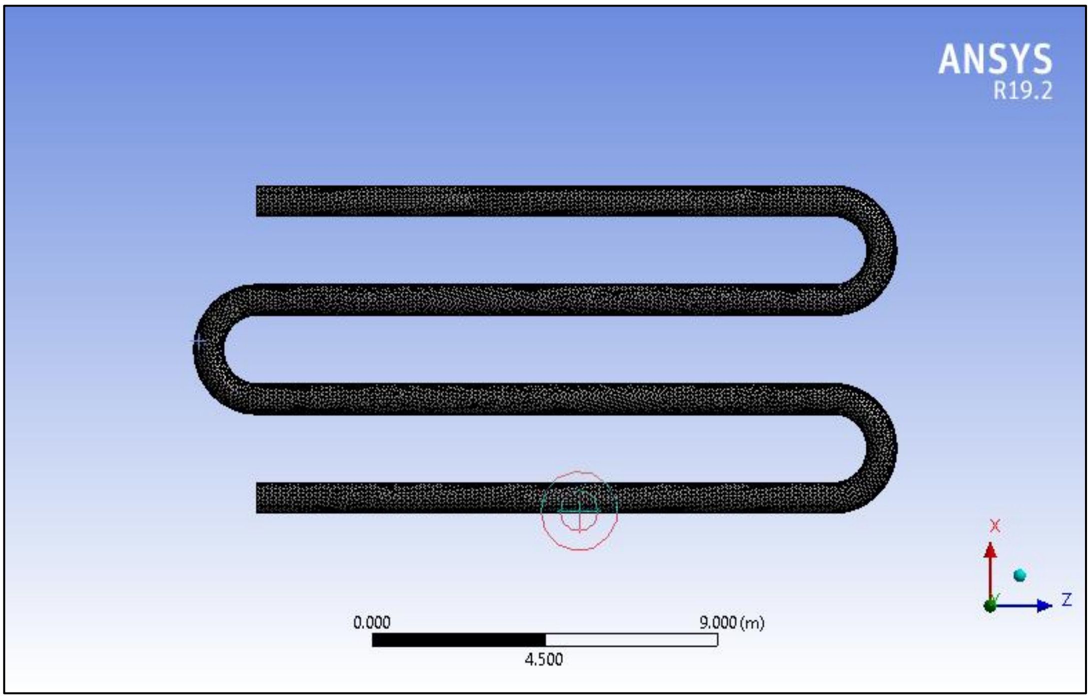


Figure 5.4: Meshing of geometric model of horizontal ground loop pipe.

5.4.2 SOLVER SET-UP

The parameters used in the study of the optimum velocity to get the maximum temperature at the outlet of the horizontal ground loop pipe are given in Table 5.2.

Table 5.2 Simulation Parameters

Parameters	Values
Type of Solver	Pressure based
Formulation of Velocity	Absolute
Time	Steady
Model	Energy, k-ε (2- equation)
Near wall treatment	Standard wall treatment
Pressure Velocity coupling	Phase coupled simple

Used Boundary conditions

The Maximum temperature inside the ground loop can be calculated using the energy equation.

1. Define material properties and choose water as the working fluid inside the ground loop tube with 0.6 W/m-K thermal conductivity and the wall of pipe steel with thermal conductivity 16.27 W/m-K.

2. The gauge pressure for the outflow boundary condition must be set to zero because the air flow within the ground loop tube is atmospheric pressure.

3. When performing CFD analysis, different water velocity at the range of 0.6 m/s to 1.5 m/s is employed.

4. For computational fluids, the Fluent solver is employed.

Convergence Criterion

The residual values of continuous, flow variables in the x, y, and z directions, kinetic energy, and turbulent energy rate of dissipation are used to calculate the convergence criterion. When the total of the residual values falls below a particular convergence criterion, the solution is said to be converged. For better convergence results, the residual values of all of the flow variables were assigned values of 103 in the current simulation work. At 1000 iterations, the convergence findings are achieved.

5.4.3 POST PROCESSING

The acquired results are plotted into various contour form in post processing. Figure 5.5 to Figure 5.8 show the temperature change at the outlet of a horizontal ground loop pipe.

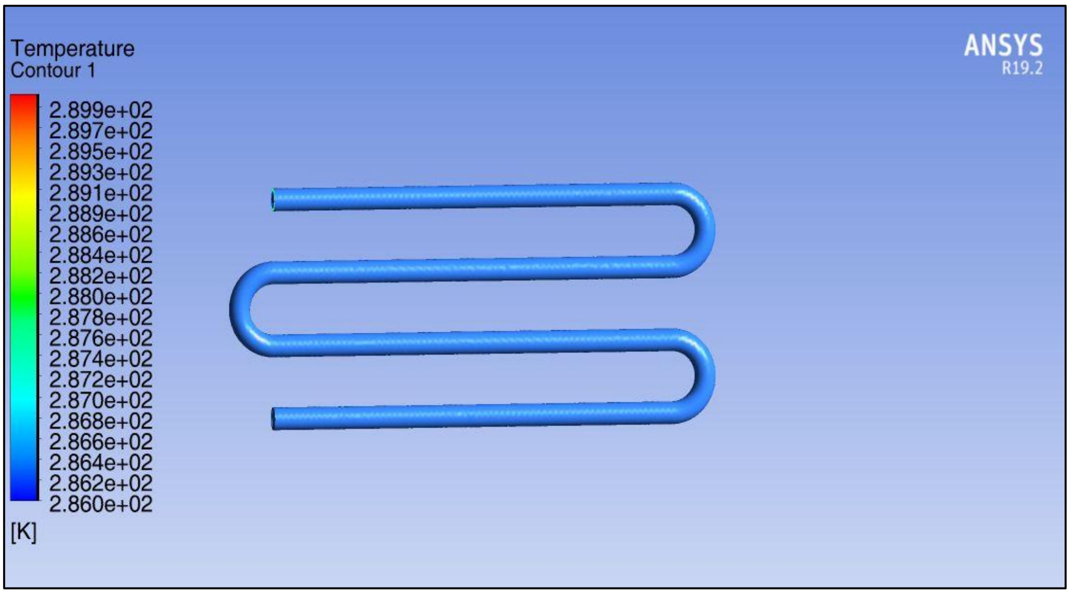


Figure 5.5: Contour results of temperature at the outlet of horizontal ground loop pipe when the water velocity is at 0.6m/s.

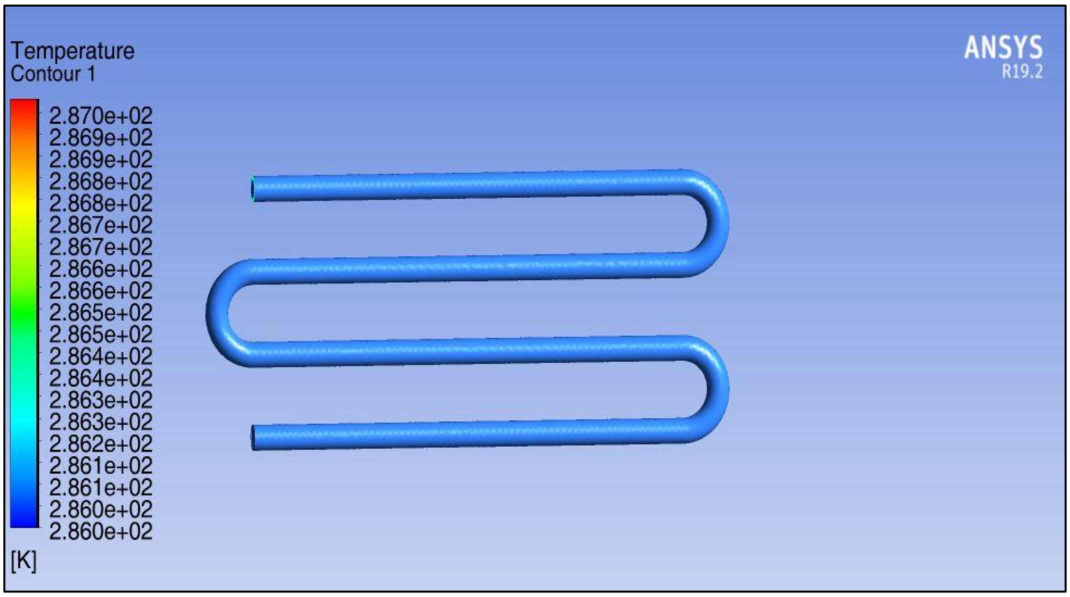


Figure 5.6: Contour results of temperature at the outlet of horizontal ground loop pipe when the water velocity is at 1 m/s.

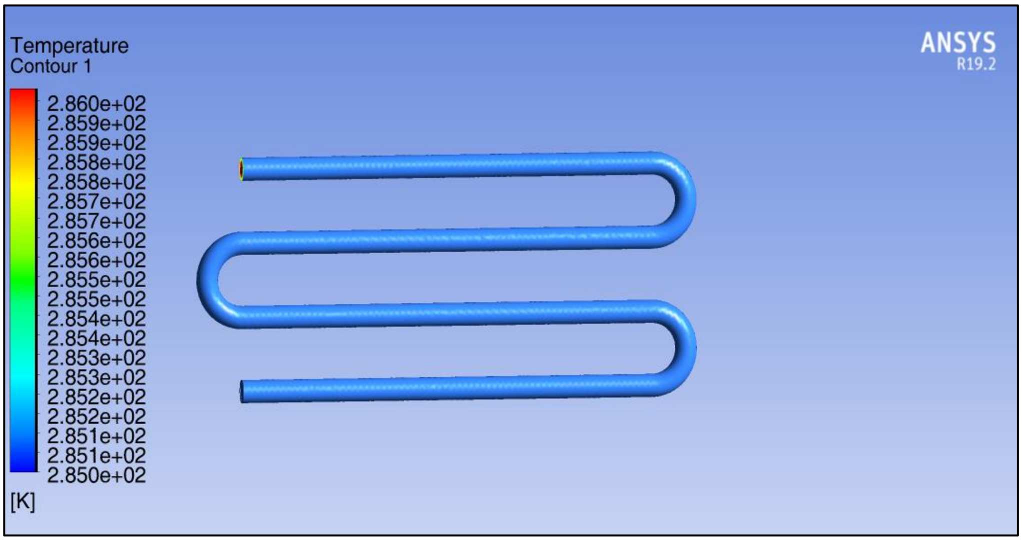


Figure 5.7: Contour results of temperature at the outlet of horizontal ground loop pipe when the water velocity is at 1.5 m/s.

The temperature distribution over the horizontal ground loop pipe is identical to the expected findings, as shown by the contour result. High temperature can be seen when the water velocity in the ground loop is slower but from this simulation, it has been observed that the maximum temperature at outlet can be observed when the water velocity in the ground loop is 0.6m/s. It has been also observed that temperature remains same below this velocity.

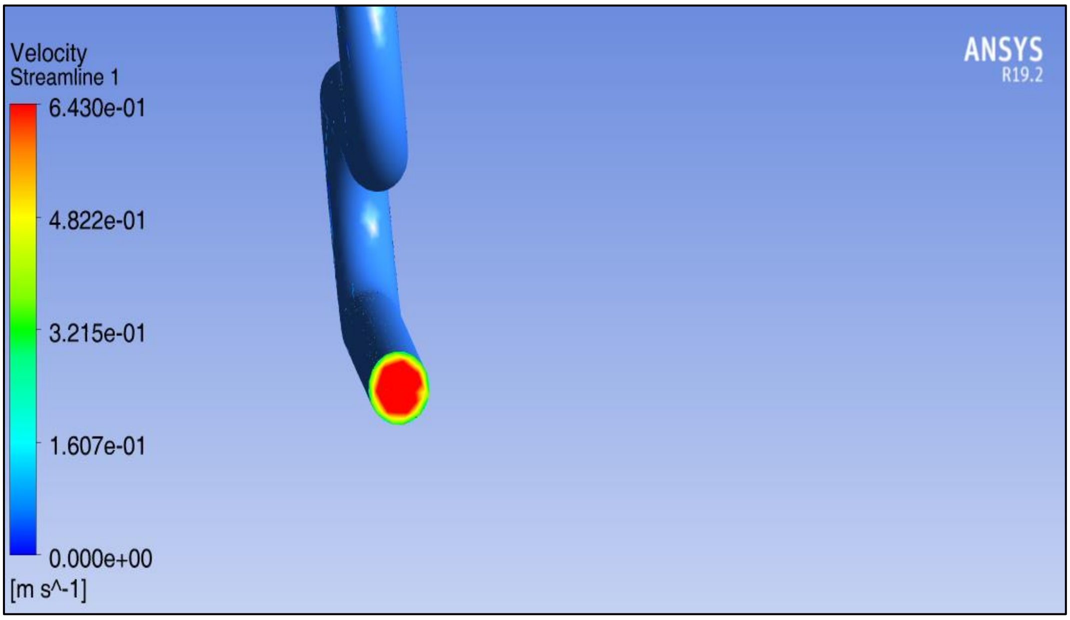


Figure 5.8: Contour results of velocity profile inside the horizontal ground loop pipe.

As expected, due to slip condition on the pipe wall there is some friction in the water velocity and which leads to zero or minimum velocity. However maximum velocity found at the center of pipe.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

The following conclusions have been determined from the performance evaluation of geothermal heating system plant and Exergy analysis:

1. For heating in DGRE Geothermal Energy can be proven as an alternate energy source of fast depleting diesel source. Also, this system can be used whole the year for warming of water for day-to-day use, which saves electrical energy that is used in geyser.
2. In the energy and exergy analysis, the parameters used for the analysis were measured in the available geothermal set up at DGRE, Manali. Exergy analysis was done along with energy analysis to obtain the exergetic efficiency and COP of the system. In this analysis the rate of exergy flowing in through compressor work and ground loop was determined and rate of exergy flowing out through air at load side was also determined. The following conclusions can be derived from the findings:
3. Using the aforementioned parameters, COP of GSHP system is determined as 5.851.
4. At a dead state temperature of -10^{o}C, the exergy efficiency values for the GSHP unit were determined as 77%. The exergetic destruction of compressor is found 0.412kW which higher than condenser and expansion valve (i.e., 0.1925kW and 0.1255kW respectively).
5. Irreversibility's in the evaporator and the condenser occur due to the temperature differences between the two heat exchanger fluids, pressure losses, flow imbalances and heat transfer with the environment. The high value of

irreversibility in compressor is fluid friction pressure drop occur and due to finite temperature difference heat transfer also occurs.

6. The outcomes can direct an engineer's attention to certain components to reduce the irreversibility’s and eventually increasing the COP (first law efficiency) and exergetic efficiency or second order efficiency.

6.2 FUTURE SCOPE

1. Efficiency of GHP can be improved using number of compressor at multistage at adequate limit.
2. At present R134a refrigerant is used in GHP for this analysis, but the same can be done using higher latent heat than R410a then it definitely will increase the efficiency of heat pump.
3. By improving drilling technology initial cost can be reduced.
4. Same unit can be used for cooling purpose also by reversing the operation of Heat pump; if it uses then it will save lot of electricity.
5. Capital cost and operational cost of GHP unit can be reduced by modifying and placing the small and separate GHP units for each building using their existing water bore well.
6. In addition to heat generation from the existing GHP, a small turbine can be placed in the existing GHP circuit to generate electrical power.

APPENDIX

EES PROGRAM FOR GEOTHERMAL HEATING SYSTEM PLANT

```
Te =1
Tc =36.3
 "Energy Analysis"
 Pe=p_sat(R134a,T=Te)
Pc=p_sat(R134a,T=Tc)
 h1=h1s+Cpr*(T1-T1s)
T1=Te
T1s=Tf4
Tf4=T_SAT(R134a,P=Pe)
h1s=hg1s
hg1s=ENTHALPY(R134a,T=Tf4,x=1)
s1=s1s+Cpr*ln((T1+273)/(T1s+273))
s1s=sg1s
sg1s=ENTROPY(R134a,T=Te,x=1)
Cpr=1.47
s1 = s2s
s2s=entropy(R134a,T=T2s,P=Pc)
h2s=enthalpy(R134a,T=T2s,P=Pc)
n1 = 0.85-0.046667*(Pc/Pe)
n1 = (h2s-h1)/(h2-h1)
h2=enthalpy(R134a,T=T2,P=Pc)
s2=entropy(R134a,T=T2,P=Pc)
h3=h3s-Cpr*(T3s-T3)
T3s=T_SAT(R134a,P=Pc)
```

```
T3=30
h3s=ENTHALPY(R134a,T=T3s,x=0)
s3=s3s-Cpr*ln((T3s+273)/(T3+273))
s3s=ENTROPY(R134a,T=T3s,x=0)
h3=h4
h4 = hf4+x4*(hg1s-hf4)
hf4=ENTHALPY(R134a,T=Tf4,x=0)
s4 = sf4+x4*(sg1s-sf4)
sf4=ENTROPY(R134a,T=Tf4,x=0)
Qe_dot = 10  "kW"
Qe_dot = mr_dot*(h2-h3)
Wc_dot = mr_dot*(h2-h1)
 COP = (Qe_dot)/(Wc_dot)
"Flow of exergy from different States"
ef0=0
ef1=(h1-h0)-((To+273)*(s1-s0))
h0=ENTHALPY(R134a,T=To,P=P0)
s0=ENTROPY(R134a,T=To,P=P0)
To = -10
P0=100   "kPa"
ef2s=(h2s-h0)-((To+273)*(s2s-s0))
ef2=(h2-h0)-((To+273)*(s2-s0))
ef3=(h3-h0)-((To+273)*(s3-s0))
ef4=(h4-h0)-((To+273)*(s4-s0))
"Voumetric Flow rate of water from Ground"

mw_dot*Cpw*(Tig-Tog)=mr_dot*(h1-h4)
Cpw=4.2 "kJ/KgK"
Tig=12
Tog=9
```

"Exergy Analysis Exergy Flowing IN"

```
Ex_dot_c=Wc_dot        "Compressor work"
Ex_dot_water=mw_dot*(Cpw*(Tig-Tog)-((To+273)*Cpw*ln((Tig+273)/(Tog+273))))
Total_ex_in=Ex_dot_c+Ex_dot_water
```

"Exergy Analysis Exergy Flowing Out"

```
Ex_dot_air=ma_dot*(Cpa*(Toa-Tia)-((To+273)*Cpa*ln((Toa+273)/(Tia+273))))
Cpa=1.005 "kJ/KgK"
Toa=40
Tia=20
Qe_dot=ma_dot*Cpa*(Toa-Tia)

Total_ex_out=Ex_dot_air

"Destruction=Total_ex_in-Total_ex_out"

Xdes_comp =Wc_dot-(mr_dot*(ef2-ef1))

Xdes_cond=(mr_dot*(ef2-ef3))-Ex_dot_air

Xdes_Exp=(mr_dot*(ef3-ef4))

Xdes_evap=Ex_dot_water-(mr_dot*(ef1-ef4))

Total_System_des=Xdes_comp+Xdes_cond+Xdes_Exp+Xdes_evap

n_II=(Ex_dot_air/Ex_dot_c)   "Second Law efficiency"
```

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