Experimental investigation of ground source (geothermal) heat pump system

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Abstract- This paper explain a brief description of the Ground Source Heat Pump as cooling and heating system, concentrating on thermodynamic analysis. Besides, the descriptive drawings make this paper very easy to understand. The main objective of this study is to do thermodynamic analysis on performance of the heat pump system. Therefore an experimental set up has installed and experimented in the Bit Sindri laboratories Dhanbad. The experimental results were obtained from December to March in heating mode of 2014–2015, and the average performance coefficient of the system (COPsys) was calculated by using equations given in this paper and is equal to 2.2. Results obtained from experimental measurement concluded that the GSHP systems may be used in Indian climatic conditions. This paper will be help for those who wish to understand about the basic working of different Ground Source Heat Pump especially those who wish to study Ground Source Heat Pump as cooling and heating system.

Keywords—Experimental investigation;Ground source heat pump;space heating;coefficient of performance;renewable energy;

I. INTRODUCTION

Our society has become increasingly dependent on non renewable energy sources like oil, coal and natural gas, burning them to produce energy results in emissions of greenhouse gases, including carbon dioxide (CO_2). Renewable and sustainable energy offers a viable and potent solution to counter the effects of this problem [1]. The Geothermal heat pump, also known as the Ground source heat pump, is a highly efficient renewable energy technology is used for space heating and cooling, as well as water heating [2]. This technology relies on the fact that, at depth, the Earth has a relatively constant temperature, warmer than the air in winter and cooler than the air in summer. A ground-source heat pump (GSHP) utilizes the ground as a heat source in heating and a heat sink in cooling mode operation[3].Heat collecting pipes in a closed loop, containing water (with a little antifreeze) are used to extract this stored energy, which can then be used to provide space heating and domestic hot water. In some applications, the pump can be reversed in summer to provide an element of cooling [4]. The only energy used by GSHP systems is electricity to power the compressor and heat exchanger concentrate the Earth's energy and release it inside the home at a higher temperature. Ductwork distributes the heat to different rooms. The efficiency of GSHP systems is inherently higher than that of air source heat pumps because the ground maintains a relatively stable source/sink temperature [5-6]. The employments of heat pumps in many thermal operations has shown favorable energy savings ranging from 20% to 50%, and have considerable energy-conservation potential as compared to conventional heating systems[7-8]. There are various studies on the design [9], performance [10] and economic analysis [11] and case studies [12–13] available for installation procedures of GSHP systems.

A. PROBLEM STATEMENT

a. Actually, it is hard to get software that can do an analysis or thermodynamic analysis on ground Source Heat Pump.
b. Moreover, certain equations from books are made by doing a lot of assumptions. Some of important thing that can influence the result had been neglect. So, it is not suitable to get practical result.
c. Furthermore, there are lacks of sources based on Ground Source Heat Pump thermodynamic analysis. Even we can get some information, journals or report on Ground Source Heat Pump from internet.

B. SCOPE

The project will focus on following matter.

1. Analysis on evaporator, condenser, expansion valve, compressor, capillary tube, etc experimentally.
2. Discuss the relation between various water flow rate, length of Ground Heat Exchanger and heat output by the condenser.
3. Discuss and produce the performance of heat pump over a range of source and delivery temperatures.
4. Discuss and produce the performance of heat pump over a range of evaporating and condensation temperature and pressure.

II. SYSTEM DESCRIPTION

A.EXPERIMENTAL SET UP

A schematic view of the constructed GSHP system is shown in Fig.1.This system mainly consists of three separate circuits:

a. The ground heat exchanger circuit or water-antifreeze solution circuit
b. The refrigerant circuit (reversible vapour compression cycle heat pump)
c. The fan-coil circuit or air circuit.

The main component specifications and characteristics of the GSHP system are given in Table I, to avoid freezing the water under the working conditions and during the winter, the non-toxic propylene glycol solution, 25% by weight, was prepared. The refrigerant circuit was built on the closed-loop copper tubing with working fluid is R-22. The GSHP system can be used for both heating and cooling. In the winter, the water-antifreeze solution in the pipes extracts heat from the earth and carries it into the room. In summer, the system reverses and takes heat from the room and stores it into the cooler ground. The heat transfer from earth to the heat pump or from the heat pump to earth is maintained with the fluid or water-antifreeze solution circulated through the GHE. The fluid transfers its heat to refrigerant fluid in the evaporator (the water-antifreeze solution to refrigerant heat exchanger) and vice versa.

In space heating the refrigerant, which flows through other closed loop in the heat pump, evaporates by absorbing heat from the water antifreeze solution circulated through the evaporator and then enters the compressor. The refrigerant is compressed by the compressor and then enters the condenser, where it condenses. After the refrigerant leaves the condenser, the capillary tube provides almost 10℃ superheat that essentially gives a safety margin to reduce the risk of liquid droplets entering the compressor. A fan blows across the condenser to move the warmed air to the room.

B. Measurement system

The following data were regularly recorded for one period of operation in every hour:

a. Measurement of mass flow rates of the water/antifreeze solution by a rotameter.
b. Measurement of mass flow rates of the refrigeration by a flowmeter.
c. Measurement of temperature of the water/antifreeze solution entering and leaving the GHE by copper–constantan thermocouples mounted on the unit water inlet and outlet lines.
d. Measurement of condenser and evaporator pressures by Bourdon-type manometers.
e. Measurement of ambient atmospheric pressure by a barometer.
f. Measurement of outdoor and greenhouse air temperatures and humilities by using multi-channel cable-free thermo-hygrometer.
g. Measurement of electrical power input to the compressor and circulating pump by a wattmeter.
h. Measurement and monitoring on a LCD display of instantaneous power consumptions of the heat pump compressor, the pumps and all electrical parameters by using electronic energy analyser.

TABLE I: Main components specifications

Main circuit	Element
Ground coupling circuit	Ground heat exchanger Water-antifreeze solution circulating pump
Refrigerant circuit	Heat exchanger (air cooled condenser for heating) Heat exchanger (between the water and refrigeration fluid heat transfer for heating) Capillary tube Compressor Dryer filter
Fan circuit	Fan of air cooled condenser duct

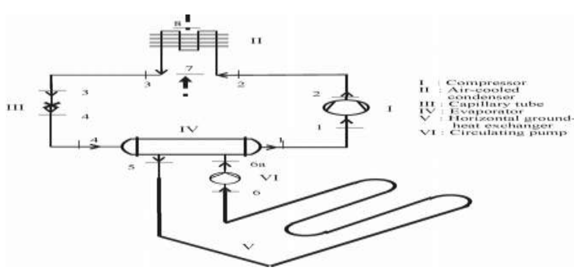

Figure 1: Schematic of GSHP system

C. Theoretical analysis

During the cycle calculations for the GSHPS, The following several assumptions were made.

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. Heat transfer and refrigerant pressure drops in the tubing connecting the components are ignored, since their lengths are short.
d. The compressor operation has an adiabatic efficiency of 80%.
e. The compressor mechanical and the compressor motor electrical efficiencies are 70% and 72%, respectively.
f. Air is an ideal gas with a constant specific heat, and its humidity content is negligible.
g. The power inputs to the fan coil fans and the circulating pumps are negligible compared with the power input to the compressor.

Under the aforementioned assumptions for a general steady state, steady flow process, the balance equations are applied to find the work output and the heat input.

The mass balance equation in rate form is given as;

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

Where $\dot{m}$ the mass flow rate, and the subscript in stands for inlet and out for outlet.
The general energy balance can be expressed as;

$$\dot{E}_{in} = \dot{E}_{out} \quad (2)$$

Rate of energy transfer in is equivalent to rate of energy out.
The general energy balance equation can be written more explicitly as;

$$\dot{Q} + \sum \dot{m}_{in} h_{in} = \dot{\mathbf{W}} + \sum \dot{m}_{out} h_{out} \quad (3)$$

Where $\dot{Q} = \dot{Q}_{net,in} = \dot{Q}_{in} - \dot{Q}_{out}$ is the rate of net heat input, $\dot{W} = \dot{W}_{net,out} = \dot{W}_{out} - \dot{W}_{in}$ is the rate of net work output, h is the enthalpy per unit mass.

The rate of heat extracted (absorbed) by the unit in the heating mode (the ground heat exchanger load), ˙Qe is calculated from the following equation;

$$\dot{Q}_e = \dot{m}_{wa} C_{p,wa} \left(T_{out,wa} - T_{in,wa} \right) \quad (4)$$

where $C_{p,wa}$ is the specific heat of the water–antifreeze solution, $\dot{m}_{wa}$ is the mass flow rate of the water/antifreeze solution and $T_{out,wa}$ and $T_{in,wa}$ is the temperature difference between the outlet and inlet of the GHE.

The heat rejection rate in the condenser is calculated by;

$$\dot{Q}_{cond} = \dot{m}_{ref} \left(h_2 - h_3 \right) \quad (5)$$

where $\dot{m}_{ref}$ is mass flow rate of refrigerant, and h_2, h_3 enthalpy of condenser at inlet and outlet respectively.

The heat transfer rate in the evaporator is:

$$\dot{Q}_{evap} = \dot{m}_{ref} \left(h_1 - h_4 \right) \quad (6)$$

where h_1, h_4 are enthalpy of evaporator at outlet and inlet respectively.The work input rate to the compressor is:

$$\dot{W}_{comp} = \frac{\dot{m}_{ref} \left(h_{2s} - h_1 \right)}{\eta_{i,comp}} \quad (7)$$

where $\eta_{i,comp}$ is isentropic efficiency of compressor and h_{2s} is isentropic enthalpy at outlet of compressor.

In case that the mass flow rate on the refrigerant side is not measured, the space heating load ˙Qsl, may be estimated as;

$$\dot{Q}_{sl} = \dot{m}_{air} C_{p,air} \left(T_{out,air} - T_{in,air} \right) \quad (8)$$

where $\dot{m}_{air}$ is the mass flow rate of air, $C_{p,air}$ is the specific heat of air, $T_{in,air}$ and $T_{out,air}$ are the average air temperatures entering and leaving the fan-coil units, respectively. For an ideal heat pump system operating between the low and high temperature reservoirs at T_L and T_H respectively, the maximum heating coefficient of performance, $COP_{carnot,hp}$ is obtained from the Carnot cycle as;

$$COP_{carnot,hp} = \frac{T_H}{T_H - T_L} \qquad (9)$$

The COP of the GSHP can be calculated as;

$$COP_{hp} = \frac{\dot{Q}_{cond}}{\dot{W}_{comp}} \qquad (10)$$

The coefficient of performance of the overall heating system COP_{sys} , which is the ratio of the condenser load to total work consumptions of the compressor, the pumps (brine and water circulation pumps), and the fan-coil unit (or the condenser fan), may be computed by the following equation;

$$COP_{sys} = \frac{\dot{Q}_{cond}}{\dot{W}_{comp} + \dot{W}_{pump} + \dot{W}_{fc}} \qquad (11)$$

TABLE II: Measured parameters

PARAMETERS	VALUE
Evaporation(low) pressure (MPa)	0.51
Condensation(high) pressure(MPa)	2.2
Evaporating temperature (℃)	-5.1
Condensing temperature (℃)	70
Temperature of water at GHE inlet (℃)	13.7
Temperature of water at GHE outlet (℃)	17
Volumetric flow rate of water (m^3/s)	0.055×10^{-3}
Volumetric flow rate of air (m^3/s)	0.6×10^{-3}
Volumetric flow rate of refrigerant(m^3/s)	0.0186×10^{-3}
Outdoor temperature (℃)	16
Outdoor relative humidity (%)	60
Soil temperature in depth of 3m (℃)	20.1
Temp. of air at fan inlet (℃)	28
Temp. of air at fan outlet (℃)	33
Compressor electric current (A)	6
Circulating pump electric current (A)	0.45
Condenser fan electric current (A)	0.71
Current of all systems (A)	7.16
Two-phase voltage (V)	220

TABLE III (Calculated parameters)

PARAMETERS	Value
Mass flow rate of refrigerant (Kg /s)	0.02
Work input to compressor (KW)	1.2
Work input to circulating pump (KW)	0.061
Work input to fan coil circuit (KW)	0.054
Total work input (KW)	0.996
Heat extraction from ground (KW)	2.43
Heating load of testing room (KW)	3.2
COP of heat pump (COP_{hp})	2.66
COP of the system (COP_{sys})	2.43

III. RESULTS AND DISCUSSION

In this study, the performance of the system designed under the conditions of Sindri, Dhanbad is analyzed using the measured data. The tests were conducted on the ground source heat pump system under steady state conditions in the heating mode. In order to analyze the performance of the system under climatic conditions, Daily average values of 12 measurements between the months December to March for the hours 09:30 to 12:00, with an interval of 15 mins are used in the calculations.Table II indicates the average measured parameters when the steady state were reached in January, after this the Table III shows the calculated parameters which has been done on the basis of above analysis.

The coefficient of performance of heat pump and system, Heat extraction capacity, the heating capacity are the key parameters of this experiment. So in this experiment these parameters have been calculated by the equations as explained in previous chapter, for this several readings have been taken. Some average experimental data and results mention below and there graph plotted in this thesis.

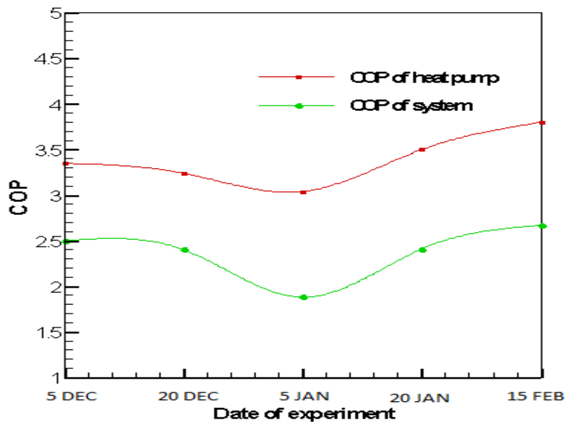

Figure 2: Variation of various COP with date of experiment

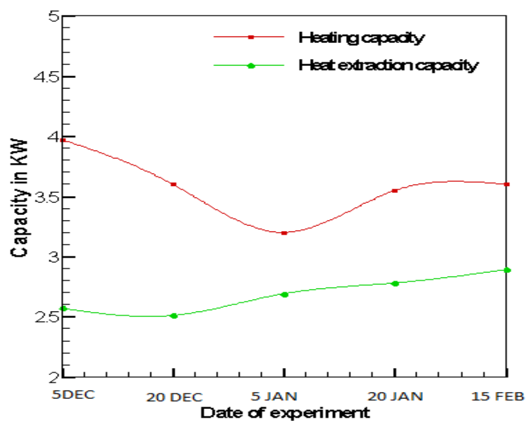

Figure 3: Variation of various heating capacity with date of experiment

Fig 2 illustrates the date wise variation of the various COP. It shows a decrease in COP_{sys} and heat pump until 5th January, and then it increases for GHE. The mean values of COP_{sys} and COP_{hp} for GHE are obtained to be 2.2 and 3.11, respectively. The highest COP the system and coefficient of performance of heat pump for GHE is found as 2.67 and 3.8 in February, respectively, while the lowest heating coefficient of the system and coefficient of performance of heat pump for HGHE is found as 1.88 and 3.04 in January, respectively

Fig.3 depicts the date wise variation of the space-heating rate and heat extraction rate of Ground source heat pump system. The mean heat rates rejected by the condenser unit to the room in the heating season for GHE found to be 3.5. The lowest heating capacities for GHE obtained as 3.2 on 5th January while the highest heating capacities for GHE 3.971 on 5th December. Also the mean heat extracted from ground is the heat extracted through evaporator is found to be 2.7 kW. The lowest heat extracted on 20th December while highest extraction is found on 15th February through ground heat exchanger

IV CONCLUSION

An experimental system was installed for investigating the thermal performance of a GSHPS for heating mode. The GSHP systems offer some proven advantages over conventional heating and cooling systems, particularly in terms of efficiency, maintenance costs, and overall operating costs.

The main conclusions that can be drawn from the present study are listed below:

a. The heat pump unit: The values for COP_{hp} varied from 2.54 to 2.95 while those for COP_{sys} were approximately 5–20% lower than COP_{hP}
b. The circulating pump: The pumping brine flow rate was found to be $0.185m^3/h$ per kW of heating capacity. Kavanaugh suggests that the optimum pumping rates for the circulating pump should range from 0.162 to $0.192m^3/h$ per kW of heating capacity. It may be concluded that the pump selected falls into the acceptable limits with a good grade.
c. The relevant soil properties are to be precisely measured before attempting the design of the GHE. Therefore, care must be taken in the design and construction of a ground loop for a heat pump application to ensure long ground loop life and reduce the installation costs.

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