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Performance Evaluation of a Ground Source Heat Pump for the Coastal Climate

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ABSTRACT

A ground source heat pump (GSHP) system is a set of equipment taking the advantage of inverse Carnot cycle to provide space heating and cooling for both residential and commercial usage. A study is undertaken to evaluate the performance of a GSHP system installed at Dholera, Gujarat. It is surrounded by the Arabian ocean on the western side with a coastline of 1600 km. Water is of prime importance when we consider a geothermal heat source. Due to the coastal areas, the geothermal heat source cannot be used directly into the heat pump. Thus the heat exchanger is one of the most important components in these areas. Presence of high salinity and heavy metals in the groundwater affects the equipment badly. The used groundwater temperature is about 45°C. The performance evaluation of the hot loop cycle of the heat pump is considered as our prime objective is power generation. As per design aspect, the temperature output at the hot loop is 75°C. From the results, it is concluded that to achieve the optimum efficiency with minimum power consumption we should maintain the inlet temperature of the hot loop at a fixed value. In our system, the temperature difference of a fixed value is maintained using a cooling tower along with Auto Tuning PID (Proportional-integral-derivative) Controller with temperature sensor.

1. INTRODUCTION

India is the second largest populated country in the world after china. The population of this country is 1.2 billion which is near about 17% of the world population. India is the worthy consumer of the energy resources. In comparison with other countries like China, USA, Russia, India has also consumed its maximum energy in agricultural, residential and commercial purpose. In recent years the power generation capacity of India has increased due to high demand. Most of the power generation plants in India uses conventional energy source like coal and oil, which produce harmful by-products to the environment, which is also known as greenhouse gas emission. Due to consistently increasing energy demand and limited storage of conventional energy source it is mandatory to utilize the abundant renewable energy resources like biomass energy, solar energy, wind energy, geothermal energy and oceanic energy. Amongst all Asian countries, India is one of them which have geothermal energy potential but the utilization is still under process. In India, most of the geothermal sources are categorized as medium enthalpy and low enthalpy (<90°C). To produce electricity by utilizing the medium and low enthalpy geothermal sources (Freeston, 1996) requires complex mechanism and the whole system is much costly. Many researches are working on this to make it competent as compared to the thermal power plants. GSHP plays a very important role to produce electricity in case of low enthalpy geothermal sources. To produce electricity the minimum temperature required for the Organic Rankine Cycle (ORC) is 75°C (Yari, 2010). GSHP is the only equipment which is capable to convert the low temperature into high (as per the requirement of the ORC) and helps to produce electricity from low enthalpy geothermal reservoir (Ahangar, 2012).

Table 1 Important geothermal well in India

Location of wells	Depth (meters)	Maximum spring temperature (°C)	Thermal discharge from springs (litres/sec)	Thermal discharge from drill holes (tones/hour)
Puga, Ladakh, Jammu & Kashmir	385	84	30	250
Chhumathang, Ladakh, Jammu &Kashmir	220	87	5	50
Manikaran, Himachal Pradesh	700	96	15	100
Tapoban, Uttarkhand	728	65	15	150
Tattapani, Chhatisgarh	620	98	1	120

2. GROUND SOURCE HEAT PUMP (GSHP)

A GSHP is a mechanical device which has the ability to increase the heat from lower temperature to higher temperature. It is not single equipment it is an assembled system. It consists of mainly four parts (a) Compressor (b) Evaporator (c) Condenser (d) Expansion valve. The evaporator and condenser are nothing but a heat exchanger. In this system the cooling and heating cycle run simultaneously with each other (Self, 2013). Compressor is responsible for heating purpose and expansion valve for cooling. The GSHP is operated by (3 phase 440 Volt) electricity which runs the compressor. This provides the necessary work for the transportation of thermal energy. Generally heat pumps operate on vapor-compression refrigeration cycle. The working fluid (refrigerant) within the heat pump has a boiling point < 0^0C.The selection of the working fluid depends upon the characteristics and requirements of the GSHP (Zarrouk, 2014).

It plays a very important role when producing electricity from low enthalpy geothermal source or we can use it for both the purpose of space heating and cooling and electricity generation (Hepbasli, 2007). It works in the following manner –

(i) Due to sufficient bottom hole pressure or by using centrifugal pump the thermal energy is transported from geothermal well to the evaporator.

(ii) The evaporator is basically a heat exchanger. In this heat exchanger the geothermal water exchanges its heat with the cool refrigerant which is present inside the heat pump. The refrigerant stored inside the heat pump in liquid dominated state. After getting the heat from the geothermal water the refrigerant converts to a low pressure vapor and the water becomes cold which is used for space cooling.

(iii) The compressor sucks the low pressure vapor refrigerant and converts it to high pressure vapor. Due to high pressure the temperature is also increased.

(iv) Refrigerant of high pressure and high temperature then enters the condenser. It is also a heat exchanger. In this heat exchanger the high pressure and high temperature refrigerant exchange its heat with the water and the refrigerant becomes comparatively cool and converts into liquid phase but in high pressure. After getting the heat from the refrigerant the warm water is used for electricity generation.

(v) The expansion valve then reduces the pressure of the refrigerant and as a result the temperature decreases. The liquid refrigerant again enters into the evaporator to repeat the same cycle.

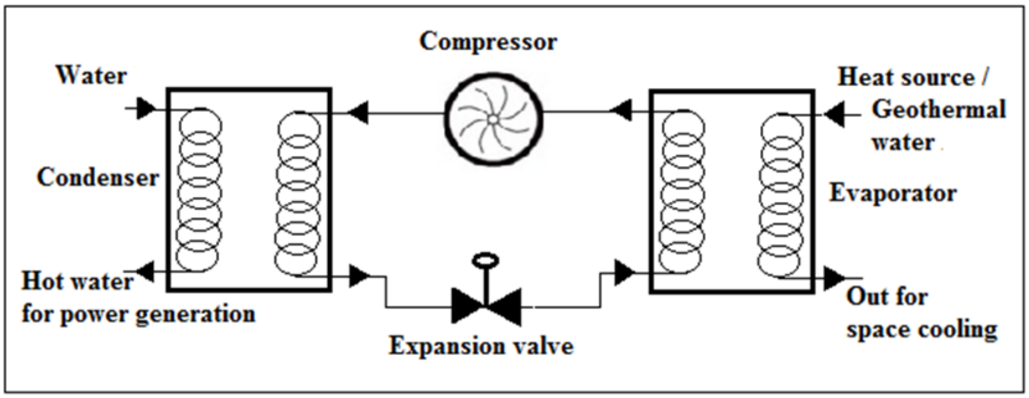


Figure 1: Working principle of the heat pump

Figure 2: Heat pump at Dholera

3. SYSTEM INSTALLED AT DHOLERA

Dholera is located at Ahmedabad district of Gujarat. Dholera thermal springs lies in the western margin of the Cambay Basin. Gujarat is the western most state of India. It is surrounded by the Arabian ocean with a coast of around 1580 sq. km. As the Tropic of Cancer passes through Gujarat, extreme temperature with humid climate exists. The soil at Dholera is loamy and mostly saline. Presence of heavy metals in the groundwater (as available in coastal areas) affects the equipment badly so plate type heat exchanger (PHE) is used for energy extraction (Bakirci, 2010). The available temperature of the well bore is 45^0C and the water obtained from the production well is 7 lts/sec. The plate type heat exchanger transfers the heat from geothermal water to fresh water and feeds to the GSHP evaporator. The output of the evaporator is sent to the AHU (Air handling unit) for cooling purpose. The output from the condenser is used for space heating purpose. As the space heating was not necessary here, we have used this heat energy for power generation. Thus we have planned to install 5 MW ORC power generation plant. Here, the cooling tower plays a vital role. It maintains the temperature of the system. The details of the system installed at Dholera are given in Figure 3.

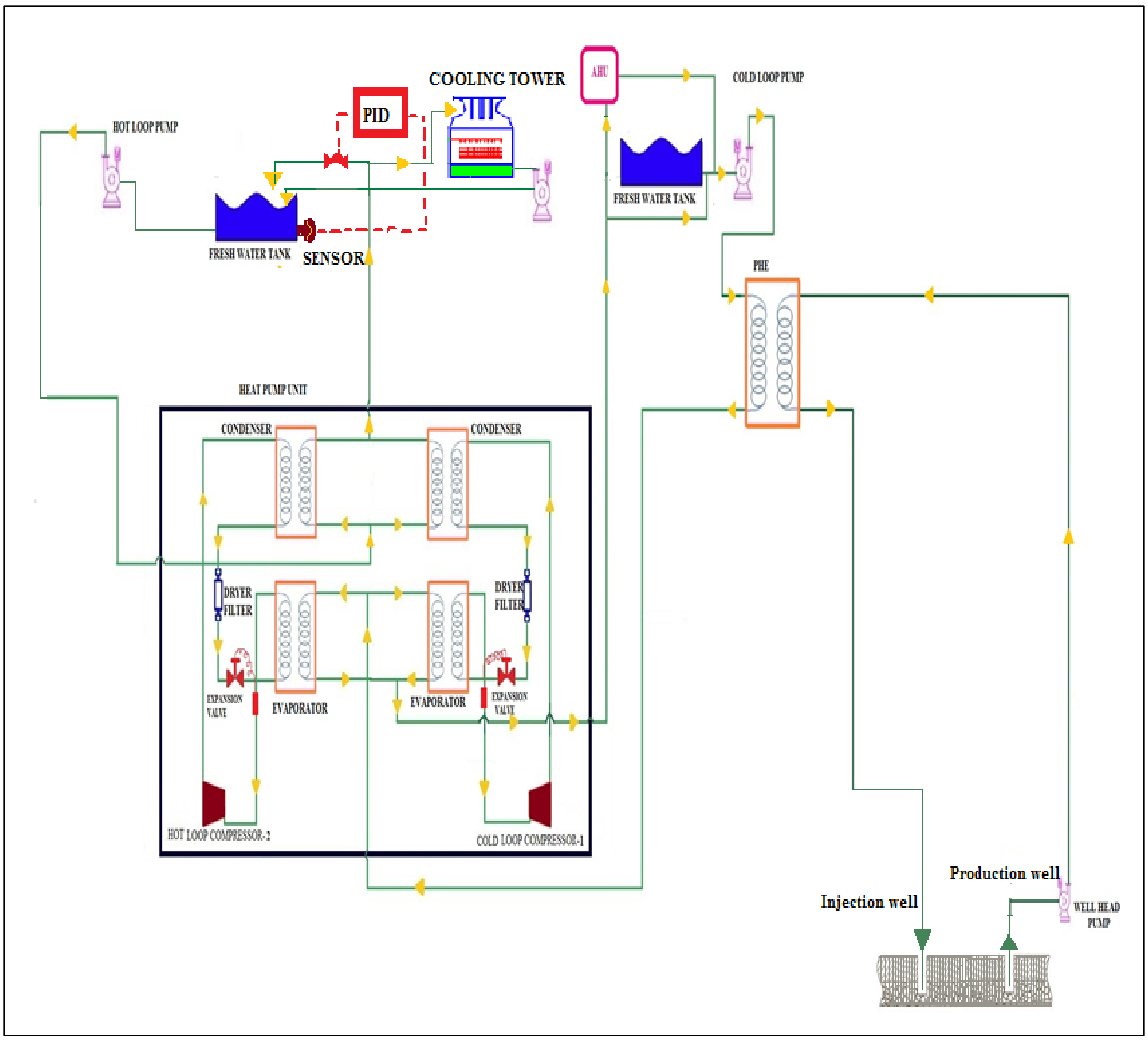
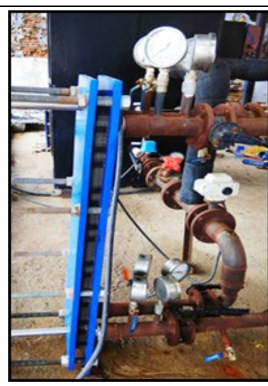
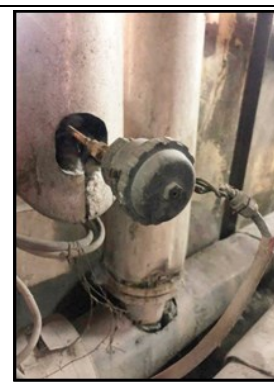


Figure 3: Piping and instrumentation diagram of the system at Dholera

4. DETAILS OF THE COMPONENTS

The components are as follows:

Scroll compressor	Evaporator	Condenser	Cooling tower
			
Model Number - Copeland ZR380KCE-TWD-523 Type - Scroll Weight - 210Kg Cooling Power - 80Kw/30Hp Displacement Capacity - 84.2 m^3/h Refrigerant - R134a Noise Level - 75dB Type of Oil - Polyester (6.3litres) Power Source -380-420V/3Phase/50Hz frequency Maximum Starting Load - 310A Maximum Working Load - 62A	Model No – GBS500H-90 Serial No - 5100346225-0002 Manufacturing year – 2016 Maximum allowable temperature - 200^{0}C Maximum allowable pressure – 450 psi Make - Kelvion	Model No – GBS700M-50 Serial No – 5100270009-0008 Manufacturing year – 2015 Maximum allowable temperature - 200^{0}C Maximum allowable pressure – 450 psi Make – GEAWTT GnbH	FRP Counter – Flow cooling tower cylinder shaped CF – series Make – Crystal Cooling capacity -5^{0}C Operating motor – 3HP, 960 rpm Internal fills packings – Honey comb designed fills

Expansion valve	Heat exchanger (Plate type)	PID controller	Temperature sensor
			
Model No. – XC-726MW55-2B Make - Emerson Material code – C155225 Suitable for working fluid – R-314a, R-12, R-401A	Type – A20A Make - Sondex Manufacturing year – 2016 Serial No. – 201605186 Heat transfer area – 2.52 m^2 Design pressure – 10 bar Test pressure – 13 bar Design temperature - 60^{0}C	Type – DC1040CT-302000-E Make - Honeywell Supply – (85 to 265 Volt) AC Frequency – 50 Hz Maximum ambient temperature - 50^{0}C	Type – RTD Sensor (PT-100) Make - Honeywell Supply – (25 Volt) DC Temperature range - 0^{0}C to 100^{0}C

5. RESULTS AND DISCUSSION

Table 2 Data analysis of the GSHP hot loop

Time	Inlet temperature	Outlet temperature	Compressor suction pressure (psi)	Compressor discharge pressure (psi)	Load (A)
10.10	48.3	51.2	22	220	39.9
10:20	50.4	53.2	22	230	41.7
10:30	53.1	56	23	240	42.9
10:40	54.9	57.8	24	250	44
11:10	59.6	62.5	26	260	46
11:20	61	63.2	26	270	46.9
11:30	62.8	65.9	28	280	47.2
11:50	65	68.2	30	290	49
12:10	67	70.1	31	300	47.4
12:30	69.6	72.5	33	302	48.9
12.50	70.9	74	34	310	49.8
13.10	72.8	75.2	37	322	55
13.35	72	74.8	35	315	50.7
14.05	73.8	75	38	330	56.8
14.40	72.6	74.9	36	320	51.3
15.05	72.9	75	35	312	52
15.45	72	75	32	315	50.5
16.15	71.8	74.5	35	315	50.1
16:45	73	75.2	38	330	54.8
17:15	72	75	32	316	50.4
18:00	72.6	75.1	36	328	54.7
18.30	72.2	75	35	320	51.1

This is an experimental set-up which is installed near Swaminarayan temple at Dholera, Gujarat. This system is currently being used for space cooling purpose at the temple Sabha Mandap. To overcome the disadvantage of ORC (high operating cost) (Shengjun, 2011) we have proposed the above solution. GSHP is the heart of the equipment as it converts water of 45^0C to 75^0C. It is the prime equipment which consumes most of the electricity. While testing we observed that in hot loop side, as per design aspect, the temperature difference should be of fixed value which is 3^0C. Use of the cooling tower cannot maintain the required temperature in constant basis. In our experiment we observed that the maximum temperature output of the system is 75^0C. According to our result when the temperature difference between the inlet and outlet is below 3^0C then the load is more but when the difference is 3^0C then the load is appropriate to obtain a good efficiency. If we maintain a fixed temperature difference, then the heat pump efficiency maximizes with low power consumption (Table 2). To maintain this fixed temperature difference we have used a temperature sensor with Auto-tuning PID controller. Here, the temperature sensor measures the hot loop inlet temperature and provide the information to the PID controller which controls the pneumatic valve operation. As a result, the flow is measured and the required temperature is maintained. The system runs for about 6 hours per day. Use of the PID controller helps us to saves around 300 units/month.

5. CONCLUSION

In case of using low enthalpy geothermal source for power production, ORC is more suitable. The minimum temperature of water, required for power generation is 75^0C. As ORC is expensive having complex machineries the power production cost are higher compared to other power generation cycles. This paper overall discusses about the reduction of the operational cost. The temperature sensor with auto-tuning PID controller has maintained the required temperature difference in the GSHP hot loop section. In future different types of controllers can be used to get better result.

6. ACKNOWLEDGEMENT

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