Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 4; April-June, 2015 pp. 288-291

http://www.krishisanskriti.org/jmsme.html

Thermodynamic Analysis of Tattapani Geothermal Site, Chhattisgarh

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Abstract—*This paper presents thermodynamic analysis of Tattapani geothermal field, which is the most promising geothermal field located on Son-Narmada lineament in Central India. Thermodynamic analysis was done considering binary power cycle. Net power output, net power output per kg of geothermal water, thermal efficiency were calculated for brine inlet temperature. This paper also tries to investigate the effect of refrigerant on net power output and efficiency. Refrigerant considered for the binary cycle are R134a, R600a, R245fa and R123, which were selected on the basis of high critical temperature, high latent heat, high density, low freezing point. Results shows that the net power output, net power output per kg of geothermal water and thermal efficiency is maximum for R134a.*

1. INTRODUCTION

Global energy need is increasing day by day and hence the reserves of fossil fuel are depleting day by day. Due to the increase in fossil fuel consumption there is increase in environmental problems such as global warming and ozone layer depletion. Hence renewable energy sources are given importance because it is clean and green energy source. Geothermal energy is one of the renewable energy sources which give clean fuel without causing any problem to the environment.

Geothermal power plants now exist all over the world to generate electricity. The major geothermal based electricity producer is USA which has an installed capacity of 3389 MW. The total installed capacity of geothermal power plant is 11765 MW. Due to the rapid rise of geothermal power plant it is expected that the rise in total installed capacity will be 18500 MW by the end of 2015 [1]. India is one of the developing countries and hence its energy consumption is increasing. Therefore we cannot rely on the non-renewable energy sources because it is present at very low amount in India. GSI has identified 340 hot springs at various regions around the country [2]. Geothermal potential of India is 10000 MW which can be generated from Himalaya, Naga Lushai, Andaman-Nicobar Islands, West Coast, Cambay Graben, Aravalli, Son-Narmada-Tapi, Godavari and Mahanadi, South Indian Cratonic geothermal provinces. Geothermal reservoir in India is low to medium temperature water dominated type [3].

There various types of geothermal system which are been designed for different temperature ranges, which are:

1. Dry steam plant for temperature greater than 200^{o}C
2. Flash steam plant for temperature 150^{o}C to 200^{o}C
3. Binary cycle plant for temperature 100^{o}C to 150^{o}C
4. Kalina cycle plant for temperature 80^{o}C to 150^{o}C

Also these systems are optimised and various design methods are implicated to exploit more energy form the brine or heat source. In the advancement in the design of geothermal system a method is found to increase the power output by increasing the flow of brine supplied to the evaporator returning the steam of brine from downstream of evaporator for a repeated passage through the that heat exchanger [4]. Self-superheating is another method to increase the performance of single flash cycle and double flash cycle, in this a part heat of brine is used to heat the steam that enters the turbines [5].By decreasing the condensation temperature the power output of the organic rankine cycle increases also by avoiding scaling and fouling problems the reinjection temperature should be maximum in the heat recovery heat exchanger and in the pipes [6].

1.1 Tattapani geothermal site, Chhattisgarh

The Tattapani geothermal field is located 100 km northeast of Ambikapur, Sarguja district, Chhattisgarh. Tattapani is most promising geothermal field in the Peninsular India. Geothermal activity is seen in the east of the Tattapani and in the west of the Jhor, which are located 50 km apart. Thermal manifestation at Tattapani is very intense in an area of 0.05 sq. km with several hot spots, hot water pools and a marshy land. GSI has concluded that the temperature of the reservoir is 180^{o}C-190^{o}C measured by Na/K thermometer and 160^{o}C measured by quartz geo thermometer. During well testing it was found that the maximum bore well temperature is 112.5^{o}C [7].

Table 1: Temperature, depth and discharge of boreholes at Tattapani geothermal site.

Borehole number	Depth(m)	Discharge(lpm)	Maximum temperature flowing (oC)
GW/Tat/6	320	255-288	111.2

GW/Tat/23	350	282-380	111
GW/Tat/25	230	218	112
GW/Tat/26	210	356-380	111.7

Twenty six boreholes have been drilled to depths ranging from 100 m to 620 m. Five wells temperature, depth, and discharge are shown in the Table 1.1 in which the blowout condition occurred. Bore hole GW-6 is the deepest well drilled to a depth of 500m.Tattapani geothermal site has a potential of 10.9 MW electricity generations for a period of 20 years up to a depth of 1.5 km by using binary cycle based geothermal power plant [8].

2. THERMODYNAMIC ANALYSISOF BINARY GEOTHERMAL POWER PLANT

Binary cycle is one the leading cycle which is used for the extraction of heat from the brine. Binary cycle is similar to rankine cycle or any other closed cycle used for extraction of heat. The process of the cycle starts with selecting an appropriate refrigerant for the heat extraction from the source of heat. The selection of refrigerant depends mainly on the property of brine. The process starts with the extraction of heat by the refrigerant in the heat exchanger due to which pressure and temperature of the refrigerant increases and it converts into vapour.

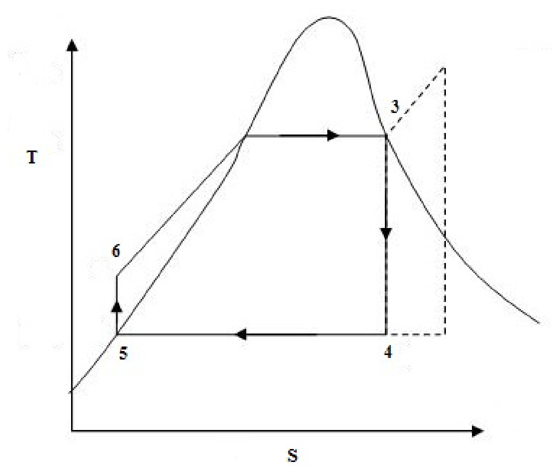

Fig. 1: T-s diagram of Binary cycle geothermal power plant

Then this vapour is passed to the turbine and vapour rotates the turbine blades. This process is called expansion. After the expansion process the partially vapour partially liquid refrigerant is passed through condenser where it rejects heat and covert into liquid. Then the liquid refrigerant is passed through the pump where the pressure is again increased and hence the cyclic process goes on again and again. A pre-heater can be used before the heat exchanger which is used to preheat the refrigerant before entering the heat exchanger from the heat available in the brine after it exchanges heat in heat exchanger.

Fig 1 shows the T-s diagram of binary cycle where process 3-4 shows the work output, 4-5 shows the heat rejection in the condenser. 5-6 shows the pump work and 6-3 shows the heat input. The dotted line shows the extension of refrigerant to superheated region.

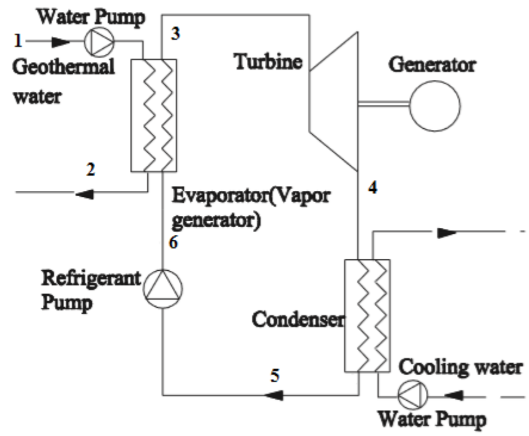

Fig. 2: Binary cycle geothermal power plant

Thermodynamic analysis can be done from the following formula:

Work done by the turbine:

$$W_{turbine} = m_{ref}(h_3 - h_4) \quad (1)$$

Work done by the pump:

$$W_{pump} = m_{ref}(h_5 - h_6) \quad (2)$$

Heat added:

$$Q_{in} = m_{ref}(h_3 - h_6) \quad (3)$$

Net power output:

$$P_{net} = m_{ref}[(h_3 - h_4) - (h_5 - h_6)] * \eta_t * \eta_m * \eta_{gen} \quad (4)$$

Net power output per ton of geothermal water:

$$P_{netg} = \frac{Pnet}{mw} \quad (5)$$

Efficiency of the binary cycle:

$$\eta = \frac{Pnet}{mref\,(h3 - h6)} \quad (6)$$

Assumption used for the thermodynamic analysis:

1. At the inlet of turbine the condition of steam is taken as saturated vapour
2. Temperature of the working fluid after the heat exchanger between brine and working fluid is taken as90^{o}C, 80^{o}C and 70^{o}C
3. As temperature of the brine at Tattapani geothermal site fluctuates between 80^{o}C to 120^{o}C, hence the temperature of the brine is taken as 90^{o}C, 100^{o}C, 110^{o}C
4. The condition of the refrigerant at the outlet of the turbine is kept constant for analysis.

3.1 Refrigerants used for the analysis

Refrigerants have an important role in system performance. There are few physical and chemical properties while selecting refrigerant such as non-toxicity, non-corrosiveness, non-flammability and stability [9]. For having a high power output refrigerant should have this following characteristics:

1. High critical temperature should be higher than maximum operating cycle temperature
2. Low freezing point should be lower than the lowest cycle operating temperature.
3. Density and latent heat of refrigerant should be high
4. Viscosity should be low and thermal conductivity should be high

Refrigerant used in the thermodynamic analysis are given below in the table 2.

Table 2: Refrigerants with their critical temperature and critical pressure

Refrigerant	Critical Temperature(˚C)	Critical Pressure(bar)
R134a	100	40
R600a	134.66	36.290
R245fa	154.01	36.510
R123	183.68	36.618

3. RESULTS AND DISCUSSIONS

Tattapani geothermal power plant site, Chhattisgarh has been investigated for different brine temperatures which are 110°C, 100°C and 90°C for the refrigerants R134a, R600a, R245fa and R123. The reason behind the selection of these refrigerants is that they are suitable for the brine condition. The mass flow rate of the brine is 40kg/s. Assumption were taken that the temperature of refrigerant after it exchanges heat with the brine is 90°C, 80°C and 70°C. The pressure at the outlet of turbine kept constant and the pressure at the inlet of the turbine is varied along with temperature. The calculation were done analytically for calculating the net power output, net power output per kg of geothermal water and thermal efficiency. First the brine heat (Q_{brine}) is calculated for different temperature for the refrigerants. Brine heat is is given by Q_{brine} and Q_{in} is the heat input to the refrigerants.As we know,$Q_{brine}= Q_{in}$, from this M_{ref} is calculated and Mref is used to calculate the net power of the cycle, net power per kg of geothermal water and thermal efficiency from the formula of their corresponding.The results of the calculation for refrigerants are given in the table 3below.

Table 3: Net power output, net power output per kg of geothermal water

Brine temperature	Refrigerant temperature at turbine inlet	Refrigerants	Mass flow rate of refrigerant (kg/s)	Pnet(kW)	Pnetg(kWs/kg)
110oC	90oC	R134a	84.67451	3507.46	87.6865
110oC	90oC	R600a	44.30497	3273.34	81.8336
110oC	90oC	R123	105.7463	2182.67	54.5668
110oC	90oC	R245fa	87.84558	2505.25	62.6313
110oC	80oC	R134a	83.43073	3410.04	85.2511
110oC	80oC	R600a	45.28082	3085.72	77.1431
110oC	80oC	R123	108.6181	1927.81	48.1952
110oC	80oC	R245fa	90.13185	2286.46	57.1616
110oC	70oC	R134a	83.36139	3270.29	81.7573
110oC	70oC	R600a	46.33635	2892.89	72.3222
110oC	70oC	R123	111.6371	1653.36	41.3340
110oC	70oC	R245fa	92.66897	2041.82	51.0457
100oC	90oC	R134a	78.74162	3261.74	81.5436
100oC	90oC	R600a	41.20069	3043.99	76.0998
100oC	90oC	R123	98.33946	2029.47	50.73687
100oC	90oC	R245fa	81.6906	2329.73	58.2432
100oC	80oC	R134a	77.585	3171.12	79.2781
100oC	80oC	R600a	42.10819	2869.51	71.7379
100oC	80oC	R123	101.0076	1792.76	44.8191
100oC	80oC	R245fa	83.81668	2126.27	53.1569
100oC	70oC	R134a	77.52058	3041.16	76.0291
100oC	70oC	R600a	42.90125	2678.43	66.9607
100oC	70oC	R123	103.8151	1537.5	38.437
100oC	70oC	R245fa	86.176	1898.77	47.4693
90oC	80oC	R134a	71.72555	2931.63	73.2908
90oC	80oC	R600a	38.92806	2652.80	68.1469
90oC	80oC	R123	93.37922	1657.37	41.4343
90oC	80oC	R245fa	77.4866	1965.69	49.1424
90oC	70oC	R134a	71.666	2811.49	70.2872
90oC	70oC	R600a	39.83547	2487.02	62.1756
90oC	70oC	R123	95.9747	1421.38	35.5345
90oC	70oC	R245fa	79.66774	1755.37	43.8843

From the tables we can desist that R134a shows the maximum power output and thermal efficiency. R134a at 110°C and

100^{o}C brine temperature as the temperature of the refrigerant at the outlet of the heat exchanger increases the mass flow rate alsoincreases.Whereas at 90^{o}C brine temperature it is found that as the temperature of the R134a at the outlet of the heat exchanger increases the mass flow rate decreases.

Table 4: Thermal efficiency of the refrigerants

Refrigerants temperature at turbine inlet	Refrigerants	ηt
90oC	R134a	16.098
80oC	R134a	15.651
70oC	R134a	15.009
90oC	R600a	15.024
80oC	R600a	14.163
70oC	R600a	13.277
90oC	R123	10.018
80oC	R123	8.848
70oC	R123	7.588
90oC	R245fa	11.498
80oC	R245fa	10.494
70oC	R245fa	9.371

R134a shows the maximum efficiency at 110^{o}C brine temperature and 90^{o}C refrigerant temperature in the turbine inlet which is about 16.098 and the efficiency decrease with decrease in the turbine inlet temperature as shown in table 4.

4. CONCLUSIONS

The thermodynamic analysis of Tattapani geothermal site, Chhattisgarh has a good potential for binary cycle based geothermal power plant. The brine condition is low temperature and water dominated which is a suitable condition for binary cycle based geothermal power plant. The calculations were made for different brine temperature by using R134a, R600a, R245fa and R123 as refrigerants. The selections of refrigerant were made on the basis of high critical temperature, high latent heat, high density, low freezing point. The analysis shows that for different brine temperature R134a shows the maximum net power output, net power output per kg of geothermal water and thermal efficiency. Hence R134a is suitable choice in refrigerants for Tattapani geothermal site, Chhattisgarh. To exploit the low temperature brine more and to maximise the power output it will be useful to use advanced optimisation and design methods for the binary cycle.

5. NOMENCLATURE

m_{ref}mass of refrigerant, kg s^{-1}

$m_w$mass of brine, kg s^{-1}

h_1 enthalpy of the brine at the inlet of heat exchanger, kJ kg^{-1}

h_2 enthalpy of the brine at the inlet of heat exchanger, kJ kg^{-1}

$h_3$enthalpy of the refrigerant at the inlet of turbine, kJ kg^{-1}

$h_4$enthalpy of the refrigerant at the outlet of turbine, kJ kg^{-1}

$h_5$enthalpy of the refrigerant at the inlet of pump, kJ kg^{-1}

h_6 enthalpy of the refrigerant at the outlet of pump, kJ kg^{-1}

P_{net} net power output, kW

P_{netg}net power per kg of geothermal water, kWs/kg

$\eta_t$thermal efficiency

REFERENCES

[1] Sadiq J. Zarrouk, Hyunsul Moon, "Efficiency of geothermal power plants: A worldwide review", *Geothermics* 51, 11 November 2013, pp. 142-153.

[2] Geological Survey of India, Geothermal fields of India, 2014 (article).

[3] S.K.Sharma, "Geothermal, A viable eco-friendly source of energy for India", *Proceedings World Geothermal Congress*, 24-29 April 2005.

[4] Aleksandra Borsukiewicz-Gozdur, Wladyslaw Nowak, "Maximising the Working Fluid Flow as a Way of Increasing Power Output of Geothermal Power Plant", Applied *Thermal Engineering 27*, 2007, pp.2074-2078.

[5] Francois Mathieu-Potvin, "Self-Superheating: A new paradigm for geothermal power plant design", *Geothermics 48*, 2013, pp.16-30.

[6] Qiang Liu, YuanyuanDuan, Zhen Yang, "Performance analyses of geothermal organic Rankine cycles with selected hydrocarbon working fluids", *Energy 63*, 2013, pp. 123-132.

[7] P.B.Sarolkar, S.N.Shukla, D.K.Mukhopadhyay, "Shallow level sub surface characters of Tattapani Geothermal field, India", *Twenty-Fourth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California*, January 25-27, 1999.

[8] Anil Basaran, Leyla Ozgener, "Investigation of the effects of different refrigerants on performances of binary geothermal power plant", *Energy Conversion and Management 76*, 2013, pp. 483-498.