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Analysis of Kalina Cycle on Tattapani Geothermal Site, Chhattisgarh

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Abstract—*Tattapani geothermal site, Chhattisgarh is one of the most promising geothermal sites in India. The paper presents the analysis of kalina cycle for the Tattapani Geothermal site. Binary mixture i.e. ammonia-water mixture is used for the analysis of kalina cycle using a concentration ratio of 0.7 on the turbine input. Net power output, Net power per ton of geothermal water and efficiency were calculated from the data of Tattapani geothermal site, Chhattisgarh. The calculations were made for different brine temperature i.e. 110°C, 100°C, 90°C as well as for different evaporator output temperature i.e. 90°C, 80°C, 70°C .The results shows that the approximate maximum power output is 4.2 MW.*

1. INTRODUCTION

The demand of energy is increasing more and more due to which the non-renewable energies for e.g. coal, petroleum etc. is depleting leaving behind a very small amount for the future generation. As for a developing country the energy is the most important factor. Hence we have to rely on renewable sources of energies as it is vast source of energy and have no chance of depletion. Renewable energy can be renewed after a small interval time which is a great advantage. Various types of renewable energy include solar, tidal, wind, geothermal etc.

Geothermal energy is being used as a source of heating and various for purposes for several past years and various countries are seeing it as a viable source to produce 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 a developing country hence the need of energy is more hence we cannot rely only on non-renewable sources of energies hence it have to look forward for other option which is renewable sources of energies. GSI (Geological Survey of India) has identified 340 geothermal sites in all over India, which has a potential of 10000 MW [2]. The regions of geothermal sites are Himalaya, Naga Lushai, Andaman-Nicobar Islands, West Coast, Cambay Graben, Aravalli, Son-Narmada-Tapi, Godavari and Mahanadi, South Indian Cratonic geothermal provinces [3].

Geothermal power plants has been categorised on the basis of temperature from high to medium to low temperature. For high temperature (above 200°C) the plant considered is dry steam power plant, for medium temperature (150°C to 200°C) the flash steam power plant and for low temperature (below 150°C) binary power plants. But by recent experimentation on geothermal power plant show that kalina cycle is a viable way to extract energy from the brine. The result shows that 15-50% more power output can be achieved by using kalina cycle than binary cycle for low temperature brine [4]. The kalina cycle also shows maximum efficiency than the binary cycle.

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°C-190°C measured by Na/K thermometer and 160°C measured by quartz geo thermometer. During well testing it was found that the maximum bore well temperature is 112.5°C [5].

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 [6].

2. ANALYSIS OF KALINA CYCLE

Kalina cycle is being used for electricity generation for several years and developed by Alexander Kalina. Kalina have high thermal efficiency and have maximum heat extraction capacity. The thermal efficiency of kalina is up to 40-60%.The reason behind the maximum heat extraction is the mixture boils at different temperature. In kalina cycle mixture of two fluids is used basically ammonia-water which shows high heat extraction capacity than the pure refrigerant.

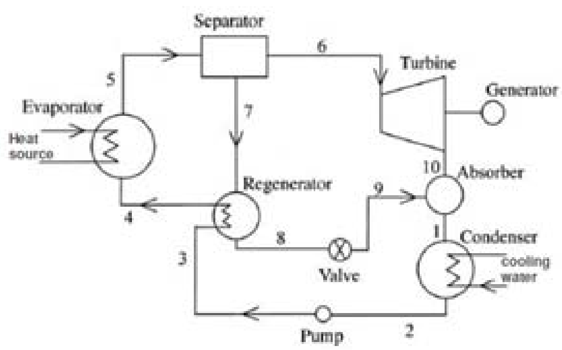

Fig. 1: Kalina Cycle

The process of kalina starts with giving heat to the NH_3-H_2O mixture from the heat source. By giving the NH_3-H_2O mixture starts boiling after that it is passed through the turbine as the mixture rotates the turbine blade which is coupled with generator. After that the mixture has high concentration of ammonia and to condense it will require very less temperature which is impossible to achieve. Hence we add a separator which will add lean mixture to the high concentration mixture decreasing the concentration of ammonia. The separator is added up between the turbine and evaporator. After that the mixture is condensed and passed through the pump. A regenerator is used before the evaporator to preheat the mixture.

Thermodynamic analysis can be done from the following formula:

Work done by the turbine:

$$W_{turbine} = m_{ref}\,(h_6 - h_{10}) \quad (1)$$

Work done by the pump:

$$W_{pump} = m_{ref}\,(h_3 - h_2) \quad (2)$$

Heat added:

$$Q_{mix} = m_{ref}\,(h_5 - h_4) \quad (3)$$

Net power output:

$$P_{net} = m_{ref}[(h_6 - h_{10}) - (h_3 - h_2)] * \eta_t * \eta_m * \eta_{gen} \quad (4)$$

Net power output per ton of geothermal water:

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

Efficiency of the binary cycle:

$$\eta = \frac{Pnet}{mref\,(h5 - h4)} \quad (6)$$

Assumptions made for the analysis of kalina cycle:

1. The condition of steam is taken as saturated vapour at the inlet of turbine.
2. Temperature of the mixture is taken as90^{o}C, 80^{o}C and 70^{o}C after the heat exchanger.
3. The temperature of the brine is taken as 90^{o}C, 100^{o}C, 110^{o}C as temperature of the brine at Tattapani geothermal site fluctuates between 80^{o}C to 120^{o}C.
4. The concentration of NH_3-H_2O at the evaporator to turbine side is taken as 0.7.

3. RESULTS AND DISCUSSIONS

The thermodynamic analysis of Tattapani geothermal site is done using kalina cycle at different source temperature i.e. 110^{o}C, 100^{o}C and 90^{o}C. The mass flow rate of the geothermal water is 40kg/s.

Table 2: Net power output, net power output per kg of geothermal water calculated for kalina cycle

Brine temperature	Refrigerant temperature at turbine inlet	Pnet(kW)	Pnetg(kWs/kg)
110oC	90oC	4266.817	106.6704
	80oC	3814.217	95.35543
	70oC	3466.273	86.65682
100oC	90oC	3259.443	81.48607
	80oC	3223.4	80.585
	70oC	3083.26	77.0815
90oC	80oC	2979.964	74.49909
	70oC	2850.4	71.26

The calculation were done analytically for calculating the net power output, net power output per kg of geothermal water and thermal efficiency. First the heat energy for geothermal water is calculated (Q_{brine}) is calculated for different temperature for the refrigerants and enthalpy at the inlet of the evaporator and at the outlet of the evaporator is calculated.After that both the heat energy i.e. from the geothermal water and at the evaporator is equated:

$$Q_{brine} = Q_{mix}$$

From this equation mass flow rate of the NH_3-H_2O mixture is calculated M_{ref} is calculated. M_{ref} calculated at different brine temperature and corresponding temperature at the outlet of the evaporator is used to calculate the net power output, net power per kg of geothermal water and thermal efficiency is calculated using the equation (4), (5), (6).

The maximum thermal efficiency is calculated which is at 110°C and shown in table 3 below.

Table 3: Thermal efficiency of kalina cycle at 110°C

Refrigerants temperature at turbine inlet	Ƞt
90oC	19.58333
80oC	17.50605
70oC	15.90909

The maximum thermal efficiency of the cycle at 90°C is 19.58 and corresponding net power output is 4266.817.

4. CONCLUSIONS

The thermodynamic analysis for kalina cycle on Tattapani geothermal site shows that the kalina cycle has good potential for power generation. The condition of brine is water dominated and low temperature hence kalina cycle is suitable for this condition. As kalina cycle has high efficiency and net power output compared with binary cycle. Therefore the cycle can be considered in Tattapani geothermal site for maximum heat extraction. The results show that the power output is maximum at 110°C brine temperature which can be 4.2 MW. The used can be further optimised to extract more heat and to generate more power.

5. NOMENCLATURE

m_{mix} 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_6 enthalpy of the refrigerant at the inlet of turbine, kJ kg^{-1}
h_{10} enthalpy of the refrigerant at the outlet of turbine, kJ kg^{-1}
h_2 enthalpy of the refrigerant at the inlet of pump, kJ kg^{-1}
h_3 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
$Ƞ_t$ thermal efficiency

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