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Parametric optimization of vapor power and cooling cycle

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Abstract

The proposed solar thermal based combined power and cooling cycle can be operated from low grade energy such as heat and well suited for domestic and industrial needs. The hybridization of vapour absorption refrigeration (VAR) and Kalina cycle system (KCS) results power in addition to cooling. The proposed plant has two turbines with super heater and reheater to recover more heat from the solar thermal collectors. The refrigerant vapour from the high pressure turbine is reheated for low pressure turbine which gives 9.3 kW of extra power. The total power and cooling are 14.05 kW and 73.58 kW respectively at 0.42 absorber concentration and 99% of turbine concentration and 150 °C of solar collector temperature. The invention also highlights the flexibility in the operation of system on only power mode or on only cooling mode. Thermodynamic analysis has been carried out with a focus on separator temperature and turbine concentration.

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Keywords: combined power and cooling, aqua-ammonia, reheater and single effect

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1. Introduction

The daily increasing rate of power consumption for both domestic and industrial usage with this enormously growing population, calls for research on sustainable and efficient power generation methods to meet the needs. Renewable energy plays a role for the safe and continuous power and thus solar thermal power plant is referred. Refrigeration accounts for majority of power used in industries as well as residential areas. The integration of power and cooling cycle helps to reduce the need of power, but common working fluid is needed. Ammonia is one of the suitable working fluid for power and cooling cycle, as proposed by Kalina [1-4]. Kalina cycles helps to recovery the energy from the power plant and useful for large scale industries. The single cycle which gives both power and cooling is developed by Goswami [5-9], but it delivers low amount of refrigeration effect.

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The proposed system helps to meet the need of both power and cooling cycle for the domestic and industries. And also makes the option for their need of only power, cooling and both. The configuration of the proposed cycle is simple compared to theSayed and Tribus [10, 11], because of single heat exchanger. The property values are developed byZigler and Trepp [12], Patek and Klomfer [13] are applied in this evaluation. The first aqua-ammonia based combined power and cooling plant is proposed by Goswami [9] and achieved the thermal efficiency of 22 %.The main objective of the proposed plant is to solve the power and cooling in combined mode and also working as individual mode. The mathematical modeling and simulation is done to find the optimum working condition at different temperature and turbine concentration

Nomenclature

F	vapor fraction
h	enthalpy
Q	heat load
m	mass
x	concentration
W	work done
Subscripts	
E	evaporator
Gen	generator
HPT	high pressure turbine
LPT	low pressure turbine
RC	reflux condenser
RH	reheater
SH	superheater

2. Working and thermodynamic formulations

Following are the assumptions considered for thermodynamic evaluation.

- The isentropic efficiency for pump and turbine is 75%.
- The concentration difference between reflux condenser (RC) outlet and inlet is considered as 0.08.
- Degrees of superheat are 10 °C for high pressure turbine (HPT) and low pressure turbine (LPT) respectively.
- The refrigerant temperature after evaporator is taken as 10 °C.
- The exit pressure of HPT is condensing pressure.
- The beam and global radiations are assumed to be 650 and 900 W/m^2 respectively.

The schematic flow diagram of the proposed cycle is shown in the Fig.1. In the proposed system, the power and cooling cycles are integrated using the common generator and the generator runs with the help of solar parabolic trough collector. It has two turbines for converting the energy available at the exit of the generator [10] to make useful energy and it has super heater and reheaters for producing energized vapor to rotate the turbines. At the exit of the HPT still the ammonia is in saturated vapor state [5] [6], so less energy is required to make the ammonia into dry vapor state. After the HPT, mass of the refrigerant is separated for power and cooling cycle depending on the need of the user. One part of saturated vapor moves to the condenser for condensation and completes the cooling cycle and the HPT reduces the condenser load. The remaining part of the refrigerant mass goes to the power cycle and gets re-heated before entering the LPT. The power cycle completes and exit refrigerant is saturated vapor. The combined power and cooling cycle has three pressure of separator pressure (high pressure), condensing pressure and sink pressure (low pressure). The high pressure based on the separator temperature and turbine concentration, sink and condensing pressure based on the atmospheric temperature. After the reflux condenser the ammonia vapor runs the HPT after reheated with high pressure to medium of condensing pressure. The LPT turbine runs with medium pressure to sink pressure with selected mass flow rate. At the exit of the HPT the flow rate of ammonia vapor can be changed according to the need of power and cooling.

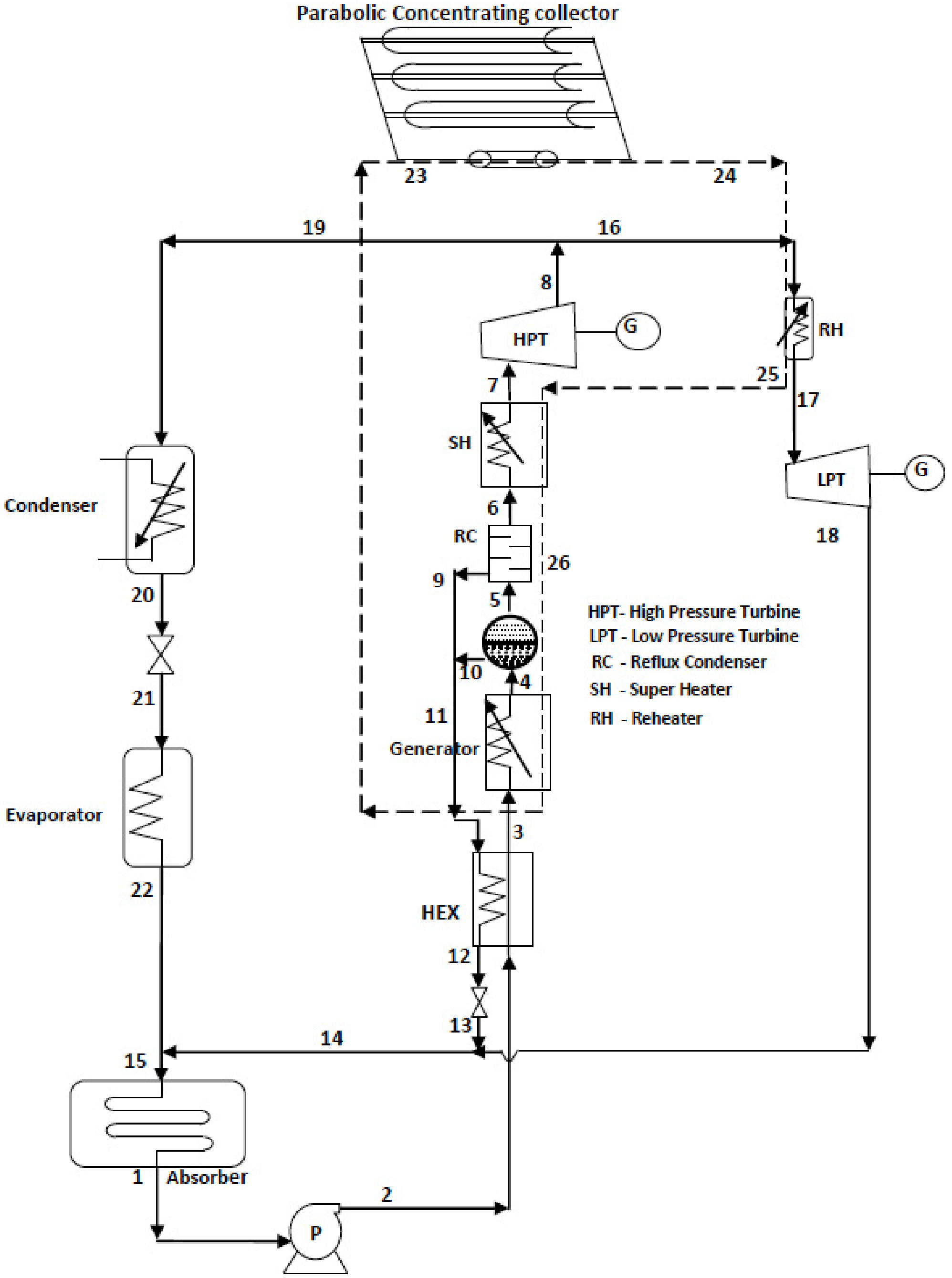

Fig. 1. Combined power and cooling cycle with double turbine.

2.1 Thermodynamic equations

The vapor fraction in separator is found by using the Eq. (1) where F is the vapor fraction, m is the mass and x is the concentration.

$$F_{Gen} = \frac{m_5}{m_3} = \frac{(x_{10} - x_3)}{(x_{10} - x_5)} \tag{1}$$

Similarly for reflux condenser the vapor fraction can find by using the Eq. (2) and suffix Gen and RC are generator and reflux condenser respectively.

$$F_{RC} = \frac{m_6}{m_5} = \frac{(x_9 - x_5)}{(x_9 - x_6)} \tag{2}$$

At the exit of the reflux condenser and separator the weak solution is returned to the absorber and the mass rate of those weak solution is found by using the Eq. (3) & (4),

$$m_9 = \frac{(x_6 - x_5)}{(x_6 - x_9)} m_5 \tag{3}$$

$$m_{10} = \frac{(x_5 - x_3)}{(x_5 - x_{10})} m_3 \tag{4}$$

Eq. (5) & (6) is used to the find the heat input to the super heater and reheater, where h is the enthalpy.

$$Q_{SH} = m_7 (h_7 - h_6) \tag{5}$$

$$Q_{RH} = m_{17} (h_{17} - h_{16}) \tag{6}$$

$$Q_{RH} = Q_{SH} + Q_{RH} \tag{7}$$

Similarly the heat supplied from the solar trough collector to the generator and work done by the pump is calculated by the Eq. (8) & (9) respectively.

$$Q_{Gen} = (m_5 h_5 + m_{10} h_{10}) - (m_4 h_4) \tag{8}$$

$$W_{Pump} = m_1 (h_2 - h_1) \tag{9}$$

The total output of the proposed cycle is the summation of the total power from HPT, LPT and cooling output and calculated by the following equation.

For cooling,

$$Q_E = m_{22} (h_{23} - h_{22}) \tag{10}$$

Work done by HPT and LPT,

$$W_{HPT} = \eta_M m_7 (h_7 - h_8) \tag{11}$$

$$W_{LPT} = \eta_M m_{18} (h_{17} - h_{18}) \tag{12}$$

$$W_{Net} = (W_{HPT} + W_{LPT}) - W_{Pump} \tag{13}$$

Cooling cogeneration efficiency,

$$\eta = \frac{W_{Net} + Q_E}{Q_{Gen} + Q_{RH}} \tag{14}$$

3. Results and discussions

Thermodynamic simulation has been carried out for the proposed vapour power and cooling cycle at the sink temperature of 30 °C. The separator temperature and turbine concentrations are identified as key parameters. Increase in separator temperature and turbine concentration increases the separator pressure and it changes the performance of the cycle. The Fig.2 (a) shows the HPT and LPT power output and Fig.2 (b) shows the variations of cooling with turbine concentration and separator temperature.

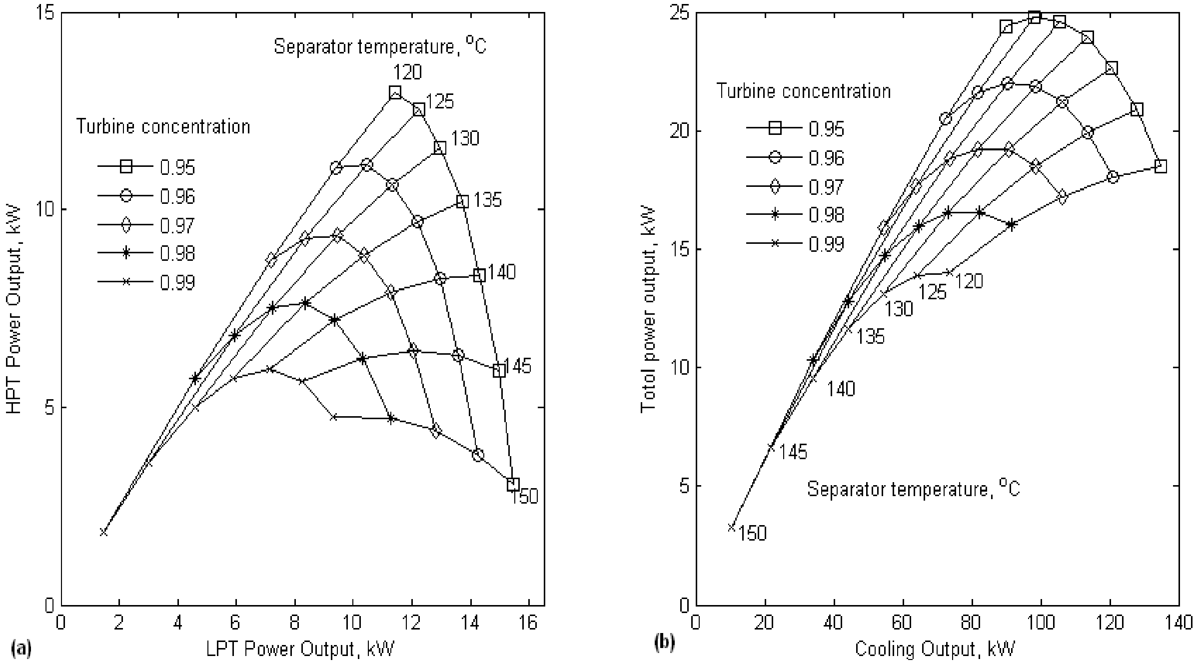

Fig. 2. (a) Analysis of HPT and LPT power output with 50:50 power to cooling mass ratio; (b) Analysis of total power and cooling output at different turbine concentration and separator temperature.

Both the HPT and LPT can be run simultaneously by adjusting the mass flow rate after the HPT, hence the HPT runs in all the conditions but the LPT runs in the need of only power and both power and cooling conditions. At the fixed turbine concentrations, the HPT power increase to peak and then decreases with respect to the increasing of the separator temperature. LPT power output continuously increases because the inlet pressure is constant and it does not depend on the separator temperature and it only depends on the super heater temperature and atmospheric temperature as shown in the Fig.2 (a). For the 50:50 powers to cooling mass ratio, the total power output increases and then decreases however the cooling output is constantly increases with increase in separator temperature due to more bubble point temperature difference as shown in the Fig.2 (b).

At condenser concentration of 0.99 and sink temperature of 30 °C, it shows well cooling output of 73.58 kW and it is high compared to Feng Xu and Goswami [9] combined mode cycle. The major advantage of splitting the power to cooling mass is that the cooling output is high and also condenser load is reduced by the turbines [10] and it is converted as useful work done. The COP is increasing by increasing the separator temperature of constant turbine concentration, because it is greater than the bubble point temperature. And it shows maximum COP of 0.17 at 120 °C with turbine concentration of 0.95 as shown in the Fig.3 (a). Decreases in turbine concentration increases in COP due to high vapor fraction and as same as the cooling COP, the efficiency of the power is high in low turbine concentration. By integrating the power and cooling cycle increases the overall efficiency of the cycle. The total power and cooling output is comparatively high with Goswami [14] cycle at atmospheric conditions of 30 °C. Maximum EUF is attained at separator temperature of 120 °C but is again high when the turbine concentration in low. Below 120 °C of separator temperature the high pressure is less than the condensing pressure and the HPT is unable work.

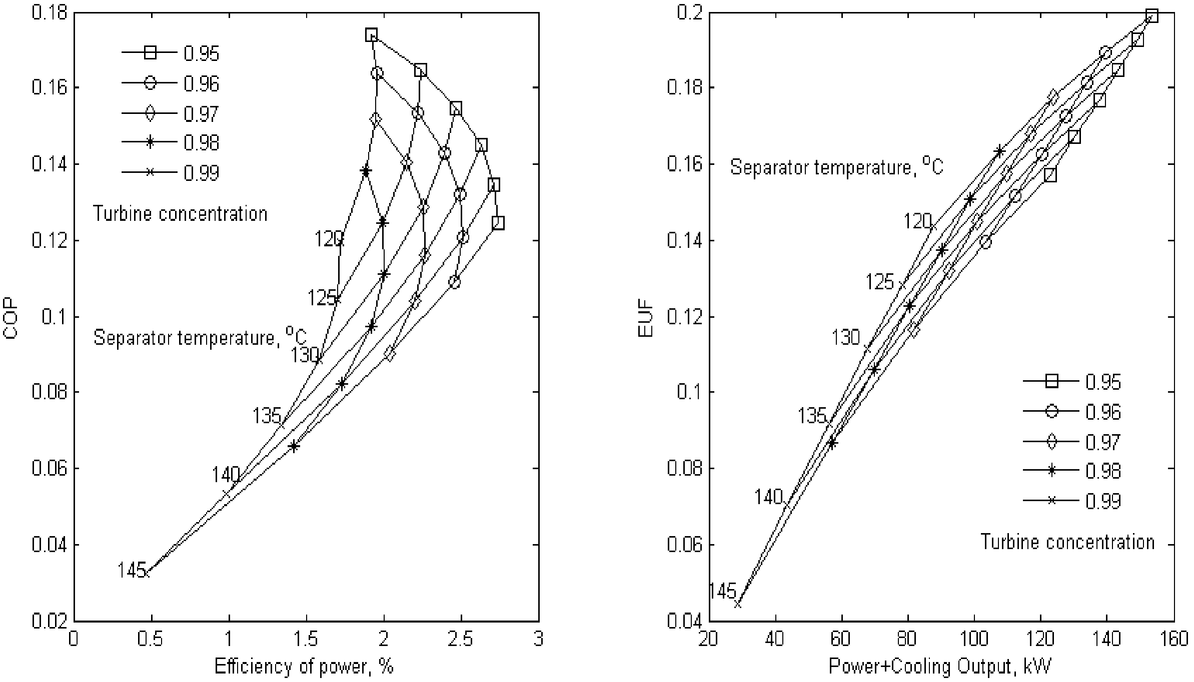

Fig. 3. (a) Parametric analysis of COP and efficiency of power at different separator temperature and turbine concentration; (b) Variation of total power and cooling output with EUF at atmospheric temperature of 30 °C .

Table.1 shows the property values of the corresponding state for the proposed design, at separator temperature of 140 °C and ambient/sink temperature of 30 °C with turbine inlet concentration of 0.99. At this conditions the cooling temperature of -17 °C is produced as same as in the refrigeration cycle and power output of 9.57 kW is achieved at 50:50 power to cooling mass ratio. The high and low pressure of 37.70 and 2.17 bar is produced with condensing pressure of 11.62 bar and it depends on the separator and atmosphere temperature

Table 1. Property values of the proposed design at respective state point.

State	**Pressure, (bar)**	**Temperature, (°C)**	**Concentration, (kg/kg)**	**Mass, (kg)**	**Enthalpy, (kJ/kg)**
1	2.17	30.00	0.42	1.00	-107.46
2	32.70	30.31	0.42	1.00	-103.41
3	32.70	40.48	0.42	1.00	-56.58
4	32.70	140.00	0.42	1.00	1666.17
5	32.70	140.00	0.91	0.07	1610.35
6	32.70	135.00	0.99	0.06	1518.75
7	32.70	150.00	0.99	0.06	1562.82
8	11.62	84.32	0.99	0.06	1475.99
9	32.70	135.00	0.41	0.01	389.42
10	32.70	140.00	0.39	0.93	416.48
11	32.70	139.95	0.39	0.94	416.22
12	32.70	129.95	0.39	0.94	366.53
13	2.17	130.08	0.39	0.94	366.53
14	2.17	25.49	0.40	0.97	399.44
15	2.17	17.97	0.42	1.00	425.78
16	11.62	84.32	0.99	0.03	1447.05
17	11.62	160.00	0.99	0.03	1637.77
18	2.17	58.59	0.99	0.03	1478.36
19	11.62	84.32	0.99	0.06	1475.99
20	11.62	30.00	0.99	0.03	134.30
21	2.17	-17.00	0.99	0.03	134.30
22	2.17	10.00	0.99	0.03	1315.49

4. Conclusion

The power used for the compression refrigeration is reduced and it provides the additional power by integrating the power and cooling system. Analysis for the HPT, LPT and cooling is done for power to cooling mass ratio of 50:50 with various separator temperature and turbine concentrations. HPT turbine will work in the need of only power, only cooling and both power and cooling mode and results more power output. LPT will operate at only power and both power and cooling mde. Total power and cooling output of 14.05 kW and 73.58 kW results at the atmosphere and separator temperature of 30 °C and 120 °C respectively with turbine concentration of 0.99.

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