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# Solar Thermal Based Power and Vapor Absorption Refrigeration System

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**Abstract**

The system combines the refrigeration cycle and power generation cycle using solar thermal as source. The current dual effect VAR system has two generators, to meet the choice of only power/only cooling/both power and cooling. The strong refrigerant solution (aqua ammonia) from the absorber is divided in to two streams and one flows to the first generator and heats by solar thermal heat, then turbine. This produces the maximum power to the maximum vapour aqua ammonia as inlet to the turbine and these changes with temperature and pressure and made the cooler effect at exit of turbine. The balance mass goes to the second generator for refrigeration and it is single effect refrigeration. Thus the system cooling and power have been integrated to get two benefits from a single system.



*Keywords:* Solar thermal powers; double generator; mass separation and aqua ammonia.

## 1. *Introduction*

In the present world the need of power is increased day by day which gives the usage of solar thermal power, simultaneously the refrigeration for both industrial and domestic. The combined power and cooling is proposed in the literature [1-11] by the various heat sources. In this proposed model, double generator is provided to increase the efficiency of power and cooling. It helps to operate both power and refrigeration or single cycle at a time (depending on the purpose). The proposed model is used to choose the cycle by using the simple valve (mass separator).The main objective of the current model is to increase the performance of combined power and cooling by the use of solar thermal by varying the pressure and mass separation with respect to solar thermal temperature. By using ammonia with waste heat as source, the power is produced and first proposed by Kalina[6-8]. In combined power and refrigeration, proposed by Goswami[1-4] the ammonia is vapour after turbine and produces cooling at

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high generator pressure. This model is designed and developed by using the thermodynamic properties of aqua-ammonia system developed by Ziegler and Trepp [14].The proposed model gives separate cooling and power at low pressure and double cooling (after turbine) with power at high pressure.

**Nomenclature**

| | |
|---|---|
| $W$ | Power |
| $Q_E$ | Evaporator cooling |
| $Q_T$ | Cooling made by turbine |
| $x$ | Concentration |

## 2. Combined Power and Cooling system

The solar thermal based combined power and cooling is shown in the Fig.1. The aqua ammonia mixture is used as source for power and cooling. In this cycle ammonia is the refrigerant and water as is the absorbent due to the high difference in their boiling point and high enthalpy. It has double generator with array of solar thermal collectors, one for refrigeration cycle and other for power cycle respectively. This cycle helps to meet the need of only power/ only cooling /both power and cooling.

### *2.1. Assumptions*

- Effectiveness of heat exchanger is considered as 85%.
- The refrigerant at evaporator exit is 5°C.
- The isentropic efficiency of the pump and turbine is 75%.
- The global solar radiation is considered as 900W/m$^2$ with a beam component of 680W/m$^2$.
- The concentration difference between the dephlegmator inlet and outlet is 8 %.
- The degree of superheat 10 °C.

The aqua-ammonia mixture from the absorber is separated by two equal mass for power and refrigeration with concentration of 40-55 %. The ammonia is converted as vapour in generator for its low boiling point with solar thermal as heat source. The rich ammonia vapour is moving to the dephlegmator (reflux condenser) with some amount of water vapour, the heat rejection takes place in the dephlegmator results in pure ammonia vapour. The rich ammonia vapour is fed to super heater before the inlet of turbine provided by solar thermal. The power is produced by the turbine and expansion process of ammonia takes place and still vapours in phase [1-2, 4]. The balance mass is fed to the second generator and the rich ammonia vapour is again divided in to two, with one half mass is fed to the inlet of the dephlegmator connected to the first generator. The remaining mass is goes to the dephlegmator, which gives pure ammonia by heat rejection process. The ammonia vapour is condensed in the condenser and the ammonia vapour is converted as saturated liquid. The expansion process takes place by throttle valve and the pressure is reduced and the temperature. By the heat absorption in the evaporator the ammonia vapour occurs at the exit.

### *2.2. Mass separation*

To meet the need of only power/only cooling/both power and cooling the double generator takes place, separated by mass separated valve 1. To get only power, the port (point 12) is closed and mass flows through point 3 and power generation takes place. If the port (point 3) is close, only cooling is produced. Both power and cooling is obtained when both point 3 and point 12 port is open. The valve 2 is used when there is a need of high power and limited cooling, (port of point 17 and point 23 are open).

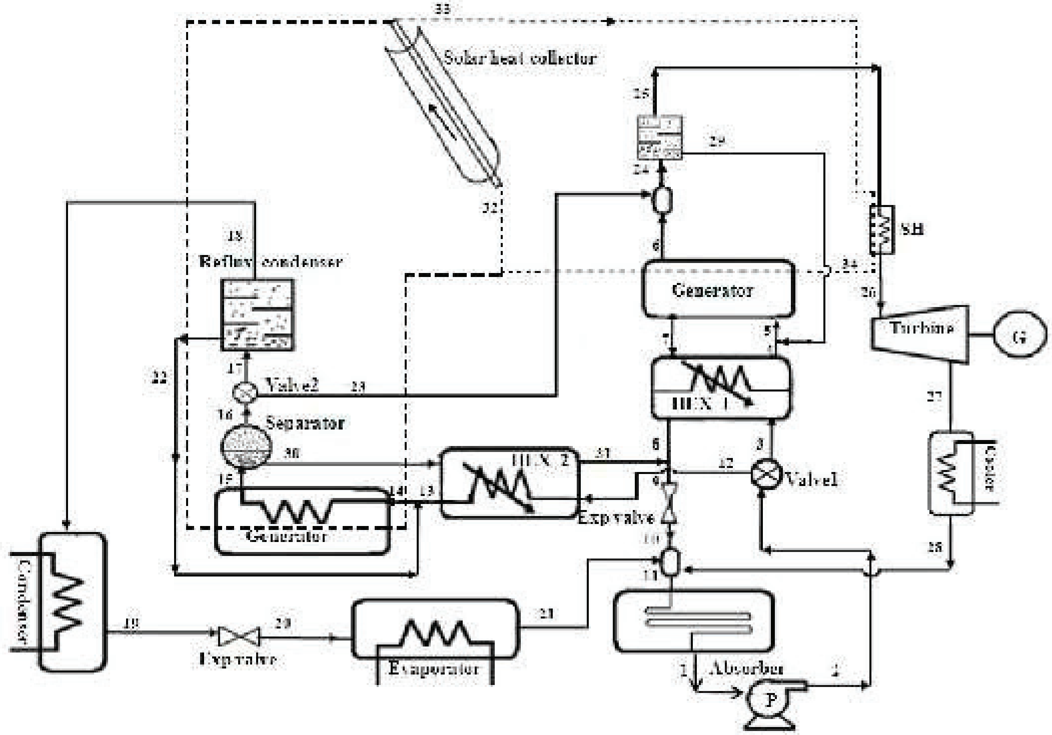


Fig .1. Diagram of proposed model

## 3. Results and Discussions

The power produced, depends on the concentration of aqua-ammonia and it gives performance at the range of 0.45.-0.6 %. It has two working pressure because of variation in the turbine exit temperature. The Fig.2 is drawn between the temperature, power output ($W$), and cooling load ($Q_E$) at various concentration. It clearly shows that the power is maximum at the certain pressure depends on the concentration and then decreases. It shows the output is depending on the solar thermal temperature for maximum power and cooling. Concentration limits to 0.43-0.58 and temperature range of 353.16-413.16 K the system will operate and by maintaining the turbine inlet concentration of 0.99.The maximum power of 58.751 kW are get at 383.16 K at x=0.58 strong solution concentration. The power (W) and $Q_T$ are increasing at certain temperature and then power gets decreasing at constant strong solution concentration. The $Q_T$ various with turbine inlet concentration and temperature and start decreasing from the room temperature when sink temperature and concentration. The need of cooling is high in both evaporator and turbine exit, the working pressure is high.

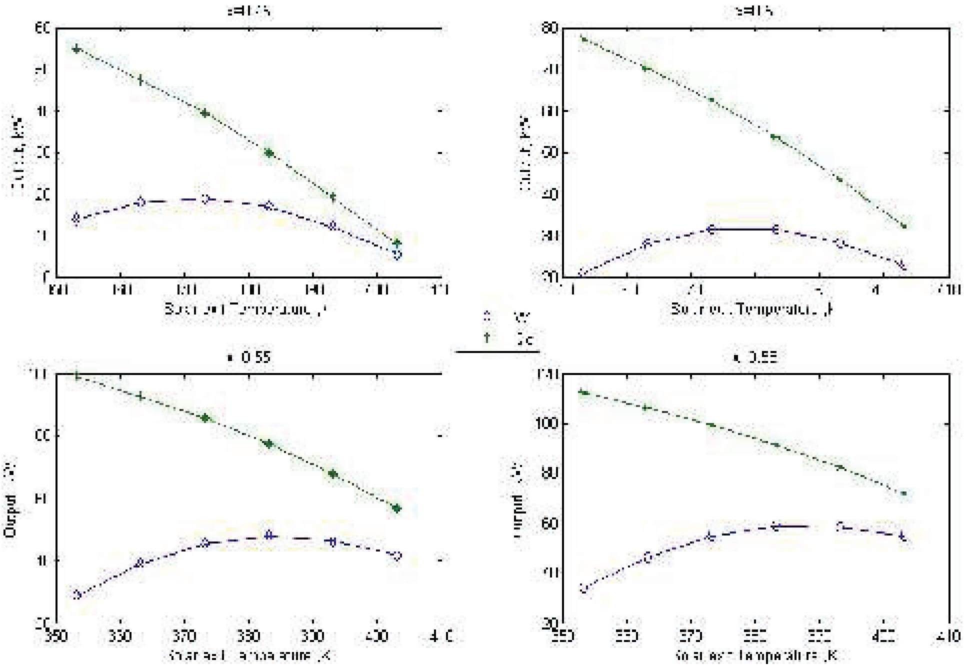

Fig. 2. Power and cooling performance variation with source temperature and turbine concentration of 0.99

Table.1. Output at various mass ratio at constant temperature and concentration

| Mass ratio (%) W : $Q_E$ | Concentration (kg/kg) | Solar exit Temperature (K) | Power (kW) | Cooling (kW) | Cooling at Turbine exit (kW) |
|---|---|---|---|---|---|
| 90:10 | 0.45 | 383.16 | 21.28 | 5.97 | 1.04 |
| 80:20 | 0.45 | 383.16 | 20.17 | 11.94 | 0.99 |
| 70:30 | 0.45 | 383.16 | 19.06 | 17.91 | 0.93 |
| 60:40 | 0.45 | 383.16 | 17.95 | 23.88 | 0.88 |
| 50:50 | 0.45 | 383.16 | 16.84 | 29.85 | 0.82 |
| 40:60 | 0.45 | 383.16 | 15.74 | 35.82 | 0.77 |
| 30:70 | 0.45 | 383.16 | 14.63 | 41.78 | 0.72 |
| 20:80 | 0.45 | 383.16 | 13.52 | 47.75 | 0.66 |
| 10:90 | 0.45 | 383.16 | 12.41 | 53.72 | 0.61 |

The solar thermal cylindrically parabolic focussing collectors helps to get temperature up to 573.16 K and more, that the system can be easily run at high temperature to get maximum power only. Table.1. shows various mass ratio for both power and cooling and it helps to choose the operating conditions. For getting both cooling and power with high efficiency, we were choosing the operating temperature of 383.16 K with 0.58 concentration and analyses are done using MATLAB, results shown in the Table.2. By considering the absorber exit mass of 1 kg/s, it gives the maximum power of 58.75 kW and 91.57 kW of cooling with turbine exit temperature of 267.58

Table.2. *Material* flow details of 0.5 mass ratios for both power and cooling at a collector temperature of 383.16 K, 0.45 strong solution concentrations, 1 kg/s of strong solution flow rate.

| State | Pressure (Bar) | Mass flow rate (kg/s) | Concentration (kg/kg) | Temperature (K) | Specific Enthalpy (kJ/kg) |
|---|---|---|---|---|---|
| 1 | 2.70 | 1.00 | 0.45 | 303.16 | -109.07 |
| 4 | 12.50 | 0.50 | 0.45 | 351.84 | 97.92 |
| 5 | 12.50 | 0.51 | 0.45 | 347.71 | 97.14 |
| 6 | 12.50 | 0.06 | 0.91 | 368.16 | 1558.20 |
| 11 | 2.70 | 1.00 | 0.45 | 318.17 | -39.73 |
| 17 | 12.50 | 0.03 | 0.91 | 368.16 | 1558.20 |
| 18 | 12.50 | 0.03 | 0.99 | 361.66 | 1457.0 |
| 19 | 12.50 | 0.03 | 0.99 | 298.16 | 109.98 |
| 20 | 2.70 | 0.03 | 0.99 | 261.31 | 109.98 |
| 21 | 2.70 | 0.03 | 0.99 | 278.16 | 1301.60 |
| 24 | 12.50 | 0.09 | 0.91 | 368.16 | 1558.20 |
| 25 | 12.50 | 0.08 | 0.99 | 361.66 | 1486.10 |
| 26 | 12.50 | 0.08 | 0.99 | 378.16 | 1499.70 |
| 27 | 12.50 | 0.08 | 0.99 | 270.31 | 1291.30 |

If the operating pressure is high, the turbine exit temperature is low (cooling) and cooling by evaporator is increased at the low pressure. But at the certain pressure we can get both double cooling and the power (optimum pressure). The proposed combined solar thermal power and cooling can be worked at various ranges of temperature depends on the need of cooling, power or both. The table clearly shows the optimum working concentration and temperature. The turbine exit cooling is obtained at 383.16 K, 12.5 bar, because it depends on the pressure. The turbine exit temperature reduces more up to 259.36 K ( $x$ =0.58) whereas the evaporator temperature is 261.31 at 0.45 concentration. At concentration 0.58 and temperature of 353.16 K, the system unable to work because of the source pressure is less compared to the sink pressure given in the Table.3.

Table.3. Optimum operating for both power and cooling at various concentration and temperature

| Concentration/ Temperature | Cooling & Temperature | 353.16 | 363.16 | 373.16 | 383.16 | 393.16 | 403.16 | 413.16 |
|---|---|---|---|---|---|---|---|---|
| 0.45 | $Q_E$ | 55.02 | 47.36 | 39.55 | 29.85 | 19.10 | 7.91 | - |
| | $T_{20}$ | 261.31 | 261.31 | 261.31 | 261.31 | 261.31 | 261.31 | - |
| | $Q_T$ | - | - | - | 0.82 | 0.97 | 0.50 | - |
| | $T_{27}$ | 300.80 | 286.31 | 276.89 | 270.31 | 266.71 | 265.21 | - |
| 0.50 | $Q_E$ | 77.14 | 70.10 | 62.68 | 53.54 | 43.29 | 32.37 | 20.41 |
| | $T_{20}$ | 267.76 | 267.76 | 267.76 | 267.76 | 267.76 | 267.76 | 267.76 |
| | $Q_T$ | - | - | - | 2.00 | 2.81 | 2.56 | 1.75 |
| | $T_{27}$ | 300.69 | 286.29 | 276.15 | 269.02 | 264.93 | 263.08 | 262.61 |
| 0.55 | $Q_E$ | 99.19 | 92.63 | 85.83 | 77.31 | 67.63 | 57.09 | 45.13 |
| | $T_{20}$ | 273.78 | 273.78 | 273.78 | 273.78 | 273.78 | 273.78 | 273.78 |
| | $Q_T$ | - | - | - | 3.60 | 5.36 | 5.52 | 4.74 |
| | $T_{27}$ | 300.63 | 286.07 | 275.64 | 268.04 | 263.46 | 261.24 | 260.50 |
| 0.58 | $Q_E$ | - | 106.15 | 99.57 | 91.57 | 82.27 | 72.01 | 60.13 |
| | $T_{20}$ | - | 277.28 | 277.28 | 277.28 | 277.28 | 277.28 | 277.28 |
| | $Q_T$ | - | - | - | 4.77 | 7.27 | 7.81 | 7.10 |
| | $T_{27}$ | - | 285.98 | 275.41 | 267.58 | 262.73 | 260.28 | 259.36 |

The only power works in the process of Goswami cycle [1, 2] and we get more power less cooling. The only cooling cycle works under refrigeration cycle and we get more cooling only. Here the integrated of both cycle gives more power and cooling and user friendly in needs. We can choose only power or only cooling or both power and cooling by simply changing the mass flow valve at point 3 & 12. The combined power and refrigeration cycle works at various ranges of temperature and concentration as shown in the Table.3 and it helps to choose the operating condition for our needs.

## 4. Conclusions

The proposed model develops the working condition for combined power and cooling at domestic and industry level. The difficulty of only power or only cooling is rectified here and proposed combined cycle is used to choose any degree of power or cooling or both power and cooling simultaneously. By integrating solar thermal based power and cooling cycle the performance of cycle is increased by getting the maximum power and cooling output. For both power and cooling we can choose the temperature of 383.16 K with concentration of 0.58. The mass 1 kg/s at exit of absorber, it gives the maximum power of 58.75 kW and 91.57 kW of cooling with turbine exit temperature of 267.58

## References

[1] Tamm G., D.Y.Goswami, S.Lu, and A.A.Hasan, 2003, Novel combined power and cooling Thermodynamics Cycle for Low Temperature Heat Sources, Part 1: Theoritical investigation, ASME J.Sol.Energy Eng, 125(2), 218-222

[2] Tamm G., D.Y.Goswami, 2003, Novel combined Power and Cooling Thermodynamic Cycle for low Temperature Heat Source, Part2: Experimental Investigation, ASME J.Sol.Energy Eng, 125(2), 223-229.

[3] Hasan A.A and D.Y.Goswami, 2003, Exergy Analysis of a combined Power and Refrigeration Thermodynamic Cycle Driven by a solar Heat Source, ASME J.Sol.Energy Eng.,125(2),55-60.

[4] Tamm G., D.Y.Goswami, S.Lu and A.A.Hasan, 2004, Theoretical and Experimental Investigation of an Ammonia-Water Power and Refrigeration Thermodynamic Cycle, Sol. Energy Eng, 76, 217-228.

[5] Zheng D., B.Chen, Y.Qi, and H.Jin, 2006, Thermodynamic Analysis of a Novel Absorption Power/Cooling Combined-Cycle, Applied Energy 83(4), 311-323.

[6] Kalina I.A., 1984, Combined Cycle System with Novel Bottoming Cycle, ASME J.Engineering for Gas Turbine and Power, 106, 737-742.

[7] Marston C.H., Parametric Analysis of the KalinaCycle, ASME J.Engineering for Gas Turbine and Power, 112,107-116.

[8] Rogdakis E.D., 1996,Thermodynamic Analysis, Parametric Study and Optimum Operation of the Kalina Cycle, International journal of energy research, 20(4), 359-370.

[9] Lebowitz H. and M.Mirolli , 1977, First Kalina Combined Cycle Plant Tested Successfully, Power Engineering, 101(5).

[10] Colonna P., and S.Gabrielli, Industrial trigeneration using ammonia-water absorption refrigeration Systems (AAR), applied Thermal Engineering, 2003, 23(4), 381-396.

[11] Wang J., Y.Dai, and L.Gao, Parametric analysis and optimization for a combined power and Refrigeration cycle, Applied energy, 2008, 85(11), 1071-1085.

[12] Aivares S.G., Ch.Trepp, Simulation of solar driven aqua-ammonia absorption refrigeration system Part1: mathematical description and system modelling, Int.J.Refrig, 1987, 10(2), 40-48.

[13] Manrique J.A.Thermal performance of an ammonia-water refrigeration system,Int,Comm.Heat Mass Transfer, 1991, 18(6), 779-789.

[14] Ziegler B., C.Trepp, 1984,Equation of State for Ammonia-Water Mixtures, International Journal of refrigeration ,7(2), 101-6.