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HIGH PRESSURE COMBINED SOLAR DESALINATION SYSTEM AND POWER CYCLE

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ABSTRACT

There is a shortage of the drinking water as well as power in worldwide due to increased in population and its necessity. Solar thermal power plant and Multi Stage Flashing (MSF) system helps to overcome the need of both power and desalinated water. This paper addresses the demand of the power and drinking water. The integration of power and desalination system is the main objective which will give two products as output by using solar energy. The modified Rankine cycle produces desalinated water by condensing the saturated steam at the exit of the turbine or by adding turbine at the exit of the flashing system produces the power and vice versa. The theoretical analysis is made for proposed system and it is suggested for placing the turbine at the exit of flashing system in the high temperature MSF. The proposed model is analyzed in solar thermal single stage flashing system producing 1000 LPD desalinated water. It results 9.33 kW of power at the flashing temperature of 160°C and the turbine inlet pressure and temperature are 5.92 bar and 170°, respectively. The high pressure on the flashing chamber avoids vacuum is the advantage in the proposed system. This proposed is used for low heat recovery and for producing both power and desalination system.

Keywords: solar, power, rankine cycle, desalinated water.

1. INTRODUCTION

The deficiency of drinking water in many places of the world is due to increasing in population and variations in the climatic conditions. The easiest way to make the water is from the sea which is having more salinity but it solves the problem of water-shortage. The separation of salts desalinated water from seawater requires large amounts of energy. Therefore, there is a need to employ environmentally-friendly energy sources in order to desalinate seawater (Fiorenza *et al*, 2003). Solar desalination is surely promising as a successful renewable energy source for producing fresh water (Ebensperge and Isley, 2005). The general perception of “solar desalination” today comprises only small scale technologies for decentralized water supply in remote places, which may be quite important for the development of rural areas, but do not addresses the increasing water deficits of the quickly growing urban centers of demand. On the other hand the usage of the power also increased by its utilization of the increased population. In most of the power plant more energy is wasted in the form of heat and the integration of any cycle will increase its efficiency form the actual cycle. It is good enough to meet the double or multi output in a single cycle by the integration of the system.

The two developing demand of the power and the water is solved by the integration of power and desalination system which will run by the solar system is the main objective. The desalination process cost can be reduced by the integrating the desalination plant with other renewable energy sources (Mohamed *et al*, 2009). Many researchers made research on the desalination process to increases its productivity in low cost and solar still is one among them. The operational parameters of single and double still solar desalination for the Indian climatic conditions are given by Garg and Mann (1976) and the only problem is the tracking of the sun. Shatat *et al* (2013) study shows more opportunities of desalination system on renewable energy. In late 1950’s Multi Stage Flashing (MSF) system is introduced which is most helpful for solving the desalination demand. Dessouky *et al*. (2004) analysis the multistage flashing desalination and made the design correlation for MSF on discharge coefficient, heat transfer coefficient etc in the terms of pressure, temperature and brine concentration. Mohammed and Weshahi (2014) proposed the integration of organic Rankine cycle to the MSF for the heat recovery system. A comparison of R134a and R245fa as working fluid in ORC is more suitable for the integration.

The integration of power cycle and MSF system improves the efficiency of the overall system. So many thermodynamic analyses on the MSF results high efficiency, more heat recovery, more output etc but the only drawback are continuous maintaining of the vacuum (Kalogirou, 2005; Darwish, 1991 and Hornburg *et al*. 1995). Ahmed *et al*. (2014) proposed the new MSF working under the high pressure and thermal energy consumption of 90 MJ/m^3 is reduced is the outcome of the analysis. The high pressure MSF will able to work on solar thermal energy and electrical energy. The MSF will work on both the low pressure and high pressure. The solar thermal parabolic trough collector will be used to raise the temperature more than 100°C. The integration of power and desalination system using the solar thermal energy addresses the problem of vacuum and also produces power. This paper suggested the new design of power and desalination by the integration of the both the cycles in non cyclic way which will produce power and desalination in single source of input. The numerical formulation is done for the proposed system and it is simulated by using the MATLAB tool.

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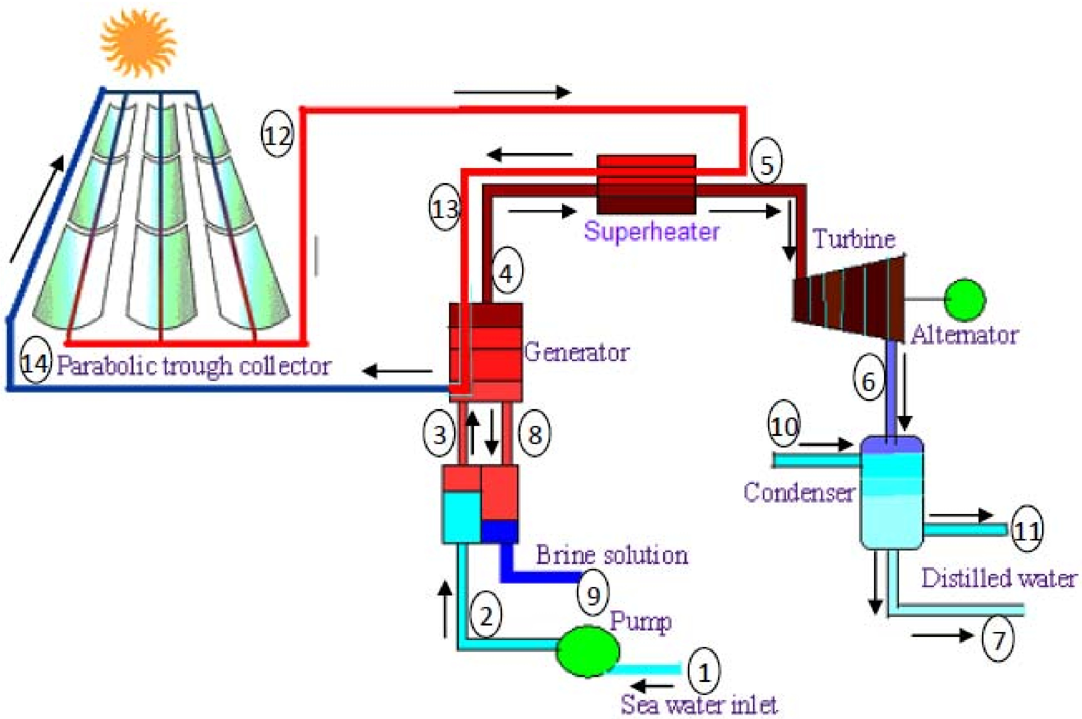

Figure-1. Proposed design of Power and Desalination layout.

2. WORKING

Figure-1 shows the proposed design of Power and Desalination output in the single system. It contains the high pressure pump, generator, turbines heat exchanger and condenser etc. The seawater is pumped (1-2) to high pressure of generator pressure through the heat recovery system (2-3). The preheated seawater is moved to the flashing chamber/generator and it is flashed in the generator at high pressure of 5.93 and the property values of the proposed system are given in the Table-1. In the flashing chamber/generator the brine water (8) and desalinated water vapor (4) gets separated but not in under vacuum. The returned brine solution from the generator is shared its heat to the inlet seawater (2) and it is disposed. The saturated desalinated water vapor is superheated in the super heater (4-5) before it fed to the turbine. After superheating the saturated vapor the inlet pressure of 5.93 bar and high temperature of 170 °C is expanded in the turbine from 5.93 bar to 0.04 bar. Hence the power is produced by the turbine with outlet temperature of 30.35 °C with saturated water vapor (desalinated water). It is easy to condense the saturated water vapor with low temperature (6) and dew point pressure. The saturated water vapor from the turbine exit is condensed in the condenser at the constant pressure of 0.04 bar and it results desalinated water as output (7).

3. METHODOLOGY

The high pressure in the generator/ flashing chamber is found by the input of brine solution concentration (7) and generator temperature (4). For the generator and super heater the heat is supplied by the solar trough collector (12-14). The sink pressure or the dew point pressure is found by input of cooling water temperature having temperature difference of 5 °C. The mechanical and isentropic efficiency of turbine and pump are 95% and 75% respectively are some of the assumptions used for the simulation of the proposed design. The beam radiation of 650 W/m^2 is assumed and it high for the Chennai city region.

3.1 Mass, energy balancing formulation

The mass and energy balancing is used for the simulation of the proposed system by fixing the known values. Seawater concentration is the known value and by fixing the brine solution concentration it is possible predict the inlet mass flow rate of seawater for the fixed desalinated water output of 1000 LPD.

$$m_3 = \frac{x_8}{x_8 - x_3} m_4 \tag{1}$$

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Table-1. Property values of the proposed system at the respective points.

Reference point	Temperature, °C	Pressure, bar	Mass, kg/s	Salt concentration g/kg	Enthalpy, kJ/kg
1	30.00	1.01	0.09	70.00	113.53
2	30.12	5.93	0.09	70.00	113.98
3	40.12	5.93	0.09	70.00	152.50
4	160.00	5.93	0.01	0.00	2760.07
5	170.00	5.93	0.01	0.00	2783.31
6	30.35	0.04	0.01	0.00	1937.15
7	30.10	0.04	0.01	0.00	126.31
8	160.00	5.93	0.08	80.00	596.51
9	147.41	5.93	0.08	80.00	552.48
10	30.00	1.01	20.44	70.00	125.89
11	30.25	1.01	20.44	70.00	126.92
12	180.00	1.01	0.53	0.00	762.80
13	179.88	1.01	0.53	0.00	762.26
14	150.00	1.01	0.53	0.00	631.81

The mass flow rate of brine solution is found by the known value of brine and seawater concentration.

$$m_8 = \frac{x_3}{x_8} m_3 \tag{2}$$

Thermic fluid mass flow rate and cooling water mass flow rate can determine by the following equations

$$m_{12} = \frac{m_4 h_4 + m_8 h_8 - m_3 h_3}{CP_{Tf}(T_{12} - T_{14})} \tag{3}$$

$$m_{10} = \frac{m_7 (h_6 - h_7)}{CP_{Tf}(T_{11} - T_{10})} \tag{4}$$

The following equations are used to find the enthalpy and temperature at the exit of the pump and solution heat exchanger. The iteration is made to predict the temperature at the exit of both the pump and heat exchanger.

$$h_2 = h_1 + v_1 (P_2 - P_1)\eta_p \tag{5}$$

$$h_9 = \frac{m_8 h_8 + m_2 h_2 - m_3 h_3}{m_9} \tag{6}$$

Heat input given to the system, power output delivered by the system and the efficiency of the power is determined by the following equations.

Power output,

$$W = m_4 (h_5 - h_6)\eta_T \tag{7}$$

Pump power input,

$$W_{Pump} = m_1 (h_2 - h_1)\eta_{Pump} \tag{8}$$

Generator heat input,

$$Q_{Gen} = m_4 h_4 + m_8 h_8 - m_3 h_3 \tag{9}$$

Condenser exit heat load,

$$Q_{Con} = m_7 (h_6 - h_7) \tag{10}$$

Super heater load

$$Q_{Sup} = m_4 (h_5 - h_4) \tag{11}$$

Efficiency of the power

$$\eta_P = \frac{W}{Q_{Gen} + Q_{Sup}} \times 100 \tag{12}$$

Cycle Energy Gain Factor

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$$EGF_{cy} = \frac{W + (m_4 \times 2505)}{Q_{Gen} + W_{Pump} + Q_{Con} + Q_{Sup}} \tag{13}$$

Plant Energy Gain Factor

$$EGF_{pl} = \frac{W + (m_1 \times 2505)}{A_{Total} I_b + Q_{Con} + Q_{Sup}} \tag{14}$$

The thermodynamic property equation of seawater used for the simulation is given by Sharqawy *et al.* (2010).

4. RESULTS AND DISCUSSIONS

The vacuum pressure present at the generator in actual flashing stage desalination system is eradicated. The efficiency of the power produced in the proposed system is simulated in the temperature range of 150-180°C and the brine solution concentration range of 80-120 g/kg. The turbine starts producing the power at the separator temperature of 80°C hence the analyses are made in the following temperature range as shown in the Figure-2. Increase in the generator temperature at the constant brine solution concentration increases the generator pressure. It results high expansion ratio and produced more power. High power efficiency of 27.3 % is achieved at the turbine inlet temperature of 180°C and the brine solution concentration of 120 g/kg. The power output also increases with increase in brine solution concentration and generator temperature. The graph shows (Figure-2) the power output rise is in decrement order with rise in generator temperature.

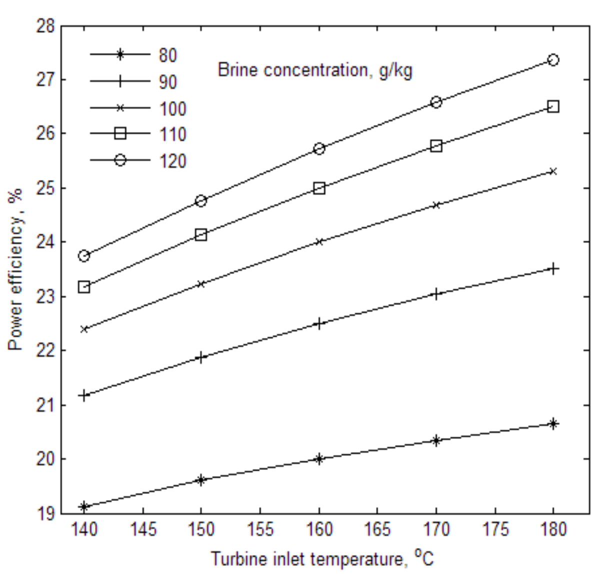

Figure-2. Efficiency of Power at different turbine inlet temperature and brine solution concentration.

Integration of the two cycles of flashing desalination and Rankine cycle performances is expressed in terms of Energy Gain Factor (EGF). Here the power and desalinated water are the two outputs with common source input of solar thermal. The cycle EGF is analyzed at different turbine inlet temperature and brine concentration of 140-180°C and 80-120 g/kg respectively. The cycle EGF is analyzed at different turbine inlet temperature and brine concentration. Cycle EGF changes were different at different turbine inlet temperature, the decrement factor for brine concentration 80 and 90g/kg is high compared to higher brine concentration. Due to the fixed desalinated water output of 1000 LPD of desalinated water the trends shows in increment order for above 90g/kg of brine concentration and it is decreases with corresponding brine concentration of 80 g/kg at 150°C of turbine inlet temperature as shown in the Figure-3. For producing the brine concentration of 120 g/kg as exit in the generator it requires more heat input, hence the cycle EGF is decreases. At 170°C of turbine inlet temperature and 5.93 bar of pressure produces 0.68 of EGF at 110g/kg of brine concentration.

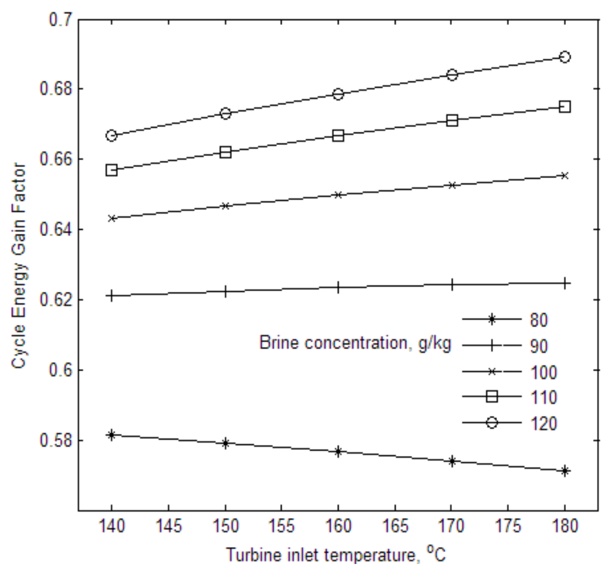

Figure-3. Analysis of cycle EGF at different turbine inlet temperature.

Figure-4 shows the performance variations of the plant EGF with respect to turbine inlet temperature and brine concentration for the fixed beam radiation of 650 W/m^2 and sweater inlet concentration of 60g/kg. The consumption of heat load in the generator is high for rising the temperature in the generator that requires more solar trough collector area. It results increase in total collector area requirement which tends to decrease in EGF. The parabolic trough collector shows maximum efficiency of 65% with fixed beam radiation corresponds to decrease in plant EGF. The rate of increment for the plant EGF with respect to brine concentration is gradually decreased due to more heat consumption in the generator. Ultimate plant EGF for the proposed design lies between the range of 0.85-1.45 at the brine concentration of 80-120 g/kg and turbine inlet temperature of 140-180 °C for the fixed

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seawater concentration of 60g/kg and beam radiation of 650 W/m^2. To obtain the high plant EGF the heat recovery system need used with less approach point.

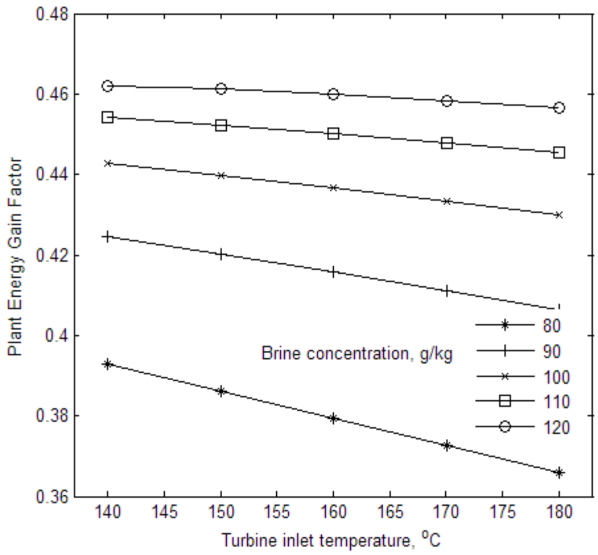

Figure-4. Analysis of plant EGF at different turbine inlet temperature.

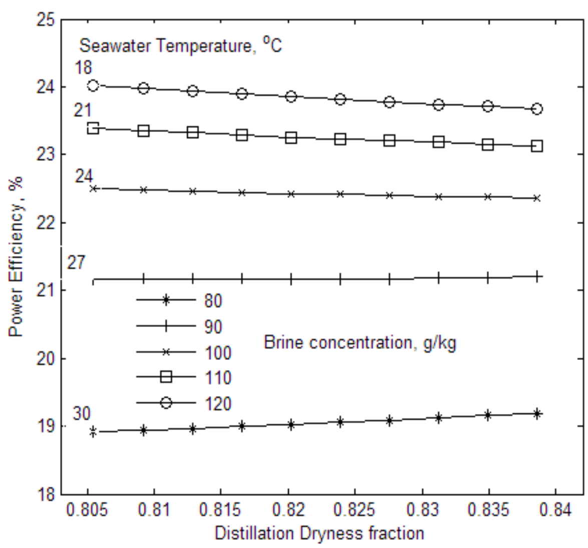

Figure-5. Performance analysis of proposed system at different atmosphere temperature.

The turbine inlet pressure and temperature is one of the most important parameter for the power efficiency. If the pressure is high the power output and efficiency is high due to the more expansion ratio and for expansion the turbine exit pressure also plays the major role. The analysis of the EGF cycle at the different turbine inlet temperature at various brine solution concentration is shown in the Figure-5. Decrease in the atmosphere temperature/cooling water temperature reduces the turbine exit pressure results high expansion, hence more power output is produced. Due to the fixed turbine inlet flow rate equal to 1000 LPD of desalinated water, the power efficiency decreases when the cooling water temperature increases.

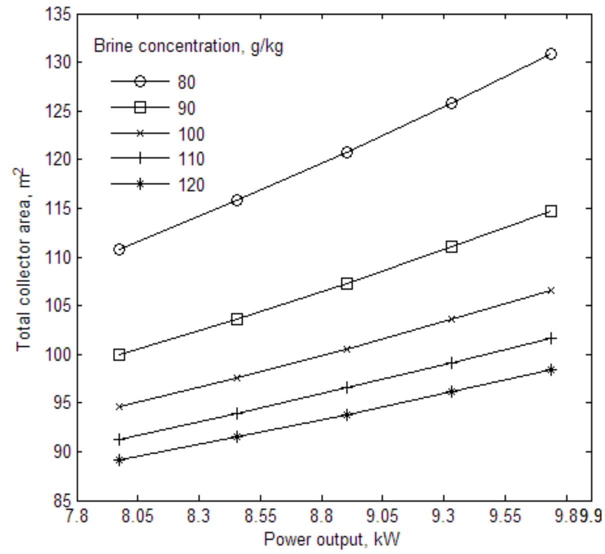

Figure-6. Requirement of total collector area for 1000 LPD of desalinated water.

Figure-6 shows the total solar trough collector area required for complete plant with respect to different brine solution concentration of 80-120 g/kg and temperature range of 140- 180°C, respectively. The usage of the collector area is increases when the turbine inlet temperature raises hence the both total collector area and power output is directly proportional to the turbine inlet temperature with constant desalinated flow rate of 0.0116 kg/s (1000 LPD).

5. CONCLUSIONS

The proposed high pressure combined power and solar desalination system produces the power as well as desalinated water by the split up of Rankine cycle or adding the turbine at the exit of the flashing chamber/generator. Analyses are done for system at different brine solution concentrations, turbine inlet temperature and atmosphere temperature. The proposed desalination system produces 9.73 kW for 1000 LPD of desalinated water output. The split up of Rankine cycle results power efficiency, cycle EGF and plant EGF of 27.3%, 0.69 and 0.46, respectively with input of 180 °C of turbine inlet temperature. The vacuum stage in the flashing chamber/generator is completely removed in addition to that the power is produce. Increasing the desalinated water output increases the power in the proposed design and it can implemented in all thermal power plant as well as in the desalination system.

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Nomenclature

CP	=	Specific heat, kJ/kg K
LPD	=	Liters per day
h	=	Specific enthalpy, kJ/kg
m	=	Mass flow rate, kg/s
MSF	=	Multi Stage Flashing
Q	=	Heat load, kW
S	=	Specific entropy, kJ/kg K
x	=	Salt concentration, g/kg
η	=	Efficiency, %

Subscripts

Con	=	Condenser
Coll	=	Collector
Gen	=	Generator
HEX	=	Solution heat exchanger
P	=	Power
T	=	Turbine

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