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Solar Thermal Power and Desalination System

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Abstract

There is a shortage of the drinking water in worldwide due to the increased population and the changes of climatic conditions; moreover there is shortage of the power too. The power is not only used for the desalination system but also for daily life of humans. This paper addresses the demand of the power and desalination system in a common cycle. The integration of power and desalination is the main objective which will give two products using solar as energy source. The Rankine cycle is modified and the problem of vacuum in the thermal desalination system is minimized. The theoretical analysis is made for proposed system and it is suggested for 1000LPD solar flat plate desalination system. It produces 3.51 kW of power for the 1000LPD solar flat plate desalination system.

Keywords: *desalination, integration, power, solar thermal etc*

1 Introduction

There is a deficiency of drinking water in many places of the world due to the increasing population and variations in the climatic conditions. The origin and continuation of living being is based on water. Water is one of the most abundant resources on earth, covering three-fourths of the planet’s surface. However, about 97% of the earth’s water is salt water in the oceans, and a tiny 3% (about 36 million km3) is fresh water contained in the poles (in the form of ice), ground water, lakes and rivers, which supply most of human and animal needs. The easiest way to make the water is from the sea which is having more salinity.

It would be feasible to address the water-shortage problem with seawater desalination; however, the separation of salts from seawater requires large amounts of energy which, when produced from fossil fuels, can cause harm to the environment. Therefore, there is a need to employ environmentally-friendly energy sources in order to desalinate seawater [1]. Desalination seems to be the most suitable solution to resolve these issues. Solar desalination is slowly but surely promising as a successful renewable energy source of producing fresh water [2]. 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 to its utilization of the increased population. In most of the power plant more heat is wasted in the form of cooling water. The integration of any cycle will increase its efficiency form the actual cycle so it is good enough to meet the double or multi need 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 [3]. Many researchers made research on the desalination process to increases the 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 [4] and the only problem is the tracking of the sun.

Mahmoud Shatat et al [5] 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. El-Dessouky et al [6] analysis the multistage flashing desalination and made the design correlation of MSF for the discharge coefficient, heat transfer coefficient etc in the terms of pressure, temperature and brine concentration. Mohammed et al [7] proposed the integration of organic Rankine cycle to the MSF for the heat recovery system and made comparisons of the R134a and R245fa as working fluid which is more suitable for the integration. This integration of power cycle and MSF system improves the efficiency of the overall system.
So many thermodynamic analyses on the MSF results and the only drawback is continuous maintaining of the vacuum [6, 8, 9 &10]. Attia & Abdel-Rehim [11] 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. And also the high pressure MSF will able to work of solar thermal energy and electrical energy. The MSF will work on both low and high pressure on

using solar thermal energy. This paper suggested the new design of power and desalination integration in non cyclic way which will produce power as extra output.

2 Solar thermal power and desalination systems.

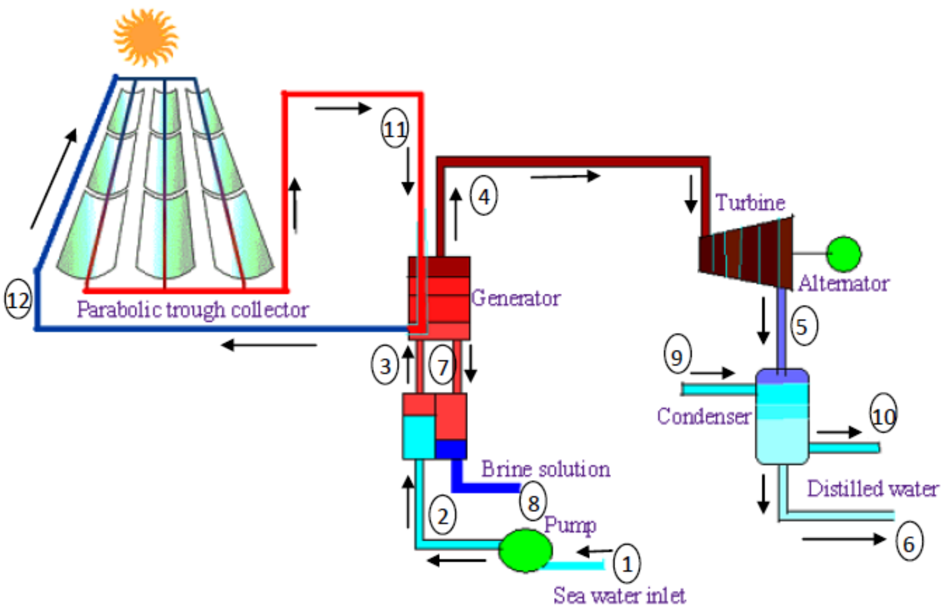

Figure.1 Proposed design of Non Cyclic Power and Desalination layout.

Fig.1 shows the proposed design of Non Cyclic Power and Desalination (NCPD) which 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 high pressure is found by the input of brine solution concentration (7) and generator temperature (4) and the condensing pressure is produced by the input of cooling water temperature. The seawater is flashed in the generator where desalination occurs and the pure high pressure water vapor (4) is expanded in the turbine from high pressure (4) to condensing pressure (5). The expansion of high pressure to condensing pressure results power output and it depends on the expansion ratio and turbine inlet temperature. High expansion ratio produces saturated vapor at the exit of the turbine (6) which reduces the condensing load. This saturated vapor is condensed in the condenser gives output as desalinated water. Some of the assumptions for the proposed NCPD are mechanical and isentropic efficiency of turbine and pump efficiency are 95% and 75% respectively. The beam radiation of 650 W/m^2 is assumed and it high for the Chennai city region

2.1 Mass, Energy and Exergy balancing Formulation

The seawater concentration is the known value and by fixing the brine solution concentration it is possible predict inlet mass flow rate of seawater for the desalinated water output of 1000 LPD.

$$m_3 = \frac{x_7}{x_7 - x_3} m_4 \tag{1}$$

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

$$m_7 = \frac{x_3}{x_7} m_3 \tag{2}$$

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

$$m_{11} = \frac{m_4 h_4 + m_7 h_7 - m_3 h_3}{CP_{Tf}(T_{11} - T_{12})} \tag{3}$$

$$m_9 = \frac{m_6 (h_5 - h_6)}{CP_{Tf}(T_{10} - T_9)} \tag{4}$$

The following equations are used find the enthalpy and temperature at the exit of the pump and solution heat exchanger and the temperature is found by the iteration.

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

$$h_8 = \frac{m_7 h_7 + m_2 h_2 - m_3 h_3}{m_8} \tag{6}$$

The exergy balancing is used to find the feasibility working condition of proposed NCPD model. And the following equation gives the exergy of the components.

For pump,

$$\psi_P = T_0(S_2 - S_1) \quad (7)$$

For solution heat exchanger,

$$\psi_{HEX} = \psi_2 m_2 + \psi_7 m_7 - \psi_3 m_3 - \psi_8 m_8 \quad (8)$$

For generator,

$$\psi_{Gen} = \psi_3 m_3 + \psi_{11} m_{11} - \psi_4 m_4 - \psi_7 m_7 - \psi_{12} m_{12} \quad (9)$$

For turbine,

$$\psi_{Tur} = T_0(S_5 - S_4) \quad (10)$$

For condenser,

$$\psi_{Con} = \psi_5 m_5 + \psi_9 m_9 - \psi_{10} m_{10} - \psi_6 m_6 \quad (11)$$

For solar trough collector,

$$\psi_{Coll} = m_{11}(h_{11} - T_0 S_{11}) \quad (12)$$

Total exergy of the components,

$$\psi_{Tot} = \psi_P + \psi_{HEX} + \psi_{Gen} + \psi_{Tur} + \psi_{Con} + \psi_{Coll} \quad (13)$$

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,

$$W = m_4(h_4 - h_5)\eta_T \quad (14)$$

Pump power input,

$$W_{Pump} = m_1(h_2 - h_1)\eta_{Pump} \quad (15)$$

Generator heat input,

$$Q_{Gen} = m_4 h_4 + m_7 h_7 - m_3 h_3 \quad (16)$$

Condenser exit heat load,

$$Q_{Con} = m_6(h_5 - h_6) \quad (17)$$

Efficiency of the power

$$\eta_P = \frac{W}{Q_{Gen}} \times 100 \quad (18)$$

Cycle Energy Utilization Factor

$$EUF_{cy} = \frac{W + (m_1 \times 2504.9)}{Q_{Gen} + W_{Pump} + Q_{Con}} \tag{19}$$

Plant Energy Utilization Factor

$$EUF_{pl} = \frac{W + (m_1 \times 2504.9)}{A_{Total} I_b + Q_{Con}} \tag{20}$$

3 Result and Discussions

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For the theoretical modeling of the any thermal design the thermodynamic property equation is necessary and the thermodynamic equations used for the simulation is given by the Ref [12].

Table.1 Property state points at the generator temperature of 150 °C and brine solution concentration of 80g/kg.

Points	Temperature (K)	Pressure (Bar)	Salt concentration (g/kg)	Mass flow rate, (kg/s)	Enthalpy (kJ/kg)	Entropy (kJ/kg K)	Exergy (kJ/kg K)
1	30.00	1.01	60.00	0.05	115.35	0.39	-1.71
2	30.09	4.60	60.00	0.05	115.69	0.39	-1.72
3	40.09	4.60	60.00	0.05	154.63	0.52	-0.42
4	150.00	4.60	0.00	0.01	2747.93	6.86	703.62
5	30.35	0.04	0.00	0.01	2429.43	8.45	411.15
6	30.10	0.04	0.00	0.01	126.31	0.44	-4.38
7	150.00	4.60	80.00	0.03	561.64	1.62	78.34
8	135.44	4.60	80.00	0.03	509.71	1.50	62.91
9	30.00	1.01	60.00	25.99	125.89	0.44	-4.39
10	30.25	1.01	60.00	25.99	126.92	0.44	-4.37
11	160.00	1.01	0.00	0.53	675.12	1.94	96.03
12	140.00	1.01	0.00	0.53	588.80	1.74	70.50

The property state points of proposed design of Fig.1are shown in the Table.1. The generator temperatures of 150 °C and brine concentration of 80 g/kg produces 4.6 bar of generator pressure. The vacuum pressure present at the generator in actual flashing stage desalination system is eradicated.

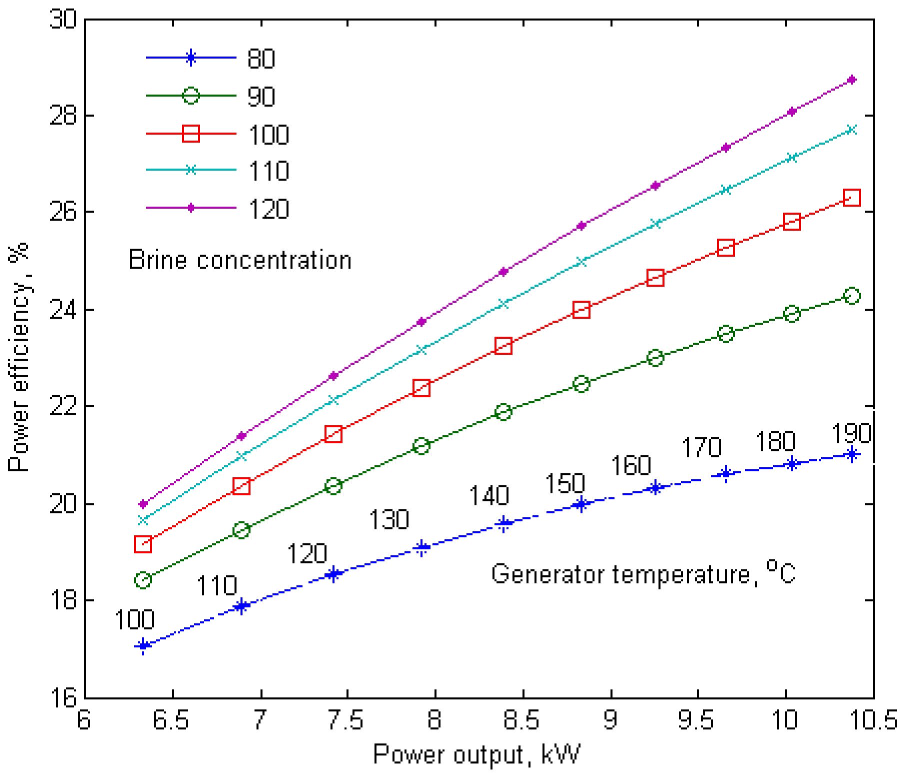

Figure.2. Power output and efficiency of NCPD at different generator temperature and brine solution concentration.

To analyze the efficiency of the power produced in the proposed system is simulated in the temperature range of 100-190 °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 so the analyses are made in the following temperature range as shown in the Fig.2 increases in the generator temperature at the constant brine solution concentration increases generator pressure results high expansion ratio gives more power output. High power efficiency of 29.3 % is achieved at the turbine inlet temperature of 190 °C and the brine solution concentration of 120 g/kg. The power output also increases with increase in brine solution concentration and generator temperature but the power output rise in decrement order with rise in generator temperature.

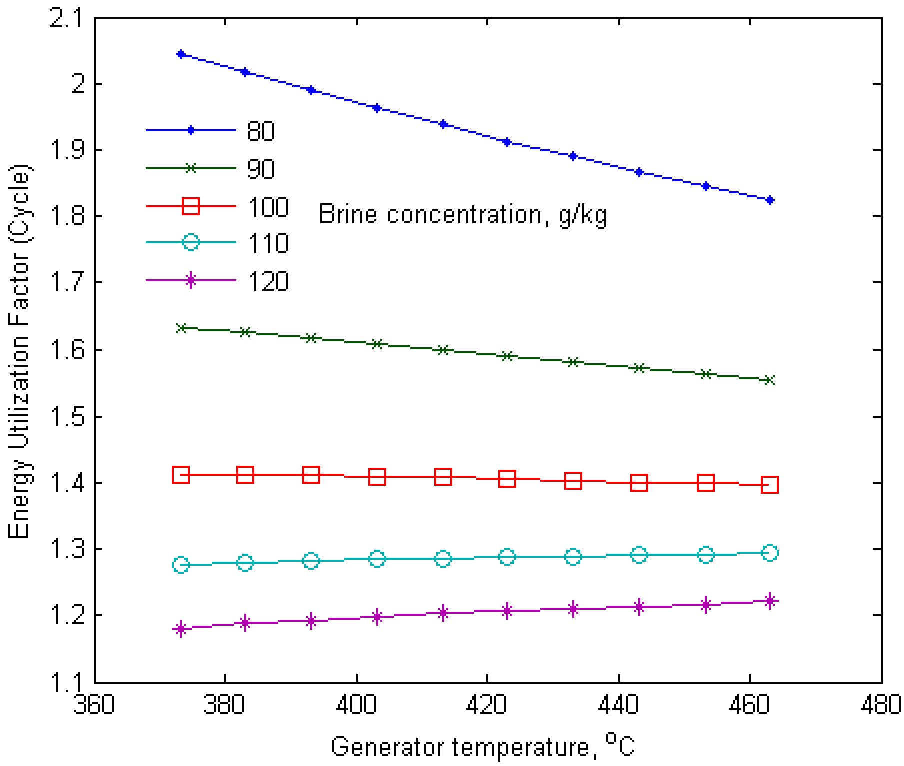

Figure.3 Performance analysis of proposed system at the atmosphere temperature of 30 °C.

Integration of the two cycles combined output performances is expressed in terms of Energy Utilization Factor (EUF). When the system coupled with any refrigeration system the efficiency will be more than 100% and so that system is expressed in EUF. Here the power and desalinated water are the two outputs with common source input of solar thermal. The cycle EUF is analyzed at different generator temperature and brine concentration of 100-190 °C and 80-120 g/kg respectively. The cycle EUF changes were different at different generator temperature whereas the changes for the brine concentration are in the increment order. Due to the fixed desalinated water output 1000LPD the trends acting like that and the corresponding brine concentration output for the 1000LPD is 100g/Kg at 150 °C of generator temperature and 60g/kg of seawater concentration as shown in the Fig.3. For producing the brine concentration of 120 g/kg it requires more heat input hence the cycle EUF is decreases.

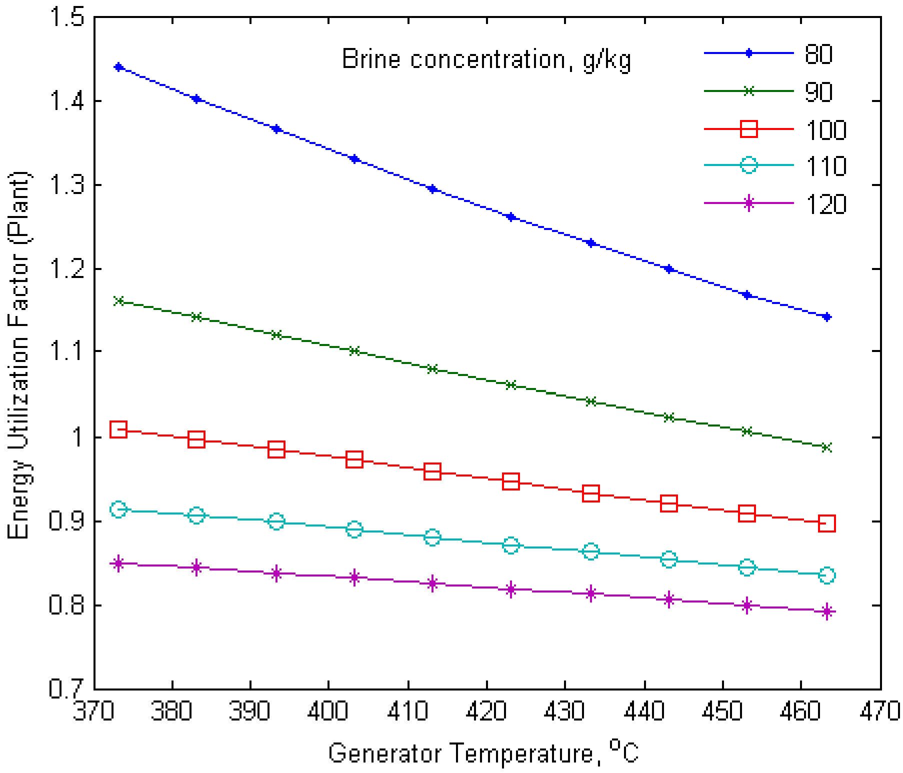

Figure.4 Generator temperature vs plant energy utilization factor

Fig.4 shows the performance variations of the plant EUF with respect to generator 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 producing the high temperature for that the total collector area requirement is increased. The parabolic trough collector efficiency is maximum of 65% and the plant EUF in decrement order because of the collector efficiency and fixed beam radiation. The rate of increment for the plant EUF with respect to brine concentration is gradually decreased in order due to more heat consumption in the generator. Ultimate plant EUF for the proposed NCPD lies between the range of 0.85-1.45 at the brine concentration of 80-120 g/kg and generator temperature of 100-190 °C for the fixed seawater concentration of 60g/kg and beam radiation of 650 W/m^2.

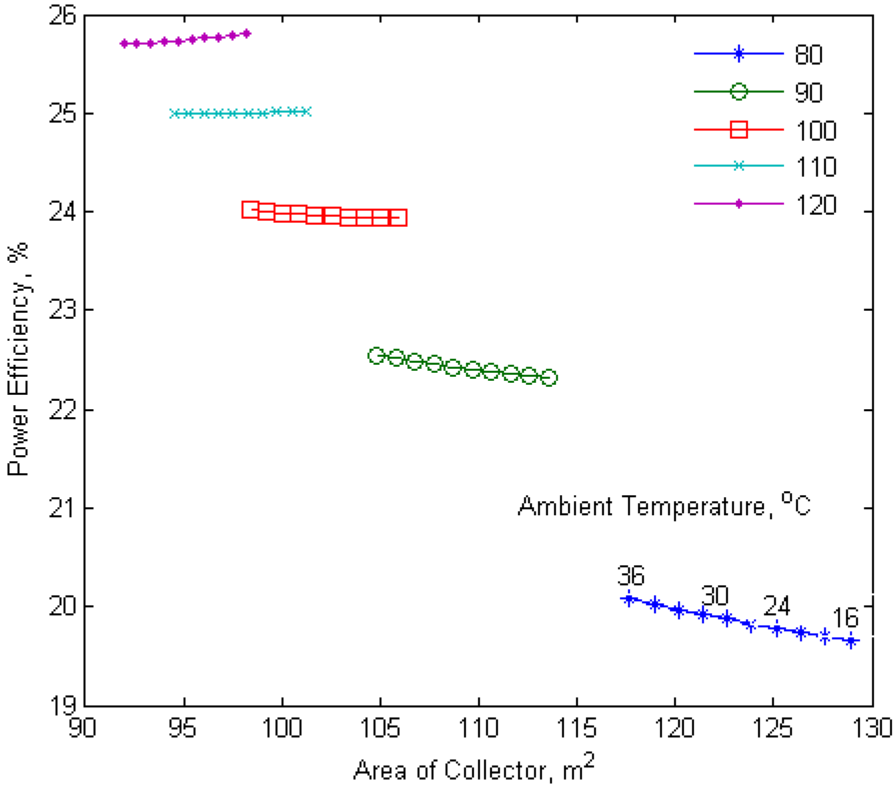

Figure.5 Analysis between the efficiency of power Vs area of collector

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. For the expansion the turbine exit pressure also plays the role and the analysis of the EUF cycle at the different generator temperature at various brine solution concentration is shown in the Fig.5. Decrease in the atmosphere temperature/cooling water temperature reduces the condensing pressure results high expansion, hence more power output is produced. Due to the fixed turbine inlet flow rate of 1000LPD, the power efficiency decreases when the cooling water temperature increases. As well as the total solar trough collector area required for the complete plant is increased.

Table.2 Performance description of components for the proposed NCPD

Description	Output
Pump, kW	0.07
Heat exchanger, kW	3.58
Generator, kW	71.99
Power output, kW	3.51
Condenser, kW	20.24
Irreversibility of pump, kJ/kg K	0.07
Irreversibility of HEX, kJ/kg K	1.25
Irreversibility of generator, kJ/kg K	7.67
Irreversibility of turbine, kJ/kg K	0.02
Irreversibility of condenser, kJ/kg K	1.13
Desalination output, liters/Day	1000
Energy Utilization Factor (cycle)	2.63
Energy Utilization Factor (plant)	1.60
Power efficiency, %	13.92
Total collector area, m^2	201.85

The generator shows heat gain of 71.99 kW and it is high due to separation process of brine and desalinated water. The condenser load is changed according to the turbine inlet pressure and temperature and if the pressure is high it produced saturated vapor results 0.77 of vapor fraction at the turbine inlet pressure of 4.6 bar and temperature of 150 °C with exit condensing pressure of 0.04 bar. The irreversibility of the generator and solution heat exchanger is seems to be high of 7.67 and 1.25 kJ/kgK respectively and the irreversibility's of the solution heat exchanger can be reduce by the minimizing the pinch point variation.

4 Conclusion

The new integration of power and desalination system is made and the analysis are done in both energy and exery method. The proposed power integration in the desalination system is analyzed for the 1000LPD of solar flashing stage desalination column. By the integration it results power efficiency, cycle EUF and plant EUF of 13.92%, 2.63 and 1.6 respectively is achieved for 1000 LPD of the desalinated water with input of 150 °C of generator temperature. The vacuum stage in the flashing system is completely removed in addition to that the power is produce. Increasing the desalinated water output increases in the power output in the proposed solar thermal power and desalination system and it can implemented in all thermal power plant.

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
ψ	=	Exergy, kJ/kg K
η	=	efficiency, %

Subscripts

Con	=	condenser
Coll	=	collector
Gen	=	generator
HEX	=	solution heat exchanger
P	=	power

T = turbine

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