Novel solar driven cooling system integrated with solar still system

Faculty and PostDoc, Science and Engineering

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Abstract

Novel integrated solar cooling and solar distillation system is introduced to meet the high cooling and fresh water demands in hot and arid regions such as Qatar. The system is composed of a solar-driven ejector cooling system coupled with a single-slope solar still. The introduced novel system is the first study that integrates two solar systems for cooling and water production with outputs significantly higher than any existing system. The results show that the productivity of the solar still is improved by enhancing the evaporation rate (using heating coil) and by increasing the condensation rate (using cooling coil). Simultaneously, this improved the COP of the ejector system by increasing its entrainment ratio with a slight increase in the required solar collector area. The performance of four different scenarios of integration between the proposed cooling and distillation systems is investigated. The results showed that the productivity of the still is five times higher than that of the conventional solar still. The annual produced water considering the hourly variation of the radiant flux was 5067 kg/year, which is 5.7 times more than the conventional systems. The estimated cost of one-liter distilled water per 1 m^2 area of the present solar still is $0.04, which is only 18% of the water cost of other still technologies.

Introduction

- In hot climate regions, cooling demand has the highest part of the consumed energy and the most contributor to the peak load of the grid [1, 3,5].
- Besides, these regions usually suffer from the shortage of freshwater resources [6].
- Furthermore, these regions receive relatively high intensity of solar radiation energy that could be utilized to operate a hybrid cooling and water production system with superior performance potential, which is the main goal of the present study [5].
- The novelty of the proposed system includes that (1) this coupling of the solar ejector and still systems has not been introduced before in open literature; (2) in opposite to studies in open literature, the two integrated systems are both solar and (3) the outputs (cooling effect and water productivity) of the proposed system are significantly higher than any existing system.
- Figure 2 shows the working principle of the proposed system.

Description

- The generator of the ejector system is heated by hot water.
- The hot water is being heated by solar energy utilizing evacuated tube solar collector (ETSC).
- The ETSC can provide hot water with temperature higher than 373 K.
- On the left-hand side of Figure 5, the solar still system composed of saline water basin with heating coil (passed across it), condensing chamber with cooling coil, solar still room and glass cover to permit the solar radiation of the sun to the basin.
- The incident solar radiation is absorbed by the basin of the still with small part being reflected by the glass cover.
- With the increase of the basin temperature, the saline water starts to vaporize generating freshwater vapor (FWV).
- The FWV is transferred to the condensing chamber and to the inner surface of the glass cover to be condensed

Benefits of the study

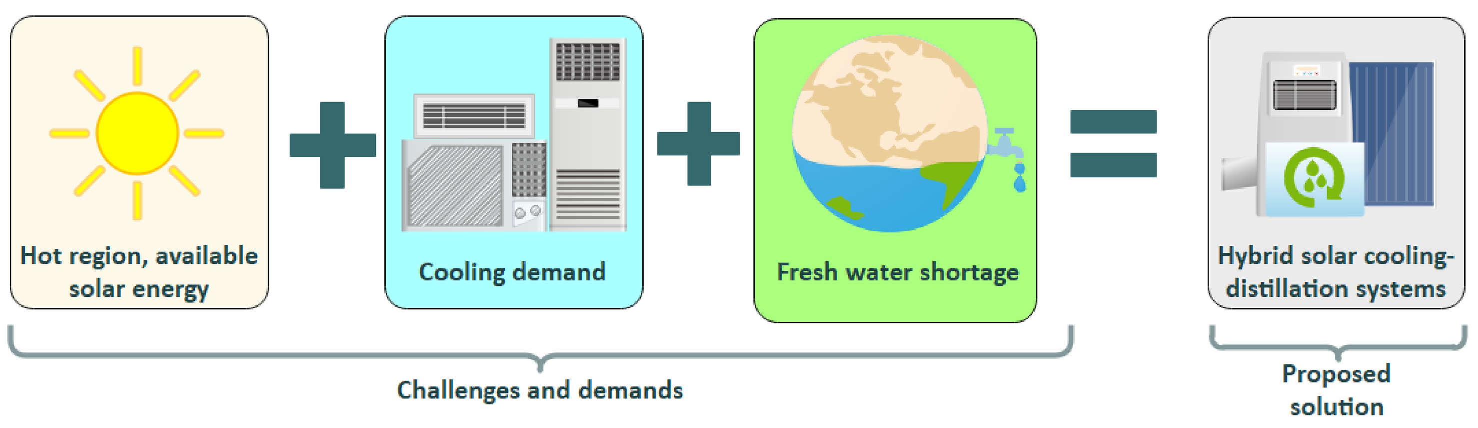

Figure 1. Challenges, demands, and solution provided by the proposed system.

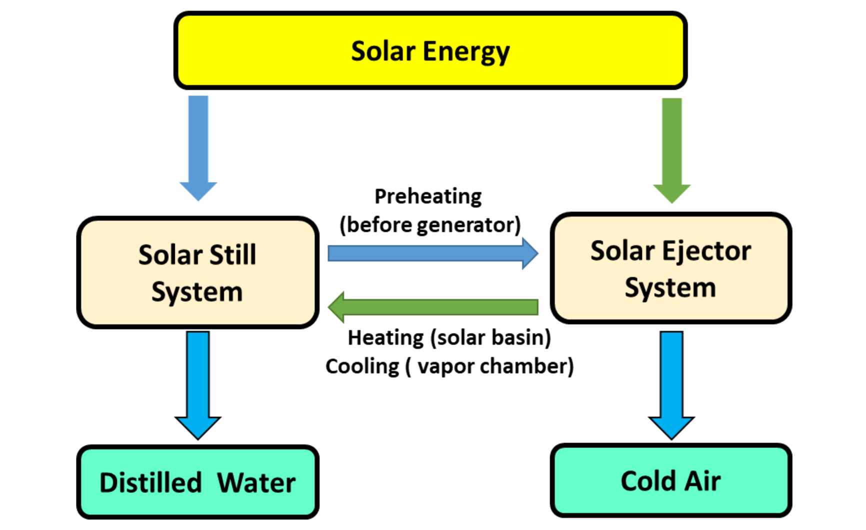

Figure 2. The working principle of the proposed system [2].

Referring to Figure 3 and Figure 4,

- The coefficient of performance of the solar ejector system is given as:

$$COP = \frac{Q_e}{(Q_{ETC} - Q_{h,ss}) + \dot{W}_{pump}} \quad (1)$$

- The efficiency of the solar still system is given as:

$$\eta_{ss} = \frac{Q_{ev}}{G \times A_{sw} + Q_{h,ss}} \quad (2)$$

- The distilled water per day is obtained by:

$$m_{distilled} = \sum_i^j \left(\frac{Q_{ev,sw-gl,i}}{h_{fg,v,i}}\right) \times 3600 \quad (3)$$

- The efficiency of the solar collector field is expressed as:

$$\eta_{sc} = F_R(\tau\alpha) - F_R U_L\left(\frac{T_{coll,in} - T_a}{G}\right) \quad (4)$$

- The payback period of the solar still system is calculated by:

$$\mathbf{PBP} = (C_N)/(C_{L,CSS*}\, m_d) \quad (5)$$

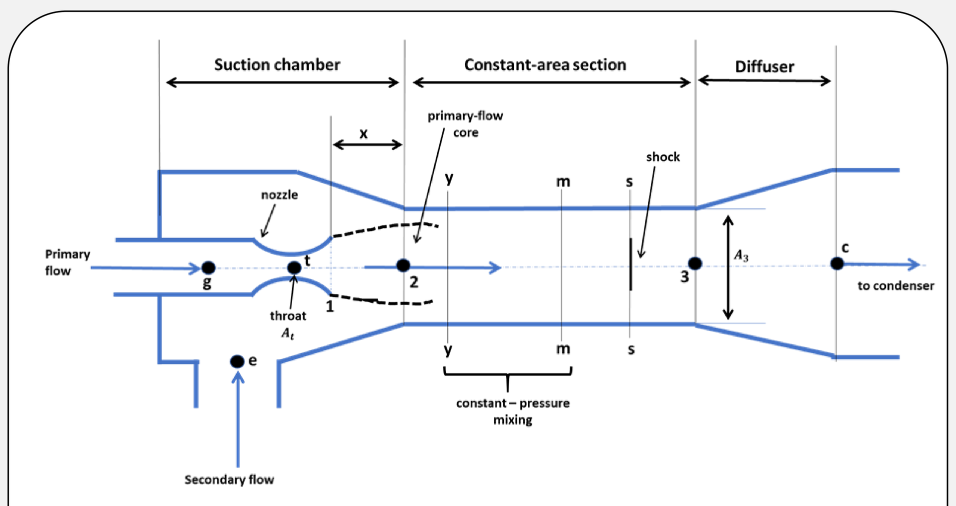

Figure 3. Schematic diagram of the ejector [2].

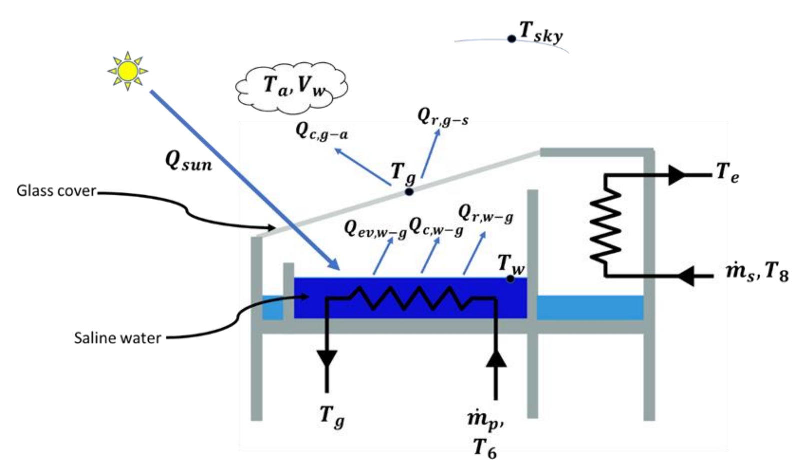

Figure 4. Schematic diagram of the solar still [2].

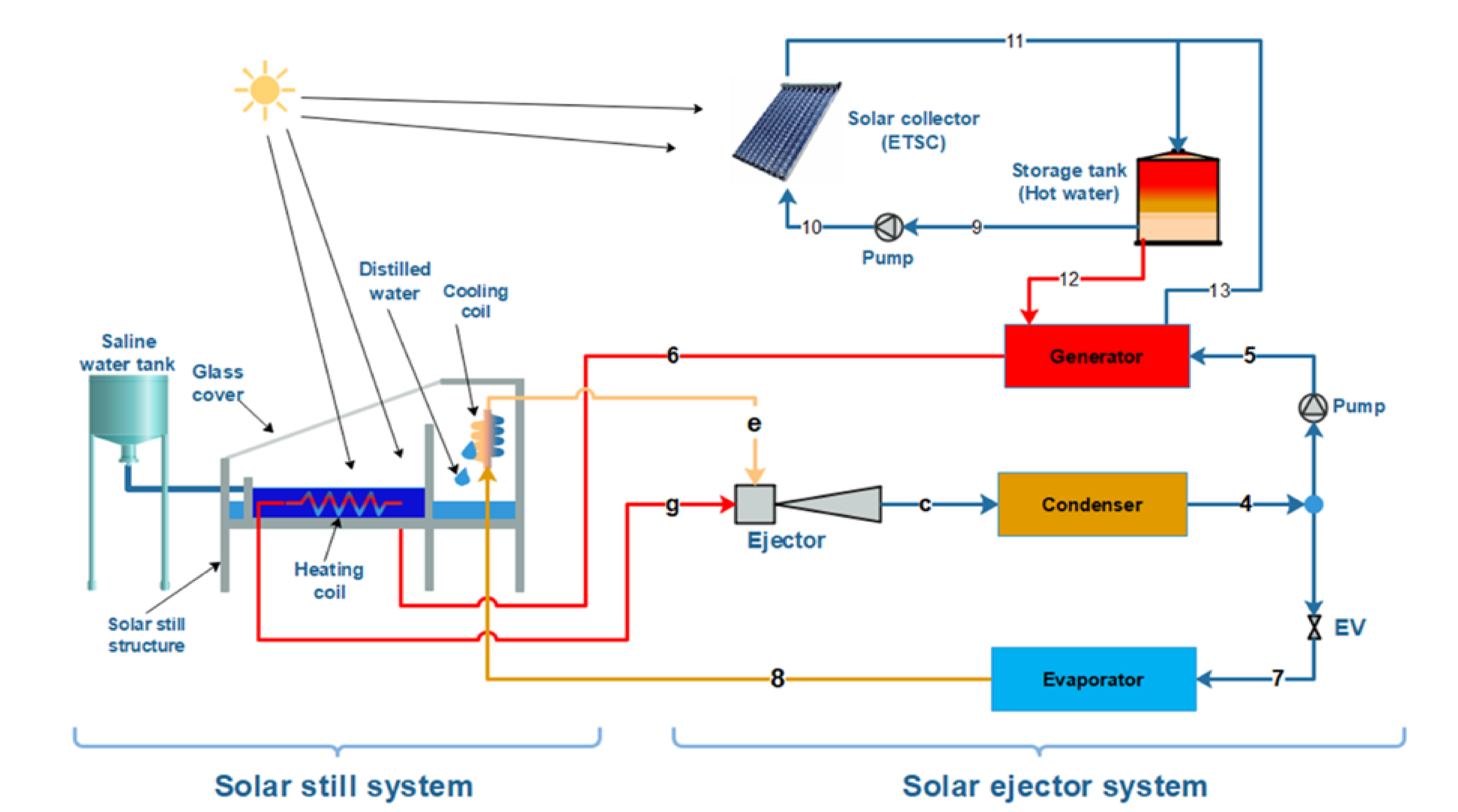

Figure 5. Schematic diagram of the proposed system [2]

Results

- Simulations were performed for four different integration scenarios; S1: the two systems operate separately, S2: the ejector primary flow passes through the heating coil only, S3: the ejector secondary flow passes through the cooling coil only and S4: ejector primary and secondary flows passes through heating and cooling coils, respectively.
- The increase of the generator temperature, reduces the COP of the ejector system and slightly reduces the productivity of the still (See Figure 6).
- The increase of the generator pressure, reduces the COP of the ejector and increases the productivity of the still (See Figure 7).
- The increase of the evaporator temperature, increases the COP of the ejector system (See Figure 8).
- For the studied working fluids (R134a, R290, R152a, R142b, R124), R290 yields the highest COP while R152a yields the highest still productivity. However, for its overall performance, safety and environmental issues, R134a is recommended (See Figure 11 and Figure 12).
- Effects of solar radiation variation in steady and transient modes are presented in Figure 9.
- The annual produced water considering the hourly variation of the radiant flux during any given day in the year, reached 5067 kg/year that is 5.7 times more than that in S1.
- The cost of one liter distilled water per 1 m^2 area of the present solar still in S4 is $0.04, which is only a small fraction (18%) of the cost of water produced by another technology that uses solar still coupled with packed bed and a parabolic trough collector (See Figure 10).

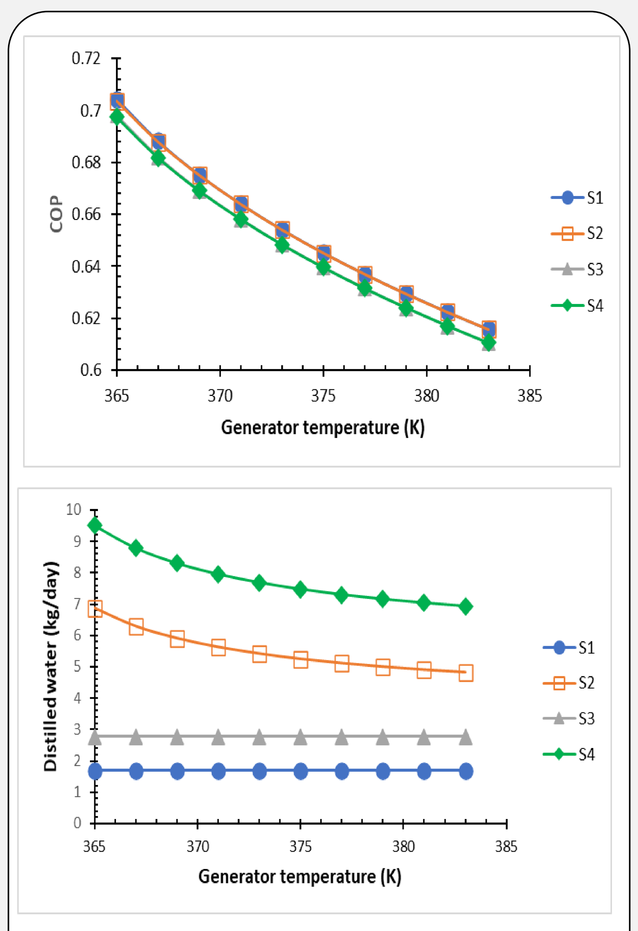

Figure 6. Effect of the generator temperature [2].

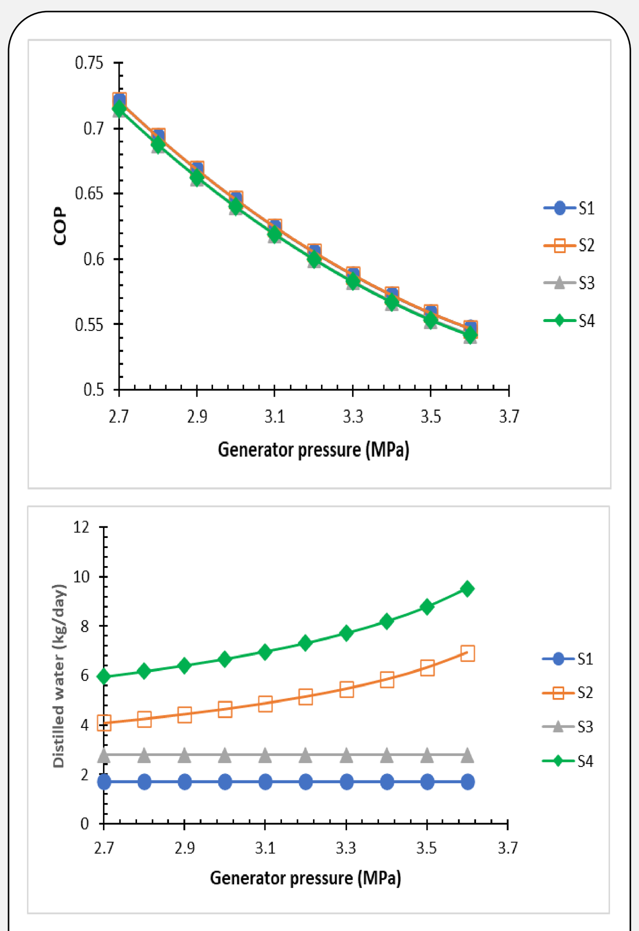

Figure 7. Effect of the generator pressure [2].

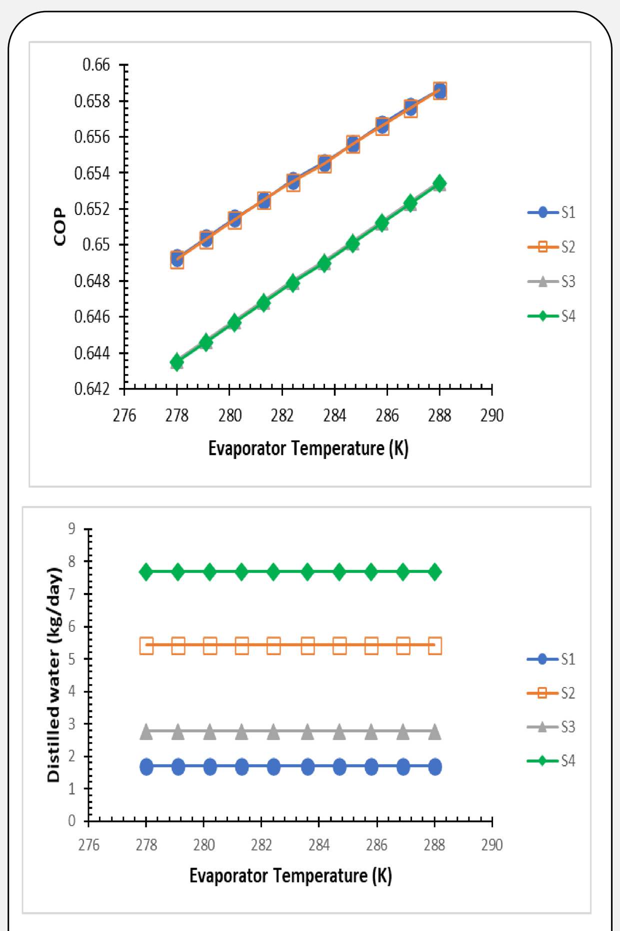

Figure 8. Effect of the evaporator temperature [2].

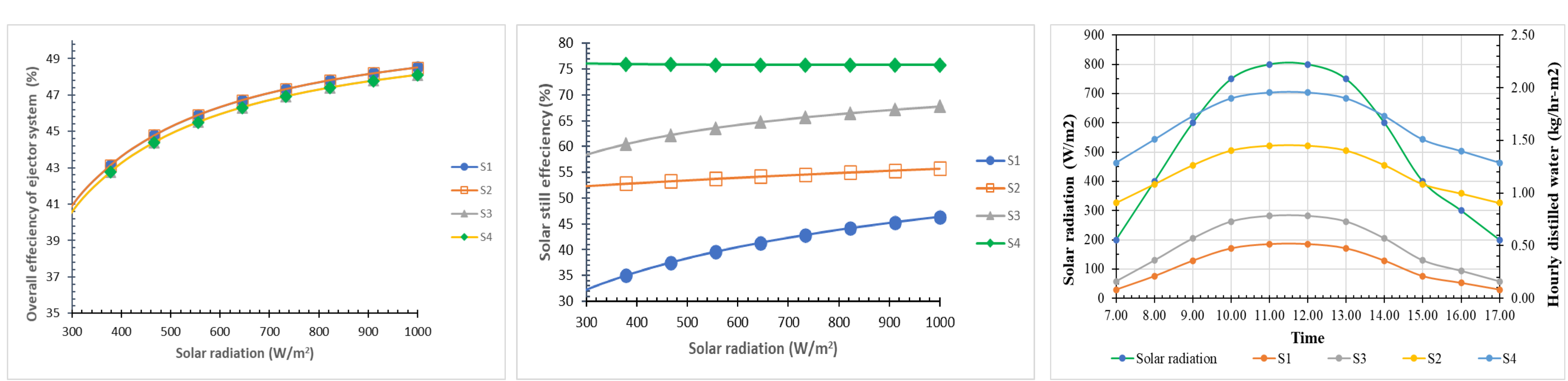

Figure 9. Effects of the solar radiation with its steady and transient variations [2].

Comparison

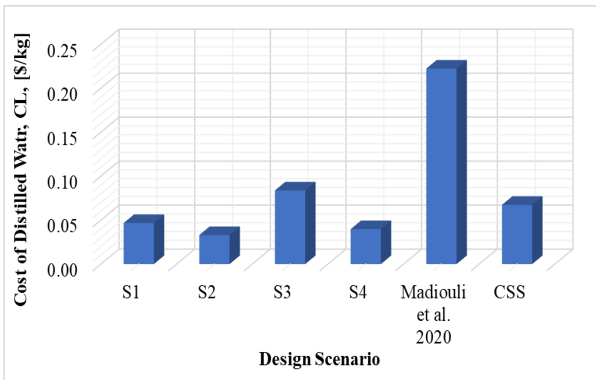

Figure 10. Comparison of distilled water cost [2, 4].

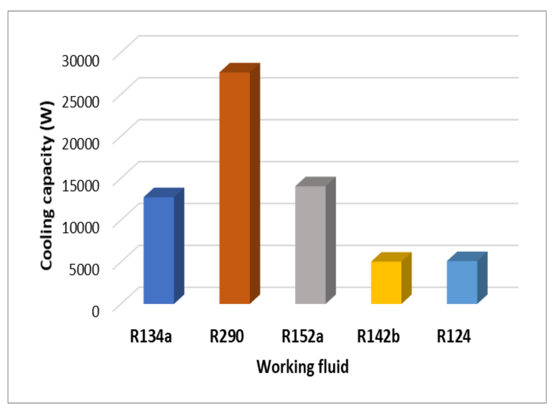

Figure 11. Effect of working fluid on the cooling capacity of the system [2].

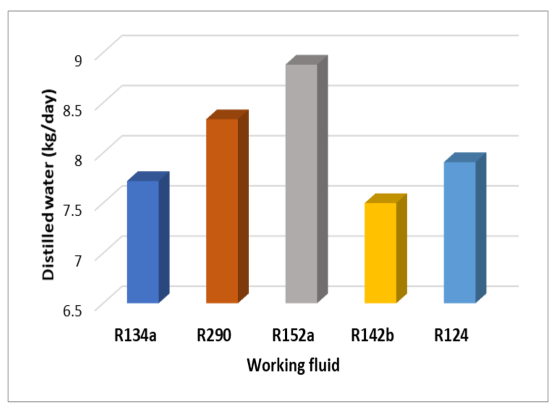

Figure 12. Effect of the working fluid on the distilled water [2].

Conclusions.

- A novel hybrid solar distillation and cooling system that produces both fresh water and cooling effect is proposed and investigated.
- The effects of the major operating conditions including the generator temperature, generator pressure, evaporator temperature, solar radiation, and working fluid on the performance of the system are investigated and plotted.
- In scenario 4, the water productivity of the still increased by more than five times compared to the conventional still (scenario 1)
- The solar still efficiency in scenario 3 is higher than that of scenario 2. However, the still productivity in scenario 2 is higher than that of S3.
- The cost of one liter distilled water per 1 m^2 area of the present solar still in S4 is $0.04, which is only 18% of the cost of water produced by proposed solar still systems.
- Experimental validation and further thermoeconomic investigations are required for future works.

Acknowledgement

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