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Thermodynamic Analysis of Ejector Absorption Refrigeration Machine

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Abstract— **In this investigation a hybrid ejector single-effect lithium-bromide water cycle is theoretically studied. The system presents a conventional single-effect cycle activated by an external steam-ejector loop. Based on a mathematical model of the whole system, simulations are carried out to study the effect of the major parameters of the hybrid cycle on its performances, and comparison with the conventional cycle is also presented. The ejector performance is also investigated. Results show that the entrainment ratio rises with steam pressure and condenser temperature, while it decreases with increasing generator temperature. The effect of the evaporator temperature on ejector performance is negligible. It is shown also that the hybrid cycle exhibits better performances compared with the basic cycle. However, the performance improvement is limited to a specific range of the operating parameters. Outside this range, the hybrid system behaves similar to a conventional cycle. Inside this range, the COP increases, reaches a maximum then decreases and rejoin the behaviour of the basic cycle. The maximum COP, which can be as large as that of a conventional double-effect cycle, about 1, is obtained at lower temperatures than in the case of single-effect cycles.**

***Keywords*—absorption refrigeration, ejector, lithium bromide, simulation.**

I. Introduction

Cooling and air conditioning are essential for small scale and industrial process applications. While compressor refrigerator cycles worked with fluids presenting carbon dioxide emission. Absorption cycles using water-lithium bromide are alternative. But, they have a low coefficient of performance. That's why new hybrid and combined configurations where the integration of new component, such as ejector, in the basic absorption cycles, to enhance to performances, were studied.

Various configuration integrating ejector were studied; Combined cycle was investigated, in which the ejector is at the absorber inlet [1-4], COP of this cycle was higher by about 2–4% than conventional cycle. Principally, investigations indicate that COP of the combined configuration are greater or equal to that of single effect cycles at low generator temperatures.

Also, another configuration was studied, where the ejector is located in the condenser inlet of the single effect absorption cycle. Theoretical studies [5,6], confirm that the coefficient of performances was higher than single effect cycle. Experimental study [7] show that the combined cycle is 30-60% higher as compared to the COP of the basic absorption and almost reaches the COP of double-effect absorption systems .Besides, modified configuration by adding a flash tank between ejector and evaporator was designed [8-9].

Ejector double effect absorption systems were investigated [10-11], so the COP of the proposed new ejector refrigeration cycle, increases with the temperature of the heat source until the temperature of the heat source was higher than 150 °C the new cycle worked as a double effect cycle.

Novel configuration was studied where the ejector was coupled to vapour generator, [12,13] to enhance the concentration process by compressing the vapour produced from the lithium bromide solution in order to re-heat the solution from which it came. Results showed that COP of the new cycle can increase specially with the heat source temperature.

In this paper, a water lithium bromide hybrid ejector single effect cycle is investigated. The entrainment ratio as ejector performances is carried out for different generator, condenser and ejector temperature. Also a comparison with the basic single effect absorption cycle and the evolution of the coefficient of performances are studied.

II. System description

Fig. 1 (a) and (b) present a schematic diagram of a conventional single effect system and an hybrid ejector-single effect system.

A conventional single effect absorption cycle is composed of evaporator, absorber, condenser and generator, expansion solution valve pump, solution heat exchanger and refrigerant expansion valve, as presented in fig. 1 (a). While a steam-ejector-generator loop is coupled to the conventional single effect via the solution generator, as presented in fig. 1 (b). The steam-ejector loop is composed of a steam ejector, a steam generator vapor, a water pump and an expansion valve.

The steam-ejector-generator loop is used to enhance the cycle performance by enhancing the concentration process. The steam ejector is the main key of the enhancement process. A high pressure flow (18) coming from the steam generator enters the primary nozzle of the ejector, its pressure drops at the exit of the nozzle point (i), as shown in fig. 2, and its velocity becomes very high so it entrain a secondary flow, the vapor (19)

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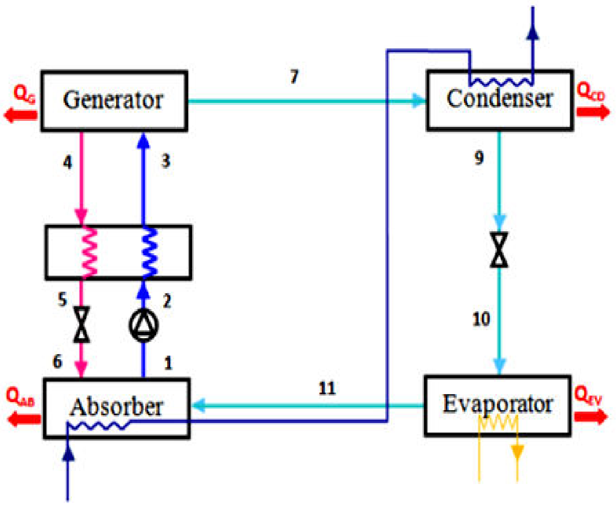
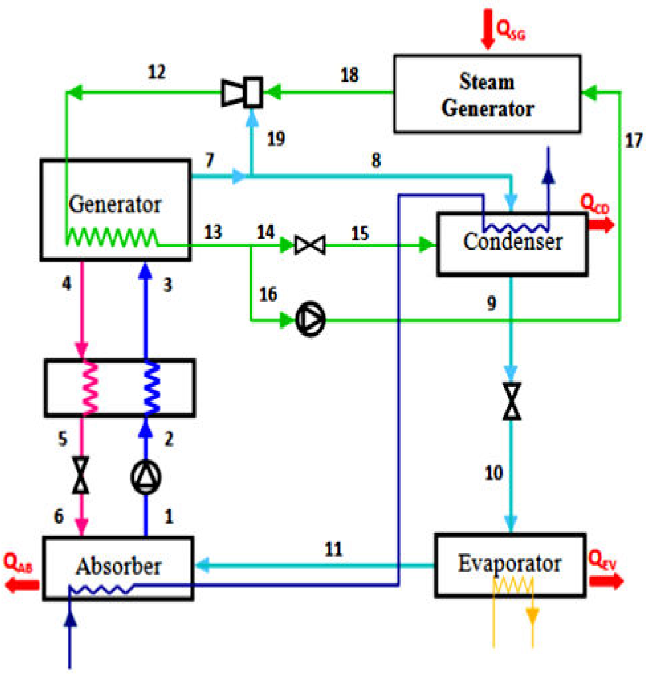
as part of the total vapor (7) produced from the solution generator, the two streams are mixed in the mixing chamber and then, compressed in the ejector, to exit at backpressure (12). This flow condenses in the solution generator and exceeds condensation heat until become liquid saturated (13). The condensation heat is used to concentrate the saline solution by producing vapor from the diluted solution entering the solution generator (3). Part of the flow (3) undergoes to the condenser and the other part (19) is pumped to the steam generator. For purpose of illustration, the chiller cycle is represented in Fig. 3 in the usual Oldham-diagram.



(a)



(b)

Fig. 1 Single effect absorption system: (a) Conventional, (b) hybrid

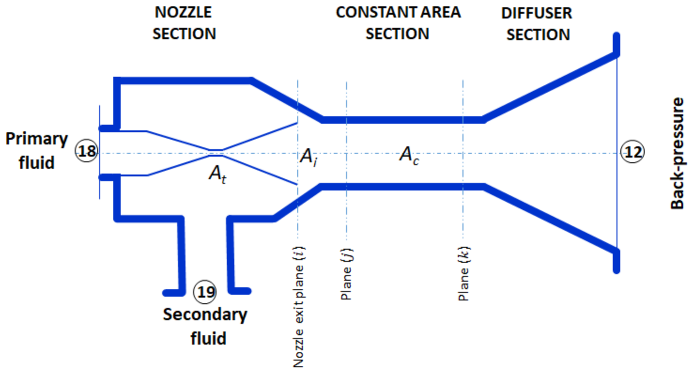


Fig. 2 Ejector schematics

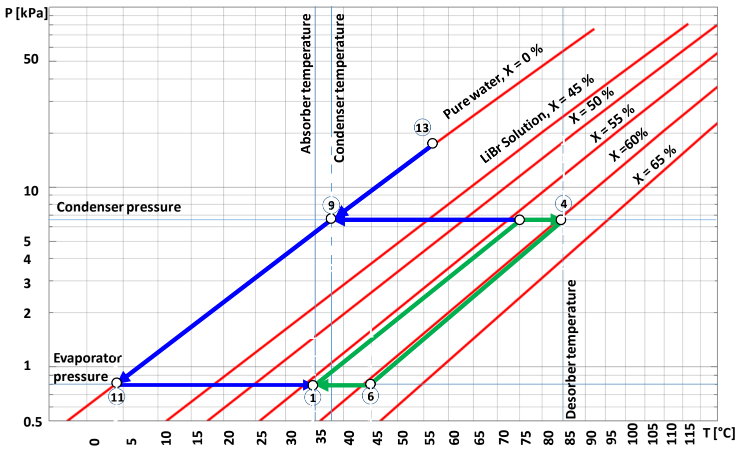


Fig. 3 Chiller cycle representation in the Oldham-diagram ($T_{SG} \approx 200°C$; $T_G = 85°C$; $T_{EV} = 4°C$; $T_{CD} = 37°C$)

III. BASIC AND HYBRID EJECTOR SINGLE-EFFECT ABSORPTION CYCLE MODEL

The mathematical model of the cycle is based on mass and energy balances written for each machine element. For a steady state process and neglecting kinetic and potential energy variations, balance equations for global mass (Eq. 1), salt mass (Eq. 2), and energy (Eq. 3) write, respectively:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \qquad (1)$$

$$\sum \dot{m}_{in} X_{in} = \sum \dot{m}_{out} X_{out} \qquad (2)$$

$$\sum \dot{Q} - \sum \dot{W} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_{in} h_{in} \qquad (3)$$

$\dot{Q}$ and $\dot{W}$are heat and transfer rates between machine element and its surroundings. The performances COP_{basic} of the basic absorption cycle is expressed as Eq. (4) and the COP_{hybrid} of the hybrid absorption cycle is expressed as Eq. (5), as follow :

$$COP_{basic} = \frac{\dot{Q}_{EV}}{\dot{Q}_G + \sum \dot{W}_P} \quad (4)$$

$$COP_{hybrid} = \frac{\dot{Q}_{EV}}{\dot{Q}_{SG} + \sum \dot{W}_P} \quad (5)$$

IV. RESULTS AND DISCUSSION

A computer program has been developed using the software Engineering Equation Solver (EES) [14] to thermodynamically analysis the proposed hybrid single effect absorption refrigeration system. In the program, the thermo-physical properties of LiBr-H2O are used as internal functions from the EES database where the temperature reaches 500°K for all composition range.

The following conditions are used as simulation inputs :

- The evaporator temperature is equal to 4°C,
- Condenser temperature is equal to 30°C,
- Absorber temperature is equal to Tc-2°C because it is cooled via water cooling tower,
- Effectiveness heat exchangers are equal to 0.8,
- Flow rate leaving the absorber is equal to 2Kg/s.

A. *Ejector performances*

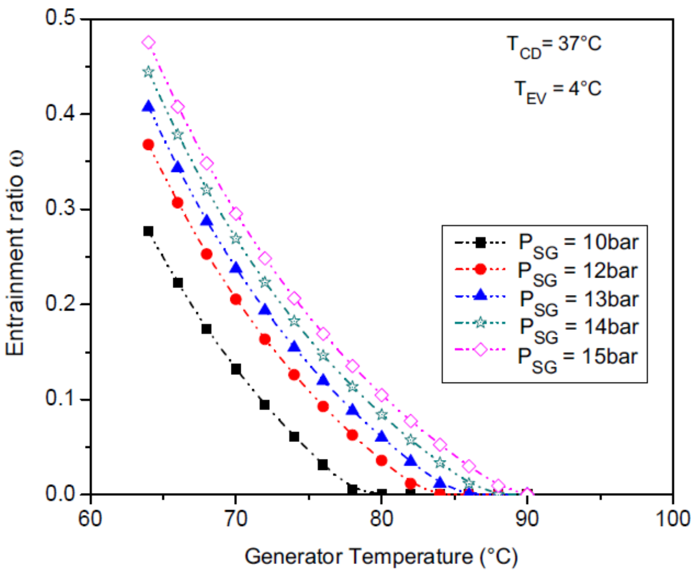


Fig. 4 ω vs. T_G for various primary pressure P_{SG}

Fig.4 presents the evolution of entrainment ratio ω with solution generator temperature T_G. For a fixed primary pressure P_{SG} which is the steam pressure, curves indicate that the entrainment ratio depend on the steam generator pressure, while it deceases with increasing the generator temperature. The steam pressure is the primary pressure. The entrainment ratio reaches zero respectively at generator temperature of 80, 83, 85, 87, 90°C for steam pressure of 10, 12, 13, 14, 15bar.

Ones the entrainment ratio is zero, the flow is no more entrained inside the ejector, so the ejector is off design and its geometry should be changed.

Fig. 5 depicts effect of generator temperature and steam pressure on the entrainment ratio. Results show that the entrainment ratio increases with the condenser temperature and decreases with increasing the generator temperature, when the pressure at generator is set at 15bar. When the generator temperature becomes equal to 90°C, the entrainment ratio becomes equal to zero. The calculated entrainment ratio is between from 0.2 to 0.4, from 0.12 to 0.2, from 0.7 to 0.1 and from 0.03 to 0.05 when the temperature in the generator is 70, 75, 80 and 85°C respectively.

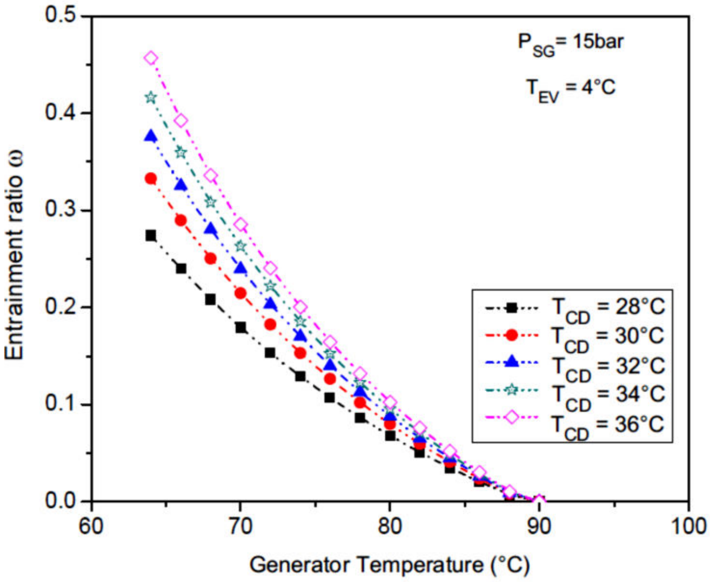


Fig. 5 ω vs. T_G for various condenser temperature T_{CD}

Fig. 6 depicts the evolution of the entrainment with the solution generator temperature. Curves show that the entrainment ratio is practically identical for every generator temperature. The entrainment ratio is about 0.3, 0.18, 0.1 and 0.05 when the generator temperature is set as 70, 75, 0, 85°C respectively.

In the hybrid cycle the evaporator temperature practically don't has effect on the ejector inlet and outlet parameters so that's why the entrainment ratio is almost same for all the evaporator temperature.

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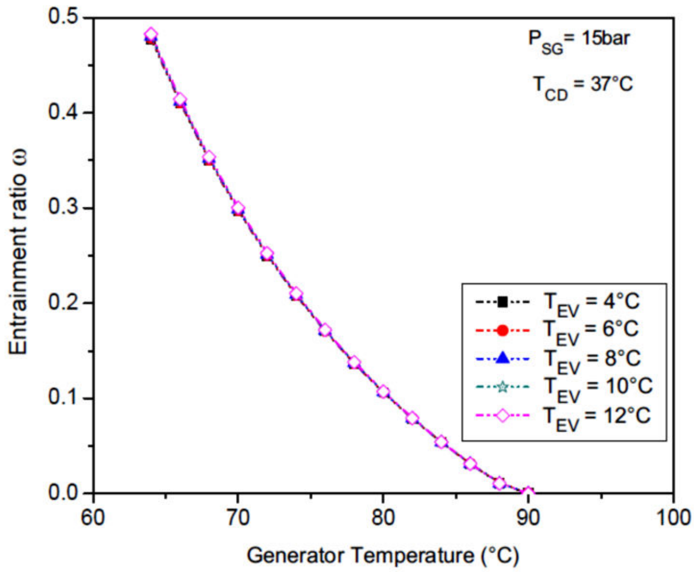

Fig. 6 ω vs. T_G for various evaporator temperature T_{Ev}

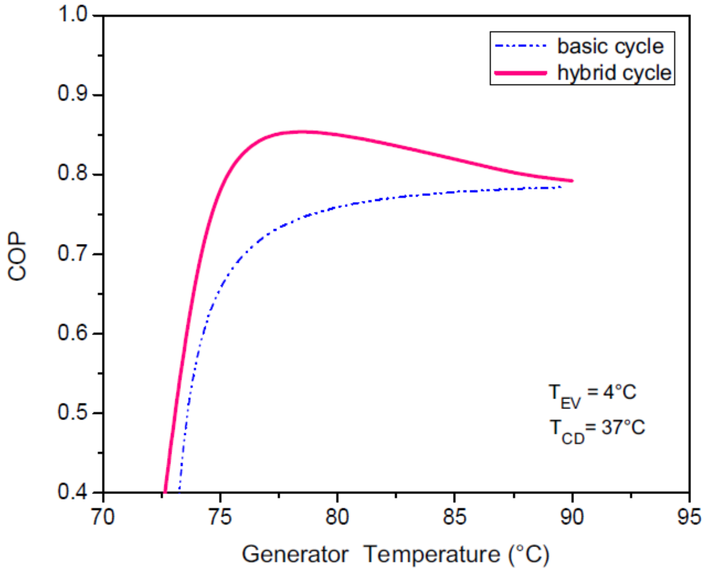

Fig. 7 COP of hybrid and conventional cycle vs. machine generator temperature, T_G (P_{18}=15bar)

B. *Hybrid and basic cycle performances*

In the studied cycle, first a basic comparison was done between the basic single effect cycle and the hybrid ejector single effect absorption. Thus the effect of generator temperature, condensation and evaporation temperature is studied.

Fig. 7 indicates the evolution of the coefficient of performances of both conventional and hybrid cycles with the temperature in the solution generator.

The coefficient of performances is more important for the hybrid cycle until the temperature in the generator become equal to a 90, as shown in fig. 7. After 90°C, the COP of the hybrid cycle reaches the same COP of the basic cycle because the entrainment ratio with these parameters is zero as shown in fig.6 (a). The COP of the hybrid cycle reaches a maximum as 0.88 for 78°C while the basic cycle reaches 0.8 at 90°C. Thus the ejector in the hybrid cycle improves the cycle performances at low generator temperature.

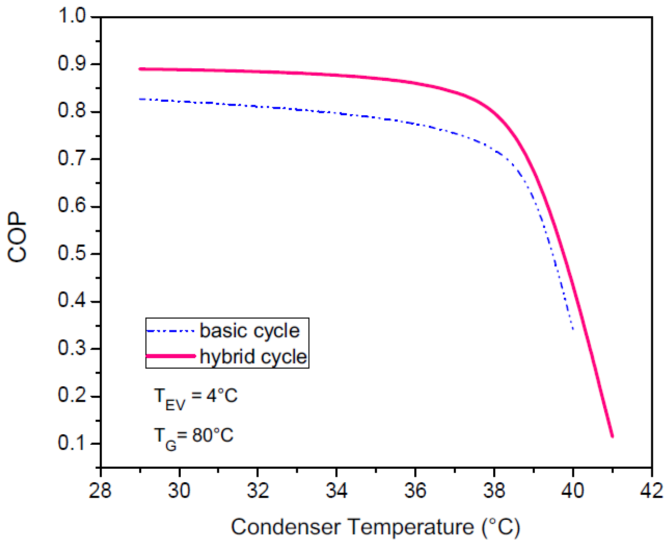

Fig. 8 COP of hybrid and conventional cycle vs. condenser temperature T_{CD}

Fig.8 presents the evolution of the coefficient of performance of both hybrid and basic cycle with the condenser temperature. Results show that the coefficient of performance of the two cycles decrease with the condenser temperature. Also, it is shown that the COP of the hybrid cycle is higher than the basic cycle. The hybrid cycle coefficient of performance reaches 0.9 when the evaporator and generator temperatures are at 4 and 80°C.

Fig.8 indicates the effect of solution generator temperatures and steam pressure generator on COP of hybrid cycle.

So according to this figure, results show the coefficient of hybrid and basic cycles increases with increasing the evaporator temperature. Also, when the condenser temperature

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is at 37°C and the generator temperature is 80°C, the COP of hybrid cycle is 13% higher than that of basic single effect cycle.

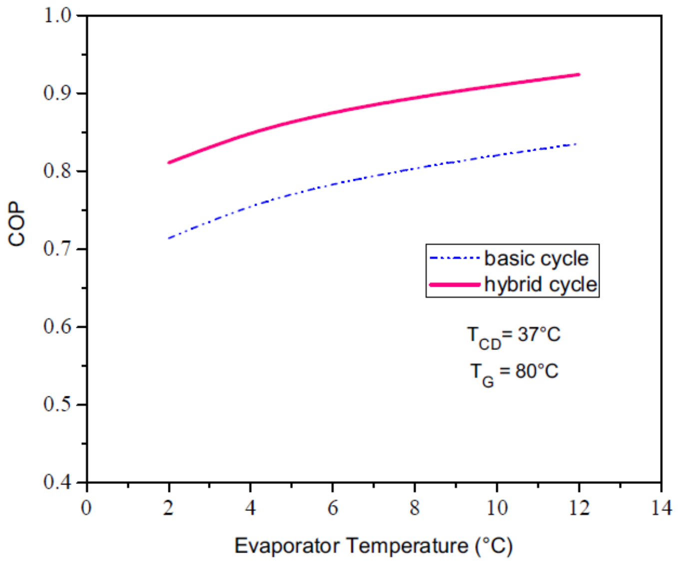

Fig.8 COP of hybrid and conventional cycle vs. evaporator temperature, T_{EV}

Fig. 9 shows: The higher the steam-generator pressure (and consequently temperature), the larger the machine-generator temperature range where the cycle performance is improved, and the higher the maximum COP that could be reached inside this interval. On the opposite, when the steam generator pressure P_{SG} is decreased to 10 bar, practically no improvement more of the cycle performance is observed under the prevailing conditions.

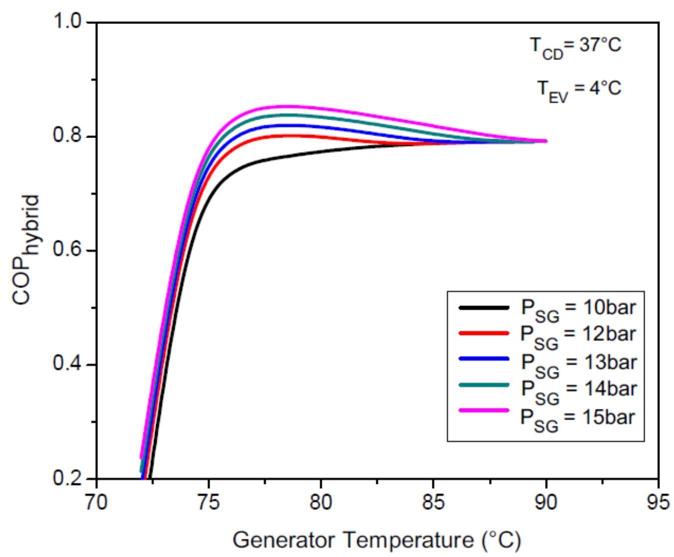

Fig. 9 COP_{hybrid} vs. T_G for various steam-generator temperatures, T_{SG}

V. Conclusions

In this study an hybrid cycle composed of steam-ejector loop coupled with single effect absorption refrigeration cycle working with water lithium-bromide. Mathematical model of the hybrid cycle and the ejector were detailed. Results show that entrainment ratio of the ejector depend on steam pressure and condenser temperature. While, it is slightly depend on the evaporator temperature. Comparing the basic cycle performances to the hybrid cycle performance, it was found that the COP of the hybrid one is higher than the basic one when the temperature of the generator is less than 90°C.

It was concluded that the COP of the new cycle is higher for lower generator temperature, until 90°C when the entrainment ratio become equal to zero, the hybrid COP reaches COP's of the basic cycle.

The COP of the hybrid cycle increases with the steam pressure and increases with the generator temperature until 90°C, which refers to entrainment ratio equal to zero.

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