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ON SOLAR ABSORPTION REFRIGERATOR'S PERFORMANCES

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ОТНОСНО ХАРАКТЕРИСТИКИТЕ НА ХЛАДИЛНИК РАБОТЕЩ СЪС СЛЪНЧЕВА АБСОРБЦИЯ

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Abstract: Solar absorption refrigerator's performances are analysed by a conceptual optimization. The simulation is based on hierarchical decomposition, on the principles of the endoreversibility, respectively of the exoreversibility of the solar absorption refrigerators. Optimization is carried out by adopting the method of Lagrange multipliers. This methodology was been applied to absorption cycle composed of a solar concentrator (hot source), a thermal solar converter (thermal engine 1), an intermediate source, a cold source and four main elements: a generator, an absorber, a condenser and an evaporator. The generator and the absorber constitute a thermal engine ET2 and the whole condenser evaporator forms the thermal receptor RT. The parameterization of the installation comprises fluxes and powers and the temperatures that reign in the thermal machine compartments. This made it possible to get out two equation systems which guarantee the coupling of general optimal performance characteristics of a simple effect solar absorption cycle. The functional and conceptual characteristics are studied. In particular, the effect of the external sources temperatures on the performances is discussed. These results are interesting in absorption machine’s conception viewpoint. They encourage studies in an irreversible way.

Keywords: Absorption refrigerator, Solar energy, Optimization, Hierarchical decomposition, Endoreversibility, Exoreversibility.

1. INTRODUCTION

The ideal solar absorption refrigerator's performance coefficient, COP_{Carnot}, possesses greater values compared to those of real irreversible machines. The latest kind of machines cannot achieve COP_{Carnot}. For this reason it doesn't have a convenient utility. However, it is necessary to get a coefficient of real irreversible performance, so it is necessary to pass by intermediate approaches as endoreversible and exoreversible ones. During latest years, several works [1-8] have been dedicated to the solar driven refrigeration. They have been interested in the thermodynamic of absorption refrigerators. Others [9-18] studied the performance analysis according to the intermediate models i.e. the endoreversible or irreversible models. Using a transfer Newton law, the performances of four sources models were investigated in the works of Chen and al. [18-20], Shi and Chen [21]. All these researches are oriented toward the absorption machines efficiency improvement.

The ideal performance coefficient, COP_{Carnot}, possesses greater values compared to those of real irreversible machines. For this reason it doesn't have a convenient utility. However, endoreversible and exoreversible models present a COP values closer to the real irreversible one. In this paper, a comparison is made between results achieved by both an endoreversible and an exoreversible absorption refrigerator models. Hierarchical decomposition is associated to the endoreversibility and exoreversibility principles. Optimization is carried out by adopting the method of Lagrange multipliers.

Nomenclature

A : *Area (m^2)*
COP : *Coefficient of performance (-)*
Q : *Cooling/Heating load (kW)*
T : *Temperature (K or °C)*
U : *Global heat exchange coefficient (kW/m^2.K)*
W : *Power (kW)*
R : *Efficiency*
l : *Lagrange multiplier*

Subscriptions

a : *Absorber*
c : *Condenser*
cs : *Solar collector*
e : *Evaporator*
fc : *Coolant fluid*
g : *Generator*
h : *High temperature*
r : *Low temperature*
ref. : *Refrigeration*
sf : *Cooled source*
si : *Intermediate source*
u : *Utile*

2. HIERARCHICAL DECOMPOSITION OF THE MODEL

Hierarchical decomposition is usually used in mechanical structure engineering. Here, the methodology is applied to an absorption refrigeration cycle. It is composed by a solar concentrator (hot source), a thermal solar converter (thermal engine 1), an intermediate source, a cold source and four main elements: a generator, an absorber, a condenser and an evaporator. Both the generator and the absorber constitute a thermal engine TE2 and both the condenser and the evaporator form the thermal receptor TR. The exchanged fluxes and powers that reign in the different compartments of the machine are mentioned in Fig. 1.

The decomposition, represented in Fig. 2, consists in a four levels subdivision. The first level (L.I) presents the compact global system (TE_1 + TE_2 + TR). This level is decomposed in two sublevels (N.II.1 and 2) the thermal converter (TE_1) and the command and refrigeration system (TE_2+TR). This last is subdivided to give the two sublevels composed by the thermal engine TE_2 and the thermal receptor TR. The level (L.VI) is composed essentially by the four elements: generator, absorber, condenser and evaporator.

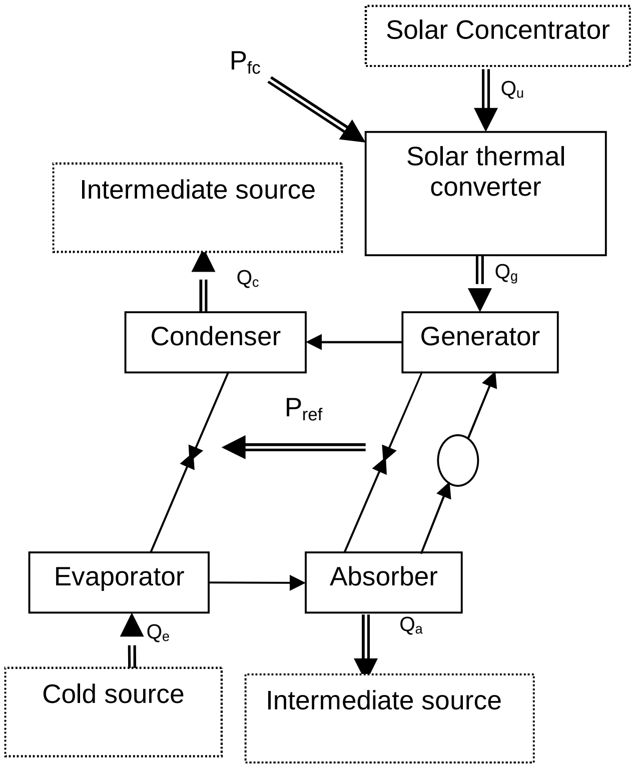


Fig. 1. Composition of a solar absorption refrigerator.

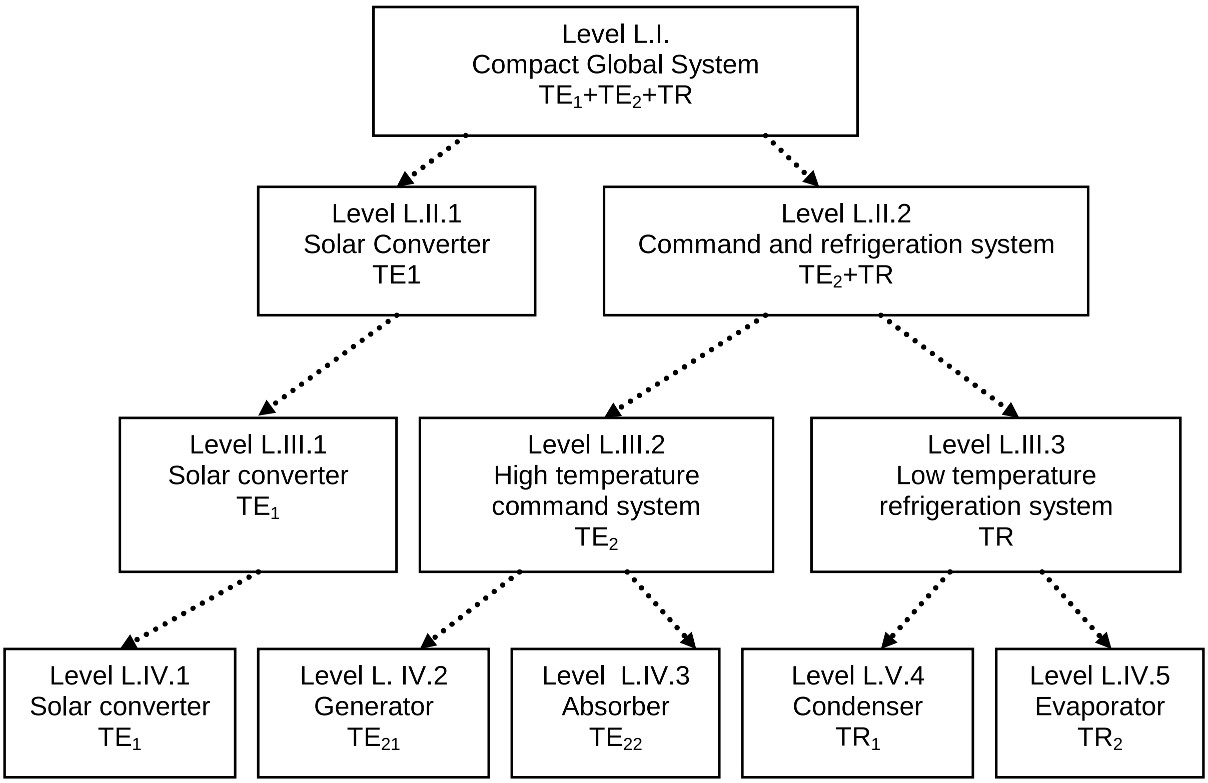


Fig. 2. Hierarchical decomposition of the solar absorption refrigerator.

3. GENERAL CHARACTERISTICS OPTIMIZATION

According to the functional and conceptual unknowns' apparition in the mathematical model, the study could concern a sublevel, a level or a set of sublevels. Mathematical equations present then some couplings between the optimal performance characteristics of the cycle. Let's consider, as an example, the subsystem formed by the solar thermal converter (TE_1). The Fig. 3 represents its equivalent model.

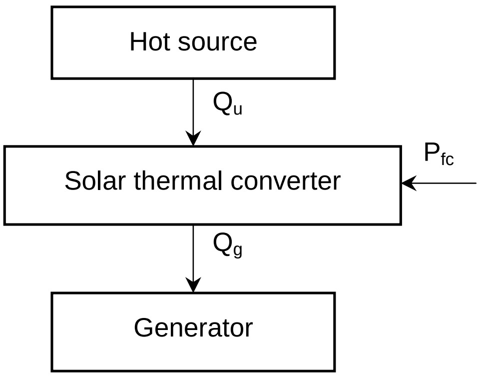


Fig. 3. Thermal solar converter model (TE_1)

The heat transfers obey a linear law. They are defined as follow:

(1) $Q_g = U_g A_g (T_{cs} - T_g)$

This subsystem also receives the Q_u flux of the solar concentrator defined by:

(2) $Q_u = UA_u (T_{sc} - T_{cs})$

The coefficient of performance is expressed according to the type of machine. For a refrigerator, it is equal to:

(3) $$COP = \frac{Q_e}{Q_g + W}$$

While disregarding the power W, the coefficient of performance for an absorption refrigerator is written:

(4) $$COP = \frac{Q_e}{Q_g}$$

Introducing the power P_{ref} exchanged between the thermal engine TE2 and the thermal receptor TR, the expression (4) could be written as:

(5) $$COP = \frac{P_{ref}}{Q_g} \frac{Q_e}{P_{ref}}$$

The two ratios in this last expression are the efficiencies respectively of TE_2 and of the TR. While replacing theses efficiencies by their mathematical expressions [15], the COP takes the form:

(6) $$COP = \left\{ 1 - \frac{T_{si}}{T_{sc} - \frac{Q_g}{A_h U_h}} \right\} \left\{ \frac{T_{sf} - \frac{Q_e}{U_r A_r}}{T_{si} - T_{sf} + \frac{Q_e}{U_r A_r}} \right\}$$

where:

(7) $$U_h = \frac{U_g U_a}{\left(\sqrt{U_g} + \sqrt{U_a}\right)^2}$$

and:

(8) $$U_r = \frac{U_e U_c}{\left(\sqrt{U_e} + \sqrt{U_c}\right)^2}$$

The heat transfer areas of the thermal engine and the thermal receptor are respectively:

(9) $A_h = A_g + A_a$

(10) $A_r = A_c + A_e$

(11) $A = A_h + A_r$

The Lagrange function is [4]:

(12) $$L(l, T_j) = F + l_k \left(\sum Q_i\right) + l_{k+1} \left(\sum \frac{Q_i}{T_j}\right)$$

where T_j is the temperature of the heat sink corresponding to the interface i.

In the case of a three sources refrigerator, and the presence of the first and the second principle of thermodynamic in the constraints in the Lagrange multipliers optimization, the mathematical system regrouping the functional and conceptual parameters could be deduced:

- For the endoreversible model:

(13) $$-1 + l \frac{T_{cs}}{T_g^2} = 0$$

(14) $$UA_g + UA_u - l \left[UA_u \frac{T_{sc}}{T_{cs}^2} + UA_g \frac{1}{T_g^2} \right] = 0$$

(15) $$UA_u \frac{(T_{sc} - T_{cs})}{T_{cs}} - UA_g \frac{(T_{cs} - T_g)}{T_g} = 0$$

- For the exoreversible model:

(16) $$-1 + l \frac{T_{cs}}{T_{sc}^2} = 0$$

(17) $$-1 + l \frac{T_{cs}}{T_g^2} = 0$$

$$(18)\quad UA_u \frac{(T_{sc}-T_{cs})}{T_{sc}} - UA_g \frac{(T_{cs}-T_g)}{T_g} = 0$$

The partial derivatives of the Lagrange L in relation to the multiplier λ and to the temperatures T_j form a hyper-static system of equations. This system does not present all necessary parameters to the definition of the functional and conceptual features of the cycle. To have a system including all the unknown parameters, it will be necessary to apply this optimization step successively to different levels of the sub-structuring.

4. RESULTS AND DISCUSSION

The analysis of the endoreversible model has permitted to derive that the frigorific fluid and the rich solution temperatures respectively in the condenser and the absorber are equal according to the same external source connection of the two elements.

The point of merit is that in the chosen temperature ranges, the COP has a real aspect. It varies from 0.28 to 0.575, which define the convenient work zone. Regarding the influence of the intermediate source's temperature T_{si} (Fig. 4), the existence of an optimal temperature T_{si} equal to 28°C with a correspondent COP of 0.48 could be notified. It has a great influence on the cycle performances. But, there is no need to increase infinitely the temperature T_{sc}. It makes a COP asymptotic variation. The COP takes then a constant value 0.455. The exoreversible results shows that the maximal COP related to the temperature ranges is in the order of 0.385 for a T_{si} of 27°C (Fig. 5).

Mathematical relations between the interfaces conductances and the thermal solar converter one have been derived. The Fig. 6 shows the influence of the intermediate source's temperature T_{si} on the ratio of the interface i conductance and the solar converter conductance UA_i/UA_u, renowned α. The endoreversible simulations prove that in the chosen temperature ranges of T_{si}, α varies from 0.32 to 1.6. When the T_{si} values are greater than 50°C, the ratios have tendency to converge toward the equality. The ratio related to the evaporator is the biggest when compared to those of the condenser, generator and finally the absorber. These results are interesting regarding the absorption machines design viewpoint. In fact, they permit the conceptual feature deduction. As an example, for T_{si} equal to 40°C, the UA_i/UA_u of the evaporator, the condenser, the generator and the absorber are respectively equal to 1.62, 1.2, 0.96 and 0.55.

The variations of the COP according to the variations of the heat transfer areas A_h and A_r, are also studied (Fig. 7). For the endoreversible model, when A_h increases, the output of the thermal receptor R_{TR} decreases and the thermal motor one R_{TE2} increases (Fig. 7.a). An intercept point exists and it corresponds to the equality between the two outputs (in the order of 0.68). This point corresponds also to A_h and A_r respectively equal to 0.35 m^2 and 0.625 m^2. In this case, the COP is equal to 0.46. When T_{si} increases, the thermal receptor efficiency R_{TR} increases and the thermal engine one R_{TE2} decreases. When T_{sf} increases, it exist an intercept point corresponding to the equality between the two efficiencies (in the order of 0.68). This point corresponds to T_{si}, T_{sf} and T_{sc} respectively equals to 28°C, 10.5°C, and 116°C and to a COP value equal to 0.46.

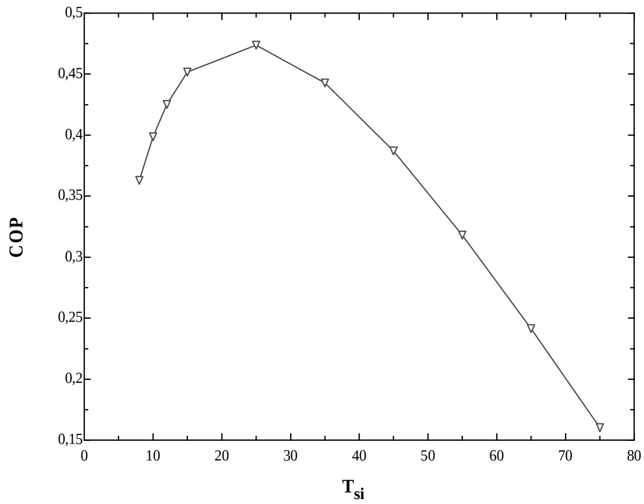


Fig. 4. Influence of intermediate source temperature T_{si} on the COP for endoreversible model.

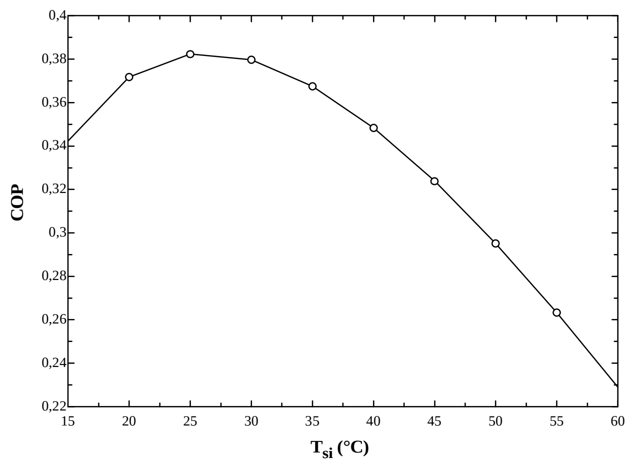


Fig. 5. Influence of intermediate source temperature T_{si} on the COP for exoreversible model.

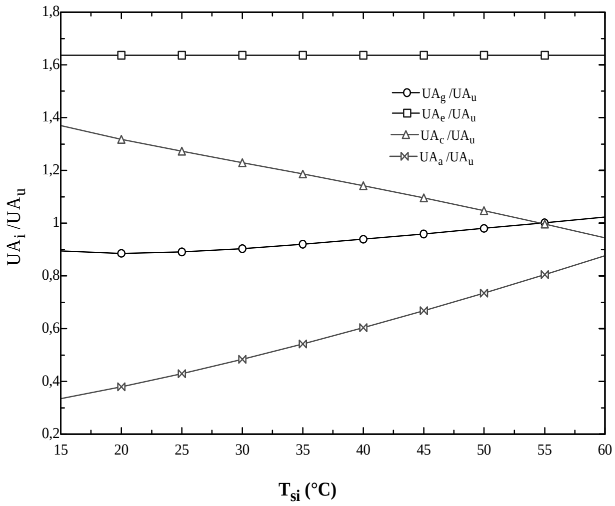
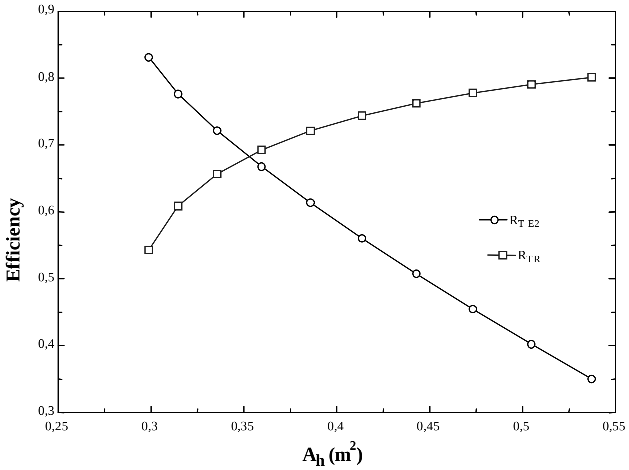
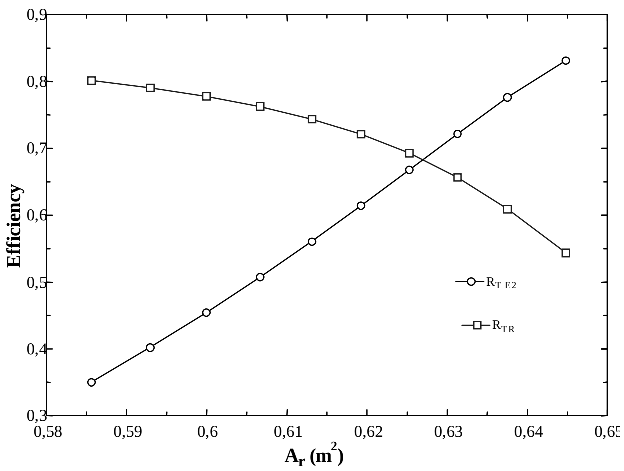


Fig. 6. Influence of intermediate source temperature T_{si} on U_{Ai}/U_{Au}.



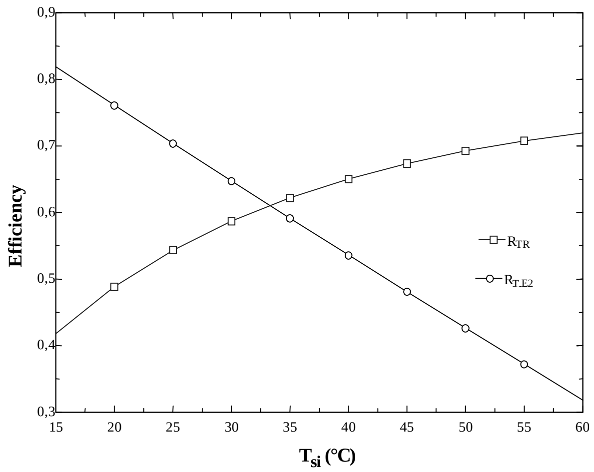
(a)



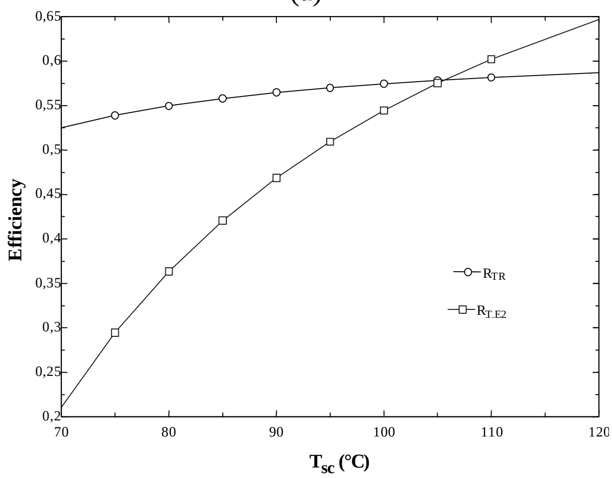
(b)

Fig. 7. Influence of heat transfer areas A_h and A_r on the efficiencies of the thermal receptor R_{TR} and the thermal engine R_{TE2} for endoreversible model.

Concerning the exoreversible simulation and for T_{si}, T_{sc} and T_{sf} equal respectively to 35°C, 106°C and 10°C, the efficiencies R_{TR} and R_{TE2} are optimal and equal to approximately 0.6 (Fig. 8).

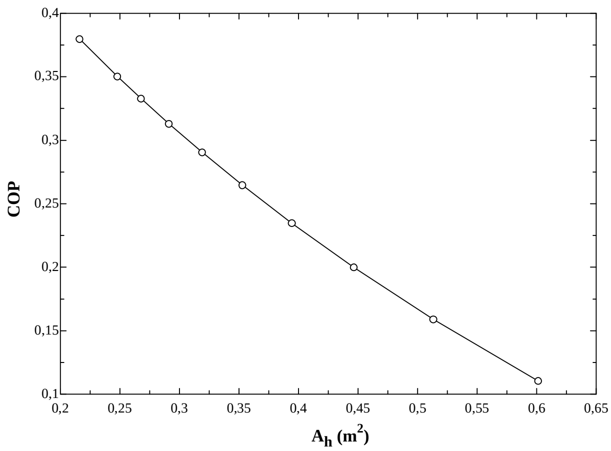


(a)

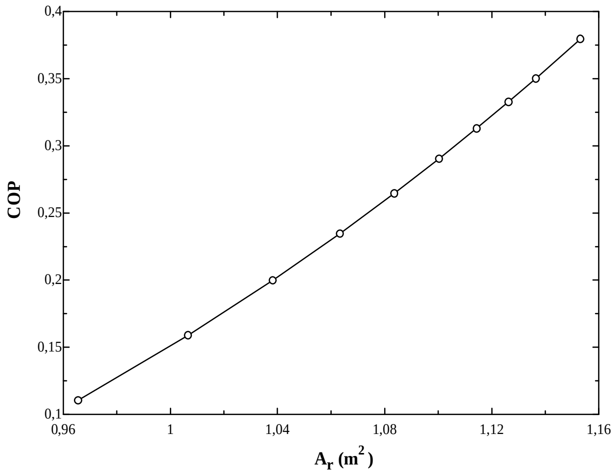


(b)

Fig. 8. Influence of the intermediate source temperature T_{si} and the hot source temperature T_{sc} on the efficiencies of the thermal receptor R_{RT} and the thermal engine R_{MT2} for exoreversible model.



(a)



(b)

Fig. 9. Influence of heat transfer areas A_h and A_r on the COP.

For the weak values of A_h and relatively important values of A_r, the COP is relatively important. For example, for an A_h of about 0.25 m^2 and A_r of about 0.25 m^2, the COP is equal to 0.35 (Fig. 9).

5. CONCLUSION

A solar refrigerator conceptual design is proposed. Both hierarchical decomposition and endoreversible and exoreversible models are used. Optimal conceptual and functional parameters are coupled into interesting relations. One of the established mathematical model features is to get relations between the exchange areas and the temperatures. Therefore, it permits the optimized sizing of the installation. The influence of the external sources temperatures on the general performance is studied. The exchange areas A_i coupled to the global heat exchange coefficients U_i varies sensitively with the sources temperature variations. The aspect of the compromise between the performances of the cycle and the areas is discussed. Indeed, the efficiencies of the thermal receptor R_{TR} and the thermal motor R_{TE2} and the COP are very sensitive to the variation of heat transfer areas A_h and A_r.

The features of this work are important. They concern the optimal relations establishment with a simple but universal method. It passes in the researches disciplinary decentralization.

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