THERMODYNAMIC EVALUATION OF DIFFERENT HEAT PUMP VARIATIONS FOR WATER PURIFICATION

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Abstract

As an alternative method for water purification researchers are intending the use of heat pumps. The absorption heat pumps turn in to be an attractive option to use low temperature energy and by means of a thermodynamic cycle rise it to high temperature energy. It can be possible by means of the circulation of a secondary circuit of diluted and concentrated solutions of a working pair formed by lithium bromide / water or Carrol / water solutions.

The use of a single stage absorption heat transformer (SSHT) has been proposed and optimised for water purification.

Thermodynamic evaluations of two working pairs are shown, lithium bromide / water and Carrol / water. These evaluations show that it is possible to use waste energy to carry out the water purification in residential areas far from the supply of drinkable water in Mexico.

The thermodynamic efficiency has been calculated for different operation conditions. The coefficient of performance (COP) has been optimised in function of the generation and evaporation temperatures, when the SSHT operates at temperatures near to the ambient temperature.

The results show the operation conditions for both mixtures with the main and dominant environmental conditions in the central region of Mexico with out drinkable water supply.

1. INTRODUCTION

Mexico has a population of 100 million dispersed inhabitants in all its national territory; there are some populations far from the net of drinkable water, that maintains them far from the desirable conditions of health.

Great part of the Mexican territory presents favourable conditions for the use of solar collectors for heating of water, however, the temperatures of flat plate solar collectors operating far from the net of drinkable water, are limited in providing enough energy at the temperatures required to purify water.

The temperatures at which a flat plate solar collector can operate are inferior to 90 °C, reason why it is necessary to use a method of production of drinkable water that uses temperatures below the boiling point of water at atmospheric pressure.

2. DESCRIPTION OF THE SYSTEM

This article intends the proposal of a single stage heat transformer (SSHT) to elevate low temperature energy to a level that is enough to guarantee the purification of water [Holland, 2000].

A thermal transformer is a heat pump used to elevate the entering temperature to the cycle up to a higher desired level [Rivera, 1998].

A heat transformer operates as follows: Energy vaporizes refrigerant from the strong solution at medium pressure and medium temperature in a generator, in which it concentrates a salt solution, the vapour condenses in the condenser, then the condensate is pumped to an area of high pressure in which it evaporates at high pressure and medium temperature. Inside the absorber the vapour contacts with the strong salt solution coming from the generator, this causing the absorption process delivering heat at a higher temperature in the area of high pressure. This heat is used to purify water at atmospheric pressure without being in contact with the salt solutions. The diluted salt solution formed inside the absorber returns to the generator preheating before entering the generator the strong salt solution with a heat exchanger (economizer), concluding this way the operation cycle of operation of the system. See diagram 1.

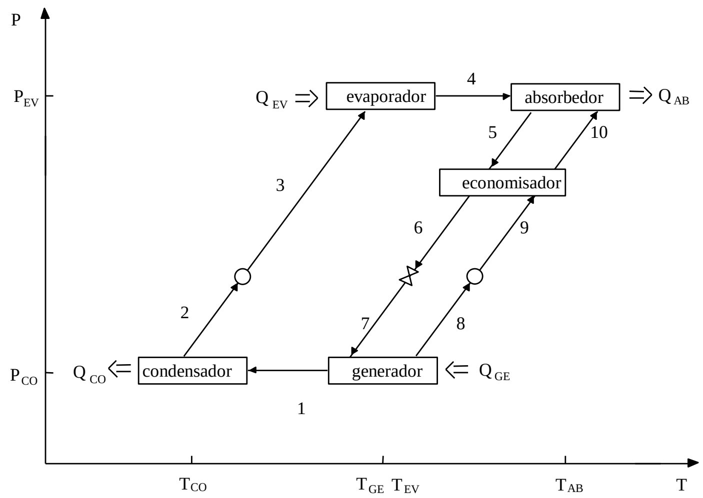

Diagram 1. Single stage heat transformer

3. WORKING PAIRS USED

To carry out the study of the behaviour of the system it was simulated with two appropriate mixtures for their use in heat transformers. Lithium bromide and water was used and the other is a solution of Carrol (lithium bromide and ethylenglycol 3.5:1 weigh ratio) in water [Rivera, 1998b]. These couples have been considered for this study due to the operation conditions that are needed for the purification of water and in which the selected pairs can operate in a SSHT.

4. CONSIDERATIONS

In order to carry out this study the following considerations were made: the temperatures at which the SSHT can supply energy are lower than 90° C and the temperatures at which it can condense the refrigerant in the SSHT are between 20 and 30°C, close to the ambient temperature (T_{AMB}). These temperatures cover the central region of Mexico. With these considerations, the behaviours of two SSHT have been simulated, one using lithium bromide and the other Carrol in water solutions respectively. Both have an economizer with an effectiveness (η) of 0.7.

To determine the thermodynamic efficiency of the system the Coefficient of Operation (COP) is used [Rivera, 2001]

$$COP = Q_{AB} / Q_T \quad (1)$$

$$Q_T = (Q_{GE} + Q_{EV}) \quad (2)$$

This COP is based on derived calculations of the enthalpies calculated in each part of the SSHT to determine the quantity of available energy to be used in the purification of water (Q_{AB}) in relationship of the given energy (Q_T). Q_T is parameterised in function of the energy given to the evaporator of the cycle (Q_{EV}) equal to 1 kW, because the quantity of remaining energy is given in the generator (Q_{GE}) and it varies as function of the conditions at which the condensation (T_{AMB}) and the generation of the refrigerant (T_{GE}) are carried out.

$$T_{CO} \approx T_{AMB} \quad (3)$$

The thermodynamic efficiency (I_E) has been calculated [Abrahamsson, 1993] as the relationship of the COP calculated in function of the enthalpies regarding the COP of Carnot (COP_C).

$$I_E = COP / COP_C \quad (4)$$

$$COP_C = f\,(T_{AB}, T_{EV}, T_{CO}) \quad (5)$$

COP_C is independent of the used pair. The production of purified water (P_W) it has been calculated as function of the useful heat liberated in the absorber.

$$P_W = f\,(Q_{AB}) = Q_{AB} / \lambda \quad (6)$$

5. RESULTS

The simulations carried out to determine the quantities of water purified in function of the existent operation conditions in the central part of Mexico are shown In these figures, the quantity of purified water by hour is shown as a function of the generation temperature, for different operation conditions.

Figures 1 to 4 show the behaviour of lithium bromide in water solutions water purification using a single stage heat transformer, and figures 5 to 8 show the behaviour for Carrol – water solutions.

In Fig. 1, the production of purified water (P_W) is shown to vary from 1.9 to 2.1 kg/hr for the conditions of T_{EV} = 60 and T_{GE} from 70 to 83 °C. This graph shows in the second axis the thermodynamic efficiency (I_E), which diminishes when increasing T_{GE}.

In Fig. 2, P_W is shown to vary from 1.85 to 2.15 kg/hr with T_{EV} = 65 and T_{GE} from 65 to 81 °C. I_E shows a relative maximum for the different values of T_{AMB}.

In Fig 3, P_W is shown to vary from 1.8 to 2.15 kg/hr for values of T_{EV} = 70 and T_{GE} from 60 to 80 °C. Again I_E shows a relative maximum for each T_{AMB}.

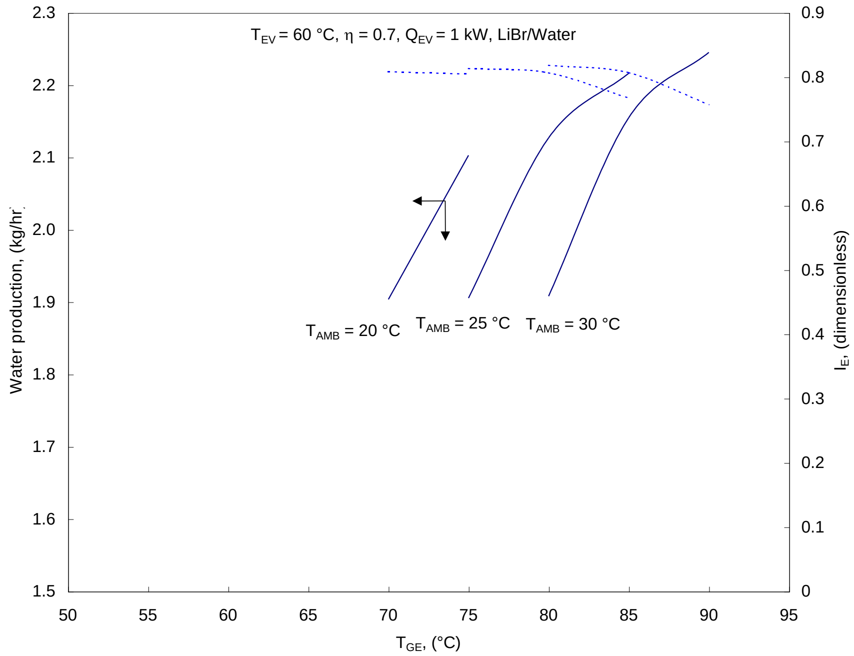

Figure 1. Water production and thermodynamic efficiency as function of generator temperature for three ambient temperatures and 60°C of evaporator temperature in a SSHT.

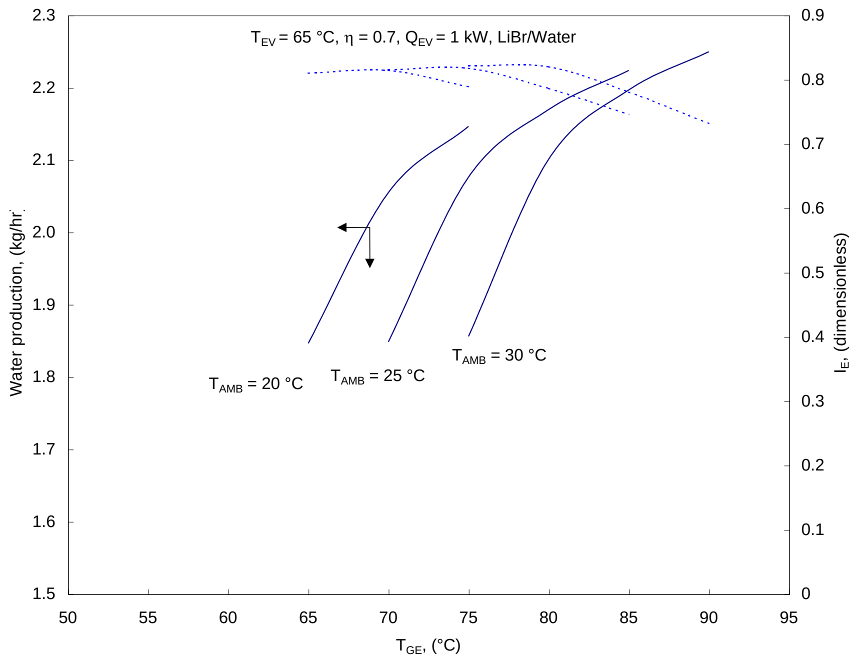

Figure 2. Water production and thermodynamic efficiency as function of generator temperature for three ambient temperatures and 65°C of evaporator temperature in a SSHT.

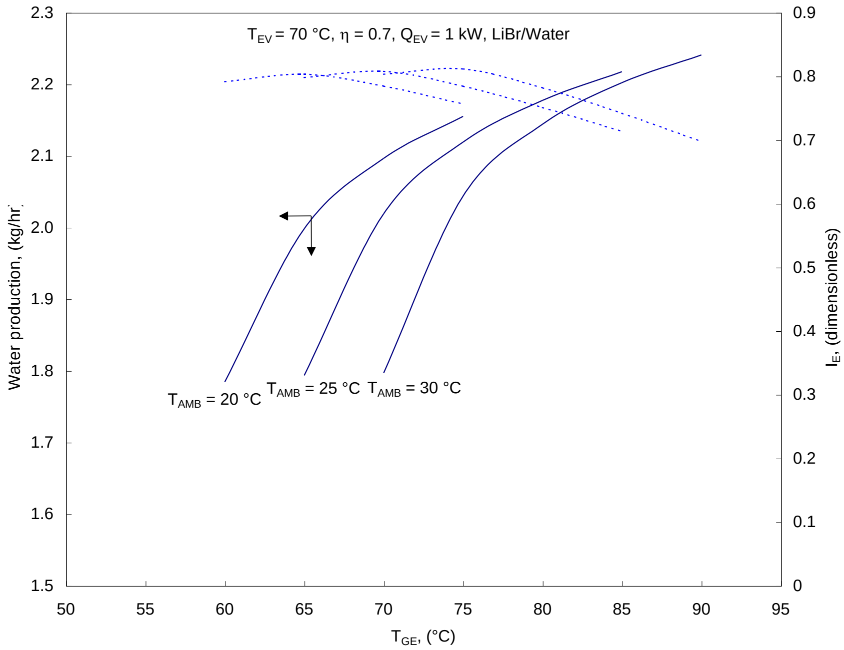

Figure 3. Water production and thermodynamic efficiency as function of generator temperature for three ambient temperatures and 70°C of evaporator temperature in a SSHT.

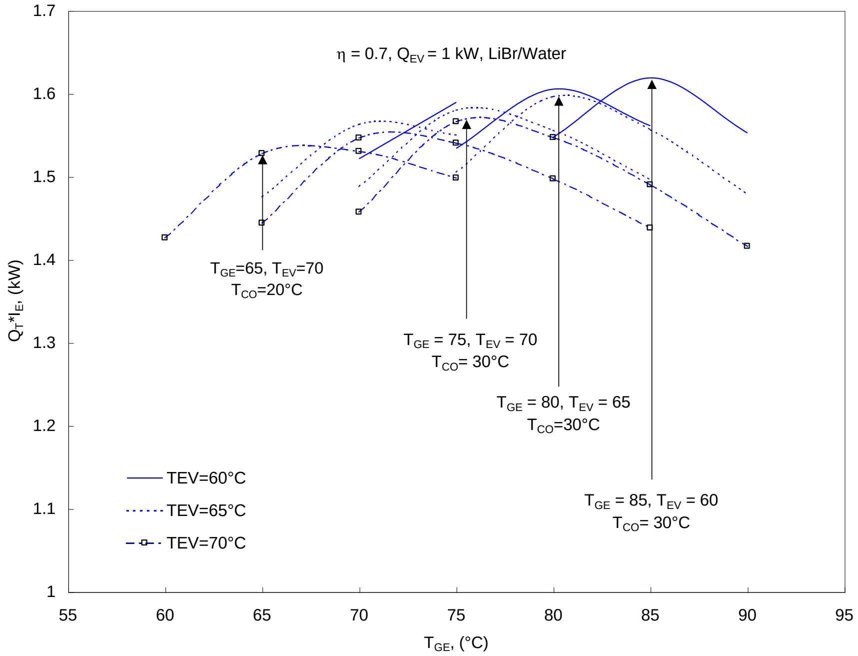

Figure 4. Available energy for water purification in a SSHT as function of generator temperature using lithium bromide.

In Fig. 4 the product Q_T*I_E is shown, it represents the available energy of the system for P_W and it is larger than 1 kW, used as a basis of calculation in Q_{EV}. In this graph a family of curves are shown for each condition of $T_{EV,}$ in order to determine the condition in which the biggest energy availability is obtained. However, the conditions depend on T_{AMB}. In this figure it is shown that the smallest value relative to the maximum value corresponds to T_{EV} = 70, T_{GE} = 65 and T_{CO} = 20°C, this is a condition optimised for production of P_W. However, if locations with ambient conditions making it difficult to achieve T_{CO} = 20°C, it will be a good condition for upper values of T_{GE}.

In Figure 5 for Carrol/water, P_W is shown to vary from 1.88 to 2.18 kg/hr for T_{EV} = 60 and T_{GE} from 70 to 90 °C.

In Fig. 6, P_W is shown from 1.85 to 2.20 kg/hr for T_{EV} = 65 and T_{GE} from 65 to 90 °C.

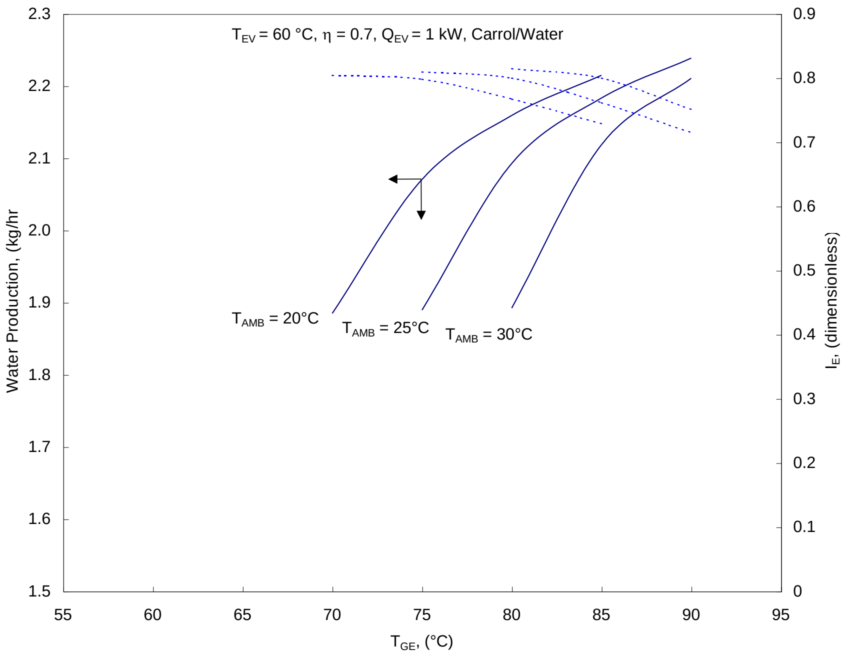

Figure 5. Water production and thermodynamic efficiency as function of generator temperature for three ambient temperatures and 60°C of evaporator temperature in a SSHT using Carrol.

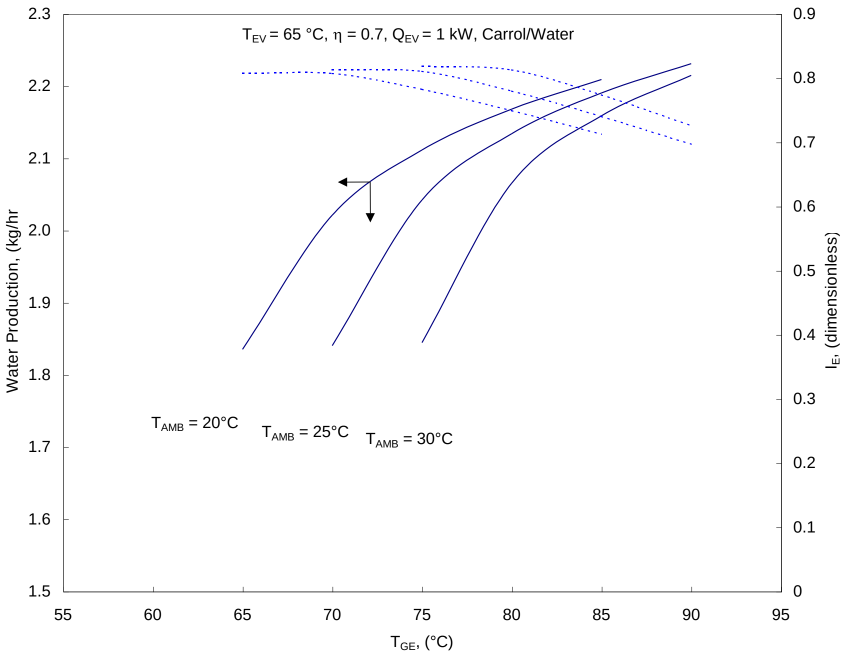

Figure 6. Water production and thermodynamic efficiency as function of generator temperature for three ambient temperatures and 65°C of evaporator temperature in a SSHT using Carrol.

In Fig. 7, P_W is shown from 1.77 to 2.20 kg/hr for T_{EV} = 70 and T_{GE} from 65 to 87 °C. In Figs. 5, 6 and 7 the values of I_E diminish when increasing the value T_{GE}.

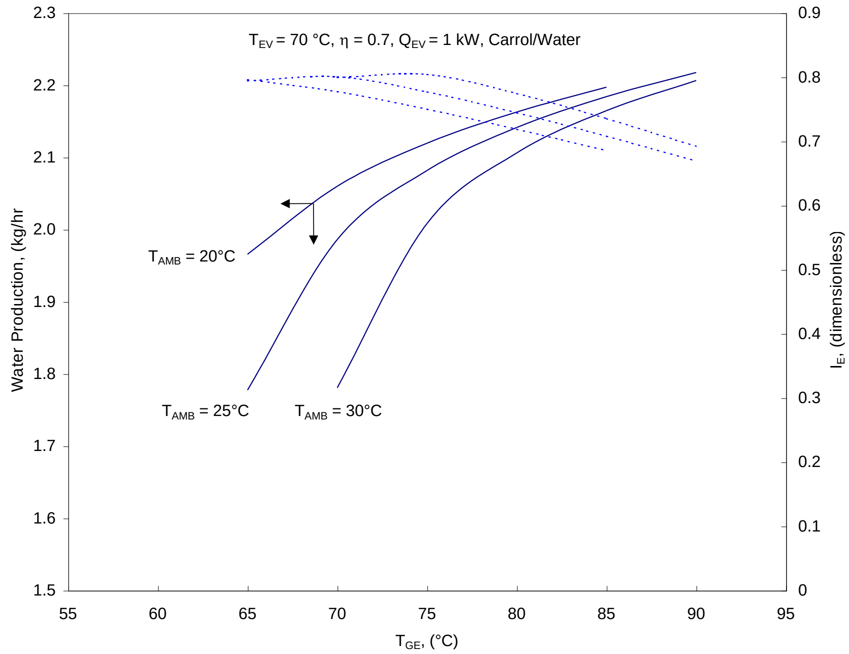

Figure 6. Water production and thermodynamic efficiency as function of generator temperature for three ambient temperatures and 65°C of evaporator temperature in a SSHT using Carrol.

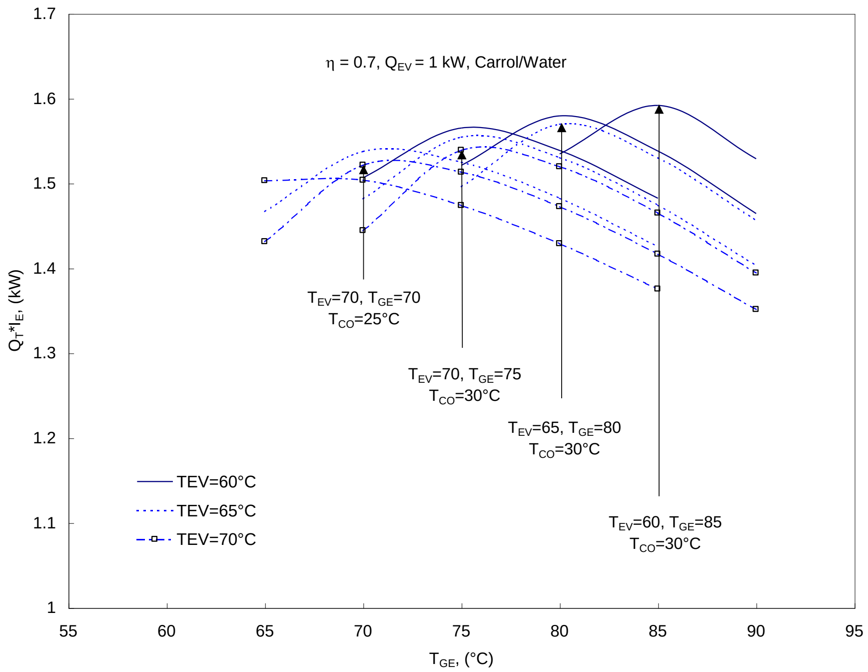

Figure 8. Available energy for water purification in a SSHT as function of generator temperature using Carrol.

In Fig. 8, similar to Fig. 4 for lithium bromide, the product Q_T*I_E is shown. It is shown that the smallest value in the relative maximum values corresponds for T_{EV} = 70, T_{GE} = 70 and T_{CO} =

25°C that it is an optimised condition for production of P_W. However, for T_{CO} = 30°C a better condition second condition is obtained for T_{GE} = 75 °C.

6. DISCUSSION

In this article the possible conditions have been shown for the purification of water using energy with temperature levels lower than 90°C, demonstrating that it is possible to purify water with good thermodynamic efficiency with lithium bromide - water solutions at temperatures of 70°C if T_{AMB} = 20 °C and in the cases with T_{AMB} = 30 °C, with temperatures of 75 °C.

In the case of the Carrol – water,solutions it is shown that an optimised value of P_W can be obtained for T_{GE} = T_{EV} = 70°C when T_{AMB} = 25 °C and in the case of T_{AMB} = 30 then the optimum value is T_{GE} = 75 °C.

7. CONCLUSION

Conditions have been shown for the production of purified water with a SSHT using temperatures lower than 75 °C for the environmental conditions of the central part of Mexico and the best conditions have been determined for different values of the ambient temperatures.

The concept of Thermodynamic Efficiency was used in order to be able to determine the best conditions in particular for each condition of the two working pairs used in single stage heat transformer.

It has been shown that when giving 1 kW of thermal energy at low temperature (75°C) to the evaporator of the SSHT, around 1.77 to 2.1 kg/hr of purified water can be obtained under typical ambient conditions of the central part of Mexico.

8. NOMENCLATURE

COP	Coefficient of performance
COP_C	Carnot coefficient of performance
f	function
I_E	Thermodynamic efficiency
P_W	Production of purified water
Q_{AB}	Absorber energy
Q_{EV}	Evaporator energy
Q_{GE}	Generator energy
Q_T	Total inlet energy
T_{AMB}	Ambient temperature
T_{CO}	Condenser temperature
η	Economizer effectiveness
λ	Latent heat of vaporisation
λ	

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