Resorption Heat Transformers Operating with the Ammonia-Lithium Nitrate Mixture

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Abstract

Absorption heat transformers (AHT) are interesting devices for recovering and upgrading thermal energy which consume very low amount of primary energy. To date, H_2O-LiBr is the most common working pair used in absorption heat transformers. However, H_2O-LiB mixture has several well-known drawbacks. On the other hand, heat transformers operating with NH_3-H_2O are not so common because they should operate at very high pressures. The use of a resorption circuit in heat transformers is an interesting alternative to reduce the high pressure level. A resorption heat transformer (RHT) is very similar to an absorption heat transformer, where the evaporator-condenser circuit is replaced by a second desorber-absorber circuit. In the literature it has been reported very few studies about resorption heat transformers operating with the NH_3-H_2O working pair. In this paper, the modeling and thermodynamic analysis of a single stage absorption heat transformer (AHT) and a single stage resorption heat transformer (RHT) operating with the NH_3-$LiNO_3$ mixture is presented. The systems using the NH_3-$LiNO_3$ do not require rectification process; therefore the systems using this mixture are simpler than those operating with NH_3-H_2O. In the present study the coefficients of performance, the exergetic efficiencies and the gross temperature lifts are analyzed as function of the main operating system temperatures.

Keywords: Absorption Heat Transformer; Resorption Heat transformers; Ammonia-Lithium Nitrate.

Nomenclature

1-24	thermodynamic state points
A	absorber
AHT	absorption heat transformer
C	condenser
COP	coefficient of performance (-)
D	desorber
E	evaporator
EV	expansion valve
G	generator

Subscripts

A	absorption
C	condensation
D	desorption
E	evaporation
G	generation
H	high
L	low
M	medium
P1	pump 1
P2	pump 2

GTL	gross temperature lift (°C)
h	specific enthalpy (kJ/kg)
H_2O	water
LiBr	lithium bromide
$LiNO_3$	lithium nitrate
$\dot{m}$	mass flow rate (kg/s)
NH_3	ammonia
P	pressure (kPa)
$\dot{Q}$	thermal capacity (kW)
R	resorber
RP	pressure ratio
RHT	resorption heat transformer
SHE	solution heat exchanger
t	temperature (K)
T	temperature (°C)
$\dot{W}$	mechanical power (kW)
X	solution concentration (kg refrigerant/kg solution)
R	resorption
SA	strong-absorption
SR	strong-resorption
WA	weak-absorption
WR	weak-resorption

Greek letters

η	exergetic efficiency (-)
υ	specific volume (m^3/kg)

1. Introduction

The largest sources of waste heat for most industries are exhaust gases from burners in process heating; lower temperature gases from heat treating furnaces, dryers, and heaters; and heat from heat exchangers, cooling liquids, and gases. Waste heat within liquids includes cooling water, heated wash water and blow-down water. [1]. According with the “Waste Heat Recovery: Technology and Opportunities in U.S. Industry report [2] the waste heat sources can be classified in three categories: high temperature (>650 ºC), medium temperature (230°C–650°C), and low temperature (<230°C). The report also identifies uncovered waste heat in different temperature ranges just in the United States, concluding that the amount of heat wasted above 25ºC reference temperature is 433.1 x 10^9 kW per year and lowers to 75 x 10^9 kW per year if the reference temperature is raised to 149°C. Industries working in this range of temperatures are food industries, textile, paper, drying and synthetic rubber among others.

Absorption heat transformers (AHT) are some of the most interesting devices for energy saving which are characterized to consume a very low amounts of primary energy [3]. These devices are considered promising because they can operate with thermal energy, which can be obtained from industrial waste heat or renewable energies such as geothermal or solar. Furthermore, these systems can transform low quality thermal energy at high temperature levels [4]. Typically, they can recover up to 50% of waste heat and do not require high operating costs and maintenance [5].

In the literature there are some comprehensive studies on heat transformers operating with different working fluids. Parham et al. [6] analyzed simple and advanced systems with their applications in different industrial processes. Donnellan et al. [7] analyzed heat transformers with an emphasis on optimization studies, alternative configurations cycles, working fluids and industrial applications. Rivera et al. [8] reported the state of the art of theoretical and experimental studies of simple and advanced systems operating with conventional and alternative mixtures. Arh and Gaspersic [9] showed a method for calculating the coefficients of performance of different advanced absorption cycles. The cycles analyzed operated with four temperature levels and two or three pressure levels operating with the H_2O-LiBr and NH_3-H_2O mixtures. They concluded that it was necessary to find new working mixtures that could be used in multistage absorption systems. Kripalani et al. [10] presented a theoretical study of a single stage heat transformer operating with different working fluids such as: H_2O-LiBr, R21-DMF, R22-DMF and R22-DMETEG. They concluded that the H_2O-LiBr and R21-DMF mixtures were the best, producing temperature increments of about 30 °C. Tyagi et al. [11] presented a theoretical study of a single stage heat transformer using various binary mixtures as working fluids: NH_3-1,4 butanediol, NH_3-2,3 butanediol, NH_3-TEGDME and SO_2-DMA. They concluded that mixtures using NH_3 have good potential.

To date, AHTs using the mixture H_2O-LiBr are the best known and developed systems. However, the LiBr-H_2O mixture has some drawbacks, such as: high corrosivity and low solubility which limits the temperature rise in the absorber due to crystallization problems. Meanwhile, heat transformers operated with NH_3-H_2O are not common, because they must operate at high pressures. Using a circuit of resorption in the heat transformer is interesting to reduce the pressure level in the high zone. The resorption heat transformer (RHT) is very similar to an absorption heat transformer (AHT), the difference is that the evaporator-condenser circuit is replaced by a second absorption-generating circuit (referred resorber-desorber, respectively).

There are just few studies about resorption heat transformers. Bhatt et al. [12, 13] presented a theoretical study of resorption heat pumps and heat transformers operating with the R21-NMP and R21-DMA mixtures. They demonstrated that the systems with resorption achieve higher temperature increments (47 K) than simple heat transformers. The R21-NMP mixture achieved the best COPs which varied between 0.33 and 0.50, while the R21-DMA mixture achieved higher temperature increments. Stephan and Seher [14, 15] discussed single and double stage heat transformers and a resorption heat transformer. Tyagi [16] presented the theoretical performance of single and double stage heat transformers and a simple system with resorption using the NH_3-H_2O mixture. They showed that single stage heat transformers have better COP than the system with resorption and they concluded that the proposed mixture could be quite attractive to be used in heat transformers.

Based on the literature review, it is clear that there are just few studies related with resorption heat transformers and none of them use the NH_3-$LiNO_3$ mixture. Because of this, in this paper, the modeling and thermodynamic analysis of a single stage absorption heat transformer (AHT) and a single stage resorption heat transformer (RHT) operating with the NH_3-$LiNO_3$ mixture is presented. The systems using the NH_3-$LiNO_3$ do not require rectification process; therefore the systems using this mixture are simpler than those operating with NH_3-H_2O. In the present study the coefficients of performance, the exergetic efficiencies and the gross temperature lifts are analyzed for both systems as function of the main operating system temperatures.

2. Description of the systems

2.1 Absorption Heat Transformer (AHT)

An AHT is evidently a single effect absorption heat pump (or absorption chiller) working inversely [17], basically it consists of five heat exchangers: an evaporator, a condenser, a generator, an absorber and a solution heat exchanger; also it uses two pumps and an expansion valve, as shown in Figure 1.

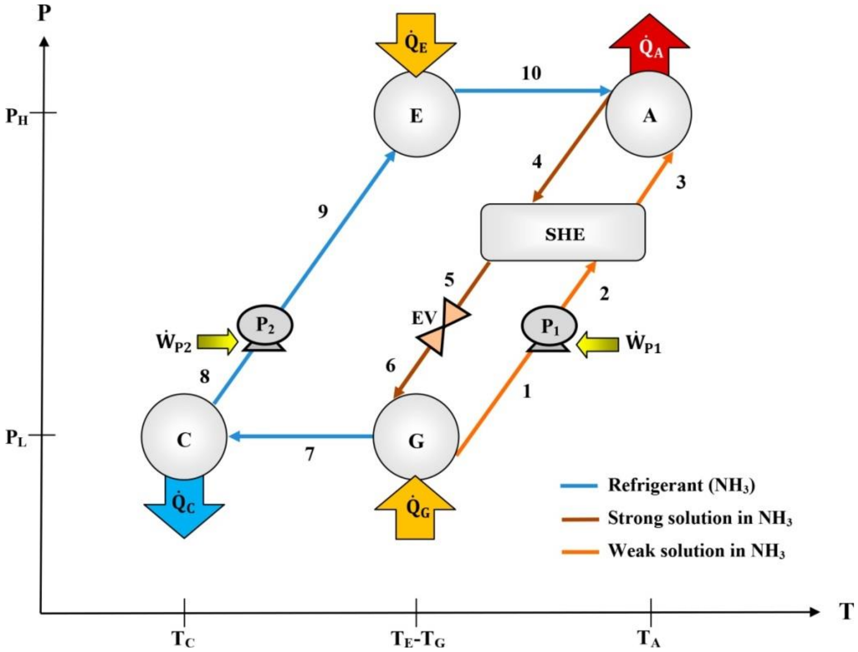

Figure 1. Schematic diagram of a single-stage heat transformer (AHT).

Heat is supplied at intermediate temperature $T_E = T_G$ to the evaporator $\dot{Q}_E$ and generator $\dot{Q}_G$, respectively. With the heat supplied to the generator, the solution with high concentration of refrigerant (6) boils, so a part of the refrigerant vaporizes (7) leaving the remaining solution with low refrigerant concentration (1). The solution with low concentration of refrigerant leaving the generator (1) is pumped to the absorber (3), passing previously through the solution heat exchanger (2) where is preheated. Meanwhile, the refrigerant produced in the generator (7) passes to the condenser where it is condensed rejecting heat ($\dot{Q}_C$) at ambient temperature T_C, and then is pumped to the evaporator (9) where it is evaporated. Then, the refrigerant vapor produced is sent to the absorber (10) where it is absorbed by the solution coming from the generator (3). As a result of the absorption process, an amount of useful heat ($\dot{Q}_A$) at high temperature T_A is produced. Then, the solution with high temperature and high refrigerant concentration (4) is sent to the solution heat exchanger and then to the generator (6). In the heat exchanger the solution with low refrigerant concentration is preheated (3), while the solution with high refrigerant concentration is cooled (5).

2.2 Resorption Heat Transformer (RHT)

A RHT is a device with great potential for waste heat recovery and energy saving. Usually, in an absorption heat pump, the cooling fluid in the condenser is about 5 to 10 K lower than the condensation temperature, and the source temperature in the evaporator is about 5 to 10 K above the boiling point of the refrigerant. These irreversibilities can be reduced if the condenser and evaporator are replaced by a resorber and a desorber [12, 13]. RHT is composed of two solution circuits: an absorption circuit between the absorber-generator (1-2-3-4-5-6-1) and a resorption circuit between resorber-desorber (8-9-10 -11-12-13-8), as can be seen in Figure 2.

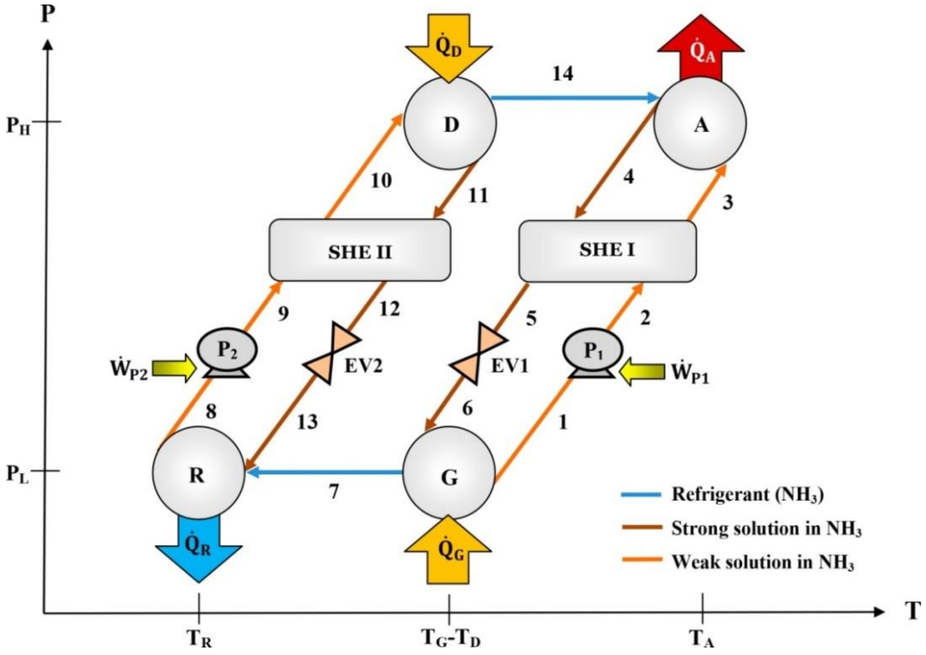

Figure 2.Schematic diagram of a resorption heat transformer (RHT).

The absorption circuit has the same operating principle as explained in Figure 1, while the resorption circuit operates inversely to the absorption circuit. The vapor produced in the generator is absorbed in the resorber at the minimum temperature T_R (7). Then, the solution with high refrigerant concentration (8) of the resorption circuit is sent to the desorber (10) to produce vapor (14) at intermediate temperature $T_G = T_D$. Then, the produced vapor is sent to the absorber (14). The weak solution of the absorption circuit (3) is again responsible to absorb the vapor producing the useful heat at the maximum system temperature T_A. The vapor produced in the absorption circuit is reabsorbed in the resorption circuit, and vice versa, thus the cycle operation is restarted.

The resorber and desorber operate by the Lorenz process, which considers finite differences of temperature and low differences between the input and output mass flow rates producing low exergy losses [18]. Therefore, the main advantages of a RHT regarding to AHT are [18, 19]: (a) lower pressure difference between the high and low zone and therefore less pumping work, (b) higher coefficients of performance and, (c) lower irreversibilities (Lorenz process). In addition, another favorable point when using the resorption circuit is to operate with a binary mixture instead of a pure fluid (in AHT high and low pressures are determined by the states in the condenser and evaporator where it is considered only the vapor pressure of pure refrigerant), which allows to have lower operating pressures. This fact could be very important for systems using NH_3 as refrigerant due to the high operating pressures.

Figure 3 shows a pressure-temperature diagram of a resorption heat transformer. The right parallelogram represents the absorption circuit (1-2-3-4-1) and the left one represents the resorption circuit (5-6-7-8-5). The concentrations of the resorption circuit, (weak and strong solution X_{WR}, X_{SR}) are obtained from T_E and P_H, and T_C and P_L, respectively. Meanwhile, the concentrations of the weak solution X_{WA} and strong solution X_{SA} of the absorption circuit are obtained from T_G and P_L and T_A and P_H, respectively.

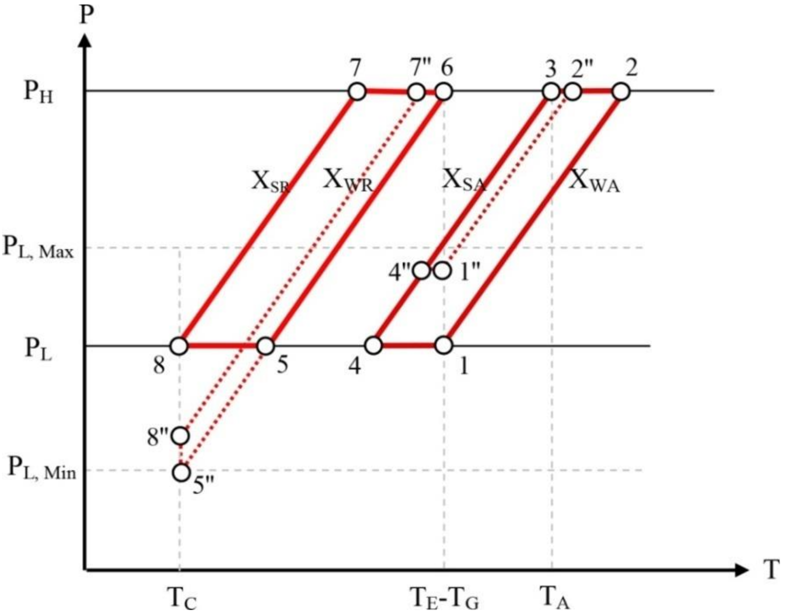

Figure 3. Diagram log P against 1/T for a RHT.

In order that a RHT can operate, it must be met that $X_{SR} > X_{WR} > X_{SA} > X_{WA}$, so that it is always possible to form parallelograms of the two circuits without overlap. Therefore, the limit operating conditions of a RHT are based on the four concentrations. To find the limit operating conditions, first a maximum pressure P_H should be defined appropriate to the system components. After T_E and T_A are defined, therefore X_{WR} and X_{SA} could be obtained (point 6 and 3, respectively). If it holds that $X_{WR} > X_{SA}$, then there are two limit operating conditions in which the system can operate: a maximum low pressure ($P_{L,Max}$) and a minimum low pressure ($P_{L,Min}$). The $P_{L,Max}$ is obtained when the parallelogram of the absorption circuit tends to overlap, that is, when the concentration gradient between X_{SA} and X_{WA} tends to zero (1"-2"-3-4"-1"). Thus, so that the system can operate should ensure that when a T_G and P_L are fixed, X_{WA} always be less than X_{SA} (1). Moreover, the $P_{L,Min}$ is obtained when the concentration gradient between X_{SR} and X_{WR} tends to zero (5"-6-7"-8"-5"). Thus, it should ensure that when a T_C and P_L are fixed, the X_{SR} always be greater than X_{WR} (8).

3. Theoretical analysis

In order to analyze the performance of the different heat transformers, mathematical models have been developed based on the thermodynamic properties of the mixture NH_3-$LiNO_3$, the mass and energy balances for each component of the cycles and some modeling assumptions. The properties of NH_3 were taken from Tillner-Roth [20], meanwhile for the NH_3-$LiNO_3$ mixture, the data and equations generated from the CREVER group [21] were used.

3.1 Modeling Assumptions

With reference to Figures 1 and 2, the assumptions for modeling the thermodynamic cycles are the following:

- The system operates in thermodynamic equilibrium.
- The pressure drops are negligible.
- The expansion valves are considered isenthalpic.
- At the exit of evaporator, condenser and desorber, the refrigerant is considered in saturated conditions.
- At the exit of generator, absorber, resorber and desorber, the solution is considered in saturated conditions.
- Not heat losses to the environment are considered from the system components.
- The restrictions for the operating temperatures are:

$$T_A > T_E = T_G > T_C \text{ (AHT)}$$
$$T_A > T_D = T_G > T_R \text{ (RHT)}$$

3.2 Performance parameters

In order to compare the different systems, the coefficient of performance (COP), the gross temperature lift (GTL) and the exergetic efficiency (η) were determined. The COP can be considered as the most important parameter that quantifies the performance of the system and the goal is to obtain the maximum possible value. The system COP is defined as the ratio of the useful heat produced in the absorber to the energy supplied to the system in the evaporator and the generator, which can be written as:

$$\mathrm{COP} = \frac{\dot{\mathrm{Q}}_{\mathrm{A}}}{\dot{\mathrm{Q}}_{\mathrm{E}} + \dot{\mathrm{Q}}_{\mathrm{G}} + \sum \dot{\mathrm{W}}_{\mathrm{pumps}}} \tag{1}$$

On the other hand, the purpose of a heat transformer is to increase the temperature of a waste heat source. Therefore, the GTL is introduced to quantify this increase in temperature and it is defined as the temperature difference between the absorber and the evaporator of the heat transformer:

$$\mathrm{GTL} = \mathrm{T}_{\mathrm{A}} - \mathrm{T}_{\mathrm{E}} \tag{2}$$

The exergetic efficiency (η) is based on the second law of thermodynamics, it represents the quantity and quality (temperature level) of heat input and useful heat output of the system. The η is defined as the ratio of exergy delivered in the absorber to the total exergy supplied to the system:

$$\eta = \frac{\dot{\mathrm{Q}}_{\mathrm{A}}\left(1 - \frac{\mathrm{t}_{\mathrm{c}}}{\mathrm{t}_{\mathrm{a}}}\right)}{\left(\dot{\mathrm{Q}}_{\mathrm{E}} + \dot{\mathrm{Q}}_{\mathrm{G}}\right)\left(1 - \frac{\mathrm{t}_{\mathrm{c}}}{\mathrm{t}_{\mathrm{e}}}\right) + \sum \dot{\mathrm{W}}_{\mathrm{pumps}}} \tag{3}$$

Finally, the pressure ratio (PR) is a parameter used only in cycles with resorption (RHT) and it is used to define the low pressure system from the maximum operating pressure, thus, the RP is defined as:

$$\mathrm{RP} = \frac{\mathrm{P}_{\mathrm{H}}}{\mathrm{P}_{\mathrm{L}}} \tag{4}$$

3.3 Mass and energy balances

Tables 1 and 2 show the mass and energy balances for the AHT and the RHT respectively.

Table 1. Mass and energy balances for an AHT.

Component	Mass and energy balances
Absorber	$\dot{m}_4 = \dot{m}_3 + \dot{m}_{10}$
	$\dot{m}_4 X_4 = \dot{m}_3 X_3 + \dot{m}_{10} X_{10}$
	$\dot{Q}_A = \dot{m}_3 h_3 + \dot{m}_{10} h_{10} - \dot{m}_4 h_4$
Generator	$\dot{m}_6 = \dot{m}_1 + \dot{m}_7$
	$\dot{m}_6 X_6 = \dot{m}_1 X_1 + \dot{m}_7 X_7$
	$\dot{Q}_G = \dot{m}_1 h_1 + \dot{m}_7 h_7 - \dot{m}_6 h_6$
Evaporator	$\dot{m}_9 = \dot{m}_{10}$
	$\dot{m}_9 X_9 = \dot{m}_{10} X_{10}$
	$\dot{Q}_E = \dot{m}_{10}(h_{10} - h_9)$
Condenser	$\dot{m}_7 = \dot{m}_8$
	$\dot{m}_7 X_7 = \dot{m}_8 X_8$
	$\dot{Q}_C = \dot{m}_8(h_7 - h_8)$
Pump 1	$\dot{W}_{P1} = \upsilon_1(P_2 - P_1)$
	$\dot{W}_{P1} = \dot{m}_1(h_2 - h_1)$
Pump 2	$\dot{W}_{P2} = \upsilon_8(P_9 - P_8)$
	$\dot{W}_{P2} = \dot{m}_8(h_9 - h_8)$
COP	$\mathrm{COP} = \dot{Q}_A/(\dot{Q}_E + \dot{Q}_G + \dot{W}_{P1} + \dot{W}_{P2})$
GTL	$\mathrm{GTL} = T_4 - T_{10}$
η	$\eta = \frac{\dot{Q}_A\left(1 - \frac{t_8}{t_4}\right)}{\left(\dot{Q}_E + \dot{Q}_G\right)\left(1 - \frac{t_8}{t_{10}}\right) + \dot{W}_{P1} + \dot{W}_{P2}}$

Table2. Mass and energy balances for a RHT.

Component	**Mass and energy balances**
Absorber	$\dot{m}_4 = \dot{m}_3 + \dot{m}_{14}$
	$\dot{m}_4 X_4 = \dot{m}_3 X_3 + \dot{m}_{14} X_{14}$
	$\dot{Q}_A = \dot{m}_3 h_3 + \dot{m}_{14} h_{14} - \dot{m}_4 h_4$
Generator	$\dot{m}_6 = \dot{m}_1 + \dot{m}_7$
	$\dot{m}_6 X_6 = \dot{m}_1 X_1 + \dot{m}_7 X_7$
	$\dot{Q}_G = \dot{m}_1 h_1 + \dot{m}_7 h_7 - \dot{m}_6 h_6$
Desorber	$\dot{m}_{10} = \dot{m}_{11} + \dot{m}_{14}$
	$\dot{m}_{10} X_{10} = \dot{m}_{11} X_{11} + \dot{m}_{14} X_{14}$
	$\dot{Q}_D = \dot{m}_{11} h_{11} + \dot{m}_{14} h_{14} - \dot{m}_{10} h_{10}$
Resorber	$\dot{m}_8 = \dot{m}_7 + \dot{m}_{13}$
	$\dot{m}_8 X_8 = \dot{m}_7 X_7 + \dot{m}_{13} X_{13}$
	$\dot{Q}_R = \dot{m}_7 h_7 + \dot{m}_{13} h_{13} - \dot{m}_8 h_8$
Pump 1	$\dot{W}_{P1} = \upsilon_1 (P_2 - P_1)$
	$\dot{W}_{P1} = \dot{m}_1 (h_2 - h_1)$
Pump 2	$\dot{W}_{P2} = \upsilon_8 (P_9 - P_8)$
	$\dot{W}_{P2} = \dot{m}_8 (h_9 - h_8)$
COP	$\mathrm{COP} = \dot{Q}_A / (\dot{Q}_D + \dot{Q}_G + \dot{W}_{P1} + \dot{W}_{P2})$
GTL	$\mathrm{GTL} = T_4 - T_{14}$
η	$\eta = \dfrac{\dot{Q}_A \left(1 - \frac{t_8}{t_4}\right)}{\left(\dot{Q}_D + \dot{Q}_G\right)\left(1 - \frac{t_8}{t_{14}}\right) + \dot{W}_{P1} + \dot{W}_{P2}}$

4. Results

Table 3 shows the operating conditions and the input parameters assumed for the thermodynamic cycles.

Table 3. Input parameters and operating conditions for the heat transformers.

Input parameter	Cycles	
	AHT	RHT
Condensing temperature (°C)	30-40	30-40
Supply temperature (°C)	70-110	70-110
High pressure (kPa)	--	2000-3000
RP	--	2-6
SHE efficiency (%)	70	70
Pump efficiency (%)	80	80

For the system components operating with the resorption cycle, it is considered a suitable maximum pressure between 2000 and 3000 kPa. In addition, 1 kg/s of refrigerant produced in the generator is considered for both cycles. In order to investigate the behavior of the performance parameters, a sensitivity analysis has been carried out varying the absorption temperature (T_A), at different temperatures of the heat supplied ($T_E = T_G$) and different condensation temperatures (T_C).

4.1 Absorption Heat Transformer (AHT)

Figure 4 shows the COP and the η against the absorber temperature for different generator and evaporator temperatures at a condensation temperature of 30 °C for an AHT.

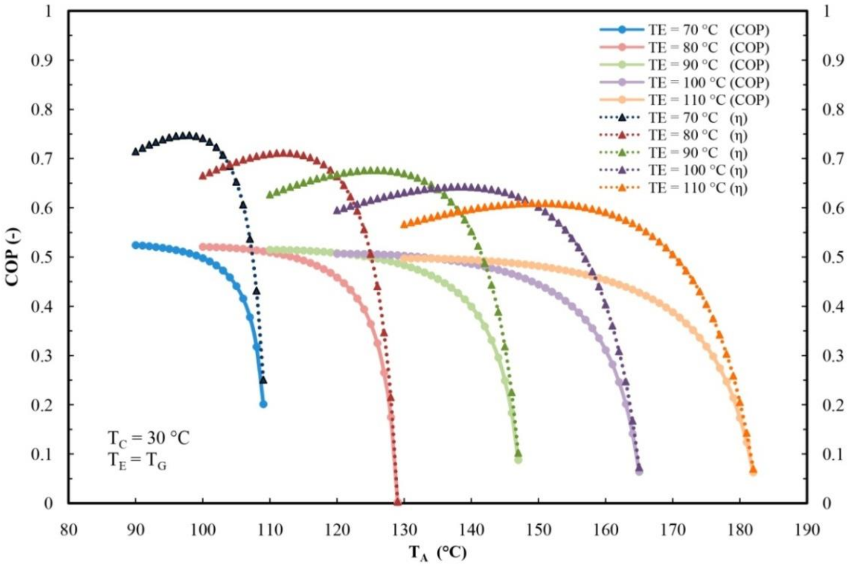

Figure 4. Effect of absorption temperature on COP and η at different temperatures ($T_E = T_G$) for a AHT cycle.

As can be seen, the COP decreases with an increment of T_A for all the generator and evaporator temperatures. This happen because when the absorber temperature increases, keeping constant the generator temperature, the concentration difference between the generator and the absorber decreases, thus decreasing the capability of the component to absorb the refrigerant and therefore Q_A and COP decrease too. Something similar occurs with η but in this case it can be observed a light increment of the values of this parameter and then the η decreases with the increment of the absorber temperature. Also it can be seen that both the COP and η increase with the increment of the generator and evaporator temperatures. This behavior was expected since an increase of the generator and evaporator temperatures causes a higher refrigerant production, thus increasing $\dot{Q}_A$ and therefore the COP and η. The maximum values of the COP and η at a $T_G = T_E$ of 70 °C are 0.52 and 0.73, respectively. Meanwhile, at a $T_G = T_E$ of 110 °C, the maximum COP and η values are 0.50 and 0.60, respectively. Finally, it can be observed that the increase of $T_G = T_E$ allows the system to achieve higher GTL, since as it was previously mentioned, GTL = $T_A – T_E$. For $T_G = T_E$ values of 70, 80, 90, 100 and 110 °C, the maximum GTL achieved were 39, 48, 56, 65 and 71 °C, respectively.

4.2Resorption Heat Transformer (RHT)

Figure 5 shows the variation of COP and η against the absorber temperature for a RHT. For this configuration, the COP and η have similar trends than those reported for an AHT in Figure 4, but the values are slightly lower.

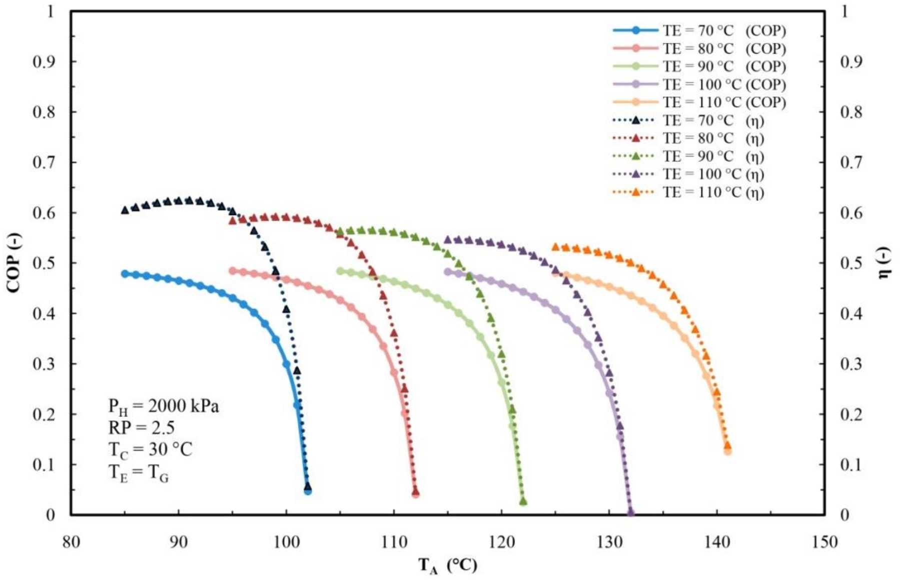

Figure 5. Effect of absorption temperature on COP and η at different temperatures ($T_E = T_G$) for a RHT cycle.

In this case, the maximum COP is 0.49 at a $T_E = T_G$ of 110 °C, while the maximum η is 0.62 at a $T_E = T_G$ of 70 °C. The biggest difference between the AHT and the RHT is related with the values of the GTL, since the AHT system may achieve much higher values than those achieved with the RHT. Figure 6 shows the COP as function of the absorber temperature varying the RP for the RHT cycle. As it was previously mentioned, the RP is a variable that defines the low pressure system resorption. It can be seen that at higher values of RP, the COP decreases but the GTL increases. For a RP = 2.5, the maximum values of COP and GTL are 0.49 and 32 °C, respectively, while for a RP of 5.0, the maximum values are 0.33 and 53 °C. The RP is a variable that has a flexible measure of the operating conditions for resorption systems. Depending on the needs or the RHT applications the GTL can be increased sacrificing COP values, or vice versa. For example, for industrial processes where heat is discharged at a T_E= 90 °C and a small temperature increment is required, for instance GTL = 26 °C, a COP as big as 0.41 can be obtained with RP between 2.5 and 4.0. Meanwhile, for requirements of absorption temperature of 130 °C (GTL = 40 °C), COPs between 0.30 and 0.26 are achieved for RP of 4.5 and 5.0, respectively. Finally, if a GTL of 48 °C is desired, the maximum COP obtained will be 0.15.

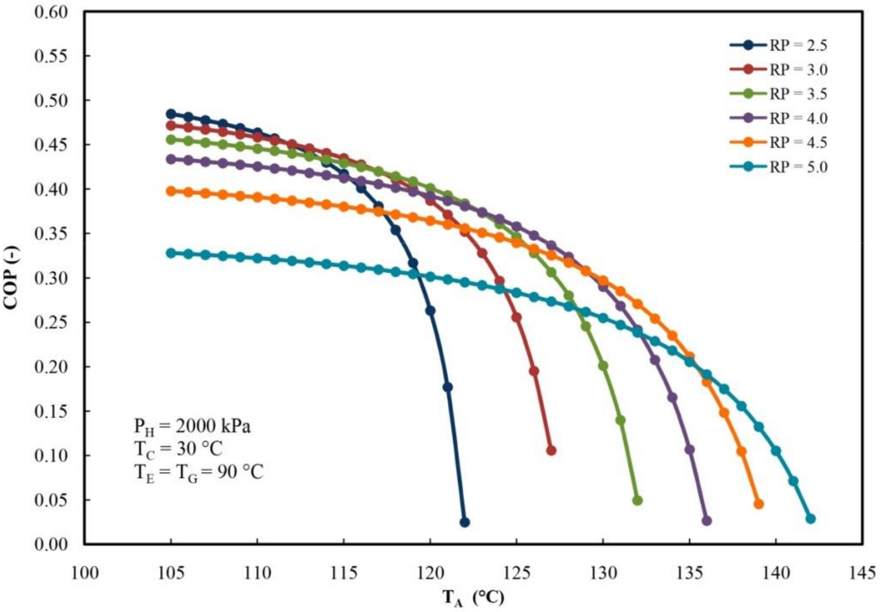

Figure 6.Effect of absorption temperature on COP at different RP for a RHT cycle.

4.3 Comparison between systems

Table 4 shows the comparison of the performance indicators for a single stage AHT and a RHT at different operating conditions.

As can be observed from Table 4, the conventional system without resorption (AHT) have better COP and η than the (RHT), however, the former operates at very high pressures, which establishes an important limitation of the NH_3-$LiNO_3$ mixture for some applications. For the established conditions, the AHT cycle has operating pressures between 5071 and 1167 kPa, while the RHT has considerable lower pressures between 2000 and 571 kPa. Therefore, the implementation of circuits with resorption will help to solve the problem of the high pressures using the NH_3-$LiNO_3$ mixture, and in general for systems operating with NH_3. Operation with higher pressures require more robust components and complex, and therefore more expensive, which represent a disadvantage.

Table 4. Performance indicators, thermal loads, pumping works and pressure levels for AHT and RHT cycles at operating conditions of: T_C=30 °C, T_E = T_G =90 °C and T_A=120 °C (GTL=30 °C).

Parameter	Cycle AHT	RHT
Performance indicator		
COP (-)	0.509	0.401
η (-)	0.669	0.525
Thermal capacity (kW)		
Useful heat output ($\dot{Q}_A$)	1368	2028
Condensation heat load ($\dot{Q}_C$)	1322	1358
Thermal evaporation load ($\dot{Q}_E$)	1116	1380
Thermal generation load ($\dot{Q}_G$)	1546	1966
Pumping capacity (kW)		
Pump 1 ($\dot{W}_{P1}$)	20.6	29.2
Pump 2 ($\dot{W}_{P2}$)	8.1	10.6
Operating pressures (kPa)		
P_H	5071	2000
P_L	1167	571 (RP=3.5)

5. Conclusions

In the present study a thermodynamic analysis of AHT and RHT cycles operating with NH_3-$LiNO_3$ working mixture was carried out. In order to analyze the system, different performance parameters such as the coefficient of performance, exergy efficiency and the gross temperature lift were used. The results showed that the NH_3-$LiNO_3$ mixture can be used in applications of heat transformers. For the AHT cycle the COP and η are higher compared to the RHT system, however, the AHT operates at very high pressures, which could be an important limitation in the application of the NH_3-$LiNO_3$ mixture. Therefore, the resorption circuit presents an alternative in heat transformers to minimize the problem of high pressure with working mixtures using NH_3.

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