Performance Analysis of Different Working Fluids for an Absorption Refrigeration Cycle

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Abstract   Absorption refrigeration systems have been subject of study, because they mainly use thermal energy to function; the fluids conventionally used (NH_3-H_2O and H_2O-LiBr) have low efficiencies. This work analyses six different working fluids (H_2O/LiBr, NH_3/H_2O, NH_3/NaSCN, NH_3/$LiNO_3$, H_2O/LiCl and H_2O/$CaCl_2$); and their thermodynamic and energetic characteristics are stablished with the objective of analyzing the system efficiency, as well as its thermophysical properties. For the parametric analysis, a mathematical model based on the first law of thermodynamics was developed. Results showed that H_2O/LiCl and H_2O/LiBr showed the higher coefficient of performance (COP) with a value of 0.8, operating at A/C conditions.

Keywords   Absorption refrigeration cycle, Efficiency, Thermodynamic, NH_3-H_2O y H_2O-LiBr, H_2O/LiBr, NH_3/H_2O, NH_3/NaSCN, NH_3/$LiNO_3$, H_2O/LiCl y H_2O/$CaCl_2$

1. Introduction

In places with extreme weather conditions as the north of the Mexican Republic, the consumption of electricity is very high, especially in summer. This has caused a serious problem, not only environmental, but social and economic, principally because of the use of air-conditioning and refrigeration systems are based on electric energy consumption. In the particular case of the city of Mexicali, residential consumption represents nearly 40% of annual total consumption of electric energy due to air-conditioning systems. Absorption cooling systems have the advantage of consuming a small quantity of electric energy, in comparison to vapor compression systems, because of the possibility of using solar energy to apply heat in the generator [1], what has been of interest to the technological community. Working fluids H_2O/LiBr and NH_3/H_2O are the most conventionally used in absorption cooling systems, due to their excellent thermic properties that make them capable to be used in cooling systems at commercial level. However, the disadvantage that has in the case of H_2O/LiBr is that the working fluid presents risk of crystallization on concentrations over 68% and cannot work at A/C conditions. On the other hand, NH_3/H_2O showed a low efficiency for the system. This work Analyses the study of the proposes for the

working fluids NH_3/$LiNO_3$, NH_3/NaSCN, H_2O/LiCl and H_2O/$CaCl_2$ with the purpose of analyzing their thermophysical characteristics and their working conditions for refrigeration as an alternative for this system.

2. Methodology

The software Engineering Equation Solver (EES) was used as a tool for computer simulation, using the properties of working fluids that the database of the software and the biographical references [5] provided, being applied to a simple absorption refrigeration cycle [4] for application of air-conditioning. The efficiency of the solutions was compared, as well as their thermodynamic characteristics, based on the results of the simulation.

The energy balance was obtained using the diagram for a simple absorption refrigeration system shown in figure 1, which gives us the mathematical model used in the software.
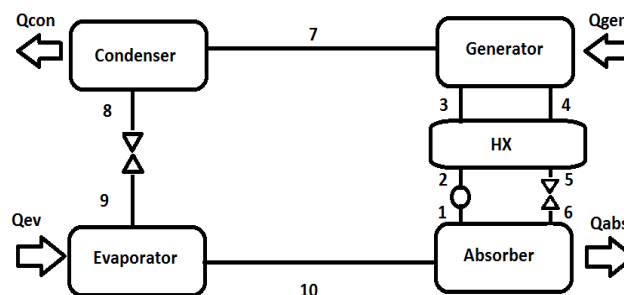

Figure 1.   Diagram of a simple absorption refrigeration system

Generator

$$m_7 + m_4 = m_3 \quad (1)$$

$$m_7 x_7 + m_4 x_4 = m_3 x_3 \quad (2)$$

$$m_7 h_7 + m_4 h_4 = m_3 h_{3+Qgen} \quad (3)$$

Absorber

$$m_{10} + m_6 = m_1 \quad (4)$$

$$m_{10} x_{10} + m_6 x_6 = m_1 + x_1 \quad (5)$$

$$m_{10} h_{10} + m_6 h_6 = m_1 h_{3+qabs} \quad (6)$$

Condenser

$$m_7 = m_8 \quad (7)$$

$$m_7 x_7 = m_8 x_{8+Qcon} \quad (8)$$

Rectifier

(for NH$_3$/H$_2$O solution)

$$m_7 = m_8 + m_9 \quad (9)$$

$$m_7 x_7 = m_8 x_8 + m_9 x_9 \quad (10)$$

$$m_7 h_7 = m_8 h_8 + m_9 h_{9+Qrec} \quad (11)$$

3. Results

The SSAS was simulated at A/C conditions: Condenser temperature = 40°C, evaporator temperature = 10°C, absorber temperature = 35°C, the temperature of the generator was varied from 60 to 120 C. The heat exchanger and solution pump have a efficiency of 85%.

Figures 2 and 3 show the COP in function of the generator temperature and the mass fraction, respectively. Graphics illustrate that all working fluids show a behavior of stabilization over 100ºC; at the same time, H$_2$O/LiCl and H$_2$O/LiBr present a small range of operation due to crystallization problems. Figure 3 shows that the mixture at previously established work conditions H$_2$O/CaCl$_2$ operates in a short range of lower concentration %X = 0.05, while the mixture NH$_3$-LiNO$_3$ obtains a value of %X = 0.2.
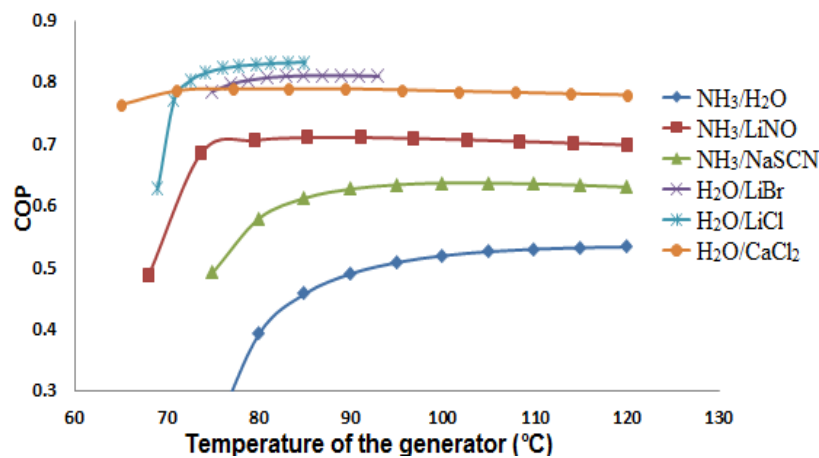

Figure 2. Relation between the generator temperature (°C) and the COP of the system
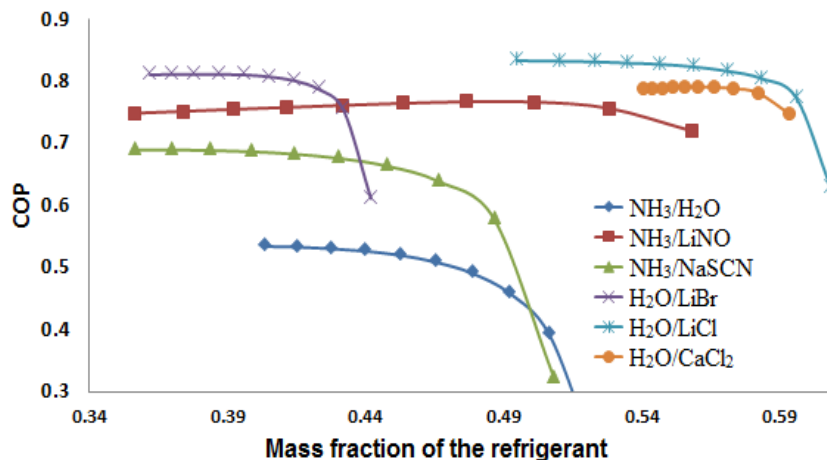

Figure 3. Relation between the COP and the mass fraction of the refrigerant

Figures 4, 5 and 6 show the density, viscosity and specific heat as function of the refrigerant mass fraction. The density of each fluid decreases when the mass fraction increases, as shown in figure 4. H_2O-LiBr is the working fluid with the highest density with a value of around 1,700 kg/m^3. Figure 5 shows that each working fluid has different behavior while increasing the mass concentration and the generator temperature.
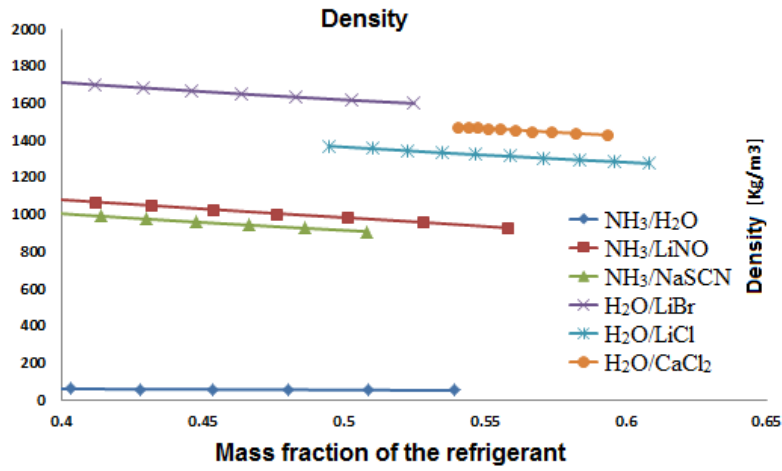

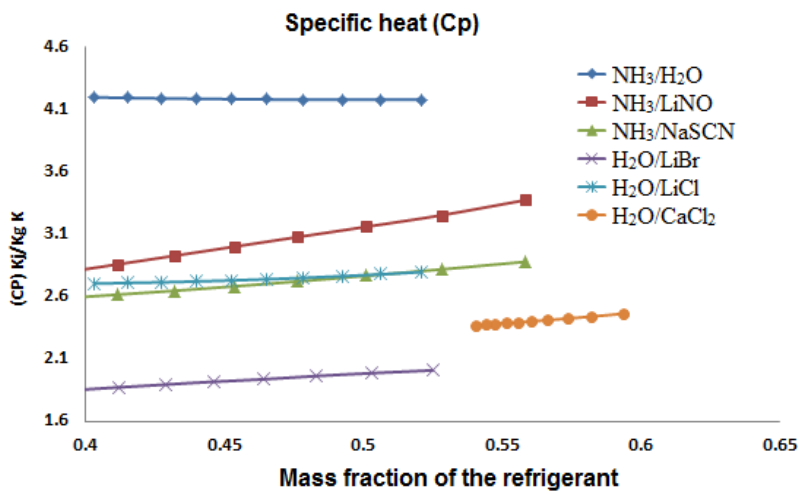**Figure 4.** Relation between density and the concentration of refrigerant

Figure 5. Relation between viscosity (kg/m s) and the concentration of refrigerant (%)
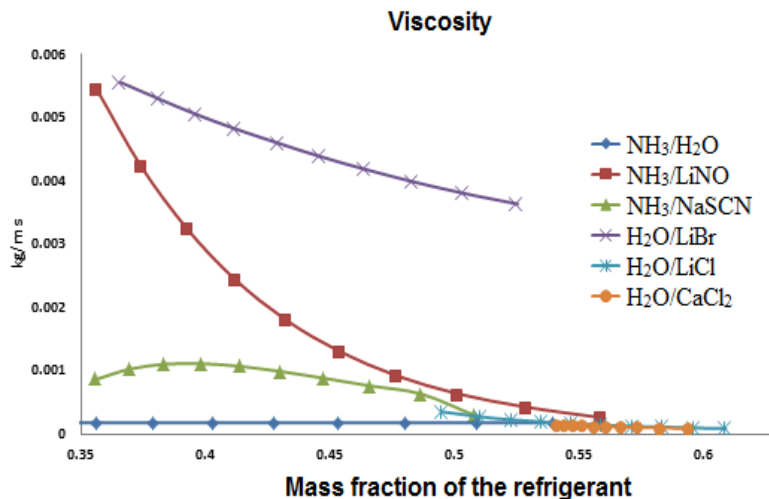

Figure 6. Relation of heat capacity to the concentration of refrigerant

The H_2O-LiBr mixture had the highest viscosity (0.006 – 0.004 kg/m s), while the lowest was for the NH_3-H_2O mixture. The concentration's effect and the generator's temperature had a same effect on the NH_3-H_2O, H_2O/LiCl and H_2O/$CaCl_2$ mixtures. An exception was NH_3/NaSCN fluid, which showed a maximum of 0.96 kg/m s and then diminished throughout its range; at the same time the NH_3/$LiNO_3$ showed a significant change in its operating range going from 0.0055 to less than 0.001 kh/m^{-s}

In figure 6, the specific heat (Cp) of each fluid shows a high value for NH_3/H_2O; unlike H_2O/LiBr that shows a low Cp for which requires less energy to increase its temperature.

3.1. Crystallization analysis of Work Fluids

Crystallization range of each work fluid depends on the operating temperature. As can be seen in Figure 2, H_2O/LiBr crystallizes at a concentration higher than 68% in absorbent weight, its operation range can be appreciated in Figure 7.
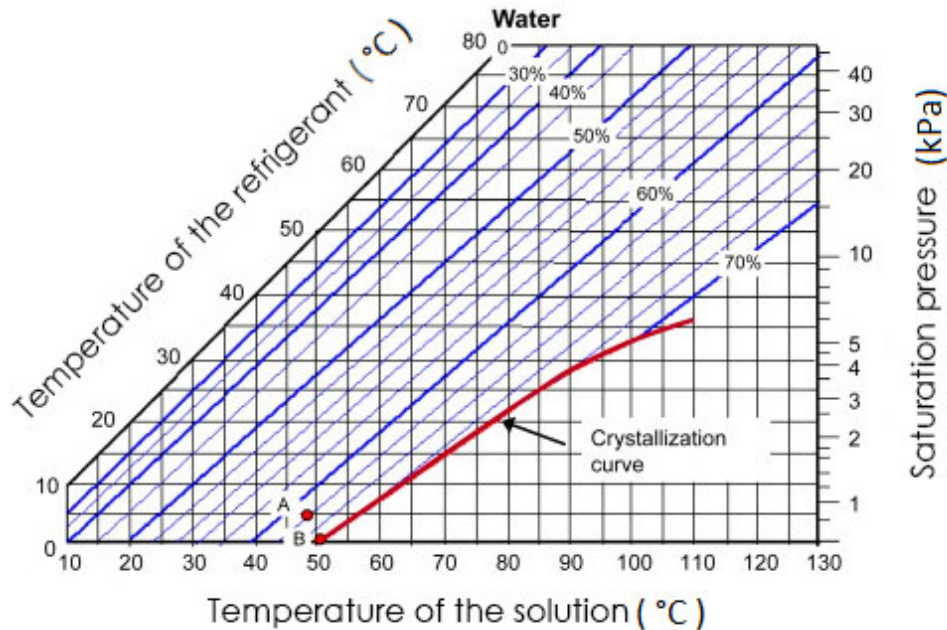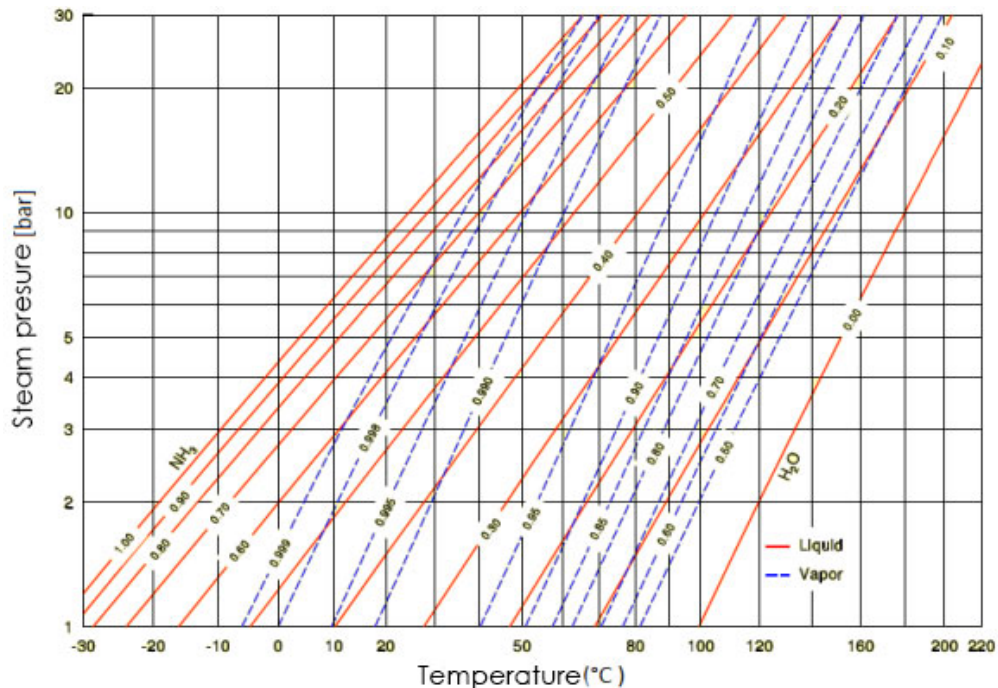

Figure 7.   Crystallization curve of H_2O/LiBr [7]

Figure 8.   Temperature and pressure of NH_3/H_2O [6]

Figures 9 and 10 show crystallization curves of NH_3-$LiNO_3$ mixture in function with concentration and temperature. Both fluids have the advantage to operate below 0°C in a cooling system. However, they have the risk of crystallization, as Figure 9 shows the NH_3-$LiNO_3$ mixture crystallizes at concentrations below the 25% of mass fraction [2]. While the NH_3/NaSCN mixture has the risk of crystallization at concentrations below 35% of mass fraction [2], as can be seen in Figure 10.

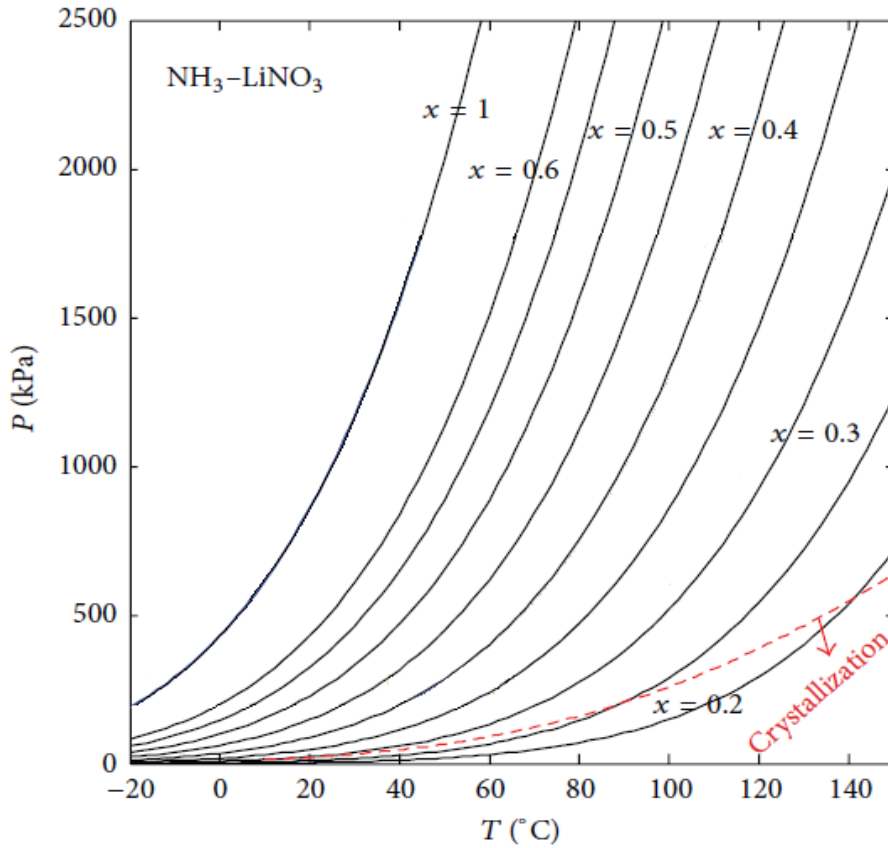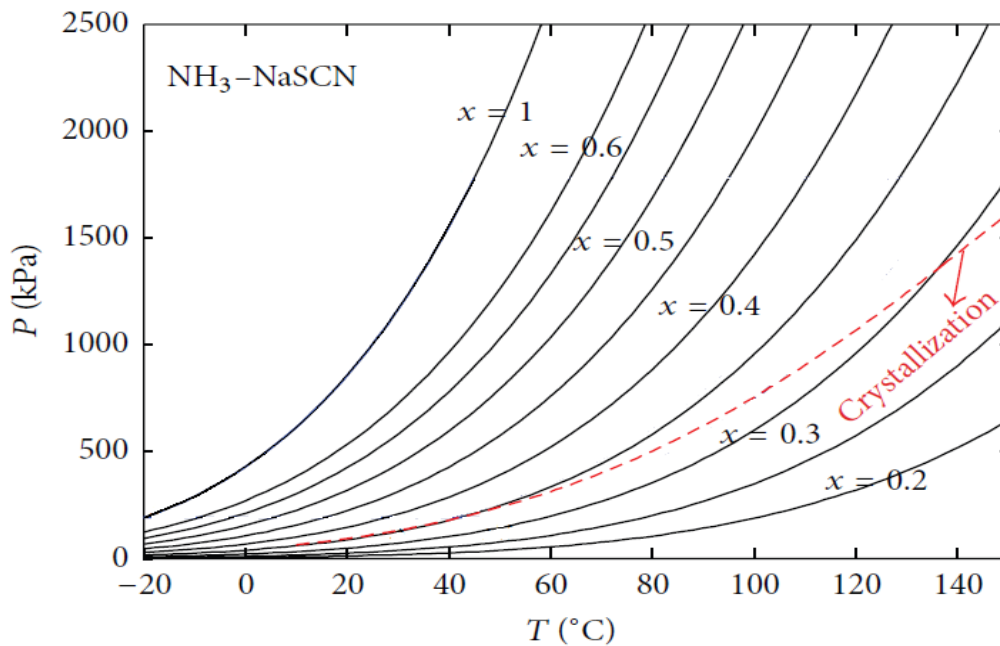**Figure 9.** Crystallization curve of NH_3/$LiNO_3$

Figure 10. Crystallization curve of NH_3/NaSCN

In Figure 3, $H_2O/LiCl$ and $H_2O/CaCl_2$ show a short range of operation in comparison to the rest of the work fluids. Due that they work, respectively, in ranges of 39 to 50% and 40 to 45% at 40°C in the absorber. This is because in their range exists the risk of crystallization at these operation conditions, as we can observe in Figure 11 and 12.
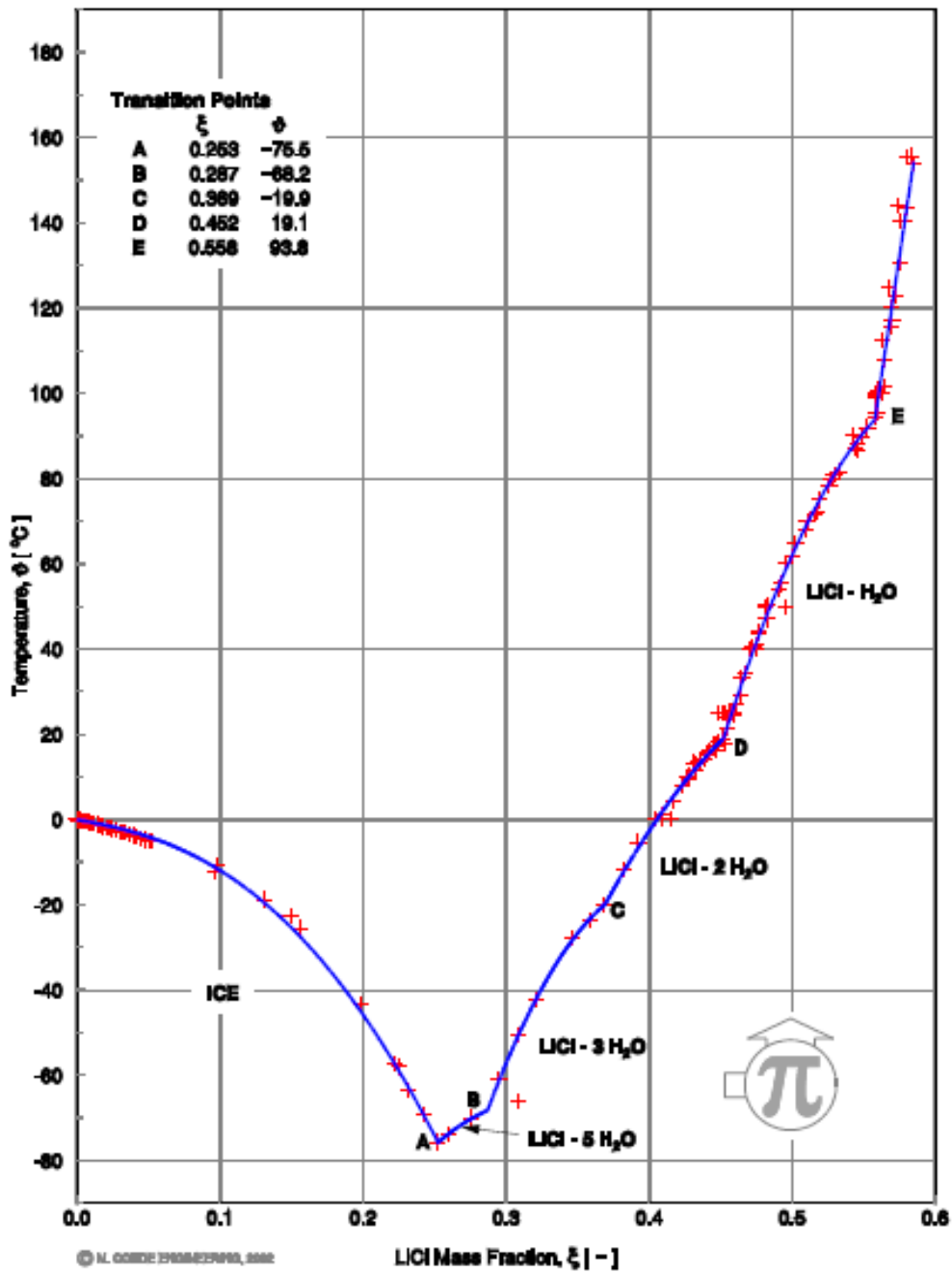

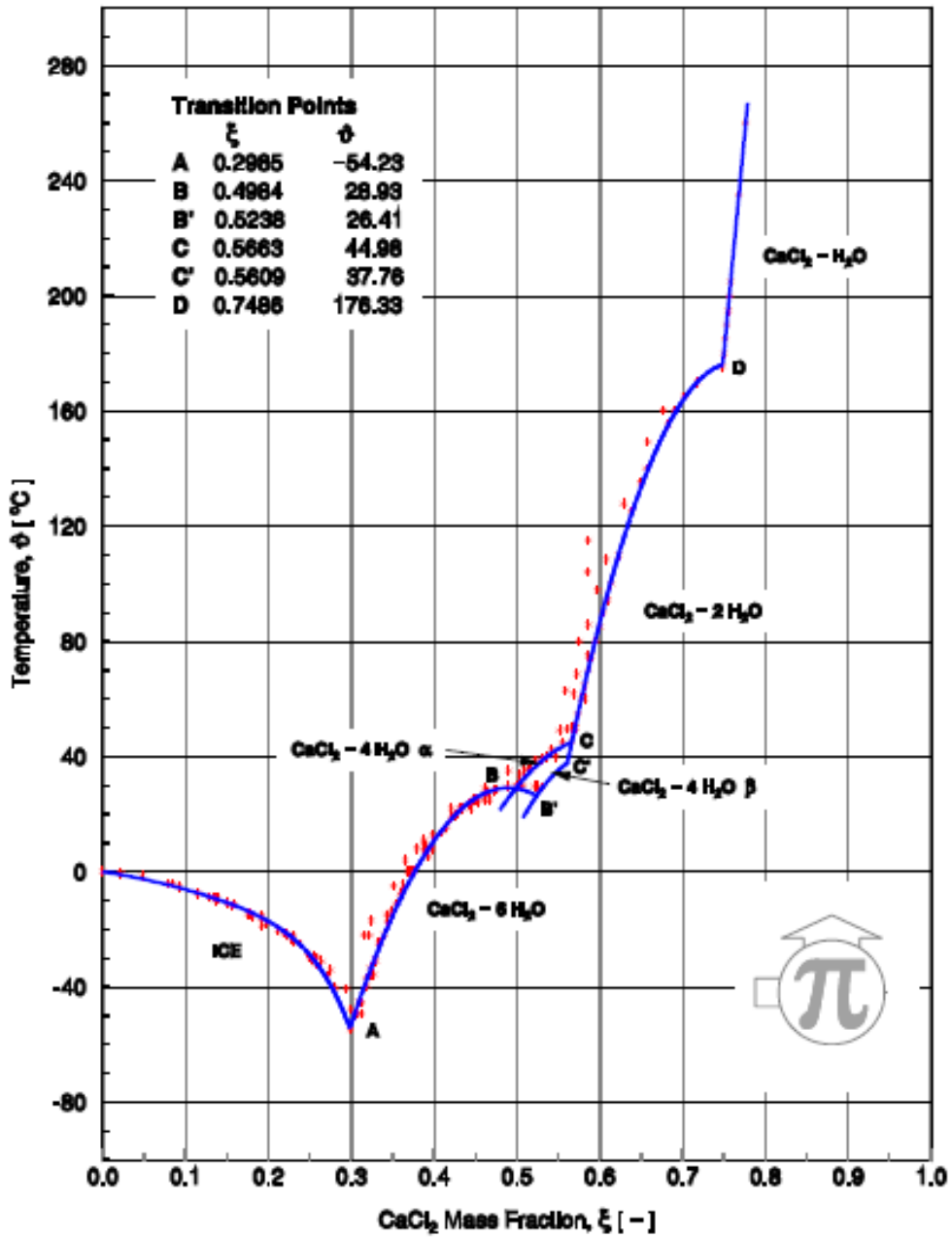**Figure 11.**   Crystallization curve of $H_2O/CaCl_2$ [5]

Figure 12. Crystallization curve of H_2O/LiCl [5] In table 1, some of the thermodynamic characteristics of each working fluid in AC conditions are shown. The viscosity of H_2O/LiBr is at least 4 times higher than other work fluids studied, meaning that the mass transference of the refrigerant in the solution in the absorber would be difficult.

Table 1. Thermodynamic characteristics based of maximum COP

	COP	T (°C)	X %weight	Density kg/m³	Viscosity, Kg/m⁻ˢ	Cp kJ/kg °C
H_2O/LiCl	0.83	85.0	49.48	1368.0	0.350	2.70
H_2O/LiBr	0.81	85.0	39.60	1682.0	4.598	1.89
H_2O/$CaCl_2$	0.79	89.4	54.74	1464.0	0.147	2.38
NH_3/$LiNO_3$	0.71	91.1	45.35	1027.0	1.307	2.99
NH_3/NaSCN	0.63	105.0	39.85	1006.0	1.111	2.61
NH_3/H_2O	0.53	120.0	31.23	64.2	0.174	4.19

3.2. Analysis of the Components

In Figure 13, the COP behavior at the change of the evaporator temperature can be observed, being less efficient at the necessity of lower temperature. The working fluids that use water as refrigerant can't work below 0°C, since water freezes at that temperature and the solutions $H_2O/CaCl_2$ and $NH_3/LiNO_3$ show a similar behavior.
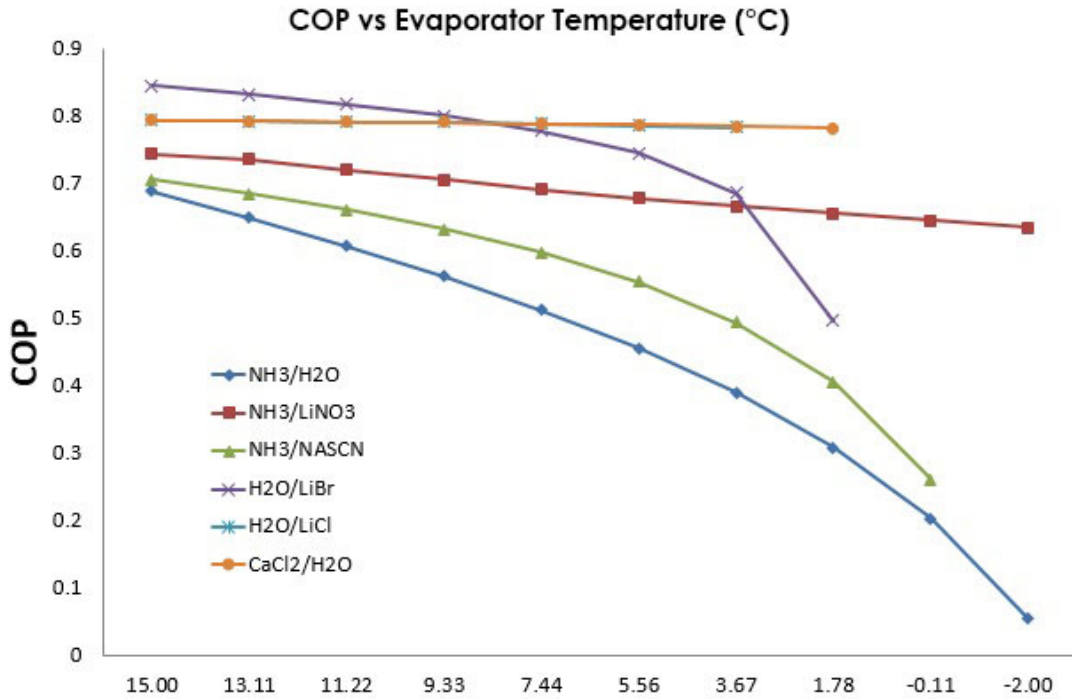

Figure 13.   Relation between the evaporator Temperature and the COP of the system

In Figure 14 can be seen that with the decreasing of the absorber temperature the COP increases, which helps the refrigerant absorption. The solutions $H_2O/CaCl_2$ and $NH_3/LiNO_3$ show a similar behavior, being part of the most efficient of the system
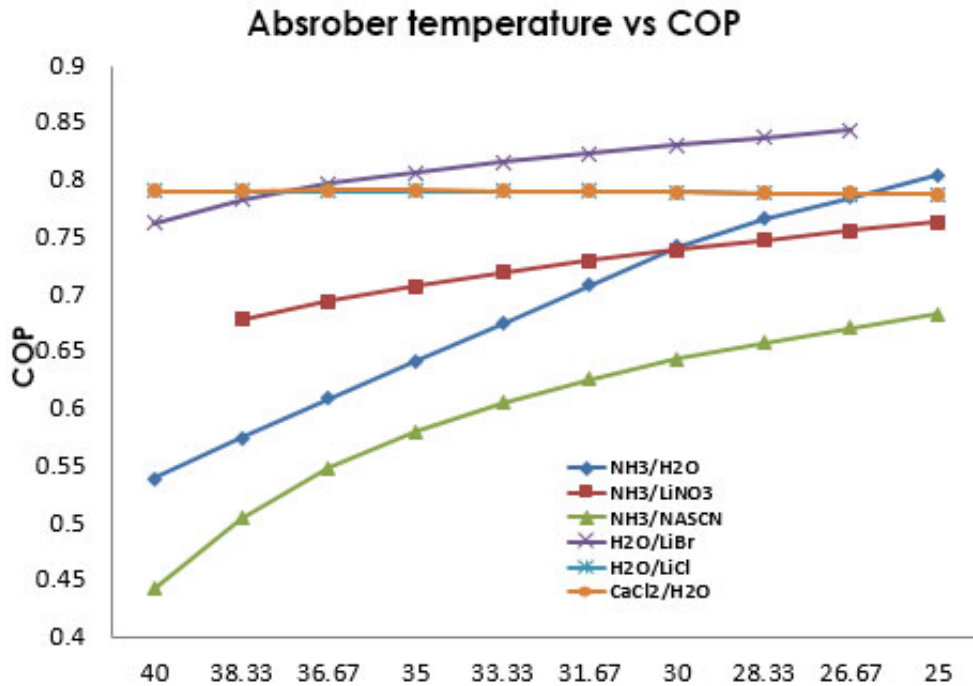

Figure 14.   Relation between the absorber Temperature and the COP of the system

In Figure 15, the thermal load of each component can be observed, The solution NH_3/H_2O is the one that has the highest thermal load over 2 kW and the solutions with less heat flow are the ones that have water as refrigerant.

Energy of the system

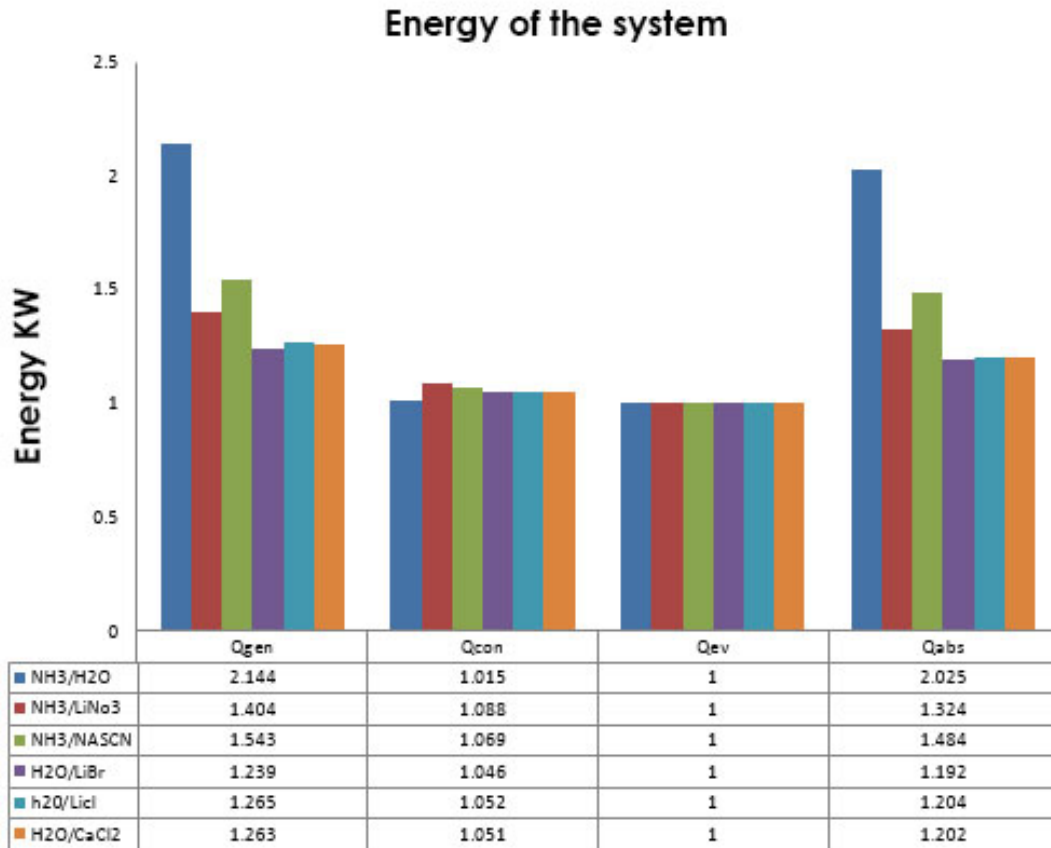|	Qgen	Qcon	Qev	Qabs
NH3/H2O	2.144	1.015	1	2.025
NH3/LiNo3	1.404	1.088	1	1.324
NH3/NASCN	1.543	1.069	1	1.484
H2O/LiBr	1.239	1.046	1	1.192
h2O/Licl	1.265	1.052	1	1.204
H2O/CaCl2	1.263	1.051	1	1.202

Figure 15.   Heat flow of the components of the system

In figure 16 the COP of each working fluid in a absorption refrigeration cycle can ve observed at the same working conditions (Condenser temperature = 40°C, evaporator temperature = 10°C, absorber temperature = 35°C and generator temperature =80 °C), the most efficient working fluid at these conditions is $H_2O/LiBr$ with a COP above 0.8 flowed by $H_2O/LiCl$ and $H_2O/CaCl_2$ with a COP aof 0.79. The solution NH_3/H_2O is the most inefficient working fluid of the six with a COP less than 0.5.

COP of the system

H2O/CaCl2   h2O/Licl   H2O/LiBr   NH3/NASCN   NH3/LiNo3   NH3/H2O

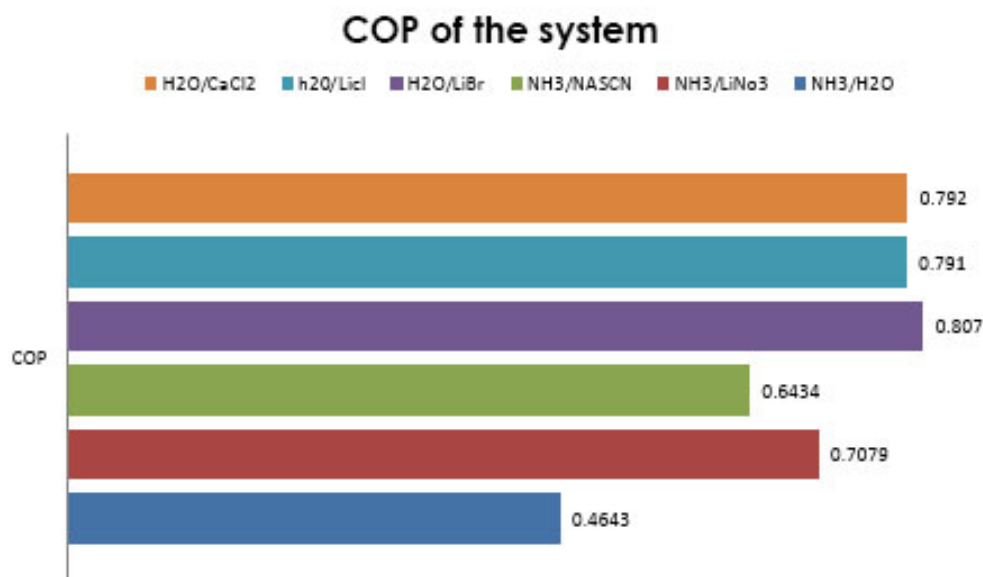| COP	
H2O/CaCl2	0.792
h2O/Licl	0.791
H2O/LiBr	0.807
NH3/NASCN	0.6434
NH3/LiNo3	0.7079
NH3/H2O	0.4643

Figure 16.   System COP of each solution

4. Conclusions

A simulation of a simple cooling cycle with six different work fluids was carried out, in which the less efficient fluid was NH_3/H_2O with a COP of 0.53. One of the causes of NH_3/H_2O low efficiency is because of the need of a rectifier, its high cp of 4.17 kg kJ/kg °C, and it had the lowest viscosity and density of all. $H_2O/LiBr$ and $H_2O/LiCl$ solutions had the highest COP of all the evaluated solutions (around 0.81) because they have a lower cp using less energy for its performing. $NH_3/LiNO_3$ y $NH_3/NaSCN$ solutions show a similar behavior respectively. However, $NH_3/LiNO_3$ is more efficient with a COP of 0.71, in contrast to $NH_3/NaSCN$ with a COP of 0.63. Both had similar density but a difference in their Cp which can be a less value of COP for this work fluid. $H_2O/CaCl_2$ solution shows a lower Cp after $H_2O/LiBr$ solution, which gives one of the causes the makes it efficient. Since $H_2O/LiBr$ solution doesn't require a great amount of energy to increase its temperature while presents high density and low viscosity, which helps the system bomb.

The Solutions that use H_2O as refrigerant have a disadvantage, they cannot work in the evaporator at temperatures below 0°C, because water freezes at said temperature. Therefore, restricting its application only in AC in contrast with the ones that have NH_3 as refrigerant, because they can work below 0°C and turn them apt to freezers.

ACKNOWLEDGEMENTS

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