

EXERGY ANALYSIS OF ABSORPTION REFRIGERATION SYSTEM WITH AMMONIA-WATER AND LITHIUM BROMIDE-WATER PAIRS

Cavalcanti, E.J.C.⁽¹⁾, educanti@ufrnet.br
Lima, H. P.⁽²⁾, hugolimabr@yahoo.com.br

⁽¹⁾ Universidade Federal do Rio Grande do Norte (UFRN), Departamento de Engenharia Mecânica, Campus Universitário, S/N, Natal-RN, 59072-970

⁽²⁾ Universidade Federal Rural da Amazônia (UFRA), Av: Presidente Tancredo Neves, Nº 250, Montese, Belém-PA, 66.077-530.

Abstract: Absorption refrigeration systems are an alternative for conventional systems. An exergy analysis of two absorption systems with simple-effects was performed. One system operating utilizing ammonia-water and other with water-lithium bromide. Both absorption systems have the same cooling capacity of 5 TR (17.58 kW) and used as a heat source natural gas combustion. The input parameters were defined to compare the two systems, as the temperature of the condenser and evaporator temperature 37°C to 5°C. A model with mass balance, energy and exergy was developed. The absorption system with water-ammonia presented the highest exergy destruction rate as long as the system with lithium bromide-water the highest efficiency. It was defined the system component with the highest exergy destruction.

Palavras-chave: Exergy, absorption, modeling.

1. INTRODUCTION

Absorption refrigeration systems are one of the oldest cooling methods. The pairs most commonly used in these systems are water-ammonia mixtures and water-lithium bromide. In the absorption refrigeration systems are used two fluids (pairs), one of them as refrigerant and the other as absorbent. The most common are the ammonia (NH₃) - water (H₂O) (ammonia operate as the refrigerant and water as the absorbent), and the water (H₂O) - lithium bromide (LiBr) (water as the refrigerant and lithium bromide as the absorbent).

The absorption system does not consume as much energy as the system of compression refrigeration. The absorption system use a heat source, while the system of compression refrigeration operates with the compressor. The energy in the form of heat is cheaper than in the form of work used in the compressor. Hot combustion products are the most frequent heat source for these systems. Natural gas is burned with excess air. A heat exchanger between the absorber and the generator was installed to reduce fuel consumption and improve overall efficiency.

Kotas (1985) describes exergy balance in plants. The exergy analysis permits to identifier where is happening the greatest loss of available energy.

In this paper were evaluated the exergy destruction in each system's equipment with ammonia water and water-lithium bromide. A model was developed to evaluate the performance of the system. The thermodynamic model was developed based on mass balance, conservation of chemical species, energy and exergy within each device. The two cooling systems have the same components and similar parameters for comparison. Observe a schematic of the system in the figure below.

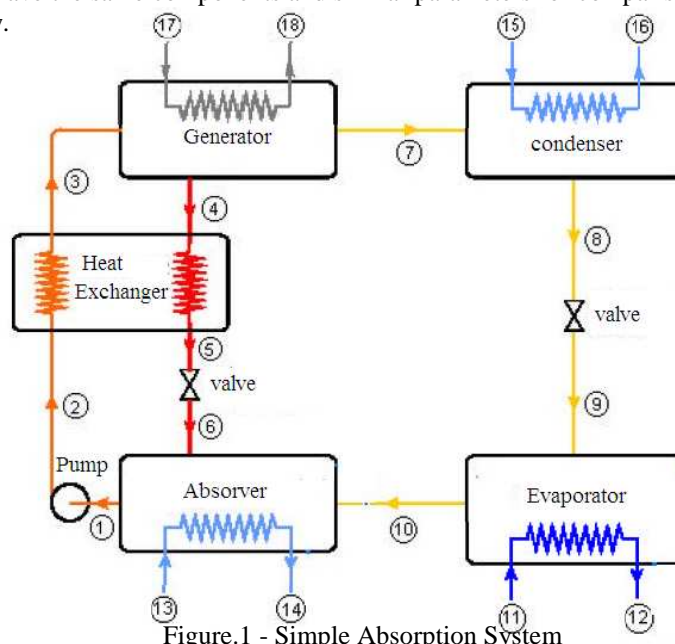


Figure.1 - Simple Absorption System

The temperature of the condenser and evaporator are 37 ° C and 5 ° C, respectively. The evaporator is cools water from 12 ° C to 7 ° C. Hot combustion gases are supplied to the generator entering at 400 °C and leaving at 300°C. The Absorber and condenser are refrigerated by serial water circuit, wher water enters at 29.5 ° C and leaves at 35 ° C. The pump is assumed to be isentropic and the Heat transfer efficiency is 68.80%. The temperature of the mixture leaves the absorber is 34.44 ° C.

The fuel is natural gas from Paraíba Gas Company with the following composition by volume: 87.59% CH₄, 9.13% C₂H₆, 0.36% C₃H₈, 1.74% CO₂ and 1.18% N₂. The Natural Gas is completely burned; all carbon present in the fuel is burned to carbon dioxide. The combustion products are burned with air excess and the adiabatic flame temperature reaches 400°C.

For systems comparison with the same refrigeration capacity, the flows (1) and (4) are saturated. The concentration of the solutions, the evaporator and condenser pressure and dead state are indicated below.

Table 1. Data of Systems Absortion Lithium Bromid-water and water-ammonia

	LiBr-H ₂ O	NH ₃ -H ₂ O
Strong solution concentration	64%	54.33%
Wake solution concentration	48%	39.62%
Dead state	H ₂ O, 25°C, 101.3 kPa	NH ₃ -H ₂ O 54.33%, 35°C, 101.3 kPa
Pressure of evaporator	0.87 kPa	5.16 kPa
Pressure of condenser	6.275 kPa	1433 kPa

The dead state of the two systems are different because the ammonia water system have the same reference that the system lithium bromide water exergy would be negative at some points.

The Coefficient of performance of the absorption cycle (COP) is defined as:

$$COP = \frac{\text{refrigeration_rate}}{\text{rate_of_heat_of_generator}} \quad (1)$$

The COP to the absorption system is appreciable lower than for the vapor-compression cycle. Its value is about 0.6 in comparison with about 3.0 for the vapor compression system. The absorption and compression refrigeration systems are similar, being different fundamentally in the type of energy consumed. The first uses thermal energy and the other electrical energy. However the low value of COP of the absorption system is compensated for the schep energy in the form of heat rather of work at the vapor-compression cycle (Stoecker and Jones, 1985).

The exergy analysis has already become an essential parameter for the equipments' and thermal systems' optimization to reducing the detected irreversibilities (Bejan *et al.*, 1996).

The Exergy rate balance for control volumes for steady-state was defined for the equation below:

$$\dot{I}_{cv} = \left(\sum \dot{m}_{in} \cdot e_{in} - \sum \dot{m}_{out} \cdot e_{out} \right) + \sum \left(1 - \frac{T_o}{T_j} \right) \cdot \dot{Q}_{cv} - \dot{W}_{cv} \quad (2)$$

According to (Van Wylen at al., 2003) the rate of exergy destruction is equal rate of exergy transfer at the inlet and exit of the control region (E) accompanying mass flow plus rate of exergy associated with rate of heat transfer on the boundary at temperature T_j plus rate of exergy transfered by work.

The specific flow exergy (e) can be represented in a convenient form as:

$$e = (h - h_o) - T_o \cdot (s - s_o) + \frac{v^2}{2} + g \cdot z \quad (3)$$

Where h and s represent the specific enthalpy and entropy, respectively. The subscripts o represent the values of these properties at the dead state. The kinetic and potential energy effects are ignored.

2- RESULTS AND DISCUSSION

The description of plants allowed to develop the balance of mass, energy and exergy in all its components. The data for both systems at each point shown in figure 1 are represented in table 2. The parameters indicated are temperature (T), pressure (P), solution concentration (x), mass flow rate (m), specific enthalpy (h), specific entropy (s), specific exergy (e) and exergy (E).

Table 2. Properties for the Absorption System with mixture Lithium Bromid-Water

Points	T [°C]	P [kPa]	x [%]	\dot{m} [kg/s]	h [kJ/kg]	s [kJ/kg.K]	e [kJ/kg]	E [kW]
1	34.44	0.87	54.9	0.05	83.4	0.2211	22.22	1.116
2	34.44	6.275	54.9	0.05	83.41	0.2211	22.22	1.116
3	63.6	6.275	54.9	0.05	143.2	0.4053	27.09	1.360
4	91.13	6.275	64	0.043	231.2	0.4864	90.89	3.914
5	52.13	6.275	64	0.043	161.5	0.2827	81.92	3.528
6	52.13	0.87	64	0.043	161.5	0.2827	81.92	3.528
7	80.59	6.275	0	0.007	2654	8.560	94.34	0.673
8	37	6.275	0	0.007	154.9	0.532	1.06	0.007
9	5	0.87	0	0.007	154.9	0.558	6,633	0.046
10	5	0.87	0	0.007	2510	9.025	176.3	1.251
11	12	-	-	0.804	50.24	0.180	1,176	0.946
12	7	-	-	0.804	29.31	0.106	2.337	1,880
13	29.5	-	-	1.673	123.5	0.430	0.1513	0.253
14	32.45	-	-	1.673	135.9	0.470	0.4041	0.676
15	32.45	-	-	1.673	135.9	0.470	0.4041	0.676
16	35	-	-	1.673	146.5	0.505	0.7173	1.200
17	400	-	-	0.196	290.6	7.642	305.5	60.06
18	300	-	-	0.196	183.3	7.422	263.9	51.87

Table 3. Properties for the System Absorption with mixture Water-Ammonia

Points	T [°C]	P [kPa]	x [%]	\dot{m} [kg/s]	h [kJ/kg]	s [kJ/kg.K]	e [kJ/kg]	E [kW]
1	34.44	516.9	60.57	0.06601	-82.5	0.3567	0.662	0.0437
2	34.48	1433	60.57	0.06601	-81.36	0.3567	1.803	0.119
3	67.22	1433	60.57	0.06601	68.49	0.8194	13.7	0.9041
4	98.22	1433	39.62	0.04993	212.7	1.226	36.7	1.832
5	54.36	1433	39.62	0.04993	14.62	0.6587	7.737	0.3863
6	54.57	1433	39.62	0.04993	14.62	0.6621	6.745	0.3368
7	82.22	1433	1.0	0.01608	1426	4.594	245.6	3.949
8	37	1433	1.0	0.01608	176.1	0.6099	183.8	2.955
9	5	516.9	1.0	0.01608	180.1	0.6567	173.9	2.796
10	5	516.9	1.0	0.01608	1273	4.570	100.5	1.617
11	12	-	-	0.8394	50.46	0.1804	186.2	156.3
12	7	-	-	0.8394	29.51	0.1063	187.3	157.2
13	29.5	-	-	2.032	123.7	0.4296	185.1	376.1
14	32.64	-	-	2.032	136.8	0.4727	185.4	376.6
15	32.64	-	-	2.032	136.8	0.4727	185.4	376.6
16	35	-	-	2.032	146.7	0.5049	185.6	377.2
17	400	-	-	0.2705	290.6	7.642	305.5	82.64
18	300	-	-	0.2705	183.3	7.422	263.9	71.39

The pressure difference among the points (1) and (2) is lower in the system LiBr-H₂O than in NH₃-H₂O system, and therefore the enthalpy difference is also lower in the system LiBr-H₂O. This fact indicates a higher consumption of pump work in the system NH₃-H₂O.

The mixture's temperature at the generator output at point (4) is greater in NH₃-H₂O system, indicating that this system requires a higher consumption of heat to promote the separation of refrigerant and absorbent. The heat transfer in all components of absorption system was calculated and is shown in table.

Table 4. Heat Transfer of the both Cooling Systems.

Componentes	Generator	Condenser	Evaporator	Absorber	Heat Exchanger
Heat Transfer (kW) System LiBr-H ₂ O	21,1	17,84	17,58	20,69	3,002
Heat Transfer (kW) systems NH ₃ -H ₂ O	29,02	20,09	17,58	26,65	13,08

As the generator consumes more heat in NH₃-H₂O system to promote the separation, the flow at the generator output is slightly higher at points (7) and hence the condenser should exchange more heat to the flow reach at the same temperature of 37°C at inlet of condenser.

The evaporator has similar temperatures, but the refrigerant in the LiBr-H₂O system is the water while NH₃-H₂O is ammonia. The enthalpy of water evaporation in the LiBr-H₂O system, estimated by the enthalpy's difference among the points (9) and (10) is 2355.1 kJ/kg, is about twice the enthalpy of evaporation of ammonia in the NH₃-H₂O system whose value is 1092.9 kJ/kg. Therefore the flow of refrigerant in the evaporator LiBr-H₂O system is about half the flow of refrigerant in the NH₃-H₂O system for the same refrigeration capacity of 5 RT (17.58 kW).

The heat generated in the absorber is a function of mass flow and the exothermic reaction generated by the mixture. The absorber of NH₃-H₂O system generates more heat, and it is observed that all the mass flows in the absorber system NH₃-H₂O in points (1), (6) and (10) are larger than the LiBr-H₂O system.

The heat exchanger of each system has the same efficiency and therefore the temperature profile is relatively similar. The heat exchanged in the NH₃-H₂O system is higher that of LiBr-H₂O. This effect occurs due to specific heat ($c_p = \Delta h / \Delta T$) of the solution in NH₃-H₂O system (4.577 kJ/kg) is higher than the specific heat of the solution in LiBr-H₂O system (2.050 kJ/kg), and mass flows in the NH₃-H₂O system is slightly higher than the LiBr-H₂O system.

In both system, the component that revealed to have the more higher exergy destruction was the generator following of absorber like showing Fig. 2

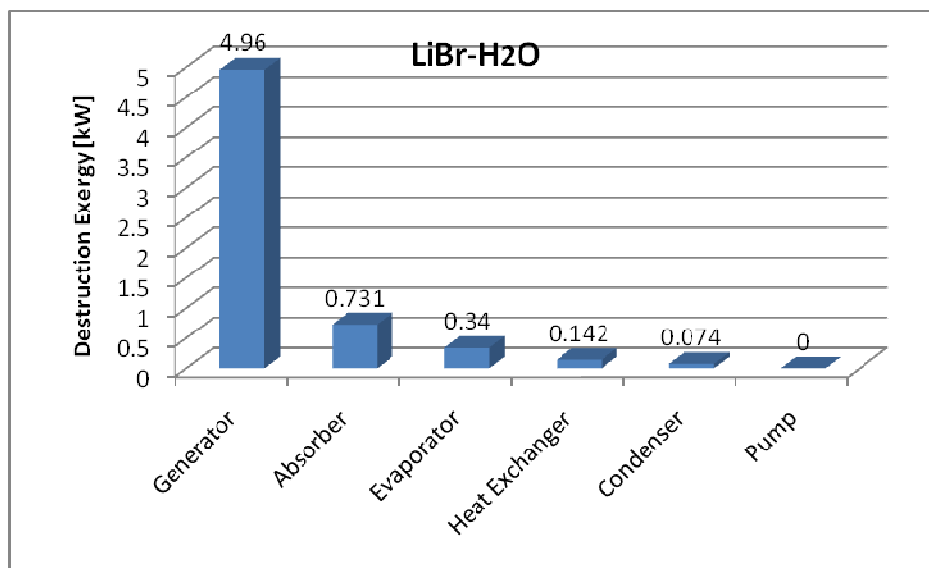


Figure.2 - Exergetic destruction of the LiBr-H₂O system components

The exergy destruction at system NH₃-H₂O is showed at Fig. 3.

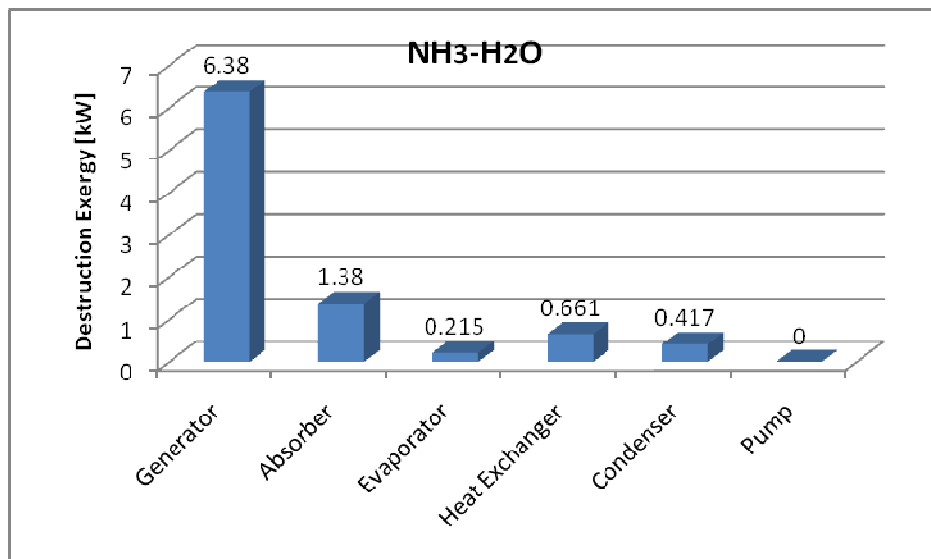


Figure.3 - Exergetic destruction of the NH₃-H₂O system components

Using the eq. (1), the coefficients of performance were determined. The value of the COP of the system NH₃-H₂O is 0.6057 while the value of the COP of the system LiBr-H₂O is 0.8332. The generator of NH₃-H₂O system consumes more heat to promote the separation of the refrigerant and the absorbent while the value of cooling capacity is similar. Hence the COP of the system NH₃-H₂O becomes smaller.

3- CONCLUSION

The modeling approach for the absorption systems hereby presents, allowed the evaluation of the absorption of heat exchange in all components, work consumption at the pump, the exergy destruction and overall coefficient performance. The higher heat exchange and exergy destruction occur in the generator, indicating that further improvements must be done in this equipment. The system operating with the mixture LiBr-H₂O presented the higher performance and lower exergy destruction in all components.

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