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A Study on an Absorption Refrigeration Cycle by Exergy Analysis Approach

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Abstract. In this study, an absorption refrigeration cycle with the working fluid of water-lithium bromide is considered. The needful energy for generator is supplied by the steam at 100 ℃ and in one atmospheric pressure. The exergy analysis is conducted on the whole cycle and it is calculated based on the first and the second laws of thermodynamics. Various components are compared in terms of thermodynamic efficiency. Finally the coefficient of the mentioned cycle is obtained. According to the simulation results, the highest rate of exergy destruction is in the absorber, and it is equal to 35.87 % of the destruction and the main cause of this irreversibility is heat transfer with the high-temperature difference. To improve this, we should increase heat exchange and then reduce the temperature difference. For the system performance improvement, particular attention should be paid to this part to reduce the outlet exergy.

1. Introduction

Limitations and prohibitions of the use of fluorocarbon gases have encouraged engineers to work more with absorption systems [1]. Exergy analysis [2]–[4] is of the methods widely used today to study engineering systems. This method combines the first and the second laws of thermodynamics [5] which relies mainly on the second law of thermodynamics, and serviceability. With the help of exergy analysis, it can be determined in which areas the level of serviceability is lost, based on the fact that the one can take actions to improve the system. Working fluid mixture for combined cycles can be divided into two categories: ammonia-water mixtures [6] and lithium-bromide [7]. Lithium bromide is a combination of an alkali metal salt (lithium) and a halogen in the form of white crystals which appears very similar to table salt (sodium chloride) dissolved in water and alcohol [8]. In the air, it will not be decomposed which owns a stable mix.

In this study, an absorption refrigeration cycle with the working fluid of water-lithium bromide with capacity of 500 tons is considered. The needful energy for generator is supplied by the steam at 100 ℃ and in one atmospheric pressure. The exergy analysis is conducted on the whole cycle and it is calculated based on the first and the second laws of thermodynamics. Various components are compared in terms of thermodynamic efficiency, and then the coefficient of the mentioned cycle is obtained.

2. Description of Absorption Refrigeration Cycle and Assumptions

In Figure 1, a single effect absorption cycle is plotted. In an absorption system, condenser [9], evaporator [10]on the left breast and stifling cycle are the three components of the conventional vapor compression cycles. However, instead of compressors, four components are used in this paper: absorbers [11], pumps [12], expansion valves [13] and generators [14] as shown in Figure 1.

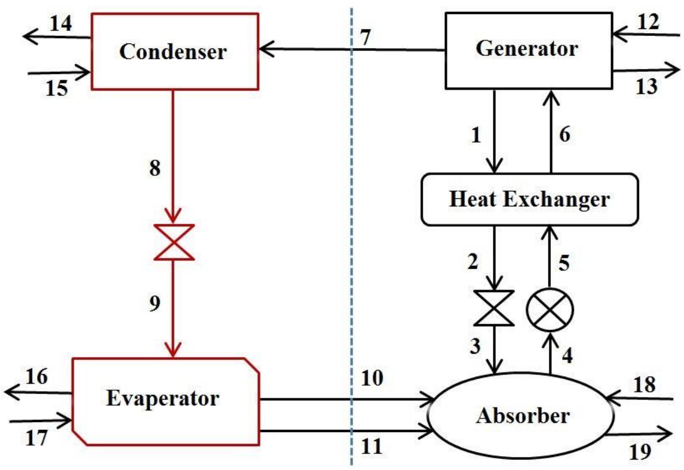

Figure 1. Schematic view of the absorption refrigeration cycle.

3. Exergy Analysis

Exergy analysis is a combination of the first and the second law of thermodynamics. We have the first law of thermodynamics for a sustainable flow-control volume as follows.

$$\dot{Q}-\dot{W}=\sum \dot{m}_{out}\left(h_{out}+\frac{V_{out}^{2}}{2}+gz_{out}\right)-\sum \dot{m}_{in}\left(h_{in}+\frac{V_{in}^{2}}{2}+gz_{in}\right) \tag{1}$$

$$S_{gen}=\sum \dot{m}_{out}\dot{s}_{out}\sum \dot{m}_{in}\dot{s}_{in}+\frac{\dot{Q}_{sur}}{T_{0}} \tag{2}$$

$$\dot{Q}_{sur}=-\dot{Q} \tag{3}$$

By eliminating Q in Eq. 1 and Eq. 2 and ignoring the entropy production (reversible), we can come to the exergy equation which is the maximum work from the beginning to the final state of the environment

$$\varphi=(\mathrm{h}-\mathrm{h}_{0})-T_{0}(\mathrm{s}-\mathrm{s}_{0})+\frac{V^{2}}{2}+gz \tag{4}$$

Exergy analysis assesses the system performance based on the exergy. Exergy is the maximum reversible work receivable from a system in transition from the initial state to a state of equilibrium with the environment.

For exergy of mass flow solution we have:

$$\varphi=\left[h_{(\mathrm{T,x})}-h_{0}\right]-T_{0}\left[s_{(\mathrm{T,x})}-s_{0}\right] \tag{7}$$

We calculated the exergy destruction in every component using the following equation:

$$\dot{E}_{D}=\dot{E}_{in}-\dot{E}_{out} \tag{8}$$

$$\dot{E}_{D}=\sum \dot{E}_{in}-\sum \dot{E}_{out}-\dot{Q}\left(1-\frac{T_{0}}{T}\right)-\dot{W} \tag{9}$$

We have examined the contribution of each component in exergy destruction with destruction percent relative to the total destruction cycle.

$$Y_{D,i}=\frac{\dot{E}_{D,\mathrm{i}}}{\dot{E}_{D,tot}} \tag{10}$$

Coefficient of performance (COP) expresses the energy ratio taken from cold water in the evaporator to the whole energy given to the system:

$$COP = \frac{\dot{Q}_e}{(\dot{Q}_e + \dot{W}_E)} \tag{11}$$

The second law efficiency expresses the ratio of useful exergy obtained from the system in evaporator to the exergy reported to the system in the generator.

$$E_{cooling} = \frac{\dot{E}_{15} - \dot{E}_{16}}{\dot{E}_{11} - \dot{E}_{12}} \tag{12}$$

Enthalpy of water and lithium bromide solution is calculated by Eq. 13. Moreover, solution entropy of data is taken from paper by Chow et al [8]. Enthalpy of lithium bromide and water solution according to the temperature and the concentration is calculated by the following equation:

$$h = E_1(x) + \mathrm{E}_2(\mathrm{x})\mathrm{T} + \mathrm{E}_3(x)T^2 \tag{13}$$

$$E_1(x) = -2024.18588321 + 163.2976010204x + 4.881268653177x^2 + 6.30250843\times10^{-2}x^3 \\ -2.91350364\times10^{-4}x^4 \tag{14}$$

$$E_2(x) = 18.2816227619 - 1.169094163968x + 3.24785672\times10^{-2}x^2 - 4.03390218\times10^{-2}x^3 \\ +1.85192774\times10^{-6}x^4 \tag{15}$$

$$E_3(x) = 3.70056321\times10^{-2} + 2.88756514\times10^{-3}x - 8.13075689\times10^{-5}x^2 + 9.91097142\times10^{-7}x^3 \\ -4.44381071\times10^{-9}x^4 \tag{16}$$

In exergy calculations, unlike energy, there is no survival principle, and entry and exit of exergy do not match. We can calculate entry and exit of exergy to any system component by calculating exergy of the mass flow rate and through it; we obtain the destruction of exergy in each component. In Table 1, by comparing the exergy of different currents, we see that in places where water and lithium bromide flow, it has a considerable amount of more exergy that is due to solving two components (refrigerant and absorbent), and on the left side of the cycles only the refrigerant flows. On the right of the cycle, path (1) has the highest rates of exergy, which is the exit point solution with high-temperature generator.

According to the results in Table 2, the highest rate of destruction in absorber is 35.87 that have total destruction. The main cause of this is irreversibility is heat transfer with high temperature difference. To improve this, we can increase heat exchange and reduce temperature difference. This, on the other hand, increases initial cost. To improve system performance, particular attention should be paid to this part to reduce exergy exit. In addition, The Percentage of Exergy destruction of system components compared to total Exergy destruction of the system are shown in Figure 2.

Table 1. Characteristics of the Exergy cycle and calculated for each flow

Stream (i)	Temperature (C)	Pressure (Kpa)	Enthalpy (kj/kg)	Entropy (kj/Kg k)	Mass flow rate (kg/sec)	X (%LiBr)	Exergy (Kw)
1	98.67	8.687	249.0258	0.5058	9.046	64.6	929.87
2	58.3	8.687	176.257	0.3017	9.046	64.6	821.79
3	53.22	0.8756	176.257	0.3017	9.046	64.6	821.79
4	42.39	0.8756	117.775	0.2323	9.82	59.5	520.91
5	42.39	8.687	117.775	0.2323	9.82	59.5	520.91
6	76.83	8.687	183.892	0.432	9.82	59.5	585.78
7	93.3	8.687	2674.96	8.48	0.7756	-	118.21
8	43.11	8.687	180.45	0.6134	0.7756	-	1.67
9	5.056	0.8756	180.265	0.645	0.7756	-	-5.78

10	5.056	0.8756	2510.78	9.0255	0.7767	-	-131.91
11	5.056	0.8756	21.11	0.077	0.0189	-	0.05
12	100	101.325	2675.99	7.3556	1.112	-	543.23
13	100	101.325	419.012	1.3067	1.112	-	37.93
14	30	101.325	125.75	0.4365	77.1	-	13.03
15	36	101.325	150.822	0.5178	77.1	-	78.15
16	15	101.325	63.023	0.2236	52.53	-	46.55
17	7	101.325	29.508	0.1057	52.53	-	131.61
18	30	101.325	125.75	0.4365	112.97	-	19.09
19	35	101.325	146.44	0.504	112.97	-	84.05

Table 2. Destruction of Exergy and Exergy destruction percentage

Component	**Input Exergy (Kw)**	**Output Exergy (Kw)**	**Exergy Destruction (Kw)**	**Exergy Destruction Ratio (%)**
Absorber	709.03	604.96	104.07	35.87
Generator	1129.01	1086.01	43.00	14.82
Evaporator	40.77	-0.25	41.03	14.14
Heat Exchanger	1450.78	1407.58	43.03	14.89
Condenser	131.24	79.82	51.43	17.72
Refrigeration	1.67	-5.78	7.45	2.57
Solution Pump	520.935	520.91	0.025	0.000087
Overall System	3462.50	3172.34	290.17	100
		COP=0.7 , E=0.17		

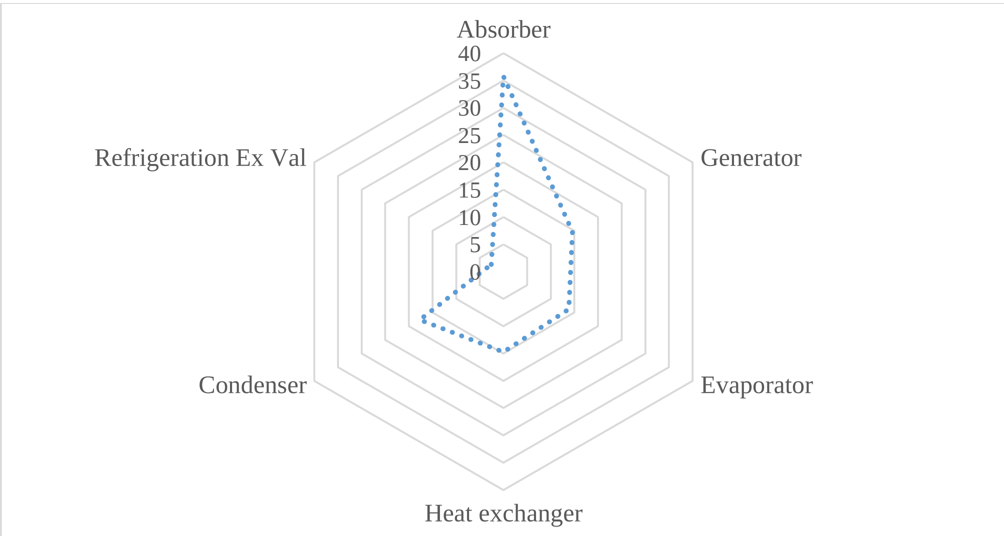

Figure 2. Percentage of Exergy destruction of system components compared to total Exergy destruction of the system

4. Conclusion

In this research, an absorption refrigeration cycle with lithium bromide as its working fluid is studied where the exergy analysis is conducted on the mentioned cycle. According to the simulation results, the highest rate of exergy destruction is in absorber and it is equal to 35.87 % of the total destruction. The main cause of this irreversibility is heat transfer with high temperature difference. To improve this, we should increase heat exchange and then reduce temperature difference. On the other hand, increases initial cost. To improve system performance, particular attention should be paid to this part to reduce exergy exit.

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