ADVANCED EXERGY ANALYSIS OF LiCl-H$_2$O ABSORPTION AIR CONDITIONING SYSTEM

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Abstract—Increasing energy demand for air conditioning due to climate change is posing a continuous threat to the environment. Absorption air-conditioning systems driven by solar thermal or waste heat energy are an alternative for providing cooling comfort in a sustainable manner. The crystallization problem of high performance LiBr-H$_2$O absorption cooling system hinders its small-scale applications. In this study, the potential of a 10 kW LiCl-H$_2$O absorption refrigeration system is discussed and analyzed. The new concept of advanced exergy analysis is coupled with conventional thermodynamic analyses, which provides the available potential of each component for overall system performance improvement. The analyses uncovered that only 45% of the total exergy loss is due to each component's own internal irreversibilities, whereas the remaining is through the interaction of the irreversibilities of other components in the system. The analyses also reveal that 43% of the total exergy loss is unavoidable and 57% can be reduced by improving the overall system efficiency.

Keywords- LiCl-H$_2$O; vapor absorption refrigeration; exergy analysis; advanced exergy analysis

I. INTRODUCTION

Global warming poses a continuous threat to the environment. At the same time, air-conditioning demand is increasing significantly on a global scale as a result of climate change, population growth, standard of living conditions and industrialization. Presently, air conditioning alone accounts for 40% to 55% of the total building energy consumption [1], which is a major sector of the total world energy consumption and carbon emissions [2]. The traditional vapor compression air-conditioning system is usually used for providing this cooling comfort, but consumes a huge amount of electricity, triggering the construction of new fossil fuel power plants worldwide. Therefore, it is imperative to employ renewable energy technologies in order to minimize climate change while meeting the increased energy demand. A vapor absorption air conditioning system, driven by solar thermal energy, can replace the traditional vapor compressor by a thermally-driven one by using an environmentally friendly refrigerant, without utilizing grid electricity.

The most common absorbent-refrigerant working pairs for this cooling system are LiBr-H$_2$O and NH$_3$-H$_2$O. The higher efficiency LiBr-H$_2$O absorption system dominates in large scale air-conditioning applications. However, due to the crystallization problem, the LiBr-H$_2$O absorption system cannot be scaled down for small residential applications. Meanwhile, the thermophysical properties of LiCl-H$_2$O shows promise for small residential-scale applications. Many researchers have shown that LiCl-H$_2$O has advantages over a LiBr-H$_2$O system in terms of cycle performance as well as low energy consumption [3, 4-8]. Hence, it is important to perform a detailed thermodynamic analysis of a LiCl-H$_2$O vapor absorption refrigeration system (VARS) in order to improve the cycle performance.

To quantify the potential of useful energy in any system, exergy analysis identifies the irreversibilities of the system components through the exergy destruction and losses. This process determines the true inefficiencies in the system and where the losses are taking place. Exergy analysis measures the actual improvement potential of the system. Exergy signifies the maximum work potential of a system that can be produced when the system proceeds from initial state to final state in relation to the surrounding environment. In this study, the exergy analysis was performed for each component and the total exergy destruction of each component was divided into endogenous, exogenous, unavoidable, and avoidable exergies. This relatively new exergy analysis is known as advanced exergy analysis. Finally, a comparison of conventional and advanced exergy analyses was performed on the component(s) that need to be improved via reducing the exergy losses.

II. SYSTEM DESCIPTION

The schematic of a single-effect LiCl-H₂O absorption cooling system is shown in Fig. 1. The core components of this cooling system are the absorber, generator, condenser and evaporator. Two expansion (throttle) valves are used for reducing the pressure. A solution heat exchanger is considered to preheat the weak solution of LiCl-H₂O leaving the absorber with the heat of the high temperature strong solution that flows back from the generator to the absorber.
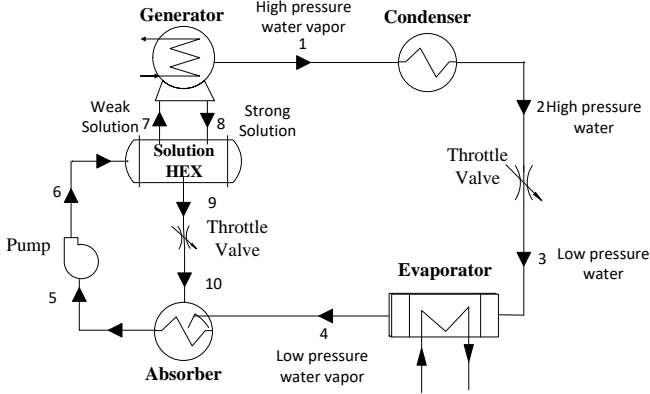

Figure 1: LiCl-H₂O Vapor Absorption Refrigeration System (VARS)

III. THERMODYNAMIC ANALYSIS

For a thermodynamic model of a vapor absorption refrigeration cycle, the principles of mass and energy conservation, and exergy balances was applied for each component of the system. The main components: generator, condenser, evaporator, absorber, and solution heat exchanger have been considered. To analyze the thermodynamic cycle, a control volume was applied to each component. All analyses were performed by considering the system under steady-state conditions.

A. Conventional Exergy Analysis

The mass and the energy balance of each component of the LiCl-H₂O refrigeration cycle in a control volume can be written as

Mass Conservation:

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \qquad (1)$$

Energy Conservation:

$$\sum \dot{Q} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_{in} h_{in} + \dot{W} \qquad (2)$$

where $\dot{m}$ is the mass flow rate (kg/s), $\dot{Q}$ is the heat transfer rate (kW), h is the specific enthalpy (kJ/kg) and $\dot{W}$ is the rate of work leaving the control volume (kW).

The exergy balance in a control volume can be determined by [9]

$$\dot{E}_D = \sum (\dot{m}e)_{in} - \sum (\dot{m}e)_{out} + \sum \dot{E}_{Q_{in}} - \sum \dot{E}_{Q_{out}} + \sum \dot{W} \qquad (3)$$

where $\dot{E}_D$ represents the rate of exergy destruction (loss) in the system. $(\dot{m}e)_{in}$ is the rate of exergy entering the control volume, $(\dot{m}e)_{out}$ is the rate of exergy leaving the control volume, $\dot{E}_Q$ represents the rate of exergy destruction in terms of heat transfer, to/from the component, and $\dot{W}$ is the mechanical work done by or on the control volume.

At any constant temperature (T),

$$\dot{E}_Q = \dot{Q}(1 - \frac{T_{ref}}{T}) \qquad (4)$$

The overall exergy per unit mass of a fluid can be calculated by [10]

$$e = (h - h_o) - T_{ref}(s - s_o) \qquad (5)$$

where e is the specific exergy, h is the specific enthalpy and s is the entropy at a given temperature T, and h_o is the enthalpy, and s_o is the entropy at the environmental temperature T_{ref}. The reference temperature and pressure are $T_{ref} = 273.15$ K and $P_{ref} = 101.325$ kPa, respectively. The specific exergy, specific enthalpy and entropy of a LiCl-H₂O solution at a given temperature and pressure were calculated by using EES software [11]. In conventional exergy analysis, the exergy destruction [12] and the exergy destruction ratio [13] can be written as

$$\dot{E}_{D,k} = (\dot{E}_k)_{in} - (\dot{E}_k)_{out} \qquad (6)$$

$$y_k = \frac{\dot{E}_{D,k}}{\dot{E}_{D,total}} \qquad (7)$$

In Equations (6) & (7), $\dot{E}_{D,k}$ is the exergy destruction rate of kth component, $(\dot{E}_k)_{in}$ and $(\dot{E}_k)_{out}$ are the exergy entering/leaving to/from the kth component, y_k is the exergy destruction ratio of the kth component over the total exergy destruction of the system. The exergy destruction provides the thermodynamic inefficiency of each component of the system [14]. The energy and the exergy equations of each component of the LiCl-H₂O absorption refrigeration system are shown in Table 1.

B. Advanced Exergy Analysis

The exergy destruction of each component can be split into endogenous/exogenous and unavoidable/avoidable exergy destruction parts [15]. Dividing exergy destruction of a component into endogenous and exogenous parts provides the actual exergy destruction caused by the component itself and the exergy destruction of that component caused by the remaining components of the system. As a result, it will provide information as to whether the focus to improve the system performance should be in the component itself or on the remaining components of the system. Alternatively, when the component operates at actual (real) and theoretical conditions, dividing the exergy destruction into unavoidable and avoidable parts determines the exergy destruction that cannot be eliminated. Table 2 shows the different operating conditions that were applied for this advanced exergy analysis.

Cycle Components	Energy balance equation	Exergy balance equation
Generator	$\dot{Q}_{gen} = \dot{m}_1 h_1 + \dot{m}_7 h_7 - \dot{m}_6 h_6$ $X_6 \dot{m}_6 = X_7 \dot{m}_7$	$\dot{E}_{D,gen} = \dot{m}_6 e_6 - \dot{m}_1 e_1 - \dot{m}_7 e_7 + \dot{Q}_{gen}(1 - \frac{T_o}{T_{gen}})$
Condenser	$\dot{Q}_{con} = \dot{m}_1(h_1 - h_2)$	$\dot{E}_{D,con} = \dot{m}_1(e_1 - e_2) - \dot{Q}_{con}(1 - \frac{T_o}{T_{con}})$
Evaporator	$\dot{Q}_{eva} = \dot{m}_4 h_4 - \dot{m}_3 h_3$	$\dot{E}_{D,eva} = \dot{m}_1(e_3 - e_4) + \dot{Q}_{eva}(1 - \frac{T_o}{T_{eva}})$
Absorber	$\dot{Q}_{abs} = \dot{m}_8 h_8 + \dot{m}_4 h_4 - \dot{m}_5 h_5$	$\dot{E}_{D,abs} = \dot{m}_4 e_4 + \dot{m}_8 e_8 - \dot{m}_5 e_5 - \dot{Q}_{abs}(1 - \frac{T_o}{T_{abs}})$
Solution HEX	$T_6 = \frac{\dot{m}_7}{\dot{m}_5}\eta_{HEX}T_7 + \left(1 - \frac{\dot{m}_7}{\dot{m}_5}\eta_{HEX}\right)T_5$ $h_8 = h_7 - \frac{\dot{m}_5}{\dot{m}_7}(h_6 - h_5)$	$\dot{E}_{D,HEX} = \dot{m}_7 e_7 + \dot{m}_5 e_5 - \dot{m}_8 e_8 - \dot{m}_6 e_6$
		$\dot{E}_{D,total} = \dot{E}_{D,gen} + \dot{E}_{D,con} + \dot{E}_{D,eva} + \dot{E}_{D,abs}$

X is the LiCl mass fraction in solution; η_{HEX} is the heat exchanger efficiency

Cycle Components	Algorithm*	Ideal cycle	Real cycle*	Unavoidable cycle*
Generator	$P_{gen} = P_{cond}(1 - \Delta P_{gen})$ $T_{gen} = (T_{gen} - \Delta T_{gen})$	$\Delta P_{gen} = 0$ $\Delta T_{gen} = 0$	$\Delta P_{gen} = 2\%$ $\Delta T_{gen} = 5\,°C$	$\Delta P_{gen} = 0.2\%$ $\Delta T_{gen} = 0.5\,°C$
Condenser	$T_{cond} = (T_{cond} + \Delta T_{cond})$ $T_{cond} \rightarrow P_{cond}$	$\Delta T_{cond} = 0$	$\Delta T_{cond} = 5\,°C$	$\Delta T_{cond} = 0.5\,°C$
Evaporator	$T_{eva} = T_{eva} + \Delta T_{eva}$ $T_{eva} \rightarrow P_{eva}$	$\Delta T_{eva} = 0$	$\Delta T_{eva} = 2\,°C$	$\Delta T_{eva} = 0.2\,°C$
Absorber	$T_{abs} = T_{abs} + \Delta T_{abs}$ $P_{abs} = P_{eva}(1 - \Delta P_{abs})$	$\Delta T_{abs} = 0$ $\Delta P_{abs} = 0$	$\Delta T_{abs} = 5\,°C$ $\Delta P_{abs} = 2\%$	$\Delta T_{abs} = 0.5\,°C$ $\Delta P_{abs} = 0.2\%$
Solution HEX	$\Delta T_{HEX} = T_7 - T_6$	$\Delta T_{HEX} = 0$ $\eta_{HEX} = 100\%$	$\Delta T_{HEX} = 5\,°C$ $\eta_{HEX} = 80\%$	$\Delta T_{HEX} = 0.5\,°C$ $\eta_{HEX} = 95\%$
Solution concentration	$X_{strong} = \varphi(T_{gen}, P_{gen})$			

*[12]

Endogenous/Exogenous Exergy Destruction

The total exergy destruction ($E_{D,k}^{real}$) of a component (k) can be divided into endogenous ($E_{D,k}^{EN}$) and exogenous ($E_{D,k}^{EX}$) parts and can be written as [9]

$$\dot{E}_{D,k}^{real} = \dot{E}_{D,k}^{EN} + \dot{E}_{D,k}^{EX} \qquad (8)$$

The endogenous exergy destruction of a component is associated with the internal irreversibilities of that component only when the other components are without irreversibilities. This can be determined by considering the case where this component will work on real operating conditions while the other components of the system will work in ideal (theoretical) operating conditions. Therefore, the endogenous exergy destruction is only due to the inefficiency of the k component. The remaining exergy destruction is the exogenous exergy destruction in that component. This exergy destruction represents the inefficiency of the k component and the inefficiencies of the remaining components of the system.

Unavoidable/Avoidable Exergy Destruction

In real operating conditions, every component of a system works with some limitations such as technical and design limitations including material availability or cost of the materials etc. Therefore, some part of the total exergy destruction of a component cannot be reduced. This is called the unavoidable exergy destruction ($E_{D,k}^{UN}$). The rest of the total exergy destruction of the component is avoidable ($E_{D,k}^{AV}$), which is represented by Equation (9). The unavoidable exergy destruction of a component is calculated assuming that the component is isolated from the system. The most reasonable operating conditions for calculating the unavoidable exergy destruction are the lowest temperature difference and pressure losses [15-17]. The unavoidable conditions are determined based on the maximum improvement that can be achieved for the component.

$$\dot{E}_{D,k}^{real} = \dot{E}_{D,k}^{UN} + \dot{E}_{D,k}^{AV} \qquad (9)$$

Combination of Two Dimensions of Exergy Destruction

The unavoidable exergy destruction of a component can be split again into endogenous unavoidable exergy destruction and exogenous unavoidable exergy destruction of that component. The exogenous unavoidable parts of a component cannot be reduced any more due to the technical limitations of the other components of the system for a given design and structure [17]. For a component, it can be determined by subtracting the endogenous unavoidable exergy destruction from the total unavoidable exergy destruction of that component and is defined by

$$\dot{E}_{D,k}^{UN} = \dot{E}_{D,k}^{EN-UN} + \dot{E}_{D,k}^{EX-UN} \qquad (10)$$

The endogenous avoidable part of the exergy destruction of a component can be reduced by improving the efficiency of that component. It can be can be determined by

$$\dot{E}_{D,k}^{EN} = \dot{E}_{D,k}^{EN-UN} + \dot{E}_{D,k}^{EN-AV} \qquad (11)$$

Likewise, the exogenous avoidable exergy destruction of a component can be reduced by the improving the design and structure of the overall system and also by improving the efficiency of the remaining components of the system. It is defined by

$$\dot{E}_{D,k}^{EX} = \dot{E}_{D,k}^{EX-UN} + \dot{E}_{D,k}^{EX-AV} \qquad (12)$$

Therefore, the effect of the exergy destruction of each component on the overall system performance can be determined through this advanced exergy analysis. The total exergy destruction of a component is

$$\dot{E}_{D,k}^{real} = \dot{E}_{D,k}^{EN-UN} + \dot{E}_{D,k}^{EN-AV} + \dot{E}_{D,k}^{EX-UN} + \dot{E}_{D,k}^{EX-AV} \qquad (13)$$

C. Theoretical Considerations

The following assumptions have been used for analyzing the thermodynamic cycle in this study:

1. The system is operating under steady state conditions.

2. LiCl-H_2O solutions are assumed to be in equilibrium in the generator and in the absorber at their corresponding pressures and temperatures.

3. The throttle valve is a constant enthalpy adiabatic process.

4. The vapor leaving the generator is 100% water vapor.

5. The refrigerant leaving the condenser is saturated water, and leaves the evaporator as water vapor.

6. The air cooling is considered for cooling of the condenser and the absorber at an atmospheric temperature of 25°C.

IV. RESULTS AND ANALYSIS

The thermodynamic values of different states of a 10 kW LiCl-H$_2$O refrigeration cycle obtained from conventional exergy analysis under ideal (theoretical) and real operating conditions are summarized in Table 3. The exergy destruction ($E_{D,K}$) and exergy destruction ratio ($y_{D,K}$) of each component under ideal, real, and unavoidable operating conditions are shown in Table 4. Table 4 shows that the highest exergy destruction is in the absorber followed by the condenser, the generator and the evaporator for ideal and unavoidable operating conditions. However, the solution heat exchanger has the second highest exergy destruction after the absorber in real operating condition because of the heat exchanger effectiveness. These losses are due to high irreversibilities occurring in the absorber and the generator. This is because of the high temperature difference across the heat exchanger in the absorber, mass transfer between the two differently concentrated solutions and the mixing losses in the absorber and the generator [18]. Furthermore, the refrigerant (water) vapor is superheated when it leaves the generator/separator. As a result, a higher temperature is required under the same operating conditions, and this leads to higher thermodynamic losses in the generator. In addition, the condenser requires more cooling in order to cool the superheated water vapor that comes from the generator and this generates more exergy destruction in the condenser. This conventional exergy analysis suggests that the exergy loss in the absorber needs to be reduced first to improve the overall system efficiency. However, the irreversibilities of the other components in the system are partly responsible for the generator and condenser exergy destructions, and the extent of responsibility can be determined by advanced exergy analysis.

In advanced exergy analysis, the exergy destruction of each component is split into four parts. The analyses have been performed based on the operating conditions in Table 2. The results of this analysis are shown in Table 5.

TABLE 4: RESULTS OF CONVENTIONAL EXERGY ANALYSIS OF A 10 KW LiCl-H$_2$O ABSORPTION REFRIGERATION CYCLE UNDER DIFFERENT OPERATING CONDITIONS

Cycle Components	Ideal		Real		Unavoidable	
	$E_{D,k}$ (kW)	$y_{D,k}$ (%)	$E_{D,k}$ (kW)	$y_{D,k}$ (%)	$E_{D,k}$ (kW)	$y_{D,k}$ (%)
Generator	6.13	18.8	10.31	13.6	6.18	18.8
Condenser	7.54	23.1	7.70	10.1	7.51	22.9
Evaporator	6.13	18.8	7.53	9.7	6.11	18.6
Absorber	10.3	31.6	33.04	42.7	10.47	31.9
Solution HEX	2.53	7.8	18.76	24.3	2.60	7.9

It can be found from Table 5 that in a 10 kW LiCl-H$_2$O absorption air conditioning system, the exogenous exergy destruction ($\dot{E}_{D,k}^{EX}$) of the absorber and the solution heat exchanger is higher than the endogenous exergy destruction ($\dot{E}_{D,k}^{EN}$). This is opposite for generator, condenser and evaporator. This demonstrates that the other components' irreversibilities have high impact on the absorber and the solution HEX performance. Whereas, the internal irreversibility of the generator, the condenser and the evaporator itself needs to be reduced. Therefore, to improve the overall system efficiency, the components themselves should be examined for design and performance improvement.

TABLE 3: THERMODYNAMIC PROPERTIES AT DIFFERENT STATES IN LiCl-H$_2$O ABSORPTION CYCLES UNDER IDEAL & REAL OPERATING CONDITIONS

State	Temperature (°C) Ideal/Real	Pressure (kPa) Ideal/Real	Mass flow (g/s) Ideal/Real	% Concentration Ideal/Real	Enthalpy (kJ/kg) Ideal/Real	Entropy (kJ/kgK) Ideal/Real	Exergy, e (kJ/kg) Ideal/Real
Bubble pump generator refg exit (1)	78/75	5.63/7.2	4.2/4.3	100	2646/2640	8.6/8.5	87/120
Condenser refg exit (2)	35/40	5.63/7.2	4.2/4.3	100	147/168	0.51/0.57	0.59/1.43
Evaporator refg inlet (3)	7/9	1/1.15	4.2/4.3	100	147/168	0.51/0.57	0.59/1.43
Evaporator refg exit (4)	7/9	1/1.15	4.2/4.3	100	2513/2517	8.97/8.92	-157/-139
Absorber sol exit (5)	35/40	1/1.15	25/45.9	41.07/42.95	155/182	0.31/0.35	-72/-2.3
Sol HEX inlet (6)	35/40	5.63/7.2	25/45.9	41.07/42.95	155/182	0.31/0.35	-72/-2.3
Generator sol inlet (7)	78/68	5.63/7.2	25/465.9	41.07/42.95	268/254	0.65/0.57	78/89
Generator sol exit (8)	78/75	5.63/7.2	21/45.5	49.41/43.35	327/275	0.210.62	150/95
Sol HEX exit (9)	35/47	5.63/7.2	21/45.5	49.41/43.35	190/202	0.16/.039	91/44
Absorber sol inlet (10)	35/47	1/1.15	21/45.5	49.41/43.35	190/202	0.16/0.39	91/44

refg = refrigerant; sol = solution

The percentage of exogenous exergy destruction rate of the solution heat exchanger (87%), the absorber (63%), and the generator (42%) are higher than that of the evaporator (17%) and the condenser (2%).

TABLE 5: RESULTS OF ADVANCED EXERGY ANALYSIS OF A LiCl-H$_2$O ABSORPTION REFRIGERATION CYCLE

Components	$\dot{E}_{D,k}^{real}$ (kW)	$\dot{E}_{D,k}^{EN}$ (kW)	$\dot{E}_{D,k}^{EX}$ (kW)	$\dot{E}_{D,k}^{UN}$ (kW)	$\dot{E}_{D,k}^{AV}$ (kW)	UN		AV	
						$\dot{E}_{D,k}^{EN-UN}$ (kW)	$\dot{E}_{D,k}^{EX\_UN}$ (kW)	$\dot{E}_{D,k}^{EN-AV}$ (kW)	$\dot{E}_{D,k}^{EX-AV}$ (kW)
Generator	10.31	6.03	4.28	6.18	4.13	6.0	0.18	0.03	4.1
		58%	42%	60%	40%	58%	2%	0%	40%
Condenser	7.70	7.54	0.16	7.5	0.2	7.45	0.05	0.09	0.11
		98%	2%	97%	3%	97%	1%	1%	1%
Evaporator	7.53	6.22	1.31	6.14	1.39	6.11	0.03	0.11	1.28
		83%	17%	82%	18%	81%	0%	1%	17%
Absorber	33.04	12.38	20.66	10.47	22.57	10.43	0.04	1.95	20.62
		37%	63%	32%	68%	32%	0%	6%	62%
Solution HEX	18.76	2.53	16.23	2.6	16.16	2.48	0.12	0.05	16.11
		13%	87%	14%	86%	13%	1%	0%	86%
Total	77	34.7	42.6	32.9	44.5	32.5	0.4	2.2	42.2
		45%	55%	43%	57%	42%	0.5%	3%	54.5%

% are determined according to Equations (8), (9), & (13).

It is also noted from Table 5 that the total unavoidable exergy destruction ($\dot{E}_{D,total}^{UN}$) of the system is 33 kW which is 43% of the total exergy destruction rate. While $\dot{E}_{D,total}^{EN-UN}$ = 32 kW (42%) is due to the components themselves. Therefore, the minimum exergy destruction rate of the system is 33 kW and this cannot be reduced further. In practice, only the avoidable part of the total exergy destruction can be reduced. It is noticed that the avoidable part of the exergy destruction is 57% (44 kW) of the total exergy destruction rate ($\dot{E}_{D,total}^{real}$ = 77 kW). However, only 3% (2.2 kW) of the total exergy destruction can be eliminated by improving the components' own efficiencies, and 54.55% (42 kW) will be lowered by improving overall system efficiency. The value of $\dot{E}_{D,abs}^{EN-AV}$ in Table 5 indicates only 6% of the exergy destruction of the absorber can be reduced by technological improvement. It is also noticed that the exogenous avoidable is much higher than the endogenous avoidable exergy destruction ($\dot{E}_D^{EX-AV} >> \dot{E}_D^{EN-AV}$) for all components. Therefore, the improvement of the efficiencies of other components plays a significant role in enhancing the overall system efficiency.

To evaluate the overall system performance in advanced exergy analysis, the avoidable exergy destruction is the focus as this has the potential for improvement. However, it is shown in Fig. 2 that the endogenous exergy destruction of the overall system is 45%, out of which, 42% is unavoidable. Whereas, almost all of 55% of the exogenous exergy destruction is avoidable as shown in Fig 2. These results show the interaction between the components and how the internal irreversibilities of each component influence the overall system efficiencies. In this analysis, the higher unavoidable exergy destruction rate indicates that the system efficiency can be optimized by optimizing the operating conditions. The technological improvement of the system component, the size of the component, and the high heat and mass transfer mechanism can also have the positive impact to reduce the unavoidable exergy destruction rate.
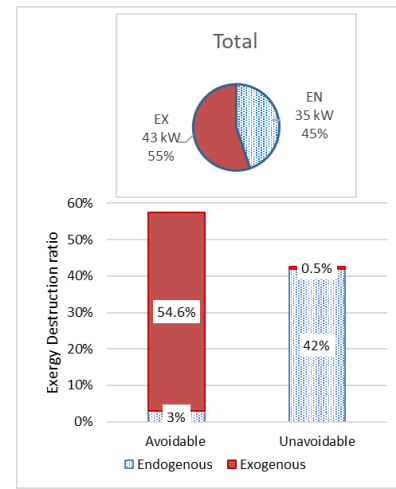

Figure 2: Exergy destruction ratio of the overall VAR system based on advanced exergy analysis.

Furthermore, based on the conventional and advanced exergy analyses, the influence of each component on the overall exergy destruction is shown in Fig. 3. Conventional exergy analysis concludes that the highest potential for improvement is the absorber, followed by the solution HEX and the generator, in order to improve the overall system performance. However, the advanced exergy analysis suggests that 32% (10.47 kW) of the total exergy destruction in the absorber is unavoidable, and 6% is available by improving the absorber itself. Whereas, all avoidable exergy destruction of the generator (40%), the solution HEX (86%), and the evaporator (17%) are exogenous avoidable. This clearly indicates that the irreversibilities of the overall system should be reduced for the system performance improvement. Furthermore, it is also noticed that 98% of the condenser exergy destruction is due to its internal irreversibilities, of which, 97% are unavoidable and 1% can be improved by improving other components efficiency.
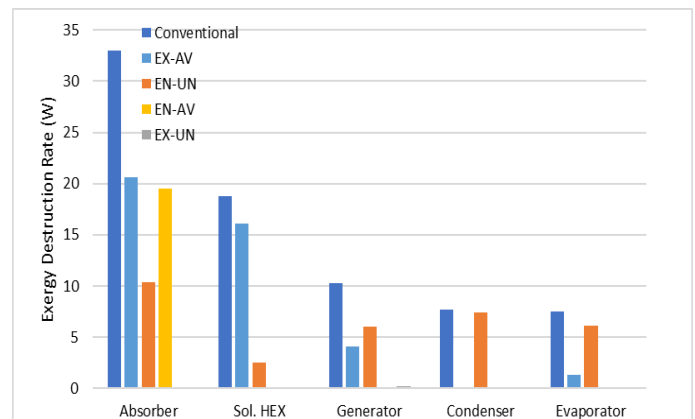

Figure 3: Exergy destruction rate of each component of a LiCl-H$_2$O absorption refrigeration cycle based on conventional exergy and advanced exergy analyses.

I. Conclusions

The advanced exergy analysis of a 10 kW LiCl-H$_2$O absorption air-conditioning system offers useful information in identifying the component that has the most potential for the overall system improvement. This information cannot be provided by a conventional exergy analysis. The avoidable exergy destruction identifies the potential of each component that can be improved by technological improvement. The endogenous avoidable and exogenous avoidable exergy destruction relate the interactions between the components' irreversibilities and quantify the importance of the relative improvement of each component and the overall system.

Finally, the analysis in this study is a very effective tool for the exergoeconomic optimization of energy conversion systems. It can provide useful information to the designer for investment in order to reduce the endogenous avoidable and exogenous avoidable parts of exergy destruction and to measure the potential improvement of the overall system structure.

Acknowledgment

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