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Research paper

Thermodynamic Analysis of Hybrid Absorption Compression System

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Abstract

The Virtual Reality realistic image content is a technology to enable building imaginary space by This paper presents thermodynamic studies conducted on a GAX hybrid absorption-compression (HYBRID) cycle using ammonia-water as working fluid for air-conditioning applications. The effect of generator, condenser and absorber temperatures on exergy destruction has been investigated. The effect of absorber pressure on the exergy destruction of the cycle has also been studied. It is found that generator and absorber are the major contributors in the total exergy destruction of the hybrid cycle. Comparison of hybrid cycle with conventional GAX cycle shows hybrid cycle has lower value of exergy destruction than the conventional GAX cycle. It is also found that at same thermal conditions assumed in this work the hybrid cycle gives 18 percent increases in average exergetic efficiency when compared to the conventional GAX cycle.

Keywords: *Virtual reality, 360 realistic Image, Technology, Pipe-line,Multi-view*

1. Introduction

Global warming, one of the major threat to the earth is caused by CO_2 emissions. Waste heat recovery during the thermal processes reduces the CO_2 emissions and absorption chillers can use waste heat as its heat source. Performance of absorption chillers can be improved by minimizing the total exergy destruction. By applying the exergy analysis, high exergy destructing components of a system can be identified and the exergy destruction minimized. There are several studies on the exergy balance of absorption refrigeration systems available in published literature. Fartaj (2000) illustrated the limitations and advantages of exergy and entropy balance methods and also showed that the results of exergy and entropy balance are consistent. Kelly *et al*. (2009) discussed four different approaches (Approach based on thermodynamic cycles, Engineering approach, Exergy balance method, Equivalent component method) for calculating the endogenous part of exergy destruction. They concluded that all approaches are lead to comparable and acceptable results. The distinction between the exergy and second law efficiencies emphasized and highlighted (Lior and Zhang 2007) the errors due to the not carefully defined equations and systems. Misra *et al*. (2002) applied thermo economic optimization technique to optimize a $LiBr/H_2O$ vapour absorption refrigeration system for air-conditioning applications. They observed that the overall thermo economic cost of the product is decreased while the overall coefficient of performance improves from 0.714 to 0.765 and the second law efficiency improves from 10.3 to 11%. Temperature-entropy (T-s) diagram developed by Chua *et al*. (2000) for irreversible absorption chillers for volatile and nonvolatile pair. They claimed that this approach is a useful tool for system analysis and only requires the inlet and outlet state points as inputs. Chua *et al*. (2000) developed a general definition of the process average temperature of the absorption chiller. They incorporated mass transfer mechanism into the absorber and imposed the upper limit of cooling capacity.

Izquierdo *et al*. (2000) studied the entropy generated and the exergy destroyed in the water-lithium bromide absorption thermal compressors of single and multiple effects. They found that though triple-effect thermal compressor destroys less exergy it does not compensate the increase of corrosion and control problems. Aphornratana and Eames (1995) proposed a new method for second law analysis of single-effect absorption refrigerator cycle and a novel graphical format for presenting the results. A simple analytic irreversible thermodynamic model is derived (Chua *et al*. 1997) to analyze the entropy generation of absorption chillers, heat pumps and heat transformers. They checked the validity of simulation results against experimental data and found that the model can be used to determine the optimal absorption system operating conditions. Meunier *et al*. (1996) studied the second law analysis of absorption systems and found that internal irreversibilities are dominant in the actual COP degradation. The entropy generation in single stage and two stage ammonia-water absorption refrigeration systems studied and explained (Adewusi and Zubair 2004) the anamoly of two-stage system having high COP and high entropy generation. Kilic and Kaynakli (2007) found that highest exergy loss occurs in the generator of the single-stage water-lithium bromide absorption refrigeration cycle. An availability analysis carried out (Karakas *et al*. 1990) on water-lithium bromide and ammonia-water solar absorption-cooling cycles and found that lithium bromide-water is more effective and has high COP when evaporator temperature is above 0°C.

. Pereira and Bugarel (1989) have proposed optimal working conditions by performing an exergy analysis on water-lithium bromide absorption system. Ishida and Jun (1999) have also analysed a single stage absorption heat transformer with the aid of a graphical exergy methodology based on the energy utilization diagram.

Vidal *et al*. (2006) carried out exergy analysis on a new combined power and refrigeration cycle. They also simulated the cycle as an irreversible process and obtained the exergetic efficiency value of around 50 percent. Talbi and Agnew (2000) carried out exergy analysis on a single-effect absorption refrigeration cycle with water-lithium bromide as the working fluid pair. They showed the reason why absorption refrigeration cycle is effective in demonstrating the advantages of the exergy method. Zheng *et al.* (2007) studied GAX ammonia absorption chiller. They proposed a new method for analysing the cycle using energy quality factor and found that GAX cycle has 31.7 percent higher exergetic efficiency than single stage cycle at T_g = 120°C , T_c = T_a = 25°C and T_e = 5°C . The present study applies the exergy analysis to study the performance of a GAX compression-absorption cycle.

Rameshkumar and Udayakumar (2008) also discussed the optimum compressor pressure ratio for hybrid cycle of 3.514 kW capacity. The optimum COP for the desorber temperatures 110°C, 130°C, 150°C and approach temperature 14°C at all optimum pressure ratios are found to be 1.00, 0.97 and 0.94, respectively. In addition Jawahar and Saravanan (2010) undertook a comprehensive review of several different GAX cycle configurations. Jelinek et al. (2012) showed that triple pressure absorption cycle operated with mechanical compressor increases the COP and decreases the circulation ratio. Rameshkumar et al (2009) analysed 1 TR hybid cooler and claimed that the COP is 27 percent higher than the conventional cycle.

Velázquez et al (2010) has been carried out using a Linear Fresnel Reflector Concentrator (LFRC) as generator in Solar-GAX cycle and found that efficiency calculated is 17.9% higher than a single effect water–lithium bromide cycle coupled in an indirect form with a Parabolic Trough Solar Collector system. Using the pinch point analysis Saravanan et al (2010) shown that the COP of GAX cycle increases from 17 to 56% higher than that of a conventional cycle with respect to the operating conditions. Rameshkumar et al (2009) have done heat transfer analysis of hybrid cycle and shown that UA of the absorber and high temperature generator (HTG) have significant impact on COP and cycle capacity. Saravanan et al (2011) experimentally proved that incorporating GAX in the simple absorption cycle 30 to 40% of the total internal heat recovered in the cycle.

Rameshkumar and Udayakumar (2008) examined the performances of three absorbent-refrigerant pairs NH_3-H_2O, NH_3-$LiNO_3$ and NH_3-NaSCN both GAX and hybrid cycles in terms of approach temperature. They concluded that ammonia-lithium nitrate hybrid cycle is the suitable alternative to the ammonia-water GAX cycle. However, thermodynamic second law analysis of hybrid cycle has not been studied. Hence, the present study applies the exergy analysis to study the performance of a hybrid cycle.

2. Simulation Study

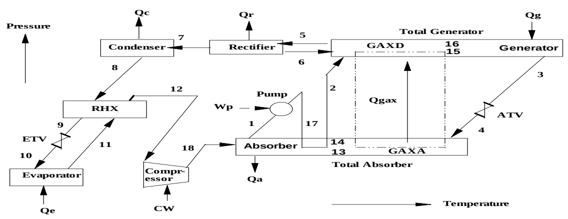

Figure 1: Schematic diagram of hybrid cycle

In this work, thermodynamic properties of all state points, COP and exergy destruction of every component of the ammonia-water hybrid cycle of capacity 13.18 kW are obtained using the Engineering Equation Solver software (2007). The procedure of determining mass flow rate at all state points and heat capacity of various components of the ammonia-water hybrid cycle was taken from published literature (2007). The generator temperatures were varied from 150°C to 190°C in steps of 10°C. The absorber temperatures were varied from 50°C to 65°C in steps of 5°C . The condenser temperatures were varied from 40°C to 55°C in steps of 5°C. The environment temperature is taken as 25°C.

The specific exergy can be evaluated as

$$e = (h - h_0) - T_0(s - s_0) \qquad (1)$$

The exergetic balance applied to a fixed control volume is given as (Bejan A, Tsatsaronis G, Moran 1996)

$$\Sigma m_i e_i - \Sigma m_o e_o + Q\,[1 - (T_0 / T)] - W = E_d \qquad (2)$$

The first term on the left hand side of the equation (2) is the sum of the exergy input. The second term is the sum of the exergy output. The maximum work obtained from heat energy transformation at the temperature T, with the environment temperature T_0 is represented by third term. The fourth term is the mechanical power interaction with the system. In the following section equations based on exergy destruction of each component of the ammonia-water HYBRID cycle is presented.

Total Absorber

$$E_{abstot} = m_{18}e_{18} + m_4e_4 + m_{17}e_{17} - m_1e_1 - m_2e_2 - Qa\,[1 - (T_0 / T_a)]\ Qgax\,[1 - (T_0 / Tgax)] \qquad (3)$$

Absorber throttle valve

$$E_{ATV} = m_3\,(e_3 - e_4) \qquad (4)$$

Total Generator

$$E_{gentot} = m_2e_2 + m_6e_6 - m_5e_5 - m_3e_3 + Qgax\,[1 - (T_0/ Tgax)] + Qg\,[1 - (T_0/ T_g)] \qquad (5)$$

Rectifier

$$E_r = m_5e_5 - m_6e_6 - m_7e_7 - Qr\,[1 - (T_0/ T_r)] \qquad (6)$$

Condenser

$$E_c = m_7e_7 - m_8e_8 - Qc\,[1 - (T_0/ T_c)] \qquad (7)$$

Refrigerant heat exchanger

$$E_{rhx} = m_8\,(e_8 - e_9) + m_{11}\,(e_{11} - e_{12}) \qquad (8)$$

Evaporator throttle valve

$$E_{ETV} = m_9\,(e_9 - e_{10}) \qquad (9)$$

Evaporator

$$E_e = m_{10}e_{10} - m_{11}e_{11} + Qe\,[1 - (T_0/ T_e)] \qquad (10)$$

Compressor

$$E_{comp} = m_{12}\,(e_{12} - e_{18}) + CW \qquad (11)$$

Pump

$$E_p = m_1\,(e_1 - e_{17}) + W_p \qquad (12)$$

The exergetic effciency can be expressed as

$$\xi = [- Qe\,(1 - T_0 / T_e)] / [\,Q_g\,(1 - T_0 / T_g) + W_p + CW] \qquad (13)$$

3 Results and Discussion

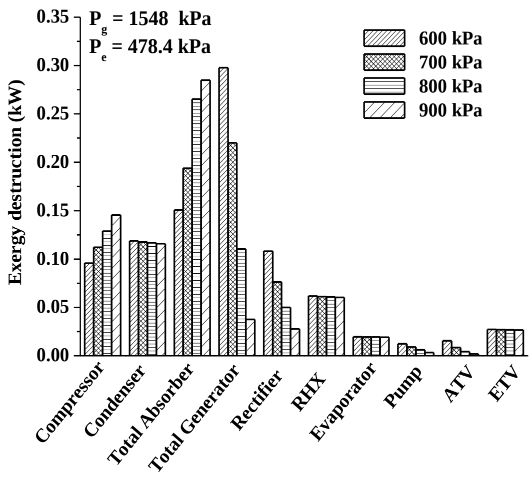

Figure 2: Variation of the exergy destruction of every component of the system for different absorber pressure [T_g = 150°C , T_c = 40°C , T_a = 60°C , T_e = 5°C]

Fig. 2 shows the exergy destruction of every component of the system for various absorber pressures. The pressure of generator and evaporator are kept constant at 1548 kPa and 478.4 kPa respectively. It can be seen that though the exergy destruction incompressor increases with the absorber pressure, the total exergy destruction of the system decreases. The reason is that apart from absorber and compressor the exergy destruction at all the other components of the system decreases with increases in the absorber pressure. Increasing the absorber pressure, increases the mass flow rate at state point 14. This in turn increases the internal heat recovery from the GAX absorber and reduces the total exergy destruction of hybrid cycle

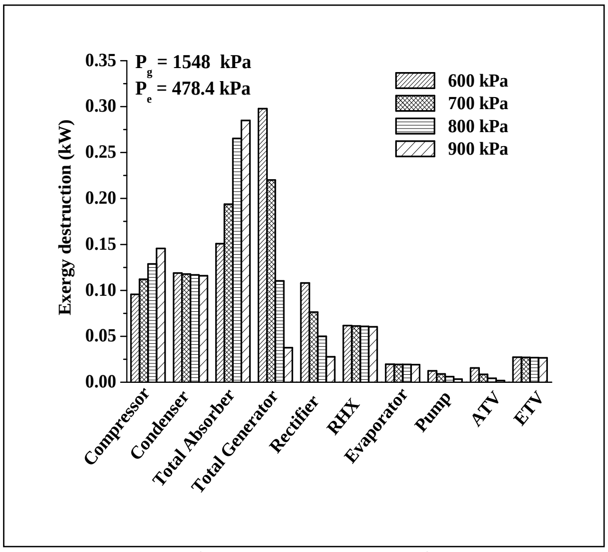

Figure 3: Variation of the exergy destruction of every component of the system for different generator temperature [P_a = 1078.4 kPa ,T_c = 40°C , T_a = 60°C , T_e = 5°C]

Fig. 3 shows the exergy destruction of every component of the system for various generator temperatures. The temperature of absorber, condenser and evaporator are kept constant at 60°C, 40°C and 5°C respectively. From Fig.3 and Fig.4 it is observed that the trend of changes in exergy destruction is similar in all cycle components except compressor and rectifier. Constant absorber the trend of changes in exergy destruction is similar in all cycle components except compressor and rectifier. Constant absorber pressure does not cause any changes in exergy destruction in compressor. The entropy generation in rectifier while increasing absorber pressure at constant Tg decreases from 0.108 kW to 0.028 kW. However the exergy destruction is a constant value 0.108 kW when Tg increases at constant absorber pressure

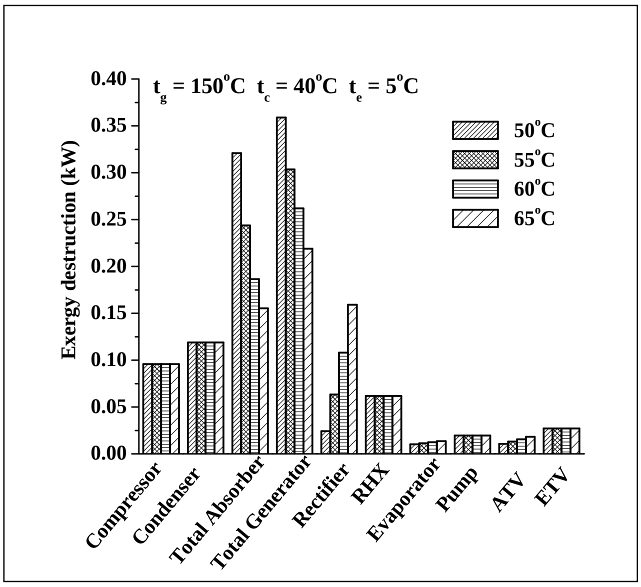

Figure 4: Variation of the exergy destruction of every component of the system for different absorber temperature [P_a = 1078.4 kPa , T_g = 150°C , T_c = 40°C , T_e = 5°C]

Fig. 4 shows the exergy destruction of every component of the system for various absorber temperatures. The temperature of generator, condenser and evaporator are kept constant at 150°C , 40°C and 5°C respectively. The increase in absorber temperature decreases the exergy destruction. Though there is no change in the exergy destruction in the compressor, the absorber and generator experiences decreases in exergy destruction.

Fig. 5 shows the exergy destruction of every component of the system for various condenser temperatures. The temperature of generator, absorber and evaporator are kept constant at 150°C, 60°C and 5°C respectively. Increase in the condenser temperature increases the total exergy destruction of the cycle. The reason is except the compressor and condenser exergy destruction increases with the increase in the condenser temperature

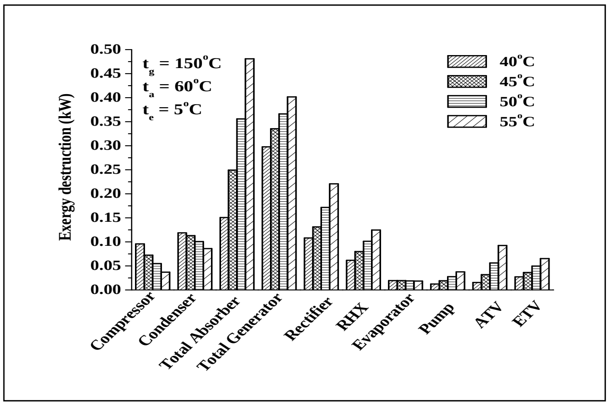

Figure 5: shows the exergy destruction of every component of the system for various condenser temperatures

Increasing the condenser temperature increases the condenser pressure and the weak solution concentration. These effects in turn decrease the degasing range. This leads to the larger amount of heat rejection in the absorber and eventually the total exergy destruction increases. The exergy destruction of every component of the ammonia-water hybrid cycle by changing generator, absorber, condenser temperatures and absorber pressure have shown from Fig. 2 to Fig. 5. From this study, it is also observed that an evaporator temperature of interest (5°C), an ammonia-water hybrid cycle with low condenser (40°C) and generator temperatures (150°C) and high absorber pressure (900 kPa) produces least exergy destruction

It is also seen that increase of exergy destruction in total absorber (comprises of absorber and GAXA) and total generator (comprises of generator and GAXD) have major contribution in the total exergy destruction in ammonia-water hybrid cycle. Table 2 gives the exergy destruction in GAXA, absorber, generator and GAXD in this simulation work. It can be observed from the Table 2 that in most of the thermal conditions, absorber and generator have the major contribution in exergy destruction. Hence, more attention should be given while designing these components for less total exergy destruction.

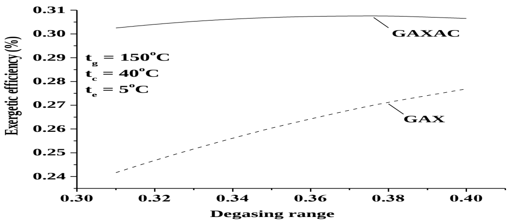

Figure 6: Comparison of GAX and GAXAC cycle

Fig. 6 compares the influence of the degasing range on exergetic efficiency for GAX conventional and hybrid cycles. The total exergetic efficiency is high for the hybrid cycle compared to the conventional GAX cycle at all degasing ranges. At same thermal conditions

[T_g = 150°C, T_c = 40°C , T_e = 5°C , P_e = P_a = 478.4kPa, P_c = 1548 kPa for the GAX cycle and

T_g = 150°C, T_c = 40°C , T_e = 5°C, P_e= 478.4 kPa, P_c= 1548 kPa and P_a = 1078.4 kPa for the hybrid cycle] the hybrid cycle of 13.18 kW capacity gives 18 percent increases in average exergetic efficiency when compared to the conventional GAX cycle.

4. Conclusion

A hybrid cycle was analyzed based on exergy balance. The conclusions made are

1. Generator and absorber are the major contributors in the total entropy generation of the hybrid cycle.
2. Given evaporator temperature a hybrid cycle with low condenser and generator temperatures and high absorber pressure produces least total exergy destruction.
3. For a capacity of 13.18 kW the hybrid cycle gives 18 percent increases in average exergetic efficiency when compared to the conventional GAX cycle.
4. At chosen operating parameters hybrid cycle has 0.98797 kW lower value of total exergy destruction than the GAX cycle.

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