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Thermal analysis of sustainable composite material absorption refrigeration system for cold storage application

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Abstract

Present study deals with thermal analysis of absorption refrigeration system (ARS) and generator-absorber heat exchanger (GAX) based absorption refrigeration system by using green composite like aqua-ammonia. Evaporator temperature is 0°C for cold storage application, condenser temperature is 50°C as per Indian weather condition, mass stream rate of strong solution through the pump is 1 kg/s, and effectiveness of solution heat exchanger and refrigerant heat exchanger is 0.7 considered for present comparative study. This study is carried out to examine the variation in COP of both types of absorption refrigeration system for various functioning factors. Outcomes indicate GAX based ARS provides superior performance than that of conventional ARS for various operating parameters. It is concluded that COP of both the systems are higher at higher degasing range, lower pressure ratio and higher value of effectiveness of refrigerant heat exchanger (RHE). It can be also concluded that generator temperature is higher at higher value of degasing range and pressure ratio for the fixed value of all other operating parameters.

Keywords: *Composite material, Absorption refrigeration, COP, degasing range, GAX, pressure ratio, thermal analysis.*

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INTRODUCTION

The broad utilization of petroleum product brings about natural issues like an Earth-wide temperature boost, greenhouse effect, environmental change, and ozone depletion potential. Looking towards the fuel economy, requirement of reduction of fossil fuel consumption, fuel emission and environmental impact, it is preferable to find out another possible source of energy. "According to the Internal Energy Agency (IEA), global energy demand will increase by 35% from 2010 and 2035" [1]. It is accounted for in IIR (International Institute of Refrigeration) report that 10 to 20% of all power created is consumed for refrigeration and cooling. Low grade energy operated cooling frameworks are promising arrangement in this unique circumstance. Refrigeration is largely used in human life as well as it is one of the leading electricity consumer. Researchers are focusing much on absorption chillers/absorption refrigeration due to increase in fossil fuel prices and destructive effect of the use of CFCs and HCFCs refrigerants on environment. Use of the green composite is highly preferable. Absorption refrigeration system have many advantages as compared to compression based refrigeration system in specifically probability to utilization of low grade energy like sun oriented energy, squander heat, geothermal energy as well as their similarity with the climate.

Based on the refrigerant-absorbent pair two sorts of absorption refrigeration cycles are highly popular namely NH_3-H_2O and H_2O-LiBr. Ammonia-water working fluid pair works as one of the green composite. In ammonia-water absorption system, ammonia is the refrigerant and water is the absorbent. Ammonia has good solubility in water, but difference is the boiling point of ammonia and water is 133.3ºC, so vapour leaving the generator contains some amount of water. Therefore rectifier is required for ammonia-water absorption refrigeration system. Ammonia-water pair has high partiality, high steadiness, absence of crystallization zone, positive system pressure, ability to produce subzero temperature, non-corrosive, and evaporator temperature can go down even up to -60ºC, therefore it is suitable for air conditioning, industrial refrigeration, and freezing applications. Aqua-ammonia absorption refrigeration systems are generally suitable for all refrigeration purposes i.e. below and above 0°C.

Authors [2,3] carried out thermal analysis of absorption refrigeration system to obtain maximum performance of the system for various operating parameters. "It was concluded that circulation ratio is invasively proportional to generator and evaporator temperatures". High exergetc efficiencies were obtained for a COP of 0.65 and 0.70 which implies high value of total thermal conductance which may be against economic point of view. Sozen and Ozalp [4] presented "aqua-ammonia absorption system by locating ejector at the absorber inlet". "Use of ejector at inlet to absorber provides absorber pressure higher than evaporator pressure, hence system works with triple pressure". It was reasoned that for the presented framework, COP and exergetic efficiency enriched by 49% and 56% correspondingly and circulation ratio reduced by 57% for the ARS at lower generator temperatures. Researchers [5-8] have done thermal analysis for the performance prediction of green composite aqua-ammonia absorption refrigeration framework utilizing squander energy as heat source. It was concluded that COP of absorption system was straightforwardly relative to generator and evaporator temperatures and contrarily corresponding to condenser and absorber temperatures. According to the researchers waste heat of diesel engine can be provided to the generator of absorption refrigeration system and yields considerable act of the system. Bouaziz et al. [9] offered a hybrid compression-absorption cooling system which operates at three pressure levels. In their proposed system, absorber pressure was taken as intermediate pressure between condenser and evaporator pressure and results were compared with conventional system. It was observed that intermediate pressure has great influence on betterment of COP as well as also impact on reducing generator temperature.

"Researchers [10-13] investigation of aqua-ammonia absorption refrigeration system. Theoretical work was carried out to evaluate the influence of system operating parameters to the COP of the system". Experimental results were compared with theoretical results and found satisfactory. "Al-Falahi carried out simulation of absorption refrigeration system using parabolic trough and evacuated tube collectors" [14, 15]. Their results showed that ARS with PTC provides substandard plan viewpoint and least paces of hourly expenses while ARS with ETC provides lower thermo-economic product cost. According to their results, LiBr-H_2O with PTC provides the best results based on design and hourly cost and lowest results of exergy destruction rates. Talpada and Ramana [16] "reviewed on development of new working fluid pairs and mixture of nano-particles and refrigerant to improve COP of the system". "Comparison of absorption refrigeration system using different working fluid pair as well as effect of nano-particles on different performance parameters and COP of the system were presented in their study". Researchers [17,18] presented GAX based absorption refrigeration system using aqua-ammonia as working pair for the capacity of 3 TR system. It was concluded that GAX based absorption cooling system has potential to compete technically. "It was also observed that heat can be provided by concentrating collectors like parabolic troughs or CPC" [17,18]. Gulati et al. [19] carried out thermal analysis of ARS by seeding Nanoparticles directly in the working fluid. It was observed that thermal performance of the system improves due to immersion and sprinkle upshot of Nanoparticles.

Based on literature study it can be said that aqua-ammonia absorption cooling system is one of the promising system for refrigeration as it works on low grade energy. Present challenge related to the aqua-ammonia absorption system is to improve its performance and economic aspect. It is also observed from literature that only few work have been done in GAX based absorption system. Hence, present work deals with comparative study of conventional and GAX centered aqua-ammonia absorption refrigeration arrangement. In current article both the systems are compared based on different operating parameters to understand its effect on system performance.

DESCRIPTION OF ABSORPTION REFRIGERATION SYSTEM

Fig. 1 shows aqua-ammonia absorption refrigeration system. While, Fig. 2 shows GAX based absorption refrigeration system using aqua-ammonia as working fluid pair. In aqua-ammonia absorption refrigeration system water works as absorbent and ammonia works as refrigerant.

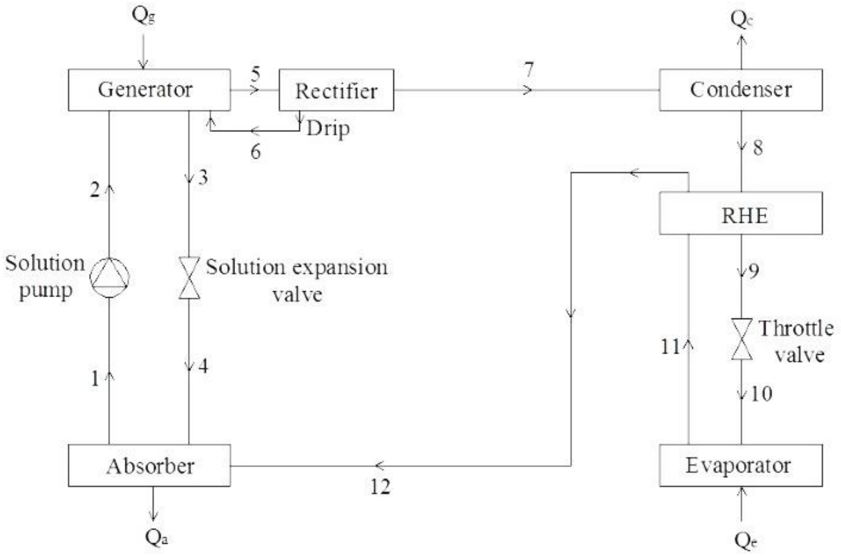

Fig. 1: *Schematic diagram of aqua-ammonia absorption refrigeration system [2]*

Compressor of vapour compression refrigeration system is supplanted by 3 components namely absorber, solution pump, and generator in absorption refrigeration system. Other auxiliary components like solution expansion valve/throttle valve and rectifier can also be used. In absorber, refrigerant absorbs by absorbent at approximately condenser temperature and strong solution occurs. Solution pump increases pressure of strong solution and delivers it to the generator. The generator splits the paired arrangement of absorbent and refrigerant by vaporizing refrigerant. The remaining weak solution flows down and expanded and enters to the absorber for additional cooling as it gets new refrigerant vapour and becomes strong solution. In aqua-ammonia ARS, the ammonia vapour from generator goes through the rectifier for conceivable detachment of some leftover water vapour and enters to the condenser. High pressure refrigerant gas is condensed in condenser, and condensate is then passed through the throttle valve after passing through refrigerant heat exchanger to the evaporator as low pressure liquid refrigerant. The low pressure liquid refrigerant in the evaporator is utilized to cool the space to be chilled and vapour refrigerant is formed.

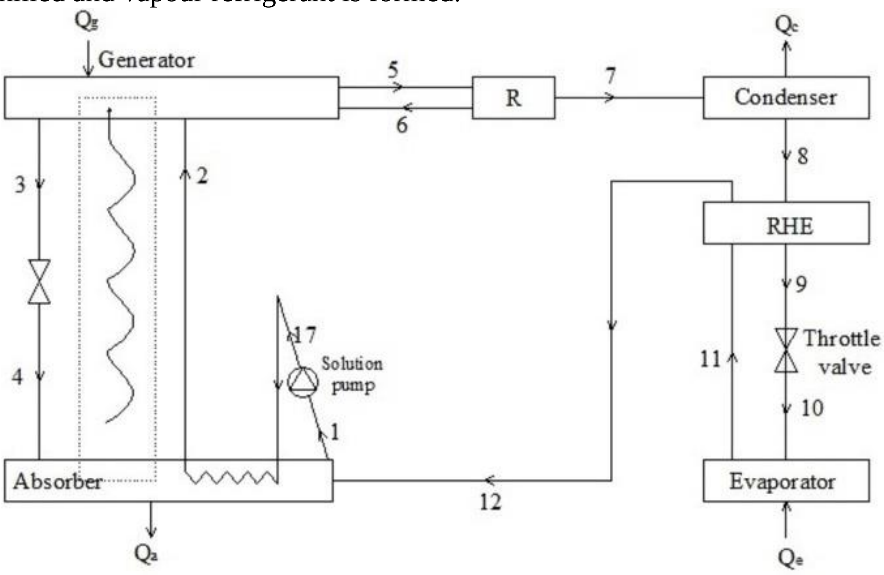

Fig. 2: *Schematic diagram of absorption refrigeration cycle with GAX [17,18]*

The vapour refrigerant is absorbed in absorber after passing through refrigerant heat exchanger. “GAX means generator-absorber heat exchanger. GAX cycle works by using aqua-ammonia as working fluid pair”. In GAX cycle heat recovery is done within the cycle by using absorber and generator as counter flow heat exchanger. Weak solution from generator and vapour refrigerant from evaporator enters in to the absorber. Heat is rejected by the absorber to retain ability to absorb vapour refrigerant by the absorbent. Rich solution enters at top of generator from absorber. Here, the refrigerant becomes dry out from solution as it is heated by using heat rejected from the top section of absorber. The difference between strong and weak solution concentration is called degasing range. Rich solution circulation depends on degasing range.

WORKING FLUID PAIR

Present study deals with thermal analysis of ARS and GAX based ARS using green composite of ammonia-water as working fluid pair. Following are the mechanical properties of both the fluids [20].

Table 1: *Mechanical properties/physical properties of ammonia & water [20]*

Mechanical Property	Ammonia	Water
Molecular weight/Molar mass (g/mol)	17.03	18.02
Density (kg/m^3)	0.73	1000
Boiling point (°C)	-33.3	100
Melting point (°C)	-77.7	0

GOVERNING EQUATIONS

A complete mathematical model of aqua-ammonia absorption refrigeration system and GAX absorption refrigeration system is prepared to carry out thermal analysis of absorption refrigeration system. Assumptions of present study are as follows [13].

- Liquid and vapour leaving the condenser and evaporator are saturated at their respective temperatures.
- Absorber temperature is same as that of condenser temperature.
- Pump efficiency is 50%.
- Mass fraction of ammonia at outlet of rectifier is 99.8%.
- Pressure drop in the system and connecting pipes are neglected.

Following equations are used for the mass balance, energy balance, and to calculate COP of the absorption refrigeration system. Table 2 shows the mass balance, energy balance, COP and exergetic efficiency equations used for both aqua-ammonia absorption refrigeration system and GAX absorption refrigeration system as per state points mentioned in Figure 1 and 2 respectively.

Table 2: *Mass balance, energy balance, COP and exergetic efficiency equations of absorption refrigeration system and GAX based system [7,17,18]*

Particular	Aqua-ammonia absorption refrigeration system	GAX absorption refrigeration system
Mass balance	$\sum \dot{m} = 0$	$\sum \dot{m} = 0$
Refrigerant mass balance	$\sum \dot{m}x = 0$	$\sum \dot{m}x = 0$
Energy balance in condenser	$q_c = \dot{m}_9 \left(h_9 - h_{10} \right)$	$q_c = \dot{m}_7 \left(h_7 - h_8 \right)$
Effectiveness of refrigerant heat exchanger	$\varepsilon_{rhe} = \dfrac{T_8 - T_9}{T_8 - T_{11}}$	$\varepsilon_{rhe} = \dfrac{T_8 - T_9}{T_8 - T_{11}}$
Energy balance in throttle valve	$h_{10} = h_9$	$h_{10} = h_9$
Energy balance in evaporator	$q_e = \dot{m}_{10} \left(h_{11} - h_{10} \right)$	$q_e = \dot{m}_{10} \left(h_{11} - h_{10} \right)$

Energy balance in absorber	$q_a = \dot{m}_{12}h_{12} + \dot{m}_4h_4 - \dot{m}_1h_1$	$q_a = \dot{m}_{12}h_{12} + \dot{m}_4h_4 + \dot{m}_{17}h_{17} - \dot{m}_1h_1 - \dot{m}_2h_2 - \dot{m}_{15}h_{15}$
Energy balance in solution expansion valve	$h_4 = h_3$	$h_4 = h_3$
Energy balance in desorber/generator	$q_g = \dot{m}_3h_3 + \dot{m}_5h_5 - \dot{m}_2h_2 - \dot{m}_6h_6$	$q_g = \dot{m}_5h_5 + \dot{m}_3h_3 - \dot{m}_2h_2 - \dot{m}_6h_6 - \dot{m}_{16}h_{16}$
Pump work	$W_p = \frac{\dot{m}_1v_1(p_2 - p_1)}{\eta_p}$	$W_p = \frac{\dot{m}_1v_1(p_{17} - p_1)}{\eta_p}$
Coefficient of performance	$COP = \frac{q_e}{q_g + W_p}$	$COP = \frac{q_e}{q_g + W_p}$
Exergetic efficiency	$\eta_{exe} = \frac{-q_e \times \left(1 - \frac{T_0}{T_e}\right)}{\left(q_g \times \left(1 - \frac{T_0}{T_g}\right)\right) + W_p}$	$\eta_{exe} = \frac{-q_e\left(1 - \frac{T_0}{T_{11}}\right)}{q_g\left(1 - \frac{T_0}{T_3}\right) + W_p}$

RESULTS AND DISCUSSION

Effect of degasing range on COP of aqua-ammonia ARS and GAX absorption refrigeration system is shown in Fig. 3 for the condenser temperature of 50°C as per Indian atmospheric condition, evaporator temperature of 0°C for the cold storage application, the mass stream pace of arrangement of solution through the pump is 1 kg/s and effectiveness of RHE of 0.7. It is observed that with the increase of degasing range COP of both the systems increases. This is due to fact that with the increase of degasing range rich solution circulation decreases which ultimately results in increase of COP. It is also concluded that COP of GAX absorption refrigeration system is higher as compared to aqua-ammonia absorption refrigeration system. However at lower value of degasing range COP of aqua-ammonia absorption refrigeration system is higher as compared to GAX absorption system. It can be also concluded that percentage increment in GAX absorption refrigeration system increases with increase of degasing range as compared to aqua-ammonia absorption refrigeration system. Maximum % increase in COP of GAX based ARS found as 83.39% as compared to conventional aqua-ammonia ARS at degasing range of 0.35.

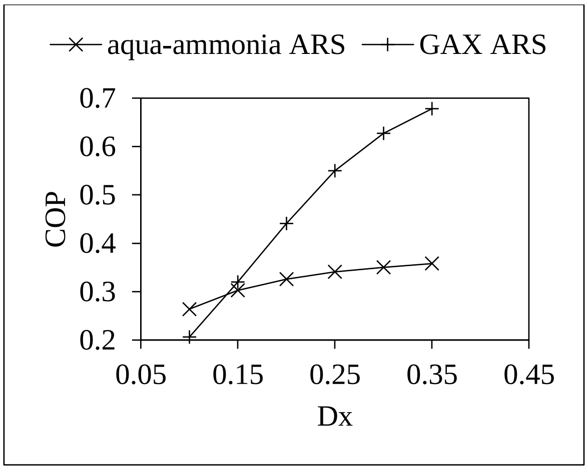

Fig. 3: *Influence of degasing range on COP*

Fig. 4 illustrates the influence of degasing range on generator temperature. It is observed that with the increase of degasing range generator temperature of both the system increases. However it is same for both the systems. Generator temperature increases by 46.39% in both the systems when degasing range increased from 0.10 to 0.35.

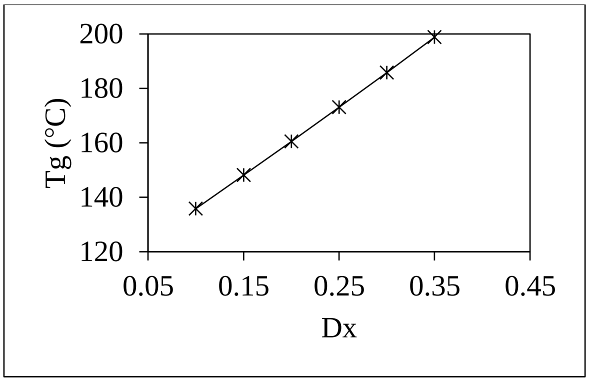

Fig.4: *Influence of degasing range on generator temperature*

Influence of pressure ratio on COP of absorption refrigeration system is presented in Fig. 5 for the degasing range of 0.3, effectiveness of RHE of 0.7, and the mass stream pace of arrangement through the pump is 1 kg/s. It is observed that with the increment of pressure ratio COP of both the system decreases. It is also concluded that COP of GAX absorption refrigeration system is higher related to conventional aqua-ammonia absorption refrigeration system for all values of pressure ratio. Maximum % increase in COP of GAX based absorption refrigeration system found as 121.68 % as compared to conventional absorption refrigeration system at lower pressure ratio of 1.95. In present study pressure arte increments with the increment of condenser temperature and decline of evaporator temperature. It very well may be reasoned that lower condenser and higher evaporator temperatures are ideal for the better exhibition of the absorption refrigeration framework. However selection of condenser temperature depends on whether condition where refrigeration system can be used and that of evaporator temperature depends on cooling application. Similarly, Fig. 6 indicates the consequence of pressure ratio on generator temperature. It is seen that with the upturn of pressure ratio required generator temperature increases. It is same for both the systems. Generator temperature increases by 89.79% in both the systems when pressure ratio increased from 1.95 to 7.21.

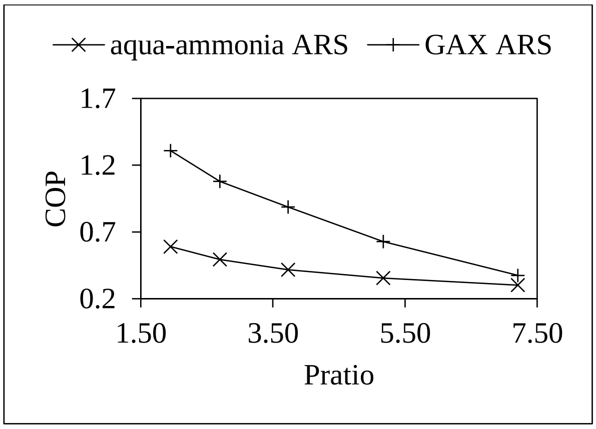

Fig. 5: *Effect of pressure ratio on COP*

Fig. 7 shows the impact of effectiveness of RHE on COP of both the systems for the condenser temperature of 50°C, evaporator temperature of 0°C, the mass stream pace of arrangement through the siphon is 1 kg/s, and degasing range of 0.3. It is reasoned that COP of both the frameworks increments with the increment of viability of RHE. Execution of GAX retention refrigeration framework is better when contrasted with water-ammonia assimilation refrigeration framework for all chose upsides of viability of RHE.

This is due to fact that with the increase of effectiveness of RHE heat absorbed by the evaporator increases for a similar worth of generator heat obligation, which brings about increment of COP of absorption systems. It is seen that, maximum % rise in COP of GAX based absorption refrigeration system found as 79.04% as compared to conventional absorption refrigeration system at effectiveness of RHE as 0.8.

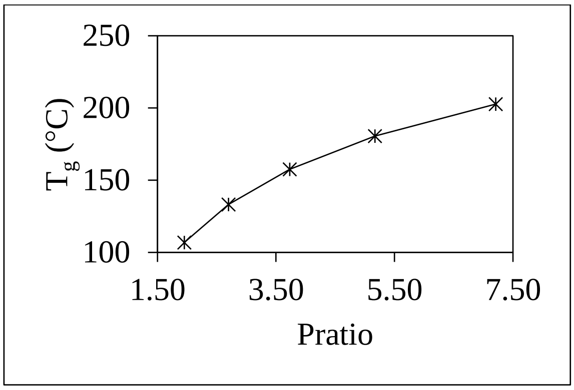

Fig. 6: *Effect of pressure ratio on generator temperature*

Fig. 8, 9, and 10 represents the influence of degasing range, pressure ratio, and effectiveness of refrigerant heat exchanger on exergetic efficiency of aqua-ammonia ARS and GAX based ARS respectively. Effects are found under the similar conditions of other operating parameters as same as that for COP. It is observed that trends of the graph is similar to that of COP trends. Exergetic efficiency of GAX based ARS seen as more as compared to conventional aqua-ammonia ARS for completely designated operating parameters.

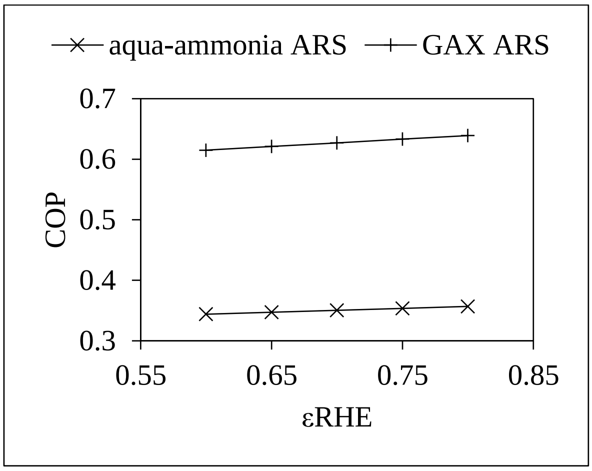

Fig. 7: *Influence of effectiveness of RHE on COP*

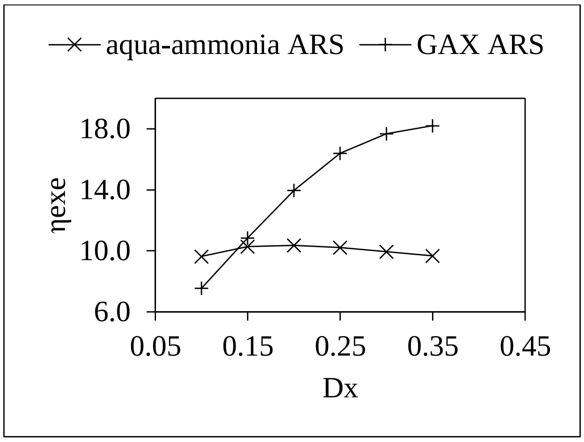

Fig. 8: *Effect of degasing range on exergetic efficiency*

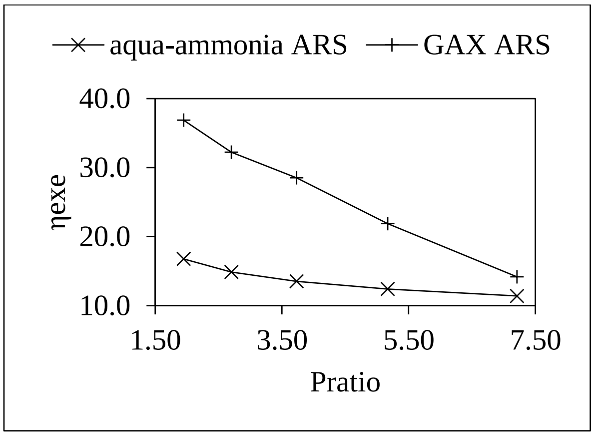

Fig. 9: *Effect of pressure ratio on exergetic efficiency*

It is concluded that maximum % increase in exergetic efficiency of GAX based ARS found as 88.31% as compared to conventional aqua-ammonia ARS at degasing range of 0.35. Calculated results showed that maximum % increase in exergetic efficiency of GAX based absorption refrigeration system found as 119.86% as compared to conventional absorption refrigeration system at lower pressure ratio of 1.95.

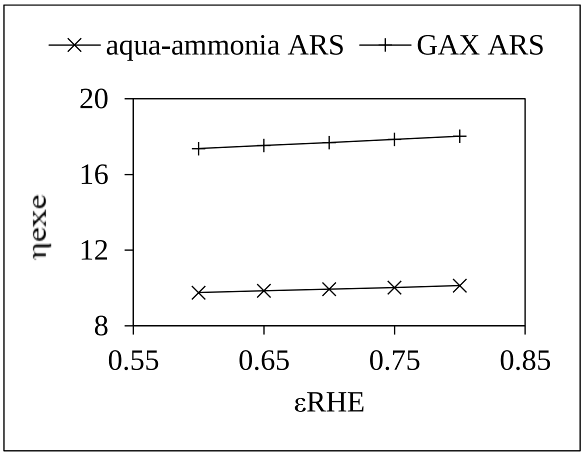

Fig. 10: *Influence of effectiveness of refrigerant heat exchanger on exergetic efficiency*

It is also observed that maximum % increase in exergetic efficiency of GAX based absorption refrigeration system found as 78.07% as compared to conventional absorption refrigeration system at effectiveness of RHE as 0.75.

CONCLUSIONS

Present study deals with thermal analysis of aqua-ammonia ARS and GAX based ARS. Effect of degasing range and pressure ratio on COP and generator temperature as well as effectiveness of RHE on COP have been studied in present thermal analysis. Form the study following conclusions are drawn.

- With the increase of degasing range COP and generator temperature increases of conventional and GAX based absorption refrigeration arrangement for the fixed values of condenser, absorber and evaporator temperatures as well as effectiveness of RHE. However, values of generator temperature are same for both conventional and GAX based ARS. It is also concluded that at lower degasing range COP of conventional ARS found higher as compared to GAX based ARS, and then COP of GAX based ARS is higher as compared to conventional ARS with the increase of degasing range.
- Lower pressure ratio is preferable to obtain higher COP of both the systems. It is also observed that for all selected values of pressure ratio, COP of GAX based ARS is higher than that of conventional ARS for fixed values of all other operating parameters.
- COP of both the systems upsurges with the growth of effectiveness of RHE. However, for all values of effectiveness of RHE, COP of GAX based ARS is higher as compared to conventional ARS for the fixed value of all other operating parameters.
- COP of GAX based ARS is 5.65% to 89.39% higher as compared to conventional ARS for the degasing range from 0.15 to 0.35. However, COP of GAX based ARS is 21.94% lower than that of conventional ARS for the degasing range of 0.10.
- COP of GAX based ARS is 121.68% to 24.38% higher as compared to that of conventional ARS for the pressure ratio in the range of 1.95 to 7.21.
- COP of GAX based ARS is 78.78% to 79.04% higher as compared to conventional ARS for the effectiveness of RHE in the range of 0.6 to 0.8.
- Generator temperature increases by 89.79% with the increase of pressure ratio from 1.95 to 7.21.
- Generator temperature increases by 46.39% with the increase of degasing range from 0.10 to 0.35.

It is observed that effect of degasing range, pressure ratio, and effectiveness of refrigerant heat exchanger on efficiency provides better results of GAX based ARS as compared to conventional ARS.

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