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THERMAL OPTIMIZATION OF GAX BASED AMMONIA-WATER ABSORPTION REFRIGERATION SYSTEM

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Abstract

Generator-absorber heat exchanger (GAX) based absorption refrigeration system provides better performance as compared conventional absorption refrigeration system. Ammonia-water pair is used as working fluid pair in this study. This article presents thermal optimization of GAX based absorption refrigeration system using Taguchi method of design of experiments to find optimum parameters for the maximum COP. Based on Taguchi design, maximum COP is obtained as 1.346 at condenser temperature (T_c) = 35°C, evaporator temperature (T_e) = 2°C, generator temperature (T_g) = 180°C, and effectiveness of refrigerant heat exchanger (ε_{RHE}) = 0.8. Results also indicate that condenser temperature has maximum influence on the performance of the GAX based absorption refrigeration system.

Keywords: absorption refrigeration, COP, GAX, Taguchi design.

1. INTRODUCTION

In many of the industries after utilizing energy produced from fossil fuels is rejected to the atmosphere. This energy which is called waste heat as well as solar energy and other source of low grade energy can be useful in refrigeration system, such as absorption refrigeration system. The heat operated refrigeration system as compared to electricity based refrigeration system, reduces problems related to environment like greenhouse effect from CO_2 emission. As well as vapour compression refrigeration system mainly uses CFCs and HCFCs refrigerants due to its favorable thermo-physical properties, which also causes environmental issues. Therefore, now-a-days absorption refrigeration system are becoming more and more popular even though it's COP is less as compared to vapour compression refrigeration system due to environment aspect. Looking towards the practical prospective researchers are continuously working for the improvement of COP of the absorption refrigeration system.

A detailed survey on absorption fluids presented by Macriss et al. [1]. In their survey, 38 different refrigerant compounds and 187 absorber compounds were discussed. Though, it was concluded that ammonia-water and LiBr-H_2O were most common working fluid pairs. Ammonia-water pair is one of the most suitable refrigerant-absorbent pair in absorption refrigeration system due to its high stability at wide range of operating pressure and temperature. Freezing point temperature of ammonia is -77.7°C hence it can be used for both air-conditioning as well as cold storage applications.

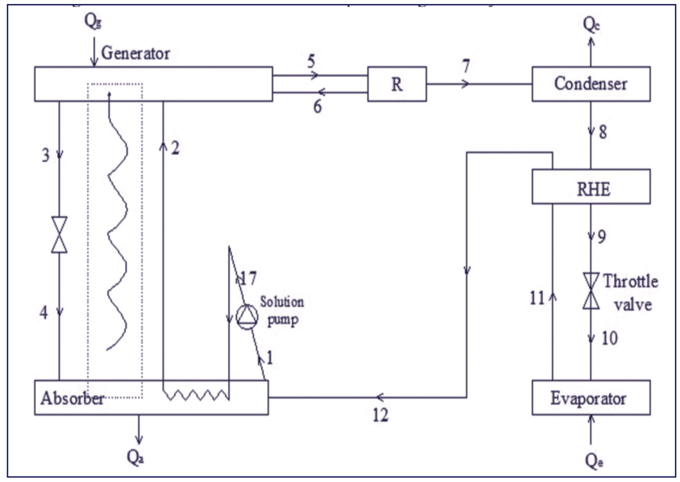
Kang et al. [2] analyzed ammonia-water absorption heat pump systems and developed a model which was applied to design of different system components namely absorber, desorber, rectifier, condenser, and evaporator. Solution flow rate effects on heat transfer coefficient was examined by performing experiments with and without absorption phenomena [3] for ammonia-water absorption refrigeration. Their study provided Nu-Re relation which can be used to design coiled tube heat exchanger. Absorber is one of the important component in absorption refrigeration system. Looking towards this, Selim and Elsayed [4] presented ammonia-water absorption refrigeration system to predict the performance of the packed bed absorber design for various operating parameters. Their results showed that absorption efficiency found more than 91% at height of bed greater than 0.7 m. A numerical model of ammonia-water absorption refrigeration system for helical coil rectifier on the basis of heat and mass transfer and balance was presented by Fernandez-Seara [5]. Coil height and cross section of coil were selected as the main parameters for their analysis. Rectifier performance on the basis of heat and mass transfer coefficients were considered and discussed in their analysis. In the absorption refrigeration system electrically driven pump is required. Ammonia-water diffusion absorption refrigeration were experimentally investigated for cooling in off-grid regions by Najjaran et al. [6]. This system found as unique system due to electrically driven pump was absent. Their results showed that, COP found in the range of 0.11-0.26 for the cooling output in the range of 79-104 W. Wijaksana et al. [7] studied on effect of concentration of ammonia on the COP of absorption refrigeration system with the use of water floated evaporator. Their results showed that COP and cooling capacity was increases with increase value of ammonia concentration. The ammonia concentration used in their study was of 18%, 27%, 37%, 47%, and 59% and found maximum COP of 0.829 at 59% concentration of ammonia.

Kang et al. [8] presented a model to design a rectifier for the three different geometric configuration in GAX heat pump using ammonia-water solution pair. Rectifier was highly influenced by heat transfer coefficient and concluded that vapour region found more dominant than liquid and coolant region. Potnis et al. [9] simulated GAX based ammonia-water system for the liquid film absorption and flow boiling deposition. Their simulation was mainly to detect appropriate system component design and convincing approximation of COP of the system. Simulation of GAX based small capacity of 5 TR was presented by Priedeman et al. [10] to predict system COP. Their results showed that COP of the system found as 0.68 at full load condition. Their results were satisfied existing market research which showed that GAX based chillers have potential to obtained COP of 0.7. Rameshkumar et al. [11] studied effect of heat transfer conductance of different system components on performance and cycle capacity of generator-absorber-exchange absorption compression cycle with the use of ammonia-water working fluids. It was concluded that maximum COP found of 1.185 at 11.56 cooling capacity. Mehr et al. [12] investigated two GAX models, in first model ejector was used to increase absorber pressure and in second ejector was used to increase condenser pressure. Results of both the models were compared with standard GAX cycle. Their results showed that COP of second model found 16.7% greater than standard GAX cycle. GAX hybrid absorption-compression system for air conditioning applications were analyzed by Ramesh Kumar [13] with the use of ammonia-water working fluid pair. It was found that hybrid cycle provides 18% higher average exergetic efficiency than conventional GAX cycle. Al-Amir and Khudair [14] studied branched GAX absorption refrigeration system with the use of ammonia-water working fluid pair. COP and cooling capacity was increased with increase of generator and evaporator temperature, decrease of condenser temperature, and increase in difference in ammonia concentration. From literature it is concluded that GAX based absorption refrigeration system provides better performance as compared to conventional absorption refrigeration system. Absorption refrigeration system have potential to use for cooling systems with the requirement of improvement in its COP. And GAX absorption system provides it. Therefore, in this study thermal optimization of GAX based absorption refrigeration is carried out.

2. SYSTEM DESCRIPTION

Figure 1 shows block diagram of GAX based absorption refrigeration system. GAX means generator-absorption heat exchanger. It is also called desorber/absorption heat exchanger. It consist of condenser, refrigerant heat exchanger (RHE), evaporator, absorber, generator, rectifier, two pumps, generator-absorber heat exchanger, and two throttle valve as main components. Strong solution leaving the absorber is supplied to GAX desorber after pumping. The strong solution is heated in generator and produces high concentration ammonia. The weak solution leaving the generator passes to the absorber through throttle valve to the GAX absorber where rejected heat is transferred to the solution passing through the GAX desorber. By this way in GAX based absorption refrigeration system COP of the system increases. Remaining all other component functioning is same as that of conventional absorption refrigeration cycle.

Figure 1. Block diagram of GAX based absorption refrigeration system



3. SIMULATION MODEL

GAX based absorption refrigeration system using ammonia-water as working pair is simulated in present study. Following assumptions are made in present analysis.

- The kinetic and potential energies are neglected.
- Pressure losses in all system components and pipes are neglected.
- The concentration of vapour leaves the rectifier is 99.5%.
- The ammonia leaves the evaporator is saturate vapour at evaporator temperature.
- The ammonia leaves the condenser is saturated liquid at condenser temperature.
- The capacity of system is 10 TR.
- Condenser and absorber temperatures are same.

The general equations used for the present study are as under.

Mass balance is given by following equation

$$\sum m_{in} = \sum m_{out} \tag{1}$$

Refrigerant mass balance is given by following equation

$$\sum (\dot{m}X)_{in} = \sum (\dot{m}X)_{out} \tag{2}$$

Energy balance is given by following equation

$$\sum q + \sum W + \sum (\dot{m}h)_{in} = \sum (\dot{m}h)_{out} \tag{3}$$

COP of the system is given by following equation

$$COP = \frac{q_e}{W_p + q_g} \tag{4}$$

4. OPTIMIZATION FOR COP OF GAX BASED ABSORPTION REFRIGERATION SYSTEM

In present analysis condenser, evaporator, and generator temperatures as well as effectiveness of refrigerant heat exchanger are selected as independent variables. COP is consider as dependent variable. Four different levels of four parameters as shown in Table 1 are selected. Total 256 combinations are produced.

Table 1. Factors and their levels

Factor	Level 1	Level 2	Level 3	Level 4
Condenser temperature, T_c (°C)	35	40	45	50
Evaporator temperature, T_e (°C)	-4	-2	0	2
Generator temperature, T_g (°C)	120	140	160	180
Effectiveness of RHE, ε_{RHE}	0.65	0.70	0.75	0.80

Taguchi design is used in this study to optimize design parameters. For the selected four independent variables and their four levels, L16 orthogonal array is used. Taguchi design is shown in Table 2. Based on Taguchi design sixteen different combinations of the different independent variables are shown in Table 3 and COP is calculated. Results of COP of all different sixteen combination are mentioned in Table 3. Regression equation is also obtained for maximum COP and it is as under.

$$COP = 1.10 - 0.0467T_c + 0.0366T_e + 0.01T_g + 0.034\varepsilon_{RHE} \quad (5)$$

S = 0.0294238 R^2 = 99.5% R^2 (adj) = 99.4%

Table 2. Taguchi design

1	1	1	1
1	2	2	2
1	3	3	3
1	4	4	4
2	1	2	3
2	2	1	4
2	3	4	1
2	4	3	2
3	1	3	4
3	2	4	3
3	3	1	2
3	4	2	1
4	1	4	2
4	2	3	1
4	3	2	4
4	4	1	3

Table 3. Results of COP for Taguchi design

T_c (°C)	T_e (°C)	T_g (°C	ε_{RHE}	COP
35	-4	120	0.65	0.532
35	-2	140	0.7	0.843
35	0	160	0.75	1.11
35	2	180	0.8	1.346
40	-4	140	0.75	0.53
40	-2	120	0.8	0.341
40	0	180	0.65	1.041
40	2	160	0.7	0.951
45	-4	160	0.8	0.502
45	-2	180	0.75	0.706
45	0	120	0.7	0.182
45	2	140	0.65	0.494
50	-4	180	0.7	0.435
50	-2	160	0.65	0.32
50	0	140	0.8	0.219
50	2	120	0.75	0.069

4.1 SN ratio analysis: Signal-to-noise (SN) ratio is used to analyze Taguchi design. It is used to predict optimum results. MINITAB is used for the setting of parameters with larger is better concept. To maximize response for the "Larger is better" category following equation of SN ratio is used. Table 4 shows SN ratio for COP of the GAX based absorption refrigeration system.

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Yi^2}\right] \quad (6)$$

Table 4. SN ratio for COP

T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	COP	SN
35	-4	120	0.65	0.532	-5.4818
35	-2	140	0.7	0.843	-1.4834
35	0	160	0.75	1.11	0.9065
35	2	180	0.8	1.346	2.5809
40	-4	140	0.75	0.53	-5.5145
40	-2	120	0.8	0.341	-9.3449
40	0	180	0.65	1.041	0.349
40	2	160	0.7	0.951	-0.4364
45	-4	160	0.8	0.502	-5.9859
45	-2	180	0.75	0.706	-3.0239
45	0	120	0.7	0.182	-14.799
45	2	140	0.65	0.494	-6.1255
50	-4	180	0.7	0.435	-7.2302
50	-2	160	0.65	0.32	-9.897
50	0	140	0.8	0.219	-13.191
50	2	120	0.75	0.069	-23.223

Figure 2. Main effect plot for means

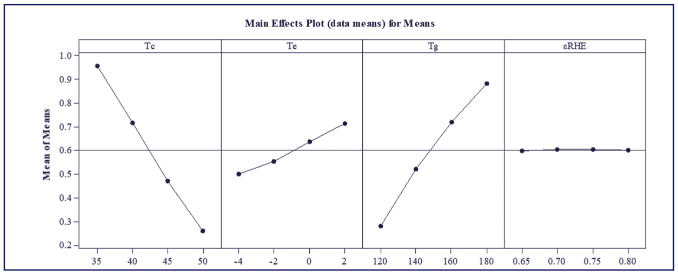
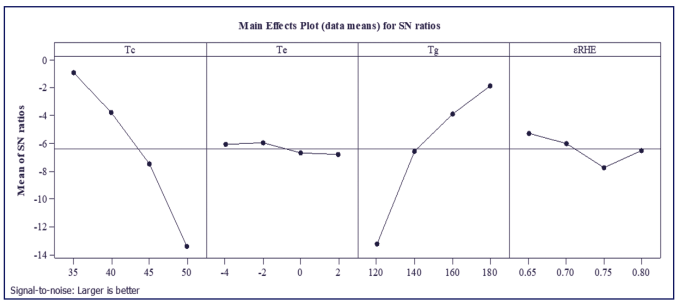


Figure 2 and 3 shows main effect plot of means and SN ratio respectively. Figure 2 shows $T_c = 35°C$, $T_e = 2°C$, $T_g = 180°C$, and $\varepsilon_{RHE} = 0.8$ are suitable parameters for maximum value of COP based on mean of means. Same way, $T_c = 35°C$, $T_e = -2°C$, $T_g = 180°C$, and $\varepsilon_{RHE} = 0.65$ are suitable parameters for maximum COP of the GAX based absorption refrigeration system based on SN ratios.

Figure 3. Main effect plot for SN ratios



5. RESULTS AND DISCUSSION

Thermal optimization of GAX based ammonia-water absorption refrigeration is studied in this article. For the optimization, Taguchi method of design of experiment is used in this study. Taguchi design is applied to find optimum operating parameters for the maximum COP of the absorption refrigeration system. It is found that value of coefficient of determination (R^2) for COP is 99.5%. Which means that measure of goodness of fit is very well in the present analysis. From the results of COP based on Taguchi design it can be said that maximum COP is 1.346 at $T_c = 35°C$, $T_e = 2°C$, $T_g = 180°C$, and $\varepsilon_{RHE} = 0.8$. Table 5 and 6 indicates response of means and SN ratios for COP respectively. It is observed from both the tables that influence of condenser temperature is maximum on COP.

Table 5. Response for means

Level	T_c	T_e	T_g	ε_{RHE}
1	0.9578	0.4998	0.281	0.5968
2	0.7158	0.5525	0.5215	0.6028
3	0.471	0.638	0.7208	0.6038
4	0.2608	0.715	0.882	0.602
Delta	0.697	0.2153	0.601	0.007
Rank	1	3	2	4

Table 6. Response for SN rations

Level	T_c	T_e	T_g	ε_{RHE}
1	-0.8695	-6.0531	-13.212	-5.2888
2	-3.7367	-5.9373	-6.5786	-5.9872
3	-7.4835	-6.6836	-3.8532	-7.7137
4	-13.385	-6.801	-1.8311	-6.4853
Delta	12.5159	0.8637	11.381	2.4249
Rank	1	4	2	3

6. CONCLUSIONS

In present study, thermal optimization of 10 TR GAX based absorption refrigeration system using ammonia-water working fluid pair is presented. Taguchi method of design of experiment is used to carry out thermal optimization. Then SN ratio is used to analyze Taguchi design to predict the optimum operating parameters. Condenser, evaporator, and generator temperatures as well as effectiveness of RHE are selected as independent variables and COP is consider as dependent variable. Optimization is performed to optimize operating parameters for the maximum COP. Taguchi design results show that maximum value of COP is 1.346 at $T_c = 35°C$, $T_e = 2°C$, $T_g = 180°C$, and $\varepsilon_{RHE} = 0.8$. But, results of SN analysis show that $T_c = 35°C$, $T_e = 2°C$, $T_g = 180°C$, and $\varepsilon_{RHE} = 0.8$ are suitable parameters for maximum value of COP based on mean of means. And, $T_c = 35°C$, $T_e = -2°C$, $T_g = 180°C$, and $\varepsilon_{RHE} = 0.65$ are suitable parameters for maximum COP based on SN ratios. From response of means and SN ratios, it is also concluded that condenser temperature has maximum influence on the COP of the GAX based absorption system.

REFERENCES

[1] *R. A. Macriss, J. M. Gutraj, T. S. Zawacki. Absorption fluids data survey: Final report on worldwide data. Oak Ridge National Lab., TN (USA); Institute of Gas Technology, Chicago, IL (USA) 1988.*

[2] *Y. T. Kang, W. Chen, R. N. Christensen. Generalized component design model by combined heat and mass transfer analysis* NH_3-H_2O *absorption heat pump system. ASHRAE Transaction. PH-97-3-2, 1997.*

[3] *S. Jeong, S. K. Lee, K. K. Koo. Heat transfer performance of a coiled tube absorber with working fluid of ammonia/water. ASHRAE Transaction. SF-98-21-4, 1998.*

[4] *A.M. Selim, M.M. Elsayed. Performance of a packed bed absorber for aqua ammonia absorption refrigeration system. International Journal of Refrigeration 1999; 22:283–292.*

[5] *J. Fernandez-Seara, J. Sieres, M. Vszquez. Heat and mass transfer analysis of a helical coil rectifier in an ammonia–water absorption system. International Journal of Thermal Sciences 2003; 42:783–794.*

[6] *A. Najjaran, J. Freeman, A. Ramos, C. N. Markides. Experimental performance analysis of an ammonia-water*

diffusion absorption refrigeration cycle. 13th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics 2017: 950-955.

[7] *H. Wijaksana, I. N. S. Winaya, M. Sucipta, A. Ghurri. The investigation of influence ammonia concentration variations to the performance of a pump less ammonia-water absorption refrigeration system with water flooding evaporator. AIP Conference Proceedings 2019; 2062: 020053:https://doi.org/10.1063/1.5086600.*

[8] *Y.T. Kang, W. Chen, R.N. Christensen. Development of design model for a rectifier in GAX absorption heat pump systems. ASHRAE Transaction 1996:102.*

[9] *S.V. Potnis, A. Gomezplata, R.A. Papar, G. Anand, D.C. Erickson. GAX component simulation and validation. ASHRAE Transaction 1997:103.*

[10] *D. K. Priedeman, M. A. Garrabrant, J. A. Mathias, R. E. Stout, R. N. Christensen. Performance of a residential-sized GAX absorption chiller. Transactions of the ASME 2001; 123:236-241.*

[11] *A. Rameshkumar, M. Udayakumar, R. Saravanan. Heat transfer studies on a GAXAC (generator-absorber-exchange absorption compression) cooler. Applied Energy 2009; 86:2056–2064.*

[12] *A. S. Mehr, M. Yari, S.M.S. Mahmoudi, A. Soroureddin. A comparative study on the GAX based absorption refrigeration systems: SGAX, GAXH and GAX-E. Applied Thermal Engineering 2012; 44:29-38.*

[13] *A. Ramesh kumar. Thermodynamic analysis of hybrid absorption compression system. International Journal of Engineering & Technology 2018; 7:445-448.*

[14] *Q. R. Al-Amir, N. Y. Khudair. Theoretical analysis on the performance of branched GAX chiller cycle. The Iraqi Journal for Mechanical and Material Engineering 2018; 18(4):550-563.*