Ranjana Kushwaha, 2022, 10:1
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

Performance Optimization of Absorption Refrigeration Systems Using Box-Behnken Design and Central Composite Design

M.Tech Scholar Ranjana Kushwaha, Prof. Dr. Nitin Tenguria
Department of Mechanical Engineering,
SIRT,Bhopal,MP,India

Abstract- In this paper, the statistical analyses of the ammonia-water absorption refrigerant system (ARS) are presented. For this purpose, different surface response methods, including the Central composite design (CCD) and Box- Behnken design (BBD), have been studied and compared first to obtain the best response. An attempt is made to study the effect of generator, evaporator, condenser and absorber temperature on the system's response. Based on the design of experiment analysis, regression models are presented to quantify the effects of these parameters on coefficient of performance (COP) of the LiBr-water absorption refrigerant cycle..

Keywords- Central composite design, Box- Behnken design, LiBr-water absorption refrigerant cycle, coefficient of performance, Response surface methodology.

I. INTRODUCTION

The decrease of fossil fuels such as natural gas, coal, oil and the increase of the negative impact of these fuels increase the need for renewable energy sources day by day. Therefore, in the last few years, the use of absorption refrigeration systems (ARSs) instead of vapor compression refrigeration systems is currently gaining momentum.

The most important advantages of ARSs are as follows: They do not destroy the ozone layer depending on the working fluid pairs used in the system and can benefit from various renewable energy sources (i.e., geothermal energy or solar energy).

Tugcu et al. (2016) optimized the single stage geothermal energy assisted ARS, working with NH3-H2O, for different solution concentrations and design parameters. In this study, for the optimum design, COP of the system was determined as 57.22% while the exergy efficiency was calculated as 62.01%. Saleh and Mosa (2014) examined the single-effect ARS powered by a flat-plate collector for hot regions and optimized the performance of the system. They found that the overall system performance takes its optimal value at temperatures between 75 ^{o}C and 80 ^{o}C, adopting typical values encountered in hot regions.

In literature, there are many studies on the thermodynamic analysis of ARSs and the performance characteristics of the cycle.

Karamangil et al. (2010) presented a comprehensive literature review on the ARS and they examined the influence of the effectiveness's of solution, refrigerant and solution-refrigerant heat exchangers (SHE, RHE and SRHE), the operating temperatures (generator, evaporator, condenser, and absorber) and the selection of working fluid (LiBr-H2O, NH3-H2O, NH3-LiNO3) on the system performance indicators (COP and circulation ratio, CR). In that study, it was concluded that SHE has the most significant effect on COP since it increases the system COP by 66% compared to RHE and SRHE.

Li et al. (2017) performed a thermodynamic analysis of a novel air-cooled non-adiabatic ejection-absorption refrigeration cycle with R290/oil mixture driven by exhaust heat.
Ouadha and El-Gotni (2013) performed the thermodynamic analysis of an ARS driven by waste

heat from a Diesel engine. The thermodynamic study of the cycle performed for several working conditions by changing the temperatures of generator, condenser, absorber and evaporator. They determined that higher performance of the system is obtained at high generator and evaporator temperatures and also at low condenser and absorber temperatures.

Bademlioglu et al. (2018) examined the impact weights of parameters on ORC's first-law efficiency by utilizing Taguchi and ANOVA methods. In this study, the most efficient parameters on the thermal efficiency of the ORC (evaporator temperature, condenser temperature and turbine isentropic efficiency) were determined and the total effect ratios of these parameters were calculated to be 70%. Coskun et al. (2012) analyzed the performance of waste heat recovery application with the aid of the Taguchi method, and determined the significant parameters and optimum operating conditions.

Arslanoglu and Yigit (2017) examined the parameters that have the most significant effect on the optimum insulation thickness, in accordance with the importance order by utilizing Taguchi method. Moreover, impact ratio for each parameter was determined with the help of ANOVA.

Nonetheless, a detailed study analyzing all these parameters and determining their contribution ratios on the system's performance with a statistical approach has not been encountered in the literature. For this reason, the purpose of this study is to examine the parameters that present the most significant effect on the ARS's COP values and determine the importance order of these parameters by utilizing Taguchi and ANOVA methods. Moreover, the best and worst working conditions are determined by different statistical analysis methods and the results are compared.

II. THEORETICAL STUDIES

Extensive studies have been carried out on the compression-absorption systems by various researchers regarding the first law analysis of the system as reported in the literature which are explained in the following section. Saleh and Mosa (2014) examined the single-effect ARS powered by a flat-plate collector for hot regions and optimized the performance of the system. They found that the overall system performance takes its optimal value at temperatures between 75°C and 80°C, adopting typical values encountered in hot regions.

Karamangil et al. (2010) presented a comprehensive literature review on the ARS and they examined the influence of the effectiveness's of solution, refrigerant and solution-refrigerant heat exchangers (SHE, RHE and SRHE), the operating temperatures (generator, evaporator, condenser, and absorber) and the selection of working fluid (LiBr-H2O, NH3-H2O, NH3-LiNO3) on the system performance indicators (COP and circulation ratio, CR). In that study, it was concluded that SHE has the most significant effect on COP since it increases the system COP by 66% compared to RHE and SRHE.

Li et al. (2017) performed a thermodynamic analysis of a novel air-cooled non-adiabatic ejection-absorption refrigeration cycle with R290/oil mixture driven by exhaust heat. Ouadha and El- Gotni (2013) performed the thermodynamic analysis of an ARS driven by waste heat from a Diesel engine. The thermodynamic study of the cycle performed for several working conditions by changing the temperatures of generator, condenser, absorber and evaporator. They determined that higher performance of the system is obtained at high generator and evaporator temperatures and also at low condenser and absorber temperatures.

Sencan (2007) performed the performance analysis of NH3-H2O ARS based on the artificial neural network model. Novella et al. (2017) performed the thermodynamic analysis of an absorption refrigeration cycle used to cool down the temperature of the intake air in an internal combustion engine using the exhaust gas of the engine as a heat source. In general, in these studies, the different parameters affecting the first law efficiency of the ARS were examined and the effects of the system on the COP were analyzed.

Studies in the literature show that there are various parameters affecting the energetic and exergetic performance of ARS such as the generator, evaporator, condenser and absorber temperature, the effectiveness of SHE, RHE and SRHE and pump isentropic efficiency. Nonetheless, a detailed study analyzing all these parameters and determining their contribution ratios on the system's performance with a statistical approach has not been encountered in the literature. For this reason, the purpose of this study is to examine the parameters that present the most significant effect on the ARS's COP values and determine the importance order of these parameters by utilizing RSM method. Moreover, the best and worst working conditions are determined by different statistical analysis methods and the results are compared.

III. RESEARCH OBJECTIVES

- To optimize the single effect vapour absorption system using RSM technique
- To study the effect of performance parameters on COP of cycle
- To quantify the results based on statistical technique using Design expert software

IV. PARAMETERS AND LEVELS

In this study four parameters are considered for the optimization of absorption refrigeration system such as generator temperature, evaporator temperature, condenser temperature and absorber temperature. The levels of parameters are chosen based on literature review as shown in Table 1.

RSM method uptimes the system performance by using Box-Behnken design [5]. In engineering, many phenomena are modeled on their own theories, such that some of them do not have the ability to have a mathematical model due to a large number of controlling factors, unknown mechanisms, or computational complexity.

Response surface methodology (RSM) is one of the exploration approaches in designing experiments and engineering related sciences. It is a set of mathematical and statistical approaches profitable for the modeling and analysis of problems in which response parameter is affected by several variables, and optimized.

In this procedure, it is examined to find a way to estimate interactions, quadratic effects and even the localized surface of the response using a suitable test design. After numerical simulation of the single stage LiBr-water absorption system in computer code by EES and ensuring the accuracy of computations, it is necessary to determine the appropriate mathematical model to investigate the role of each desired parameter. A response surface methodology is a set of advanced design of experiments (DOE) techniques that help better understand and optimize response. Table 1 shows the ranges of parameters (adopted from Canbolat 2019) for the analysis on the COP.

Table 1. Ranges of parameters (adopted from Canbolat 2019) for the analysis on the COP.

Parameters	Levels		
	-1	0	1
Generator temperature, Tg	90	110	130
Condenser temperature, Tc	28	33	38
Absorber temperature, Ta	28	33	38
Evaporator temperature, Te	-5	2.5	10

V. RESULTS AND DISCUSSION

1. Validation of Results:

Before proceeding to statistical analysis, EES code validation has been carried out through contrasting the current simulation outcomes with that of Ketfi et al. [17], Kaushik et al. [16] and Modi et al. [15].

Table 2. Comparison of validation results of COP with the published literature.

Sr. No.	Published literature	Tg (°C)	Tc (°C)	Ta (°C)	Te (°C)	COP	COP Estimated using EES code	Deviation
1	Ketfi et al. [17]	90	40	40	7	0.775	0.753	-2.83%
2	Modi et al. [15]	87.8	37.8	37.8	7.2	0.7615	0.812	6.63%
3	Kaushik et al. [16]	87.8	37.8	37.8	7.2	0.7609	0.812	6.71%

A comparison of simulation results has been shown in Table 2. The deviation in COP is -2.83% when compared with Ketfi et al. [17]. Similarly, the deviation in COP is +6.63% and +6.71% of present simulation results when compared with the results of Modi et al. [15] and Kaushik et al. [16], respectively.

The variation in results is due to irreversibility distribution among every element of the absorption mechanism. Also, the current single-impact vapor absorption system is satisfactory for the simulation.

2. COP Results:
Table 6 presented a summary of some statistical results of the models. For COP, the Predicted Rsquared of 0.9962 is in reasonable agreement with the Adjusted R-squared of 0.9985. The ratios presented in Table 3 represent a suitable signal. These models can be applied to move around the design space.

Table 3. Statistical data from CCD and BBD for COP

	COP	
	CCD	BBD
SD	0.041	0.042
Mean	0.876	0.862
R^2	0.9986	0.9977
Adjusted R^2	0.9985	0.9975
Predicted R^2	0.9978	0.9962

3. Comparison Between Predicted and Simulation Value:
The conformation of the fitted model was carried out to know its sufficient approximation to the actual values. The optimization of the fitted response surface probably provides poor or misleading results until the model shows the satisfactory fit [3]. The model satisfactoriness was confirmed with the diagnostic plots such as predicted vs. simulation values. The plots also exhibited the relationship between predicted and experimental values.

The diagnostic plots of the response are exhibited in Figure 1. The data points on this plot recline reasonably close to the straight line and this indicated an adequate agreement between the real data and the data obtained from the models. The normality of the residuals was checked by analyzing the data. The normal probability plot shown in Fig. 2 depicts the normal distribution of the residuals. The residuals provide the difference between the observed value of a response and the value that is fitted under the theoretical model. The small residual value indicates that the model prediction is accurate [2]. The data points lie reasonably close to straight line in Figure 5.4. Some scatter was also found with normal data and it could be concluded that the data are normally distributed.

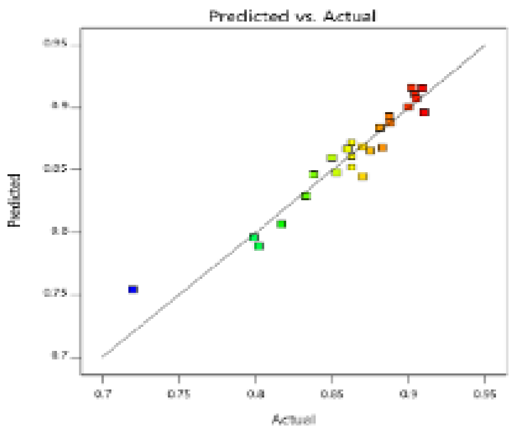

Fig 1. Comparison between predicted and simulation values.

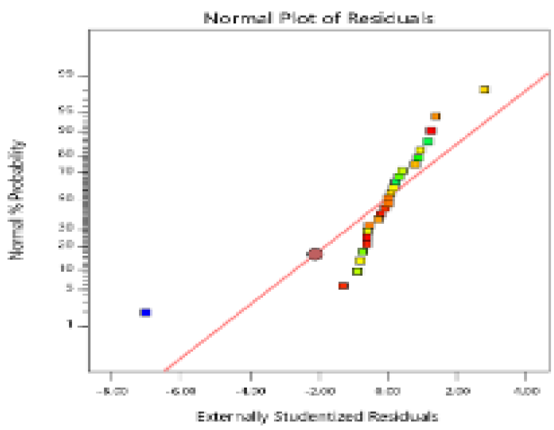

Fig 2. Normal probability plots of standardized residuals.

As seen in Figure 2, the plots of residual for COP are randomly distributed and not followed by any ordered pattern. Hence, it can be derived that the residual analysis does not demonstrate any model inadequacy or the model is suitable for predicting the responses at a confidence level of 95%.

VI. CONCLUSION

In the present research, RSM designs such as BBD and CCD are used to fit quadratic equations are compared. Thus, the method of BBD of RSM has been adopted to study the effective parameters on the LiBr- water absorption refrigerant system.
The simulation code of LiBr-water absorption refrigerant system was studied in the EES at different

maximum/minimum pressure and concentration of solution and pure ammonia, different isentropic efficiency of the pump, mass flow rate and also different effectiveness factor of the heat exchanger.

This study showed that using the Central Composite Design (CCD) predicts better responses more closed to the actual values compared to the Box–Behnken Design (BBD). Thus, the method of central composite design of RSM has been adopted to study the effective parameters on the LiBr- water absorption refrigerant system.

REFERENCES

[1] Abed, A.M., Alghoul, M.A., Sirawn, R., Al-Shamani, A.N., Sopian, K., 2015. Performance enhancement of ejector-absorption cooling cycle by re-arrangement of solution streamlines and adding RHE. Appl. Therm. Eng. 77, 65-75.
[2] Acir, A., Canli, M.E., Ata, I., Cakiroglu, R., 2017. Parametric optimization of energy and exergy analyses of a novel solar air heater with grey relational analysis. Appl. Therm. Eng. 122, 330-338.
[3] Aman, J., Ting, D.S.K., Henshaw, P., 2014. Residential solar air conditioning: energy and exergy analyses of an ammonia-water absorption cooling system. Appl. Therm. Eng. 62, 424-432.
[4] Arslanoglu, N., Yigit, A., 2017. Investigation of efficient parameters on optimum insulation thickness based on theoretical-Taguchi combined method. Environ. Prog. Sustain. Energy 36, 1824-1831.
[5] Bademlioglu, A.H., Canbolat, A.S., Yamankaradeniz, N., Kaynakli, O., 2018. Investigation of parameters affecting Organic Rankine Cycle efficiency by using Taguchi and ANOVA methods. Appl. Therm. Eng. 145, 221-228.
[6] Bao, Z., Yang, F., Wu, Z., Nyamsi, S.N., Zhang, Z., 2013. Optimal design of metal hydride reactors based on CFD-Taguchi combined method. Energy Convers. Manag. 65, 322-330.
[7] Celik, N., Turgut, E., 2012. Design analysis of an experimental jet impingement study by using Taguchi method. Heat Mass Transf. 48, 1408-1413.
[8] Jawahar C, Raja B and Saravanan R. Thermodynamic studies on NH3–H2O absorption cooling system using pinch point approach. Int J Refrig 2010; 33: 1377–1385.
[9] Berdasco M, Vall es M and Coronas A. Thermodynamic analysis of an ammonia/water absorption-resorption refrigeration system. Int J Refrig 2019; 103: 51–60.
[10] Takeshita K and Amano Y. Optimal operating conditions and cost-effectiveness of a single-stage ammonia/ water absorption refrigerator based on exergy analysis. Energy 2018; 155: 1066–1076.
[11] Le Lostec B, Galanis N and Millette J. Simulation of an ammonia–water absorption chiller. Renewable Energy 2013; 60: 269–283.
[12] Darwish N, Al-Hashimi S and Al-Mansoori A. Performance analysis and evaluation of a commercial absorption–refrigeration water–ammonia (ARWA) system. Int J Refrig 2008; 31: 1214–1223.
[13] Du S, Wang R and Chen X. Analysis on maximum internal heat recovery of a mass-coupled two stage ammonia water absorption refrigeration system. Energy 2017; 133: 822–831.
[14] Chen X, Wang R and Du S. Heat integration of ammonia-water absorption refrigeration system through heat-exchanger network analysis. Energy 2017; 141: 1585–1599.
[15] B. Modi, A. Mudgal, and B. Patel, “Energy and Exergy Investigation of Small Capacity Single Effect Lithium Bromide Absorption Refrigeration System,” Energy Procedia, vol. 109, no. November 2016, pp. 203–210, 2017, doi: 10.1016/j.egypro.2017.03.040.
[16] S. C. Kaushik and A. Arora, “Energy and exergy analysis of single effect and series flow double effect water-lithium bromide absorption refrigeration systems,” Int. J. Refrig., vol. 32, no. 6, pp. 1247–1258, 2009, doi: 10.1016/j.ij refrig.2009.01.017.
[17] O. Ketfi, M. Merzouk, N. K. Merzouk, and S. El Metenani, “Performance of a Single Effect Solar Absorption Cooling System (Libr-H2O),” *Energy Procedia*, vol. 74, pp. 130–138, 2015, doi: 10.1016/j.egypro.2015.07.534.