

Performance Optimization of Absorption Refrigeration Systems Using Box-Behnken Design

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Abstract- 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.

Keywords- BBD, Performance optimization, ANOVA, absorption refrigeration systems.

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 $\text{NH}_3\text{-H}_2\text{O}$, 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 °C and 80 °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 ($\text{LiBr-H}_2\text{O}$, $\text{NH}_3\text{-H}_2\text{O}$, $\text{NH}_3\text{-LiNO}_3$) 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.

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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.

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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 optimisation 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 optimise 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, T _g	90	110	130
Condenser temperature, T _c	28	33	38
Absorber temperature, T _a	28	33	38
Evaporator temperature, T _e	-5	2.5	10

V. RESULTS AND DISCUSSION

1. Anova Results And Regression Model:

Determination coefficient R^2 , adjusted R^2 , predicted R^2 , and coefficient of variation (CV%) were determined to check the adequacy and accuracy of the developed models. The R^2 indicates the proportion of the total variation in the response predicted by the models. The higher correlation coefficients confirm the suitability of the models and correctness of the calculated constants.

The **Model F-value** of 9.77 implies the model is significant. There is only a 0.03% chance that an F-value this large could occur due to noise. **P-values** less than 0.0500 indicate model terms are significant. In this case B, D, AB, AD, A², D² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

The ANOVA of the quadratic regression model demonstrates that the model was highly significant. This was evident from the Fisher's F-Test (F value=9.77) and a low probability value (p=0.0003). The CV% obtained is 2.04 for the response. The low value of CV% indicates the degree of precision with which the simulation are carried out. A low value of CV% suggests a high reliability of the experiment [19, 20]. Adequate precision value measures the signal-to-noise ratio, and a ratio greater than 4 is generally desirable which indicates adequate model discrimination [21, 22]. The adequate precision value obtained in this study is 12.13 which indicated adequate signal.

2. Interaction Between the Operational Variables:

To demonstrate the effect of operational parameters on response function, the two-dimensional contours based on the quadratic models obtained in terms of the input factors (actual variables) to predict the COP as response functions are plotted and discussed.

Figures 4.3 and 4.8. The 2D contours can be useful in understanding the effects of selected independent variables. In Figures 4.3, the response surface of the COP as functions of generator and condenser temperature is presented. One of the most interesting outputs of the RSM is its feasibility to draw a map of response values as function of the input parameters. Response surface plots can represent the visualization of the predicted model equation. The response surfaces have also been drawn as three-dimensional plots of two factors, whereas the others were kept constant.

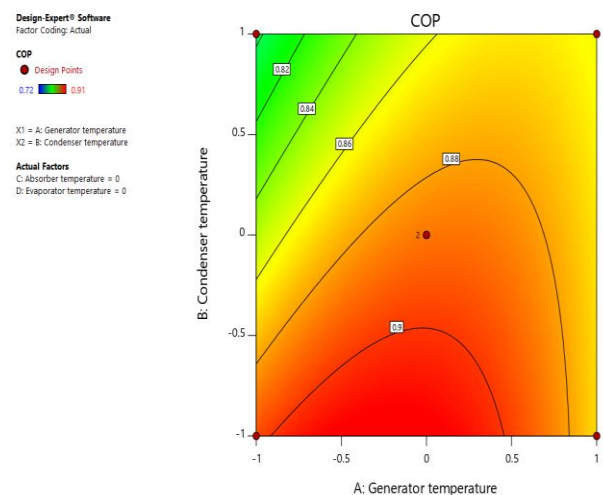


Fig 1. Effect of generator and condenser temperature on COP.

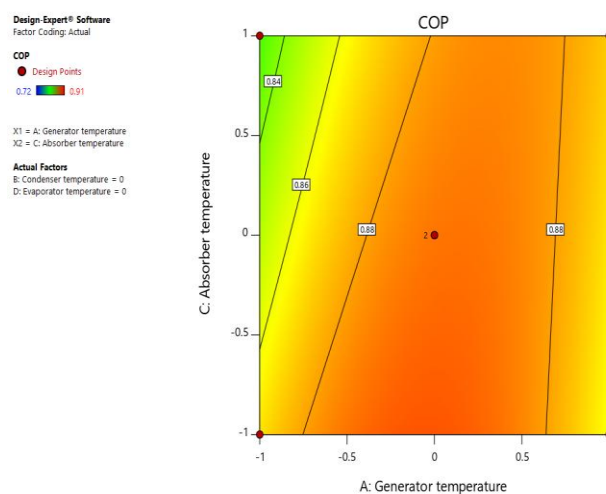


Fig 2. Effect of generator and absorber temperature on COP.

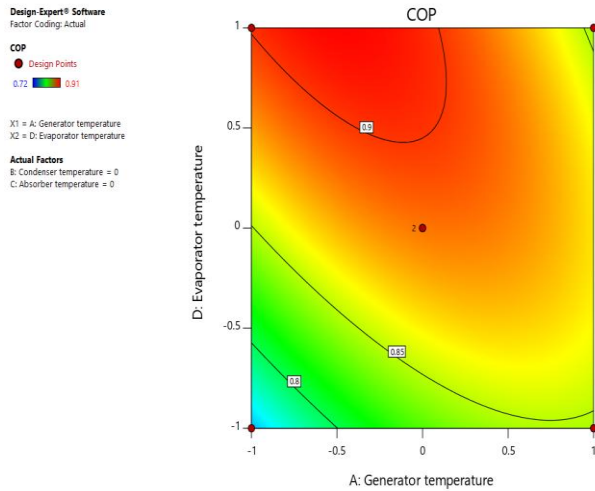


Fig 3. Effect of generator and evaporator temperature on COP.

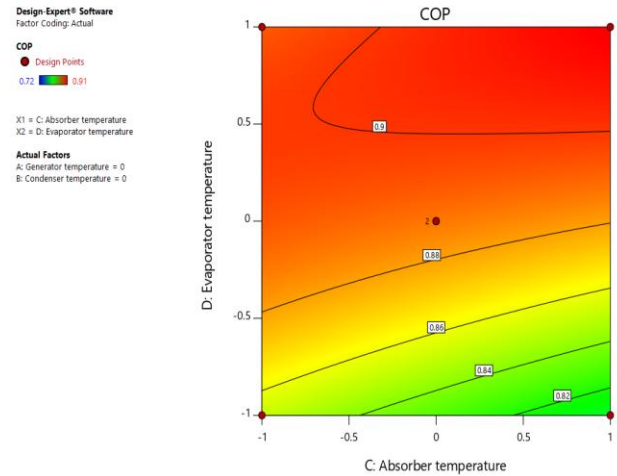


Fig 6. Effect of absorber and evaporator temperature on COP.

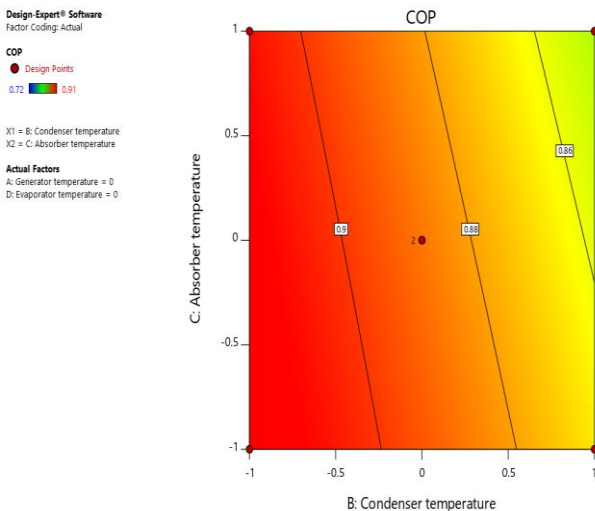


Fig 4. Effect of condenser and absorber temperature on COP.

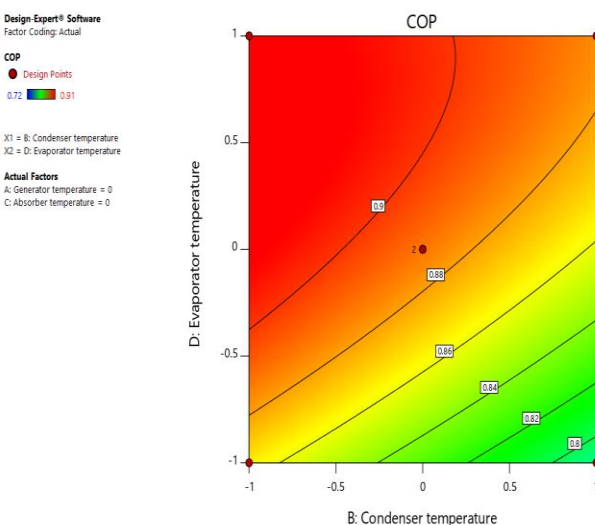


Fig 5. Effect of condenser and evaporator temperature on COP.

3. Selection of Optimum Conditions:

An optimum condition was determined to obtain for maximum COP. Second-order polynomial models developed in this study were utilized for each response in order to obtain specified optimum conditions. Since the most significant parameters are defined so far, the next step is to determine the best values of these parameters that lead to the best value of the COP. Derringer's desirability function method was used for optimization of multiple responses. Fig. 4.9 shows the optimized conditions for COP. The optimum value of COP is obtained is 0.716.

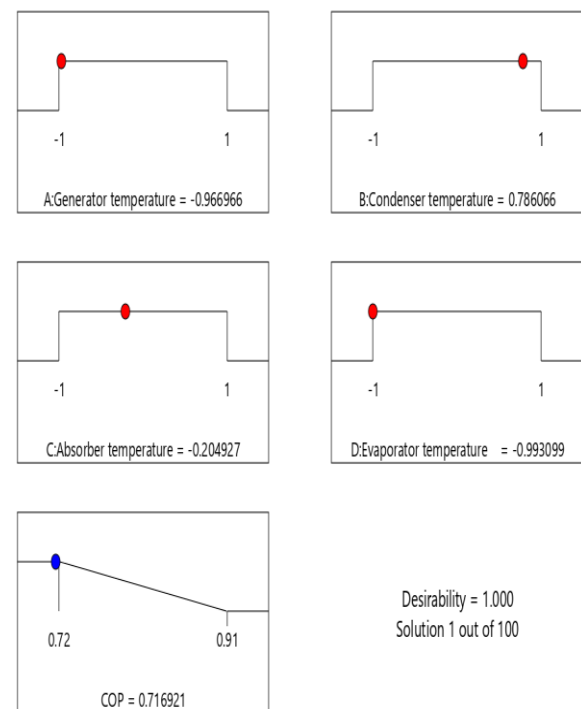


Fig 7. Optimum parameter plot.

VI. CONCLUSION

In the present research, RSM designs such as BBD is 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. An ANOVA analysis was used to study the effect of several factors affecting the coefficient of performance.

The ANOVA of the quadratic regression model demonstrates that the model was highly significant. This was evident from the Fisher's F-Test (F value=9.77) and a low probability value ($p=0.0003$). The CV% obtained is 2.04 for the response. The low value of CV% indicates the degree of precision with which the simulation are carried out. A low value of CV% suggests a high reliability of the experiment. Adequate precision value measures the signal-to-noise ratio, and a ratio greater than 4 is generally desirable which indicates adequate model discrimination.

The adequate precision value obtained in this study is 12.13 which indicated adequate signal. Canbolat (2019) analysed the importance order of the parameters are determined by using Taguchi and ANOVA methods and the results are compared. Under the operating conditions, the best COP of the system is calculated as 0.6255 by Taguchi-Grey Relational Analysis (GRA).

However, in our study best COP calculated from RSM technique is 0.716. With increase in generator and evaporator temperature, COP increases while increase in condenser and absorber temperature COP decreases. Derringer's desirability function method was used for optimization of multiple responses. The optimum value of COP is obtained is 0.716.

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