Application of Taguchi Method to Optimize the Hybrid Solar Water Flat Plate Collector System Development – A Review

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Abstract:

In This study, designed and developed a solar water flat plate collector system, which produce electricity and heat (hot water) simultaneously. These studies are conducted inside room to check the influence of the temperature of the solar water flat plate collector cell on the solar water flat plate collector conversion efficiency. If the open circuit voltage of photovoltaic cell is reduced then conversion efficiency of the cell can be reduced at higher working temperatures. Effect of these on the photovoltaic cell as extended payback period of the photovoltaic cell and shorten the life of photovoltaic cell. In order to prevent from these problems we need to dispatch more heat form the photovoltaic cell with the help of effective cooling methods. For increasing the performance and efficiency of solar water flat plate collector we need to decreases the temperature of the solar water flat plate collector. Efficiency of the solar water flat plate collector cell is related to the temperature of solar water flat plate collector; there is linear change between Efficiency of the photovoltaic cell and temperature.

Key words: solar water flat plate collector, phase change material, taguchi method, grey relational analysis

1. 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). Optimized the single stage geothermal energy assisted ARS, working with NH_3-H_2O, for different solution concentrations.[1]

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%. 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. [2]

The studies on the energy and exergy analysis of ARS In literature, there are many studies on the thermodynamic analysis of ARSs and the performance characteristics of the cycle. The 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-H_2O, NH_3-H_2O, NH_3-$LiNO_3$) 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. [3] Performed a thermodynamic analysis of a novel air-cooled non-adiabatic ejection-absorption refrigeration cycle with R290/oil mixture driven by exhaust heat. [4] 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.[5]

Investigated the effect of heat exchangers, which are used to recover heat energy in the ARS, on the coefficient of performance (COP). In this study, it was found that the solution heat exchanger (SHE) is the most effective heat exchanger on the system performance. [6] Focused on the optimization of the utilization of the internal heat recovery of the ejector-flash tank-ARS working with NH_3-H_2O. They found that the refrigeration capacity increment of the proposed cycle with added RHE is 4.85 %. [7] Performed the performance analysis of NH_3-H_2O ARS based on the artificial neural network model. 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. [8] Performed a detailed thermodynamic analysis of the LiBr-H_2O ARS. They investigated the impacts of operating temperature and effectiveness of heat exchanger on the system performance. In this study, it was obtained that the SHE increases the COP value up to a maximum of 44%, while the RHE had an effect of only 2.8 %. Studied on the modeling and simulation of a 70 kW absorption refrigeration machine working with LiBr-H_2O solution. They examined the effect of system parameters on the coefficient of performance (COP). [9]

2. ANOVA (Analysis of variance)

ANOVA is statistical technique which is used to analyze the difference between experimental data and test procedure. There is unable to design main structure of flat plate collector through S/N ratio, which is obtained through the Taguchi experiments with various quality factors. The ANOVA estimate the experimental errors and test of significance to understand the effect of various factors.

The main goal of ANOVA, which is another statistical approach, is to determine the contribution ratios of each parameter on the performance characteristic. Due to the fact that ANOVA demonstrates the importance order of influencing factors on the response, it can also be used to validate the results obtained from Taguchi method. In this study, the effect of each parameter on the COP, eCOP and multiple performance characteristics of ARS are determined using this method and calculation results are analyzed. In the ANOVA analysis, the significance level of the statistical analyses is 0.05 which corresponds to 95 % confidence level. [10]

2.1 Grey Relational Analysis (GRA)

Taguchi is not an applicable method for simultaneously optimizing multiple purpose functions. Therefore, in this study, GRA method is applied to the ARS to obtain the order of importance of each design parameters on multiple performance characteristics of the cycle by maximizing both COP and eCOP, simultaneously. GRA method allows converting an optimization problem, which has multiple performance characteristics, into a single objective optimization problem (Deng, 1989).

Firstly, the analysis results of the responses need to be normalized in the range of 0-1. In GRA, there are three types of equations used for normalization procedure i.e., the lower is the better, the higher is the better, and nominal is the best [11] In this study, the higher is the better is used for both objective functions because it is desired to maximize both COP and eCOP.

Determining the weight factors for each response is very important in GRA. Because in real engineering problems, the importance of various responses is different. However, most of the researchers use equal weight to determine the grey relational grade of multiple responses. This situation makes the reliability of the results questionable. Consequently, it is necessary to follow an applicable procedure to calculate the weight factors according to the effect of parameters' variations on COP and eCOP.

Firstly, each parameter's average S/N (signal to noise) ratio ranges (max-min) which is called Deltah as to be calculated for each response. Then, it is necessary to calculate the sum of the Delta for each response. Lastly, the ratio of sum of the Delta of each response to the total Delta of all responses gives the weight factors. The appropriate orthogonal array table can only be selected after calculating the total degree of freedom (DOF) which is the sum of the singular degree of freedom of each factor. The number of each factor levels minus 1 gives the individual DOF for the factor [12].

In this study, the Taguchi method is applied to ARS to maximize the COP and eCOP of the system.

At the beginning of the Taguchi analysis, the results of the target functions are converted to the S/N ratio. Three types of performance characteristics can be used for the calculating of the S/N ratio i.e., the lower is the better, the higher is the better and nominal is the best. Since both target functions (COP and eCOP) are desired to be maximized in this study, the higher is the better performance characteristic is chosen. [13]

3. MATHEMATICAL MODEL

3.1 Determination of Absorption Refrigeration System Performance Characteristic

The schematic diagram of the single stage ARS for which the thermodynamic analysis is carried out. In this study, RHE cools the saturated liquid from the condenser temperature to the evaporator temperature, while SHE helps to increase the temperature of the solution entering the generator. A process similar to that in the SHE is also carried out in the SRHE and these heat exchangers increase the thermodynamic performance of the cycle (COP and eCOP) by reducing the thermal energy input required in the generator.

In this study, a thermodynamic analysis of an ARS using NH_3-H_2O has been performed. The basic equations used in the analysis of the first and second laws of thermodynamics are presented here. More detailed information can be found in the literature. [14]

3.2 Taguchi Method

The Taguchi method, which was developed by Genichi Taguchi, is one of the most commonly used statistical approaches to obtain the order of importance of different factors for the target function (Taguchi, 1987). Although, in the beginning, this method was applied to experimental studies, it can also be applied to numerical and theoretical studies [15].

In total, there are eight different parameters considered in this study, such as evaporator temperature, condenser temperature, generator temperature, absorber temperature, effectiveness of solution heat exchanger, effectiveness of refrigerant heat exchanger, effectiveness of solution-refrigerant heat exchanger and pump efficiency. The Taguchi method allows optimizing the system performance and determining the best options of parameters with less number of experiments or analyses rather than a full factorial analysis. Significant advantages of taguchi method are to reduce time, cost and effort. [16]

CONCLUSION

This study has presented the detailed results of the statistical analysis performed to analyze the effect of various parameters on the ARS performance. The effects of the process parameters on the first and second law efficiencies (COP and e COP) of the cycle are investigated, separately. Furthermore, the GRA method is used to obtain the order of importance and contribution ratios of the parameters on the multi-objective function (considering the COP and eCOP, simultaneously).

Additionally, an optimization study that maximizes both COP and eCOP is performed with GRA in this study. The effect of absorber, evaporator and generator temperatures, effectiveness of solution heat exchanger, condenser temperature, effectiveness of refrigerant heat exchanger, effectiveness of solution-refrigerant heat exchanger and pump efficiency on the multiple performance characteristics

Consequently, this optimization study will be a useful resource for researchers because it allows designing more efficient ARS considering the optimum working conditions and the contribution ratios of each parameter.

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