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Optimization of Ammonia-Water Absorption Refrigeration System using Taguchi Method of Design of Experiment

Virang H Oza[1], **Nilesh M Bhatt**[2,*]
[1] *Institute of Technology, Nirma University, Ahmedabad-382481, India*
[2] *Gandhinagar Institute of Technology, Gandhinagar-382721, India*

**Corresponding author*

Abstract

Present study deals with optimization of the parameters of ammonia-water absorption refrigeration system using Taguchi design. The analysis is carried out to obtain best equations of COP and exergetic efficiency of 3 TR absorption refrigeration system. COP and exergetic efficiency are considered as objective function and condenser, evaporator, and generator temperatures as well as solution heat exchanger and refrigerant heat exchanger effectiveness are considered as independent parameters. L16 orthogonal array is selected for Taguchi design. Multi linear regression analysis is also carried out to obtain optimum COP and exergetic efficiency equations. Results show that condenser temperature has maximum influence on COP and evaporator temperature has maximum influence on exergetic efficiency. Maximum COP is obtained at lower condenser and higher evaporator temperature and maximum exergetic efficiency is obtained at lower condenser and lower evaporator temperature for the selected Taguchi design. Optimum COP is 0.65 and optimum exergetic efficiency is 23.94% for the selected Taguchi design. From signal-to-noise ratio analysis optimum COP of 0.6612 is calculated at $T_c = 35°C$, $T_e = 10°C$, $T_g = 150°C$, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$ and optimum exergetic efficiency of 24.74% is calculated at $T_c = 35°C$, $T_e = -5°C$, $T_g = 120°C$, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$

Keywords: Ammonia-water, absorption refrigeration, COP, exergetic efficiency, Taguchi method

1. INTRODUCTION

Vapour compression refrigeration systems are widely used for the commercial and industrial applications due to its high COP, but it requires high grade energy. High grade energy is one of the major inputs for economic development of any country. This leads to high power demand which causes more CO_2 emissions. Therefore for sustainable development use of renewable energy should encouraged. This decade has observed an exceptional research interest to provide a cooling effect by vapor absorption refrigeration in order to reduce CO_2 emissions for a well environment and stable ecology. Absorption refrigeration system does not use CFCs and provides a cooling effect using various resources like waste heat and renewable energy.

Lu et al. [1] carried out a case study on U.K. industry using heat driven absorption refrigeration technology. Their results indicated that the maximum COP of the system was 0.825 and 0.86 for the evaporator temperatures of 5ºC and 10ºC respectively. The corresponding generator temperatures were 60ºC and 55ºC. Based on their economic analysis average payback period of 2.5 years was calculated for the system. Iffa et al. [2] carried out optimization of absorption refrigeration system by design of experiments method. A computer program was developed for adequate COP and low operating generator temperature. Their results showed that by incorporating a compressor between the evaporator and absorber COP of the system was quite satisfactory using the NH_3-$LiNO_3$ as working fluid pair for low generator temperature of 60ºC. Jain et al. [3] carried out performance analysis of vapour compression-absorption cascade refrigeration system with undersized evaporator and condenser. When evaporator and condenser conductance was reduced by 50% due to fouling, the compression-absorption cascade refrigeration system saves 61.3% of electrical energy. Irreversibility in the evaporator and condenser was also increased by 42.4% and 62.1% respectively, when their individual performance was degraded by 50% due to fouling. Kanabar and Ramani [4] presented review on energy and exergy analysis of vapour absorption refrigeration cycle. Their review presented comprehensive research and development of absorption refrigeration technology for practical and theoretical analysis with different arrangement of cycle. Parham et al. [5] evaluated single stage absorption chiller using LiCl-H_2O as working fluid pair and compared with absorption chiller using LiBr-H_2O as working fluid pair. Their results showed that the COP of absorption chiller using LiBr-H_2O was around 1.5 to 2% higher than that of LiCl-H_2O at the same optimum conditions. Manu et al. [6] carried out optimization of LiBr-H_2O low capacity absorption refrigeration system using Taguchi method. L9 orthogonal array was selected to identify the optimum conditions based on signal-to-noise (SN) ratio under the section “larger is the best”. Acikkalp [7] presented modified ecological function for four temperature level absorption refrigerators. An absorption refrigerator was optimized using this function. Mashayekh et al. [8] modeled absorption chillers as four heat sources i.e. generator, evaporator, condenser, and absorber. Optimal working conditions were specified for absorption chillers and effect of thermoeconomic parameter on maximum thermoeconomic criterion, COP and specific refrigeration load corresponding to the maximum value of the thermoeconomic criterion were investigated. Micallef and Micallef [9] presented a linear model for an absorption refrigeration unit using either LiBr-H_2O or ammonia-water as working fluid pair. The system response was analyzed by varying absorber, generator and condenser temperatures to ensure effective operation of the system. Osta-Omar and Micallef [10] developed a mathematical model of absorption refrigeration system equipped with an adiabatic absorber using LiBr-H_2O as working fluid pair. Their results showed that COP of the cycle increased with increase in the generator temperature and decrease in the adiabatic absorber temperature. Abbaspour and Saraei [11] carried out performance optimization of absorption refrigeration system using LiBr-H_2O as working fluid pair. The thermodynamic model based on first and second law analysis was derived and effect of different design parameters were investigated on performance of the system. The genetic algorithm technique was implemented and results showed significant improvement in the COP, second law efficiency and total cost of the system by 75%, 47% and 12% respectively. Costa and Garcia [12] applied design of experiment to vapour compression refrigeration system. To maximize cycle efficiency a quadratic polynomial model was developed. Their results gave confidence to use this approach for the purpose of design and operational improvement of the refrigeration cycle. Tashtoush [13] used statistical approach to optimize solar absorption refrigeration system for air conditioning application using ANNOVA analysis. From the optimization model maximum value of COP was found at low condenser temperature and high generator temperature.

From the literature it is clear that very few work has been reported to introduce design of experiment method to optimize absorption refrigeration system. This paper attempts to carry out optimization of ammonia-water absorption refrigeration system using Taguchi design of experiment method.

2. SYSTEM DESCRIPTION

Fig. 1 shows the schematic diagram of vapour absorption refrigeration system using ammonia-water as working fluid pair. Absorption system is similar to vaopur compression system except compressor is replaced by absorber, solution pump and generator. The system has two pressure levels. Condenser and generator operate at high pressure, while the evaporator and absorber operate at low pressure. Refrigerant vapour enters the condenser, gets condensed by removing latent heat and converted into liquid refrigerant. The liquid refrigerant from condenser enters to the refrigerant heat exchanger, gets cooled by refrigerant coming out from evaporator and then throttled in expansion valve before it produces cooling effect in the evaporator. During cooling process, the liquid ammonia vaporizes and enters to the absorber.

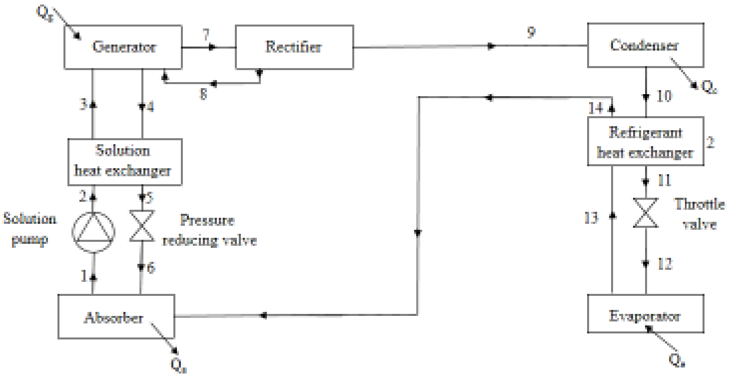

Fig. 1 Schematic of vapour absorption refrigeration system

In absorber, refrigerant is absorbed by weak solution and strong solution is formed. The strong solution from the absorber is pumped by solution pump to the generator through solution heat exchanger. In the generator the solution is heated by low grade energy like solar energy, waste heat etc. to separate out refrigerant and water. In order to remove the drops of absorbent from the fluid stream at the exit of the generator, a rectifier is used. Further, the refrigerant vapour enters the condenser and weak solution moves back to the absorber after passing through the pressure reducing valve. Solution and refrigerant heat exchangers are used to improve system performance.

3. MATHEMATICAL MODEL OF ABSORPTION REFRIGERATION SYSTEM

The first and second law analysis of ammonia-water vapour absorption refrigeration system with solution and refrigerant heat exchanger is carried out in present study.

3.1 Assumptions

Analysis of ammonia-water vapour absorption system is carried out based on following assumptions.

- All components are in steady state conditions.
- Pressure drops are negligible in all components.
- Pump efficiency is 50%.
- Absorption refrigeration system capacity is 3 TR.
- Absorber temperature is same as that of condenser temperature.
- Refrigerant leaving the rectifier is saturated vapour with mass fraction of 99.96% ammonia.
- The liquid leaving the condenser is saturated liquid at condenser temperature.
- The refrigerant vapour leaving the evaporator is saturated vapour at evaporator temperature.
- The strong solution leaving the absorber is saturated at absorber temperature.
- The weak solution leaving the generator is saturated at generator temperature.

3.2 Governing equations

Major equations used to evaluate COP of the system are as follows [14]. Various properties at salient points are denoted as suffice as per numbers given in Fig. 1.

The mass balance of strong solution, weak solution and refrigerant can be written as

$$\dot{m}_r + \dot{m}_w - \dot{m}_s = 0 \qquad (1)$$

The specific rich solution circulation f can be written as

$$f = \frac{x_9 - x_4}{x_3 - x_4} \tag{2}$$

The strong and weak solution flow rates are given by equations (3) and (4) respectively

$$\dot{m}_s = \dot{m}_r \times f \tag{3}$$

$$\dot{m}_w = \dot{m}_r \times (f - 1) \tag{4}$$

Energy balance of different components of absorption refrigeration system can be written by equations (5) to (13)

Refrigerating effect be written as

$$Q_e = \dot{m}_r \times (h_{13} - h_{12}) \tag{5}$$

Heat added in the generator can be written as

$$Q_g = \dot{m}_r \times (h_7 - h_4 + f \times (h_4 - h_3)) \tag{6}$$

Pump work can be written as

$$W_p = \frac{\dot{m}_r \times f \times v_1 \times (P_2 - P_1)}{\eta_p} \tag{7}$$

Heat rejected in the condenser can be written as

$$Q_c = \dot{m}_r \times (h_9 - h_{10}) \tag{8}$$

Heat rejected in the absorber can be written as

$$Q_a = \dot{m}_r \times (h_{14} - h_6 + f \times (h_6 - h_1)) \tag{9}$$

Heat transfer in solution heat exchanger can be written as

$$Q_{SHE} = \dot{m}_r \times ((f - 1) \times (h_4 - h_5)) \tag{10}$$

Heat transfer in refrigerant heat exchanger can be written as

$$Q_{RHE} = \dot{m}_r \times (h_{10} - h_{11}) \tag{11}$$

Coefficient of performance of the absorption refrigeration system can be written as

$$COP = \frac{Q_e}{Q_g + W_p} \tag{12}$$

Second law or exergetic efficiency of the absorption refrigeration system can be written as [15]

$$\eta_{exe} = \frac{-Q_e \times \left(1 - \frac{T_0}{T_e}\right)}{\left(Q_g \times \left(1 - \frac{T_0}{T_g}\right)\right) + W_p} \tag{13}$$

4. OPTIMIZATION FOR COP AND EXERGETIC EFFICIENCY

COP and exergetic efficiency mainly depends on six parameters i.e. condenser temperature, absorber temperature, evaporator temperature, generator temperature, solution heat exchanger effectiveness, and refrigerant heat exchanger effectiveness of absorption refrigeration system. In present study condenser and absorber temperatures are considered as same. Therefore, total five parameters are considered as independent variables. All 1024 possible combinations of five independent variables are developed based on selected range of each parameters as shown in Table 1. All parameters are selected in ascending order to make all possible combinations. Condenser temperatures are selected for the possible Indian weather conditions. Evaporator temperatures are chosen for air conditioning and cold storage applications. Generator temperature, and effectiveness of refrigerant and absorber heat exchanger range are selected based on the literature.

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)	-5	0	5	10
Generator temperature, T_g (°C)	120	130	140	150
Effectiveness of refrigerant heat exchanger, ε_{RHE}	0.6	0.65	0.7	0.75
Effectiveness of solution heat exchanger, ε_{SHE}	0.6	0.65	0.7	0.75

Taguchi method is commonly adopted for optimizing design parameters. Taguchi method of design of experiment (DOE) is used to make statistical analysis of all independence variables. Four level and five factor Taguchi design is used as given in Table 2 and sixteen different combinations are obtained based on L16 orthogonal array.

Table 2. Taguchi design

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

Based on Taguchi design, sixteen different combinations of five different independent variables are developed as per Table 3. With the help of EES software [16] COP and exergetic efficiency are evaluated for all sixteen combinations.

Table 3. Results of COP and exergetic efficiency for Taguchi design

T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}	COP	η_{exe} (%)
35	-5	120	0.6	0.6	0.4825	23.94
35	0	130	0.65	0.65	0.5527	21.15
35	5	140	0.7	0.7	0.6052	17.36
35	10	150	0.75	0.75	0.6500	13.34
40	-5	130	0.7	0.75	0.4904	22.44
40	0	120	0.75	0.7	0.5079	20.74
40	5	150	0.6	0.65	0.5495	14.82
40	10	140	0.65	0.6	0.5787	12.59
45	-5	140	0.75	0.65	0.4084	17.45
45	0	150	0.7	0.6	0.4564	15.31
45	5	120	0.65	0.75	0.507	16.44
45	10	130	0.6	0.7	0.5554	12.83

T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}	COP	η_{exe} (%)
50	-5	150	0.65	0.7	0.3743	14.99
50	0	140	0.6	0.75	0.4186	14.68
50	5	130	0.75	0.6	0.3950	11.86
50	10	120	0.7	0.65	0.4390	10.72

From simulation for all sixteen different combinations, results of COP and exergetic efficiency are obtained. COP and exergetic efficiency are considered as objective functions and condenser, evaporator, and generator temperatures, as well as effectiveness of solution and refrigerant heat exchangers as independent variables. Multi linear regression analysis provides best equations of COP and exergetic efficiency, which are as under.

The regression equation of COP is

$$COP = 0.709 - 0.0109\, T_c + 0.00762\, T_e + 0.000747\, T_g - 0.0779\, \varepsilon_{RHE} + 0.277\, \varepsilon_{SHE} \quad (14)$$

$S = 0.0133185$ $R^2 = 98.2\%$ R^2 (adj) = 97.2%

The regression equation of exergetic efficiency is

$$\eta_{exe} = 0.489 - 0.00396\, T_c - 0.00497\, T_e - 0.00116\, T_g - 0.0399\, \varepsilon_{RHE} + 0.0569\, \varepsilon_{SHE} \quad (15)$$

$S = 0.00593086$ $R^2 = 98.5\%$ R^2 (adj) = 97.8%

4.1 SN ratio analysis

Taguchi method uses a statistical measure of performance, which is called signal-to-noise (SN) ratio. SN ratio helps in data analysis and prediction of optimum results. Simulation results are transferred in to SN ratio. SN ratio response determines the control parameters such as T_c, T_e, T_g, ε_{RHE}, and ε_{SHE} on COP and exergetic efficiency. MINITAB is used for the parameter settings with the highest SN ratio, which always produces the optimum quality with lower variance. Highest values of COP and exergetic efficiency are desirable. Therefore, ‘Larger is the better’ type category of the performance characteristic for COP and exergetic efficiency are selected to analyze the SN ratio as shown in Table 4 and 5. Following equation of SN ratio is used for larger is better to maximize the response.

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Yi^2}\right] \quad (16)$$

Table 4. SN ratio for COP

T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}	COP	SN
35	-5	120	0.6	0.6	0.4825	-6.3301
35	0	130	0.65	0.65	0.5527	-5.1502
35	5	140	0.7	0.7	0.6052	-4.362
35	10	150	0.75	0.75	0.6500	-3.7417
40	-5	130	0.7	0.75	0.4904	-6.189
40	0	120	0.75	0.7	0.5079	-5.8844
40	5	150	0.6	0.65	0.5495	-5.2006
40	10	140	0.65	0.6	0.5787	-4.7509
45	-5	140	0.75	0.65	0.4084	-7.7783
45	0	150	0.7	0.6	0.4564	-6.8131
45	5	120	0.65	0.75	0.507	-5.8998
45	10	130	0.6	0.7	0.5554	-5.1079
50	-5	150	0.65	0.7	0.3743	-8.5356
50	0	140	0.6	0.75	0.4186	-7.564
50	5	130	0.75	0.6	0.395	-8.0681
50	10	120	0.7	0.65	0.439	-7.1507

Table 5. SN ratio for exergetic efficiency

T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}	η_{exe}	SN
35	-5	120	0.6	0.6	23.94	27.5825
35	0	130	0.65	0.65	21.15	26.5062
35	5	140	0.7	0.7	17.36	24.791
35	10	150	0.75	0.75	13.34	22.5031
40	-5	130	0.7	0.75	22.44	27.0205
40	0	120	0.75	0.7	20.74	26.3362
40	5	150	0.6	0.65	14.82	23.417
40	10	140	0.65	0.6	12.59	22.0005
45	-5	140	0.75	0.65	17.45	24.8359
45	0	150	0.7	0.6	15.31	23.6995
45	5	120	0.65	0.75	16.44	24.318
45	10	130	0.6	0.7	12.83	22.1645
50	-5	150	0.65	0.7	14.99	23.516
50	0	140	0.6	0.75	14.68	23.3345
50	5	130	0.75	0.6	11.86	21.4817
50	10	120	0.7	0.65	10.72	20.6039

Fig. 2 and 3 shows the main effect plot of mean of SN ratio and mean of means for COP respectively. From Fig. 2 it is observed that $T_c = 35°C$, $T_e = 10°C$, $T_g = 150°C$, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$ are suitable parameters for maximum COP. From Fig. 3 it is observed that $T_c = 35°C$, $T_e = 10°C$, $T_g = 150°C$, $\varepsilon_{RHE} = 0.65$ and $\varepsilon_{SHE} = 0.75$ are suitable parameters for maximum COP. From predicted values of Taguchi analysis, COP is 0.6612 for mean value of $T_c = 35°C$, $T_e = 10°C$, $T_g = 150°C$, $\varepsilon_{RHE} = 0.6$, and $\varepsilon_{SHE} = 0.75$.

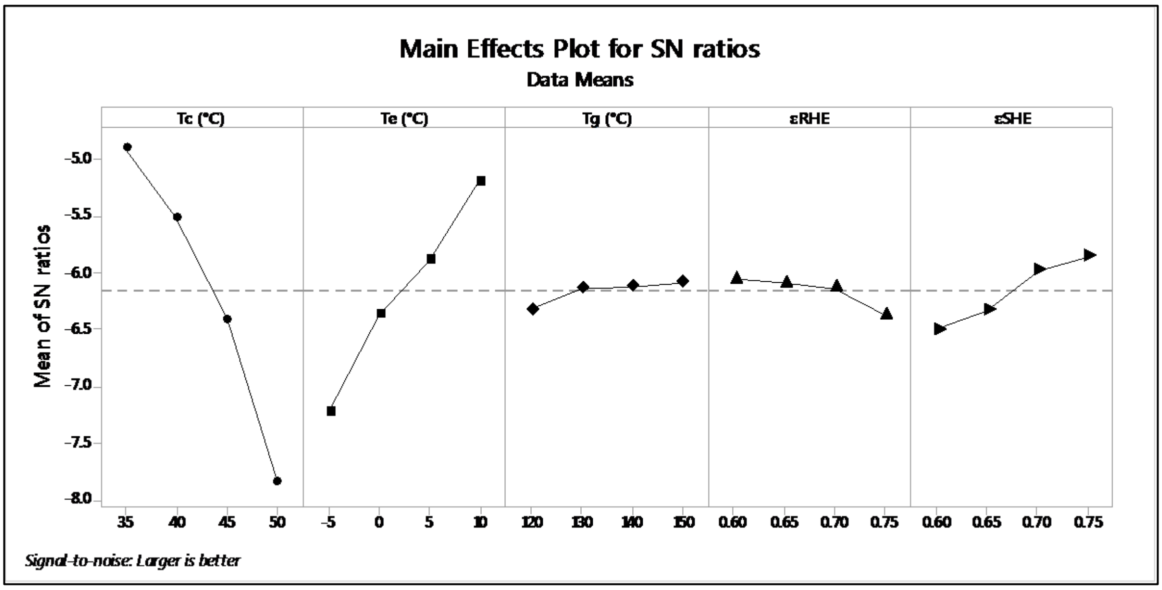

Fig. 2 Main effect plot of SN ratio for COP

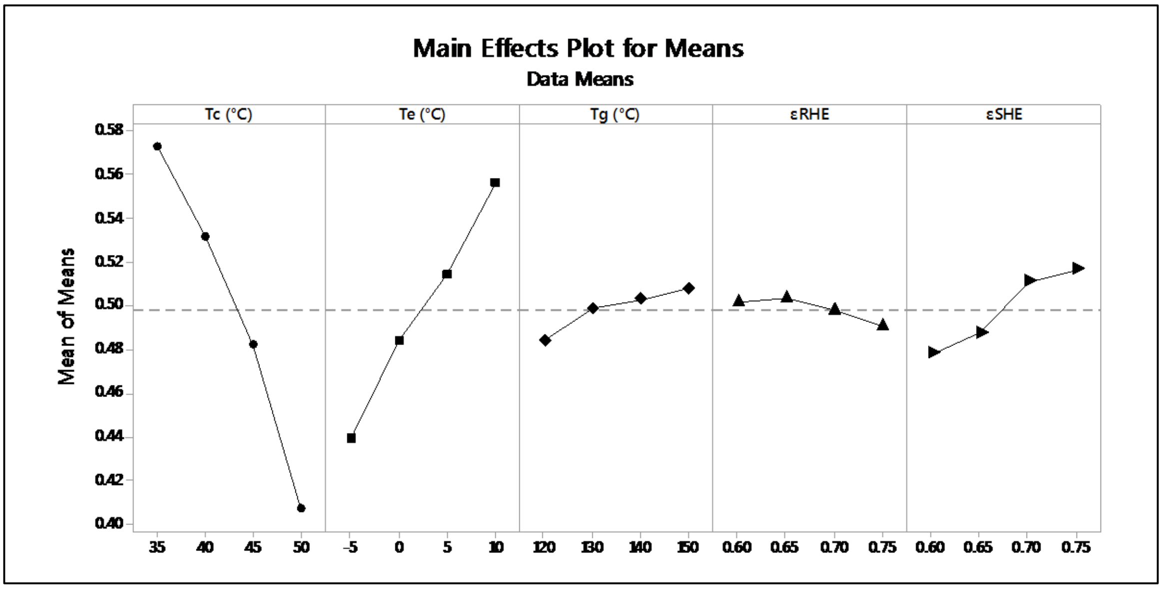

Fig. 3 Main effect plot of mean of means for COP

Fig. 4 and 5 shows the main effect plot of mean of SN ratio and mean of means for exergetic efficiency respectively.

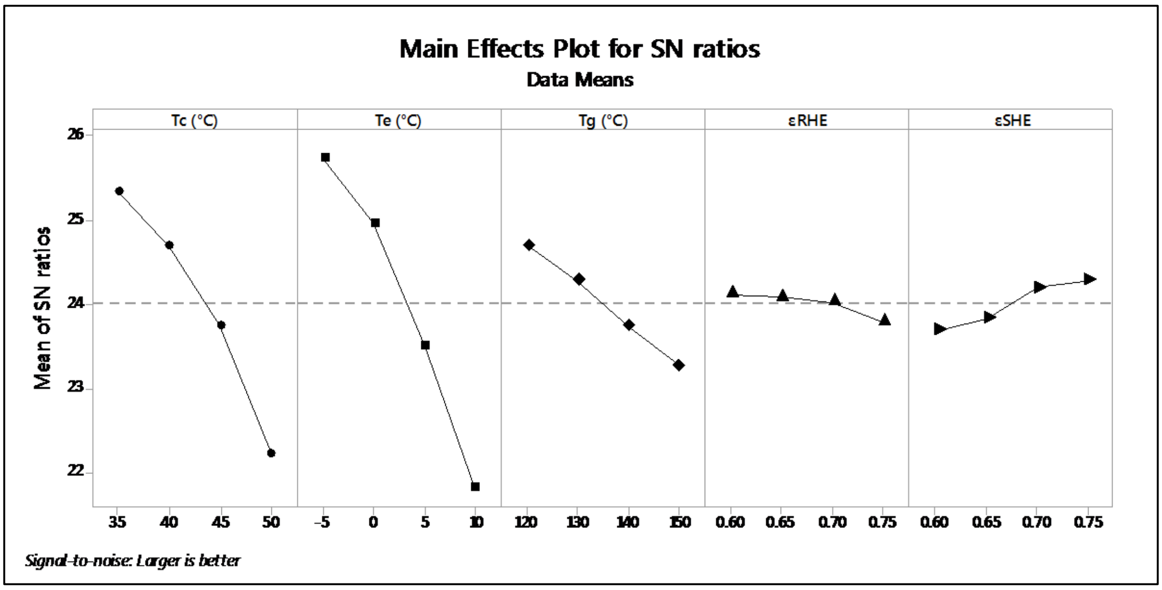

Fig. 4 Main effect plot of SN ratio for exergetic efficiency

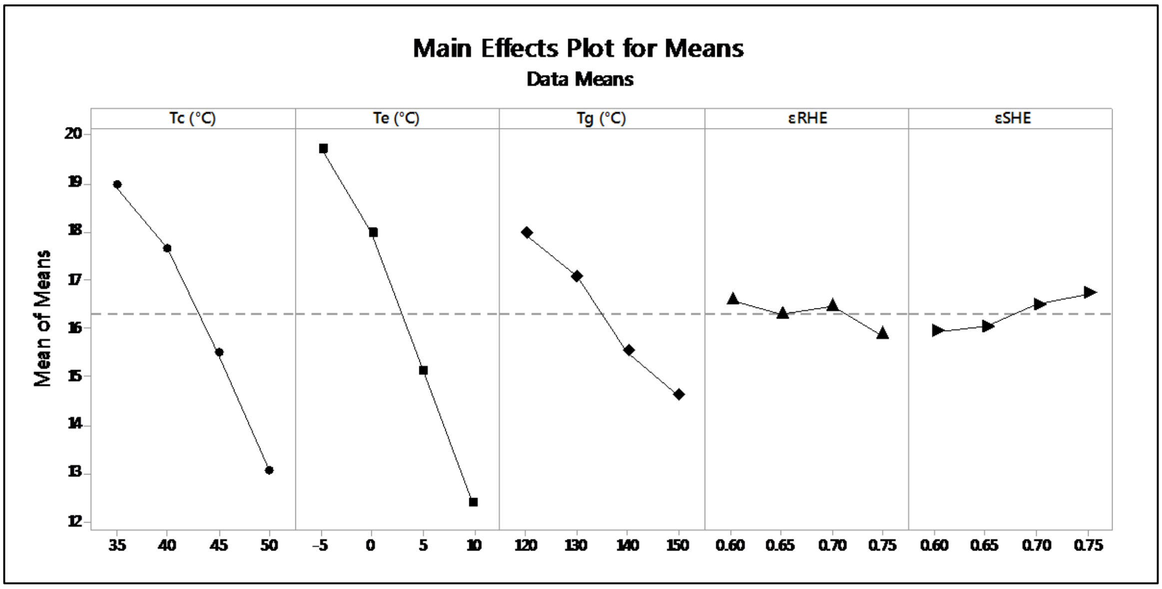

Fig. 5 Main effect plot of mean of means for exergetic efficiency

From both the plots it is observed that $T_c = 35°C$, $T_e = -5°C$, $T_g = 120°C$, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$ are suitable parameters for maximum exergetic efficiency. From predicted values of Taguchi analysis, prediction for exergetic efficiency is 24.74% for mean value of $T_c = 35°C$, $T_e = -5°C$, $T_g = 120°C$, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$.

5. RESULTS AND DISCUSSION

The multi linear regression analysis indicates that the model's degree of explaining variance in the dependent variables is $R^2 = 98.2\%$ for regression of COP and that for exergetic efficiency was 98.5%. Looking at these coefficients, it can be said that the model predicts the dependent variables very well. Table 3 shows that maximum COP of 0.65 is obtained for $T_c = 35$ºC, $T_e = 10$ºC, $T_g = 150$ºC, $\varepsilon_{RHE} = 0.75$, and $\varepsilon_{SHE} = 0.75$ and maximum exergetic efficiency is 23.94% for $T_c = 35$ºC, $T_e = -5$ºC, $T_g = 120$ºC, $\varepsilon_{RHE} = 0.6$, and $\varepsilon_{SHE} = 0.6$ for the selected Taguchi design.

Table 6. Response of SN for COP

Level	T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}
1	-4.896	-7.208	-6.316	-6.051	-6.491
2	-5.506	-6.353	-6.129	-6.084	-6.320
3	-6.400	-5.883	-6.114	-6.129	-5.972
4	-7.830	-5.188	-6.073	-6.368	-5.849
Delta	2.934	2.020	0.243	0.317	0.642
Rank	1	2	5	4	3

Table 7. Response of Means for COP

Level	T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}
1	0.5726	0.4389	0.4841	0.5015	0.4781
2	0.5316	0.4839	0.4984	0.5032	0.4874
3	0.4818	0.5142	0.5027	0.4977	0.5107
4	0.4067	0.5558	0.5075	0.4903	0.5165
Delta	0.1659	0.1169	0.0234	0.0128	0.0384
Rank	1	2	4	5	3

Table 8. Response of SN for exergetic efficiency

Level	T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}
1	25.35	25.74	24.71	24.12	23.69
2	24.69	24.97	24.29	24.09	23.84
3	23.75	23.50	23.74	24.03	24.20
4	22.23	21.82	23.28	23.79	24.29
Delta	3.11	3.92	1.43	0.34	0.60
Rank	2	1	3	5	4

Table 9. Response of Means for exergetic efficiency

Level	T_c (°C)	T_e (°C)	T_g (°C)	ε_{RHE}	ε_{SHE}
1	18.95	19.70	17.96	16.57	15.93
2	17.65	17.97	17.07	16.29	16.04
3	15.51	15.12	15.52	16.46	16.48
4	13.06	12.37	14.62	15.85	16.73
Delta	5.89	7.33	3.35	0.72	0.80
Rank	2	1	3	5	4

Table 6 and 7 show the response of SN ratio and means for COP respectively. From both the tables it can be seen that condenser temperature has maximum influence on COP of all selected parameters. Table 8 and 9 shows the response of SN ratio and means for exergetic efficiency respectively. It is observed form both the tables that evaporator temperature has maximum influence on exergetic efficiency of all selected parameters.

6. CONCLUSION

In this paper, optimization of 3 TR ammonia-water absorption refrigeration system based on Taguchi design is presented. Multi linear regression analysis is also carried out and best equations of COP and exergetic efficiency are obtained, which indicates relationship between objective function and independent variables. COP and exergetic efficiency are considered as objective function and condenser, evaporator, and generator temperatures as well as effectiveness of solution and refrigerant heat exchange are considered as independent parameters. From the optimization following conclusions have been drawn.

- For maximum COP, lower condenser and higher evaporator temperatures are desirable.
- For maximum exergetic efficiency, lower condenser and evaporator temperatures are desirable.
- Optimum COP is 0.65 and optimum exergetic efficiency is 23.94% for the selected Taguchi design.
- The optimal parameter combination for maximum COP and maximum exergetic efficiency is obtained by using the analysis of SN ratio.
- According to the results condenser temperature has maximum influence on COP and evaporator temperature has maximum influence on exergetic efficiency out of all selected parameters.
- According to SN ratio analysis, optimum COP is 0.6612 at $T_c = 35$ºC, $T_e = 10$ºC, $T_g = 150$ºC, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$ and optimum exergetic efficiency is 24.74% at $T_c = 35$ºC, $T_e = -5$ºC, $T_g = 120$ºC, $\varepsilon_{RHE} = 0.6$ and $\varepsilon_{SHE} = 0.75$.

Nomenclature

COP	coefficient of performance
f	specific strong solution circulation
$f-1$	specific weak solution circulation
h	enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
n	sample size
P	pressure (kPa)
Q	heat transfer rate (W)
s	entropy (kJ kg^{-1} K^{-1})
T	temperature (ºC)
v	specific volume (m^3 kg^{-1})
W	work (W)
x	ammonia mass fraction (kg kg of solution^{-1})
Yi	measured value of quality characteristics (COP or exergetic efficiency)
ε	effectiveness
η	efficiency (%)

Subscripts

a	absorber
c	condenser
e	evaporator
exe	exergetic
g	generator
p	pump
r	refrigerant
RHE	refrigerant heat exchanger
s	strong
SHE	solution heat exchanger
w	weak
0	ambient condition

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