Thermal Examination of Vapour Absorption System using Experimental Design Method

A.Solanki, Yashpal

Abstract: The experimental investigation has been carried out for 100 kW triple-effect vapor absorption refrigeration systems using parabolic trough collector. The data have been recorded and analyzed for designing a new vapor absorption refrigeration system with process heat for industrial applications for Gurugram regions of India. The solar resources have also been analyzed for designing of the system. The thermodynamic evaluation of 100 kW triple-effect vapor absorption refrigeration systems has analyzed for different parameters. The heat is supplied from solar thermal technology which converts solar radiation to useful heat of the total input energy of the proposed cooling system is taken from the heat transfer fluid through parabolic trough collector (PTC) as per availability of solar insolation at the pressurized water of 140-180 oC supplied to the generator at a mass flow rate of 7 kg/s. It is analyzed that in the month of November radiation drops because of cosine losses as compared to May and Direct Normal Irradiance decreases in the month of December, January, July, August, and September.

Keywords: Vapor Absorption Refrigeration, Triple Effect, Parabolic Trough Collector

I. INTRODUCTION

In India, energy demand is increasing drastically due to the change in economy and lifestyle [1][17]. Vapor absorption cooling system will play a very effective role in meeting energy demand for cooling. Thermal cooling systems work on low-grade heat which can easily meet through low cost solar thermal collectors. The energy in the form of cool, as well as heat, can be stored in a cost-effective manner, therefore, this system going to play a vital role during non-sunshine hours also [2]. Now, a day, absorption cooling systems can be operated with high COP with high-grade heat and low COP with low-grade heat. Therefore, depending upon the space availability of solar radiation, solar thermal technology and absorption systems like single effect, double effect and triple effect can be selected [3]. Moreover, solar thermal cooling systems do not have CFCs as working fluid therefore, the thermal cooling systems are also protecting from ozone deletion which is causing by compressor-based cooling systems [4].

Lithium bromide -water and ammonia-water was found most suitable for air conditioning applications and refrigeration applications. LiBs systems were preferred for air condition systems whereas ammonia water systems are selected for refrigeration where the subzero temperature is a basic requirement find the most suitable for air conditioning application [5].

As these systems are simple in design and can operate with low-temperature range, less nosy as compared to another system [6]. To overcome the size of the systems, operating cost and to increase the Coefficient of performance of the system multi-effect systems are now designed [7] already, multi-effect systems have been introduced in the market [8], having increased coefficient of performance of vapour absorption refrigeration system like double effect, triple effect system. [9]. Vapor absorption system can have a different source of heat. In order to make reliable solar thermal cooling systems, gas fired back up arrangements can be introduced. Nowadays, a multi-source of heat based systems has been applied for using vapour absorption cooling systems [10]. The system was optimized by using different types of working pairs to maximize the COP by using the first law of thermodynamics [11] and optimized for generator and C temperature and the operating temperature was calculated. For lithium bromide and water, afterward different absorbent and ref rigerant pairs were used for this system [12]. A numbers of pairs like ammonia lithium nitrate, ammonia sodium thiocyanate and ammonia-water have been attempted to optimization of single effect system for the generator temp was carried out [13] and achieved the optimal generator temperature [14] for the absorption system which was operated with four different types of aqueous salt solution with different heat inputs sources. Calculated thermo-economic optimization was carried out by a single effect cycle for obtaining high COP [15]. The optimization of single, double and triple effect with heat input by gases has been carried out for obtaining the maximum coefficient of performance up to 1.95.Scholars are performing energy analysis for vapor absorption system to calculate its performance but there is a need to do exergy analysis to study it deeply [15]. These help in detail study at each state points of vapour absorption system [16]. From all the above previous work it is concluded that the lithium bromide water best system is much suitable for air condition applications in compare to other pair of refrigerant and observant. LiBS systems have also potential to explore multi effect for improvement of COP.

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II. TRIPLE-EFFECT VAPOR ABSORPTION COOLING SYSTEM

The system consists of G_1(HTG), G_2(MTG) and G_3(LTG) for concentrating a dilute LiBr which is received from the absorber. Which flows from G_1 to G_3 via G_2. In this system, maximum Libs solution and maximum Libs solution concentration cant take place concurrently, due to this corrosion rate decreases, which helps to maintain vaccum while performing operations. hence, a system run efficiently.

Figure 1. Triple effect vapour absorption cooling system at National Institute of Solar Energy, Gurgaon.

The month-wise experimental observations for the triple-effect vapour absorption have been shown in Table 1.

Table 1. Month-wise experimental data of triple-effect vapour absorption machine.

Month	HTG (°C)	MTG(°C)	LTG(°C)	COP	T_E(°C)	DNI(W/m^2)
March	165.3	120.0	69.0	1.69	7.0	630
April	171.0	121.0	69.0	1.67	6.8	650
May	170.0	121.5	63.5	1.66	6.7	630
June	177.0	117.8	62.9	1.70	8.2	700
July	160.0	105.4	57.6	1.68	8.3	680
August	160.0	111.2	68.0	1.60	8.2	610
September	162.0	131.0	69.0	1.69	8.9	620
October	171.0	114.0	68.0	1.62	7.5	620
November	174.0	119.1	74.0	1.60	7.4	630

III. STATISTICAL APPROACH

A statistical analysis has been done to get the optimal COP of the triple-effect vapor absorption cooling system corresponding to different input variables. For the pusrpose, design of experiments approach has been adopted. Many researches have used the same statistical approach for the analysis of thermal systems [16] .

3.1 Central Composite Design (ccd) matrix and perceived responses

First, identifying the significant variables HTG, MTG, LTG and MFR that effect the response COP on the basis of the experimental results, a central composite rotatable design (CCRD) design matrix is then chosen using Design expert 6.0 for optimising the level of variables. The levels of operating variables chosen for RSM are given in Table 2.

Table 2. Levels of input variables chosen for CCD

Variables	Low Actual	High Actual	Low Coded	High Coded
HTH	142.00	166.00	-1.000	1.000
MTG	99.25	113.75	-1.000	1.000
LTG	55.45	65.15	-1.000	1.000
MFR	1.18	1.52	-1.000	1.000

3.2 Optimum conditions predicted by RSM

Optimum COP has been predicted by using numerical optimisation of the Design Expert 6.0 software using RSM and is shown in Table 2. From 30 experiments as suggested by the software, conducted on the triple effect vapour absorption system for the different input conditions the optimum value for COP are: HTG: 166°C, MTG: 113.75 °C, LTG: 65.15 °C, and MFR: 1.52. The predicted COP obtained from the optimisation is 0.846. The desirability: 1 is achieved for at least 100 numerical solutions, only first 10 solutions are shown in Table 3. However, the first numerical solution is selected since the COP has maximum value.

Table 3. Numerical optimisation of the input conditions using RSM

Solutions number desirability				
HTG	**MTG**	**LTG**	**MFR**	**COP**
166.00	113.75	65.15	1.52	0.846
166.00	113.75	65.15	1.51	0.843
166.00	113.09	65.15	1.52	0.839
166.00	113.75	65.14	1.50	0.837
165.95	113.75	64.35	1.52	0.833
166.00	113.75	64.04	1.52	0.827
161.07	113.75	65.15	1.52	0.802
165.99	111.22	63.52		0.785
166.00	109.70	65.15	1.47	0.773
166.00	113.75	60.65	1.52	0.750

IV. RESULTS

The experiments have been performed to verify the accuracy of the model predicted using RSM. The input variables suggested by the predicted model have been considered in the triple-effect vapour absorption system COP is computed. The COP has been predicted as 0.846 and is in close approximation with the experimental average value of 0.843.

Further, the variation of COP with all the operating variables viz. HTG, MTG. LTG and MFR have been shown graphicaly in Figures 2-4.

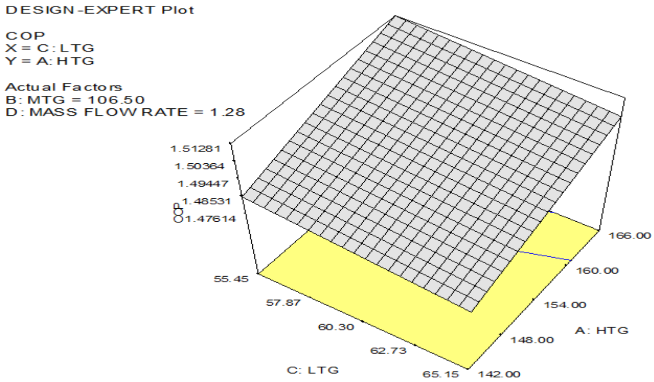

Figure 2. 3D surface plot of COP vs LTG vs HTG.

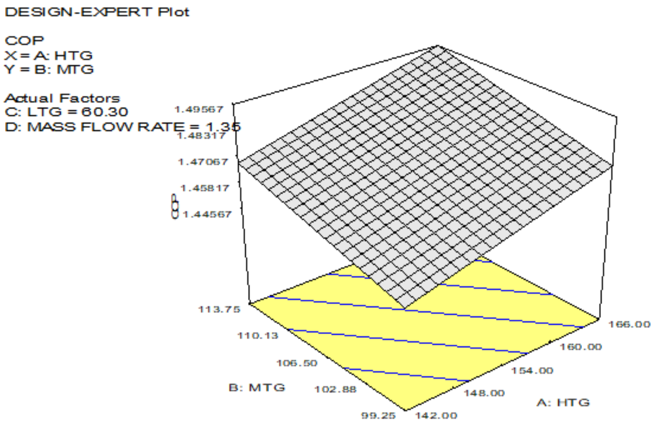

Figure 3. 3D surface plot of COP vs MTG vs HTG

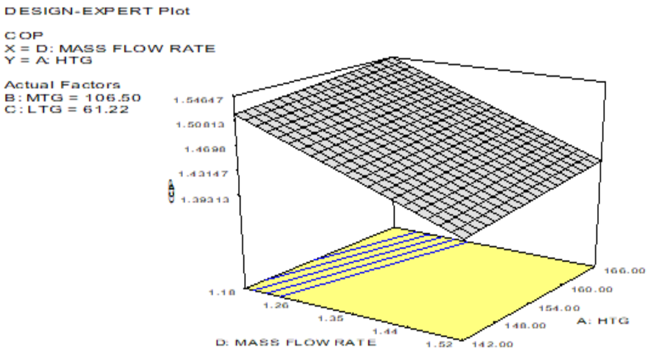

Figure 4. 3D surface plot of COP vs MFR vs HTG

V. CONCLUSION

The cumulative data of the triple-effect vapour absorption refrigeration system for the year 2016, respectively. From the results, it is observed the coefficient of performance (COP) of the vapor absorption system increases with the increase in Direct Normal Irradiance (DNI) till June and start decreasing till the month of November in the year 2016. Based on the experimental results it can be concluded that the COP directly depends on DNI. It also observed from experiment result that the plant is maintaining the evaporator temperature in the range of 6.40oC to 8.9oC for the year 2016, while the requirement is below 7oC to 12oC. when optimization was performed with the help of DOE approach the suitable suggested were at HTG 146.41, MTG 105.54, LTG 58.39 and MFR 1.49 . For obtaining the COP

REFERENCES

[1] A. Sharma and R. Kaushal, "Experimental Investigation of Hygroscopic Properties of Air in a Novel Flat Plate Dehumidifier Using Calcium Chloride as a Liquid Desiccant," vol. 11, pp. 1097–1107, 2019.

[2] A. M. Omer, "Energy, environment and sustainable development," Renew. Sustain. Energy Rev., vol. 12, no. 9, pp. 2265–2300, Dec. 2008.

[3] H. Sun, Z. Xu, H. Wang, and R. Wang, "A Solar/gas Fired Absorption System for Cooling and Heating in a Commercial Building," Energy Procedia, vol. 70, pp. 518–528, May 2015.
[4] A. Yokozeki, "Theoretical performances of various refrigerant–absorbent pairs in a vapor-absorption refrigeration cycle by the use of equations of state," Appl. Energy, vol. 80, no. 4, pp. 383–399, Apr. 2005.
[5] E. Kurem and I. Horuz, "A comparison between ammonia-water and water-lithium bromide solutions in absorption heat transformers," Int. Commun. Heat Mass Transf., vol. 28, no. 3, pp. 427–438, Apr. 2001.
[6] D. Colorado and W. Rivera, "Performance comparison between a conventional vapor compression and compression-absorption single-stage and double-stage systems used for refrigeration," Appl. Therm. Eng., vol. 87, pp. 273–285, Aug. 2015.
[7] G. D. Takalkar, R. R. Bhosale, N. A. Mali, and S. S. Bhagwat, "Thermodynamic analysis of EMISE–Water as a working pair for absorption refrigeration system," Appl. Therm. Eng., vol. 148, pp. 787–795, Feb. 2019.
[8] A. Shirazi, R. A. Taylor, S. D. White, and G. L. Morrison, "A systematic parametric study and feasibility assessment of solar-assisted single-effect, double-effect, and triple-effect absorption chillers for heating and cooling applications," Energy Convers. Manag., vol. 114, pp. 258–277, Apr. 2016.
[9] M. A. Siddiqui, "Optimal cooling and heating performance coefficients of four biogas powered absorption systems," Energy Convers. Manag., vol. 31, no. 1, pp. 39–49, Jan. 1991.
[10] M. A. Siddiqui, "Economic biogas and cooling water rates in a lithium bromide—water absorption system," Int. J. Refrig., vol. 14, no. 1, pp. 32–38, Jan. 1991.
[11] M. A. Siddiqui, "Economic analyses of the operating costs in four absorption cycles for optimizing the generator and condensing temperatures," Energy Convers. Manag., vol. 35, no. 6, pp. 517–534, Jun. 1994.
[12] I. H. Malik and M. Altamush Siddiqui, "Optimization of generator temperatures in the heat operated absorption cycle using four types of aqueous salt solutions," Energy Convers. Manag., vol. 37, no. 4, pp. 433–445, Apr. 1996.
[13] M. A. Siddiqui, "Optimum generator temperatures in four absorption cycles using different sources of energy," Energy Convers. Manag., vol. 34, no. 4, pp. 251–266, Apr. 1993.
[14] R. D. Misra, P. K. Sahoo, S. Sahoo, and A. Gupta, "Thermoeconomic optimization of a single effect water/LiBr vapour absorption refrigeration system," Int. J. Refrig., vol. 26, no. 2, pp. 158–169, Mar. 2003.
[15] M. Azhar and M. A. Siddiqui, "Optimization of operating temperatures in the gas operated single to triple effect vapour absorption refrigeration cycles," Int. J. Refrig., vol. 82, pp. 401–425, Oct. 2017.