# Thermodynamic Analysis of Vapor Absorption Refrigeration Cycle with Three Heat Exchangers: User-friendly Software

Omer Kaynakli

***Abstract***— In this study, thermodynamic analysis of the single-stage Vapor Absorption Refrigeration (VAR) systems using Ammonia-Water and Water-Lithium Bromide ($NH_3$-$H_2O$ and $H_2O$-LiBr) solutions is carried out. The system consists of three heat exchangers such as refrigerant, solution and refrigerant-solution heat exchangers (RHE, SHE and RSHE). A mathematical model is developed and a computer program is prepared by using a visual programming language. Researchers and students of engineering faculties can easily use this user friendly, practical and attractive computer program. The developed program allows analyzing in detail the effect of working conditions, the solution pump efficiency and the effectivenesses of the heat exchangers on the system performance. This study explains the thermodynamic analysis and the developed software package in detail.

***Keywords***—Absorption, Refrigeration, Software, Thermodynamic analysis.

## I. INTRODUCTION

THE vapor absorption refrigeration (VAR) systems gaining popularity, because, firstly, they operate on environment friendly fluids (refrigerants and solution pairs) confirming Montreal and Kyoto Protocol. Secondly, they harness cheap alternative energy sources, such as geothermal, biomass, solar energy or a waste by product heat source. Therefore, in recent years, many researches have been devoted to improvement of the VAR system [1-5].

A detailed thermodynamic analysis of absorption refrigeration cycle using $H_2O$-LiBr was performed in Kaynakli and Kilic (2007). The influences of operating temperatures and effectivenesses of solution and refrigerant heat exchangers on the thermal loads of components, coefficients of performance (COPc, COP) and efficiency ratio were investigated. Keçeciler et al. (2000) carried out experiments on the VAR using $H_2O$-LiBr driven by geothermal energy. Mostafavi and Agnew (1996) investigated the performance of the VAR system using $H_2O$-LiBr depending on the ambient temperature.

In the VAR systems, it is very important to select the appropriate working substance, the properties of which have a great effect on the performance of the cycles. In recent years, an increasing number studies have focused on this problem. Karamangil et al. (2010) investigated the VAR system performance using commonly encountered solution pairs ($NH_3$-$H_2O$, $H_2O$-LiBr, $NH_3$-$LiNO_3$ and Acetone-$ZnBr_2$) in the literature. Ajib and Karno [4] presented the thermal physical properties of acetone–$ZnBr_2$ solution for absorption refrigeration systems at low-drive temperatures (about 55ºC). Theoretical and experimental investigation of absorption refrigeration system using the acetone–$ZnBr_2$ solution was carried out by Karno and Ajib [5]. They found that the COP was achieved as 0.4 (by measuring) and 0.6 (by simulation). Thermodynamic and physical properties for the ammonia–lithium nitrate ($NH_3$–$LiNO_3$) and ammonia–sodium thiocyanate ($NH_3$–NaSCN) solutions were presented by Ferreira [12], and comparisons between ammonia based mixtures ($NH_3$–$H_2O$, $NH_3$–$LiNO_3$ and $NH_3$–NaSCN) were carried out by Sun [3] and Abdulateef et al. [14]. Among ammonia based mixtures, although the $NH_3$–NaSCN can be considered as an alternative solution to $H_2O$–$NH_3$, Sun [3] emphasized that this solution cannot be operated at evaporator temperatures below -10ºC for the possibility of crystallization. One of the more recent studies, Zhu and Gu [15] performed a theoretical analysis of the VAR system using NH3–NaSCN solution, where the NaSCN is used as the absorbent and the $NH_3$ is used as the refrigerant. They found that the solution is advantageous for lower generator temperatures compare to $NH_3$–$H_2O$ solution, because of the fact that the COP is about 10% higher than the ones for $NH_3$– $H_2O$ system at the same working conditions.

## II. THERMODYNAMIC ANALYSIS OF VAR SYSTEM

The schematic illustration of the single-stage VAR cycle is presented in Fig. 1. As Fig. 1 illustrates, the fundamental VAR cycle contains a generator, an absorber, a condenser, an evaporator, a pump, an expansion valves, a refrigerant heat exchanger (RHE), a solution heat exchanger (SHE) and a refrigerant-solution heat exchanger (RSHE).

Mass balance at the generator can be written as follows;

for $NH_3$-$H_2O$

$$\dot{m}_{SS} = \dot{m}_{WS} + \dot{m}_{NH_3} \quad \text{(total mass balance)} \qquad (1)$$

$$\dot{m}_{SS} X_{SS} = \dot{m}_{WS} X_{WS} + \dot{m}_{NH_3} \quad \text{(ammonia balance)} \qquad (2)$$

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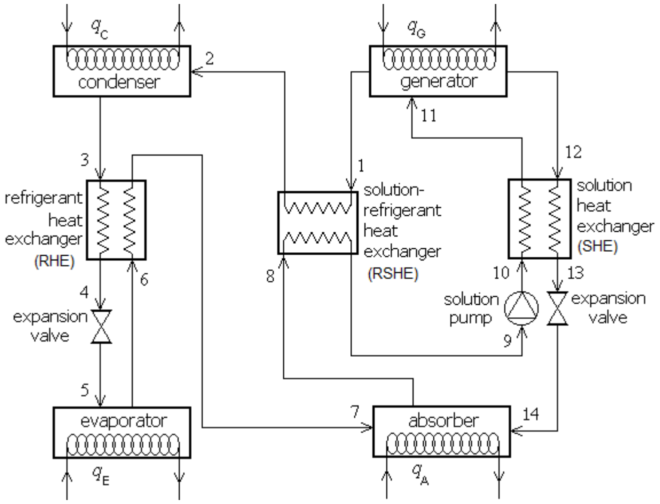


Fig 1. Vapor absorption refrigeration system

and for $H_2O$-LiBr

$$\dot{m}_{WS} = \dot{m}_{SS} + \dot{m}_{H_2O} \quad \text{(total mass balance)} \tag{3}$$

$$\dot{m}_{WS} X_{WS} = \dot{m}_{SS} X_{SS} \quad \text{(LiBr balance)} \tag{4}$$

From Eqs. 1- 4, the strong and weak solution mass flow rates can be determined as follows,

for $NH_3$-$H_2O$

$$\dot{m}_{SS} = \frac{1 - X_{WS}}{X_{SS} - X_{WS}} \dot{m}_{NH_3} \tag{5}$$

$$\dot{m}_{WS} = \frac{1 - X_{SS}}{X_{SS} - X_{WS}} \dot{m}_{NH_3} \tag{6}$$

and for $H_2O$-LiBr

$$\dot{m}_{SS} = \frac{X_{WS}}{X_{SS} - X_{WS}} \dot{m}_{H_2O} \tag{7}$$

$$\dot{m}_{WS} = \frac{X_{SS}}{X_{SS} - X_{WS}} \dot{m}_{H_2O} \tag{8}$$

The heat capacities of the main components of the VAR system can be calculated by using circulation ratio ($CR$),

$$CR = \frac{\dot{m}_{SS}}{\dot{m}_R} \tag{9}$$

$$q_E = h_5 - h_4 \tag{10}$$

$$q_C = h_1 - h_2 \tag{11}$$

for $NH_3$-$H_2O$

$$q_G = h_1 - CRh_9 + (CR - 1)h_{10} \tag{11}$$

$$q_A = h_6 + CRh_{12} - (CR - 1)h_7 \tag{12}$$

and for $H_2O$-LiBr

$$q_G = h_1 + CRh_{10} - (CR + 1)h_9 \tag{13}$$

$$q_A = h_6 + CRh_{12} - (CR + 1)h_7 \tag{14}$$

The energy balance of the heat exchangers per unit refrigerant mass flow rate can be calculated as,

$$q_{RHE} = (h_3 - h_4) = (h_7 - h_6) \tag{15}$$

$$q_{SHE} = (h_{12} - h_{13})(CR - 1) = (h_{11} - h_{10})CR \tag{16}$$

$$q_{RSHE} = (h_1 - h_2) = (h_9 - h_8)CR \tag{17}$$

Pump work per unit refrigerant mass flow rate can be determined as follows,

$$w_P = CR(p_C - p_E)v / \eta_P \tag{18}$$

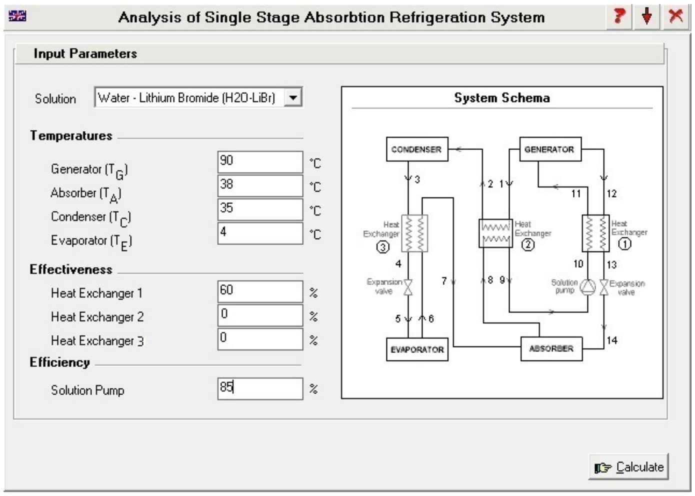
The measure of performance of refrigerators is expressed in terms of coefficient of performance (COP), defined as,

$$COP = \frac{q_E}{q_G + w_P} \tag{19}$$

## III. SOFTWARE PROGRAM

The developed software package includes screens as follow: the Input Page where the operating conditions are entered, the Output Page-1 where simulation results (the performance parameters and heat transfer rates) are shown, the Output Page-2 where the simulation results for the thermodynamic properties of solutions at each state point of cycle are shown.

The main system parameters can be entered in the Input Page which is shown in Fig. 2. After the system working temperatures, the heat exchanger effectivenesses and the solution pump efficiency are entered, if the user hits the "calculate" button, the results page appears. The results page has two sections which are, "summary" and "detail" sections. The "summary" section includes the heat capacities of main system components, the solution pump power consumption, the COP, the circulation ratio, the system working pressures and solution concentrations (see Fig. 3). The "detail" section includes the thermodynamic properties of each point (T, P, X and h) as shown in Fig. 4.


Analysis of Single Stage Absorbtion Refrigeration System

Input Parameters

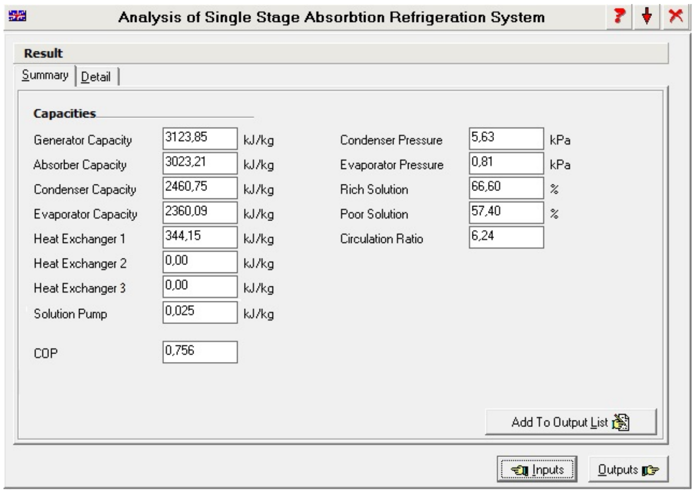
Solution: Water - Lithium Bromide (H2O-LiBr)

Temperatures
Generator ($T_G$) 90 °C
Absorber ($T_A$) 38 °C
Condenser ($T_C$) 35 °C
Evaporator ($T_E$) 4 °C

Effectiveness
Heat Exchanger 1 60 %
Heat Exchanger 2 0 %
Heat Exchanger 3 0 %

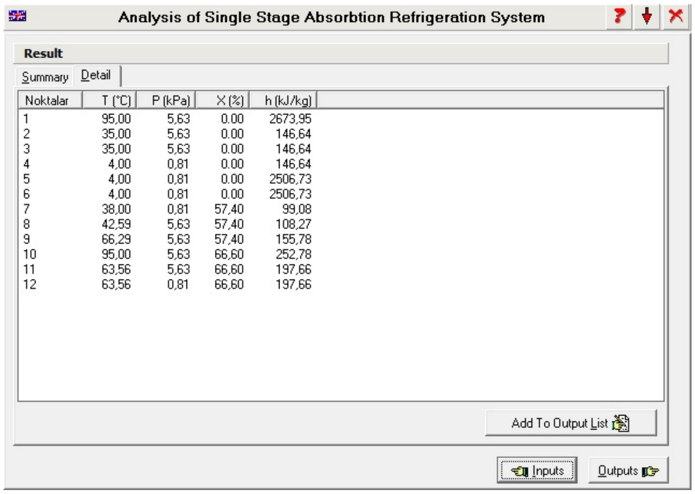
Efficiency
Solution Pump 85 %

Fig. 2. The Input Page of the software package



| | | | | | |
|---|---|---|---|---|---|
| Generator Capacity | 3123,85 | kJ/kg | Condenser Pressure | 5,63 | kPa |
| Absorber Capacity | 3023,21 | kJ/kg | Evaporator Pressure | 0,81 | kPa |
| Condenser Capacity | 2460,75 | kJ/kg | Rich Solution | 66,60 | % |
| Evaporator Capacity | 2360,09 | kJ/kg | Poor Solution | 57,40 | % |
| Heat Exchanger 1 | 344,15 | kJ/kg | Circulation Ratio | 6,24 | |
| Heat Exchanger 2 | 0,00 | kJ/kg | | | |
| Heat Exchanger 3 | 0,00 | kJ/kg | | | |
| Solution Pump | 0,025 | kJ/kg | | | |
| COP | 0,756 | | | | |

Fig. 3. The Output Page 1 (Result / Summary page)



| Noktalar | T (°C) | P (kPa) | X (%) | h (kJ/kg) |
|---|---|---|---|---|
| 1 | 95,00 | 5,63 | 0.00 | 2673,95 |
| 2 | 35,00 | 5,63 | 0.00 | 146,64 |
| 3 | 35,00 | 5,63 | 0.00 | 146,64 |
| 4 | 4,00 | 0,81 | 0.00 | 146,64 |
| 5 | 4,00 | 0,81 | 0.00 | 2506,73 |
| 6 | 4,00 | 0,81 | 0.00 | 2506,73 |
| 7 | 38,00 | 0,81 | 57,40 | 99,08 |
| 8 | 42,59 | 5,63 | 57,40 | 108,27 |
| 9 | 66,29 | 5,63 | 57,40 | 155,78 |
| 10 | 95,00 | 5,63 | 66,60 | 252,78 |
| 11 | 63,56 | 5,63 | 66,60 | 197,66 |
| 12 | 63,56 | 0,81 | 66,60 | 197,66 |

Fig. 4. The Output Page 2 (Result / Detail page)

## REFERENCES

[1] A. Sözen, "Effect of heat exchangers on performance of absorption refrigeration systems", *Energy Conversion and Management*, vol. 42, pp. 1699-1716, 2001. http://dx.doi.org/10.1016/S0196-8904(00)00151-5

[2] R. Saravanan, M. P. Maiya, "Thermodynamic comparison of water-based working fluid combinations for a vapor absorption refrigeration system", Applied Thermal Engineering, vol. 18, no. 7, pp. 553-568, 1998. http://dx.doi.org/10.1016/S1359-4311(97)00072-0

[3] D. W. Sun, "Comparison of the performance of NH3-H2O, NH3-LiNO3 and NH3-NaSCN absorption refrigeration systems", Energy Conversion, vol. 39, no. 5/6, pp. 357-368, 1998. http://dx.doi.org/10.1016/S0196-8904(97)00027-7

[4] M. M. Talbi, B. Agnew, "Exergy analysis: an absorption refrigerator using lithium bromide and water as the working fluids", Applied Thermal Engineering, vol. 20, pp. 619-630, 2000. http://dx.doi.org/10.1016/S1359-4311(99)00052-6

[5] R. D. Misra, P. K. Sahoo, S. Sahoo, A. Gupta, "Thermoeconomic optimization of a single effect water/LiBr vapour absorption refrigeration system", Int J of Refrigeration, vol. 26, pp. 158-169, 2003. http://dx.doi.org/10.1016/S0140-7007(02)00086-5

[6] O. Kaynakli, M. Kilic, "Theoretical study on the effect of operating conditions on performance of absorption refrigeration system", Energy Conversion and Management, vol. 48, no. 2, pp. 599-607, 2007. http://dx.doi.org/10.1016/j.enconman.2006.06.005

[7] A. Keçeciler, I. H. Acar, A. Doğan, "Thermodynamic analysis of the absorption refrigeration system with geothermal energy: an experimental study", Energy Conversion and Management, vol. 41, no. 1, pp. 37-48, 2000. http://dx.doi.org/10.1016/S0196-8904(99)00091-6

[8] M. Mostafavi, B. Agnew, "The impact of ambient temparature on lithium bromide-water absorption machine performance", Applied Thermal Engineering, vol. 16, no. 6, pp. 515-522, 1996. http://dx.doi.org/10.1016/1359-4311(95)00004-6

[9] M. I. Karamangil, S. Coskun, O. Kaynakli, et al. "A simulation study of performance evaluation of single-stage absorption refrigeration system using conventional working fluids and alternatives", Renewable and Sustainable Energy Reviews, vol. 14, no. 7, pp. 1969-1978, 2010. http://dx.doi.org/10.1016/j.rser.2010.04.008

[10] A. Karno, S. Ajib, "Thermodynamic analysis of an absorption refrigeration machine with new working fluid for solar applications", Heat Mass Transfer, vol. 45, pp. 71-81, 2008. http://dx.doi.org/10.1007/s00231-008-0408-2

[11] S. Ajib, A. Karno, "Thermo physical properties of acetone–zinc bromide for using in a low temperature driven absorption refrigeration machine", Heat Mass Transfer, vol. 45, pp. 61-70, 2008. http://dx.doi.org/10.1007/s00231-008-0409-1

[12] C. A. I. Ferreira, "Thermodynamic and physical property data equations for ammonia-lithium nitrate and ammonia-sodium thiocyanate solutions", Solar Energy, vol. 32, pp. 231-36, 1984. http://dx.doi.org/10.1016/S0038-092X(84)80040-7

[13] J. M. Abdulateef, K. Sopian, M. A. Alghoul, M. Y. Sulaiman, A. Zaharim, I. Ahmad, "Solar absorption refrigeration system using new working fluid pairs", Int J Energy, vol. 1, no. 3, pp. 82-87, 2007.

[14] L. Zhu, J. Gu, Thermodynamic analysis of a novel thermal driven refrigeration system", World Academy of Science, Engineering and Technology, vol. 56, pp. 351-55, 2009.