



## Study Comparison of LiBr-H<sub>2</sub>O Property and Exergy Analysis for Single Stage Vapour Absorption Refrigeration System

### KEYWORDS

LiBr-H<sub>2</sub>O properties, energy and exergy analysis of VAR system.

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**ABSTRACT** The aim of this study is to present a Gibbs Energy model to calculate the thermodynamic properties of LiBr-H<sub>2</sub>O aqueous solution with the concentration range from 0 to 70 LiBr wt% and temperature from 0 to 210°C in vapour absorption refrigeration system. The enthalpy and entropy of properties are validated within deviation limits 0.3% to 2.68% and 0.54% to 3.02% respectively. The validated properties are incorporated for energy and exergy analysis of single effect absorption refrigeration cycle with LiBr-H<sub>2</sub>O as a working fluid. The system analysis and result shows COP, COP<sub>rev</sub>, exergetic efficiency of absorption cycle are 0.7533, 2.1657 and 34.78% respectively. The percentage of non-dimensional exergy losses of different component of VARS at the same operating conditions are reported around 52.67% and 37.87% for exergy loss taking place in absorber and generator component due to poor heat and mass transfer at larger temperature difference.

### 1. Introduction

In the field of heating, ventilating and air-conditioning (HVAC) engineering, electricity has been utilized to energize the air-conditioning and refrigeration systems since last decades. It is undoubted that HVAC is one of the indispensable provisions in modern life, no matter in working or living environments. K.F.Fong and T.T.Chow et.al [1]. reported that normally one-third to half of the annual total electricity consumption is used for air-conditioning and refrigeration in the metropolis worldwide. There are two types of refrigeration system Vapour Compression System and Vapour Absorption System. They differ from compression system due to the use of a heat source as energy input to operate on the other hand, the refrigeration devices base on compression system need mechanical energy to operate. This is the main advantages of absorption system; which can run on low temp heat source as a solar, waste heat recovered from other thermal system.[2010] Hans-Martin Henning [2]. Opined that the most commercially developed solar cooling technology is the absorption systems. Compared five types of solar cooling systems at subtropical city Hong Kong, which is commonly featured with long hot and humid summer.[2006] In an absorption cycle, a refrigerant and an absorbent are a pair of substances that work together. Ammonia-water and lithium bromide-water are the most common working pairs in refrigeration and air conditioning absorption refrigeration system. LiBr-H<sub>2</sub>O aqueous solution has been widely used in the absorption refrigeration industry for a long time thanks to its outstanding thermodynamics characteristics. And its use seems not to be limited to conventional applications but extend well beyond as more researchers are trying to exploit unconventional working ranges with various absorption cycle so the need for an accurate description of the solution for wide working ranges has been growing. There were several numerical and practical studies in the past such as among the early studies, Lower [3]. presented practically all thermo-physical properties of the solution. Using a Gibbs energy equation. But the maximum solution temperature range of 130°C limits the applicable range of this study, which is rather low by present system requirement[1960]. McNeely[4]. developed a Duhring equation from the

extensive collection of equilibrium vapour pressures and calculated the solution enthalpies for wide range of temperature and concentration using Haltenburger's method. The author mentioned at high concentration region, his dew temperature inconsistent with more recent measurement and his enthalpies show a questionable trend in differential heat of dilution.[1979] Feurecker et al. [5]. carried out a study based on their own pressure measurements for solutions in concentration range from 40 to 76 LiBr wt% and temperature from 45 to 190°C. and they compared their result with McNeely and reported good agreement of equilibrium vapour pressure for solution of concentration below 60%.[1994] H.T. Chua et al [6]. have been evaluated a thermodynamically consistent set of specific enthalpy, entropy, and heat capacity for the LiBr H<sub>2</sub>O solution with the temperatures span from 0 to 190°C, and the concentrations from 0 to 75 wt% using most of the experimental data available in the different literature. The work is based on the empirical input of Duhring's gradient and intercept, specific heat capacity data at a reference concentration of 50 wt% and density data. They presented the approach the issue of negative dew point at low temperature and high concentrations.[2000] Y.Kaita [7]. developed the equations for calculating the enthalpy and entropy by using data of heat capacity for the wide range of concentrations 40-65 wt% and also form temperature range 40 to 210°C. He agreed that their results are consistent with Feurecker's results and different with Mcneely [2001]. J. Patek and J. Klomfar [8]. have developed empirical equations describing pressure, molar density, isobaric heat capacity, enthalpy and entropy for LiBr-H<sub>2</sub>O solutions from 273 to 500 K based on linear optimization procedure and multi property fitting method. They found that the largest gap in the data at temperatures above 400 K and at compositions above 60 wt% of LiBr in the solution, [2006]. D.S. Kim and C.A. Infante Ferreira [9].were determined osmotic coefficients and mean ionic activity coefficient using experimental density and vapor pressure data collected from the literature. They have calculated LiBr-H<sub>2</sub>O solution enthalpy and entropy using experimental heat capacity and differential heat of dilution based on the osmotic coefficients equation for temperature range 0 to 210°C and

concentration range 0 to 70 wt% with a Gibbs energy equation. [2006]. M.M.Talbi and B. Agnew [10]. carried out an exergy analysis on a single-effect absorption refrigeration cycle with lithium-bromide water as the working fluid pair. They conclude that the load in the condenser is slightly higher than that in the evaporator due to primarily superheating of the inlet vapour to the condenser. The condenser and evaporator loads are approximately 27.8% less than the corresponding generator and absorber loads.[2000]. G.A. Florides and S.A. Kalogirou et al

The objective of this paper is to conduct a theoretical study of the single effect LiBr- H<sub>2</sub>O vapour absorption refrigeration system, starting with the presentation on mathematical Gibbs energy model of LiBr- H<sub>2</sub>O solution properties and latter theoretical output is validated with some researcher's results available in literature.

The validated properties will then be applied to investigate the system's classical first law performance on the basis of COP and individual component heat duty. The validated properties are also use for exergy studies, it is necessary to calculate the exergy of the working fluid at different points of the system. The physical exergy of system are validated with some researcher's results available in literature.

**2. Description of Single effect LiBr -H<sub>2</sub>O Vapour Absorption System:**

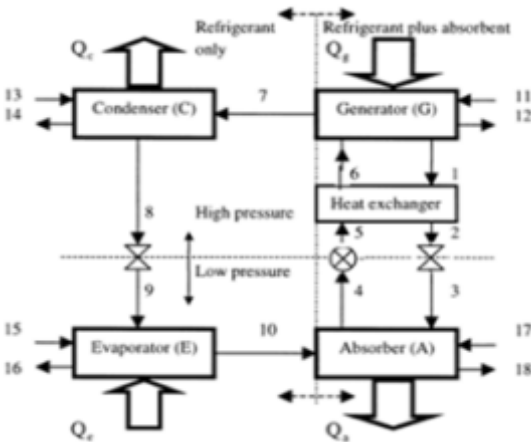


Fig.No.1.Energy flow balance for absorption cycle [14]. In this system the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by external source (heat energy). During the heating process, the vapour refrigerant is driven off by the solution and enters the condenser where it is liquefied. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

**3. Gibbs energy of an electrolyte solution:**

Thermodynamic description of electrolyte solutions requires introduction of a hypothetical 'ideal fluid' as a reference fluid for solute species because the pure solute is a solid substance in the standard state. Molality m is expressed as

$$m = \frac{x_1}{(1 - x_1)M_2} = \frac{x_{lw}}{(1 - x_{lw})M_1} \quad (1)$$

$x_1$  stoichiometric mole fraction,  $x_{lw}$  weight fraction of LiBr  
The thermodynamic properties of a system at

equilibrium consist of two types of properties, intensive and extensive properties. Other useful relationships which we will encounter are obtained through differentiation of basic thermodynamic functions

Gibbs-Helmholtz equation

$$G = H - TS = H + T \left( \frac{\partial G}{\partial T} \right) \quad (2)$$

A Gibbs dhum equation is very useful in the thermodynamics of aqueous solutions.

$$0 = \sum_i n_i \overline{dG}_i \quad (3)$$

The partial molar quantities of interest in aqueous solutions molar Gibbs free energy, enthalpy and volume which are defined The partial molar Gibbs free energy is also known chemical potential

$$\overline{G}_i = \left( \frac{\partial G}{\partial n_i} \right)_{T, P, n_{j \neq i}} \quad (4)$$

Gibbs Energy equation for LiBr aqueous solutions.[11].

$$G^J = x_1 G_1^o(T, P) + (1 - x_1) G_2^o(T, P) + x_1 v RT \left[ \ln \left( \frac{m}{m_0} \right) - 1 \right] + G^E(T, P) \quad (5)$$

Real solution differ from ideal one excess Gibbs Energy

$$G^E = x_1 v RT \left[ \ln \gamma^2 + (1 - \phi) \right] \quad (6)$$

Where  $\gamma$  mean ionic activity coefficient

$$\ln \gamma^2 = - \sum_i \left( 1 + \frac{z_i^2}{i} \right) \left( \alpha + \frac{ib_i}{2v} p \right) m^2$$

$\Phi$  osmotic coefficient

$$\phi = 1 + \sum_i \left( \alpha + \frac{ib_i}{2v} p \right) m^2$$

$$G^E = x_1 v RT \sum_i \left[ \frac{z_i^2}{i} \left( \alpha + \frac{ib_i}{2v} p \right) \right] m^2 \quad (7)$$

Enthalpy and Entropy of LiBr/H<sub>2</sub>O solution was evaluated following the procedure described by Kim and Infante Ferreira:[4].

$$\overline{h} = y_{LiBr} \overline{h}_{LiBr}^{\infty}(T, P) + (1 - y_{LiBr}) \overline{h}_{H_2O}(T, P) + \overline{h}^E(T, P, m)$$

$$h = \frac{\overline{h}}{M_{sol}} \quad (8)$$

$$\overline{s} = y_{LiBr} \overline{s}_{LiBr}^{\infty}(T, P) + (1 - y_{LiBr}) \overline{s}_{H_2O}(T, P) - y_{LiBr} v R \left[ \ln \left( \frac{m}{m_0} \right) - 1 \right] + \overline{s}^E(T, P, m)$$

$$s = \frac{\overline{s}}{M_{sol}} \quad (9)$$

**Thermodynamic modeling and assumptions:**

A thermodynamic analysis must be performed in order to obtain every thermodynamics state in the absorption refrigeration system and involves the application of mass balance as well as the first law of thermodynamics to related mass flows, enthalpies, heat transfer and power. ...Mass conservation [12]

$$\sum_i \dot{m}_{in} - \sum_i \dot{m}_{out} = 0 \quad (10)$$

Energyconservation [12]

$$\sum Q = \sum m_{out} h_{out} - \sum m_{in} h_{in} + \dot{W} \quad (11)$$

The exergy is expressed in terms of four types: physical, kinetic, potential and chemical exergy. Kinetic and potential exergy are assumed to be neglected in system.

Exergy per unit mass of a fluid stream can be defined as[17].

$$e = (h - h_0) - T_0 (s - s_0) \quad (12)$$

Where e is the specific exergy, h and s are the enthalpy and entropy of the fluid at temperature T, whereas, ho and so are the enthalpy and entropy of the fluid at environmental temperature To. In this analysis, environmental temperature To set to 298.15 K.

For the purpose of analysis, the following set of typical assumptions is considered

- Steady state operation
- Heat source is low grade steam
- The solution and refrigerant valves are adiabatic
- LiBr solutions in the generator and the absorber are in equilibrium at their respective temperatures and pressures
- Refrigerant at the condenser and evaporator exits is in a saturated state
- Strong solution of refrigerant leaving the absorber and the weak solution of refrigerant leaving the generator are saturated
- Work input to the solution pump is neglected
- Pressure losses in all the heat exchangers and the pipelines are neglected
- The reference environment is defined with  $T_0 = 25^\circ\text{C}$  and  $P_0 = 101.3\text{ kPa}$

Table No.1. Set of input data defining the base case operating conditions.[14]

Variable parameter	Symbol	Unit	Value
Evaporator Cooling Load	$Q_{eva}$	KW	201.29
Generator Temperature	T7	$^\circ\text{C}$	80
Condenser Temperature	T8	$^\circ\text{C}$	35
Evaporator Temperature	T10	$^\circ\text{C}$	5
Absorber Temperature	T4	$^\circ\text{C}$	35
Generator Heating Steam Temperature	T11	$^\circ\text{C}$	100
Condenser Cooling Water outlet Temp.	T14	$^\circ\text{C}$	33
Evaporator Chilled Water inlet Temp.	T15	$^\circ\text{C}$	20
Evaporator Chilled water outlet Temp.	T16	$^\circ\text{C}$	12
Absorber Cooling Water inlet Temp.	T17	$^\circ\text{C}$	27
Solution Heat Exchanger effectiveness	$\epsilon$	%	60
Reference Temperature	$T_0$	$^\circ\text{C}$	25
Reference Pressure	$P_0$	Kpa	101.3

4. Results and discussion.

In the present work based on the study of few researchers that thermodynamics properties of LiBr-H2O aqueous solution, they have studied different approach to use these aqueous solution in VAR systems. We have taken theoretical study of thermodynamics properties of the above taken solution using Gibbs free energy equation for the temperature ranging from 0 to 210°C with concentration 0 to 70% LiBr. On the basis of same concept our results of enthalpy and entropy values are coming very nearer to the values developed by some researcher.

Show in Fig. No. 2 to 4 the enthalpy and entropy of this study is relatively in good agreement with Y Kaita [7], T Chu[6], Mc Neely[4] and Feurecker[5] with 0.3% to 2.68% and 0.54% to 3.02% deviation respectively. On the other hand the deviation from Y Kaita has nothing to do with equilibrium vapour pressure because he diid not use his equilibrium pressure in enthalpy calculation. The average heat capacity

of solution is smaller below 60 wt% but slightly larger above this concentration, so that the result shows in enthalpy difference between this study and Y Kaita in high concentration region. McNeely enthalpy is smaller them the other resercher because his dew temperature gradient is much smaller in low concentration region.

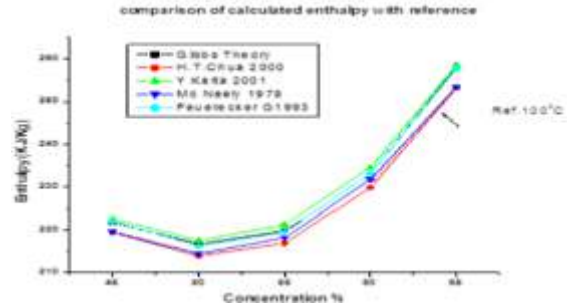


Fig.No.2. Comparison of calculated enthalpy with reference

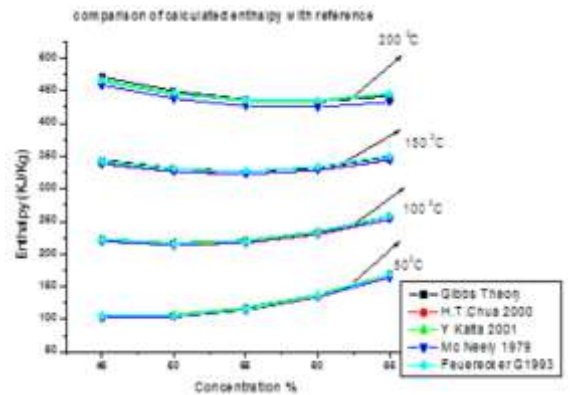


Fig.No.3. Comparison of calculated enthalpy with reference at differnet temperature

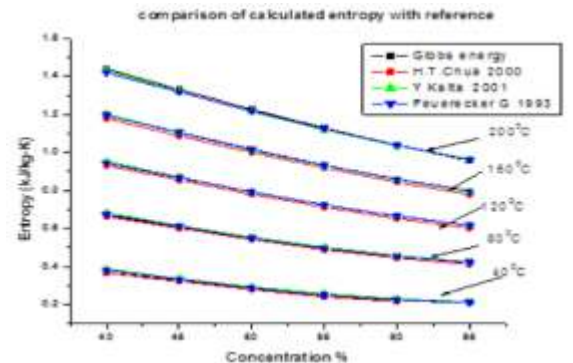


Fig.No.4. Comparison of calculated entropy with reference at differnet temperature

Table. No.2. Result of Single stage VARS on basis of First law of Thermodynamics

Sr No.	Component	Energy (KW)
1	Generator	267.22
2	Condenser	-213.12
3	Evaporator	201.29
4	Absorber	-259.05
5	Solution heat exchanger	50.58
6	COP	0.7533
7	COP <sub>max</sub>	2.1657
8	HEX	34.78 %

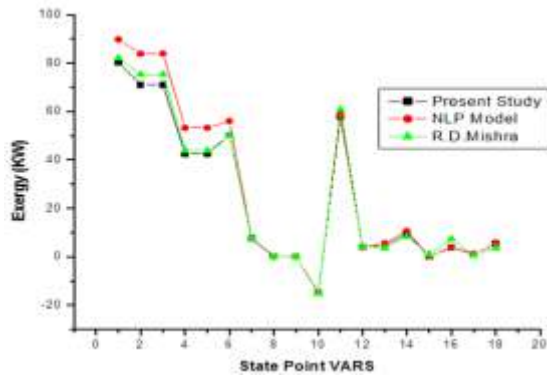


Fig.No.5. Comparison of Exergy of each state point with NLP and R.D.Mishra

Table No.2. Shows results of the first law analysis are presented, which illustrates various energy flows to and from each component of the system. It is found that the coefficient of performance, reversible coefficient of performance and exergetic efficiency of the absorption cycle are 0.7533, 2.1657 and 34.78% respectively.

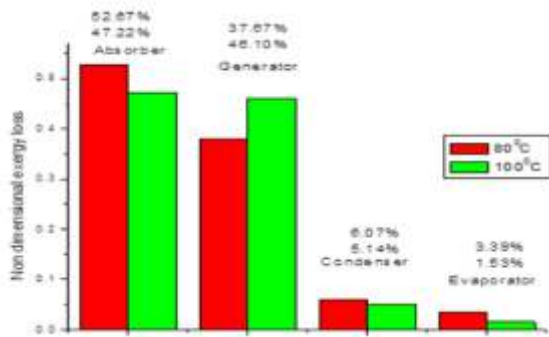


Fig.No.6. Non dimensional exergy loss of different components of system at generator temperature

The percentage of exergy losses of different component of the system at the same operating conditions are represented in Fig.No.6. It is noticed that around 52.67% of the total exergy loss is taking place in the absorption process. The second worst component from the view point of exergy loss is the generator around 37.87%. This irreversibility are due to heat transfer at large temperature difference in the absorber and mass transfer with a high concentration gradient and mixing losses in the generator and absorber.

## 5. Conclusion.

Thermodynamics properties of LiBr-H<sub>2</sub>O solution have been successfully described with Gibbs energy equation and the enthalpy and entropy of properties are validated some researcher within deviation limit 0.3% to 2.68% and 0.54 to 3.02% respectively. These properties are incorporated for thermodynamics study of VARS and results shows that around 52.67% of the total exergy loss is taking place in the absorption process. The second worst component from the view point of exergy loss is the generator around 37.87%. This irreversibility are due to heat transfer at large temperature difference in the absorber and mass transfer with a high concentration gradient and mixing losses in the generator and absorber.

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