

A COMPARATIVE STUDY ABOUT LITHIUM BROMIDE-WATER AND LITHIUM CHLORIDE-WATER SOLUTIONS IN PUMPLESS ABSORPTION SOLAR COOLING SYSTEMS IN IRAQI CIRCUMSTANCES

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Abstract: A comparative study between two solutions which they usually work as a working pairs in pumpless absorption cooling system is achieved analytically with aid of ESS (Engineering Equation Solver) 9.43 software. The pump in this system is replaced by a vertical pipe (lift tube) to ensure the pressure difference between the condenser and the evaporator. These working pairs are Lithium Bromide-Water and Lithium Chloride-Water. The study intends Iraqi summer weather as an ambient circumstances. A thermodynamics model is designed to find the energy and Exergy loss in each of system components. By solving the thermodynamic model, and assuming the same generator, absorber, condenser and evaporator temperatures in each case. It's found that the system coefficient of performance is relatively the same while the probability of agglomeration in case of Lithium Bromide-Water system is higher because of the large salt concentration. It's concluded that the Lithium Chloride-Water is most suitable in Iraqi circumstances in spite of high values of total exergy loss which is obtained in case of Lithium Chloride-Water system if it is compared with the exergy loss value in case of Lithium Bromide-Water system.

Keywords: Solar cooling, absorption system, pumpless, $LiCl-H_2O$, $LiBr-H_2O$

1. Introduction

The cooling energy demand in Iraq particularly and all over the world generally is increased

rapidly. International Institute of Refrigeration reports that approximately 15% of the total electric power generated in the world consumes by refrigeration and air conditioning systems [1]. Kumar et al 2017 [2] deduced that (70% - 75%) house hold electrical energy is consumed by air conditioning system. This occurs due to the population growth, climate changes as well as the increase in standard living. All these pervious combined factors as well as the observed deficiency in electric power supply in Iraq particularly make the solar cooling is a perfect, economical, and clean solution which is able to solve such this big problem. Pumpless absorption system or (heat driven system) is a technique in which a vertical pipe (lift tube) is used to circulate solution through the system and to ensure pressure drop between evaporator and condenser, which makes this system more economical than other solar cooling systems. The absence of pump in these systems makes it more silent than other traditional solar absorption systems [3]. The system consists of different components: generator vessel which

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appendixes by lift tube and separator, condenser, capillary tube, absorber, solution heat exchanger and evaporator. If single lift tube is used the system will be more reliable for residential applications, for large scale applications a multiple lift tube systems must be used[4]. In case of the working pairs under consideration water works as a refrigerant, which makes the evaporator temperature in these systems limits to 5°C ultimately[5]. Lithium Chloride-water or Lithium Bromide-water solutions are the absorbent. The cycle events in this system start when the solar radiation converts by a solar concentrator (usually parabolic through collector is used) to thermal energy stored in a water storage tank. The hot water flows to generator and the weak Lithium chloride-water or Lithium Bromide-water solutions evaporates there. The refrigerant pushes the strong LiCl-H₂O or LiBr-H₂O solutions and the flow is considered as two phase flow through the lift tube. The separator separates these two phases. The water vapor condenses in the condenser while the strong solution flows to absorber through a heat exchanger to recover heat to the incoming weak solution. The condensed water then flows to evaporator through the capillary tube. The refrigerant evaporates in the evaporator, and the water vapor passes to the absorber where it is absorbed by the strong solution and the cycle will be repeated as the weak solution enters the generator vessel. The early studies of this type of cooling started during the mid of 17th century by William Cullen and Nariño's attempt who they produced a small quantity of ice by using diethyl ether [6]. John Leslie 1810 used sulphuric acid and water vapor to produce cooling. to chill wine. In their technique sulphuric acid worked as an absorbent and water vapor as a refrigerant [7]. A periodic sulphuric acid recharging was necessary for continuous

cooling. An ammonia and silver chloride pair was used by Michael Faraday 1824[8] to produce cooling. Faraday used silver chloride as absorbent while ammonia was the refrigerant. Significant developments in absorption cooling were continued later, although these previous two methods were considered as the principle of absorption cooling technique. Recently many studies that deal with solar absorption cooling are achieved. Some of these researches are experimental and aim to find the optimum design of each part in the system which ensure the best heat and mass transfer, invent hybrid cycles, and using of new working pairs. [9,10]. Perez, 1984[11] found that the performance of the absorption cooling systems is strongly affected by the thermo physical properties of working pairs. Horuz 1998 [12] compared the using of H₂O-NH₃ and LiBr-H₂O solution as a working pairs in absorption cooling system in term of system COP, cooling capacity, maximum and minimum system pressure. It was found that H₂O-NH₃ provided a better performance. Jeong et al. 1998 [13] produced a dynamic simulations of an absorption cooling systems. It was assumed that the mass of solution storage in the vessels, the thermal capacity heat storage, and the solution and vapor flow rates were calculated according to the differences in pressure between vessels. Recently, to improve the system COP double effect systems are used. Extra components add which are operated at high pressure like: a generator, a condenser, and a heat exchanger. She et al. 2015 [14] proposed hybrid double effect system. The working pair used was LiCl-H₂O on the high pressure region and LiBr-H₂O on the low pressure region because of the higher vapor pressure of LiCl-H₂O if it compared with LiBr-H₂O vapor pressure. Gogoi and Konwar 2016[15] compared LiCl-H₂O and LiBr-H₂O systems for same operating conditions. They

proved LiCl-H₂O system recorded higher COP value due to the thermodynamics properties of LiCl-H₂O. Bellos et al. 2017 [16] used LiCl-H₂O as a working pair for a double effect solar absorption cooling system. It was found 8% more cooling can be achieved if it compared with a LiBr-H₂O system at same circumstances. Kumar et.al. 2017 [17] Designed and fabricated a 0.5TR Lithium bromide-water vapor absorption system. They supplied solar energy to system through solar panel. Their system consisted of a generator, Absorber, Condenser, evaporator and pump. They considered that their system can be used for air-conditioning or food protection in offices, schools, or any other place where it in use through sun rise only. Singh and Verma 2019[18] used artificial neural networks ANN to analyze LiCl-H₂O absorption cooling system. They deduced that their analysis made less than 1% as a maximum difference between predicted and experimental results. In this study a thermodynamics analysis of pump less absorption cooling system is achieved to compare LiCl-H₂O and LiBr-H₂O working pairs according to Iraqi weather

By assuming a steady state operation, and the components are perfectly insulated and they are worked at constant temperature. The generator temperature is assumed to be 75°C , the condenser and the absorber are water cooled to record a temperature of 35°C, and the evaporator is in 7°C. The refrigerant (water vapor) that leaves the condenser and the evaporator considered as saturated liquid and saturated vapor respectively. The two phase flow regime in lift tube is considered as slug flow pattern in this analysis. From the mass conservation equation for whole system as in "Fig.1".

$$\sum m_{in} - \sum m_{out} = 0 \quad (1)$$

$$m_1 = m_5 \quad (2)$$

$$m_2 = m_6 = m_7 = m_8 \quad (3)$$

$$m_1 - m_2 = m_3 = m_4 \quad (4)$$

From energy conversation equation:

$$\sum Q = \sum m_{out} h_{out} - \sum m_{in} h_{in} + W \quad (5)$$

If the generator and its appendixes are assumed as a control volume then "(5)" will be:

$$Q_G = m_2 h_2 + m_3 h_3 - m_1 h_1 \quad (6)$$

$$h_1 = h_{ws}(T_1, X_{ws}) \quad (7)$$

$$h_2 = h_{super\ heated}(T_2, P_{con.}) \quad (8)$$

$$T_1 = T_3 \left[\frac{m_{ss}}{m_{ws}} \right] \eta_{HE} + T_5 \left[1 - \left[\frac{m_{ss}}{m_{ws}} \right] \eta_{HE} \right] \quad (9)$$

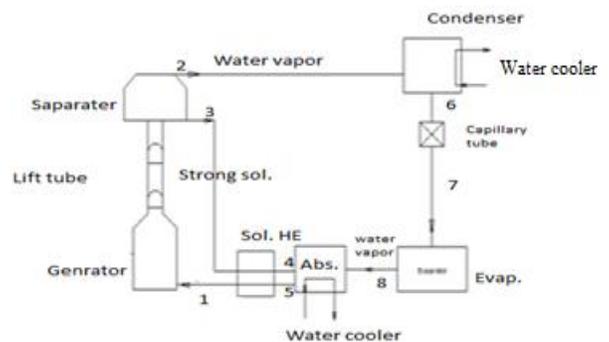


Figure 1. Schematic Diagram of pumpless Absorption Cooling System

If the energy balance equation applied for a solution heat exchanger as a control volume:

$$T_3 = T_{ss}(P_{con}, X_{ss}) \quad (10)$$

The ratio of strong solution to refrigerant flow rates is called the lifting ratio (λ). It is calculated as:

$$\lambda = \frac{m_3}{m_2} \quad (11)$$

If the condenser is taken as a control volume and by applying energy balance equation then:

$$Q_{con} = m_6(h_6 - h_2) \quad (12)$$

$$h_6 = h_{sat.liquid}(T_6) \quad (13)$$

If the evaporator is taken as a control volume and by applying energy balance equation then:

$$Q_{eva.} = m_8(h_8 - h_7) \quad (14)$$

For an isenthalpic expansion through the capillary tube then:

$$h_7 = h_6 \quad (15)$$

$$h_8 = h_{sat.vapor}(T_8) \quad (16)$$

Absorber heat rejected can be calculated as:

$$Q_{abs.} = -m_{ws}h_5 + m_{ss}h_4 + m_{ref}h_8 \quad (17)$$

If the heat gains by weak solution is assumed exactly the same as the heat rejects from strong solution in solution heat exchanger then:

$$h_4 = h_3 - \frac{m_1}{m_3}(h_1 - h_5) \quad (18)$$

$$h_5 = h_{ws}(T_5, X_{ws}) \quad (19)$$

$$T_4 = T_3 - \eta_{HE}(T_3 - T_5) \quad (20)$$

System coefficient of performance is calculated by:

$$COP = \frac{Q_{eva.}}{Q_G} \quad (21)$$

2.1 Exergy Analysis

Exergy or (availability) defined as the possible work that can be extracted from a given physical system if it is allowed to reach to the ambient conditions at P_0, T_0 at the end state [19]. For steady state system, the exergy balance in a control volume can be calculated by [20]:

$$\Psi_i = \sum(m\varphi)_{in} - \sum(m\varphi)_{out} + \sum Q \left(1 - \frac{T_0}{T}\right)_{in} - Q \left(1 - \frac{T_0}{T}\right)_{out} + \sum W \quad (22)$$

Specific exergy in each node or state in "Fig. 1" given by [20]:

$$\varphi = (h - h_0) - T_0(s - s_0) \quad (23)$$

If "(22)" is applied at each component in the system under study the following set of equations are obtained:

$$\Psi_G = m_1\varphi_1 - m_2\varphi_2 - m_3\varphi_3 + Q_G \left(1 - \frac{T_0}{T_3}\right) \quad (24)$$

$$\Psi_{con} = m_2(\varphi_2 - \varphi_6) - Q_{con} \left(1 - \frac{T_o}{T_6}\right) \quad (25)$$

$$\Psi_{abs.} = m_4\varphi_4 + m_8\varphi_8 - m_5\varphi_5 - Q_{abs.} \left(1 - \frac{T_o}{T_5}\right) \quad (26)$$

$$\Psi_{eva.} = m_8(\varphi_7 - \varphi_8) + Q_{eva.} \left(1 - \frac{T_o}{T_{eva.}}\right) \quad (27)$$

$$\Psi_{EV} = m_7(\varphi_6 - \varphi_7) \quad (28)$$

$$\Psi_{sol.HE} = m_3\varphi_3 + m_5\varphi_5 - m_1\varphi_1 - m_4\varphi_4 \quad (29)$$

$$Nondimensional\ Exergy\ loss(\theta) = \frac{\Psi_i}{\sum \Psi_i} \quad (30)$$

2.2 Flow Analysis through the Lift Tube

For a slug flow pattern through the lift tube the void fraction is calculated by the relation given by Nicklin[21] as:

$$\alpha = \frac{V'_{fg}}{C_o[V'_{fg} + v'_{fb}]} \quad (31)$$

$C_o = 1.2$ for fully turbulent flow ,or $C_o = 2$ in case of laminar flow.

$$V'_{fg} = \frac{V_{fg}}{A(gd)^{0.5}} \quad (32)$$

$$V'_{fb} = \frac{V_{fb}}{A(gd)^{0.5}} \quad (33)$$

$$V \cdot = \frac{m}{\rho} \quad (34)$$

$$v'_{fb} = 0.352[1 - 3.18\Sigma - 14.77\Sigma^2] \quad (35)$$

Σ is surface tension number which calculated as:

$$\Sigma = \frac{\sigma}{\rho g d^2} \quad (36)$$

For solution head l in the lift tube of length L Aman et al suggested a ratio of $\frac{l}{L}$ as [22]:

$$\frac{l}{L} = \left[(1 - \alpha) \left(1 + \frac{f}{2} (V'_{fg} + V'_{fb})^2 \right) \right] \quad (37)$$

Where f is calculated by knowing the solution Reynolds number as given by Reinemann et al [23]:

$$f = \frac{0.316}{Re^{0.25}} \quad (38)$$

$$Q_G = m_g h_{fg} \quad (39)$$

$$h_{fg} = \text{heat of vaporization at } T_G \quad (40)$$

2.3 Ideal System Coefficient of Performance

COPI is defined by Dalichaouch [24] as the Ideal system coefficient of performance and it's calculated as:

$$COPI = \left(\frac{T_{eva}}{T_o - T_{eva}} \right) \left(1 - \frac{T_o}{T_G} \right) \quad (41)$$

The second law efficiency is defined as the ratio of the real to ideal coefficient of performance and given by Ezzine [25] as:

$$\eta_{2nd\ law} = \frac{COP}{COPI} \quad (42)$$

3. Results and Discussions

The results in “Table 1” and “Table 2” are obtained by considering ESS 9.43 software data in order to find the thermodynamics properties of LiBr-H₂O, LiCl-H₂O solutions and water

vapor, and by solving the above thermodynamic Exchanger is assumed to be 80%, the lift tube length and diameter are 0.5 m and 10 mm respectively, and $\frac{l}{L}$ ratio is 0.8. For the same generator, condenser, absorber, and evaporator temperatures of (70, 35, 35, and 7)°C respectively, it can be noted in "Table 1" Lithium chloride-water solution works at less weak and strong solution concentrations. This make the probability of agglomeration (crystallization) of LiCl-H₂O solution highly lower than LiBr-H₂O solution. Since the solution concentration is a function of solution temperature and pressure and for a constant pressure there's a noted increase in solution concentration will be accrue as the temperature increases, and according to Iraqi summer weather it is expected that the generator's temperature reaches higher than 70°C so it is being clear that LiBr-H₂O solution is unfavorable in Iraqi circumstances. It can be observed also for the same generator temperature the LiCl-H₂O solution operate at higher heat and as the generator heat increases it

model. The efficiency of the solution heat is expected that a higher value of refrigerant will be obtained as given in "Fig. 2" which increase the cooling load in case of LiCl-H₂O solution by approximately 30% as shown in "Table 2". There is a small increase in coefficient of performance in case of LiCl-H₂O while the COPI is the same because of the same components temperatures are considered in this study. A higher lifting ratio is obtained in case of LiBr-H₂O solution which means the value of strong solution in lift tube is higher for a lower value of refrigerant. This occurs due to the higher generator heat obtained in case of LiCl-H₂O. A higher pressure can be used in case of LiCl-H₂O solution in contrast with LiBr-H₂O solution which must be work in vacuum. The total exergy loss and the exergy loss on each system components are shown in "Fig. 3" for LiBr-H₂O and LiCl-H₂O systems. Obviously a higher exergy loss is recorded in LiCl-H₂O system and this occurs due to higher values of heat exchange in the later system.

Table (1). Thermodynamics properties of LiBr-H₂O, LiCl- H₂O solutions and water

state	T(oC)		<i>m</i> (g/s)		X%		h(kJ/kg)		s(kJ/kg.K)	
	LiCl-H ₂ O	LiBr-H ₂ O								
generator exit (2)	75	75	0.324	0.2211	100(WV)	100(WV)	2640	2640	8.582	8.582
condenser exit (6)	35	35	0.324	0.2211	100(WV)	100(WV)	146.6	146.6	0.505	0.505
evaporator inlet (7)	7	7	0.324	0.2211	100(WV)	100(WV)	29.42	29.42	0.1063	0.1063
evaporator exit (8)	7	7	0.324	0.2211	100(WV)	100(WV)	2513	2513	8.973	8.973
absorber exit (5)	35	35	10.49	12.5	54.08(WS)	41.07(WS)	154.9	81.15	0.3087	0.2184

absorber inlet (4)	43	43	10.16	12.28	57.98(SS)	0.4723(SS)	146.6	142.2	0.3611	0.2446
generator inlet (1)	59.23	59.56	10.49	12.5	54.08(WS)	41.07(WS)	218.9	132	0.5089	0.3773
HE inlet (3)	75	75	10.16	12.28	62.72(SS)	0.4723(SS)	302.6	175.9	0.5997	0.439

Table (2) Absorption solar cooling system performance

	LiBr- H ₂ O	LiCl-H ₂ O
COP	0.4915	0.4922
COPI	0.8534	0.8534
$\eta_{2nd\ law}$	0.5759	0.5767
Lifting ratio λ	55.54	31,36
vapor pressure(kPa)	8.239	8.621
Q _{eva} .(KW)	0.5378	0.8049
Q _g .(KW)	1.094	1.638
Q _{abs} .(KW)	1.092	1.597
Q _{con} .(KW)	0.5398	0.8094

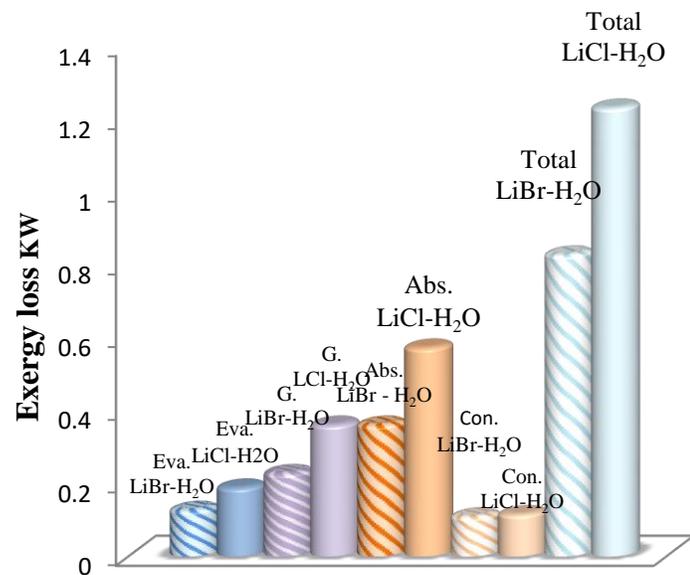


Figure 3. Total Exergy loss and component Exergy loss in LiBr-H₂O and LiCl-H₂O systems

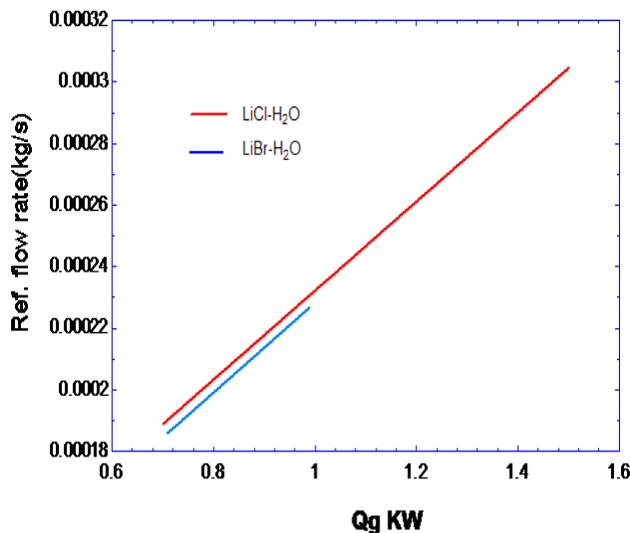


Figure 2. Refrigerant flow rate versus generator input heat

4. Conclusions

1.The efficiency of lift tube in pump less absorption solar cooling systems is highly affected by working pair thermodynamics properties.

2.For the same system components temperature the LiCl-H₂O solution is more efficient than LiBr-H₂O solution in pump less absorption solar cooling systems for many reasons:

- a) Probability of solution agglomeration in LiBr-H₂O system .

b) A higher generator heat obtained in case of LiCl-H₂O.

c) A lower lifting ratio in LiCl-H₂O which means a higher refrigerant flow rate can be achieved which increases the cooling capacity.

3. The exergy loss in LiCl-H₂O system is higher if it compared with the values in LiBr-H₂O system.

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6. Abbreviations

A	Surface area	m	Mass flow rate
COP	Coefficient of performance	p	pressure
COPI	Reversible coefficient of performance	Q	Energy (heat transfer rate)
d	Lift tube diameter	r	Radius
f	Friction factor in lift tube	Re	Reynolds number
g	Gravitational acceleration	s	Specific Entropy
h	Specific enthalpy	T	Temperature
L	Lift tube length	V	Volumetric flow rate
l	Solution height in lift tube	V'	Non-dimensional volumetric flow rate.
LiBr	Lithium bromide	W	Work
LiCl	Lithium Chloride	X	Solution concentration percentage

6.1 Greek letters

α	Void fraction	ρ	Density	kg/m ³
β	Nondimensional availability	σ	surface tension	N/m
η	Efficiency	φ	Specific availability	kJ/kg

λ	Lifting ratio	Ψ	Availability loss	kW
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6.2 Subscripts

1,2,..,8	State numbers except with r	L	Liquid
Abs	Absorber	o	Ambient conditions
con	Condenser	ref	Refrigerant
EV	Expansion valve	sol	Solution
eva	Evaporator	ss	Strong solution
G	Generator	ws	Weak solution
g	Gas	wv	Water vapor

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