

# Feasibility Studies of Single-Effect H<sub>2</sub>O-LiBr+LiI+LiNO<sub>3</sub>+LiCl Vapour Absorption Cooling System for Solar Based Applications

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## ABSTRACT

Vapour absorption refrigeration system is widely recognized as a prospective eco-friendly technology for efficient and economic use of solar heat energy for cooling applications. An intensive search for refrigerant-absorbent combinations suitable for operating at temperature levels attainable with solar energy is underway. However, thermodynamic analysis needs to be performed to find the suitability of a refrigerant-absorbent combination for a specific application. In the present work, detailed thermodynamic analysis is performed on single-effect H<sub>2</sub>O-LiBr+LiI+LiNO<sub>3</sub>+LiCl vapour absorption refrigeration system of one ton capacity. This in turn used to identify the feasibility of the systems for solar based applications and air-cooled applications. Thermodynamic analysis is performed based on mass, concentration and energy balance equations of each component of the system. The influences of operating variables on performance parameters are discussed using performance plots. Possible combinations of temperatures for optimum operation of the system are identified. Results obtained from the analysis are compared with standard fluid pair H<sub>2</sub>O-LiBr. It is found that H<sub>2</sub>O-LiBr+LiI+LiNO<sub>3</sub>+LiCl will perform better at all the operating temperatures and operating temperature range is higher than the H<sub>2</sub>O-LiBr system. Hence the system is more suitable for solar and air cooled applications.

**KEY WORDS:** Solar, Vapour absorption refrigeration/cooling system, Thermodynamic analysis, Working fluid.

## 1. INTRODUCTION

Vapour absorption systems runs on low grade energy such as solar energy. Working pairs used in the cycles are natural materials, which have no ozone depleting and global warming potential. This system is more attractive in energy and environment perspective. Even though it has the above advantages, performance of the vapour absorption system is lesser compared to vapour compression system. Hence improving the performance of absorption systems becomes the high research priority at present. Selecting the suitable working fluids is the important factor to improve the performance of absorption systems. Thermodynamic analysis is the deciding tool to predict the performance behavior of any absorption system. Thermodynamic analyses used to find the suitability of working fluids for a specific application for specific range of temperatures (Badarinarayana, 1982).

In literature, innumerable refrigerant-absorbent combinations are available for vapour absorption systems. Among them, H<sub>2</sub>O-LiBr and NH<sub>3</sub>-H<sub>2</sub>O are extensively studied refrigerant-absorbent combinations. Studies on thermo-physical properties of H<sub>2</sub>O-LiBr reveal that, the two superior properties of H<sub>2</sub>O-LiBr are non-volatility of LiBr (absorbent) and very high heat of vaporization of water (refrigerant) making it ideal for vapour absorption systems (Jian Sun, 2012). The H<sub>2</sub>O-LiBr system is relatively less complex, higher COP, lower operational pressures than NH<sub>3</sub>-H<sub>2</sub>O systems. In addition, they are eco-friendly, odorless, non-toxic and non-flammable. However, it has some disadvantages such as crystallization, corrosion and high viscosity. At high concentrations, the solution will undergo crystallization. One way to increase the solubility characteristics is by addition of extra salts in a basic H<sub>2</sub>O-LiBr which will push the crystallization limit away from the normal operating zone (Adegoke, 1993). Many salt mixtures have been tried along with H<sub>2</sub>O to overcome the above drawbacks.

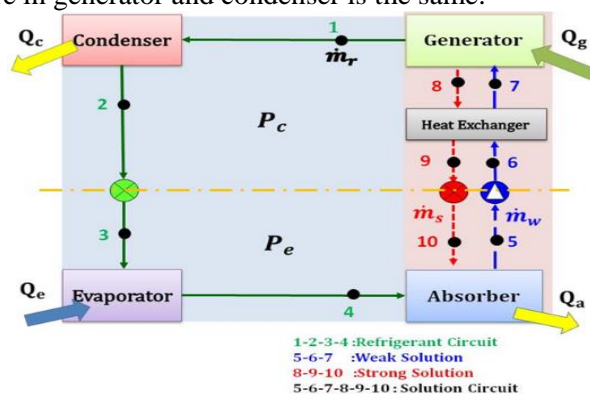
In literature, studies on mixing of salts comprise mostly of comparative analysis. Some of the authors did COP (Coefficient of Performance) based comparative study for the same limit of component temperatures to find a better performing fluid for solar thermal range of temperatures. Four aqueous solutions of LiBr, LiBr+ZnBr<sub>2</sub>, LiBr+ZnBr<sub>2</sub>-LiCl and LiBr+ZnCl<sub>2</sub>+CaBr<sub>2</sub> salts have been compared and found that performance was better for the H<sub>2</sub>O-LiBr at lower evaporator temperatures (Malik, 1996). This study emphasized the cooling range based comparison, but did not carry out temperature range comparison of other components for solar applications and air cooled applications. Sixteen water based VACS with H<sub>2</sub>O-LiBr, H<sub>2</sub>O-LiCl, H<sub>2</sub>O-LiI, H<sub>2</sub>O-NaOH, H<sub>2</sub>O-LiCl+LiNO<sub>3</sub>, H<sub>2</sub>O-LiBr+LiI, H<sub>2</sub>O-LiBr+LiNO<sub>3</sub>, H<sub>2</sub>O-LiBr+ZnBr<sub>2</sub>, H<sub>2</sub>O-LiBr+LiScN, H<sub>2</sub>O-LiCl+CaCl<sub>2</sub>+Zn(NO<sub>3</sub>)<sub>2</sub>, H<sub>2</sub>O-LiBr+ZnCl<sub>2</sub>+CaBr<sub>2</sub>, H<sub>2</sub>O-LiBr+LiCl+ZnCl<sub>2</sub>, H<sub>2</sub>O-LiBr+ZnBr<sub>2</sub>+LiCl, H<sub>2</sub>O-LiBr+LiI+C<sub>2</sub>H<sub>6</sub>O<sub>2</sub>, H<sub>2</sub>O-NaOH+KOH+CsOH and H<sub>2</sub>O-LiNO<sub>3</sub>+KNO<sub>3</sub>+NaNO<sub>3</sub> have been compared (Saravanan, 1998). It was found that H<sub>2</sub>O-LiBr+LiCl+ZnCl<sub>2</sub> mixture gives better COP and H<sub>2</sub>O-LiCl mixture can work at lower generator temperatures compared to other combinations. This study emphasized on better performing fluid combination for the same range of operating temperatures, but did not carry out temperature range based comparison for solar applications and air cooled applications.

Another category of research is to find the fluid mixture with wider range of operating temperatures for same working conditions in order to know their applicability for air cooled applications. compared In an another

comparative work six salt combinations  $\text{H}_2\text{O}-\text{LiBr}$ ,  $\text{H}_2\text{O}-\text{CaCl}_2+\text{LiCl}+\text{ZnCl}_2$ ,  $\text{H}_2\text{O}-\text{LiBr}+\text{ZnCl}_2$ ,  $\text{H}_2\text{O}-\text{LiBr}+\text{LiSCN}$ ,  $\text{H}_2\text{O}-\text{LiBr}+\text{LiCl}$ ,  $\text{H}_2\text{O}-\text{LiBr}+\text{C}_2\text{H}_6\text{O}_2$  have been compared (Iyoki, 1990). It was presented that  $\text{H}_2\text{O}-\text{LiBr}+\text{ZnCl}_2+\text{CaBr}_2$  system can work at wider range of generator and condenser temperatures hence, proposed for air-cooled systems. (Best, 2001) found that the  $\text{H}_2\text{O}-\text{NaOH}+\text{KOH}+\text{CsOH}$  system can operate with a higher range of component temperatures than  $\text{H}_2\text{O}-\text{LiBr}$  thus used in air cooled applications, though it has similar COPs.

Earlier the  $\text{H}_2\text{O}-\text{LiBr}+\text{LiNO}_3+\text{LiI}+\text{LiCl}$  was proposed as one of the potential working fluid in real absorption chillers (Okano, 1994; Tongu, 1994) for air-cooled applications. The mole ratio of  $\text{LiBr}:\text{LiNO}_3:\text{LiI}:\text{LiCl}$  was considered to be 100: 25: 75: 41. Here  $\text{LiNO}_3$  behaves as an anti-crystallization and anticorrosive agent.  $\text{LiI}$  is also selected as an anti-crystallization agent, and  $\text{LiCl}$  acts as a vapor pressure suppression agent. However, any experimental proof of mixing (mole) ratio and thermodynamic properties of the system to our knowledge has appeared in literature. Optimal mixing ratio of  $\text{H}_2\text{O}-\text{LiBr}+\text{LiNO}_3+\text{LiI}+\text{LiCl}$  system was found to be 5: 1: 1: 2 based on experimental solubility data (Koo, 1998; 1999). Thermo physical properties such as: Duhring (P-T-X) and enthalpy-concentration (h-T-X) diagrams of  $\text{H}_2\text{O}-\text{LiBr}+\text{LiNO}_3+\text{LiI}+\text{LiCl}$  working fluid were found (Lee, 2000) required for thermodynamic analysis of vapour absorption system. Present work detailed thermodynamic analysis is performed on single-effect  $\text{H}_2\text{O}-\text{LiBr}+\text{LiNO}_3+\text{LiI}+\text{LiCl}$  system of one ton capacity to know its range of operating temperatures and feasibility for solar and air cooled applications.

**Working of Single-Effect Vapour Absorption System:** Figure.1, shows a vapour absorption refrigeration system. In this system, low temperature and low pressure water (refrigerant) enters the evaporator and vaporizes by producing useful refrigeration  $Q_e$ . From the evaporator water vapour enters the absorber where it comes in contact with a strong salt solution and becomes a weak solution. The heat of absorption ( $Q_a$ ) is rejected to the external heat sink at  $T_a$ . The weak solution is pumped to high pressure to the generator where generator heat ( $Q_g$ ) at high temperature  $T_g$  is supplied, as a result refrigerant vapour is generated at high pressure. This high pressure vapour is then condensed in the condenser by rejecting heat of condensation ( $Q_c$ ) to the external heat sink at  $T_c$ . The condensed refrigerant liquid water is then throttled in the expansion device and is then fed to the evaporator to complete the refrigerant cycle. On the solution side, the hot, high-pressure strong solution is throttled to the absorber pressure in the solution expansion valve and fed to the absorber where it comes in contact with the water vapour from evaporator. Heat rejection to the external heat sink takes place at absorber and condenser ( $T_c = T_a$ ). The heat exchanger allows the solution from the absorber to be preheated before entering the generator by using the heat from the hot solution leaving the generator. A small amount of mechanical energy is required to run the solution pump. If pressure drop is neglected, then the absorption system operates between the condenser and evaporator pressures. Pressure in absorber is same as that in evaporator and similarly pressure in generator and condenser is the same.



**Figure.1. Single effects vapour absorption refrigeration system considered for analysis**

#### Thermodynamic Analysis:

**Method of Performing Thermodynamic Analysis:** (Keith 1996): Figure.1, shows the schematic of the system indicating various state points. The analysis of the system is carried out with the following assumptions:

- Steady state and steady flow
- Changes in potential and kinetic energies across each component are negligible
- No pressure drops due to friction
- Only pure refrigerant boils in the generator in the condenser, the refrigerant condenses to a saturated liquid, while in the evaporator, the refrigerant evaporates to a saturated vapour.
- The solutions leaving the generator and absorber are at the same temperature and concentration as in the generator and absorber, and they are in thermodynamic equilibrium.
- Isenthalpic process is considered in the refrigerant expansion valve and solution expansion valve and pump work has been neglected.

**Importance of thermodynamic analysis** (Arshi Banu, 2015; Eisa, 1986): Thermodynamic Analysis/First Law Analysis is performed due to following reasons:

- To find the suitability of a refrigerant-absorbent combination for a specific application.
- Thermodynamic property data obtained from analysis can be used to find the parameter range of interest for particular application such as solar energy use.
- The correlations are obtained between the operating temperatures, together with the coefficients of performance and the flow ratios. This will help the process design engineer to choose the equipment and their size, especially for the economizer heat exchanger.
- For the same value of the coefficient of performance, the flow ratio will be different from one working pair to another. Correlations can be developed for any working pair for which the appropriate thermodynamic and thermo physical data are available.
- It will provide the information on influence on performance parameters such as maximum coefficients of performance, enthalpy based coefficients of performance, circulation ratio and efficiency ratio due to changes in of operating conditions (temperature).
- It will provide the information on possible combinations of temperatures and operational limits of temperatures for the system.
- It will be useful in comparison of the performance of various working fluids.

#### Step by Step procedure to perform thermodynamic analysis:

**Finding the solution concentrations(X) of weak and strong solutions:** Empirical equation of Duhring plot or p-T-X plots are used to find concentration(X) of H<sub>2</sub>O - LiBr + LiNO<sub>3</sub> + Lil + LiCl solution at solution temperature (T<sub>s</sub>) and refrigerant temperatures (T<sub>r</sub>).

$$T_s = \sum_{i=1}^3 (A_i T_r + B_i) X \quad (\text{Lee, 2000}) \quad (1)$$

#### Performing mass balance and finding the circulation ratio (CR):

$$\text{Refrigerant mass flow rate: } \dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}_4 = \dot{m}_r \quad (2)$$

$$\text{Weak solution flow rate: } \dot{m}_w = \dot{m}_5 = \dot{m}_6 = \dot{m}_7 \quad (3)$$

$$\text{Strong solution flow rate: } \dot{m}_s = \dot{m}_8 = \dot{m}_9 = \dot{m}_{10} \quad (4)$$

#### Total mass balance:

$$\dot{m}_r + \dot{m}_s = \dot{m}_w \quad (5)$$

**Circulation ratio ( $\lambda$ ):** The circulation ratio ( $\lambda$ ) can be defined as the ratio of weak solution flow rate to refrigerant flow rate. The circulation ratio is an essential design and optimization parameter.

$$\lambda = \frac{\dot{m}_w}{\dot{m}_r} \quad (6)$$

$$\dot{m}_w = \lambda \dot{m}_r \quad (7)$$

$$\dot{m}_s = (\lambda + 1) \dot{m}_r \quad (8)$$

#### Mass balance for LiBr solution:

$$(X_s) \dot{m}_s = (X_w) \dot{m}_w \quad (9)$$

$$\lambda = \frac{X_s}{X_s - X_w} \quad (10)$$

The circulation ratio can also be calculated using weak and strong solution concentrations.

#### Finding the state point enthalpies of pure refrigerant and solution:

**Enthalpies of refrigerant (water):** Water circuit (1-2-3-4) enthalpies are found from property equations of pure water.

**Enthalpies of solution:** Empirical equation of h-T-X diagram gives specific enthalpy values at different concentrations(X) and solution temperatures (T<sub>s</sub>) for H<sub>2</sub>O - LiBr + LiNO<sub>3</sub> + Lil + LiCl solutions.

$$h = \sum_{i=1}^4 (C_i + D_i T + E_i T^2) X \quad (\text{Lee, 2000}) \quad (11)$$

Solution circuit (5-6-7-8) enthalpies h<sub>5</sub>, h<sub>8</sub>, h<sub>9</sub>, h<sub>10</sub> can be found from the above equation in the analysis.

#### Performing the energy balance of each component:

$$\text{Condenser: } Q_c = \dot{m}_r (h_1 - h_2) \quad (12)$$

$$\text{Evaporator: } Q_e = \dot{m}_r (h_4 - h_3) \quad (13)$$

$$\text{Absorber: } Q_a = \dot{m}_r [(h_4 - h_{10}) + CR(h_{10} - h_5)] \quad (14)$$

$$\text{Solution Heat Exchanger: } Q_{EX} = (CR - 1)(h_8 - h_9) = CR(h_7 - h_6) \quad (15)$$

$$\text{Generator: } Q_g = \dot{m}_r [(h_1 - h_8) + CR(h_8 - h_7)] \quad (16)$$

Hence heat interactions Q<sub>g</sub>, Q<sub>e</sub>, Q<sub>c</sub>, Q<sub>a</sub> in each component are calculated.

#### Finding the performance parameters:

Coefficient of performance (COP):

$$COP = \frac{Q_e}{Q_g + W_p} \approx \frac{Q_e}{Q_g} \quad (17)$$

Enthalpy Based Coefficient of performance (COP):

$$\text{COP} = \frac{Q_e}{Q_g} = \frac{\dot{m}_r(h_4-h_3)}{\dot{m}_r[(h_1-h_8)+\text{CR}(h_8-h_7)]} \quad (18)$$

Maximum COP/ Carnot COP:

$$\text{COP}_{\text{max}} = \left( \frac{T_e}{T_c - T_e} \right) \left( \frac{T_g - T_c}{T_g} \right) \quad (19)$$

Efficiency ratio (or) Second law efficiency ( $\eta$ ):

$$\eta = \frac{\text{COP}}{\text{COP}_{\text{max}}} = \left( \frac{Q_e}{Q_g} \right) \left( \frac{T_g}{T_g - T_c} \right) \left( \frac{T_c - T_e}{T_e} \right) \quad (20)$$

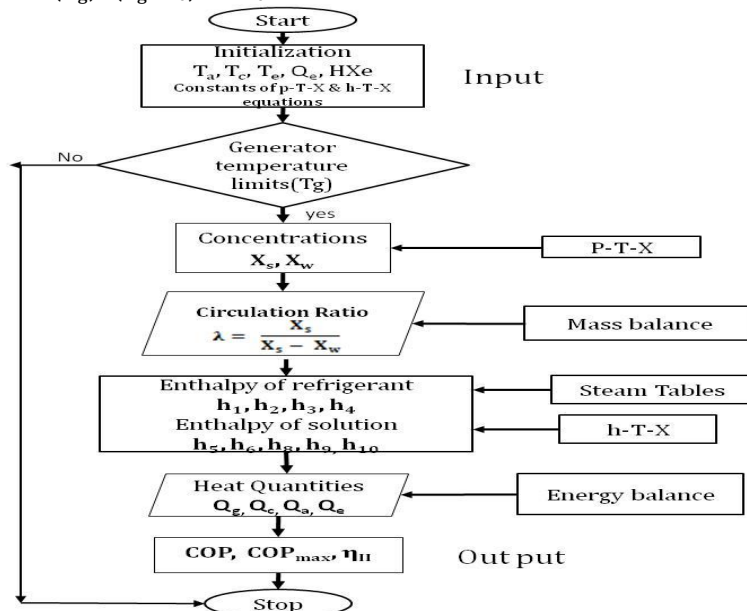


Figure.2. Flow chart used in programming the thermodynamic analysis

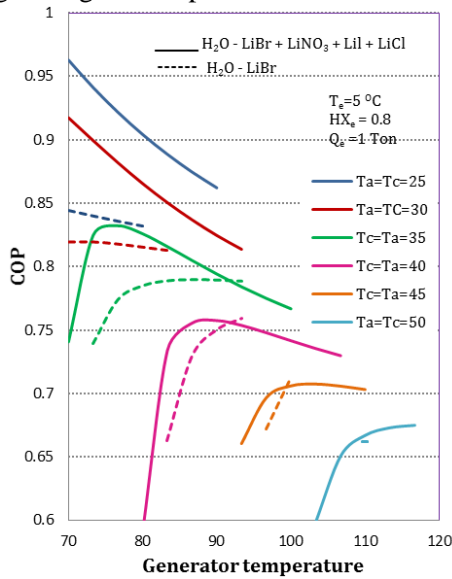
## 2. RESULTS AND DISCUSSIONS

Selection of an appropriate parameter and knowing its influence on performance is very important while performing thermodynamic analysis. Various parameters considered in analyzing single-effect vapour absorption cooling system and their importance are discussed as follows. The typical operational parameters such as generator, condenser, absorber and evaporator temperature and its influence on COP and circular ratio are considered in the thermodynamic analysis. Generator temperature range represents the intensity and amount of heat source required in vapour absorption cooling system, by which feasibility in solar thermal applications and choice of solar thermal collector can be determined. Condenser and absorber temperatures will decide whether the system is to be water cooled or air cooled to carry away rejected heat, which in turn represents the size and crystallization risk of the system. Evaporator temperature represents the cooling capacity of the equipment. The performance parameters considered for analysis are COP and circulation ratio, where the COP measures the overall efficiency and the flow ratio / circulation ratio is used to determine the size of the various heat transfer equipment of the vapour absorption system. Flow ratio also represents the solution heat exchanger load, heat losses and solution pump power requirements in vapour absorption cooling system (Arshi Banu, 2015; Eisa, 1986).

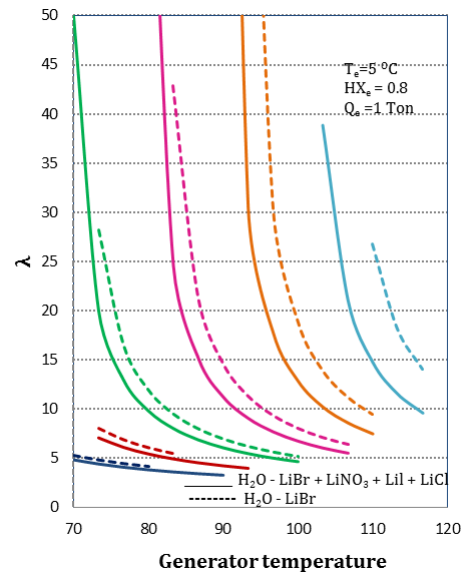
The detailed thermodynamic analysis is programmed using the flow chart shown in Figure 2 and results obtained are discussed using various performance pots to predict the behavior of the single-effect H<sub>2</sub>O - LiBr + LiNO<sub>3</sub> + Lil + LiCl vapour absorption refrigeration system as follows.

Figure.2, shows the variations of the coefficients of performance with generator temperature of H<sub>2</sub>O - LiBr + LiNO<sub>3</sub> + Lil + LiCl single-effect vapour absorption system. The absorber temperatures considered at T<sub>a</sub> = 25, 30, 35, 40, 45 and 50°C respectively. The condenser temperature (T<sub>c</sub>) was kept identical with the absorber temperature (T<sub>a</sub>). In the plotting the evaporator temperature (T<sub>e</sub>) and the heat exchanger effectiveness is considered as 5°C and 0.8 respectively for one ton capacity system. Entire pots have been compared with H<sub>2</sub>O-LiBr system. COP values decreases with increase in absorber/condenser temperatures in both the fluids. It is found that at all the absorber/condenser temperatures COP of H<sub>2</sub>O - LiBr + LiNO<sub>3</sub> + Lil + LiCl are much higher than the H<sub>2</sub>O - LiBr. Operating range of generator temperature is becoming narrow with increase in absorber/condenser temperatures due to the limitation by crystallization in both the fluids. But alternate fluid range is higher compared to H<sub>2</sub>O - LiBr. Figure3 shows the variations of the circulation ratio ( $\lambda$ ) with generator temperature with the same working conditions. Circulation ratio values increases with increase in absorber/condenser temperatures in both the fluids. The rate of decrease in flow ratio is much higher at higher absorber temperatures. But it is found that at all the absorber/condenser

temperatures circulation ratio of  $\text{H}_2\text{O} - \text{LiBr} + \text{LiNO}_3 + \text{LiI} + \text{LiCl}$  is lower compared to  $\text{H}_2\text{O} - \text{LiBr}$ . But alternate fluid range is higher compared to  $\text{H}_2\text{O} - \text{LiBr}$  in terms of circulation ratio also.

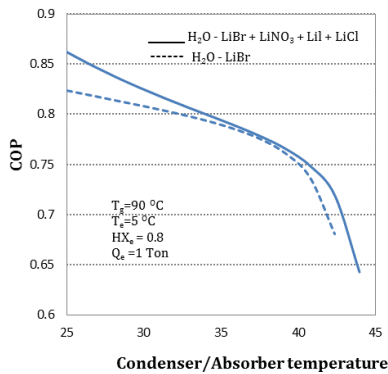


**Figure.3. Variation of COP with the generator temperature**

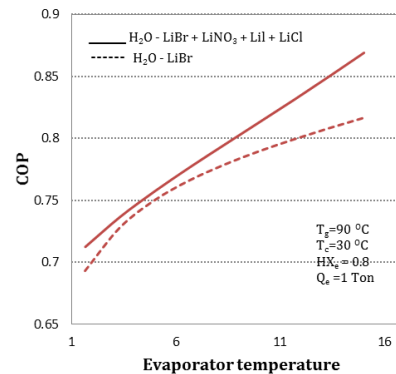


**Figure.4. Variation of COP with the Circulation ratio (CR)**

Figure.4, shows the variations of the coefficients of performance with Condenser temperature ( $T_c$ ) for  $\text{H}_2\text{O} - \text{LiBr} + \text{LiNO}_3 + \text{LiI} + \text{LiCl}$  single-effect vapour absorption system. The condenser temperature ( $T_c$ ) was kept identical with the absorber temperature ( $T_a$ ). In the plotting the evaporator temperature ( $T_e$ ), the generator temperature ( $T_g$ ) and the heat exchanger effectiveness is considered as  $5^\circ\text{C}$ ,  $90^\circ\text{C}$  and  $0.8$  respectively for one ton capacity system. The plots have been compared with  $\text{H}_2\text{O}-\text{LiBr}$  system. COP values decreases with increase in absorber/condenser temperatures in both the fluids. It is found that COP of  $\text{H}_2\text{O} - \text{LiBr} + \text{LiNO}_3 + \text{LiI} + \text{LiCl}$  is much higher than the  $\text{H}_2\text{O}-\text{LiBr}$ . Operating range of absorber/condenser temperatures is higher compared to  $\text{H}_2\text{O} - \text{LiBr}$ . It has appropriate COP, and low risk of crystallization at high absorber temperature. Hence the alternate fluid pair can be used in air cooled applications.



**Figure.5. Variation of COP with the condenser temperature**

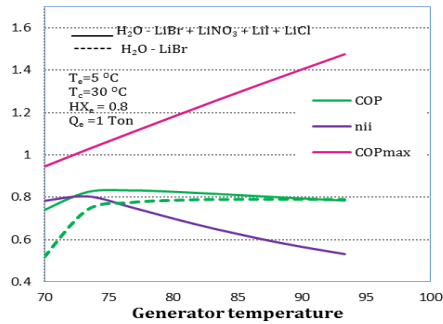


**Figure.6. Variation of COP with the evaporator temperature**

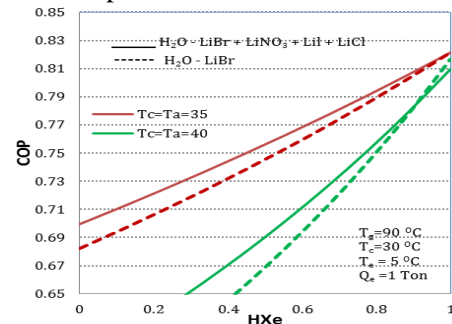
Figure.6, shows the variations of the coefficients of performance with evaporator temperature ( $T_e$ ) for single-effect  $\text{H}_2\text{O}-(\text{LiBr} + \text{LiNO}_3 + \text{LiI} + \text{LiCl})$  vapour absorption system. In the plotting the absorber/condenser temperatures was fixed at  $35^\circ\text{C}$  and the generator temperature ( $T_g$ ) and heat exchanger effectiveness is considered as  $90^\circ\text{C}$  and  $0.8$  respectively for one ton capacity system. The plots have been compared with  $\text{H}_2\text{O}-\text{LiBr}$  system. COP values increases with increase in evaporator temperature in both the fluids. It is found that COP of  $\text{H}_2\text{O} - \text{LiBr} + \text{LiNO}_3 + \text{LiI} + \text{LiCl}$  is higher than the  $\text{H}_2\text{O} - \text{LiBr}$ . Operating range of absorber/condenser temperatures is higher compared to  $\text{H}_2\text{O} + \text{LiBr}$ . It has appropriate COP, and higher cooling effect above  $5^\circ\text{C}$  of evaporator temperature.

The influences of operating temperature  $T_g$  on maximum coefficients of performance ( $\text{COP}_{\text{max}}$ ), enthalpy based coefficients of performance (COP) and efficiency ratio ( $\eta_{\text{th}}$ ) for  $\text{H}_2\text{O} - \text{LiBr} + \text{LiNO}_3 + \text{LiI} + \text{LiCl}$  single-effect vapour absorption system are given in Figure.7. For the simulation 1ton capacity system is considered. In these calculations,  $T_e = 5^\circ\text{C}$ ,  $T_c = T_a = 35^\circ\text{C}$  and  $\text{HXe} = 0.8$  were assumed. The  $\text{COP}_{\text{max}}$  and COP value increases with generator temperature ( $T_g$ ). As it is seen from the equation (19),  $\text{COP}_{\text{max}}$  directly depends on  $T_e$ ,  $T_g$  temperatures. Hence,  $\text{COP}_{\text{max}}$  value is same for all fluid pairs irrespective of their thermo physical properties. Since the increase in  $\text{COP}_{\text{max}}$  is faster than that in COP, the  $\eta$  value gradually decreases after reaching maximum value at  $76.7^\circ\text{C}$  on

increasing  $T_g$ . It is seen from Figure.8. COP value gradually increases from  $HX_e = 0$  to the best case condition  $HX_e = 1$  where strong solution outlet temperature equals weak solution inlet temperature.



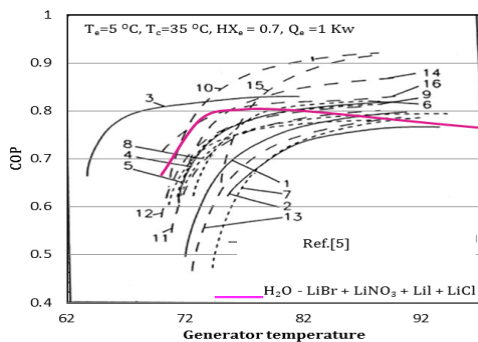
**Figure.7. Variation of performance parameters with the generator temperature**



**Figure.8. Variation of COP with the effectiveness of SHX**

**Validation:** In order to know the COP based compatibility of the single-effect  $H_2O - (LiBr + LiNO_3 + LiI + LiCl)$  vapour absorption system, the results of present working fluid system were compared with the comparative work performed (Saravanan, 1998) with sixteen different working fluid single-effect vapour absorption systems of one kilowatt capacity. The influence of generator temperature on COP has been compared in the plots as shown in Figure 9. In the plots the evaporator temperature  $T_e$ , condenser temperature  $T_c$ , absorber temperature  $T_a$  and solution heat exchanger effectiveness were fixed at  $5^\circ C$ ,  $35^\circ C$ , and  $0.7$  respectively. Under these operating conditions, COP of the present fluid combination is better than the eleven working fluids among the sixteen working fluids.

To find the temperature range based compatibility of  $H_2O - LiBr + LiNO_3 + LiI + LiCl$  single-effect vapour absorption system, the results of present system also compared with seven working fluids of single-effect vapour absorption systems (Iyoki, 1990). The plots with generator temperature versus COP are shown in Figure.10. The evaporator temperature  $T_e$  and condenser/absorber temperature  $T_c$  were fixed at  $8^\circ C$  and  $30^\circ C$ , respectively without solution heat exchanger. Under these operating conditions, the COP of this system is better than the other working fluids and operating range also compatible with the other fluids.



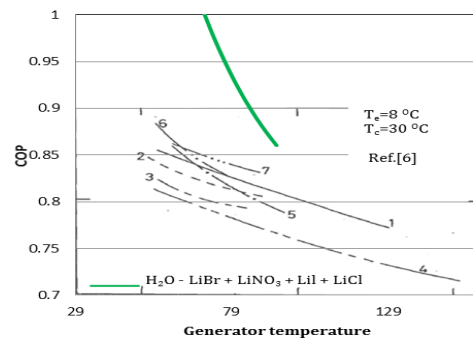
**Figure.9. Variation of coefficient of performance with generator temperature for fifteen different working fluid combinations in single effect systems.**

- (1)  $H_2O-NaOH$  (2)  $H_2O-LiI$  (3)  $H_2O-LiCl$  (4)  $H_2O-LiBr$ , (5)  $H_2O-LiCl+LiNO_3$  (6)  $H_2O-LiBr+LiI$  (7)  $H_2O-LiBr+ZnBr_2$  (8)  $H_2O-LiBr+LiNO_3$  (9)  $H_2O-LiBr+LiScN$  (10)  $H_2O-LiBr+LiCl+ZnCl_2$  (11)  $H_2O-LiBr+ZnCl_2+CaBr_2$  (12)  $H_2O-LiBr+ZnBr_2+LiCl$  (13)  $H_2O-LiBr+LiI+C_2H_6O_2$  (14)  $H_2O-NaOH+KOH+CsOH$  (15)  $H_2O-LiNO_3+KNO_3+NaNO_3$  (16)  $H_2O-LiCl+CaCl_2+Zn(NO_3)_2$ .

### 3. CONCLUSIONS

- Detailed thermodynamic analysis is performed for  $H_2O-LiBr+LiI+LiNO_3+LiCl$  vapour absorption refrigeration system of one ton capacity.
- Possible combinations and operational limits of temperatures for the  $H_2O-LiBr+LiI+LiNO_3+LiCl$  system have been identified as

$$\begin{aligned} 2^\circ C < T_e < 15^\circ C \\ 26^\circ C < T_a < 60^\circ C \\ 26^\circ C < T_c < 60^\circ C \\ 70^\circ C < T_g < 120^\circ C \end{aligned}$$



**Figure.10. Comparison of seven working fluid system for single-effect absorption refrigerating machine.**

- (1)  $H_2O-LiBr+ZnCl_2+CaBr_2$  (2)  $H_2O-LiBr$  (3)  $H_2O-CaCl_2+LiCl+ZnCl_2$  (4)  $H_2O-LiBr+ZnCl_2$  (5)  $H_2O-LiBr+LiSCN$  (6)  $H_2O-LiBr+LiCl$  (7)  $H_2O-LiBr-C_2H_6O_2$ .

- The correlation between the generator temperatures with performance parameters help to define the suitability of vapour absorption system for solar applications and also useful to choose the suitable solar collector.
- The correlation between the generator temperatures with performance parameters at various condenser and absorber temperatures help to define the suitability of vapour absorption system for air cooled applications without crystallization problem.
- The correlation between the generator temperatures with the coefficients of performance and the flow ratio presented in this work will help in the choice of equipment and their sizing, especially for the solution heat exchanger.
- This analysis is compared with standard fluid pair H<sub>2</sub>O-LiBr and it is found that COP and operating ranges are higher for the fluid pair at all possible working conditions than H<sub>2</sub>O-LiBr.

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