Vapour Absorption Refrigeration Systems Based On Water-Lithium Bromide Pair

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The objectives of this lesson are to:

1. Introduce vapour absorption refrigeration systems based on water-lithium bromide.

2. Discuss properties of water-lithium bromide solution and describe pressure temperature- concentration (p-T- ξ) and enthalpy-temperature-concentration (h-T- ξ) charts.

3. Present steady-flow analysis of a single stage, water-lithium bromide system.

4. Discuss practical problems in actual water-lithium bromide systems.

5. Describe commercial water-lithium bromide systems.

6. Discuss heat sources for water-lithium bromide systems.

7. Discuss typical application data for water-lithium bromide systems.

8. Discuss briefly the methods of capacity control in water-lithium bromide systems.

1.1. Introduction

Vapour absorption refrigeration systems utilizing water-lithium bromide pair are broadly utilized as a part of substantial limit aerating and cooling systems. In these systems water is utilized as refrigerant and an answer of lithium bromide in water is utilized as permeable. Since water is utilized as refrigerant, utilizing these systems it is impractical to give refrigeration at below zero temperatures. Subsequently it is utilized just as a part of applications obliging refrigeration at temperatures over 0 °C. Hence these systems are utilized for aerating and cooling applications. The investigation of this system is moderately simple as the vapour produced in the generator is very nearly immaculate refrigerant (water), dissimilar to ammonia water systems where both smelling salts and water vapour are created in the generator.

1.2. Properties of water-lithium bromide solutions 1.2.1. Composition:

The composition of water-lithium bromide solutions can be expressed either in mass fraction (ξ) or mole fraction (x). For water-lithium bromide solutions, the mass fraction ξ is defined as the ratio of mass of anhydrous lithium bromide to the total mass of solution, i.e.,

$$\xi = \frac{m_L}{m_L + m_W}$$

where m_L and m_W are the mass of anhydrous lithium bromide and water in solution, respectively.

The composition can also be expressed in terms of mole fraction of lithium bromide as:

$$x = \frac{n_L}{n_L + n_W}$$

where n_L and n_W are the number of moles of anhydrous lithium bromide and water in solution, respectively. The number moles of lithium bromide and water can easily be obtained from their respective masses in solution and molecular pressures, thus;

$$n_L = \frac{m_L}{M_L}$$
; and $n_W = \frac{m_W}{M_W}$

where ML (= 86.8 kg/kmol) and MW (= 18.0 kg/kmol) are the molecular pressures of anhydrous lithium bromide and water respectively.

1.2.2. Vapour pressure of water-lithium bromide solutions

Applying Raoult's law, the vapour pressure of water-lithium bromide solution with the vapour pressure exerted by lithium bromide being negligibly small is given by:

$$P = (1 - x) P_W$$

where P_W is the immersion pressure of unadulterated water at the same temperature as that of the arrangement and x is the mole part of lithium bromide in arrangement. It is observed that Raoult's law is just give or take right for exceptionally dilute solutions of water lithium bromide (i.e., as $x \rightarrow 0$). Solid aqueous solutions of water-lithium bromide are found to go astray unequivocally from Raoult's law in a negative way. Case in point, at 50 percent mass fraction of lithium bromide and 25°C, Raoult's law predicts a vapour pressure of 26.2 mbar, though real estimations demonstrate that it is just 8.5 mbar. The degree of real vapour pressure to that anticipated by Raoult's law is known as movement coefficient.

For the above case, the action coefficient is 0.324. The vapour pressure information of water-lithium bromide solutions can be helpfully spoken to in a Dühring plot. In a Dühring plot, the temperature of the arrangement is plotted as abscissa on a direct scale, the immersion temperature of unadulterated water is

plotted as ordinate on the right hand side (straight scale) and the pressure on a logarithmic scale is plotted as ordinate on the left hand side. The plot shows the pressure temperature values for different steady focus lines (isosters), which are straight on Dühring plot. Figures 1.1 shows the Dühring plot. The Dühring plot can be utilized for discovering the vapour pressure information furthermore for plotting the working cycle. Figure 1.2 shows the water-lithium bromide built absorption refrigeration system with respect to Dühring plot.

Different sorts of charts indicating vapour pressure information for water-lithium bromide systems are likewise accessible in writing. Figure 1.3 shows another outline wherein the mass portion of lithium bromide is plotted on abscissa, while immersion temperature of immaculate water and vapour pressure are plotted as ordinates. Likewise indicated are lines of steady arrangement temperature on the outline. Pressure - temperature composition information is additionally accessible as exact equation.





Fig 1.2 H2O-LiBr system with a solution heat exchanger on Dühring plot



Lithium bromide in solution, % by mass

1.2.3. Enthalpy of water-lithium bromide solutions

Since strong water-lithium bromide solution deviates from ideal solution behaviour, it is observed that when water and anhydrous lithium bromide at same temperature are mixed adiabatically, the temperature of the solution increases considerably. This indicates that the mixing is an exothermic process with a negative heat of mixing. Hence the specific enthalpy of the solution is given by:

 $h = \xi .h L + (1 - \xi) h_W + \Delta h mix$

where hL and hW are the specific enthalpies of pure lithium bromide and water, respectively at the same temperature. Figure 1.4 shows a chart giving the specific enthalpy-temperature-mass fraction data for water-lithium bromide solutions. The chart is drawn by taking reference enthalpy of 0 kJ/kg for liquid water at 0 °C and solid anhydrous lithium bromide salt at 25 °C.





1.2.4. Enthalpy values for pure water (liquid and superheated vapour)

The enthalpy of pure water vapour and liquid at different temperatures and pressures can be obtained from pure water property data. For all practical purposes, liquid water enthalpy, hW,liquid at any temperature T can be obtained from the equation:

hW,liquid = 4.19 (T - Tref) kJ / kg

where Tref is the reference temperature, 0 °C

The water vapour generated in the generator of water-lithium bromide system is in super heated condition as the generator temperature is much higher than the saturation water temperature at that pressure. The enthalpy of superheated water vapour, hW,sup at low pressures and temperature T can be obtained approximately by the equation:

$$hW$$
,sup = 2501+1.88 (T - Tref)

1.2.5. Crystallization

The pressure-temperature-mass part and enthalpy-temperature-mass portion charts (Figs. 1.3 and 1.4) show lines stamped as crystallization in the lower right segment. The area to one side and below these crystallization lines indicates solidification of LiBr salt. In the crystallization area a two-phase mixture (slush) of water-lithium bromide arrangement and crystals of immaculate LiBr exist in harmony. The water-lithium bromide system ought to work far from the crystallization district as the arrangement of solid crystals can hinder the funnels and valves. Crystallization can happen when the hot arrangement rich in LiBr salt is cooled in the arrangement heat exchanger to low temperatures.

To maintain a strategic distance from this condenser pressure lessening below a certain worth because of say, low cooling water temperature in the condenser ought to be evaded. Thus in business systems, the condenser pressure is falsely looked after high despite the fact that the temperature of the accessible warmth sink is low. This really decreases the execution of the system, yet is vital for fitting operation of the system. It ought to be noted from the property charts that the whole water-lithium bromide system works under vacuum.

1.3. Steady flow analysis of Water-Lithium Bromide Systems

Figure 1.5 shows the schematic of the system indicating various state points. A steady flow analysis of the system is carried out with the following assumptions:

i. Steady state and steady flow.

ii. Changes in potential and kinetic energies across each component are negligible.

iii. No pressure drops due to friction.

iv. Only pure refrigerant boils in the generator.

The nomenclature followed is:

.m = mass flow rate of refrigerant, kg/s

.m ss = mass flow rate of strong solution (rich in LiBr), kg/s

.m ws = mass flow rate of weak solution (weak in LiBr), kg/s





A: Absorber; C: Condenser; E: Evaporator; G: Generator; P: Solution Pump SHX: Solution HX; ER: Refrigerant Expansion valve ES: Solution Expansion valve

The circulation ratio (λ) is defined as the ratio of strong solution flow rate to refrigerant flow rate. It is given by:

$$\lambda = \frac{m_{ss}}{m}$$

this implies that the strong solution flow rate is given by:

 $m_{ss} = \lambda m$

The analysis is carried out by applying mass and energy balance across each component.

Condenser:

$$m_1 = m_2 = m$$

$$Q_c = m(h_1 - h_2)$$

$$P_c = P_{sat}(T_c)$$

where $T_{\mbox{\scriptsize c}}$ is the condenser temperature

Expansion valve (refrigerant):

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m_{2} = m_{3} = m
h_{2} = h_{3}
<u>Evaporator</u>:
m_{3} = m_{4} = m
Q_{e} = m(h_{4} - h_{3})
P_{e} = P_{sat}(T_{e})
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where Te is the evaporator temperature

Absorber:

From total mass balance:

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m + m_{ss} = m_{ws}
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m_{ss} = \lambda m \implies m_{ws} = (1 + \lambda) m
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From mass balance for pure water:

 $m + (1 - \xi_{ss})m_{ss} = (1 - \xi_{ws})m_{ws}$ $\Rightarrow \lambda = \frac{\xi_{ws}}{\xi_{ss} - \xi_{ws}}$ $Q_a = mh_4 + \lambda mh_{10} - (1 + \lambda)mh_5$ or, $Q_a = m[(h_4 - h_5) + \lambda(h_{10} - h_5)]$

The first term in the above equation m(h4 - h5) represents the enthalpy change of water as changes its state from vapour at state 4 to liquid at state 5. The second term m(h10 - h5) represents the sensible heat transferred as solution at state 10 is cooled to solution at state 5.



Solution pump:

 $m_5 = m_6 = m_{ws}$ $W_p = m_{ws} (h_6 - h_5) = (1 + \lambda) m(h_6 - h_5)$

however, if we assume the solution to be incompressible, then:

 $W_P = (1 + \lambda) m v_{sol} (P_6 - P_5) = (1 + \lambda) m v_{sol} (P_c - P_e)$

where vsol is the specific volume of the solution which can be taken to be approximately equal to 0.00055 m3/kg. Even though the solution pump work is small it is still required in the selection of suitable pump.

Solution heat exchanger:

 $m_6 = m_7 = m_{ws}$ $m_8 = m_9 = m_{ss}$

heat transfer rate in the solution heat exchanger, Q_{HX} is given by:

 $Q_{HX} = (1+\lambda)m(h_7 - h_6) = \lambda m(h_8 - h_9)$

Generator:

 $m_7 = m_8 + m_1$

Heat input to the generator is given by:

 $Q_{g} = m h_{1} + \lambda m h_{8} - (1 + \lambda) m h_{7}$ or, $Q_{g} = m [(h_{1} - h_{7}) + \lambda (h_{8} - h_{7})]$

in the above equation the 1st term on the RHS m(h1 - h7) represents energy required to generate water vapour at state 1 from solution at state 7 and the 2^{nd} term m (h8- h7) represents the sensible heat required to heat the solution from state 7 to state 8.

Solution expansion vave: $m_9 = m_{10} = m_{ws}$ $h_9 = h_{10}$ The COP of the system is given by: $COP = \frac{Q_e}{Q_g + W_P} \approx \frac{Q_e}{Q_g}$

The second law (exergetic) efficiency of the system η_{II} is given by:

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

In order to find the steady-state performance of the system from the above set of equations, one needs to know the operating temperatures, weak and strong solution concentrations, effectiveness of solution heat exchanger and the refrigeration capacity. It is generally assumed that the solution at the exit of absorber and generator is at equilibrium so that the equilibrium P-T- ξ and h-T- ξ charts can be used for evaluating solution property data. The effectiveness of solution heat exchanger, ε HX is given by:

$$\epsilon_{\rm HX} = \frac{({\rm T_7} - {\rm T_6}\,)}{({\rm T_8} - {\rm T_6}\,)}$$

From the above equation the temperature of the weak solution entering the generator (T7) can be obtained since T6 is almost equal to T5 and T8 is equal to the generator temperature Tg. The temperature of superheated water vapour at state 1 may be assumed to be equal to the strong solution temperature T8.

1.4. Practical problems in water-lithium bromide systems

Practical problems typical to water-lithium bromide systems are:

- 1. Crystallization
- 2. Air leakage, and
- 3. Pressure drops

As mentioned before to prevent crystallization the condenser pressure has to be maintained at certain level, irrespective of cooling water temperature. This can be done by regulating the flow rate of cooling water to the condenser. Additives are also added in practical systems to inhibit crystallization. Since the entire system operates under vacuum, outside air leaks into the system. Hence an air purging system is used in practical systems. Normally a two-stage ejector type purging system is used to remove air from the system. Since the operating pressures are very small and specific volume of vapour is very high, pressure drops due to friction should be minimized. This is done by using twin- and single-drum arrangements in commercial systems.

1.5. Commercial systems

Commercial water-lithium bromide systems can be:

- 1. Single stage or single-effect systems, and
- 2. Multi stage or multi-effect systems

Single stage systems operate under two pressures – one corresponding to the condenser-generator (high pressure side) and the other corresponding to evaporator absorber.

Single stage systems can be either:

- 1. Twin drum type, or
- 2. Single drum type

Since evaporator and absorber operate at the same pressure they can be housed in a single vessel, similarly generator and condenser can be placed in another vessel as these two components operate under a single pressure. Thus a twin drum system consists of two vessels operating at high and low pressures. Figure 1.6 shows a commercial, single stage, twin drum system.



Fig.1.6: A commercial, twin-drum type, water-lithium bromide system

As indicated in the figure, the cooling water (which goes about as heat sink) flows first to absorber, concentrates heat from absorber and after that flows to the condenser for condenser heat extraction. This is known as arrangement course of action. This game plan is worthwhile as the obliged cooling water flow rate will be little furthermore by sending the cooling water first to the absorber, the condenser can be operated at a higher pressure to anticipate crystallization. It is likewise conceivable to have cooling water flowing parallels to condenser and absorber; on the other hand, the cooling water necessity for this situation will be high.

A refrigerant pump circulates fluid water in evaporator and the water is spread onto evaporator tubes for good heat and mass exchange. Heater tubes (steam or high temp water or hot oil) are inundated in the solid arrangement pool of generator for vapour generation. Pressure drops in the middle of evaporator and absorber and in the middle of generator and condenser are minimized, huge measured vapour lines are eliminated and air spillages can likewise be decreased because of less number of joints. Figure 15.7 shows a solitary stage arrangement of single drum sort in which all the four segments are housed in the same vessel. The vessel is separated into high and low pressure sides by utilizing a diaphragm.





In multi-effect systems a progression of generators operating at continuously decreasing pressures are utilized. Heat is supplied to the highest stage generator operating at the highest pressure. The enthalpy of the steam generated from this generator is utilized to generate some more refrigerant vapour in the lower stage generator et cetera. In this way the heat info to the system is utilized effectively by generating more refrigerant vapour prompting higher COPs. Notwithstanding, these systems are more mind boggling in development and oblige a much higher heat source temperatures in the highest stage generator. Figures 1.8 and 1.9 show business double-effect systems. Figure 1.10 shows the double effect cycle on Dühring plot.



Fig.1.8: A commercial, double-effect, water-lithium bromide system



Fig.1.9: A commercial, double-effect, water-lithium bromide system



Fig.1.10: Double affect VARS on Dühring plot

1.6. Heat sources for water-lithium bromide systems

Water-lithium bromide systems can be driven utilizing a wide mixed bag of heat sources. Substantial limit systems are generally determined by steam or boiling hot water. Little limit systems are generally determined straightforwardly by oil or gas. A common single effect system obliges a heat source at a temperature of around 120oC to create chilled water at 7oC when the condenser operates at around 46oC and the absorber operates at around 40oC. The COPs acquired aor in the scope of 0.6 to 0.8 for single effect systems while it can be as high as 1.2 to 1.4 for multi-effect systems.

1.7. Minimum heat source temperatures for LiBr-Water systems

Application data for a single-stage water-lithium bromide vapour absorption system with an output chilled water temperature of $6.7 \,^{\circ}\text{C}$ (for air conditioning applications) is shown in Table 1.1.

Cooling water temperature (inlet to absorber & condenser)	Minimum Heat source temperature (Inlet to generator)	СОР
23.9°C	65°C	0.75
26.7°C	75 °C	0.74
29.4°C	85 °C	0.72
32.2°C	95 °C	0.71

Table 1.1. Application data for a single-stage water-lithium bromide system

The above values are simulated values, which were validated on actual commercial systems with very efficient heat and mass transfer design. If the heat and mass transfer is not very efficient, then the actual required heat source temperatures will be higher than the reported values. For given cooling water

temperature, if the heat source temperature drops below the minimum temperature given above, then the COP drops significantly. For a given cooling water temperature, if the heat source temperature drops below a certain temperature (minimum generation temperature), then the system will not function.

Minimum generation temperature is typically 10 to 15oC lower than the minimum heat source temperature. If air cooled condensers and absorbers are used, then the required minimum heat source temperatures will be much higher (\approx 150oC). The COP of the system can be increased significantly by multi effect (or multi-stage) systems. However, addition of each stage increases the required heat source temperature by approximately 50oC.

1.8 Capacity control

Capacity control means capacity reduction depending upon load as the capacity will be Limit control implies limit lessening relying on burden as the limit will be greatest with no control. Regularly under both full and additionally part stacks the outlet temperature of chilled water is kept up at a close steady esteem. The refrigeration limit is then regulated by either:

1. Regulating the flow rate of feeble arrangement pumped to the generator through the arrangement pump

2. Decreasing the generator temperature by throttling the supply steam, or by diminishing the flow rate of heated water

3. Expanding the condenser temperature by bypassing a percentage of the cooling water supplied to the condenser

System 1 does not influence the COP altogether as the obliged heat data lessens with diminishment in powerless arrangement flow rate, notwithstanding, since this may prompt the issue of crystallization, numerous a period a combination of the over three techniques are utilized as a part of business systems to control the capacity