

Lesson

15

Vapour Absorption Refrigeration Systems Based On Water- Lithium Bromide Pair

The objectives of this lesson are to:

1. Introduce vapour absorption refrigeration systems based on water-lithium bromide (*Section 15.1*)
2. Discuss properties of water-lithium bromide solution and describe pressure-temperature-concentration (p-T- ξ) and enthalpy-temperature-concentration (h-T- ξ) charts (*Section 15.2*)
3. Present steady-flow analysis of a single stage, water-lithium bromide system (*Section 15.3*)
4. Discuss practical problems in actual water-lithium bromide systems (*Section 15.4*)
5. Describe commercial water-lithium bromide systems (*Section 15.5*)
6. Discuss heat sources for water-lithium bromide systems (*Section 15.6*)
7. Discuss typical application data for water-lithium bromide systems (*Section 15.7*)
8. Discuss briefly the methods of capacity control in water-lithium bromide systems (*Section 15.8*)

At the end of the lecture, the student should be able to:

1. Draw the schematic of the water-lithium bromide system and explain its working principle
2. Evaluate the properties of water-lithium bromide solution using p-T- ξ and h-T- ξ charts
3. Evaluate the steady-state performance of a single stage water-lithium bromide system using the input data and fluid properties
4. Describe commercial water-lithium bromide systems and list practical problems in these systems
5. List typical operating temperatures and performance aspects of water-lithium bromide systems
6. Compare various capacity control methods in water-lithium bromide systems

15.1. Introduction

Vapour absorption refrigeration systems using water-lithium bromide pair are extensively used in large capacity air conditioning systems. In these systems water is used as refrigerant and a solution of lithium bromide in water is used as absorbent. Since water is used as refrigerant, using these systems it is not possible to provide refrigeration at sub-zero temperatures. Hence it is used only in applications requiring refrigeration at temperatures above 0°C. Hence these systems are used for air conditioning applications. The analysis of this system is relatively easy as the vapour generated in the generator is almost pure refrigerant (water), unlike ammonia-water systems where both ammonia and water vapour are generated in the generator.

15.2. Properties of water-lithium bromide solutions

15.2.1. 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.,

$$\xi = \frac{m_L}{m_L + m_W} \quad (15.1)$$

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:

$$x = \frac{n_L}{n_L + n_W} \quad (15.2)$$

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 weights, thus;

$$n_L = \frac{m_L}{M_L}; \text{ and } n_W = \frac{m_W}{M_W} \quad (15.3)$$

where M_L (= 86.8 kg/kmol) and M_W (= 18.0 kg/kmol) are the molecular weights of anhydrous lithium bromide and water respectively.

15.2.2. 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:

$$P = (1 - x)P_W \quad (15.4)$$

where P_W is the saturation pressure of pure water at the same temperature as that of the solution and x is the mole fraction of lithium bromide in solution. It is observed that Raoult's law is only approximately correct for very dilute solutions of water lithium bromide (i.e., as $x \rightarrow 0$). Strong aqueous solutions of water-lithium bromide are found to deviate strongly from Raoult's law in a negative manner.

For example, at 50 percent mass fraction of lithium bromide and 25°C, Raoult's law predicts a vapour pressure of 26.2 mbar, whereas actual measurements show that it is only 8.5 mbar.

The ratio of actual vapour pressure to that predicted by Raoult's law is known as **activity coefficient**. For the above example, the activity coefficient is 0.324.

The vapour pressure data of water-lithium bromide solutions can be very conveniently represented in a Dühring plot. In a Dühring plot, the temperature of the solution is plotted as abscissa on a linear scale, the saturation temperature of pure water is plotted as ordinate on the right hand side (linear 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 various constant concentration lines (isosters), which are linear on Dühring plot. Figures 15.1 shows the Dühring plot. The Dühring plot can be used for finding the vapour pressure data and also for plotting the operating cycle. Figure 15.2 shows the water-lithium bromide based absorption refrigeration system on Dühring plot. Other types of charts showing vapour pressure data for water-lithium bromide systems are also available in literature. Figure 15.3 shows another chart wherein the mass fraction of lithium bromide is plotted on abscissa, while saturation temperature of pure water and vapour pressure are plotted as ordinates. Also shown are lines of constant solution temperature on the chart. Pressure-temperature-composition data are also available in the form of empirical equations.

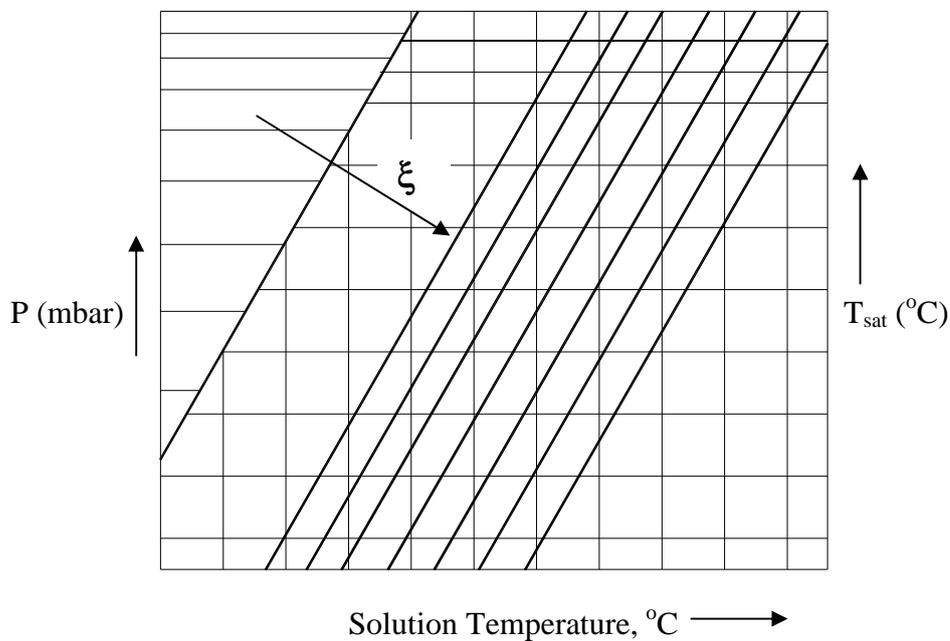


Fig.15.1.: A typical Dühring plot

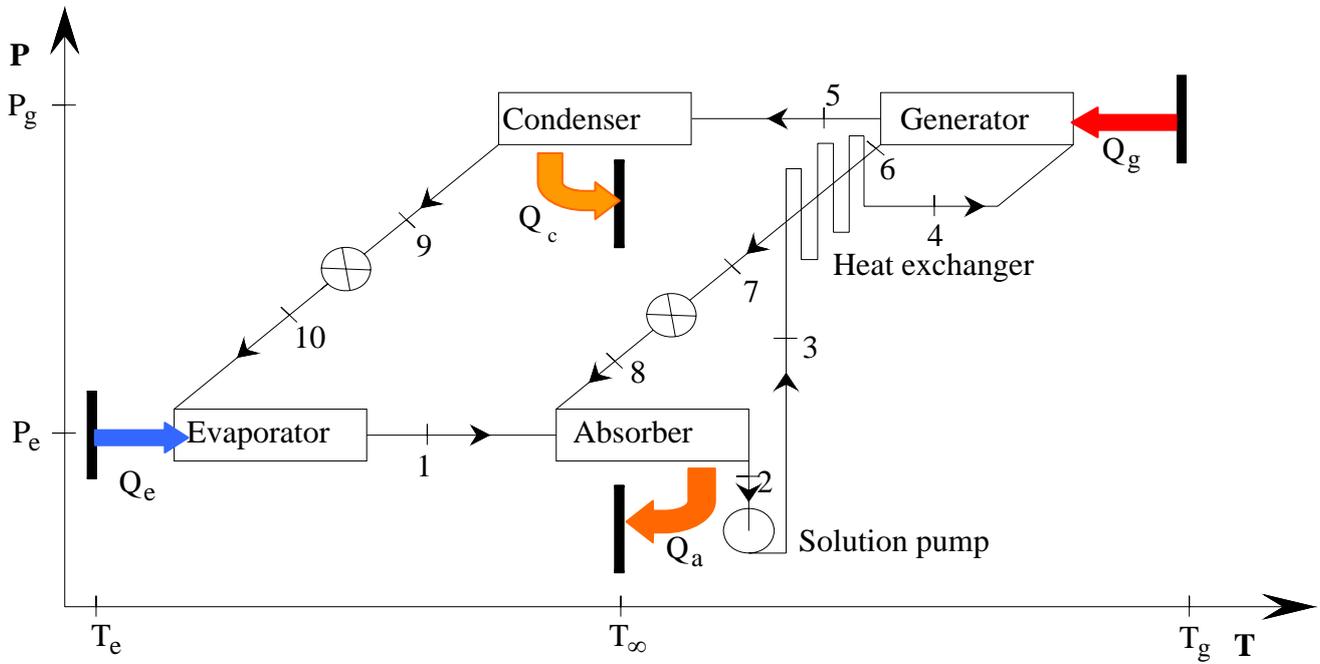


Fig.15.2: H₂O-LiBr system with a solution heat exchanger on Dühring plot

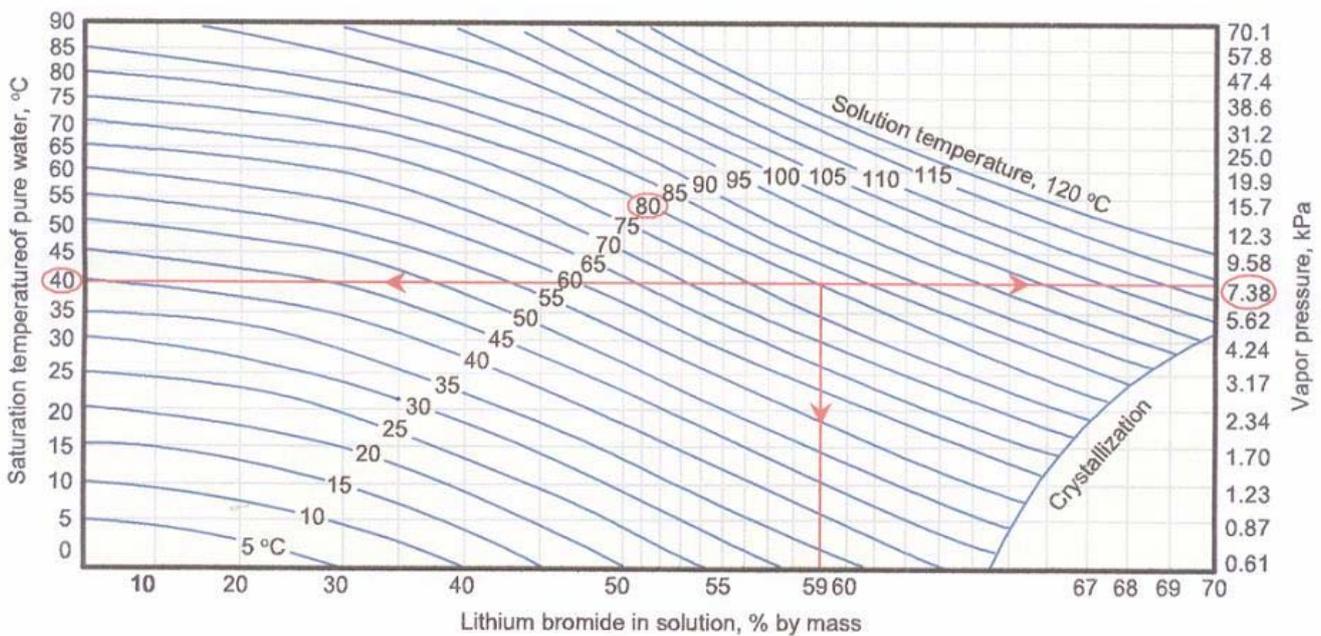


Fig.15.3: Pressure-Temperature-Concentration diagram for H₂O-LiBr solution

15.2.3. 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:

$$h = \xi h_L + (1 - \xi) h_W + \Delta h_{\text{mix}} \quad (15.5)$$

where h_L and h_W are the specific enthalpies of pure lithium bromide and water, respectively at the same temperature. Figure 15.4 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.

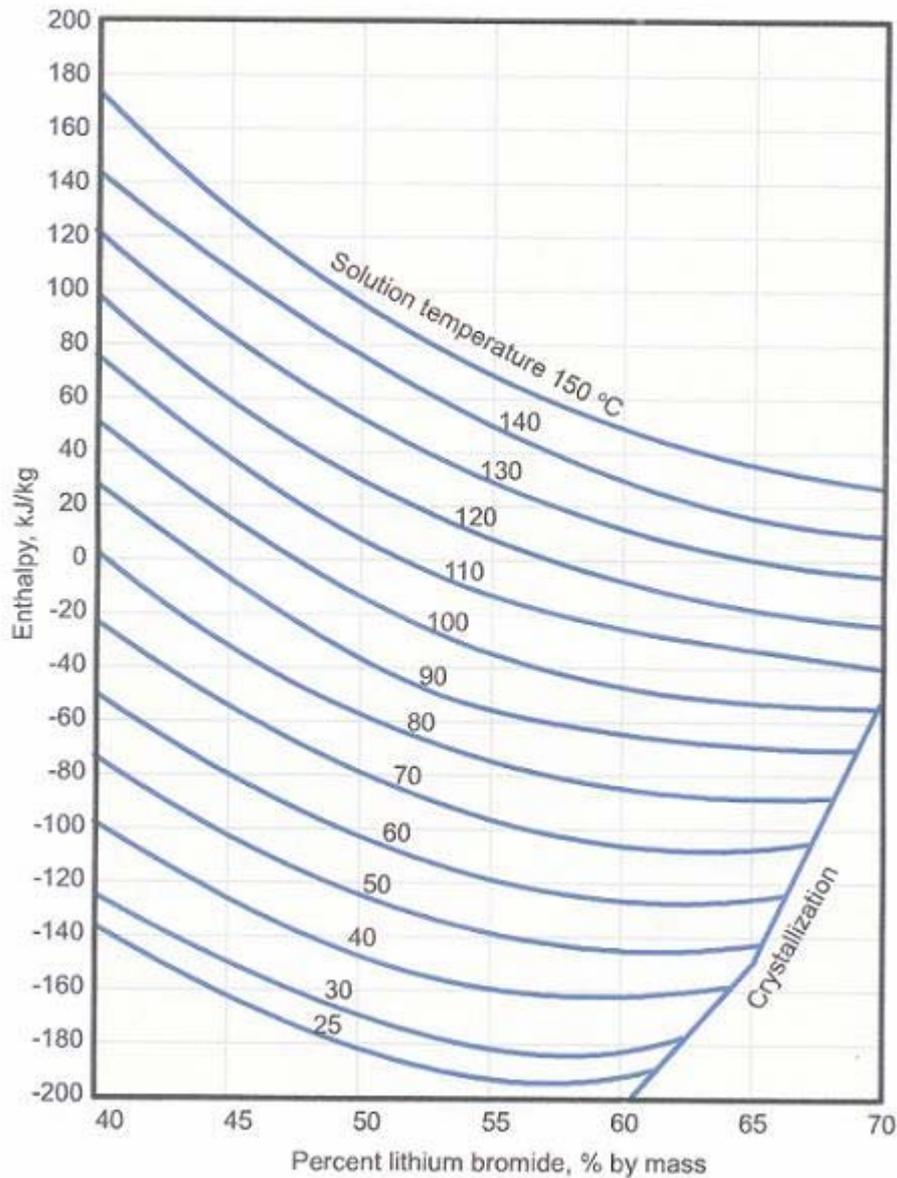


Fig.15.4: Enthalpy –Temperature - Concentration diagram for H_2O -LiBr solution

15.2.4. 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, $h_{W,liquid}$ at any temperature T can be obtained from the equation:

$$h_{W,liquid} = 4.19(T - T_{ref}) \text{ kJ / kg} \quad (15.6)$$

where T_{ref} 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, $h_{W,sup}$ at low pressures and temperature T can be obtained approximately by the equation:

$$h_{W,sup} = 2501 + 1.88(T - T_{ref}) \quad (15.7)$$

15.2.5. Crystallization

The pressure-temperature-mass fraction and enthalpy-temperature-mass fraction charts (Figs. 15.3 and 15.4) show lines marked as crystallization in the lower right section. The region to the right and below these crystallization lines indicates solidification of LiBr salt. In the crystallization region a two-phase mixture (slush) of water-lithium bromide solution and crystals of pure LiBr exist in equilibrium. The water-lithium bromide system should operate away from the crystallization region as the formation of solid crystals can block the pipes and valves. Crystallization can occur when the hot solution rich in LiBr salt is cooled in the solution heat exchanger to low temperatures. To avoid this the condenser pressure reduction below a certain value due to say, low cooling water temperature in the condenser should be avoided. Hence in commercial systems, the condenser pressure is artificially maintained high even though the temperature of the available heat sink is low. This actually reduces the performance of the system, but is necessary for proper operation of the system.

It should be noted from the property charts that the entire water-lithium bromide system operates under vacuum.

15.3. Steady flow analysis of Water-Lithium Bromide Systems

Figure 15.5 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:

\dot{m} = mass flow rate of refrigerant, kg/s

\dot{m}_{ss} = mass flow rate of strong solution (rich in LiBr), kg/s

\dot{m}_{ws} = mass flow rate of weak solution (weak in LiBr), kg/s

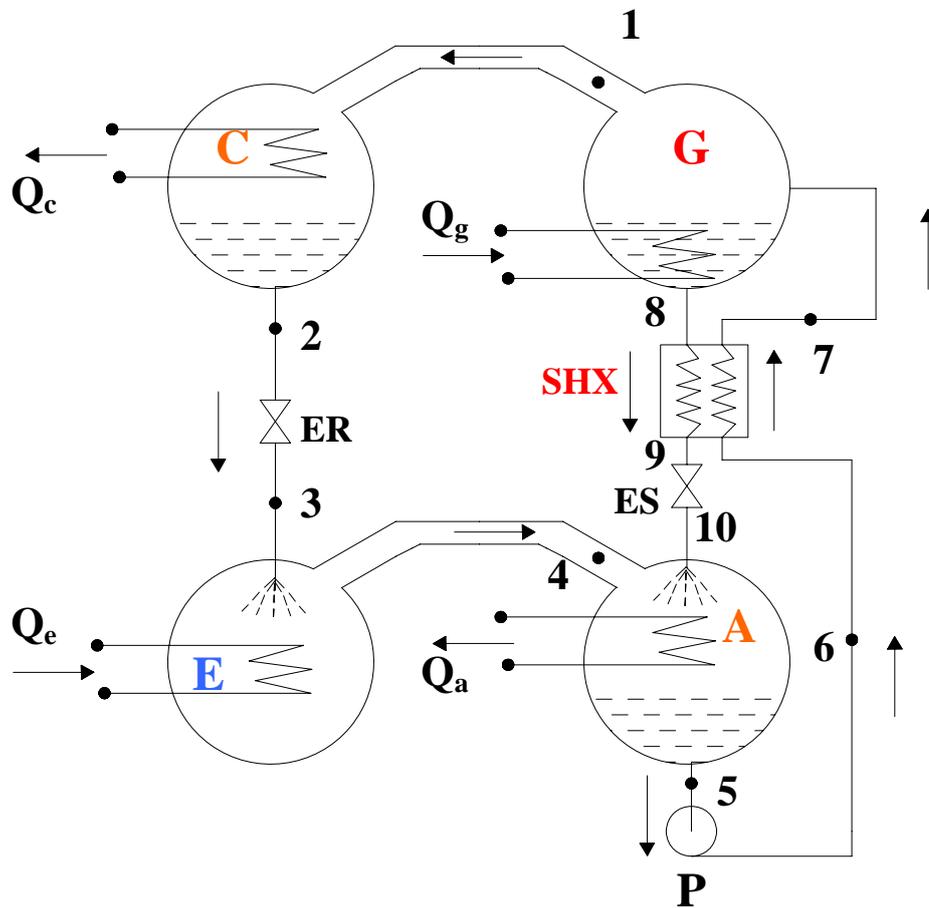


Fig.15.5: Schematic of a H₂O-LiBr system

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:

$$\lambda = \frac{\dot{m}_{ss}}{\dot{m}} \quad (15.7)$$

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

$$\dot{m}_{ss} = \lambda \dot{m} \quad (15.8)$$

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

Condenser:

$$\dot{m}_1 = \dot{m}_2 = \dot{m} \quad (15.9)$$

$$Q_c = \dot{m}(h_1 - h_2) \quad (15.10)$$

$$P_c = P_{sat}(T_c) \quad (15.11)$$

where T_c is the condenser temperature

Expansion valve (refrigerant):

$$\dot{m}_2 = \dot{m}_3 = \dot{m} \quad (15.12)$$

$$h_2 = h_3 \quad (15.13)$$

Evaporator:

$$\dot{m}_3 = \dot{m}_4 = \dot{m} \quad (15.14)$$

$$Q_e = \dot{m}(h_4 - h_3) \quad (15.15)$$

$$P_e = P_{\text{sat}}(T_e) \quad (15.16)$$

where T_e is the evaporator temperature

Absorber:

From total mass balance:

$$\dot{m} + \dot{m}_{\text{ss}} = \dot{m}_{\text{ws}} \quad (15.17)$$

$$\dot{m}_{\text{ss}} = \lambda \dot{m} \Rightarrow \dot{m}_{\text{ws}} = (1 + \lambda) \dot{m}$$

From mass balance for pure water:

$$\dot{m} + (1 - \xi_{\text{ss}}) \dot{m}_{\text{ss}} = (1 - \xi_{\text{ws}}) \dot{m}_{\text{ws}} \quad (15.18)$$

$$\Rightarrow \lambda = \frac{\xi_{\text{ws}}}{\xi_{\text{ss}} - \xi_{\text{ws}}}$$

$$Q_a = \dot{m} h_4 + \lambda \dot{m} h_{10} - (1 + \lambda) \dot{m} h_5 \quad (15.19)$$

$$\text{or, } Q_a = \dot{m} [(h_4 - h_5) + \lambda(h_{10} - h_5)] \quad (15.20)$$

The first term in the above equation $\dot{m}(h_4 - h_5)$ represents the enthalpy change of water as changes its state from vapour at state 4 to liquid at state 5. The second term $\dot{m} \lambda(h_{10} - h_5)$ represents the sensible heat transferred as solution at state 10 is cooled to solution at state 5.

Solution pump:

$$\dot{m}_5 = \dot{m}_6 = \dot{m}_{\text{ws}} \quad (15.21)$$

$$W_p = \dot{m}_{\text{ws}} (h_6 - h_5) = (1 + \lambda) \dot{m} (h_6 - h_5) \quad (15.22)$$

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

$$W_P = (1 + \lambda) \dot{m} v_{sol} (P_6 - P_5) = (1 + \lambda) \dot{m} v_{sol} (P_c - P_e) \quad (15.23)$$

where v_{sol} is the specific volume of the solution which can be taken to be approximately equal to $0.00055 \text{ m}^3/\text{kg}$. Even though the solution pump work is small it is still required in the selection of suitable pump.

Solution heat exchanger:

$$\begin{aligned} \dot{m}_6 &= \dot{m}_7 = \dot{m}_{ws} \\ \dot{m}_8 &= \dot{m}_9 = \dot{m}_{ss} \end{aligned} \quad (15.24)$$

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

$$Q_{HX} = (1 + \lambda) \dot{m} (h_7 - h_6) = \lambda \dot{m} (h_8 - h_9) \quad (15.25)$$

Generator:

$$\dot{m}_7 = \dot{m}_8 + \dot{m}_1 \quad (15.26)$$

Heat input to the generator is given by:

$$Q_g = \dot{m} h_1 + \lambda \dot{m} h_8 - (1 + \lambda) \dot{m} h_7 \quad (15.27)$$

$$\text{or, } Q_g = \dot{m} [(h_1 - h_7) + \lambda (h_8 - h_7)] \quad (15.28)$$

in the above equation the 1st term on the RHS $\dot{m}(h_1 - h_7)$ represents energy required to generate water vapour at state 1 from solution at state 7 and the 2nd term $\dot{m}\lambda(h_8 - h_7)$ represents the sensible heat required to heat the solution from state 7 to state 8.

Solution expansion valve:

$$\dot{m}_9 = \dot{m}_{10} = \dot{m}_{ws} \quad (15.29)$$

$$h_9 = h_{10} \quad (15.30)$$

The COP of the system is given by:

$$\text{COP} = \frac{Q_e}{Q_g + W_P} \approx \frac{Q_e}{Q_g} \quad (15.31)$$

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

$$\eta_{II} = \frac{\text{COP}}{\text{COP}_{\max}} = \left(\frac{Q_e}{Q_g} \right) \left(\frac{T_g}{T_g - T_c} \right) \left(\frac{T_c - T_e}{T_e} \right) \quad (15.32)$$

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:

$$\varepsilon_{HX} = \frac{(T_7 - T_6)}{(T_8 - T_6)} \quad (15.33)$$

From the above equation the temperature of the weak solution entering the generator (T_7) can be obtained since T_6 is almost equal to T_5 and T_8 is equal to the generator temperature T_g . The temperature of superheated water vapour at state 1 may be assumed to be equal to the strong solution temperature T_8 .

15.4. 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.

15.5. 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 15.6 shows a commercial, single stage, twin drum system.

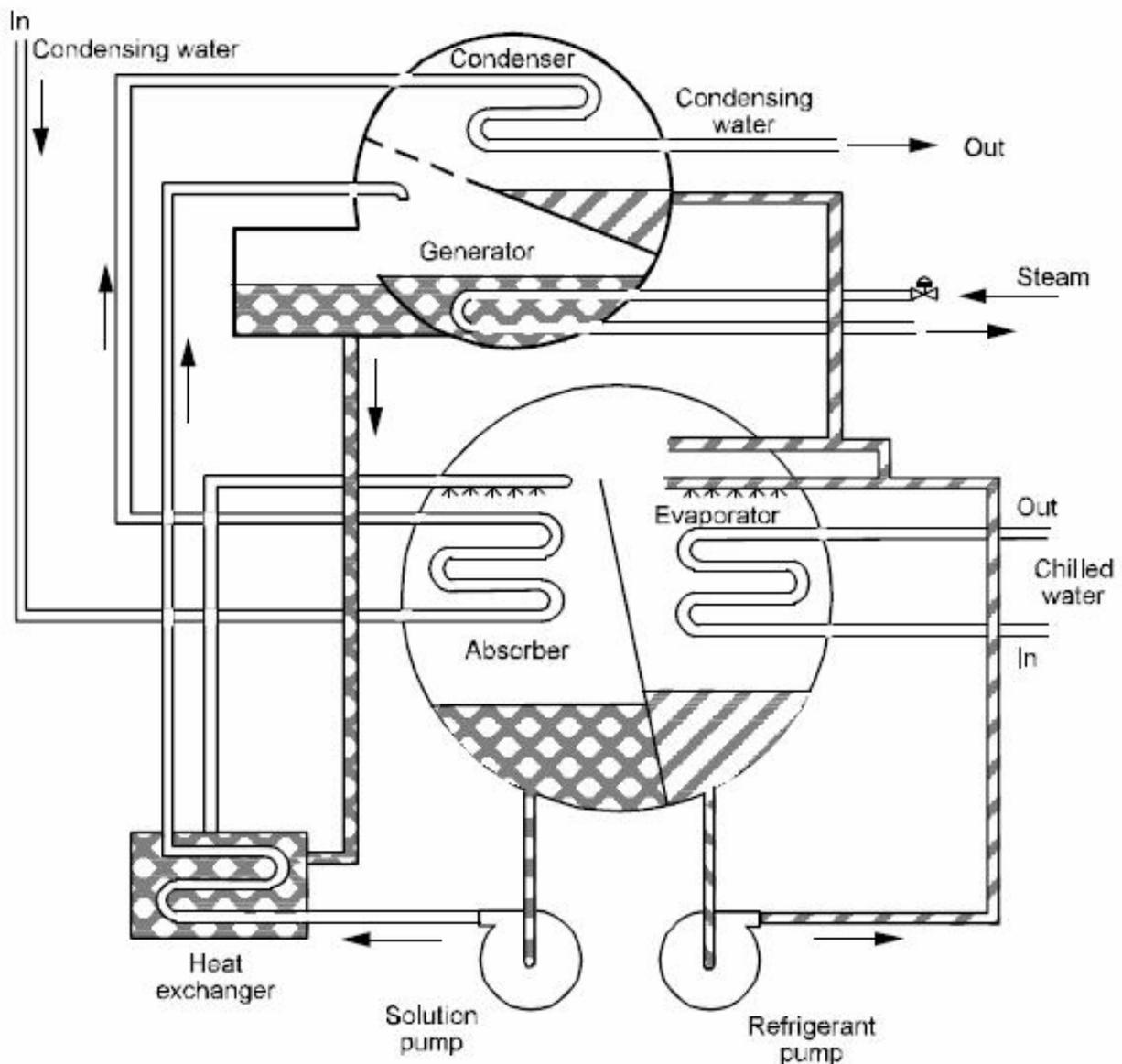


Fig.15.6: A commercial, twin-drum type, water-lithium bromide system

As shown in the figure, the cooling water (which acts as heat sink) flows first to absorber, extracts heat from absorber and then flows to the condenser for condenser heat extraction. This is known as series arrangement. This arrangement is advantageous as the required cooling water flow rate will be small and also by sending the cooling water first to the absorber, the condenser can be operated at a higher pressure to prevent crystallization. It is also possible to have cooling water flowing parallelly to condenser and absorber, however, the cooling water requirement in this case will be high. A refrigerant pump circulates liquid water in evaporator and the water is sprayed onto evaporator tubes for good heat and mass transfer. Heater tubes (steam or hot water or hot oil) are immersed in the strong solution pool of generator for vapour generation. Pressure drops between evaporator and absorber and between generator and condenser are minimized, large sized vapour lines are eliminated and air leakages can also be reduced due to less number of joints.

Figure 15.7 shows a single stage system of single drum type in which all the four components are housed in the same vessel. The vessel is divided into high and low pressure sides by using a diaphragm.

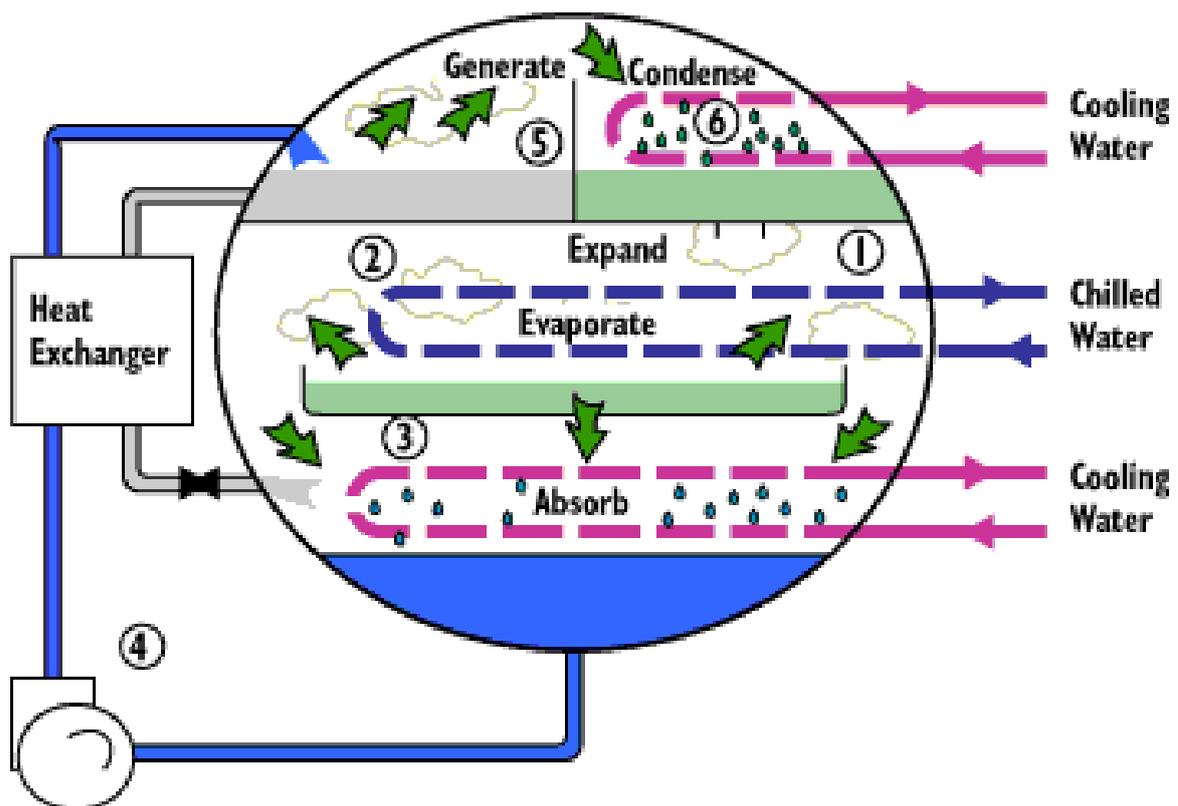


Fig.15.7: A commercial, single-drum type, water-lithium bromide system

In multi-effect systems a series of generators operating at progressively reducing pressures are used. Heat is supplied to the highest stage generator operating at the highest pressure. The enthalpy of the steam generated from this generator is used to generate some more refrigerant vapour in the lower stage generator and so on. In this manner the heat input to the system is used efficiently by generating more refrigerant vapour leading to higher COPs. However, these systems are more complex in construction and require a much higher heat source temperatures in the highest stage generator. Figures 15.8 and 15.9 show commercial double-effect systems. Figure 15.10 shows the double effect cycle on Dühring plot.

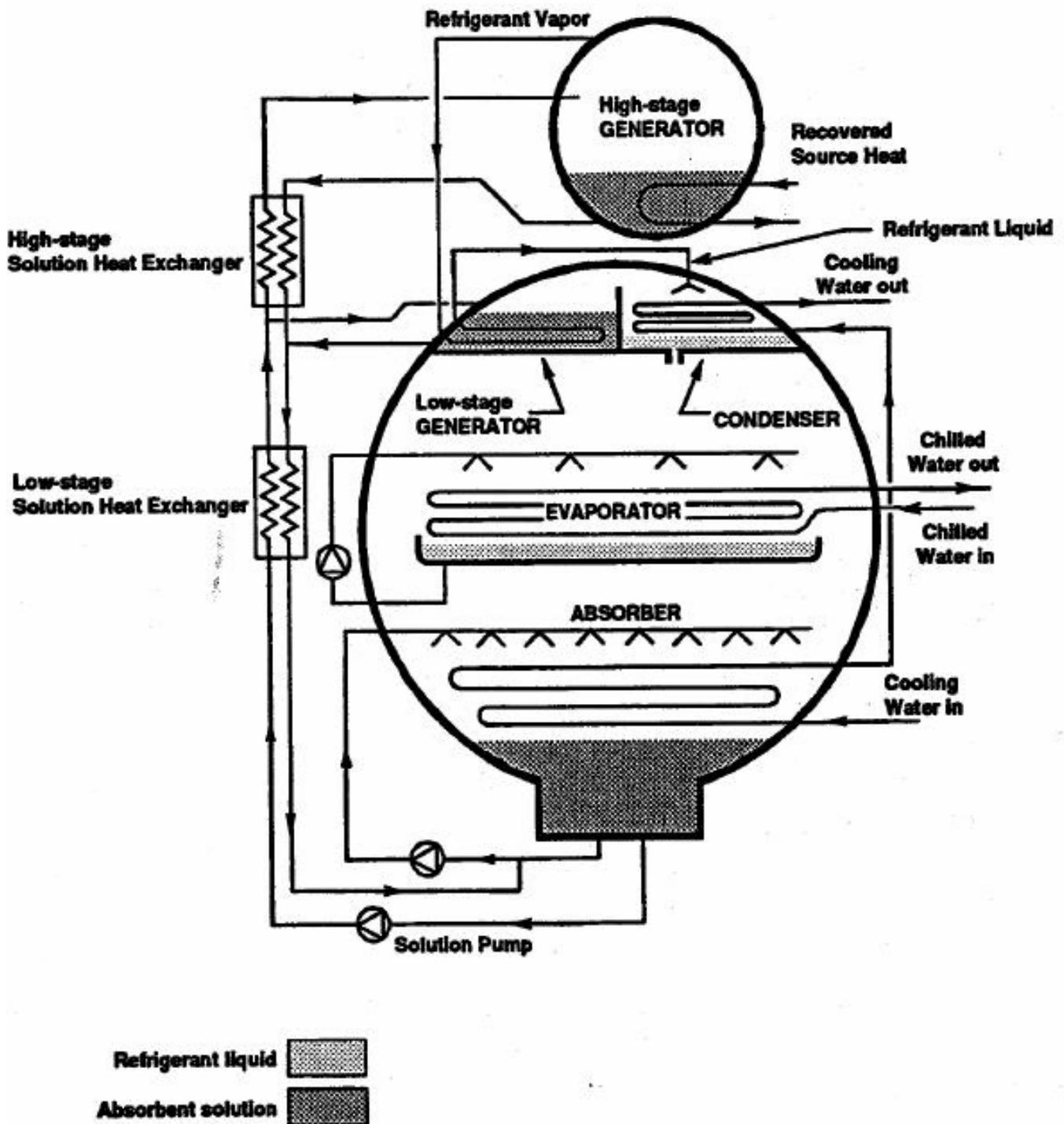


Fig.15.8: A commercial, double-effect, water-lithium bromide system

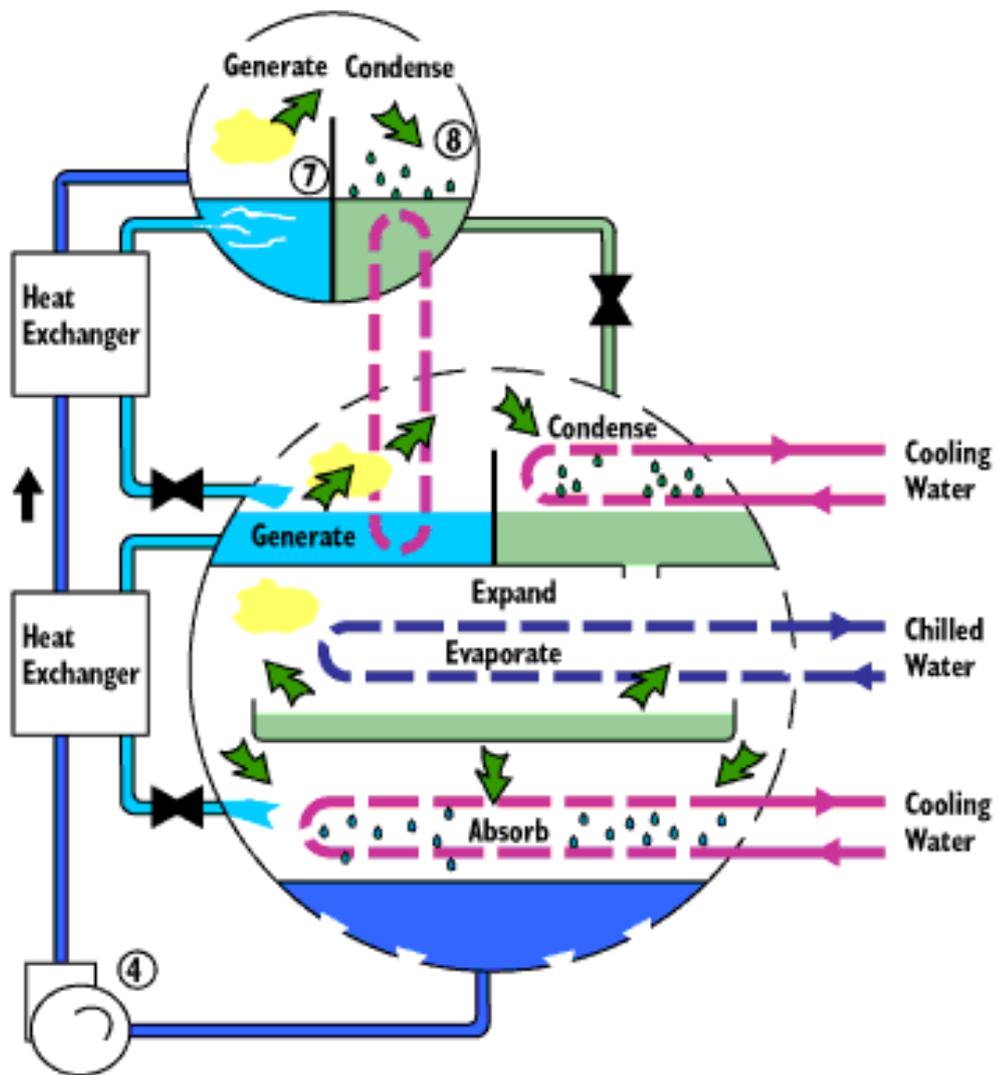


Fig.15.9: A commercial, double-effect, water-lithium bromide system

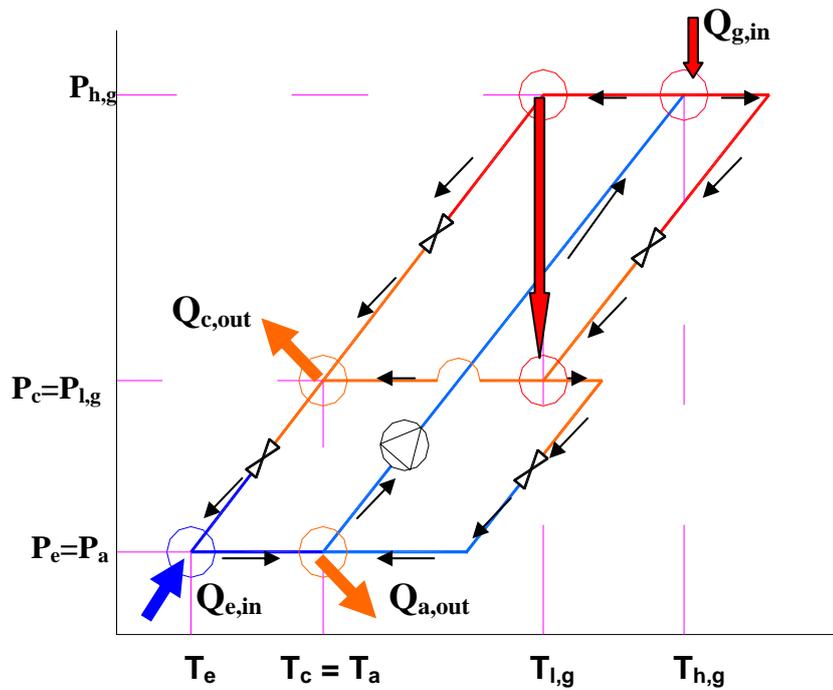


Fig.15.10: Double effect VARS on Dühring plot

15.6. Heat sources for water-lithium bromide systems

Water-lithium bromide systems can be driven using a wide variety of heat sources. Large capacity systems are usually driven by steam or hot water. Small capacity systems are usually driven directly by oil or gas. A typical single effect system requires a heat source at a temperature of about **120°C** to produce chilled water at **7°C** when the condenser operates at about **46°C** and the absorber operates at about **40°C**. The COPs obtained are in the range 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.

15.7. 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°C** (for air conditioning applications) is shown in Table 15.1.

Cooling water temperature (inlet to absorber & condenser)	Minimum Heat source temperature (Inlet to generator)	COP
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 15.1. 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 a 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 15°C 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 ($\approx 150^\circ\text{C}$). 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 50°C.

15.7 Capacity control

Capacity control means capacity reduction depending upon load as the capacity will be maximum without any control. Normally under both full as well as part loads the outlet temperature of chilled water is maintained at a near constant value. The refrigeration capacity is then regulated by either:

1. Regulating the flow rate of weak solution pumped to the generator through the solution pump
2. Reducing the generator temperature by throttling the supply steam, or by reducing the flow rate of hot water
3. Increasing the condenser temperature by bypassing some of the cooling water supplied to the condenser

Method 1 does not affect the COP significantly as the required heat input reduces with reduction in weak solution flow rate, however, since this may lead to the problem of crystallization, many a time a combination of the above three methods are used in commercial systems to control the capacity.

Questions:

1. Vapour absorption refrigeration systems using water-lithium bromide:

- a) Are used in large air conditioning systems
- b) Are used in large frozen food storage applications
- c) Operate under vacuum
- c) All of the above

Ans. a) and c)

2. For a required refrigeration capacity, the solution heat exchanger used in water-lithium bromide systems:

- a) Reduces the required heat input to generator
- b) Reduces the heat rejection rate at absorber
- c) Reduces heat rejection rate at condenser
- d) Reduces the required heat source temperature

Ans. a) and b)

3. In water-lithium bromide systems:

- a) Crystallization of solution is likely to occur in absorber
- b) Crystallization of solution is likely to occur in solution heat exchanger
- c) Crystallization is likely to occur when generator temperature falls
- d) Crystallization is likely to occur when condenser pressure falls

Ans. a) and d)

4. In commercial water-lithium bromide systems

- a) Crystallization is avoided by regulating cooling water flow rate to condenser
- b) Crystallization is avoided by adding additives
- c) An air purging system is used to maintain vacuum
- d) All of the above

Ans. d)

5. Commercial multi-effect absorption systems:

- a) Yield higher COPs
- b) Yield higher refrigeration temperatures
- c) Require lower heat source temperatures
- d) Require higher heat source temperatures

Ans. a) and d)

6. In water-lithium bromide systems:

- a) The required heat source temperature should be higher than minimum heat generation temperature
- b) The required heat source temperature decreases as cooling water temperature increases
- c) The required heat source temperature is higher for air cooled condensers, compared to water cooled condensers
- d) All of the above

Ans. a) and c)

7. In commercial water-lithium bromide systems, the system capacity is regulated by:

- a) Controlling the weak solution flow rate to generator
- b) Controlling the flow rate of chilled water to evaporator
- c) Controlling the temperature of heating fluid to generator
- d) All of the above

Ans. a) and c)

8. A single stage vapour absorption refrigeration system based on H₂O-LiBr has a refrigeration capacity of 300 kW. The system operates at an evaporator temperature of 5°C ($P_{\text{sat}}=8.72$ mbar) and a condensing temperature of 50°C ($P_{\text{sat}}=123.3$ mbar). The exit temperatures of absorber and generator are 40°C and 110°C respectively. The concentration of solution at the exit of absorber and generator are 0.578 and 0.66, respectively. Assume 100 percent effectiveness for the solution heat exchanger, exit condition of refrigerant at evaporator and condenser to be saturated and the condition of the solution at the exit of absorber and generator to be at equilibrium. Enthalpy of strong solution at the inlet to the absorber may be obtained from the equilibrium solution data.

Find:

- a) The mass flow rates of refrigerant, weak and strong solutions
- b) Heat transfer rates at the absorber, evaporator, condenser, generator and solution heat exchanger
- c) System COP and second law efficiency, and

d) Solution pump work (density of solution = 1200 kg/m³).

Given:

Refrigeration capacity	:	300 kW
Evaporator temperature	:	5°C
Condenser temperature	:	50°C
Absorber temperature	:	40°C
Generator temperature	:	110°C
Weak solution concentration, ξ_{ws}	:	0.578
Strong solution concentration, ξ_{ss}	:	0.66
Effectiveness of solution HX, ϵ_{HX}	:	1.0
Density of solution, ρ_{sol}	:	1200 kg/m ³
Refrigerant exit at evaporator & condenser	:	Saturated
Solution at the exit of absorber & generator	:	Equilibrium

Referring to Fig.15.5;

Assuming the refrigerant vapour at the exit of generator to be in equilibrium with the strong solution leaving the generator

$$\Rightarrow \text{Temperature of vapour at generator exit} = \mathbf{110^\circ\text{C}}$$

$$\Rightarrow \text{enthalpy of vapour} = 2501 + 1.88 \times 110 = \mathbf{2708 \text{ kJ/kg}}$$

From the definition of effectiveness of solution HX;

$$\epsilon_{HX} = [m_{SS}C_{p,SS}(T_8 - T_9)] / [m_{SS}C_{p,SS}(T_8 - T_6)] = 1.0 \quad (\because m_{SS} < m_{WS})$$

$$\Rightarrow \mathbf{T_9 = T_6 = 40^\circ\text{C}}$$

From the above equation, the following property data at various points are obtained using refrigerant property charts and water – LiBr solution property charts

State point	Temperature (°C)	Pressure (mbar)	Mass fraction, ξ	Enthalpy (kJ/kg)
1	110	123.3	-	2708
2	50	123.3	-	209
3	5	8.72	-	209
4	5	8.72	-	2510
5	40	8.72	0.578	-154
6	40	123.3	0.578	-154
7	-	123.3	0.578	-37.5
8	110	123.3	0.66	-13
9	40	123.3	0.66	-146
10	40	8.72	0.66	-146

The enthalpy of superheated water vapour (h_v) may be obtained by using the equation:

$$h_v = 2501 + 1.88 t, \text{ where } h_v \text{ is in kJ/kg and } t \text{ is in } ^\circ\text{C}.$$

Enthalpy of weak solution at the exit of solution HX is obtained from the energy balance equation: $m_{WS}(h_7-h_6) = m_{SS}(h_8-h_9) \Rightarrow h_7 = h_6 + m_{SS}(h_8-h_9)/m_{WS} = -37.5 \text{ kJ/kg}$

a) Required mass flow rate of refrigerant, $m = Q_e/(h_4-h_3) = 0.1304 \text{ kg/s}$ (Ans.)

$$\text{Circulation ratio, } \lambda = m_{SS}/m = \xi_{WS}/(\xi_{SS}-\xi_{WS}) = 7.05$$

\therefore mass flow rate of strong solution, $m_{SS} = \lambda m = 0.9193 \text{ kg/s}$ (Ans.)

mass flow rate of weak solution, $m_{WS} = (\lambda+1)m = 1.05 \text{ kg/s}$ (Ans.)

b) Heat transfer rates at various components:

Evaporator: $Q_e = 300 \text{ kW}$ (input data)

Absorber: From energy balance:

$$Q_a = m h_4 + m_{SS} h_{10} - m_{WS} h_5 = 354.74 \text{ kW} \quad (\text{Ans.})$$

Generator: From energy balance:

$$Q_g = m h_1 + m_{ss} h_8 - m_w h_7 = 380.54 \text{ kW} \quad (\text{Ans.})$$

Condenser: From energy balance:

$$Q_c = m(h_1 - h_2) = 325.9 \text{ kW} \quad (\text{Ans.})$$

Solution heat exchanger: From energy balance:

$$Q_{SHX} = m\lambda(h_8 - h_9) = m(\lambda + 1)(h_7 - h_6) = 122.3 \text{ kW} \quad (\text{Ans.})$$

c) System COP (neglecting pump work) = $Q_e/Q_g = 0.7884$ (Ans.)

$$\text{Second law efficiency} = \text{COP}/\text{COP}_{\text{Carnot}}$$

$$\text{COP}_{\text{Carnot}} = [T_e/(T_c - T_e)][(T_g - T_a)/T_g] = 1.129$$

$$\therefore \text{Second law efficiency} = 0.6983 \quad (\text{Ans.})$$

d) Solution pump work (assuming the solution to be incompressible)

$$W_P = v_{\text{sol}}(P_6 - P_5) = (P_6 - P_5)/\rho_{\text{sol}} = (123.3 - 8.72) \times 10^{-1} / 1200 = 0.0095 \text{ kW} \quad (\text{Ans.})$$