Refrigeration

5: Absorption Refrigeration Cycles

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ABSORPTION REFRIGERATION CYCLES

The **absorption cycle** is similar in certain respects to the vapor-compression cycle. A refrigeration cycle will operate with the condenser, expansion valve, and evaporator shown in Fig. if the low-pressure vapor from the evaporator can be transformed into high-pressure vapor and delivered to the condenser.

The vapor-compression system uses a compressor for this task. The absorption system first absorbs the low- pressure vapor in an appropriate absorbing liquid. Embodied in the absorption process is the conversion of vapor into liquid; since this process is akin to condensation, heat must be rejected during the process. The next step is to elevate the pressure of the liquid with a pump, and the final step releases the vapor from the-absorbing liquid by adding heat.

The vapor-compression cycle is described as a ***work-operated cycle*** because the elevation of pressure of the refrigerant is accomplished by a compressor that requires work. The absorption cycle, on the other hand, is referred to as **a *heat-operated cycle*** because most of the operating cost is associated with providing the heat that drives off the vapor from the high-pressure liquid. Indeed, there is a requirement for some work in the absorption cycle to drive the pump, but the amount of work for a given quantity of refrigeration is minor compared with that needed in the vapor-compression cycle.

ABSORPTION REFRIGERATION CYCLES

IDEAL THERMAL CYCLE

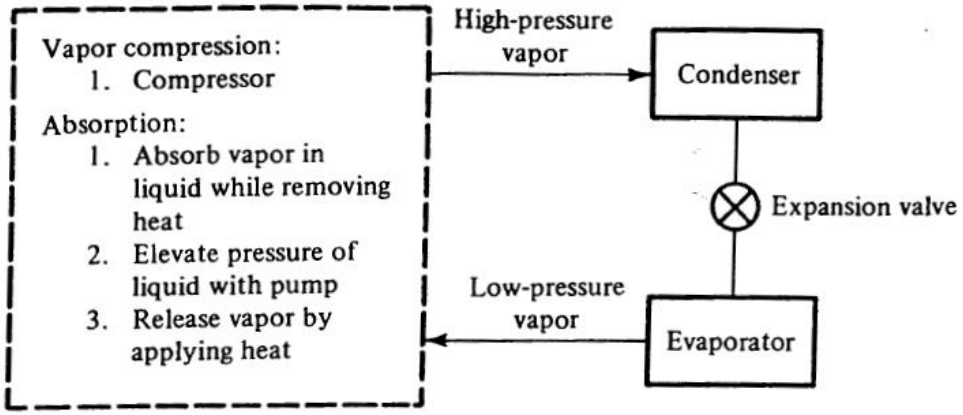


Fig 1

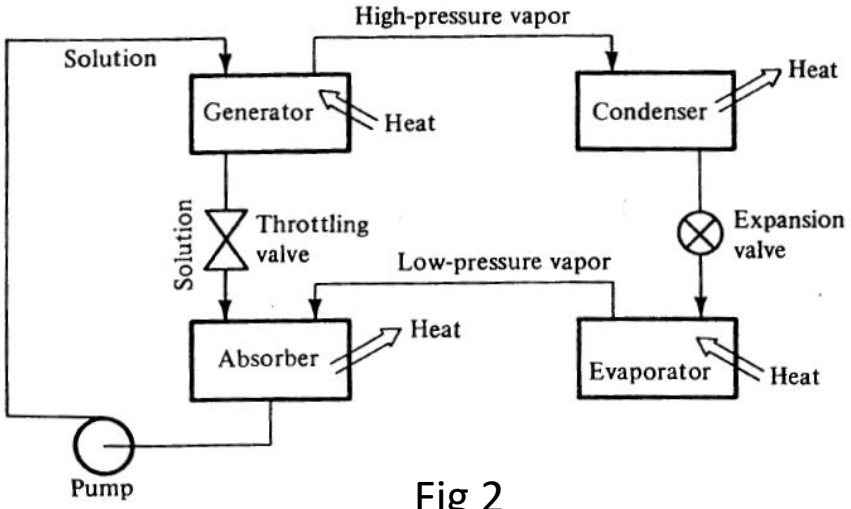


Fig 2

The basic absorption cycle is shown in Fig2. The condenser and evaporator are as shown in the right of Fig 1 , and the compression operation is provided by the assembly in the left half of Fig 1. Low-pressure vapor from the evaporator is absorbed by the liquid solution in the absorber. If this absorption process were executed adiabatically, the temperature of the solution would rise and eventually the absorption of vapor would cease. To perpetuate the absorption process the absorber is cooled by water or air that ultimately rejects this heat to the atmosphere.

ABSORPTION REFRIGERATION CYCLES

IDEAL THERMAL CYCLE

The pump receives low-pressure liquid from the absorber, elevates the pressure of the liquid, and delivers the liquid to the generator. In the generator, heat from a high-temperature source drives off the vapor that had been absorbed by the solution. The liquid solution returns to the absorber through a throttling valve whose purpose is to provide a pressure drop to maintain the pressure difference between the generator and absorber.

The pattern for the flow of heat to and from the four heat-exchange components in the absorption cycle is that high-temperature heat enters the generator while low-temperature heat from the substance being refrigerated enters the evaporator. The heat rejection from the cycle occurs at the absorber and condenser at temperatures such that the heat can be rejected to atmosphere.

ABSORPTION REFRIGERATION CYCLES

Coefficient of performance of the ideal absorption cycle

The coefficient of performance of the absorption cycle COP_{abs} is defined as:

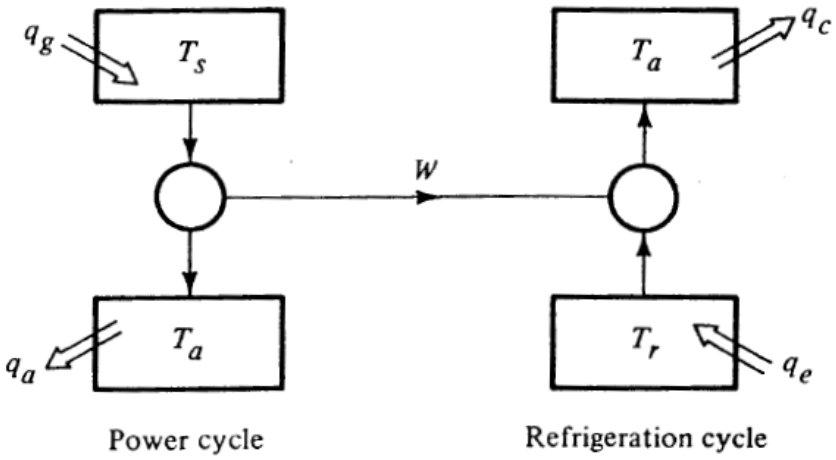
$$COP_{abs} = \frac{\text{refrigeration rate}}{\text{rate of heat addition at generator}}$$

In certain respects applying the term COP to the absorption system is unfortunate because the value is appreciably lower than that of the vapor-compression cycle (0.6 versus 3, for example). The comparatively low value of COP abs should not be considered prejudicial to the absorption system, because the COPs of the two cycles are defined differently. The COP of the vapor-compression cycle is the ratio of the refrigeration rate to the power in the form of *work* supplied to operate the cycle. Energy in the form of work is normally much more valuable and expensive than energy in the form of heat.

ABSORPTION REFRIGERATION CYCLES

Coefficient of performance of the ideal absorption cycle

Figure 3 suggests how to proceed with the analysis, because the processes in the box on the left consist of a power cycle that develops work needed to perform the compression of the vapor from the evaporator to the condenser. These two cycles are shown schematically in Fig. 3. The power cycle receives energy in the form of heat q_g at an absolute temperature T_s, delivers some energy W in the form of work to the refrigeration cycle, and rejects a quantity of energy q_a in the form of heat at a temperature T_a. The refrigeration cycle receives the work W and with it pumps heat q_e at the refrigerating temperature of T_r to a temperature T_a, where the quantity q_c is rejected.



ABSORPTION REFRIGERATION CYCLES

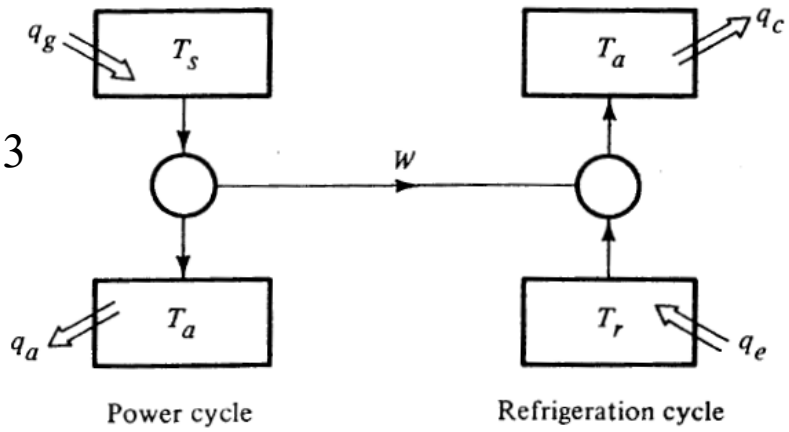
Coefficient of performance of the ideal absorption cycle

The ideal cycle operating with thermodynamically reversible processes between two temperatures is a Carnot cycle, which appears as a rectangle on the temperature entropy diagram. For the power cycle on the left side of Fig.3

$$\frac{q_g}{W} = \frac{T_s}{T_s - T_a}$$

and for the refrigeration cycle on the right side of Fig.3

$$\frac{q_e}{W} = \frac{T_r}{T_a - T_r}$$



$$\text{COP} = \frac{q_e}{q_g} = \frac{WT_r}{T_a - T_r}\,\frac{T_s - T_a}{WT_s} = \frac{T_r(T_s - T_a)}{T_s(T_a - T_r)}$$

ABSORPTION REFRIGERATION CYCLES

Coefficient of performance of the ideal absorption cycle

Example 1: What is the COP of an ideal heat-operated refrigeration system that has a source temperature of heat of 100°C, a refrigerating temperature of 5°C, and an ambient temperature of 30°C?

$$\text{COP} = \frac{q_e}{q_g} = \frac{WT_r}{T_a - T_r}\,\frac{T_s - T_a}{WT_s} = \frac{T_r(T_s - T_a)}{T_s(T_a - T_r)}$$

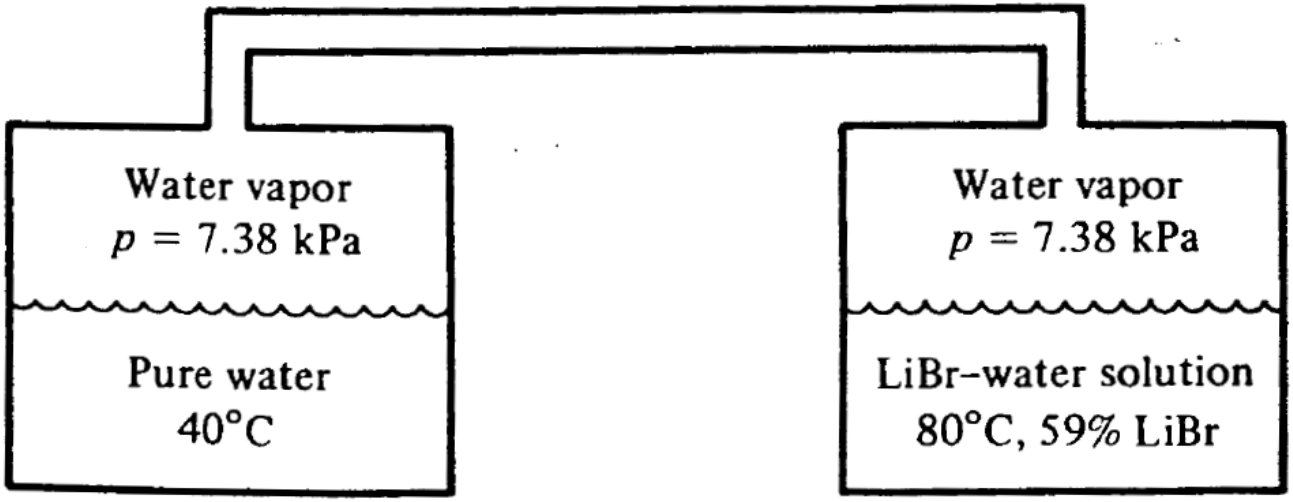
$$\text{COP} = \frac{(5 + 273.15)\,(100 - 30)}{(100 + 273.15)\,(30 - 5)} = 2.09$$

1. As T_s increases, the COP increases.
2. As T_r increases, the COP increases.
3. As T_a increases, the COP decreases.

ABSORPTION REFRIGERATION CYCLES

Temperature-pressure-concentration properties of LiBr-water solutions

Lithium bromide is a solid salt crystal; in the presence of water vapor, it will absorb the vapor and become a liquid solution. The liquid solution exerts a water-vapor pressure that is a function of the solution temperature and the concentration of the solution. If two vessels were connected as in Fig. 4, one vessel containing LiBr-water solution and the other pure water, each liquid would exert a water-vapor pressure.



ABSORPTION REFRIGERATION CYCLES

Temperature-pressure-concentration properties of LiBr-water solutions

At equilibrium the water-vapor pressures exerted by the two liquids would be equal. An example of one equilibrium condition is noted in Fig. 4. If the temperature of pure water is 40°C, its vapor pressure is 7.38 kPa. That same vapor pressure would be developed by a LiBr-water solution at a temperature of 80°C and a concentration $x = 59\%$ LiBr on a mass basis. Many other combinations of temperatures and concentrations of solution also provide a vapor pressure of 7.38 kPa.

Figure 5 is a temperature-pressure-concentration diagram for LiBr-water solutions. Concentration is the abscissa of the graph and water-vapor pressure could be considered the ordinate, as shown on the vertical scale on the right. For convenience the saturation temperature of pure water corresponding to these vapor pressures is shown as the ordinate on the left. The chart applies to saturated conditions where the solution is in equilibrium with the water vapor, as in the vessel on the right in Fig. 4.

The pressures, temperatures, and concentrations chosen as example conditions in Fig. 4 can now be verified. If the temperature of pure water is 40°C, the vapor pressure the liquid exerts is 7 .38 kPa, which can be determined from the opposite vertical scale in Fig. 5. A LiBr-water solution with a concentration x of 59% and a temperature of 80°C also develops a water-vapor pressure of 7.38 kPa. If the solution had a concentration x of 54% and temperature of 70°C, the water-vapor pressure would likewise be 7.38 kPa.

ABSORPTION REFRIGERATION CYCLES

Temperature-pressure-concentration properties of LiBr-water solutions

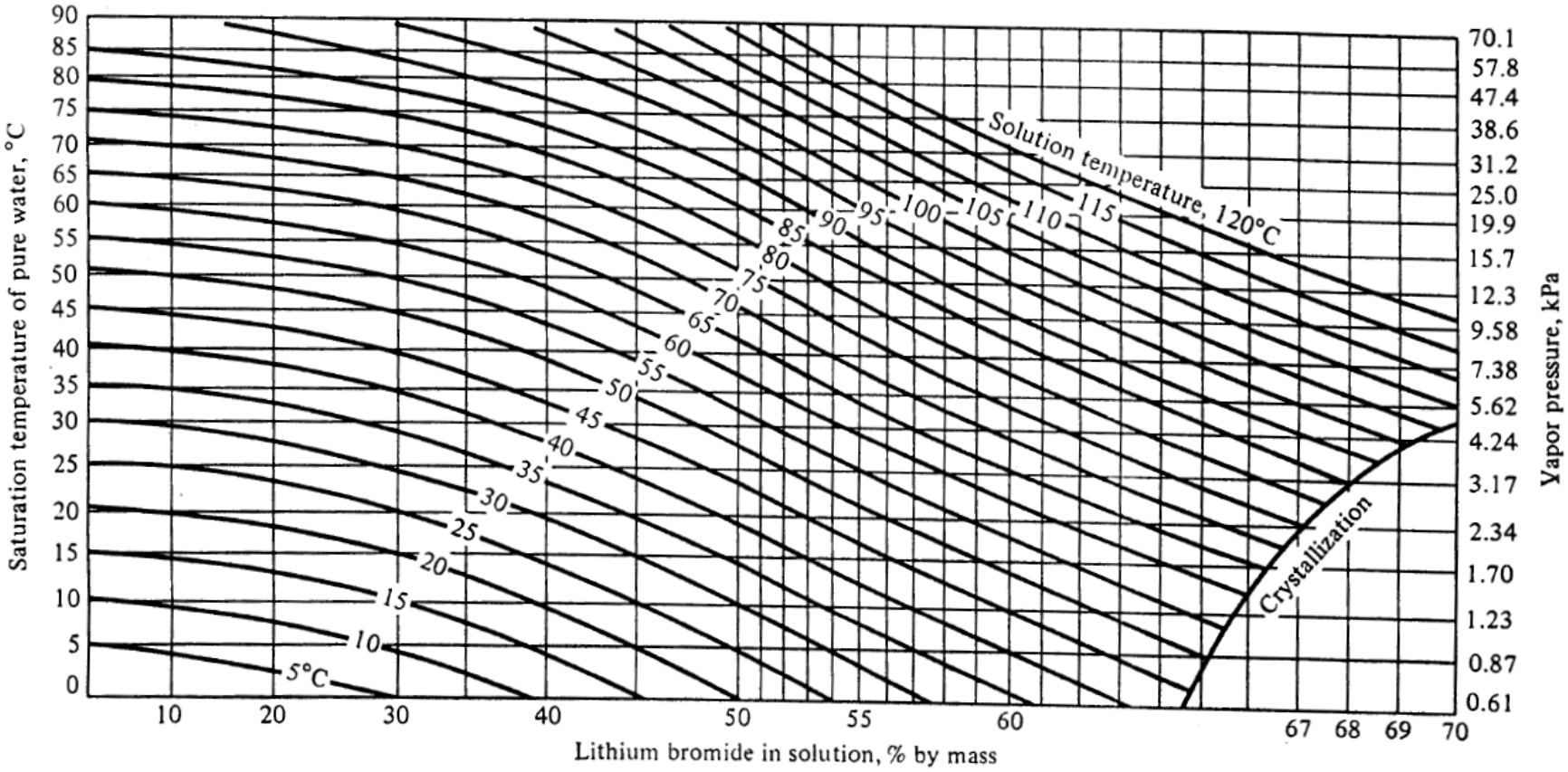


Fig. 5 Temperature-pressure-concentration diagram of saturated LiBr-water solutions

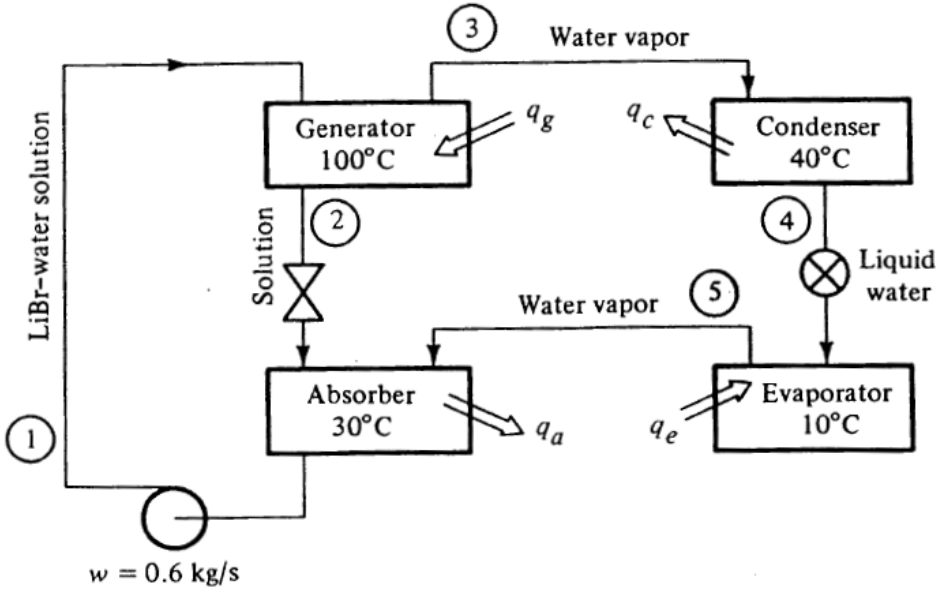
ABSORPTION REFRIGERATION CYCLES

Temperature-pressure-concentration properties of LiBr-water solutions

Calculation of mass flow rates in the absorption cycle

The first stage in analyzing the simple LiBr-water absorption refrigeration cycle can now be performed by using the property data presented in Fig: 5.

Example2: Compute the rate flow of refrigerant (water) through the condenser and evaporator in the cycle shown in Fig. 6 if the pump delivers 0.6 kg/s and the following temperatures prevail: generator, 100°C; condenser, 40°C; evaporator, 10°C; and absorber, 30°C.

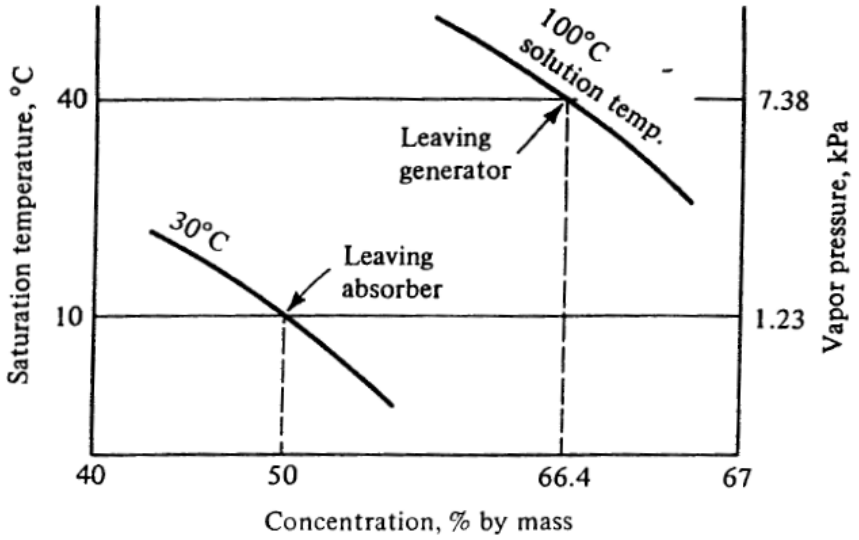


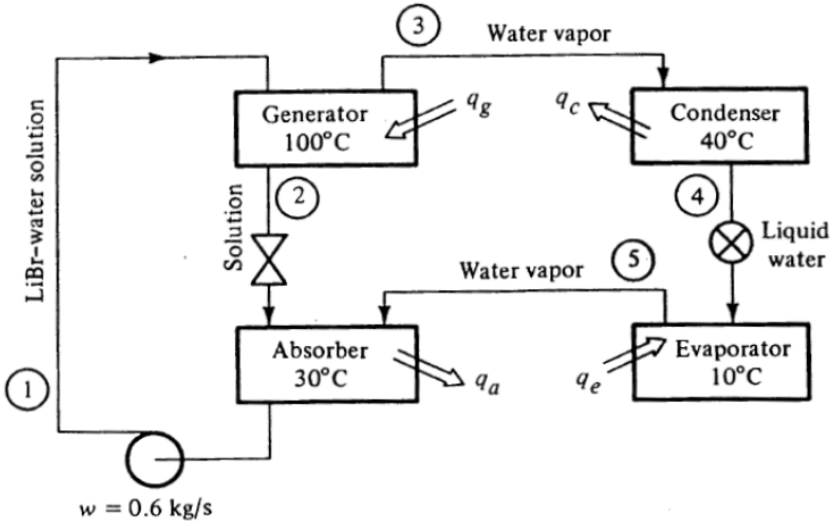
ABSORPTION REFRIGERATION CYCLES

Temperature-pressure-concentration properties of LiBr-water solutions

Total mass-flow balance:
W2 + W3 = Wl = 0.6
LiBr balance: **W1X1= W2X2**
0.6 (0.50) = w2 (0.664)
Solving the two balance equations simultaneously gives
w 2 = 0.452 kg/s and w3 = 0.148 kg/s

0.6/0.148=4.05 → Approximately 4 kg of solution is pumped for each kilogram of refrigerant water vapor developed.





ABSORPTION REFRIGERATION CYCLES

Enthalpy of LiBr solutions

Figure 8 presents enthalpy data for LiBr-water solutions. The data are applicable to saturated or subcooled solutions and are based on a zero enthalpy of liquid water at 0°C and a zero enthalpy of solid LiBr at 25°C. Since the zero enthalpy for the water in the solution is the same as that in conventional tables of properties of water, the water-property tables can be used in conjunction with Fig.8.

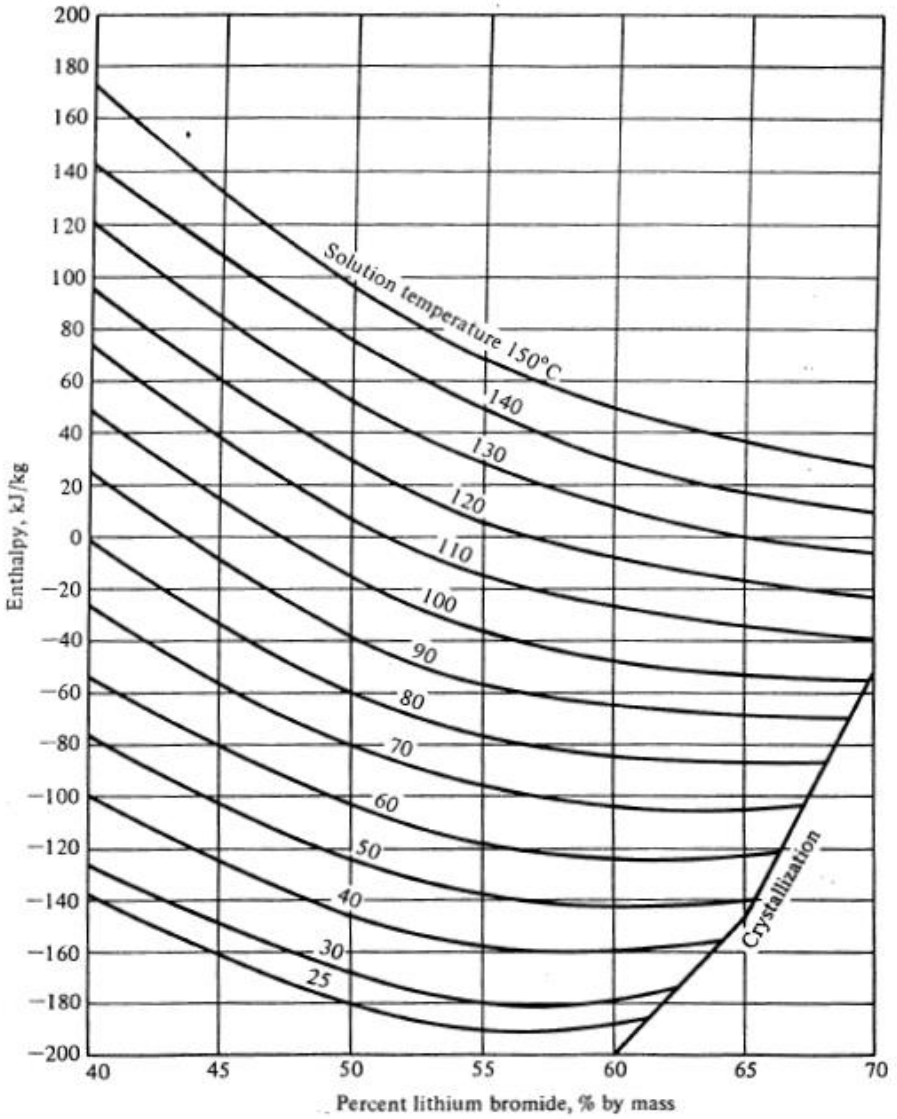


Figure 8 Enthalpy of LiBr-water solutions; data from Ref. 1.

ABSORPTION REFRIGERATION CYCLES

Enthalpy of LiBr solutions

Example 3: For the absorption system of Example 2 shown in Fig. 6 compute q_g, q_a , q_c, q_e, and the COP.

The flow rates and solution concentrations have already been determined in Example 2: w1= 0.6 kg/s, w2 = 0.452 kg/s, and w3 = w4 = w5 = 0.148 kg/s;x1 = 50%, andx2 = 66.4%.

The enthalpies of the solution can be read off Fig. 8:

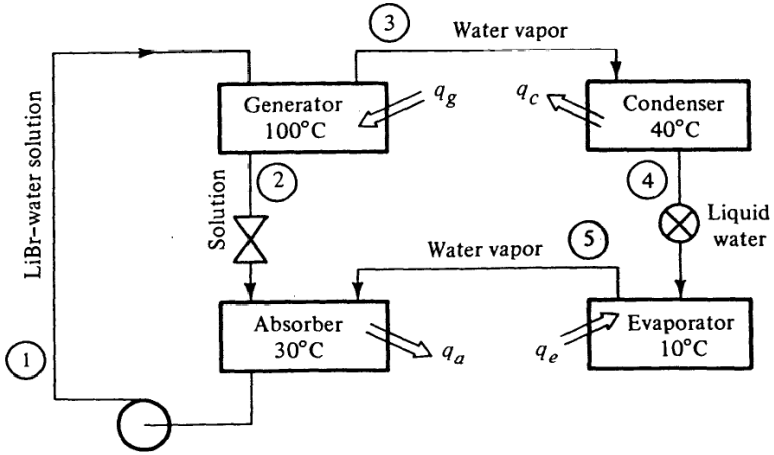
h1 =h at 30°C and x of 50% = -168 kJ/kg and h2 =h at 100°C and x of 66.4% = -52 kJ/kg
The enthalpies of water liquid and vapor are found from water Tables:
h3 = h of saturated vapor at 100°C = 2676.0 kJ/kg h4 = h of saturated liquid at 40°C = 167.5 kJ/kg h5 = h of saturated vapor at 10°C = 2520.0 kJ/kg
The rates of heat transfer at each of the components can now be computed from energy balances:

$Qg = W3h3 + W2h2 - W1h1 = 0.148(2676) + 0.452(-52) - 0.6(-168) = 473.3$ kW
$qc = W3h3 - W4h4 = 0.148(2676 - 167.5) = 371.2$ kW
$qa = W2h2 + W5h5 - W1h1 = 0.452(-52) + 0.148(2520) - 0.6(-168) = 450.3$ kW
$qe = W5h5 - W4h4 = 0.148(2520-167.5) = 348.2$ kW, Finally,

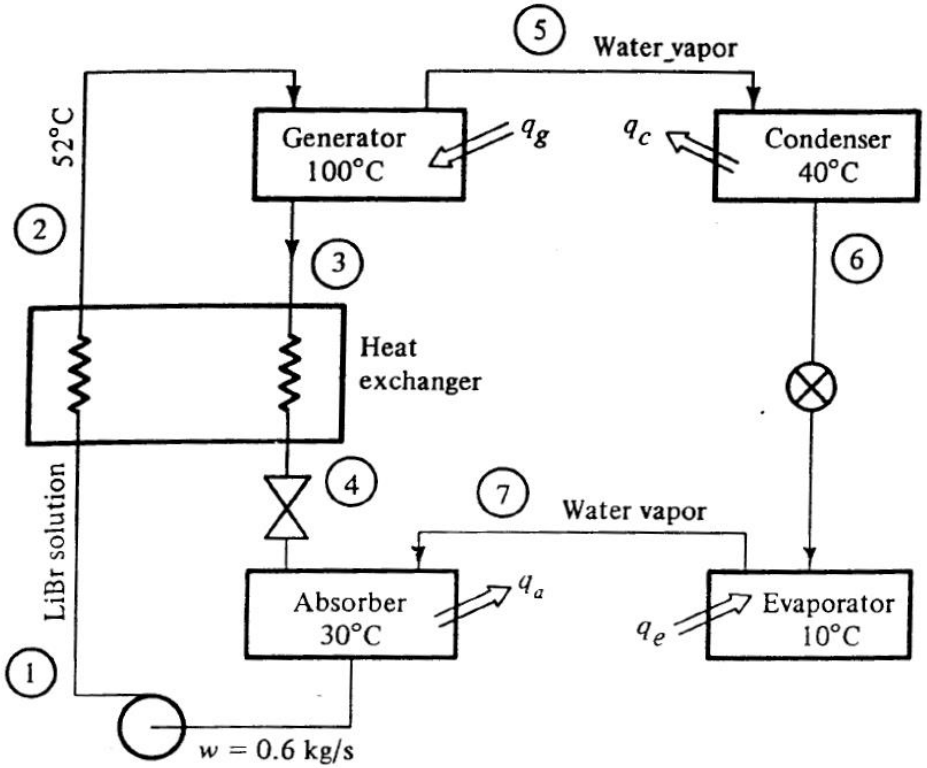
$$\mathrm{COP}_{abs} = \frac{q_e}{q_g} = \frac{348.2}{476.6} = 0.736$$

ABSORPTION REFRIGERATION CYCLES

Absorption cycle with heat exchanger



A logical addition to the simple cycle is a heat exchanger as shown in Fig 9 to transfer heat between the two streams of solutions. This heat exchanger heats the cool solution from the absorber on its way to the generator and cools the solution returning from the generator to the absorber.



ABSORPTION REFRIGERATION CYCLES

Absorption cycle with heat exchanger

Example 4: The simple cycle operating at the temperatures shown in Fig. 6 is modified by the insertion of a heat exchanger, as shown in Fig. 9, such that the temperature at point 2 is 52°C. The mass rate of flow delivered by the solution pump is 0.6 kg/s. What are the rates of energy transfer at each of the components and the COP abs of this cycle?

Certain quantities are unchanged from Examples 2 and 3:
w1 = w2 = 0.6 kg/s w3 = w 4 = 0.452 kg/s
And The enthalpies that remain unchanged are
h1 = -168 kJ/kg
h5 = 2676.0 kJ/kg
h3 = -52 kJ/kg
h6 = 167.5 kJ/kg h7 = 2520.0 kJ/kg
The heat-transfer rates at the condenser and evaporator remain unchanged
qc = 371.2 kW and qe = 348.2 kW

ABSORPTION REFRIGERATION CYCLES

Absorption cycle with heat exchanger

The temperature of the 50% solution leaving the heat exchanger at point 2 is 52°C, and the solution at that condition has an enthalpy of -120 kJ/kg, as indicated by Fig. 8. The rate of heat absorbed by the solution passing from the absorber to the generator q_{hx} is

$q_{hx} = W1\ (h2 - h1) = 0.6[-120 - (-168)] = 28.8$ kW

Since this same rate of heat transfer must be supplied by the solution that flows from the generator to the absorber,

$q_{hx} = 28.8$ kW$= W3(h3 - h4) = 0.452(-52 - h4)$

and so h4 = -116 kJ/kg

Figure 8 shows that the 66.4% solution with an enthalpy of -116 kJ/kg has a temperature of 64°C. The rates of heat transfer in the generator and absorber can now be computed

$q_g = W5h5 + W3h3 - W2h2 = 0.148(2676.0) + 0.452(-52) - 0.6(-120) = 444.5$ kW

and

$qa = W7h7 + W4h4 - W1h1 = 0.148(2520) + 0.452(-116) - 0.6(-168) = 421.3$ kW

The coefficient of performance of the system that incorporates the heat exchanger is

$$COP_{abs} = \frac{q_e}{q_g} = \frac{348.2}{444.5} = 0.783$$

This COP is an improvement over the value of 0.736 applicable to the simple system without a heat exchanger.

ABSORPTION REFRIGERATION CYCLES

Absorption cycle with heat exchanger

Another comparison of interest is that of the absorption cycle to the ideal heat operated cycle whose COP is expressed by Eq below. Equation expects just one temperature of heat rejection, *T0* , while in the absorption cycles just analyzed there are two, 30 and 40°C. Choosing the mean of those two temperatures as the heat rejection temperature gives

$$\text{COP} = \frac{q_e}{q_g} = \frac{WT_r}{T_a - T_r} \frac{T_s - T_a}{WT_s} = \frac{T_r(T_s - T_a)}{T_s(T_a - T_r)}$$

$$\text{COP}_{\text{ideal}} = \frac{(10 + 273.15)\,(100 - 35)}{(100 + 273.15)\,(35 - 10)} = 1.97$$

Therefore, the absorption COP at these conditions is less than half of that of an ideal heat-powered refrigerating unit.

Next: Refrigeration Processes and cycles

References:

- REFRIGERATION & AIR CONDITIONING BY W.F. STOECKER & J.W JHONES

Thank you