Absorption Refrigeration

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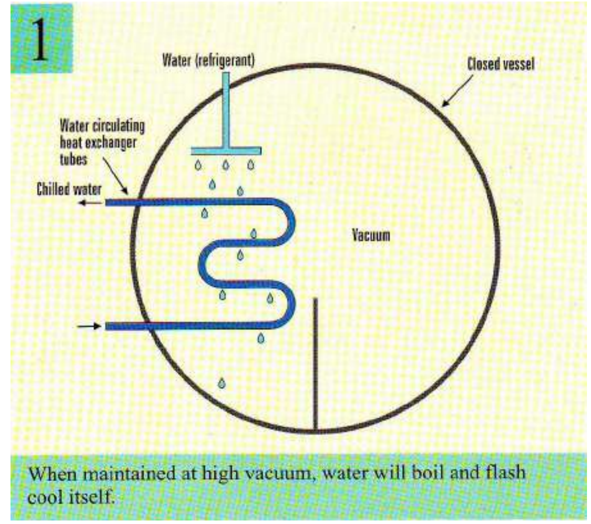
ME 415: Refrigeration & Building Mechanical Systems

Working Principle of VA Refrigeration



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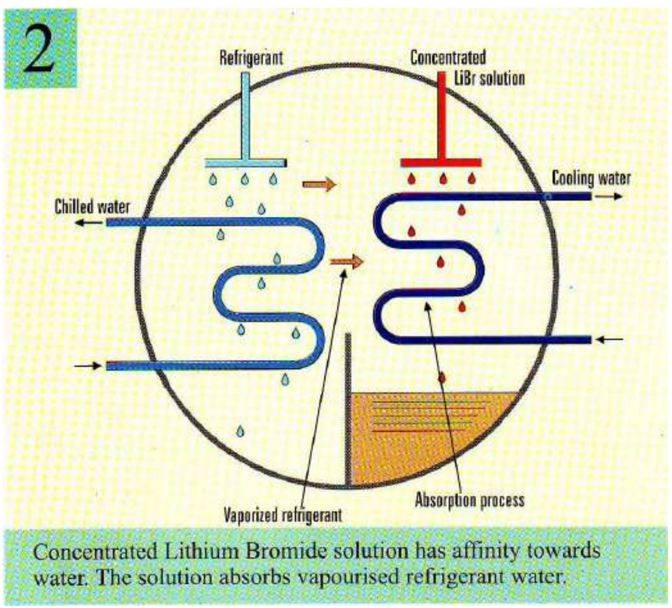

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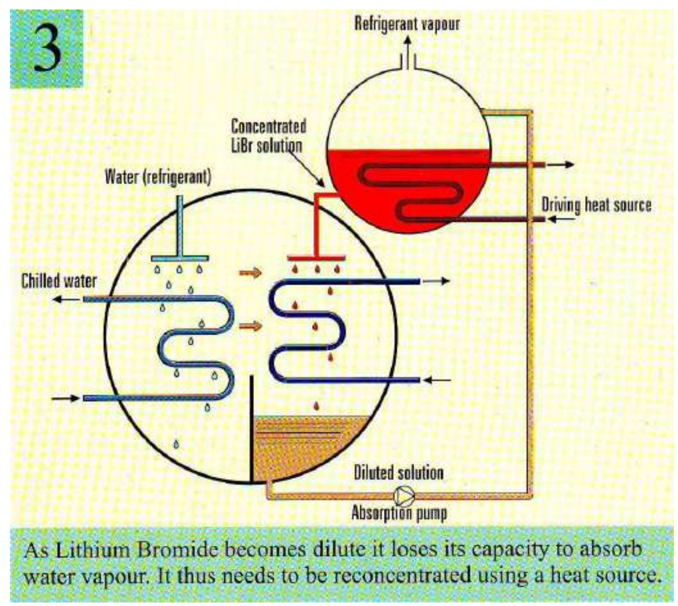

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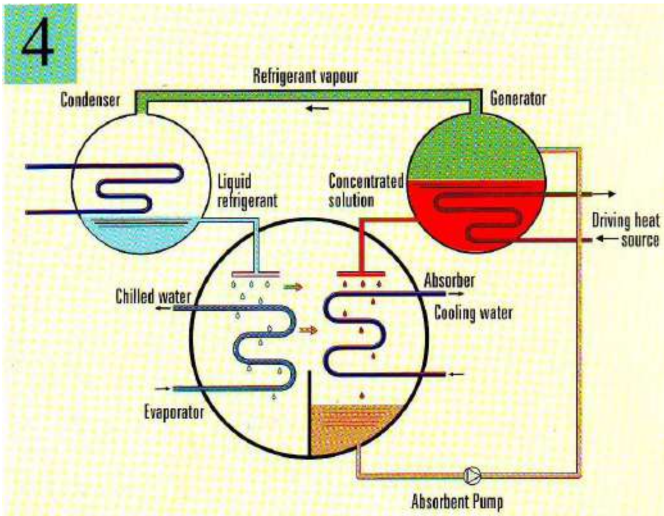

This heat causes the solution to release the absorbed refrigerant in the form of vapour. This vapour is cooled in a separate chamber to become liquid refrigerant.

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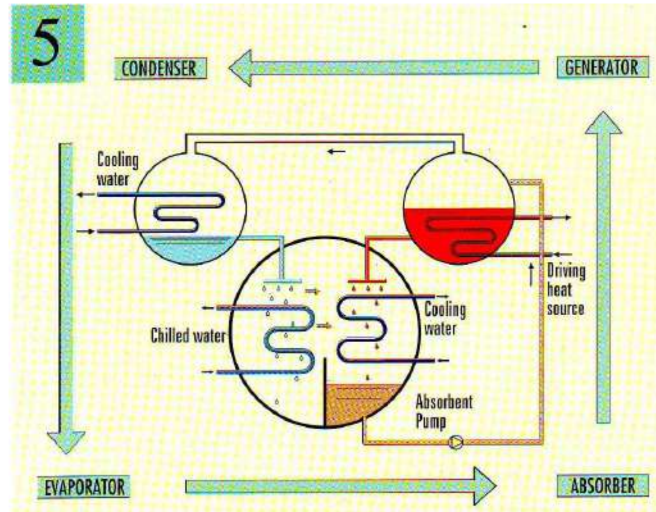

The basic operation cycle of the single effect vapour absorption chiller.

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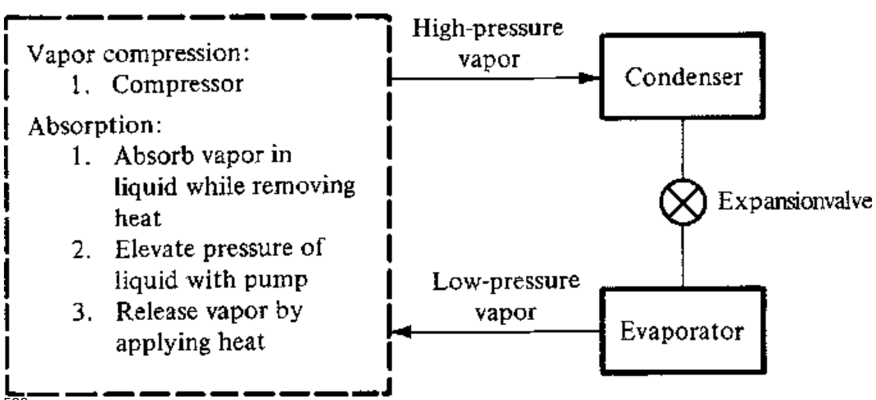
VA & VC Comparison



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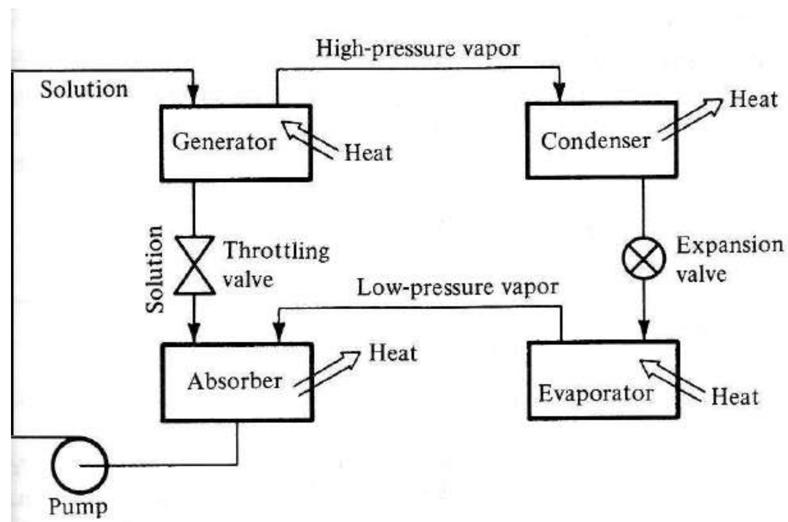
Basic VA System



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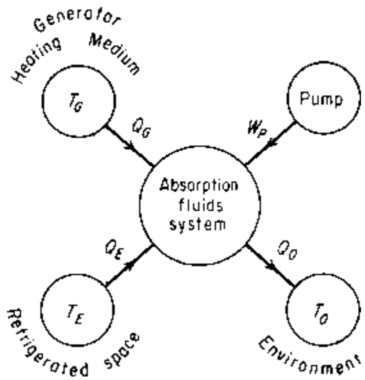

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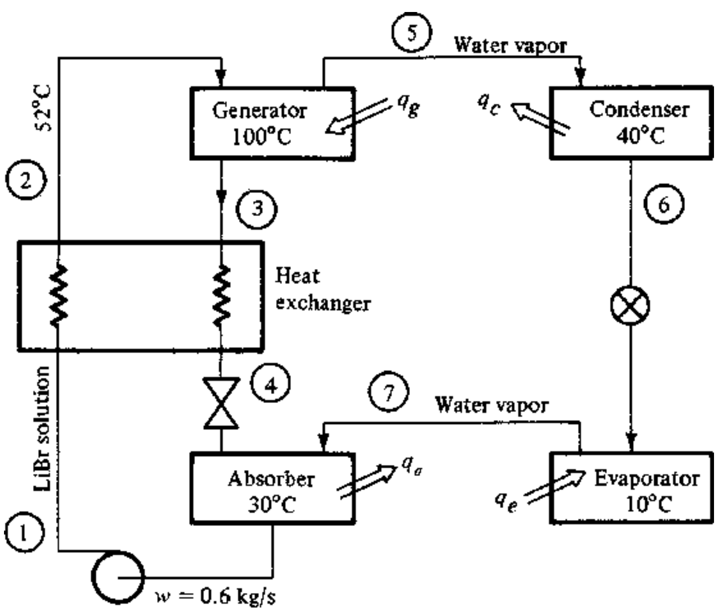
$$COP|_{max} = \frac{T_E}{T_G}\left[\frac{T_G - T_o}{T_o - T_E}\right]$$

$$T_G \uparrow \Rightarrow COP \uparrow, T_E \uparrow \Rightarrow COP \uparrow, T_o \uparrow \Rightarrow COP \downarrow$$

Example

In an absorption system using LiBr, $T_G = 100^oC$, $T_E = 10^oC$, $T_a = 30^oC$, $T_c = 40^oC$. Estimate the values of COP for the following conditions:

1. ideal/Carnot cycle
2. a real cycle if pump delivers 0.6 kg/s solution
3. if a heat exchanger is inserted after the pump and water enters the generator at 52^oC.
4. if condensing temperature is reduced to 34^oC, is there any chance of crystallization?



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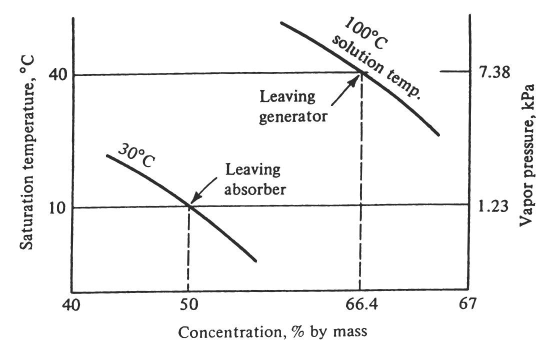
Without heat exchanger, (1) & (2) and (3) & (4) are the same.

1. Carnot cycle: Let, $T_o = (T_a + T_c)/2 = 35^oC$

$$COP = \frac{T_R}{T_G}\left[\frac{T_G - T_o}{T_o - T_R}\right] = \frac{10+273}{100+273}\frac{100-35}{35-10} = 1.97$$

Real Cycles using LiBr: Two pressures exist in the system:

1. High pressure (generator & condenser): $T_C = 40^oC \rightarrow P_H = 7.38$ kPa
2. Low pressure (absorber & evaporator): $T_E = 10^oC \rightarrow P_L = 1.23$ kPa



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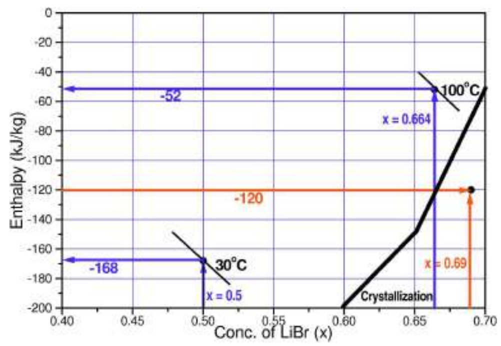
$x_1 = 0.50$ & $x_3 = 0.667$



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Using LiBr solution Chart: $h_1 = -168$ kJ/kg & $h_3 = -52$ kJ/kg

Using Steam Table:

- $h_5 = 2676.0$ kJ/kg, saturated vapour at 100°C
- $h_6 = 167.0$ kJ/kg, saturated liquid at 40°C
- $h_7 = 2520.0$ kJ/kg, saturated vapour at 10°C

2. Without heat exchanger:

- LiBr balance: $m_1 x_1 = m_3 x_3 \implies m_3 = \frac{0.5}{0.667} 0.6 = 0.452$ kg/s
- $m_1 = m_3 + m_5 \implies m_5 = 0.6 - m_3 = 0.148$ kg/s
- $q_g = m_3 h_3 + m_5 h_5 - m_2 h_2 = 473.3$ kW
- $q_e = m_7 h_7 - m_6 h_6 = 348.2$ kW
- $COP = \frac{q_e}{q_g} = 348.2/476.6 = 0.735$

3. 50% Solution leaves heat exchanger at 52°C

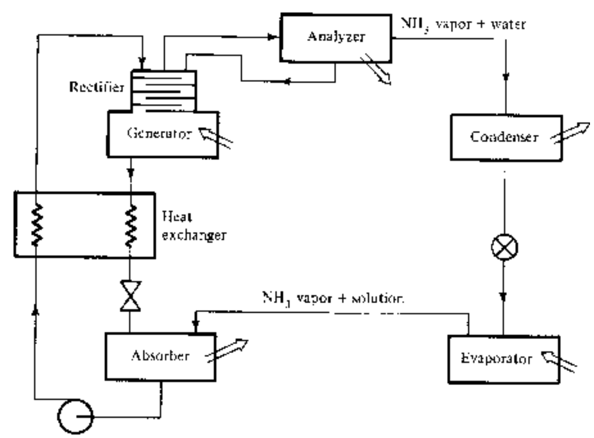
- $h_2(x = 0.50 \text{ \& } 52^o) = -120$ kJ/kg
- $q_g = m_3 h_3 + m_5 h_5 - m_2 h_2 = 444.5$ kW
- $COP = \frac{q_e}{q_g} = 348.2/444.5 = 0.783$

Note that, maximum possible COP is only 1.97, with heat exchanger COP improves from 0.736 to 0.783.

4. T_{cond} is reduced to 34°C:

- if $T_{cond} = 34^oC \Rightarrow P_{HP} = P_{sat} = 5.32$ kPa.
- $\rightsquigarrow x_3 = 0.69 \Rightarrow m_3 = 0.435$ & $m_5 = 0.165$ kg/s
- $h_1 = -168, h_2 = -120$ & $h_3(x = 0.69 \text{ \& } 100^o) = -57$ kJ/kg
- Energy balance in heat exchanger:
  $m_1(h_2 - h_1) = m_3(h_3 - h_4) \rightsquigarrow h_4 = -120$ kJ/kg
- From chart, $x = 0.69$ & $h_4 = -120) \Rightarrow$ crystallized state.
- Crystallization is most likely to occur where the solution from the generator leaves the heat exchanger.
- An operating condition conducive to crystallization is low condensing pressure/temperature. Modern systems maintains higher condensing pressure even when low-temperature condensing water is available to avoid crystallization.

Aqua-ammonia Absorption System



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Rectifier & analyser are used to minimize the presence of water vapour going to condenser and evaporator.

Aqua-ammonia vs. LiBr System

- two systems have comparable COPs.
- aqua-ammonia system can provide temperatures below 0°C, but commercial LiBr systems are limited to temperatures higher than 3°C.
- auqa-ammonia system requires extra components such as rectifier & analyser.
- aqua-ammonia system operates at pressures higher than atmospheric, LiBr systems operate at very low pressures.
- LiBr is very corrosive, hence require special inhibitors.

Problems with Vapour Absorption System

- high initial cost
- shorter life (15 yrs for VA systems, 25 yrs for VC systems.)
- requires more space
- requires more condenser water (4.4 gpm/ton for VA systems, 3.0 gpm/ton for VC systems), high capacity cooling tower and water treatment plant.
- requires chimney.
- require proper maintenance and longer downtime for overhauling.