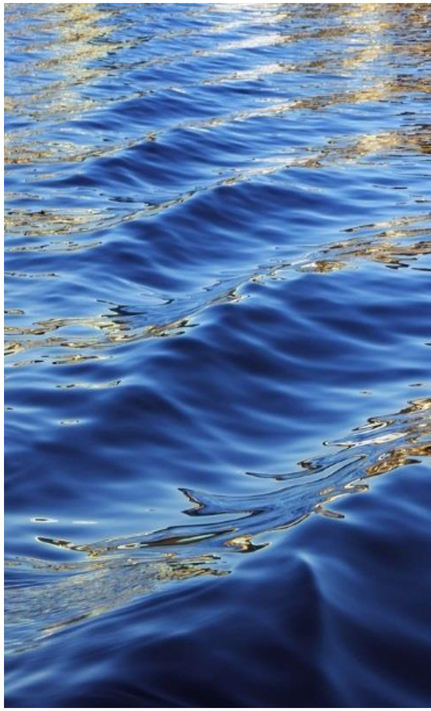
Environmental Thermal Engineering

Lecture Note #6



Professor Min Soo KIM

Absorption Refrigeration System

Backgrounds

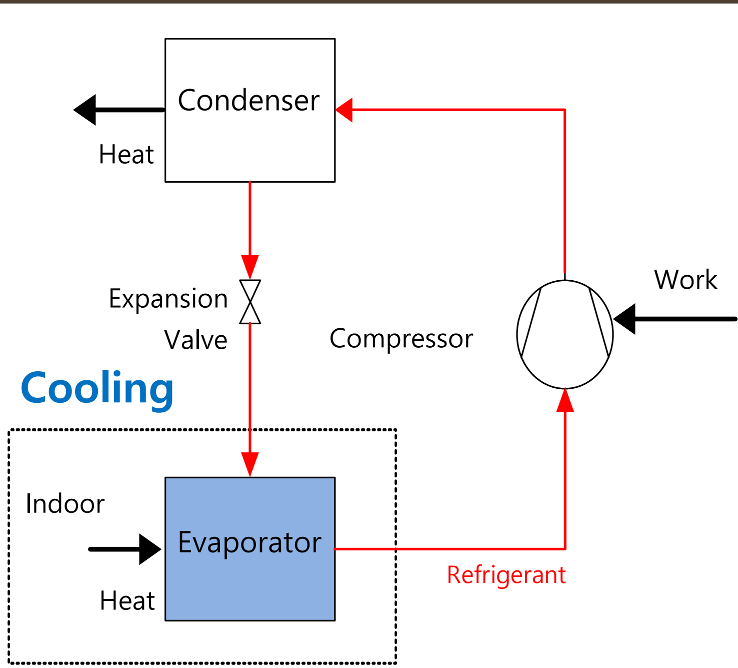
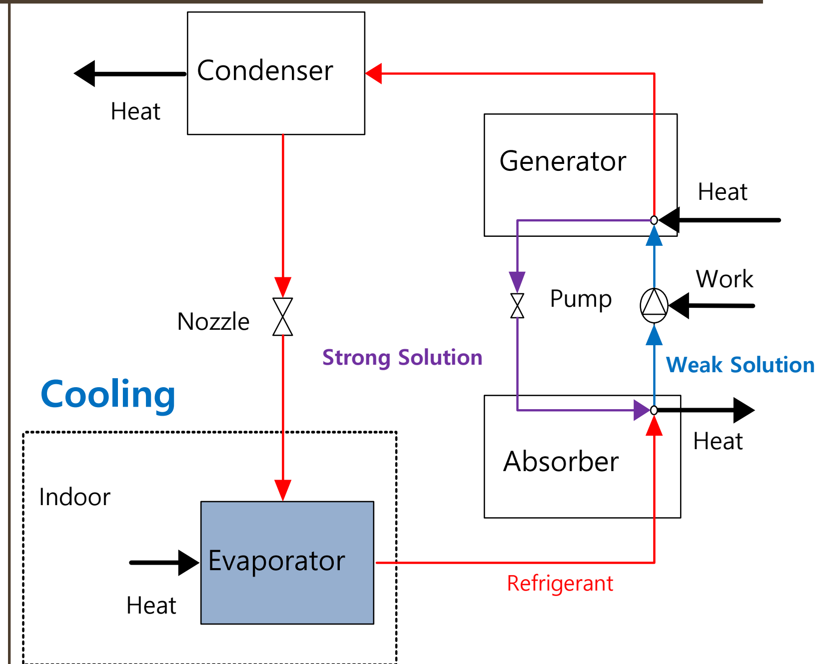
- ❑ **Vapor compression refrigeration system**
  (1) It uses electrical energy for compression work.
  (2) Electrical energy is an advanced energy form.
  (3) It demands a large amount of energy in vapor compression due to the significant change in specific volume.

- ❑ **To increase coolant pressure while minimizing work**
  - Vapor Compression → Liquid Compression

- ❑ **Absorption refrigeration system**
  - Uses natural coolant such as water or ammonia
  - Operates with gases, wasted heated or solar heat

Absorption Refrigeration System

Comparison

Type	Compression (mechanical, electric drive)	Absorption (Chemical, heat-driven)
Diagram		
Energy Source	Electricity	Gas combustion heat, Steam, Hot water
Operating Pressure	Condenser : higher than atmosphere Evaporator : Lower than atmosphere	Vacuum

Refrigerant / Absorbent of Absorption system

Refrigerant / Absorbent

❑ Water Refrigerant System (H_2O/LiBr)

- A binary system based on H2O/LiBr, and a advanced ternary and quaternary system.
- Water has large evaporative latent heat, and high COP and easily acquire.
- Due to large boiling point, it is hard to air cooling.
- It cannot acquire cold heat source below 0℃.
- Due to strong corrosiveness, it is hard to manage solution.
- Recently, water receives attention as coolant/absorber of absorption refrigerating system for solar heat.

❑ Ammonia Refrigerant System (NH_3/H_2O)

- Due to high operating pressure, it needs pressure vessel.
- Ammonia has adequate characteristic for coolant.
- Toxicity, flammable and explosiveness is critical defects.
- Applications : large absorption refrigerating system for industry, small absorption refrigerant system for air conditioning.

❑ Alcohol Refrigerant System

- The latent heat of evaporation is large and the freezing point is lower than that of water.
- Flammability problem.

❑ Halocarbon refrigerant System

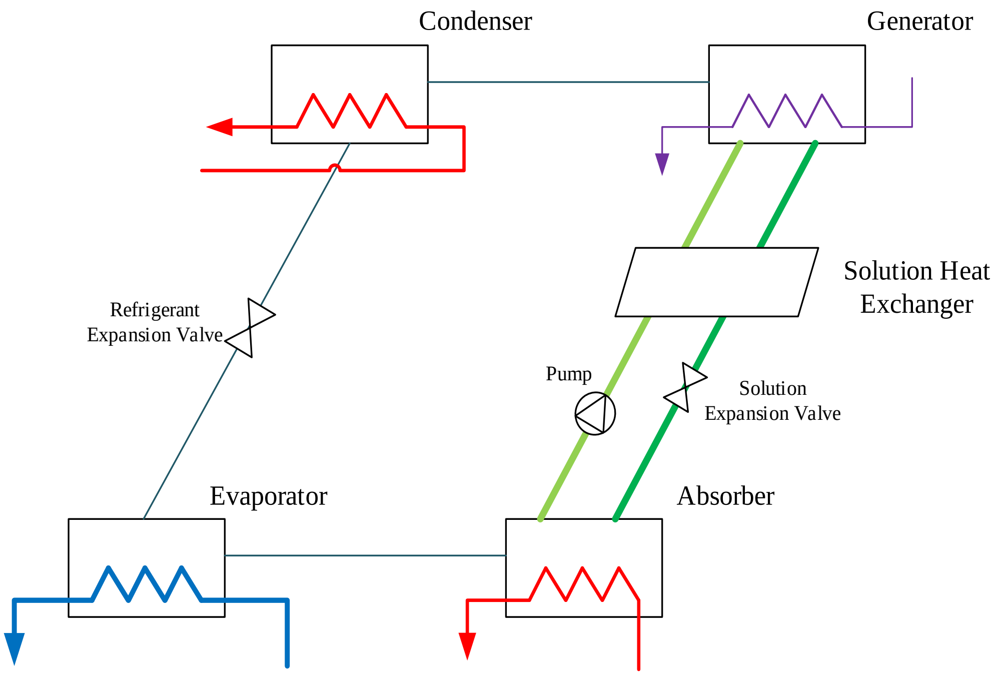
- Use dimethylformide (DMF) as absorbent.
- Refrigerant includes R21, R22, R124, R31, R123, R133a, etc

Comparison

Refrigerant/ Absorbent	NH_3/H_2O	H_2O/LiBr
Refrigerant	NH_3	H_2O
Absorbent	H_2O	LiBr
COP	0.3~0.7 (Single effect)	0.7~1.2 (Single effect)
High Pressure	4~5 bar	0.01bar
Low Pressure	10~15 bar	0.07~0.1 bar
Boiling Point	-33 ℃ at 1 atm	100 ℃
Freezing point	-77℃	0 ℃
Crystallization	N	Y
Piping material	Steal (C.S, S.S)	Steal, Copper tube
O.D.P	N	N
G.W.P	N	N
Toxicity	Y	N
Flammability	Some (Not Explosive)	N

Cycles in Absorption system

Components in Absorption cycle



❑ Absorber

It absolves evaporated refrigerant steam in evaporator and sends regenerator.

❑ Generator

It absolves coolant and heats solution from absorber, so it separates coolant and absorbent. Evaporated coolant is sanded to condenser and absorbent is sanded to absorber

❑ Condenser

It condenses refrigerant steam by heat exchanging with cooling water.

❑ Evaporator

It sprays liquid coolant from condenser on upper part of cooling pipe. Depriving the heat, this liquid is evaporated and sanded to absorber.

Cycles in Absorption System

Components in Absorption cycle

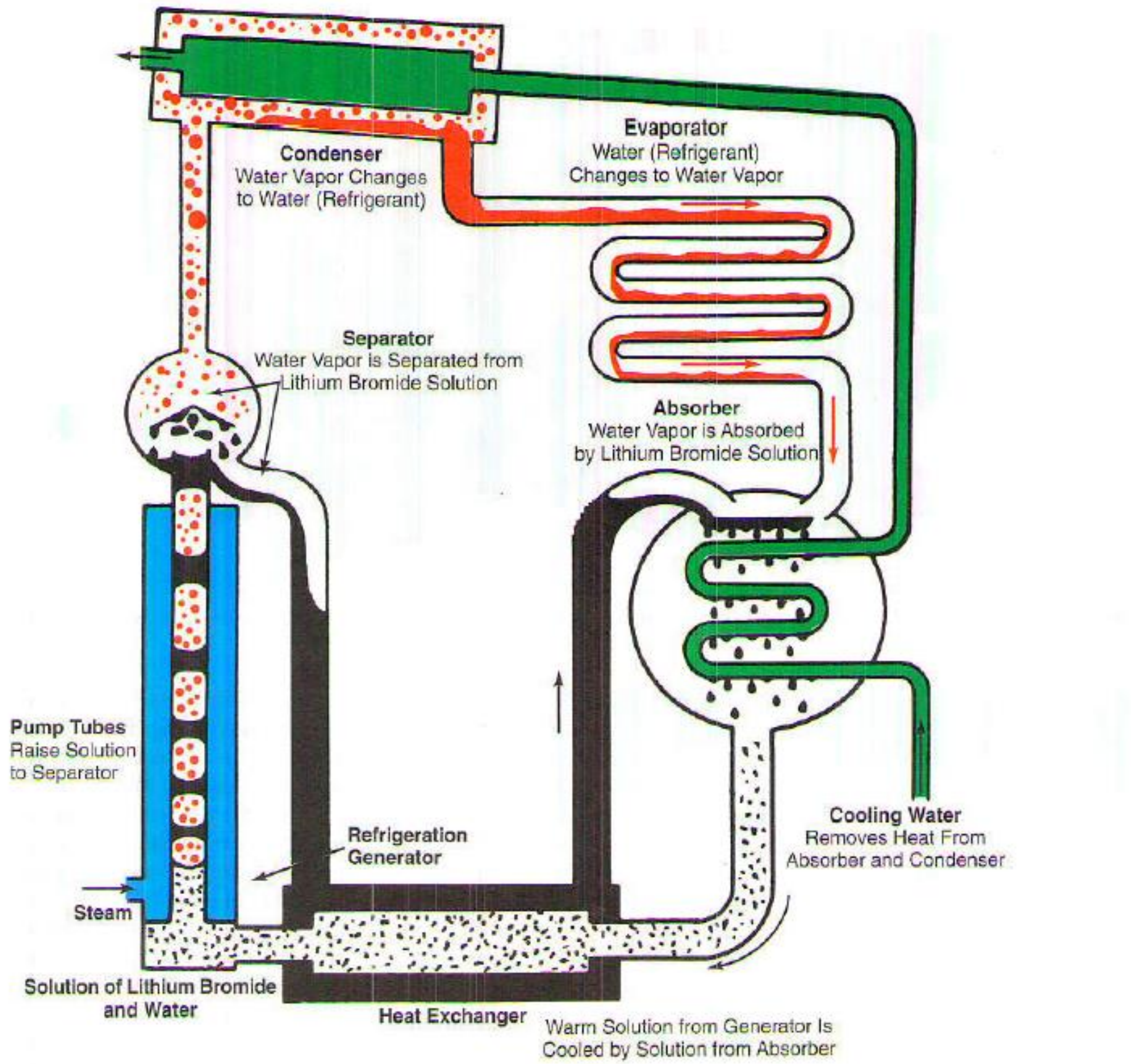


Figure 17-32. *Absorption refrigeration cycle which uses water as refrigerant and lithium bromide as absorber.*

Ref. Modern Refrigeration and Air Conditioning

Principle of Absorption System

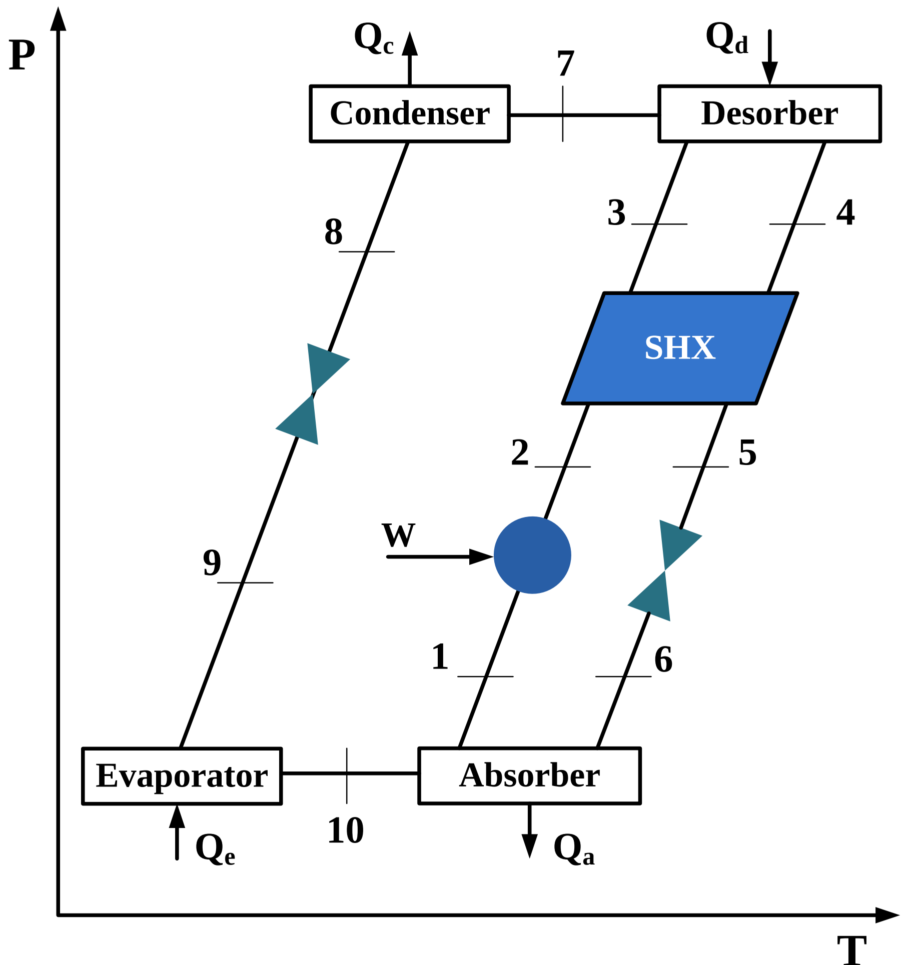


FIGURE Schematics of single effect absorption cycle

- **Absorber:** Water vapor from an evaporator is absorbed into a lithium bromide solution (Strong Solution)
- **1 → 2:** Increase the pressure of the solution by pump
- **2 → 3:** The temperature rises through heat exchange with a dilute solution in the solution heat exchanger.
- **Generator** : Water vapor generation in a high concentration solution by receiving heat (Weak Solution)
- **7 → 8:** Heat exchange with cooling water and steam condensation in Condenser.
- **8 → 9:** Pressure drop through the expansion valve.
- **9 → 10:** Evaporator absorbs external heat and evaporates.
- **10 → 1:** Steam enters Absorber and is absorbed into the lithium bromide solution.
- **4 → 5:** The temperature of the diluted solution decreases through heat exchange with the high concentration solution in the solution heat exchanger.
- **5 → 6:** Pressure drops through the expansion device.

Absorption System (Double Effect, H_2O, LiBr)

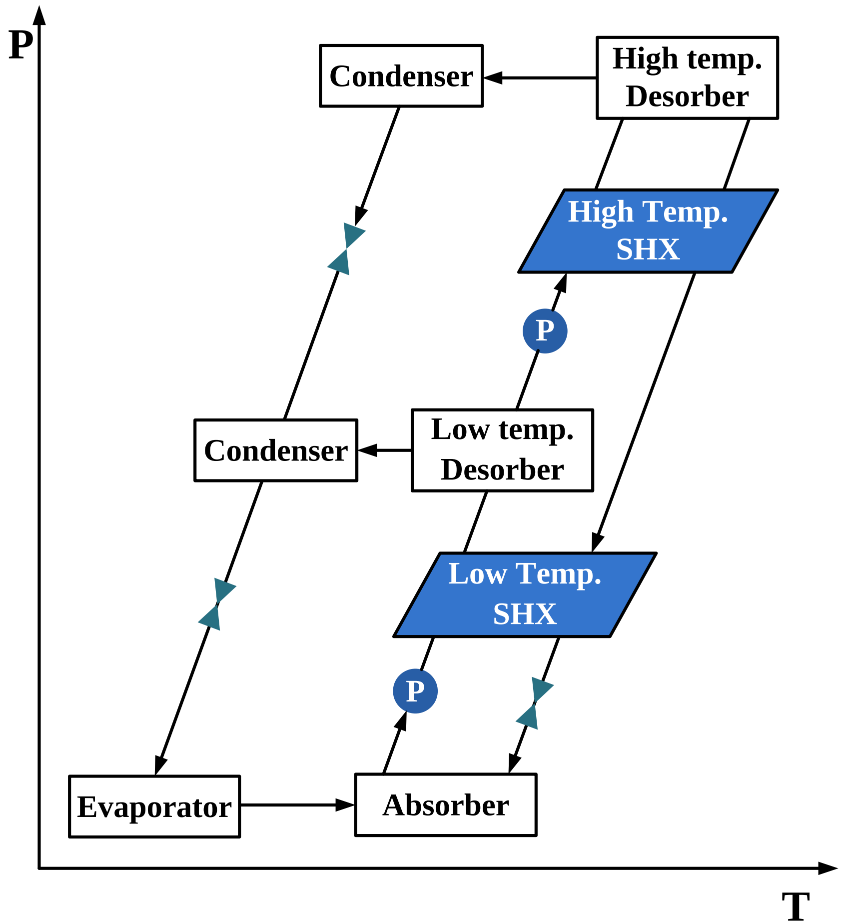


FIGURE Schematics of double effect absorption cycle (Series Flow)

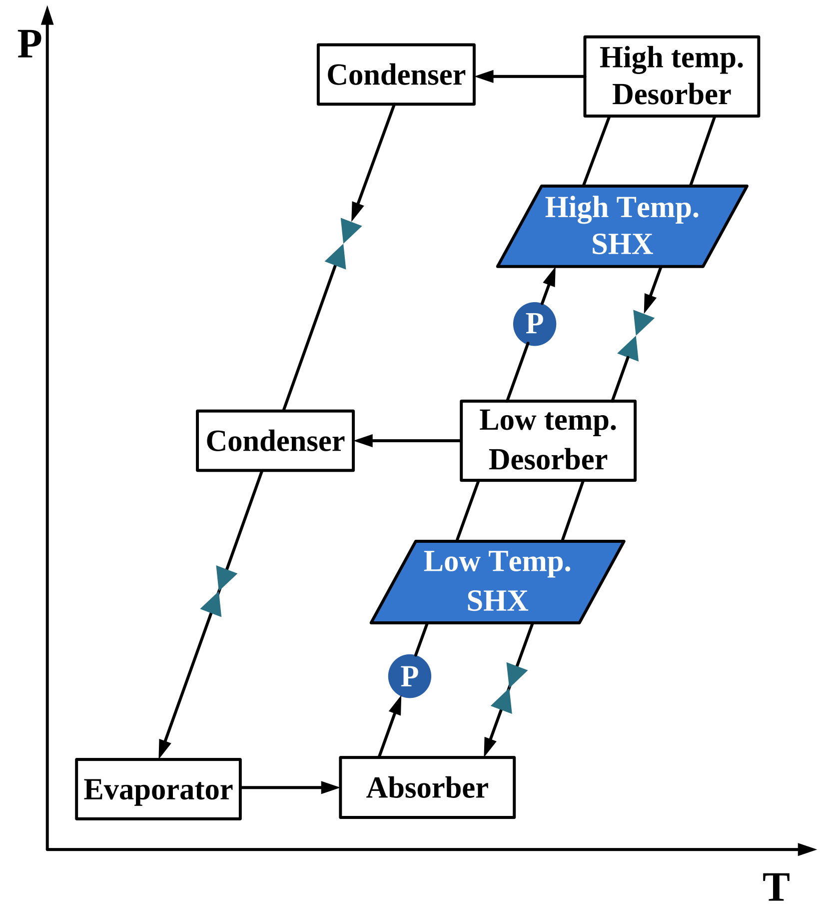


FIGURE Schematics of double effect absorption cycle (Parallel Flow)

Absorption System (Triple Effect, H_2O, LiBr)

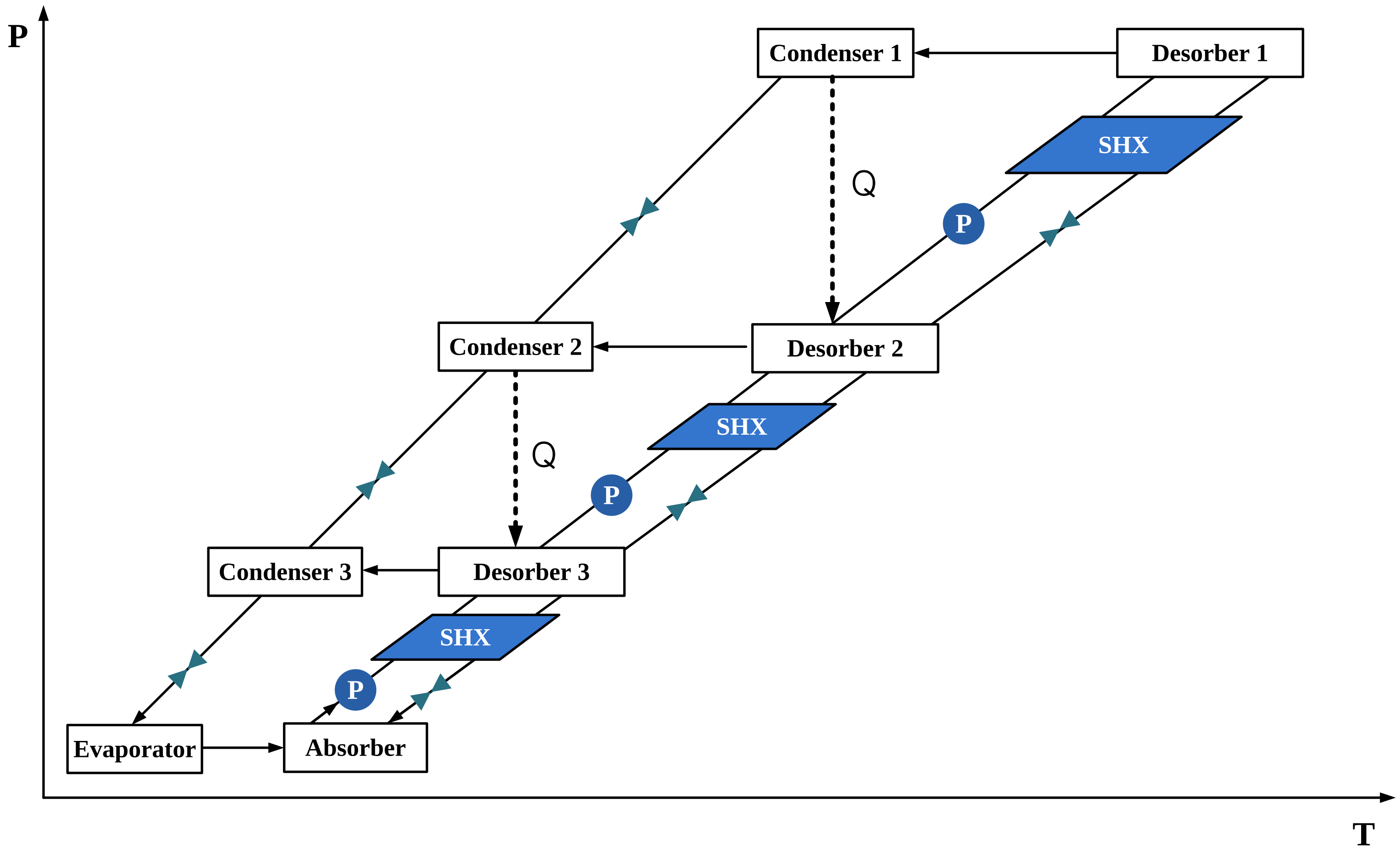


FIGURE Schematics of triple effect absorption cycle

Basic Process of Thermodynamics

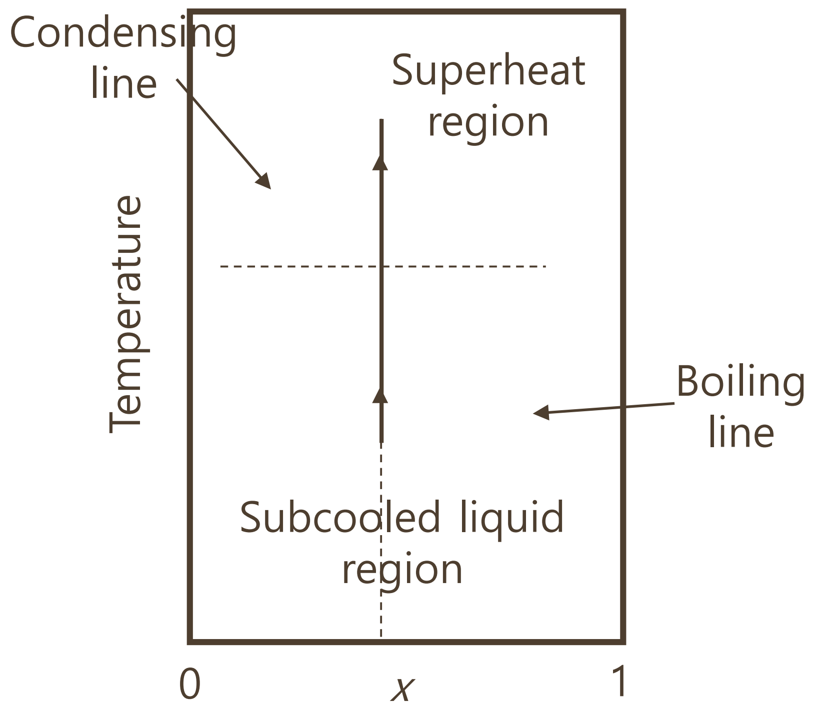


FIGURE T-x diagram of isotropic 2-fluids mixture

- **Isotropic 2-fluid mixture**
  - Uniform composition
  - It does not separated by mechanical ways
  - It needs pressure, temperature and concentration
  - Several saturated temperature in each pressure

h(i)-x diagram

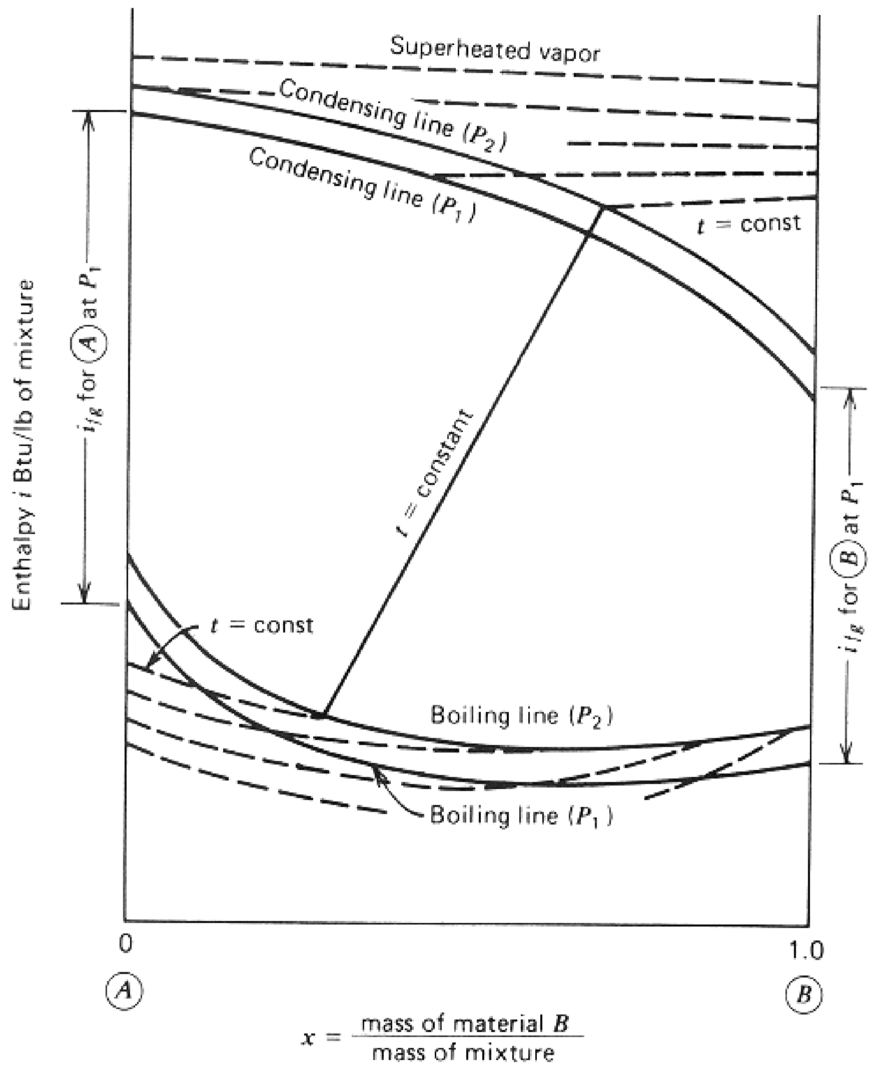
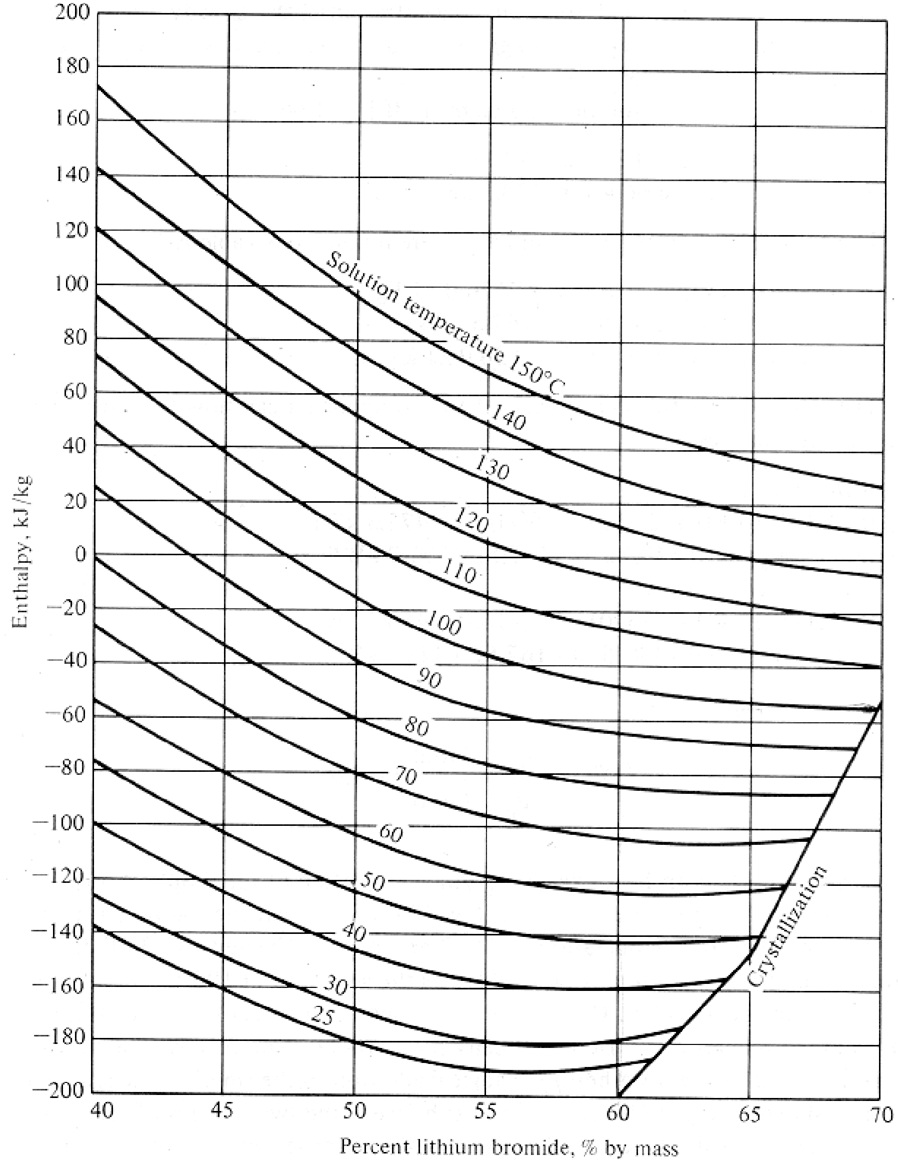


FIGURE h(i)-x diagram of isotropic 2-fluids mixture in liquid-gas region

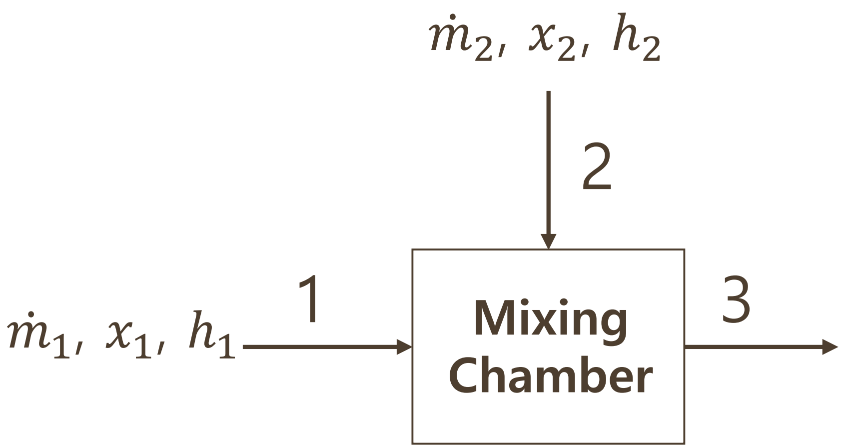
Cycles in Absorption System

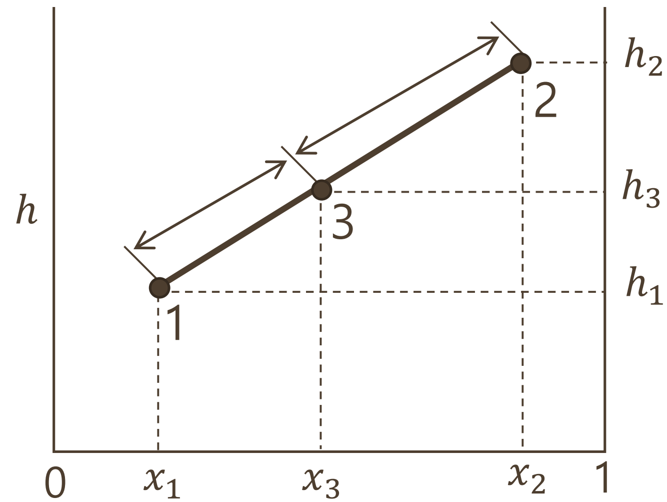
LiBr/H_2O h(i)-x diagram



Cycles in Absorption System

Adiabatic mixing – Two Streams





$$\frac{\dot{m}_1}{\dot{m}_2} = \frac{h_2 - h_3}{h_3 - h_1} = \frac{x_2 - x_3}{x_3 - x_1}$$

$$x_3 = x_1 + \frac{\dot{m}_2}{\dot{m}_3}(x_2 - x_1)$$

$$h_3 = h_1 + \frac{\dot{m}_2}{\dot{m}_3}(h_2 - h_1)$$

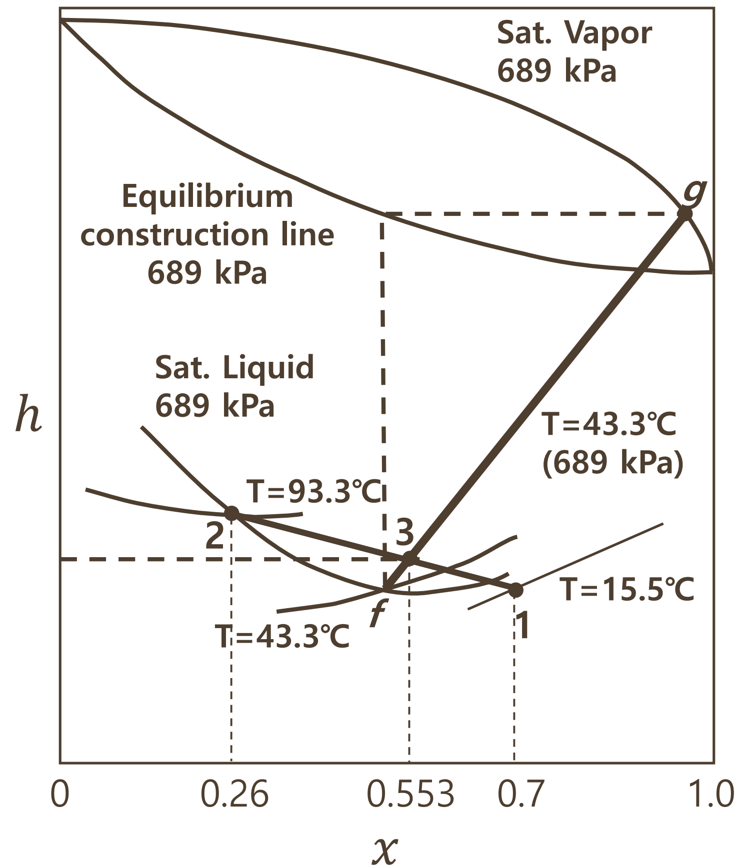
Cycles in Absorption System

Example of Adiabatic mixing

❑ Adiabatic mixing

- **Stream 1 :**
  - x = 0.7
  - 4.54 kg/min
  - 15.5℃
  - 689 kPa

- **Stream 2 :**
  - Saturated Liquid
  - 2.27 kg/min
  - 93.3℃
  - 689 kPa



➢ **A graphical method is used to obtain temperature and the composition of state 3**

Cycles in Absorption System

Heating and Cooling Process

- To increase the purity of the water-ammonia system

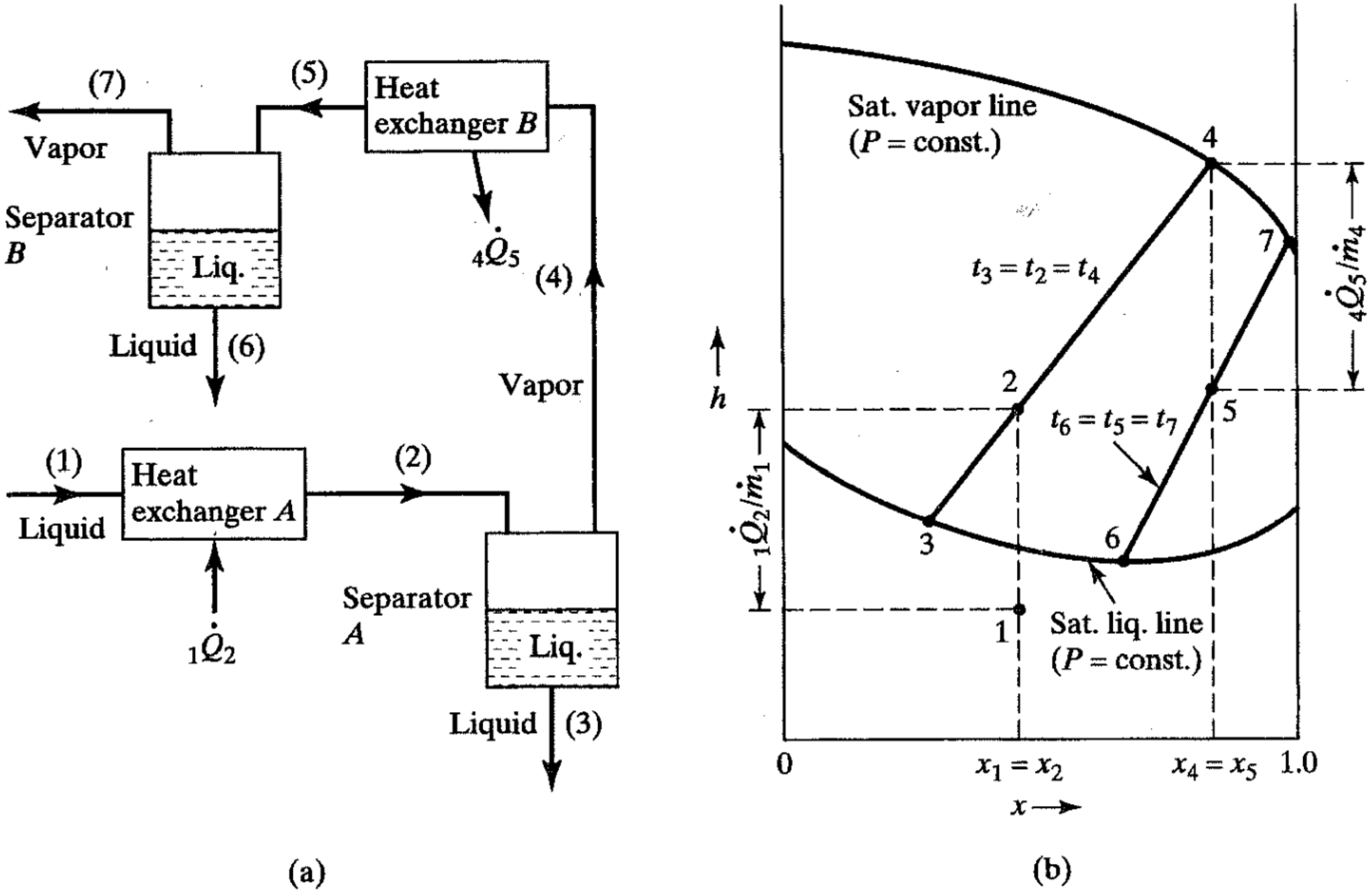


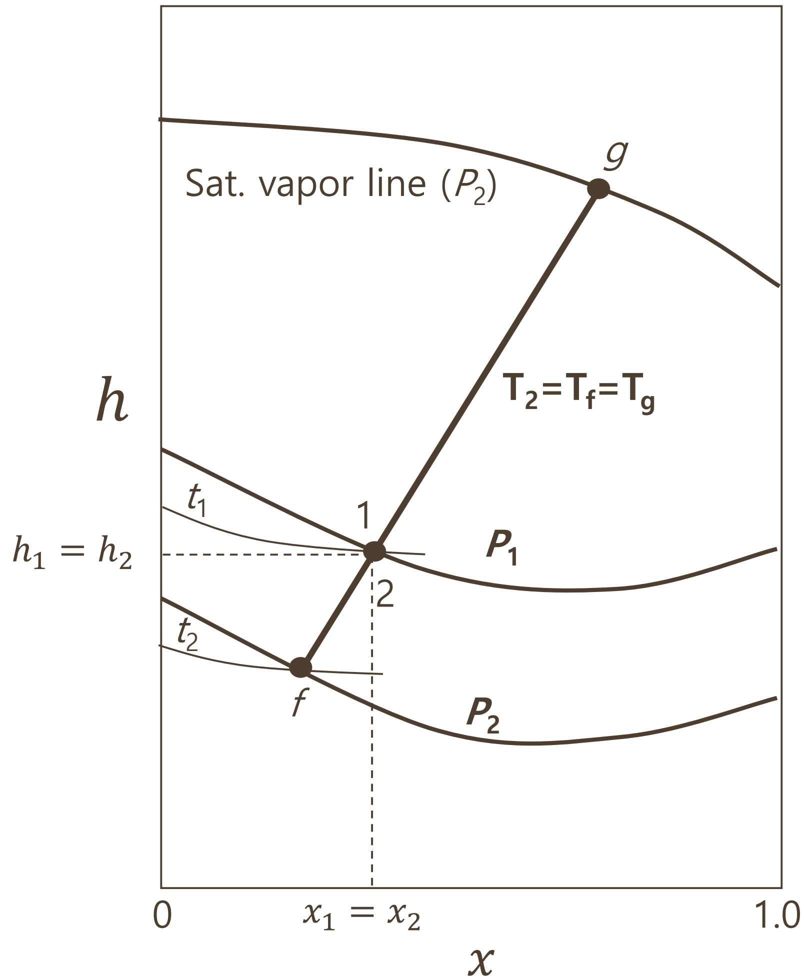
FIGURE Simple heating and cooling processes for steady-flow conditions

Adiabatic Throttling- Binary Liquid Mixture

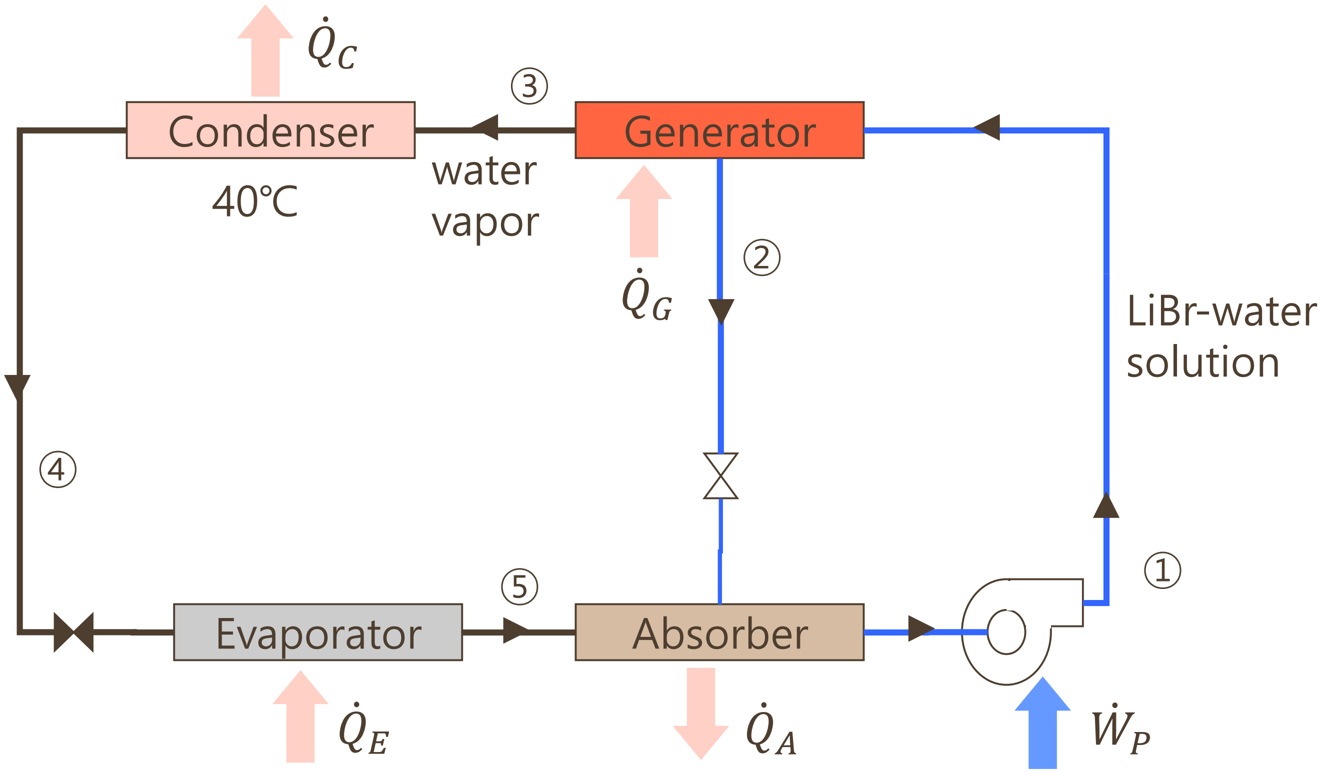
1: High pressure, Saturated solution

2: Low Pressure, Saturated condition

- **Temperature of the final state is obtained using a graphical approach**



Absorption Refrigeration System COP

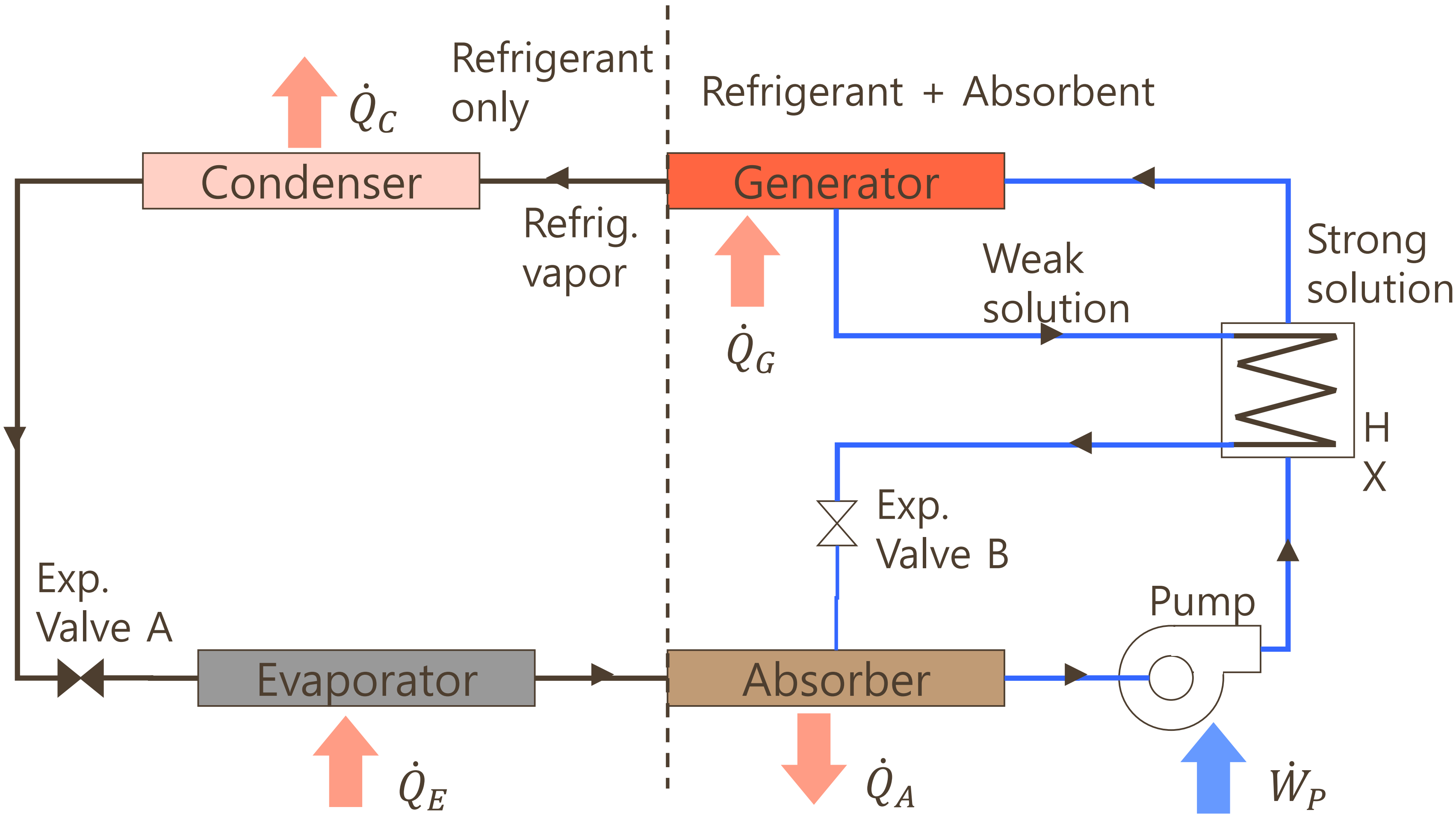


$$\dot{Q}_G = \dot{m}_3 h_3 + \dot{m}_2 h_2 - \dot{m}_1 h_1$$

$$\dot{Q}_E = \dot{m}_5 h_5 - \dot{m}_4 h_4$$

$$COP_{abs} = \frac{\dot{Q}_E}{\dot{Q}_G}$$

Calculation of heat in Absorption Ref. system



Ideal System COP

$$\dot{Q}_A + \dot{Q}_C = \dot{Q}_E + \dot{Q}_G + \dot{W}_P \qquad \dot{Q}_O = \dot{Q}_A + \dot{Q}_C$$

$$\Delta S_G = -\frac{\dot{Q}_G}{T_G} \qquad \Delta S_E = -\frac{\dot{Q}_E}{T_E} \qquad \Delta S_O = \frac{\dot{Q}_O}{T_O}$$

$$\Delta S_{total} = \Delta S_G + \Delta S_E + \Delta S_O = -\frac{\dot{Q}_G}{T_G} - \frac{\dot{Q}_E}{T_E} + \frac{\dot{Q}_O}{T_O} \geq 0$$

$$\dot{Q}_G \frac{T_G - T_O}{T_G} \geq \dot{Q}_E \frac{T_O - T_E}{T_E} - \dot{W}_P$$

$$COP = \frac{\dot{Q}_E}{\dot{Q}_G} \leq \frac{T_E(T_G - T_O)}{T_G(T_O - T_E)}$$

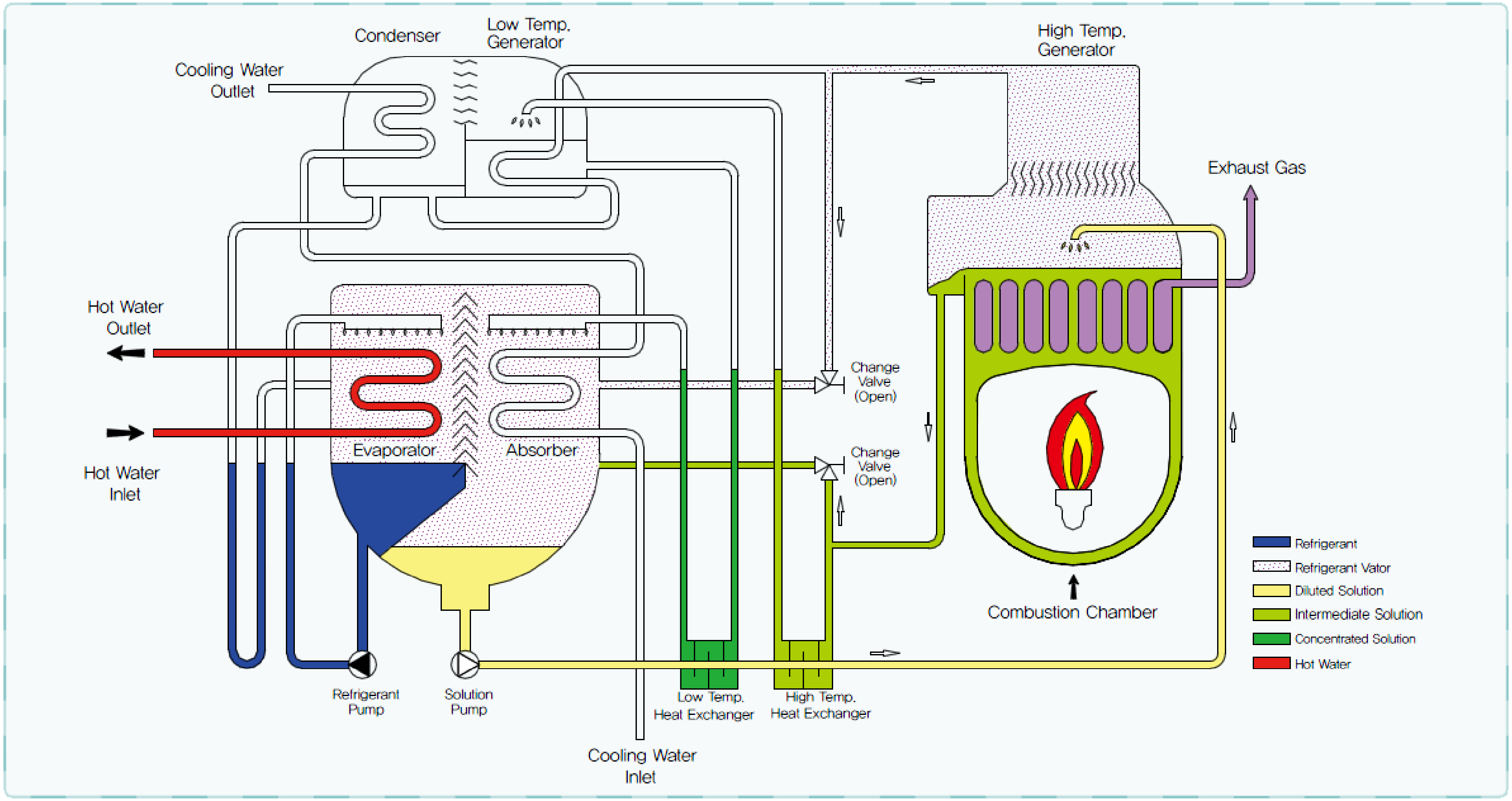
$$COP_{\max} = \frac{T_E(T_G - T_O)}{T_G(T_O - T_E)}$$

Classification of Various Absorption Refrigeration Systems

Classification of Various Absorption Refrigeration Systems

Absorption Chiller

- **Heating Cycle**

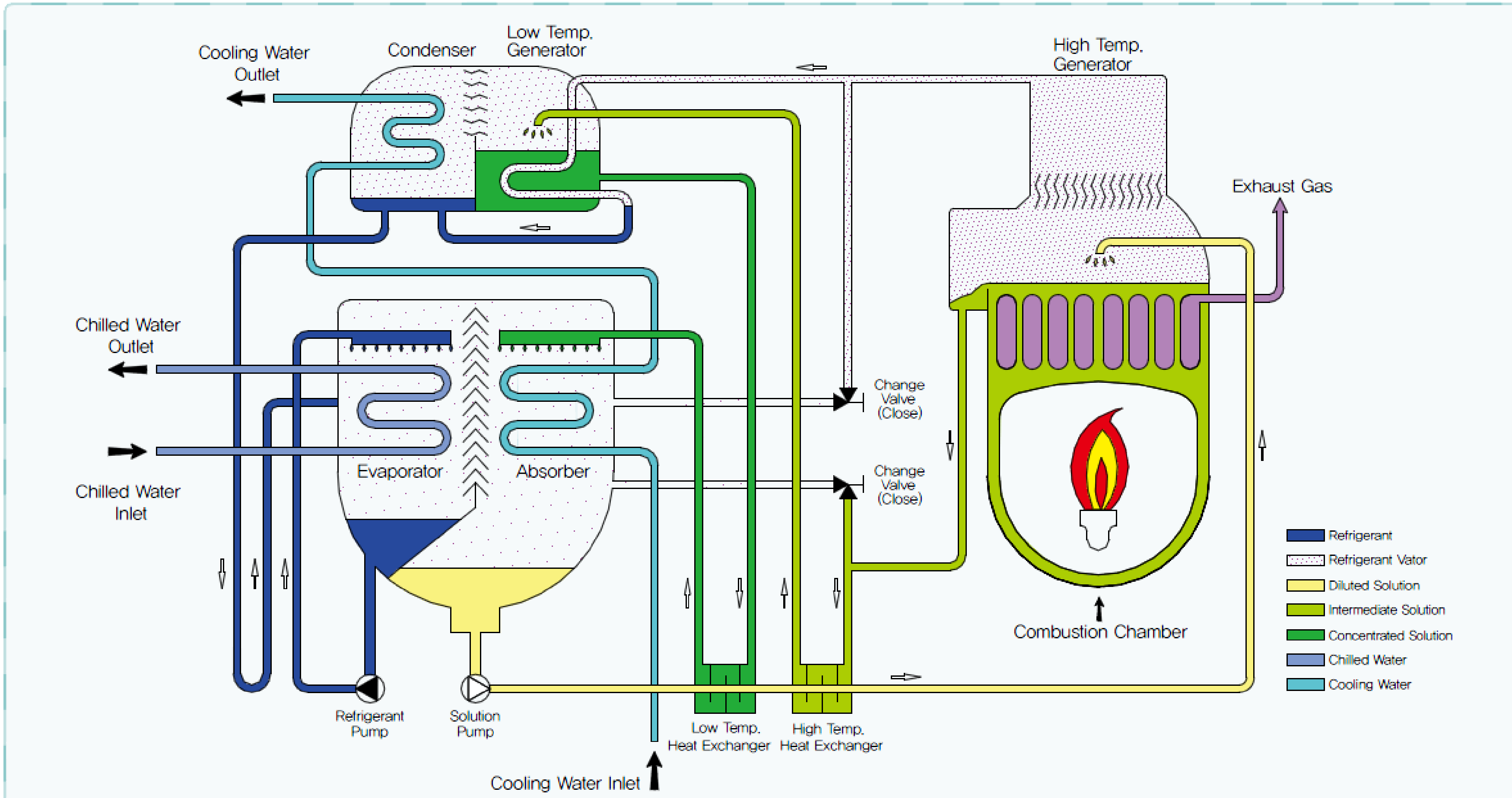


Ref. World energy catalog

Classification of Various Absorption Refrigeration Systems

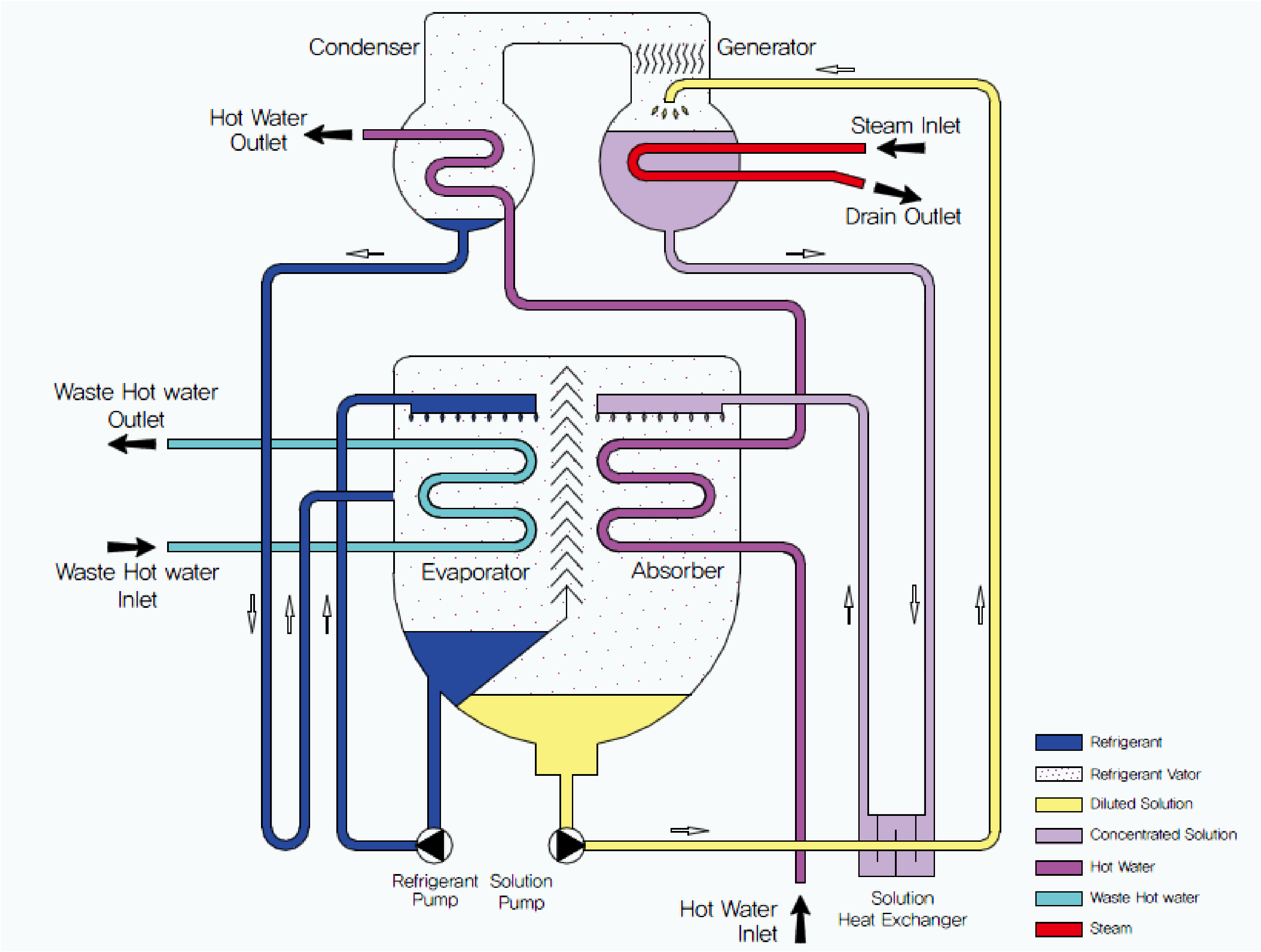
Absorption Chiller

- **Cooling Cycle**



Ref. World energy catalog

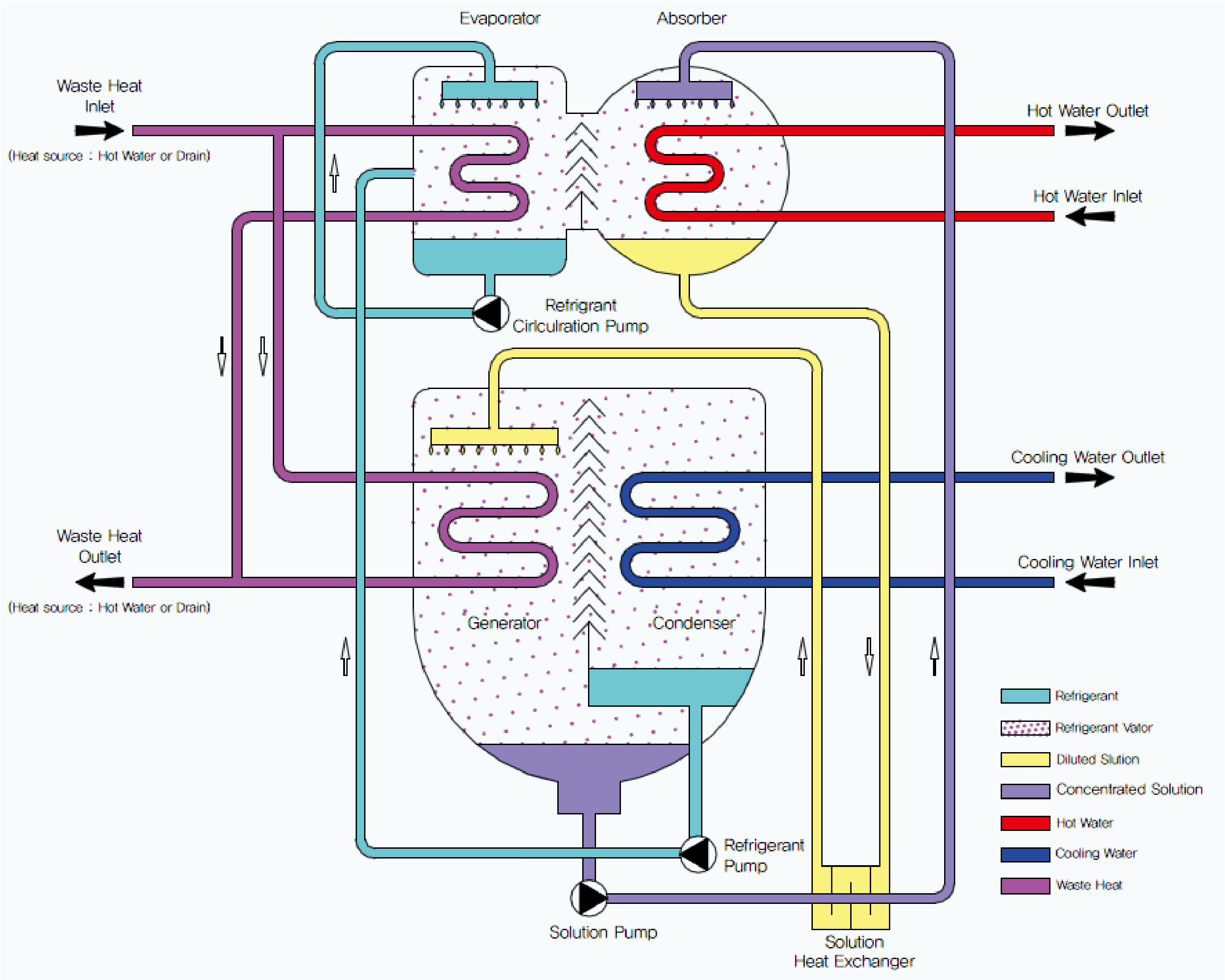
Absorption Heat Pump – Type 1



Ref. World energy catalog

Classification of Various Absorption Refrigeration Systems

Absorption Heat Pump – Type 2



Ref. World energy catalog

Classification of Various Absorption Refrigeration Systems

Water-Ammonia system for Industry

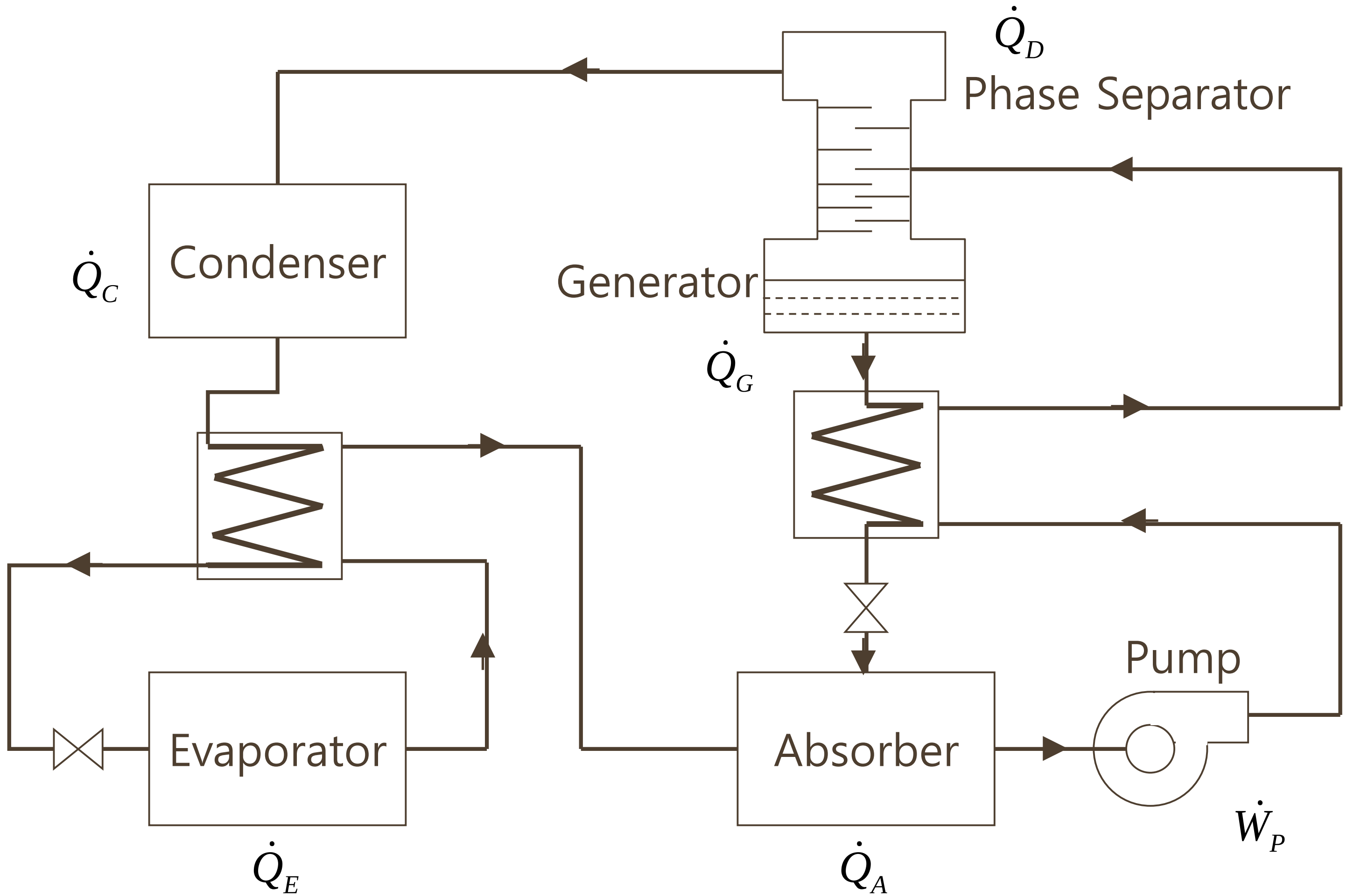


FIGURE Water-Ammonia Absorption refrigerating system for industry

Solar-Powered NH_3/H_2O Absorption System

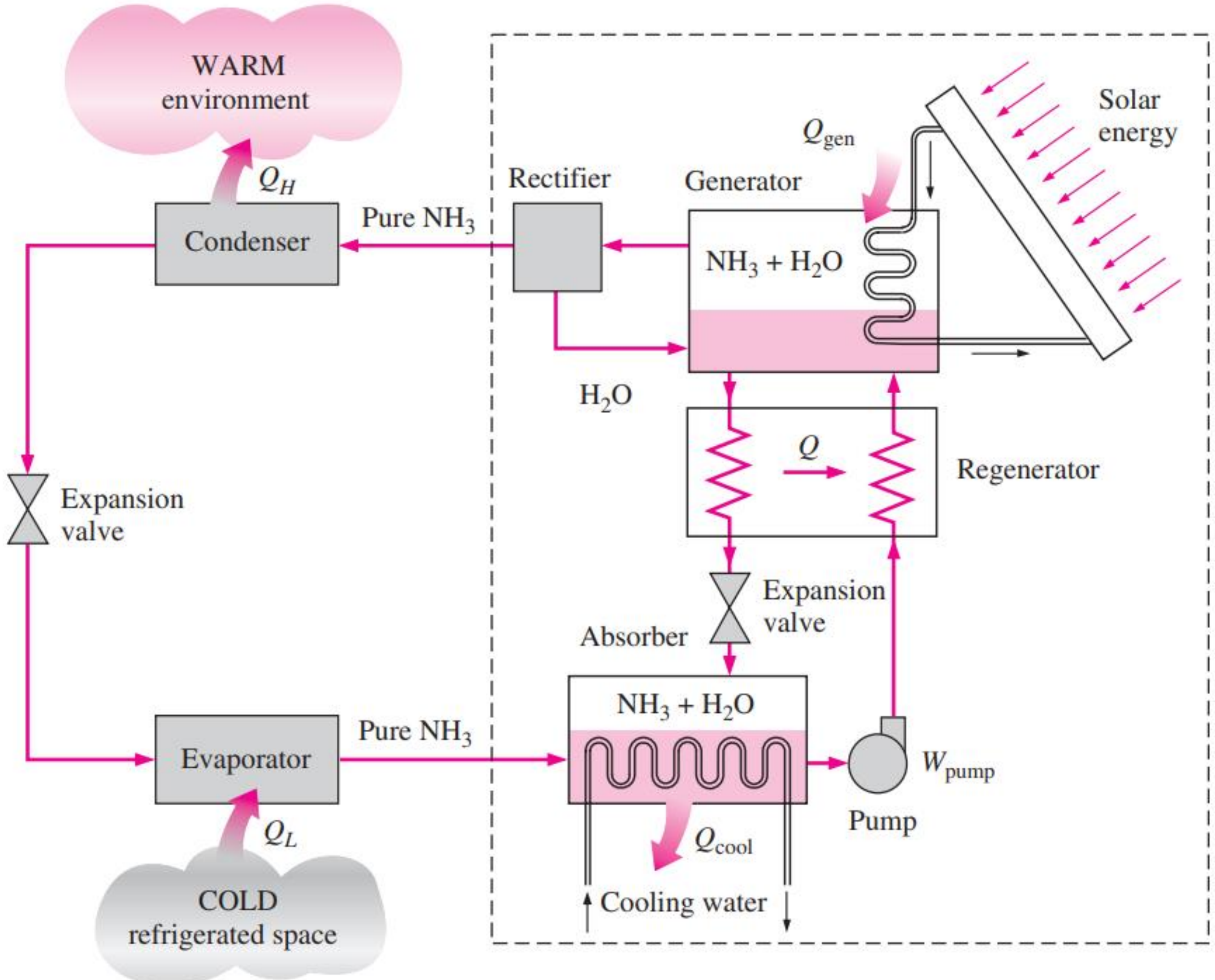


FIGURE Solar-Powered ammonia absorption refrigeration cycle

Ref. Cengel, Boles, Thermodynamics

Question and Answer Session