ME 476
Solar Energy

UNIT SIX

SOLAR ENERGY APPLICATIONS

ABSORPTION REFRIGERATION

Absorption Refrigeration

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- Absorption refrigeration systems belong to the class of vapor cycles similar to vapor compression refrigeration systems.
- However, unlike vapor compression refrigeration systems, the required input to absorption systems is in the form of heat.
- Hence these systems are also called as heat operated.
- Since these systems run on low-grade thermal energy, they are preferred when low-grade energy such as waste heat or solar energy is available.
- Since conventional absorption systems use natural refrigerants such as water or ammonia they are environment friendly.

Absorption Refrigeration

Advantages

- Natural, environmentally-friendly refrigerants (e.g. water, ammonia).
- Minimal use of electric power (heat-operated).

Disadvantages

- Lower COP than vapor compression systems.
- Physically larger equipment.
- Higher capital cost.
- Possibility of corrosion problems.

Commercial Absorption Refrigeration Systems

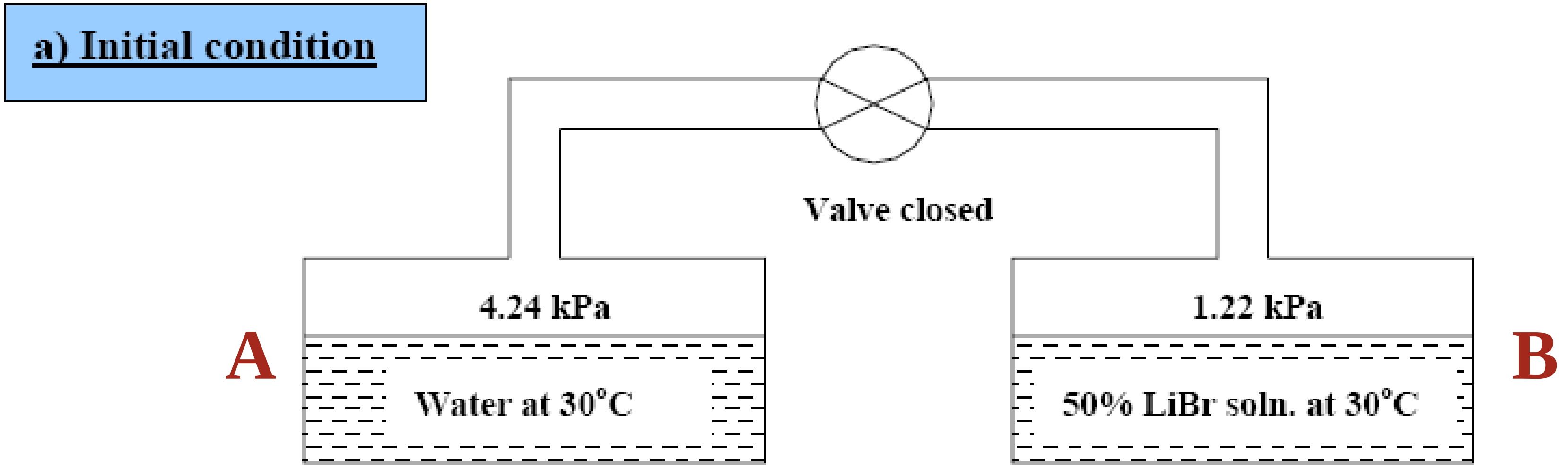
Most commercially available absorption refrigeration systems use one of the two following refrigerant-absorbent pairs:

- Water (refrigerant) + Lithium-Bromide/Water Solution (absorbent)

- Ammonia (refrigerant) + Water/Ammonia Solution (absorbent)

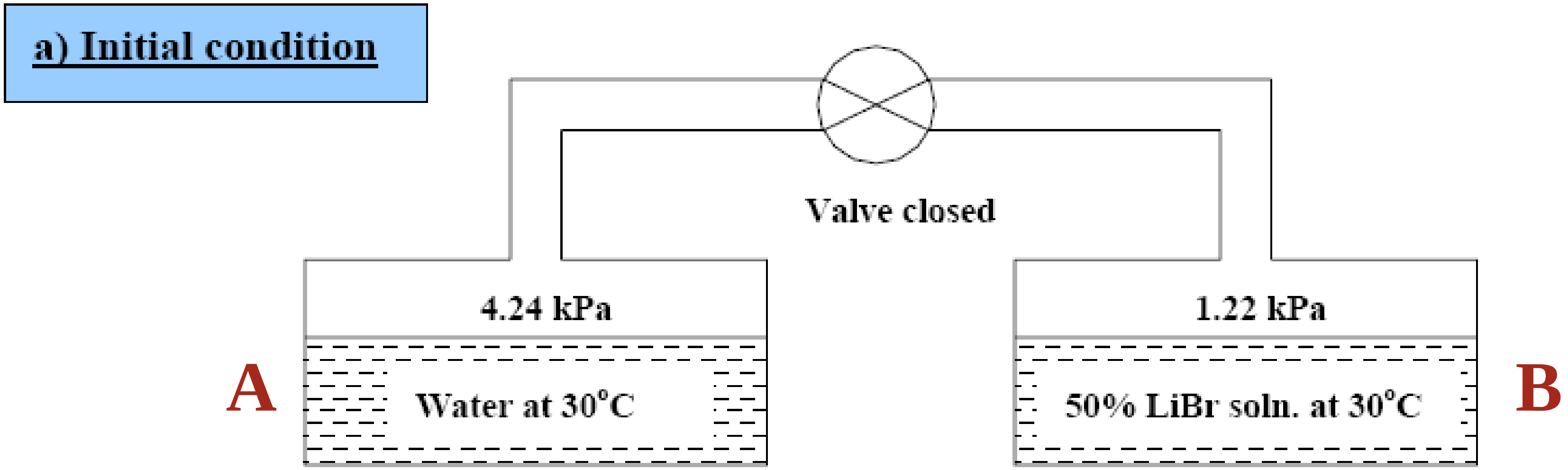
Basic Principles

- In the following example, we will consider an absorption system with water as the pure solvent and lithium bromide/water mixture as the solution.
- Consider two vessels, Vessel A containing pure solvent (water) and Vessel B containing a 50% LiBr/Water solution.



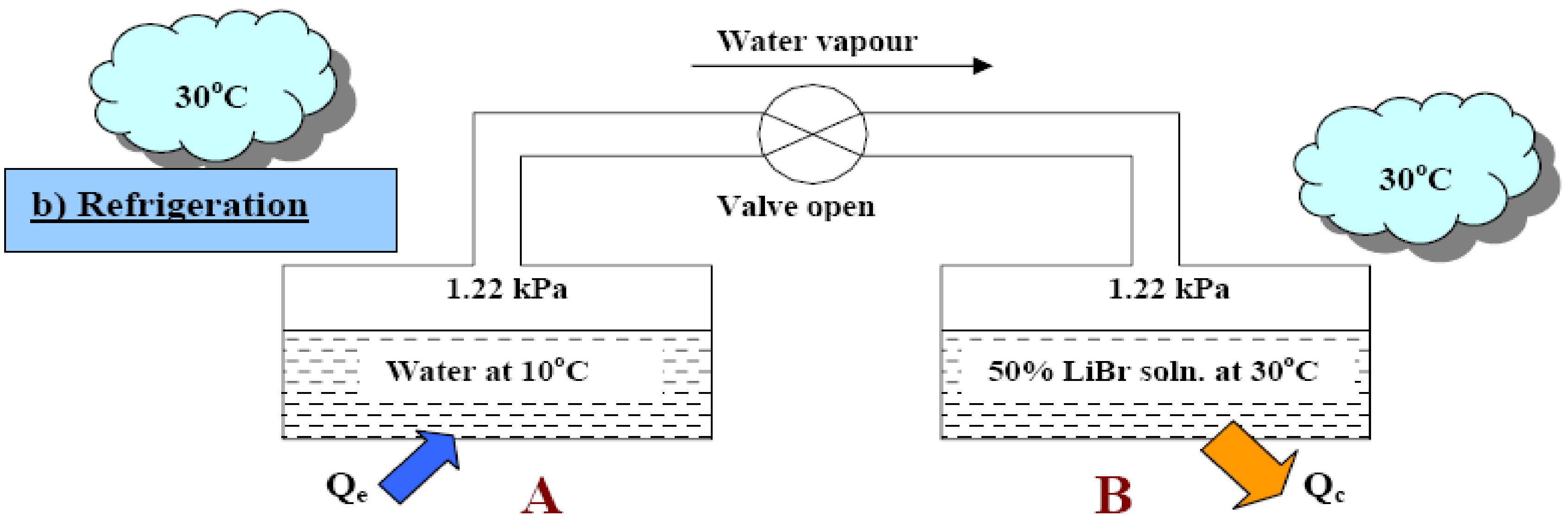
Basic Principles

- Initially, the two vessels are disconnected and the temperature is the same in both vessels.
- In this case, the vapor pressure of water in Vessel A is greater than in Vessel B.
- This is a natural characteristic of the two substances.



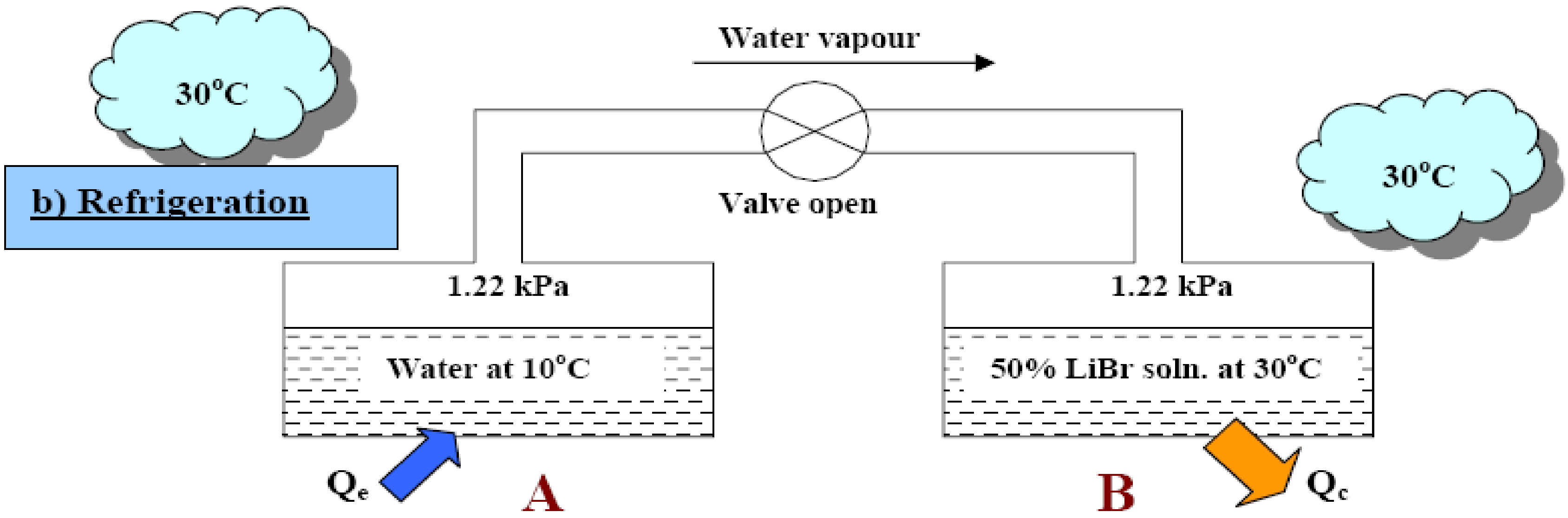
Basic Principles

- If the two vessels are connected, and the vapor pressure of the LiBr/water solution needs to be maintained, the temperature of the pure solvent will have to drop.
- If the solution is at ambient temperature, the pure solvent (water) will be at a temperature lower than the ambient.
- Hence refrigeration effect is produced at Vessel A due to this temperature difference.

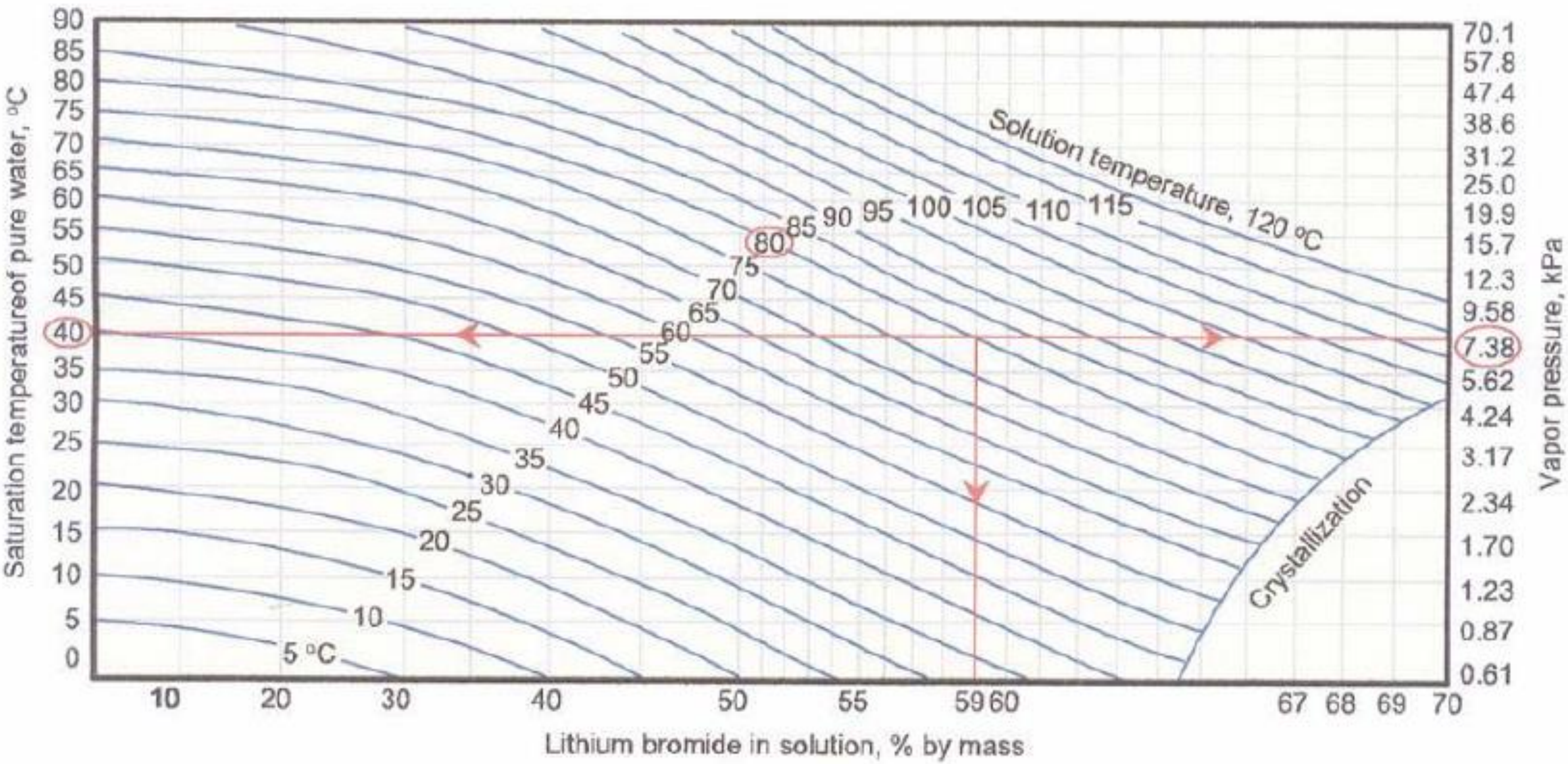


Basic Principles

- The pure solvent (water) absorbs heat from the surroundings, evaporates, flows to Vessel B, and is absorbed by the solution.
- To maintain the temperature of Vessel B, heat must be rejected



Pressure-Temperature-Concentration Diagram



Concentration (*x*) is defined as: $$x = \frac{m_{\text{LiBr}}}{m_{\text{LiBr}} + m_{\text{water}}}$$

Basic Principles

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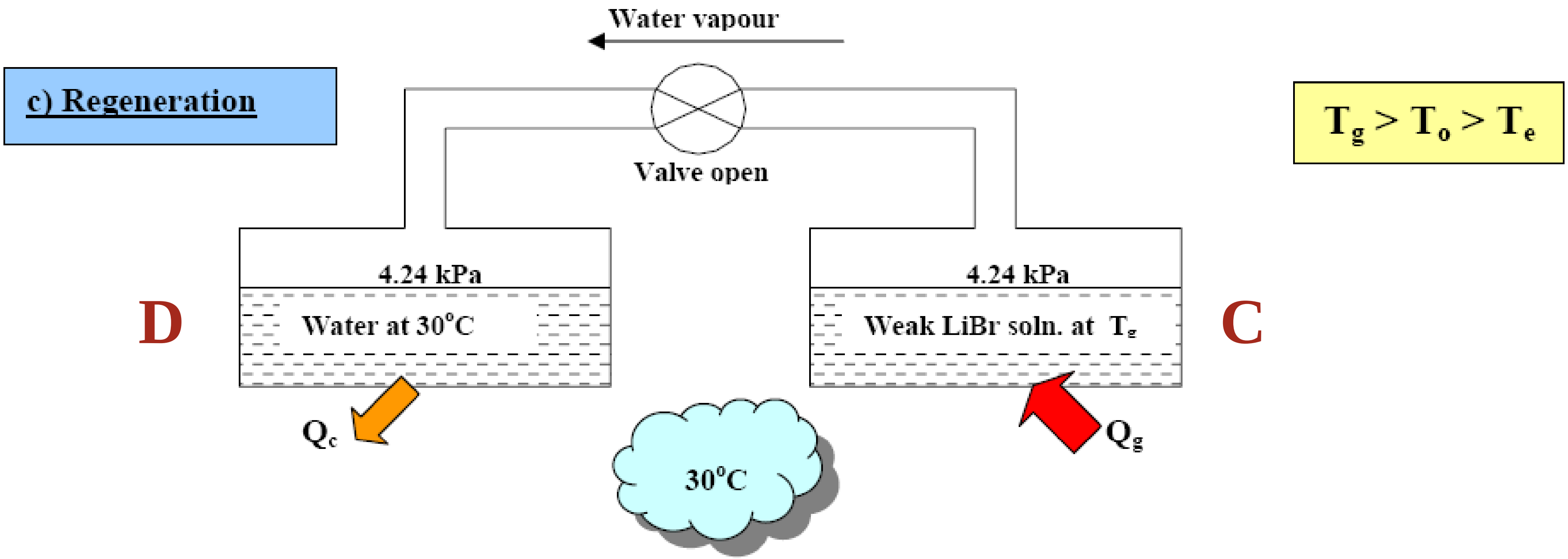
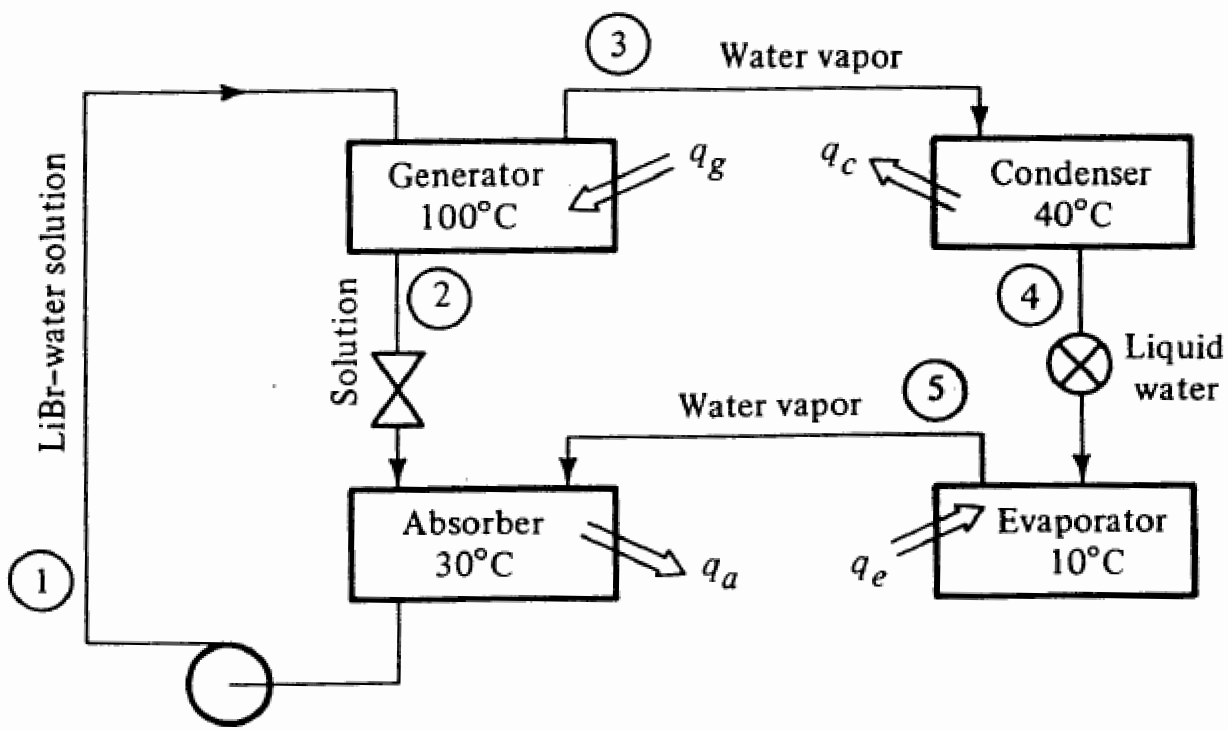
- One the other hand, consider Vessel C containing a LiBr/water solution and Vessel D containing pure solvent (water).
- Vessel C receives heat from an external source.
- LiBr/water solution drives off some of the water vapor.
- This water vapor passes to Vessel D.
- In Vessel D, the water vapor is condensed at a lower temperature by rejecting heat.



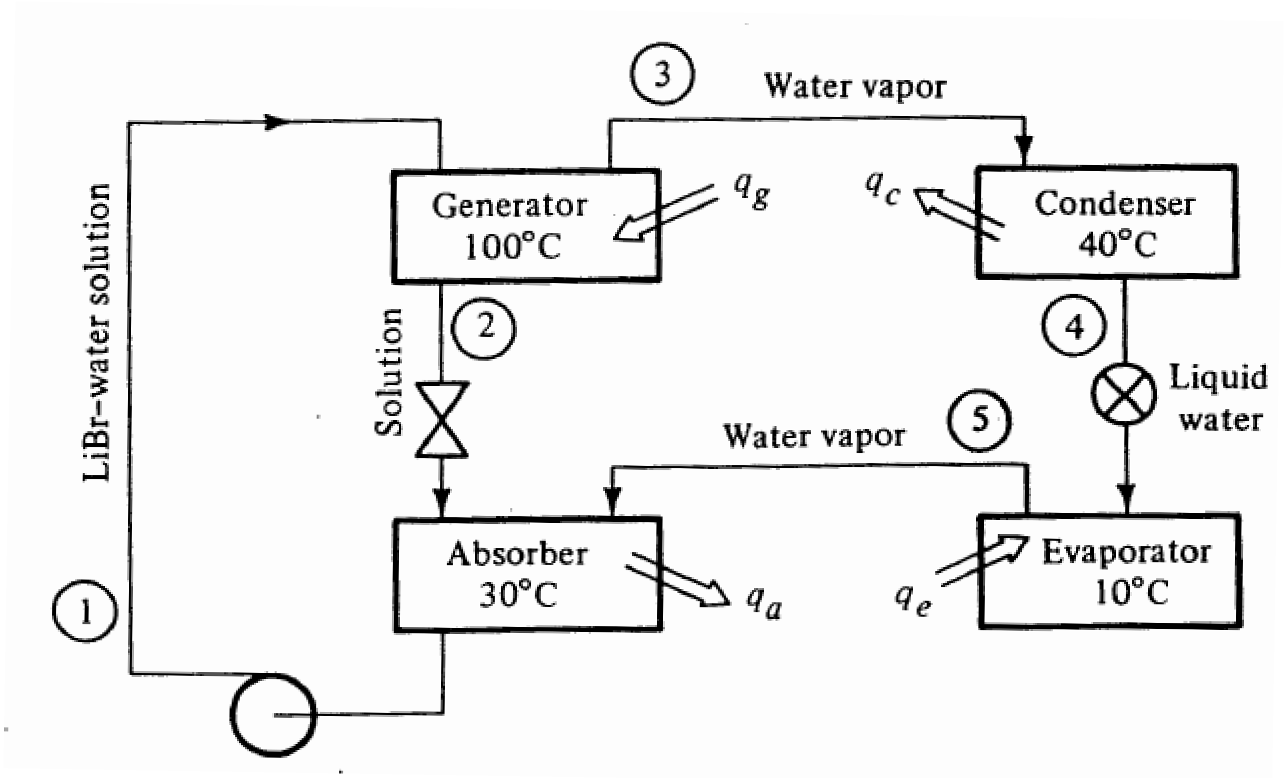
Absorption Refrigeration System

- Low-pressure vapor from the evaporator is absorbed by the liquid solution in the absorber.
- To maintain the absorber temperature, heat must be rejected.
- The pump receives low-pressure liquid from absorber, elevates its pressure, and delivers it to the generator.



Absorption Refrigeration System

- In the generator, heat from a high-temperature source drives off the vapor that had been absorbed by solution.
- The vapor enters the condenser while the liquid solution returns to the absorber through a throttling valve.



Coefficient of Performance

The general definition of the coefficient of performance is:

$$\text{COP} = \frac{\text{desired output}}{\text{required input}}$$

Therefore, in the case of absorption refrigeration, the COP is:

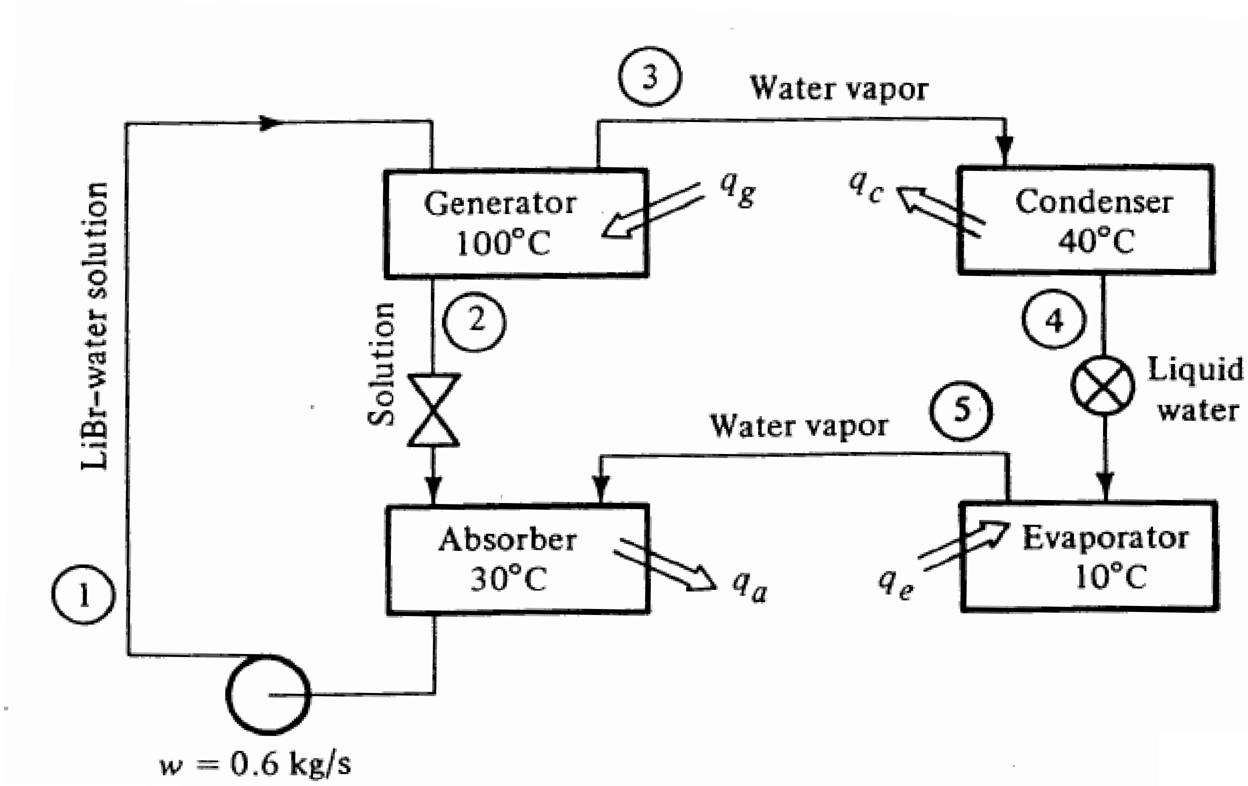
$$\text{COP}_{\text{abs}} = \frac{\text{refrigeration rate}}{\text{rate of heat addition at generator}}$$

The power consumed by the pump is not included in the COP expression because it is too small compared to the heat input.

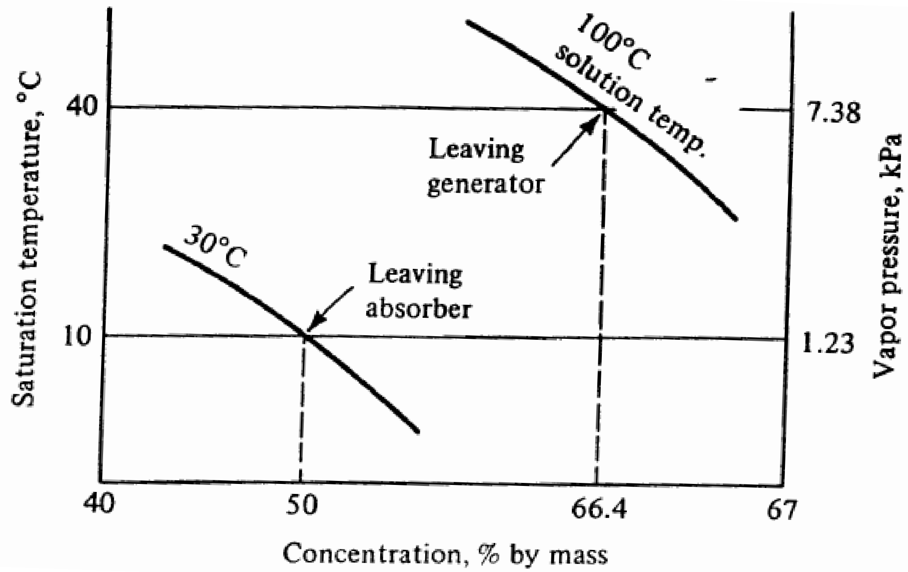
Calculation of Mass Flow Rates

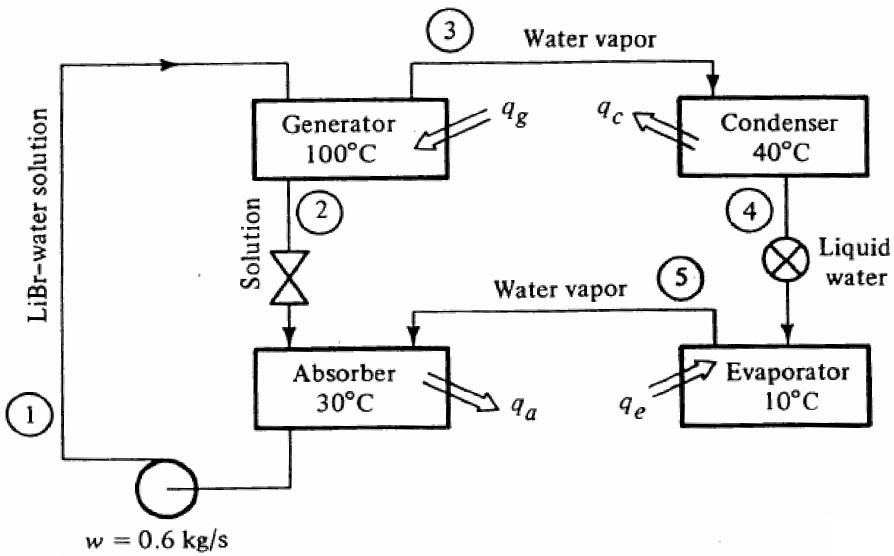
Example

Compute the mass flow rate of refrigerant (water) through the condenser and evaporator in the cycle shown below 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.



Calculation of Mass Flow Rates





Total mass-flow balance: $w_2 + w_3 = w_1 = 0.6$

LiBr balance:

$$w_1 x_1 = w_2 x_2$$

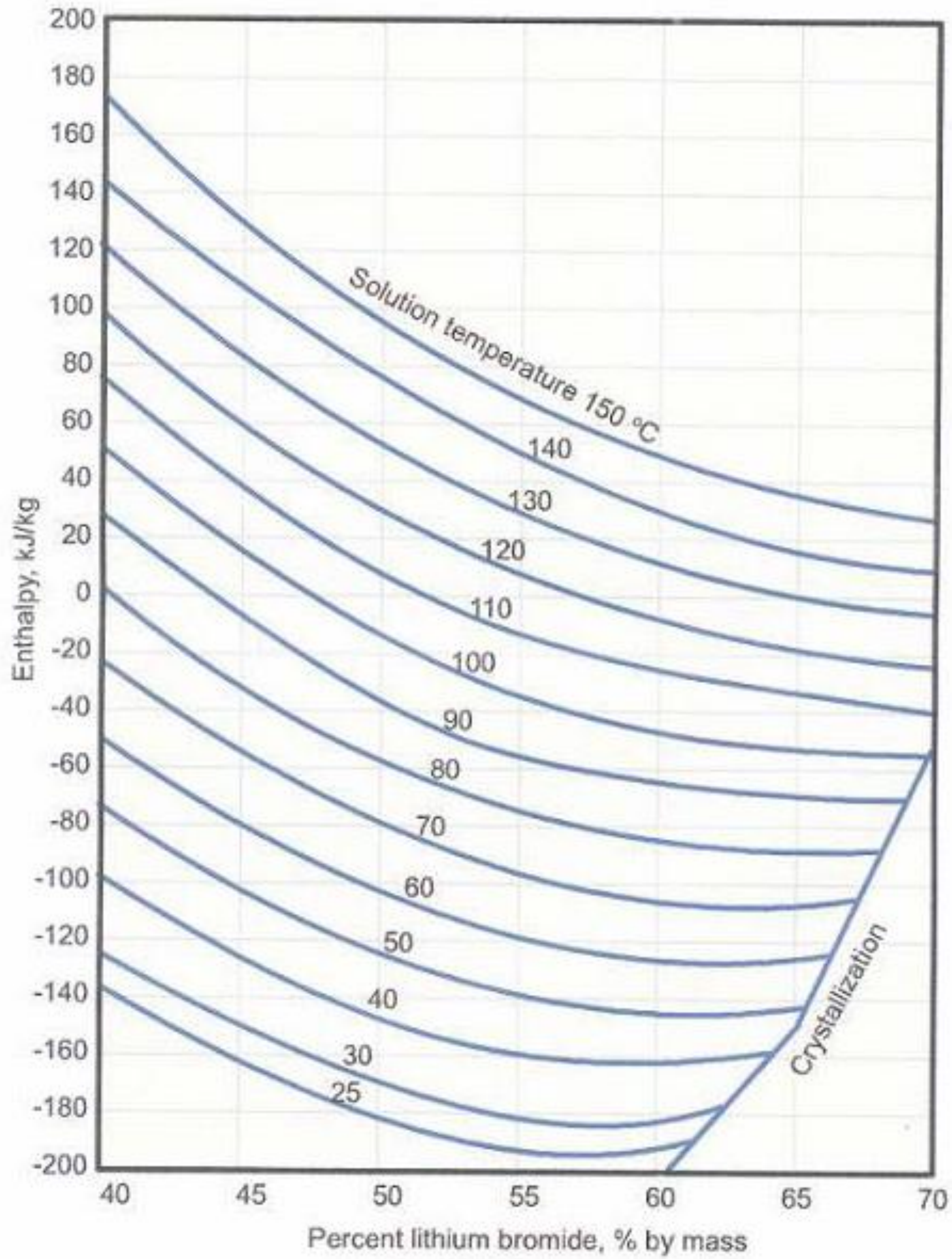
$$0.6(0.50) = w_2(0.664)$$

Solving the two balance equations simultaneously gives

$$w_2 = 0.452 \text{ kg/s} \quad \text{and} \quad w_3 = 0.148 \text{ kg/s}$$

Approximately 4 kg of solution is pumped for each kilogram of refrigerant water vapor developed.

Enthalpy of LiBr-Water Solution



Energy Balance

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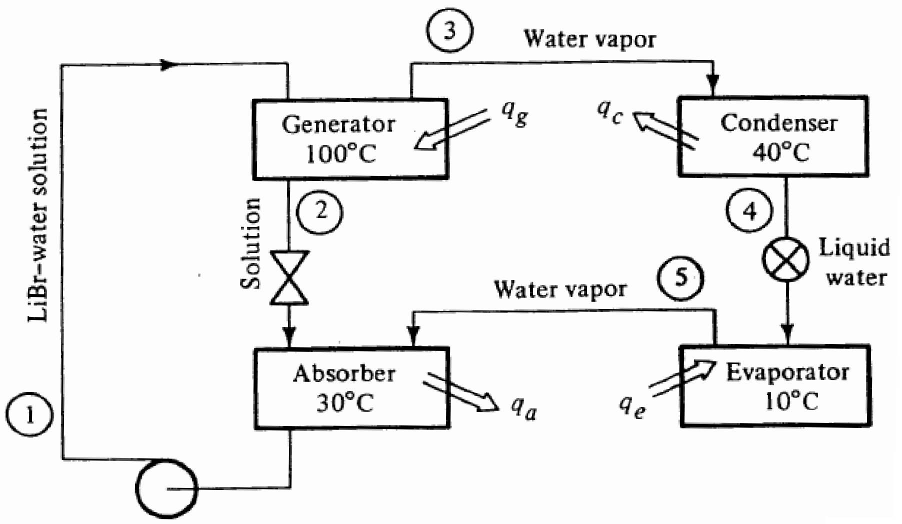
Example

For the absorption system shown, compute q_g, q_a, q_c, q_e, and the COP.



Solution The flow rates and solution concentrations have already been determined in Example 17-2: $w_1 = 0.6$ kg/s, $w_2 = 0.452$ kg/s, and $w_3 = w_4 = w_5 = 0.148$ kg/s; $x_1 = 50\%$, and $x_2 = 66.4\%$.

The enthalpies of the solution can be read off Fig. 17-8:

$h_1 = h$ at 30°C and x of 50% = −168 kJ/kg

$h_2 = h$ at 100°C and x of 66.4% = −52 kJ/kg

The enthalpies of water liquid and vapor are found from Table A-1:

$h_3 = h$ of saturated vapor at 100°C = 2676.0 kJ/kg

$h_4 = h$ of saturated liquid at 40°C = 167.5 kJ/kg

$h_5 = h$ of saturated vapor at 10°C = 2520.0 kJ/kg

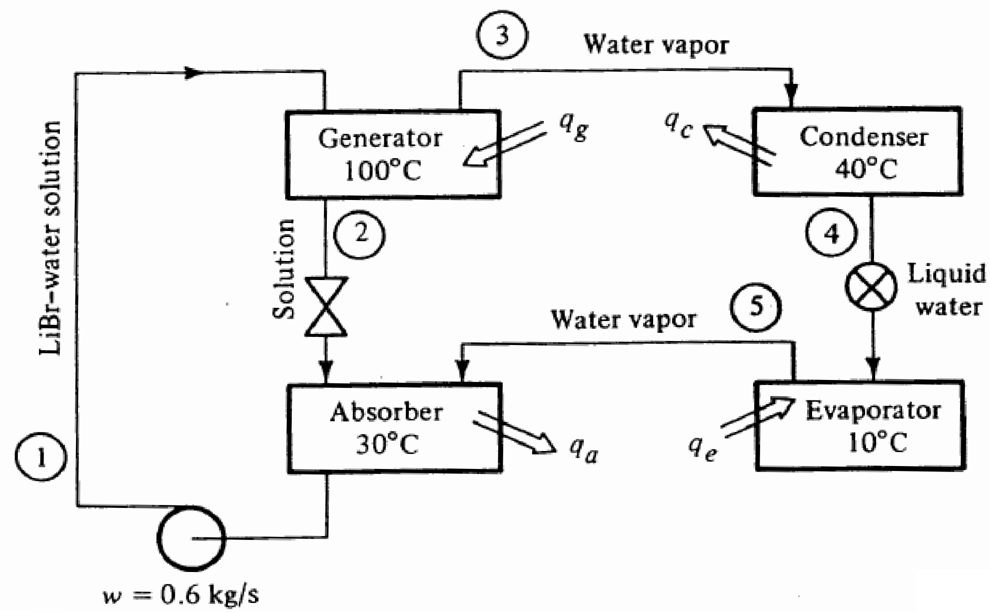
Energy Balance

The rates of heat transfer at each of the components can now be computed from energy balances:

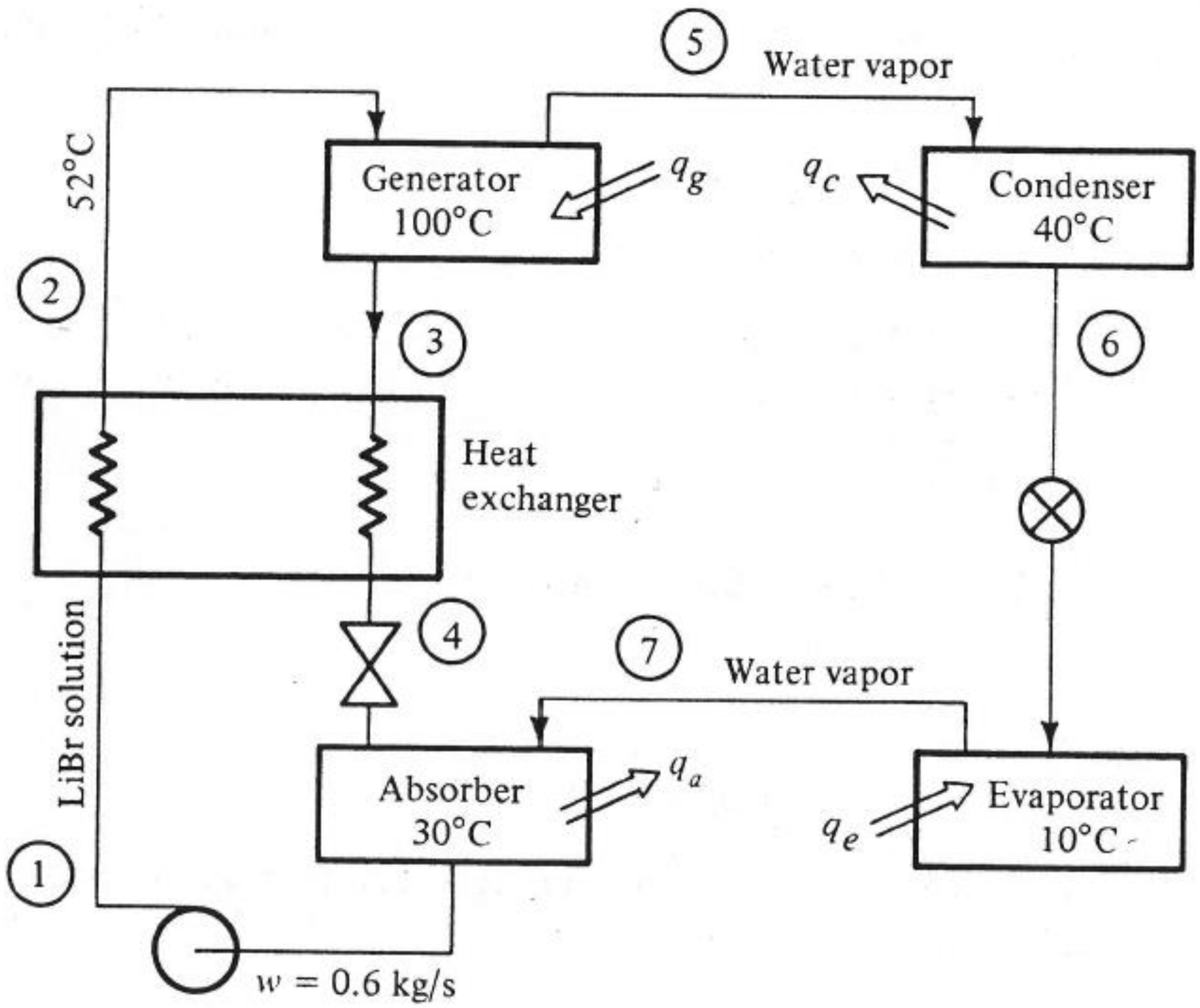
$$q_g = w_3h_3 + w_2h_2 - w_1h_1$$
$$= 0.148(2676) + 0.452(-52) - 0.6(-168) = 473.3 \text{ kW}$$
$$q_c = w_c h_3 - w_4h_4 = 0.148(2676 - 167.5) = 371.2 \text{ kW}$$
$$q_a = w_2h_2 + w_5h_5 - w_1h_1$$
$$= 0.452(-52) + 0.148(2520) - 0.6(-168) = 450.3 \text{ kW}$$
$$q_e = w_5h_5 - w_4h_4 = 0.148(2520 - 167.5) = 348.2 \text{ kW}$$

Finally,

$$COP_{abs} = \frac{q_e}{q_g} = \frac{348.2}{476.6} = 0.736$$



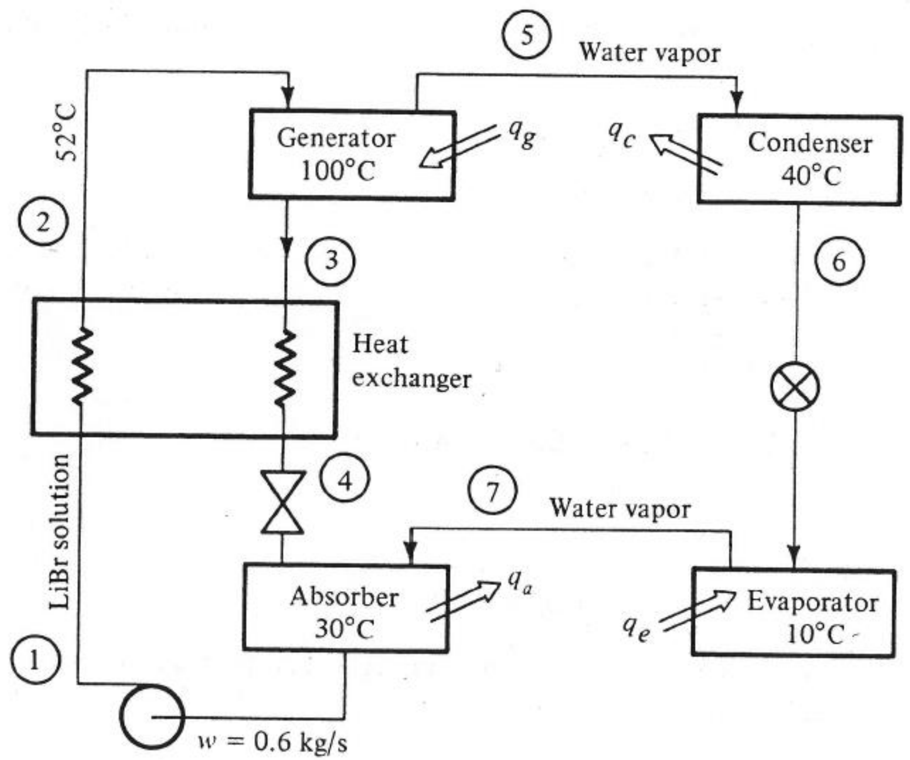
Absorption Cycle with Heat Exchanger



Absorption Cycle with Heat Exchanger

Example

The simple cycle is modified by the insertion of a heat exchanger such that the temperature at Point 2 is 52°C. The mass flow rate 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?



Absorption Cycle with Heat Exchanger

$$w_1 = w_2 = 0.6 \text{ kg/s} \qquad w_3 = w_4 = 0.452 \text{ kg/s}$$

and

$$w_5 = w_6 = w_7 = 0.148 \text{ kg/s}$$

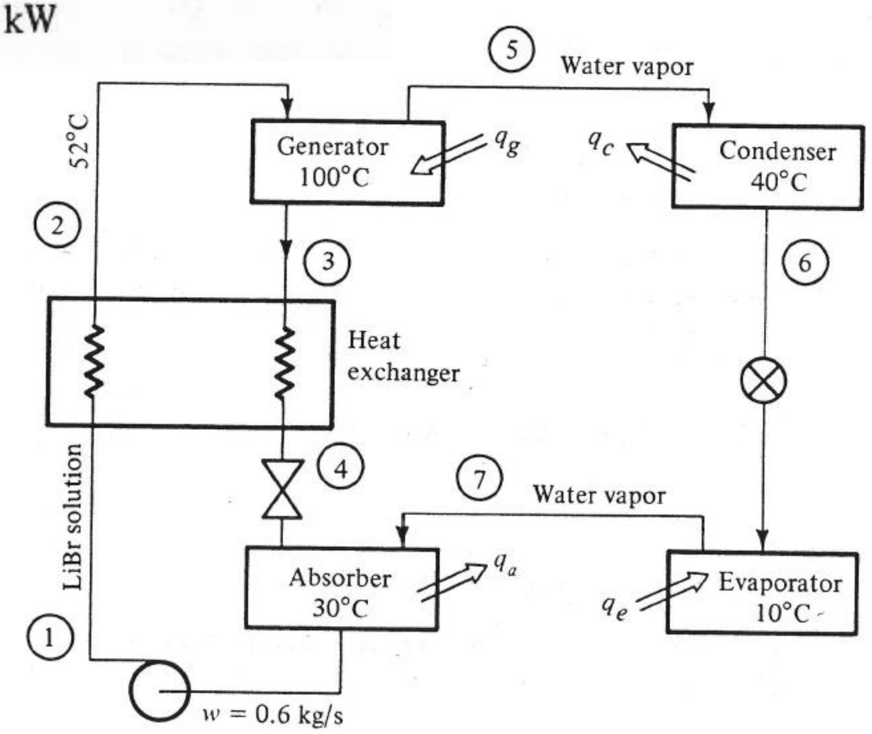
The enthalpies that remain unchanged are

$h_1 = -168$ kJ/kg $\quad h_3 = -52$ kJ/kg

$h_5 = 2676.0$ kJ/kg $\quad h_6 = 167.5$ kJ/kg $\quad h_7 = 2520.0$ kJ/kg

The heat-transfer rates at the condenser and evaporator remain unchanged

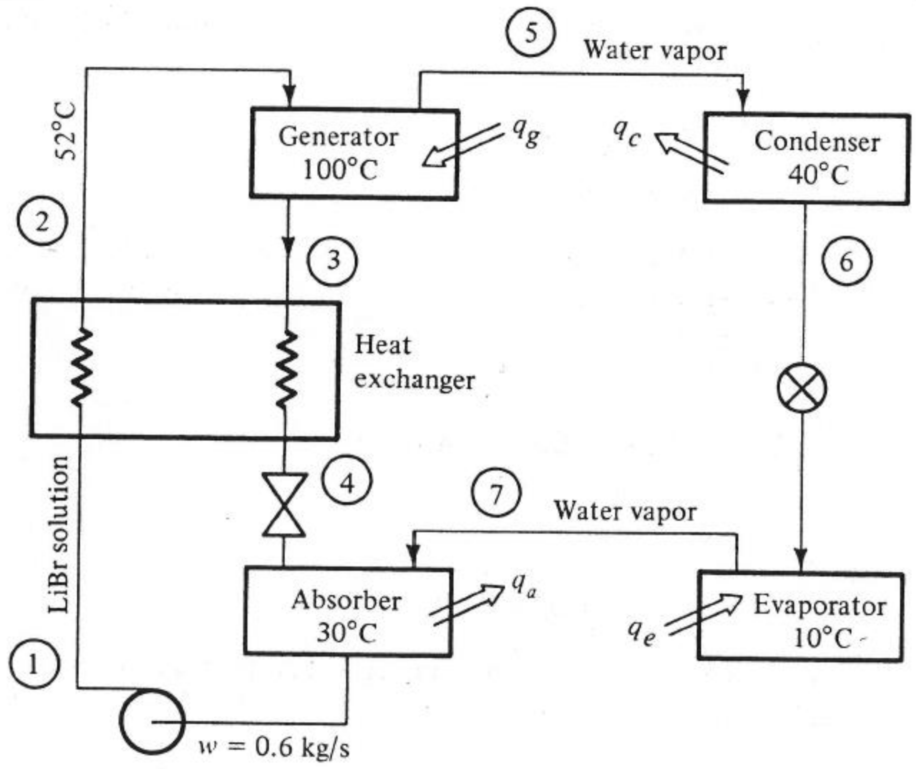
$$q_c = 371.2 \text{ kW} \quad \text{and} \quad q_e = 348.2 \text{ kW}$$



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. 17-8. The rate of heat absorbed by the solution passing from the absorber to the generator q_{hx} is

$$q_{hx} = w_1(h_2 - h_1) = 0.6[-120 - (-168)] = 28.8 \text{ kW}$$

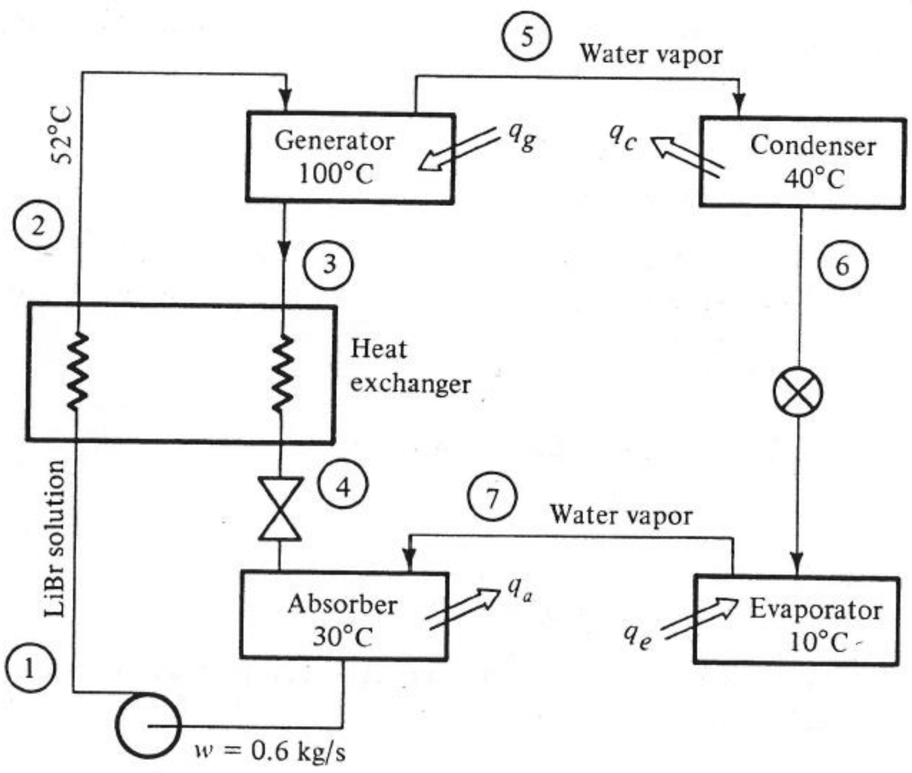


Absorption Cycle with Heat Exchanger

$$q_{hx} = 28.8 \text{ kW} = w_3(h_3 - h_4) = 0.452(-52 - h_4)$$

$$h_4 = -116 \text{ kJ/kg}$$

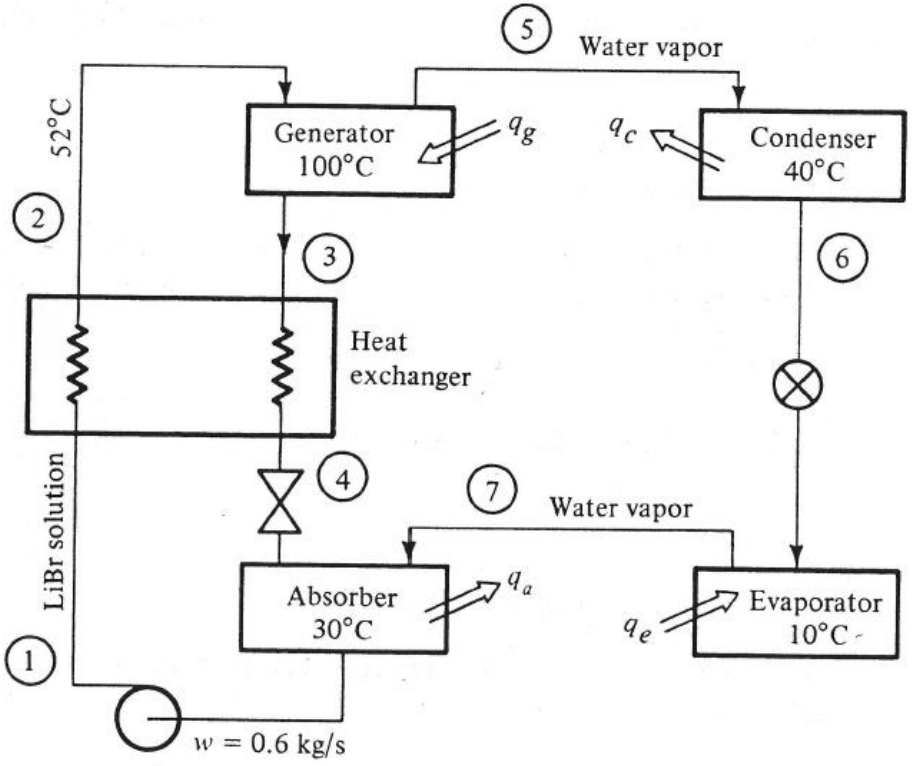
$$q_g = w_5 h_5 + w_3 h_3 - w_2 h_2$$
$$= 0.148(2676.0) + 0.452(-52) - 0.6(-120) = 444.5 \text{ kW}$$



Absorption Cycle with Heat Exchanger

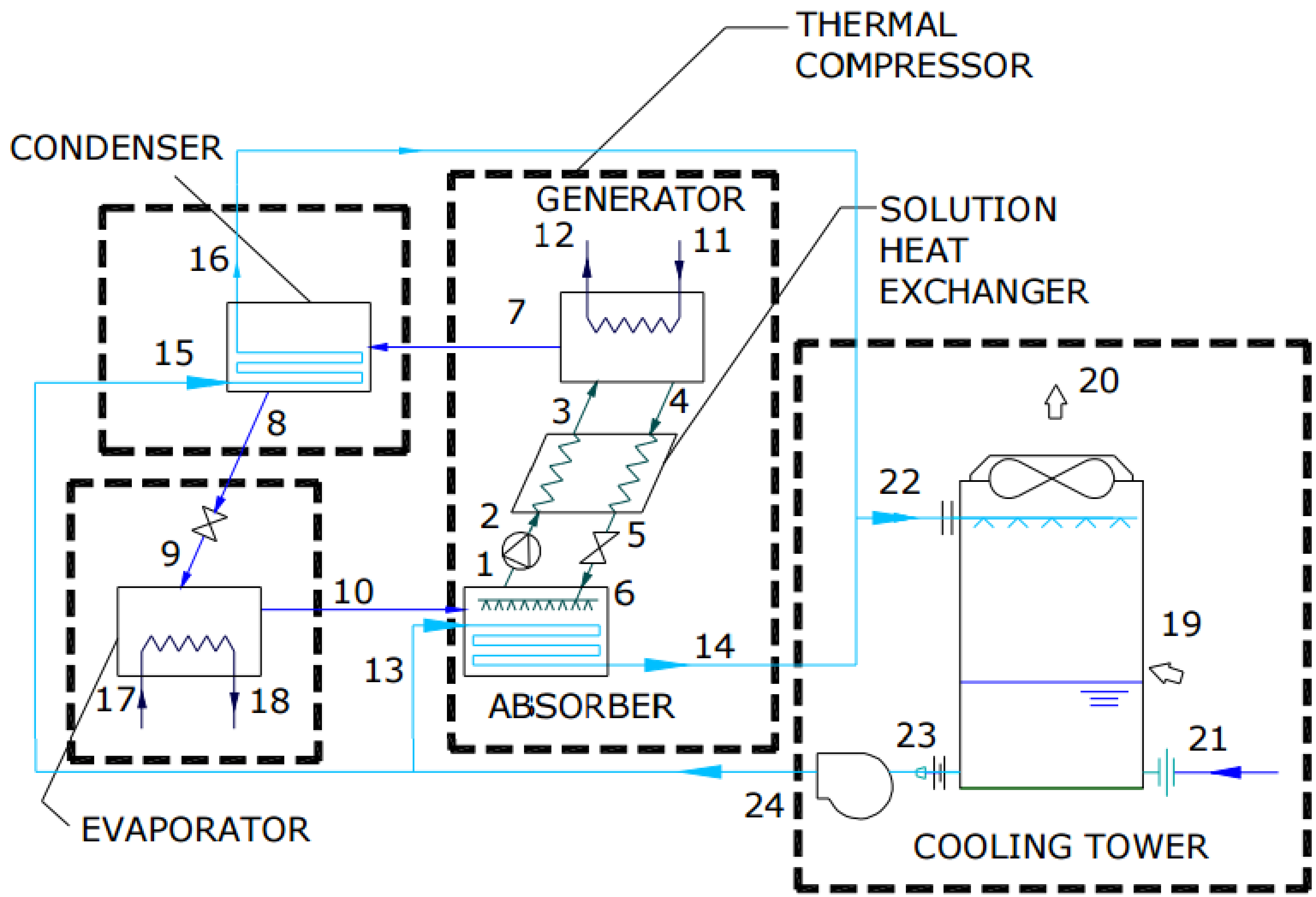
$$q_a = w_7 h_7 + w_4 h_4 - w_1 h_1$$
$$= 0.148(2520) + 0.452(-116) - 0.6(-168) = 421.3 \text{ kW}$$

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



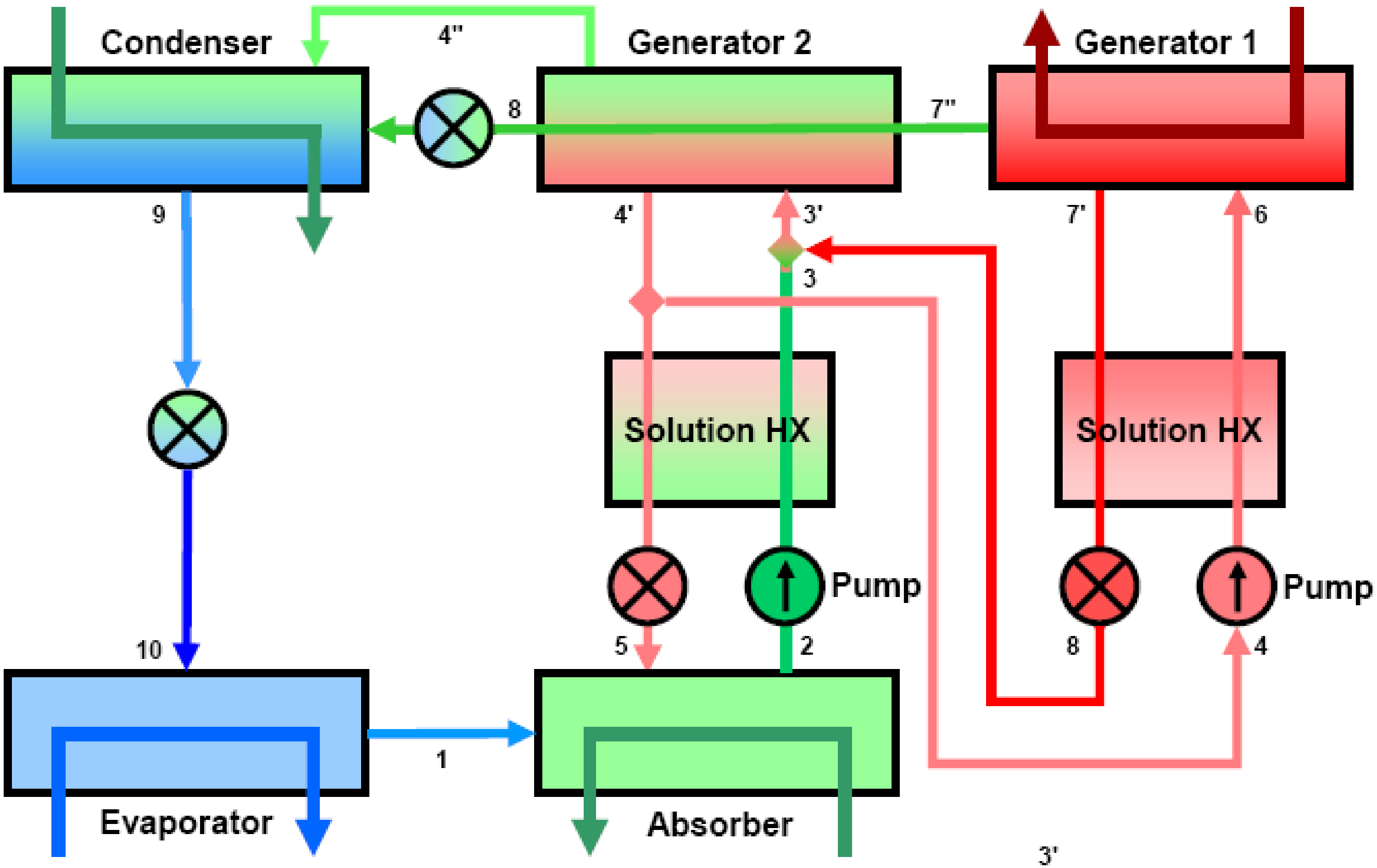
Single Effect Absorption Cycle

Configuration of a Typical Commercial System

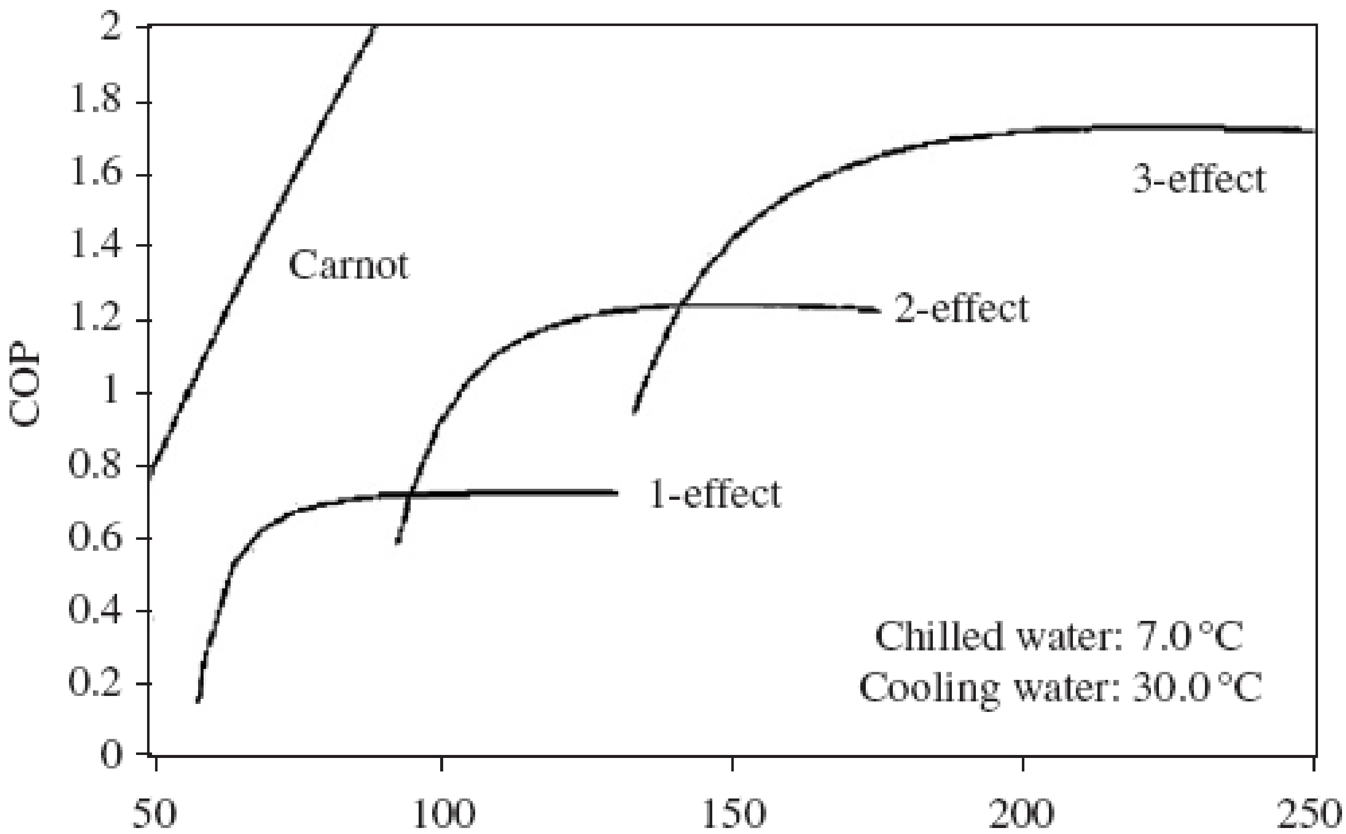


Double Effect Absorption Cycle

Configuration of a Typical Commercial System



Performance Comparison



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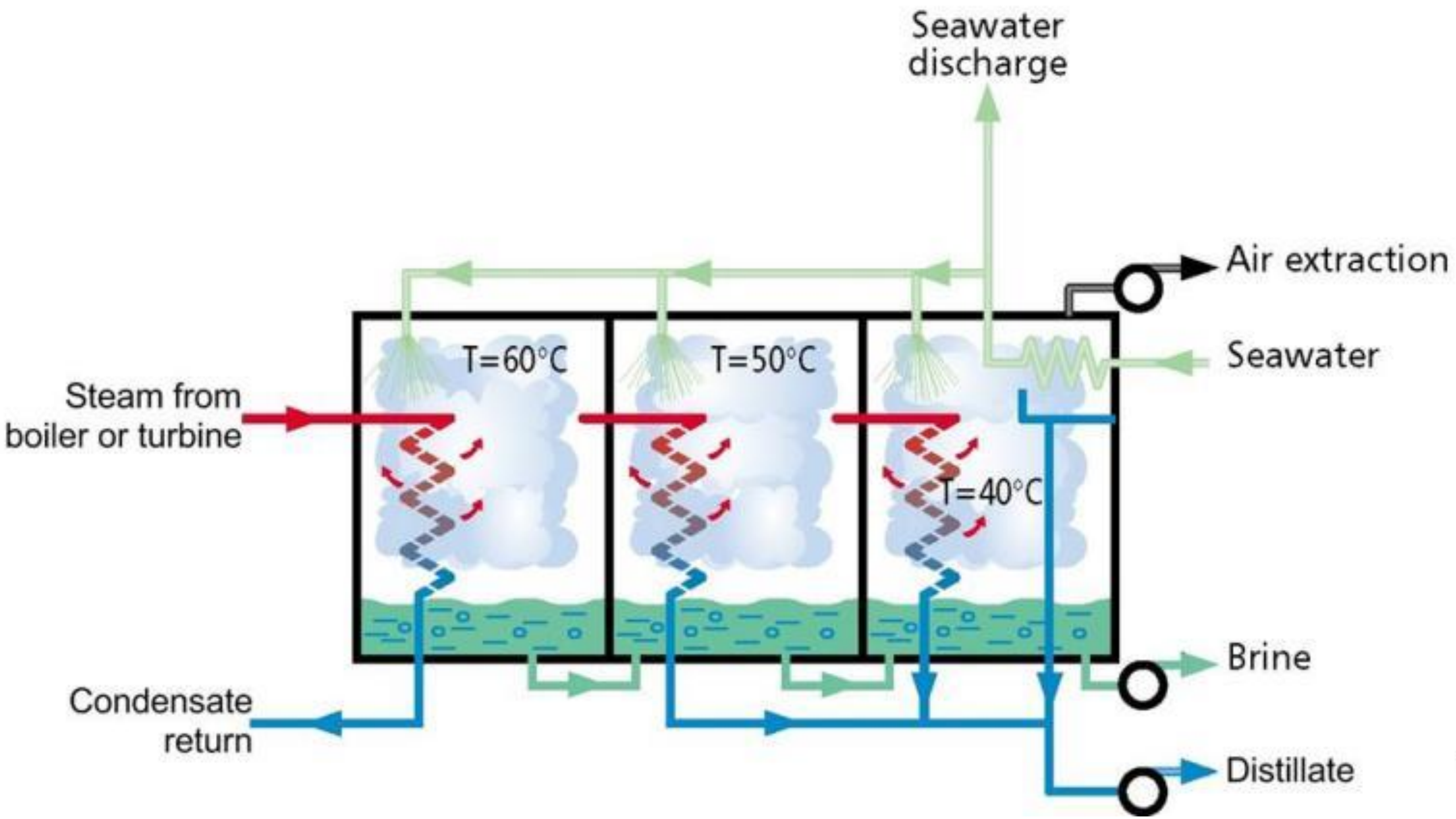
UNIT SIX

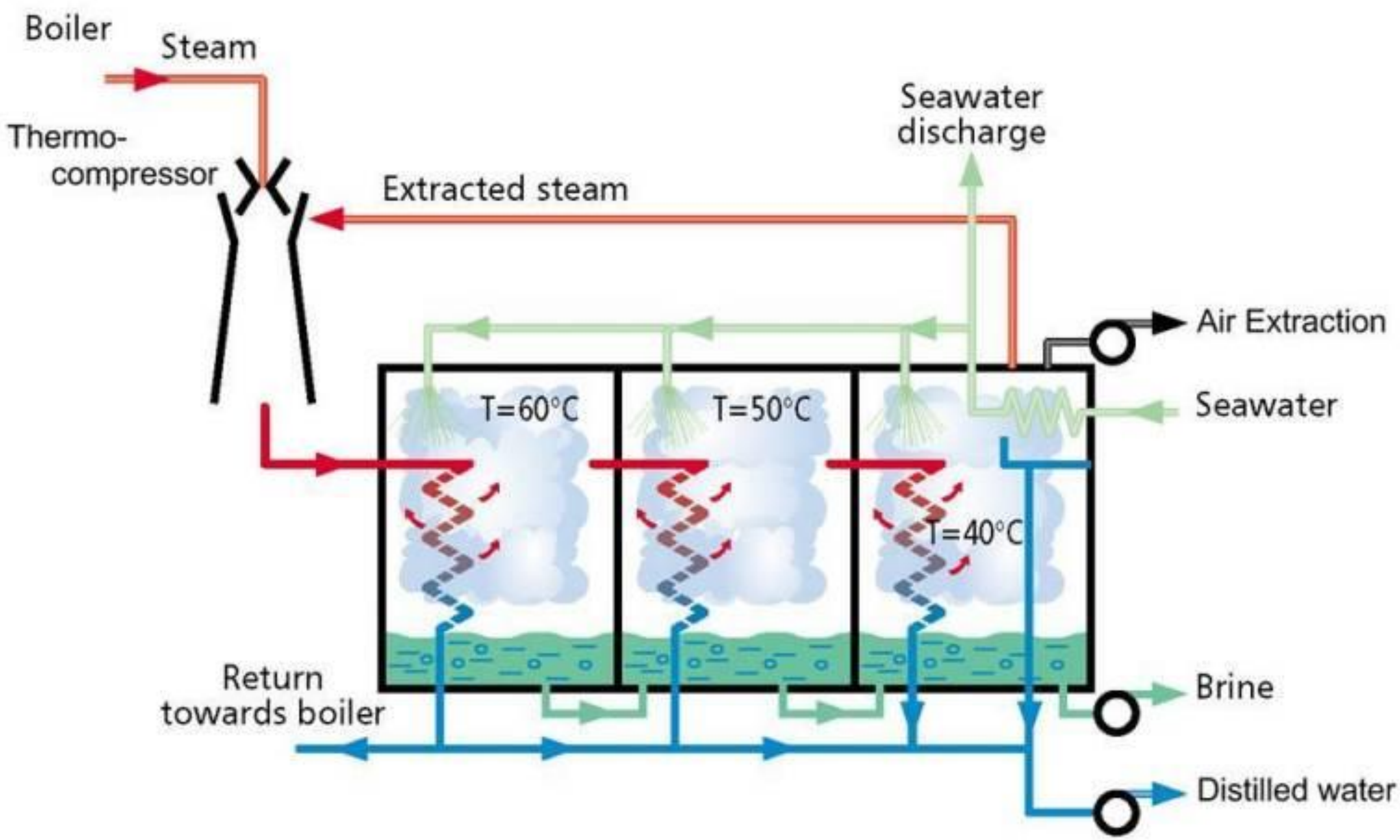
SOLAR ENERGY APPLICATIONS

THERMAL DESALINATION

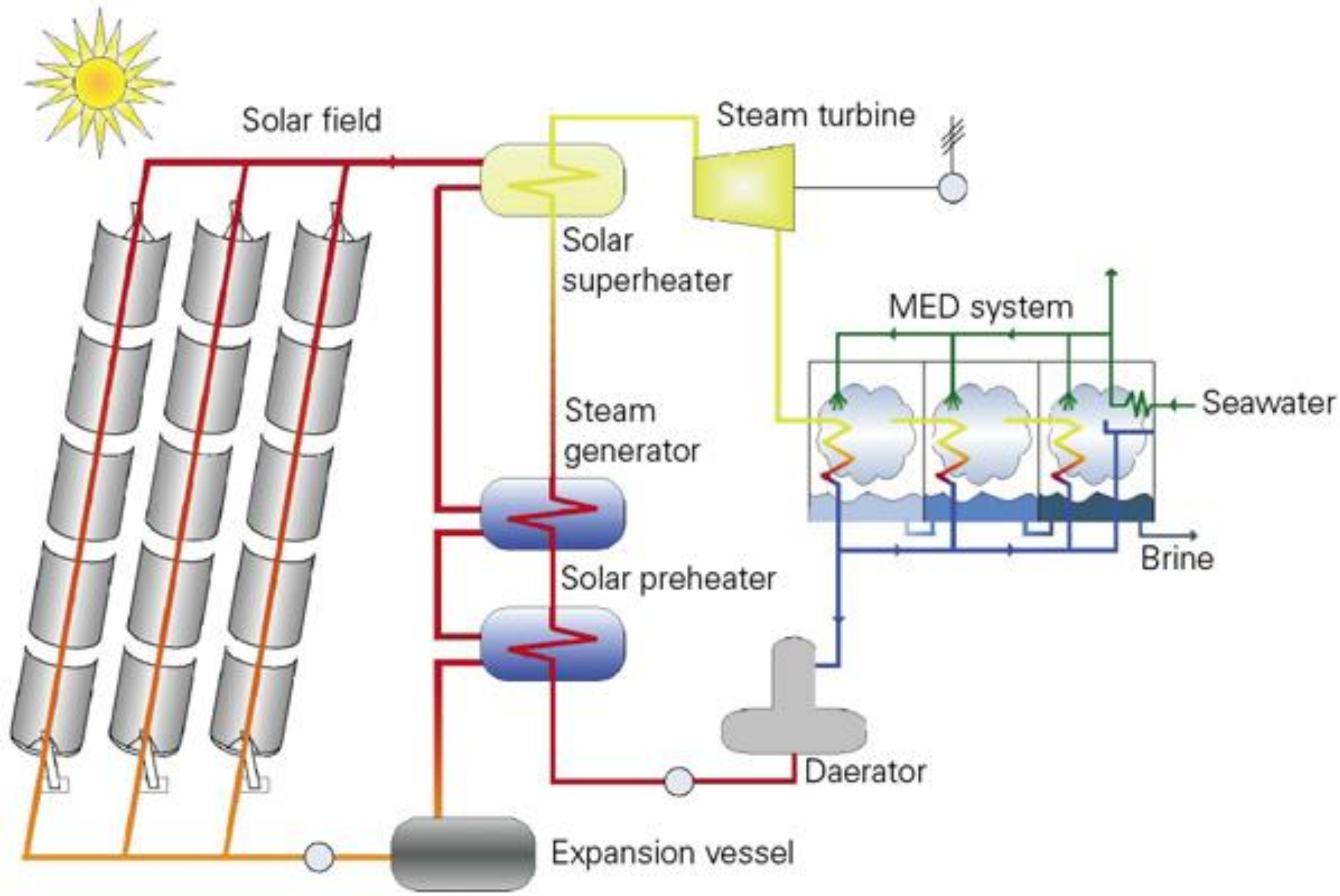
Multiple Effect Distillation (MED)



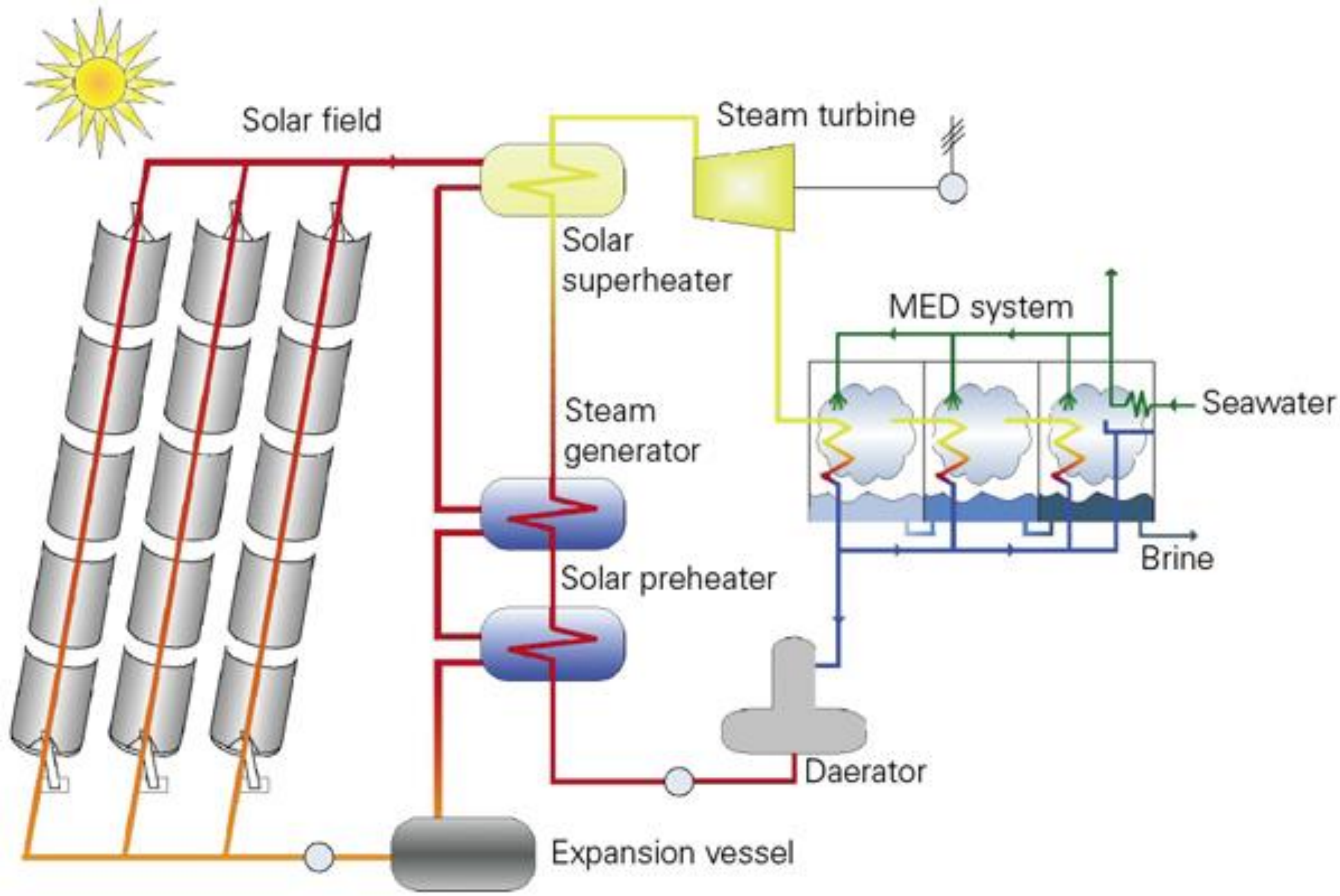
Multiple Effect Distillation with Thermal Vapor Compression (MED-TVC)



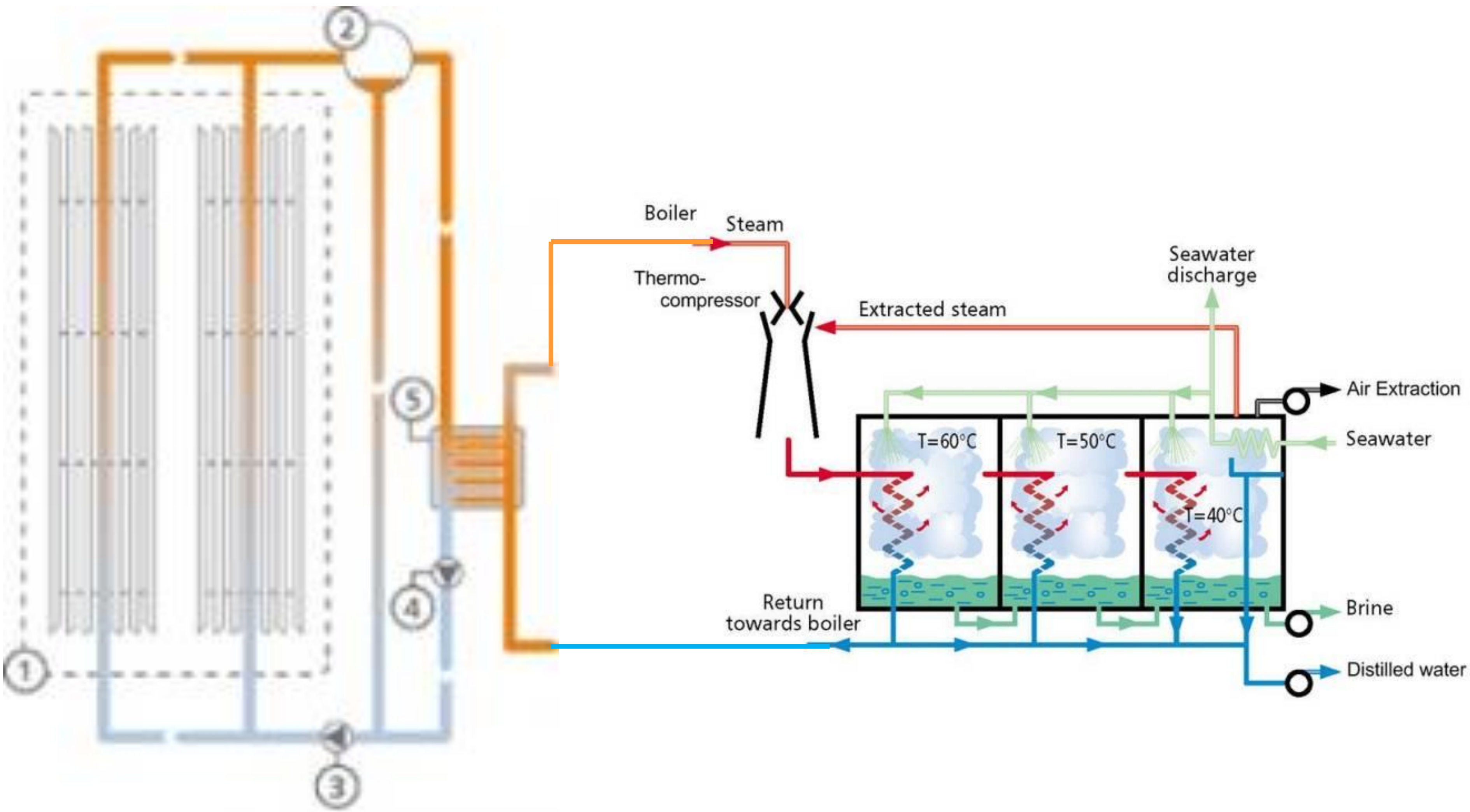
Solar MED (With Power Generation)



Solar MED (With Power Generation)

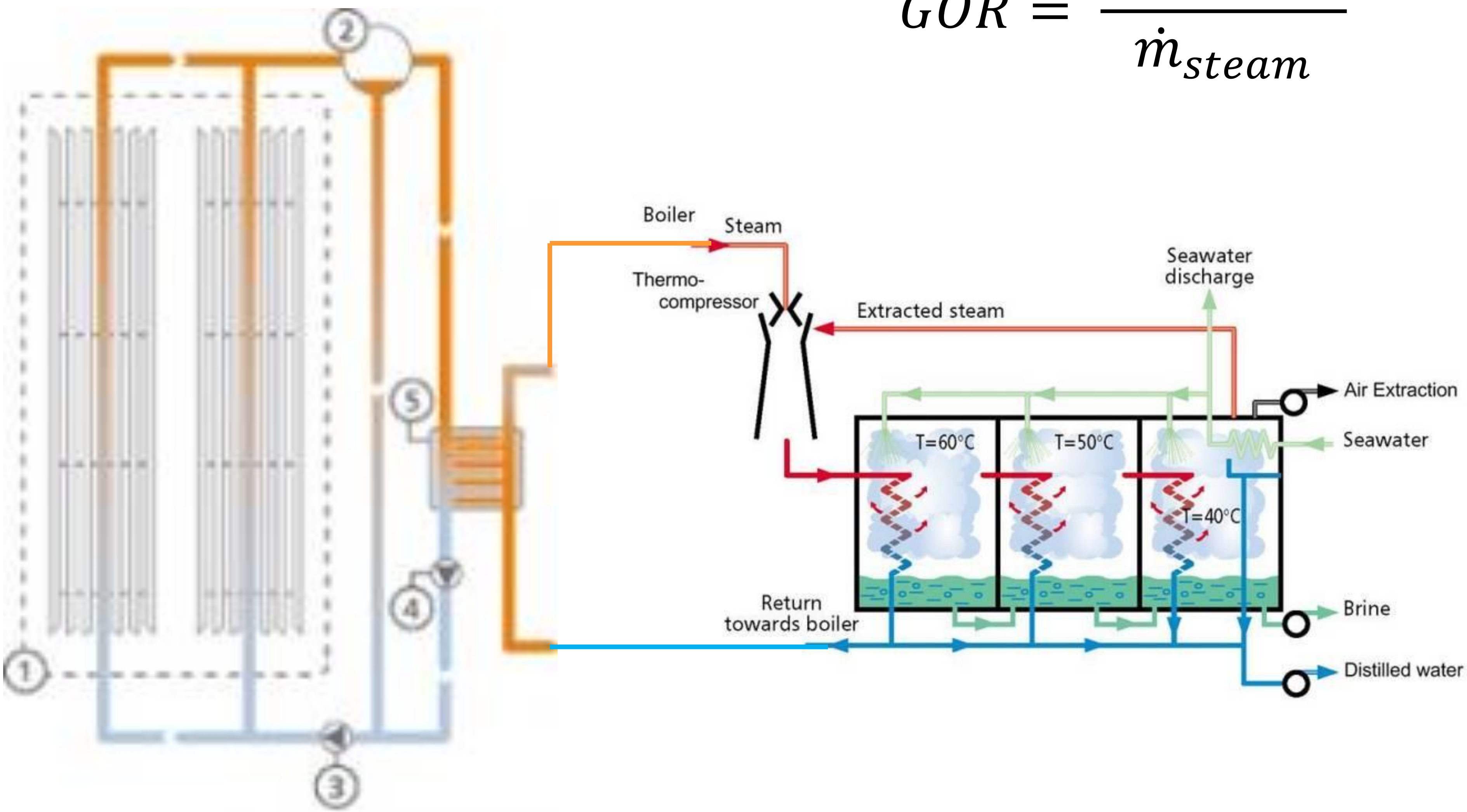


Solar MED (Without Power Generation)



Gain Output Ratio (GOR)

$$GOR = \frac{\dot{m}_{distillate}}{\dot{m}_{steam}}$$



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