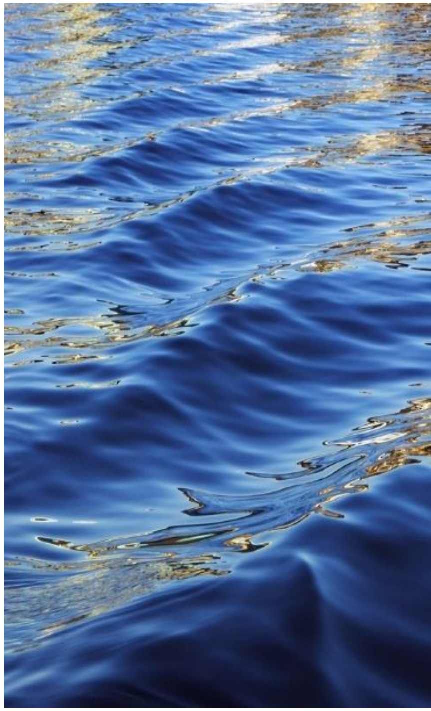
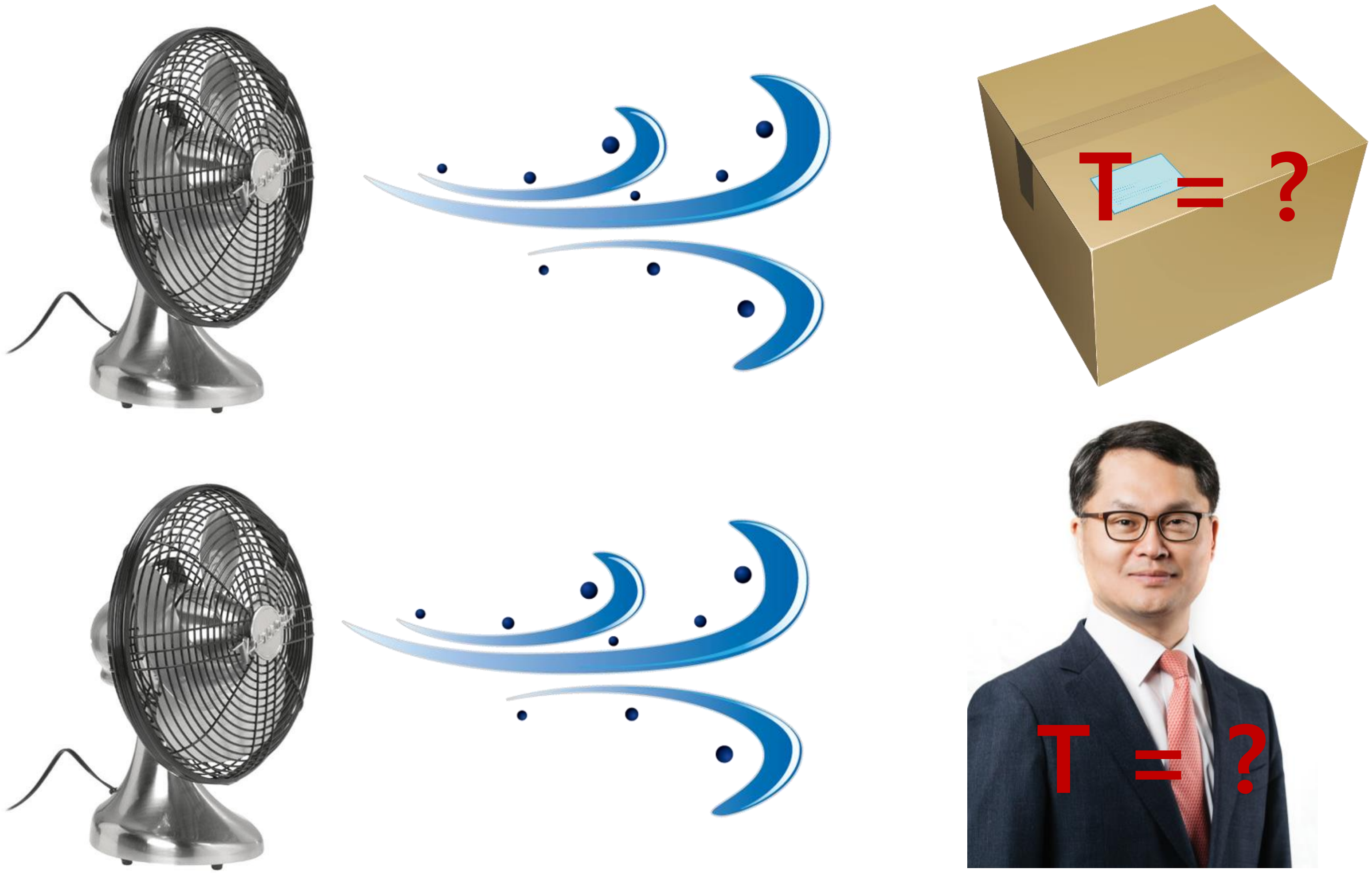
Environmental Thermal Engineering

Lecture Note #2

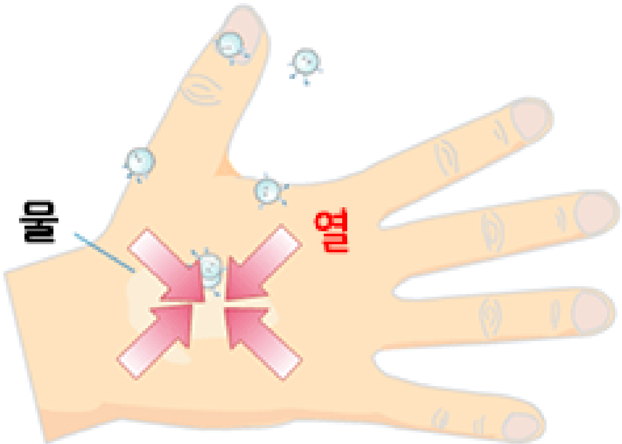
Professor Min Soo KIM



Introduction

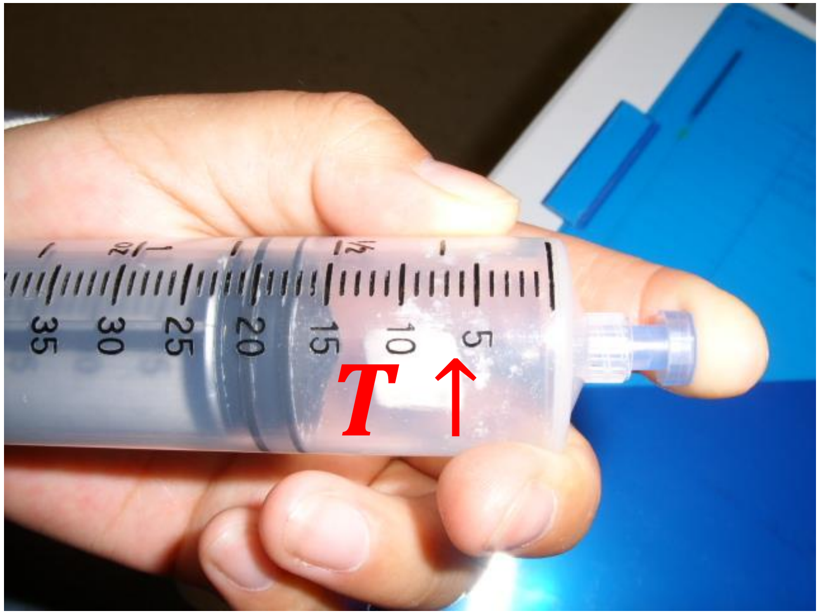


Introduction



습구 온도 (℃)	건구와 습구의 온도 차이(℃)					
	0	1	2	3	4	5
15	100	90	81	73	65	59
16	100	90	82	74	66	60
17	100	91	82	74	67	61
18	100	91	83	75	68	62
19	100	91	83	76	69	62
20	100	91	83	76	69	63

Introduction

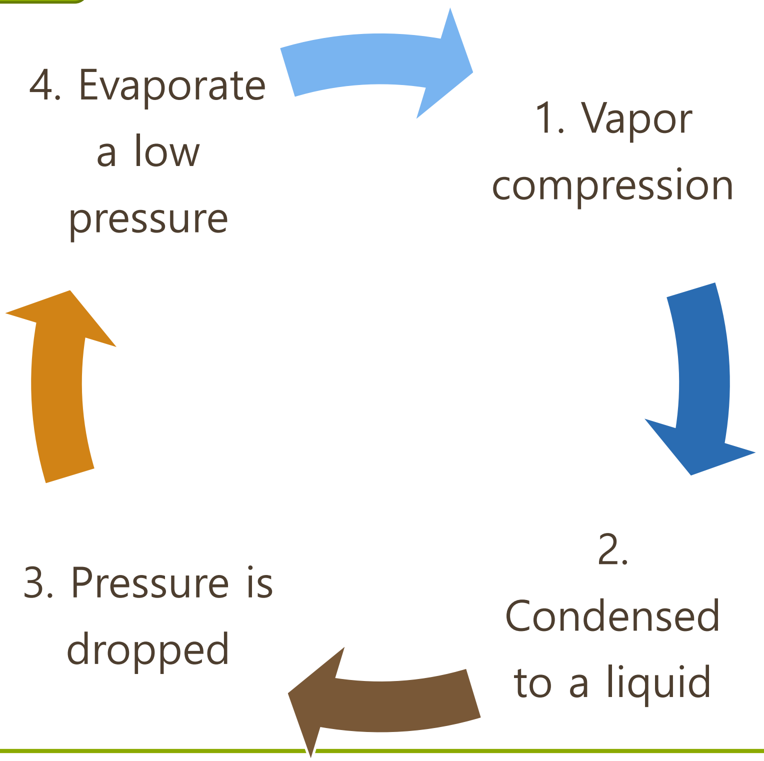


Carnot Cycle and Actual Vapor-Compression Cycle

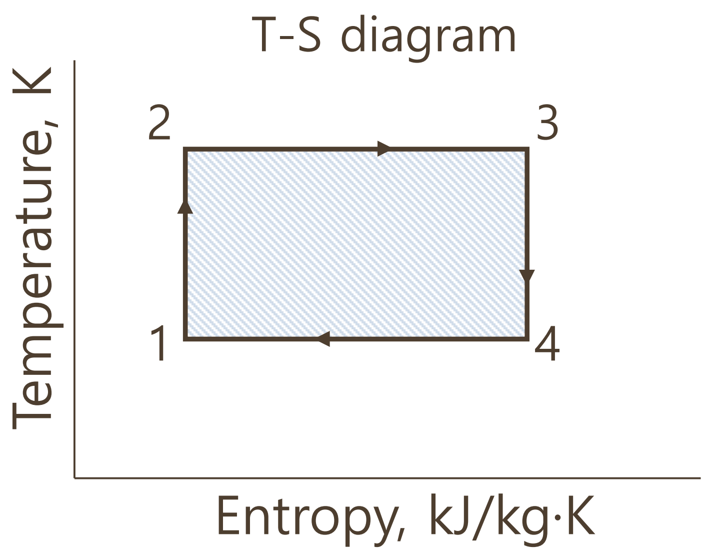
Vapor-Compression Cycle

- Most important refrigeration cycle
  (Most widely used cycle)

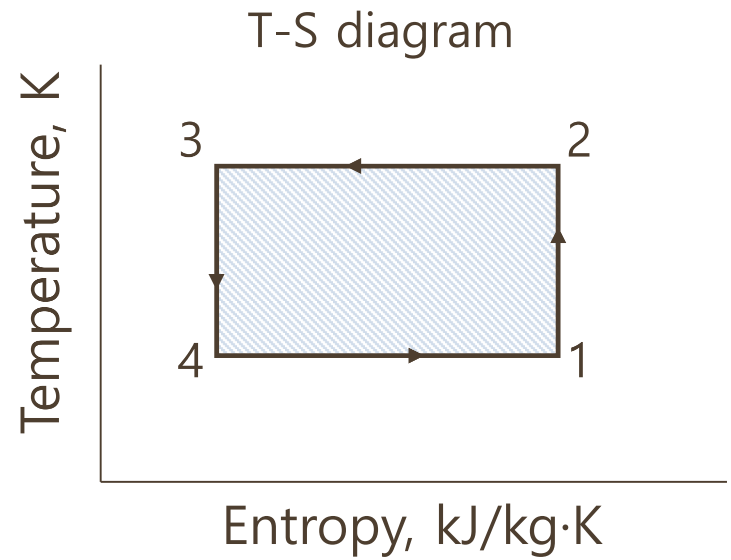
Process



Carnot Heat Engine & Refrigeration Cycle

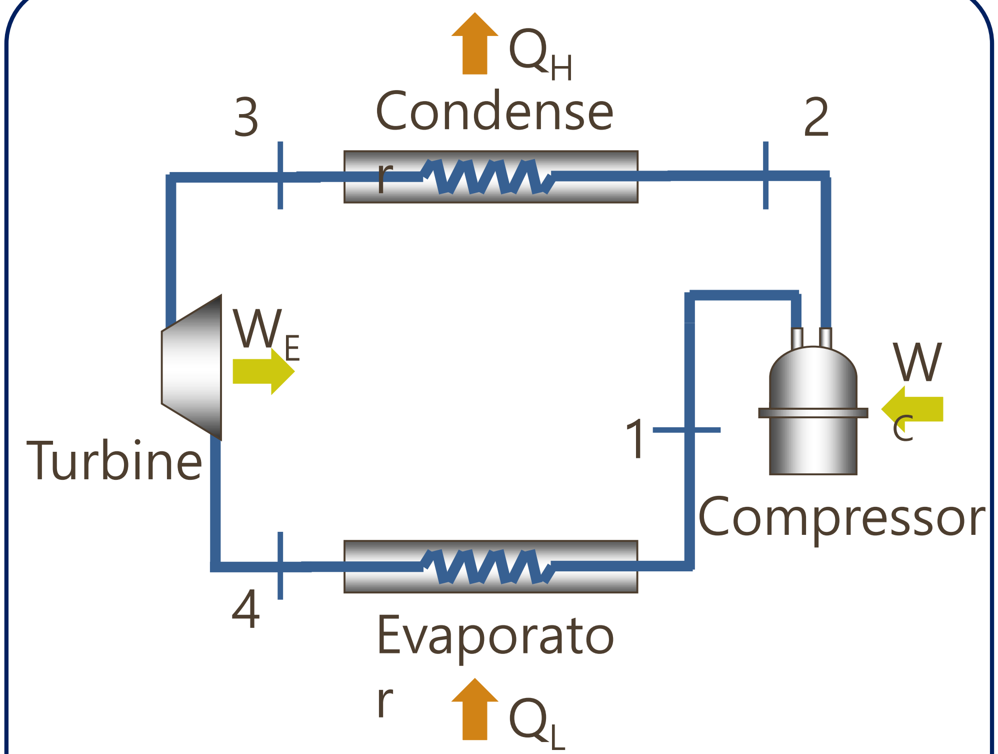


Carnot heat engine

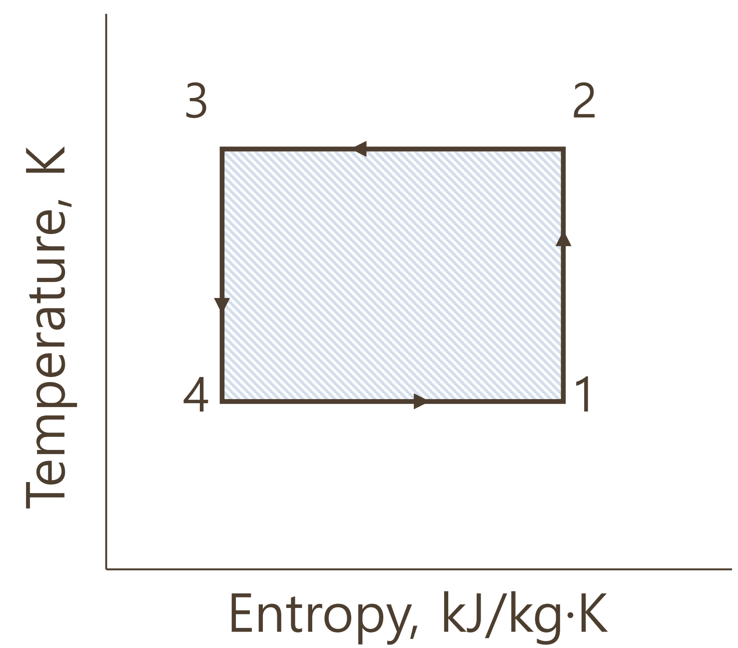


Refrigeration cycle

Carnot Refrigeration Cycle



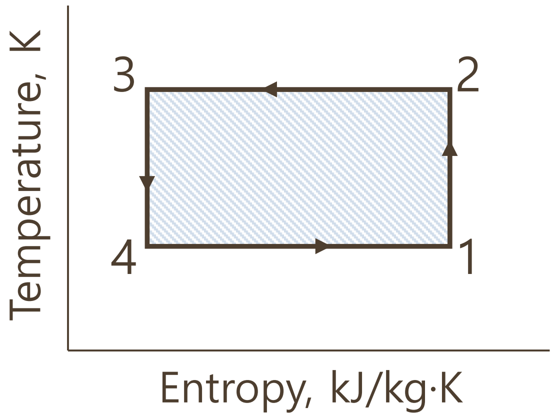
Schematics



T-S diagram

Carnot Refrigeration Cycle

Processes Of The Carnot Refrigeration Cycle



1 → 2 Adiabatic Compression

2 → 3 Isothermal Rejection Of Heat

3 → 4 Adiabatic Expansion

4 → 1 Isothermal Addition Of Heat

The Reason Why We Discuss The Carnot Cycle

- The Carnot cycle serves as a standard of comparison.
- The Carnot cycle provides a convenient guide to the temperatures the should be maintained to achieve maximum effectiveness

Coefficient of Performance

- The concept of the performance index of the refrigeration cycle is the same as efficiency.
- It represent the ratio

$$\frac{Magnitude\ \ of\ \ \ desired\ \ commodity}{Magnitude\ of\ \ expenditure}$$

Coefficient of Performance

- **The performance term in the refrigeration cycle is called the coefficient of performance (COP) , define as,**

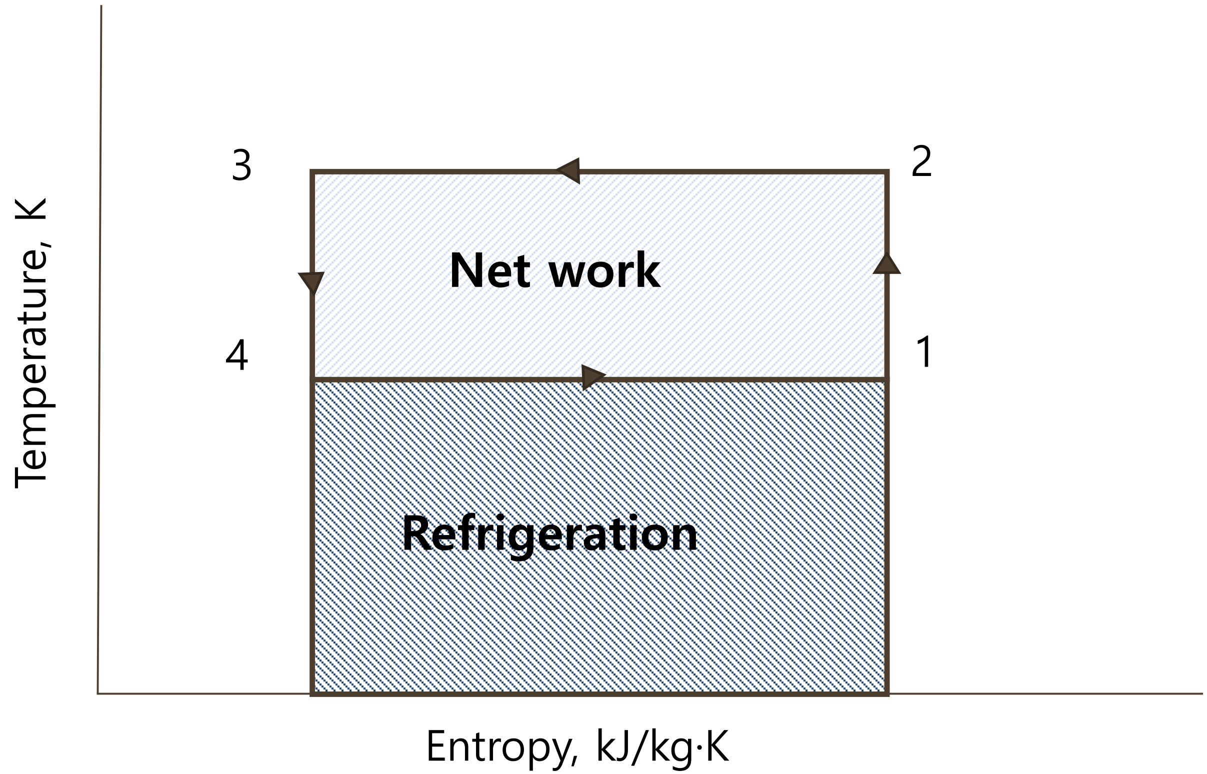
$$COP = \frac{useful\ refrigeration}{net\ work}$$

Condition for Highest COP

- **Express the COP of the Carnot cycle in terms of the temperatures that exist in the cycle. We know the heat transferred in a reversible process can express T his way.**

$$q = \int T ds$$

T-S Diagram



- **This figure can represent the amount of useful refrigeration and the net work.**

T-S Diagram

- **The useful refrigeration and net work**

$$\text{Useful refrigeration} = T_1(s_1 - s_4)$$

$$\text{Net work} = (T_2 - T_1)(s_1 - s_4)$$

- **Expression for COP of Carnot refrigeration cycle**

$$COP = \frac{T_1(s_1 - s_4)}{(T_2 - T_1)(s_1 - s_4)} = \frac{T_1}{T_2 - T_1}$$

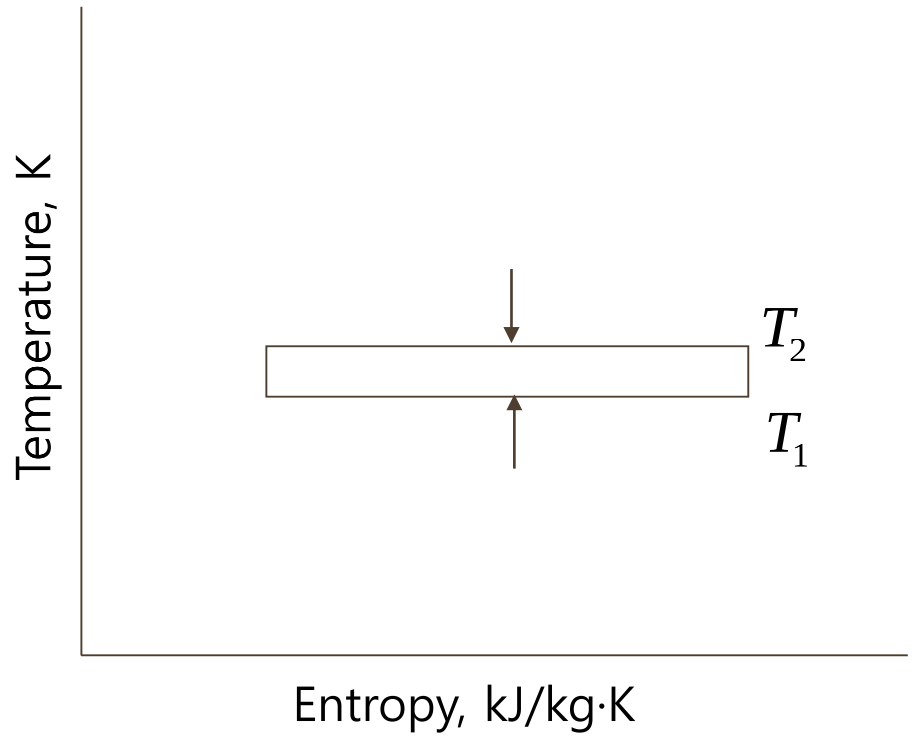
How Can we Achieve a Highest COP

$$COP = \frac{T_1}{T_2 - T_1}$$

1. A low value of T_2 will make the COP high
2. A high value of T_1 will make the COP high

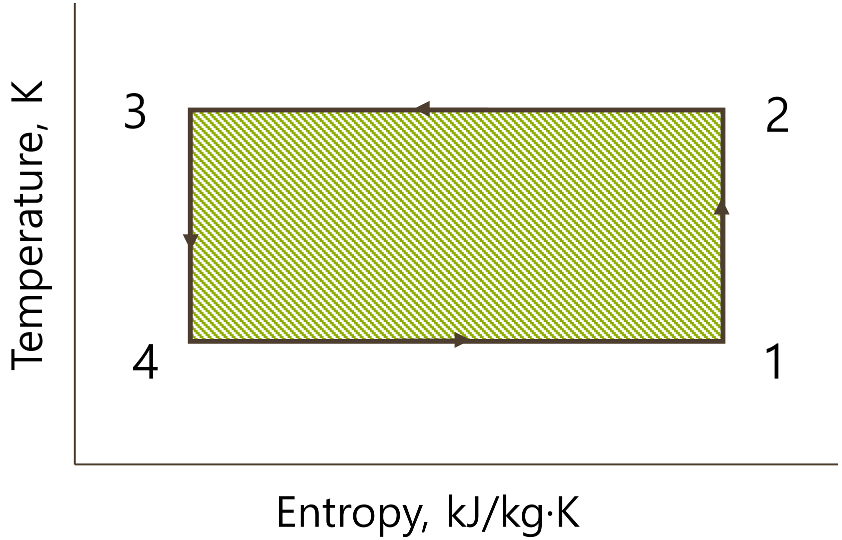
- The value of T_1 has a more pronounced effect on the COP than T_2, because a high value of T_1 increases the numerator and decreases the denominator.

Temperature Limitation



Can we have the infinite COP as T_1 is set equal to T_2 ?

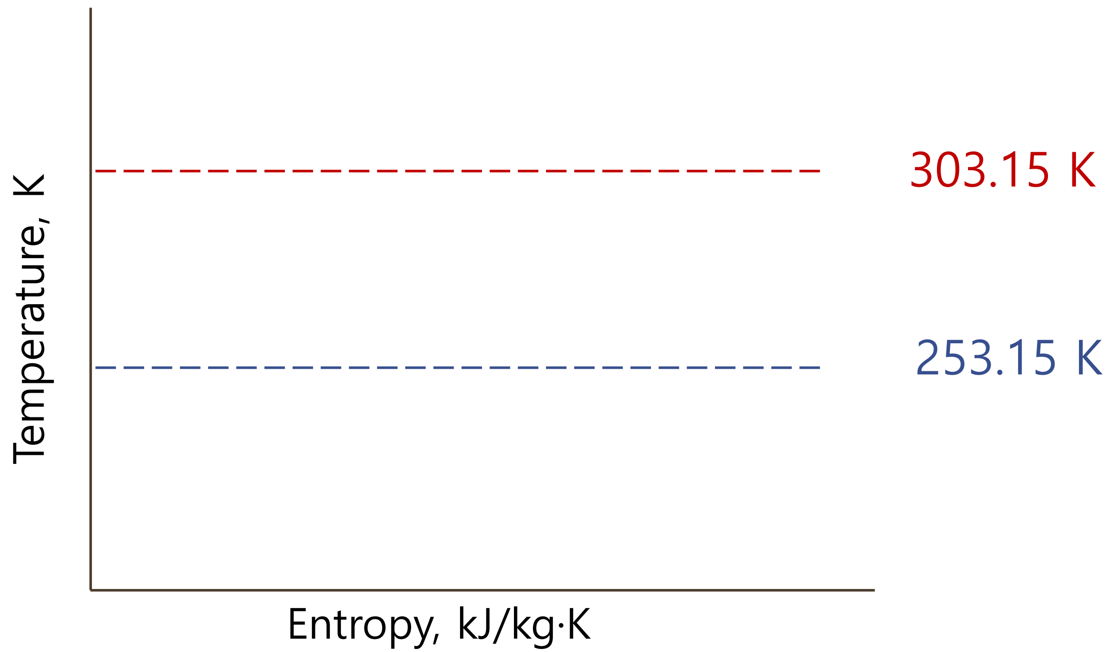
Heat Transfer



2 → 3 In this heat rejection process, refrigerant must transfer its heat to somewhere.

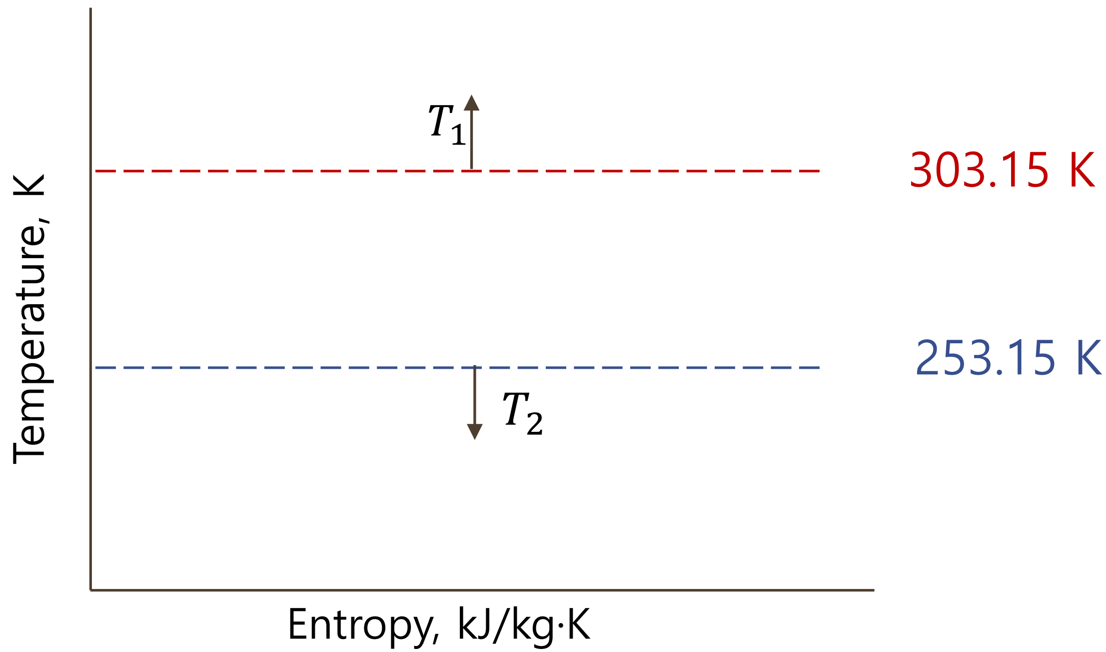
4 → 1 In this refrigeration process, refrigerant must add the heat from the cold room.

Example



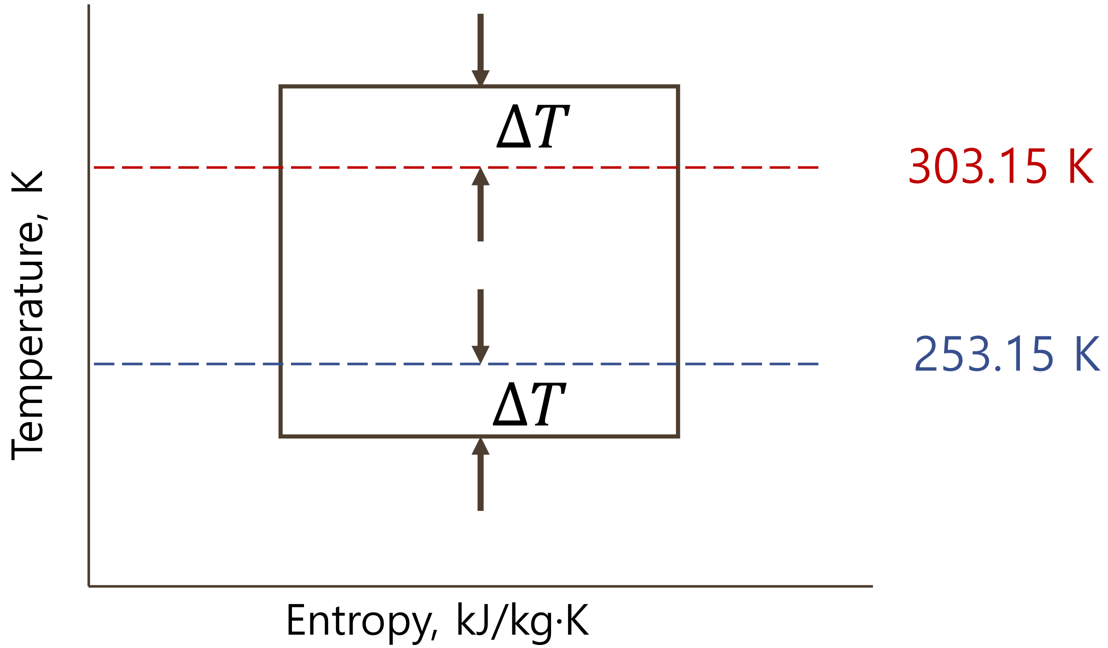
- **If the refrigeration system must maintain a cold room at – 20 ℃ and can reject heat to the atmosphere at 30 ℃, how can we control the temperatures, T_1 and T_2?**

Solution



- **T_1 must be higher than 303.15K.**
- **T_2 must be lower than 253.15K.**

Solution



- **For higher COP, we can keep the ΔT as small as possible.**

Reduction of Temperature Difference

$$q = UA\Delta T$$

q = heat, W

U = overall heat-transfer coefficient,

A = heat-transfer area,

ΔT = temperature change, K

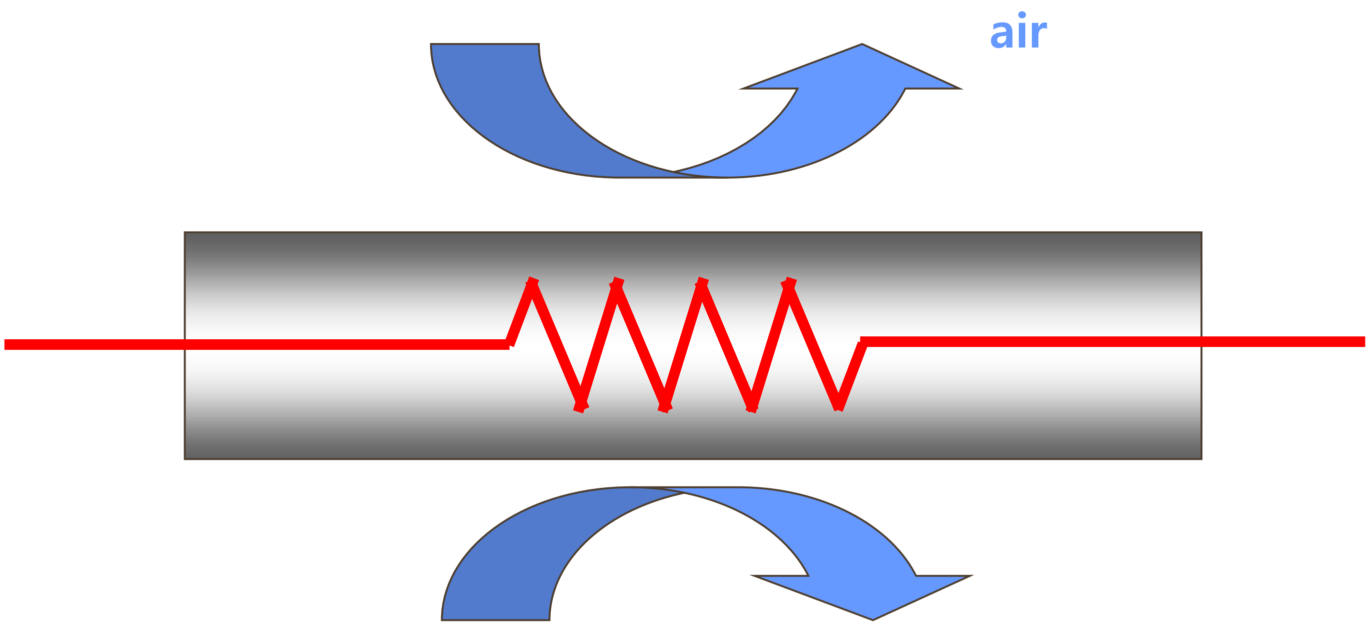
➢ **Reduction of ΔT can be accomplished by increasing A or U in equation.**

How To Accomplish High U?

- **In reality, we can make U high rather than make A high for given q, because we need to make less the space of refrigerator.**
- **But a large heat transfer area is accomplished**

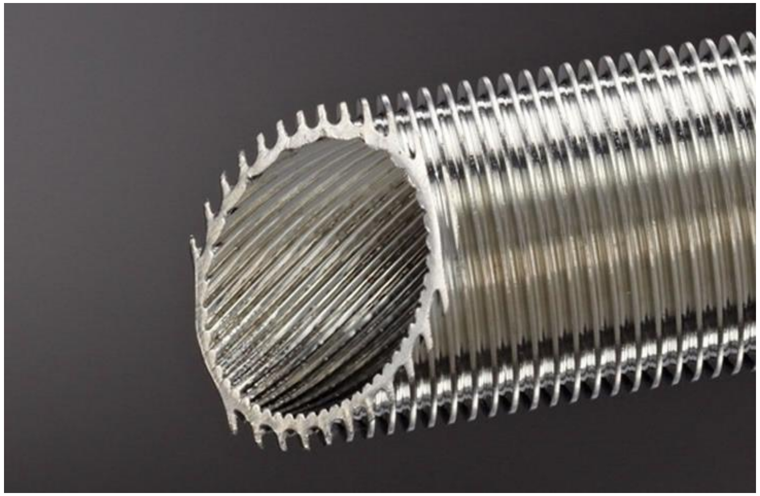
For a High Value of U

1. We can make the air speed around heat exchanger high.



For a High Value of U

2. We can use the finned tube.

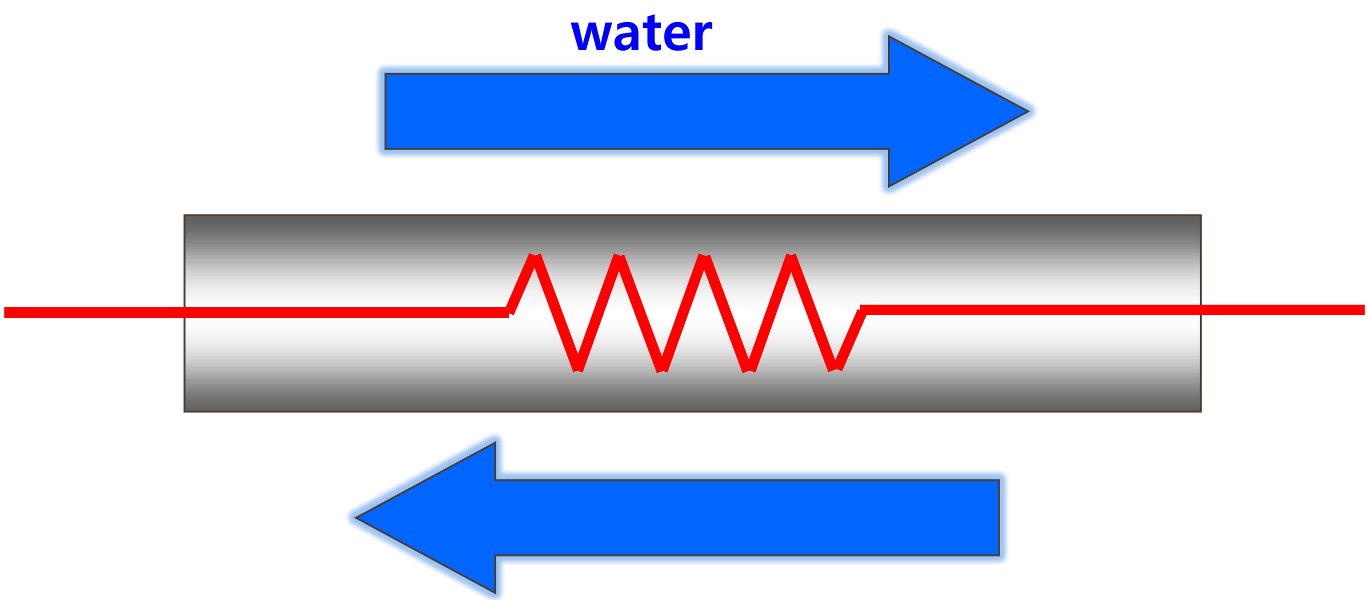


The low finned tube

Helically finned tube

For a High Value of U

3. The water around the heat exchanger will help the heat exchange.

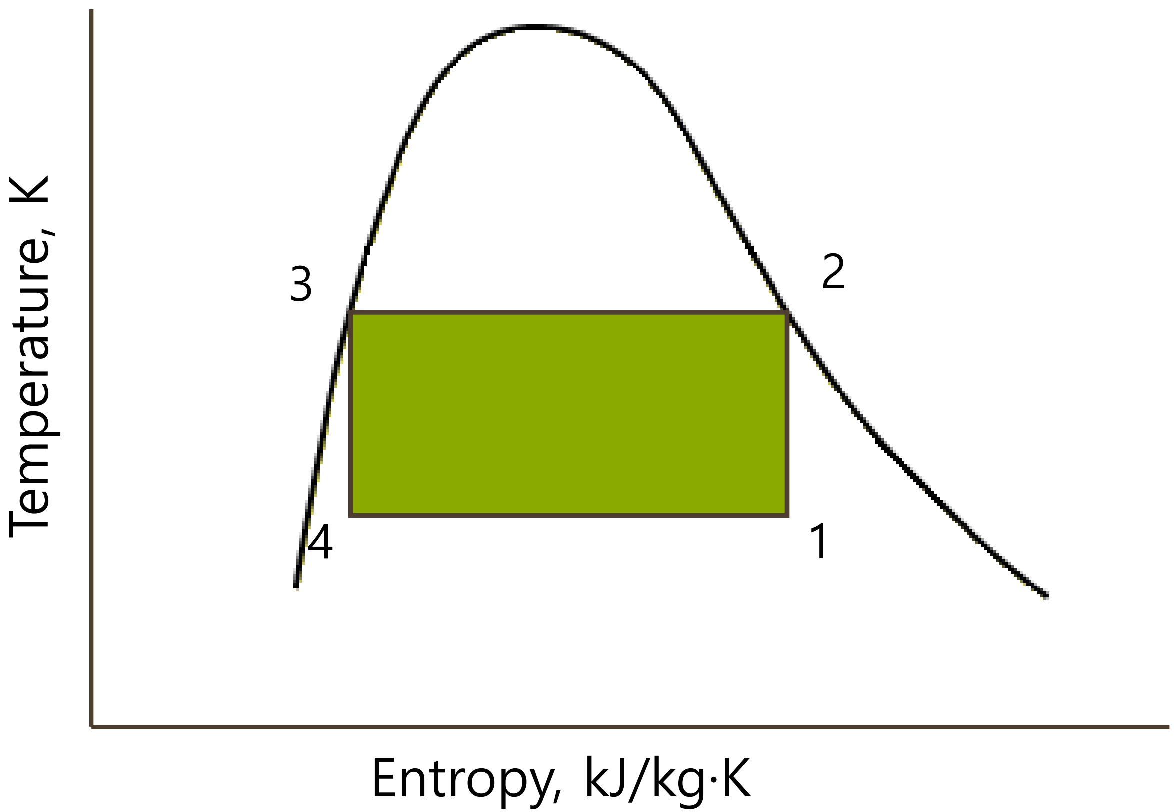


(But it will promote to corrode the heat exchanger.)

Revision of the Carnot Cycle

Revision of the Carnot Cycle

Compression Process : 1 → 2



Two Kinds of Compression

1. Wet compression

— compression with liquid droplet

2. Dry compression

— compression with no droplet of liquid

Problem of Wet Compression

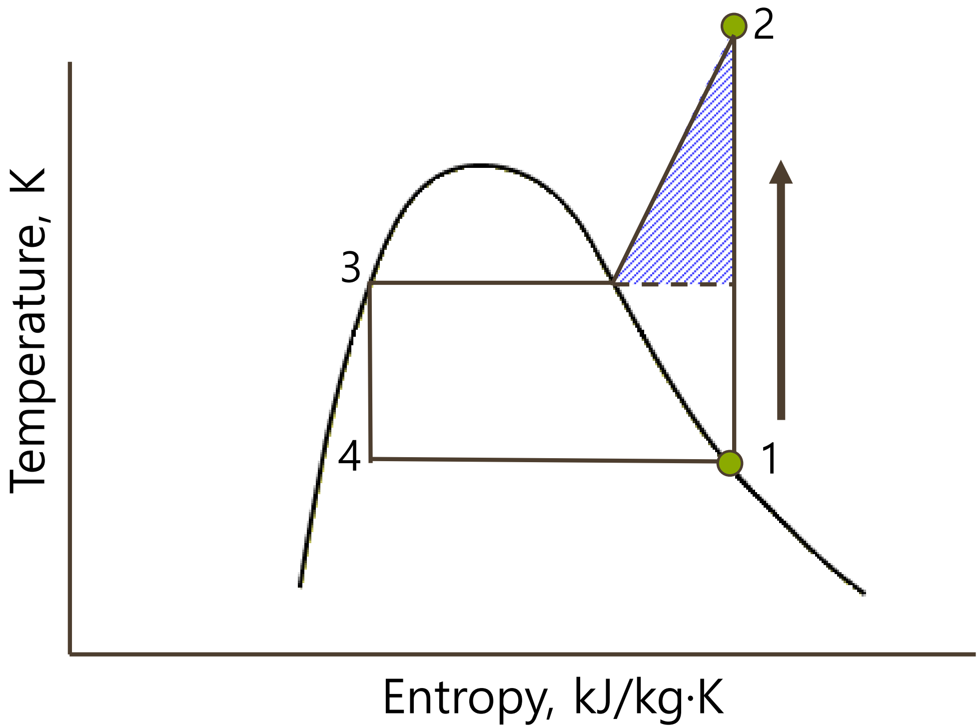
1. Liquid refrigerant may be trapped in the head of the cylinder by the rising piston, possibly damaging the valve or the cylinder head.

2. High-speed compressor are susceptible to damage by liquid because of the short time available for heat transfer.

3. The droplet of liquid may wash the lubricating oil from the walls of the cylinder, accelerating wear.

Revision of the Carnot Cycle

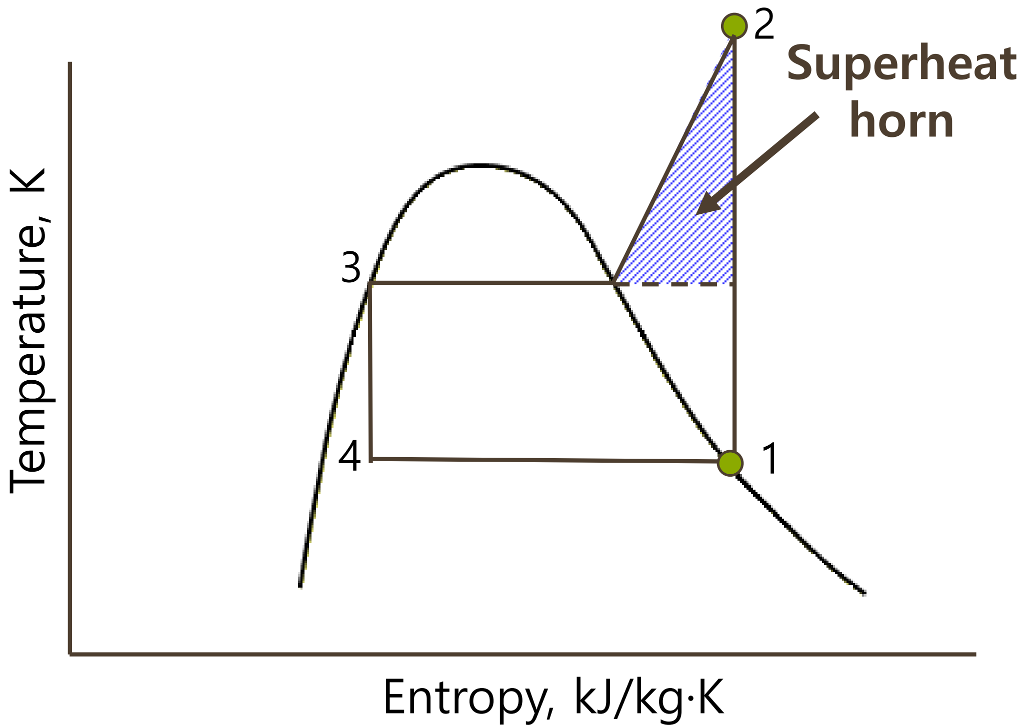
Dry Compression



- **If the refrigerant entering compressor is saturated vapor, the compression from point 1 to 2 is called dry compression.**

Revision of the Carnot Cycle

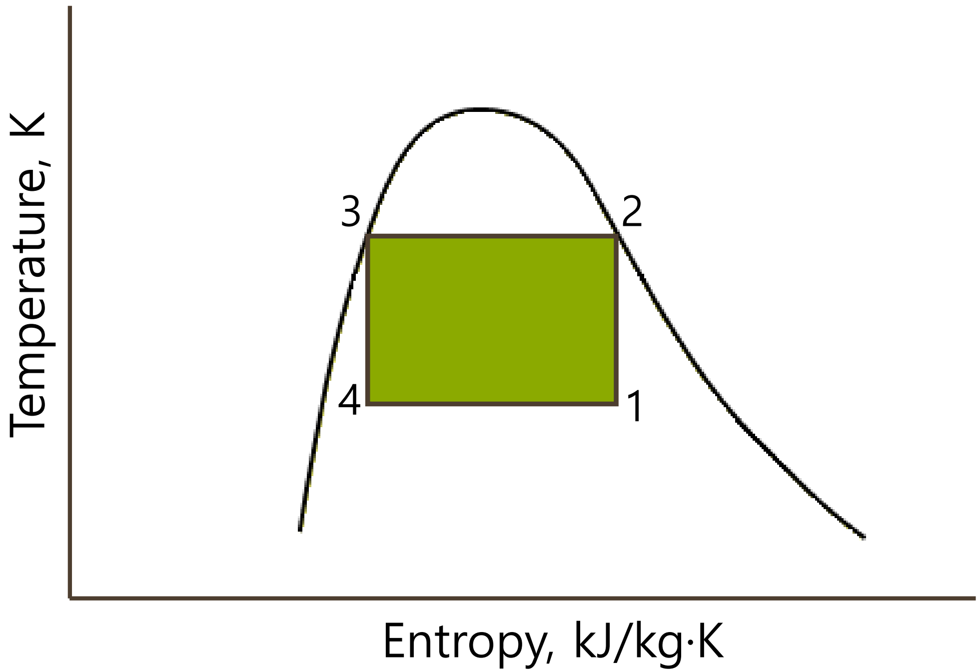
Superheat Horn



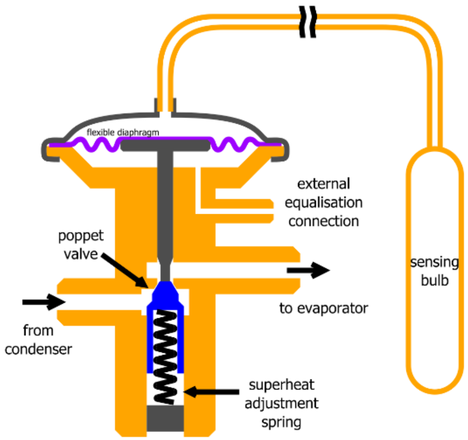
- **On the temperature-entropy diagram superheat horn represent the additional work for dry compression.**

Revision of the Carnot Cycle

Expansion Process : 3 → 4



Throttling Device



Expansion valve

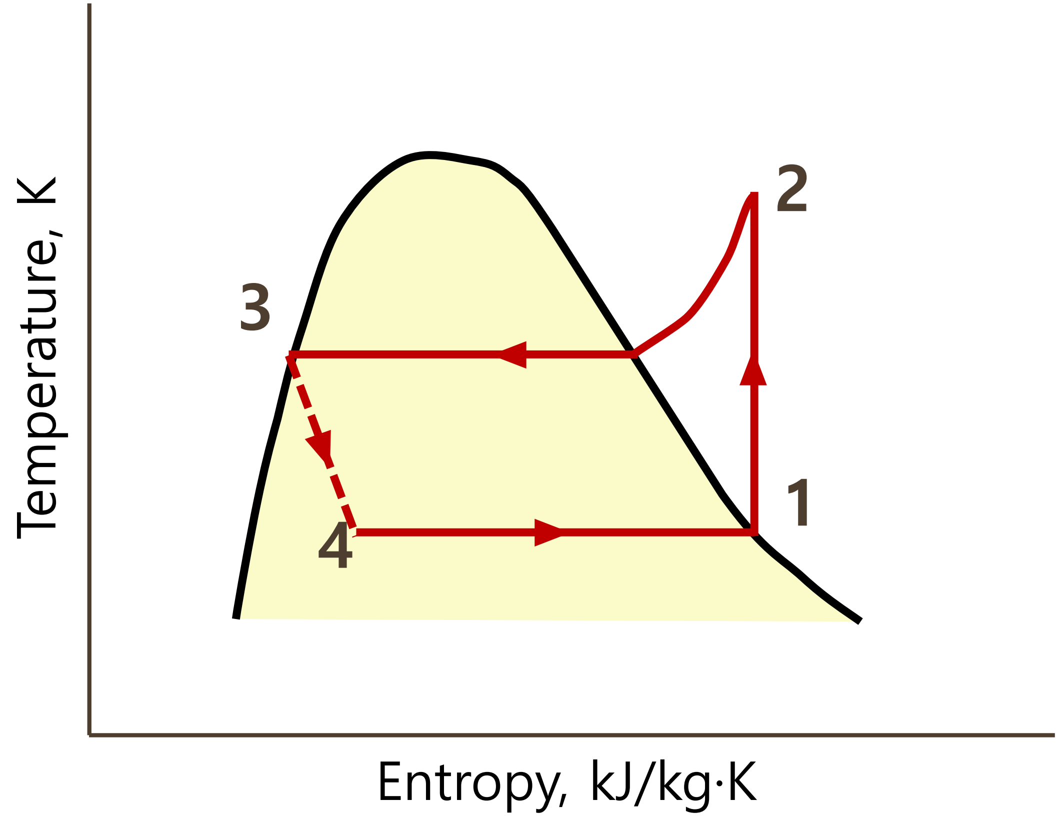
- **Because necessity still remains of reducing the pressure in the expansion process we can use throttling device such as a valve.**

Isenthalpic Process

- Throttling happens in expansion device such as an expansion valve.
- No changes in potential and kinetic energy and with no heat loss, $h_3 = h_4$; that is, the process is isenthalpic.
- The constant-enthalpy throttling process is irreversible, and during the process the entropy increases.

Revision of the Carnot Cycle

Throttling Process

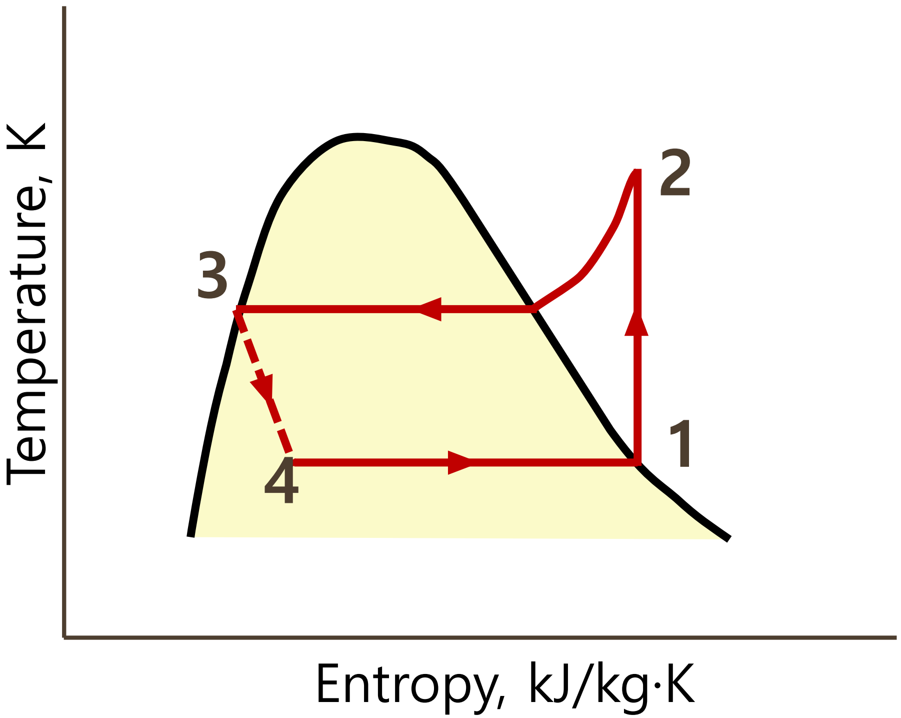


➢ **The throttling process take place 3 → 4 in this figure.**

Standard Vapor-Compression Cycle

Standard Vapor-Compression Cycle

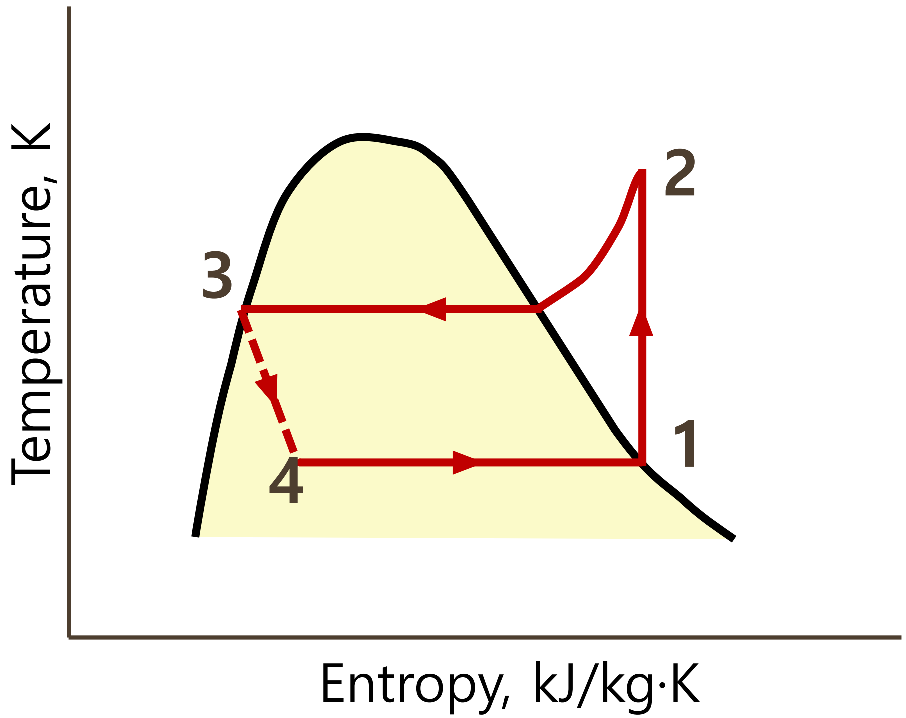
Compression Process



- **1-2 Process (Compression)**

Reversible and adiabatic compression from saturated vapor to the condenser pressure

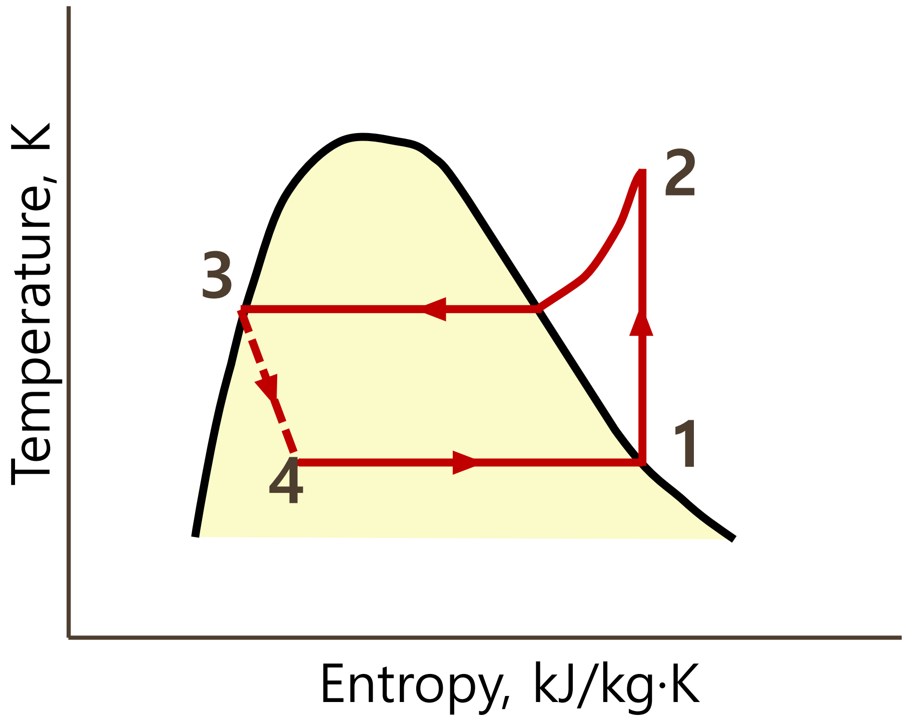
Condensation Process



- **2-3 Process (Condensation)**

Reversible rejection heat at constant pressure, causing desuperheating and condensation of the refrigerant

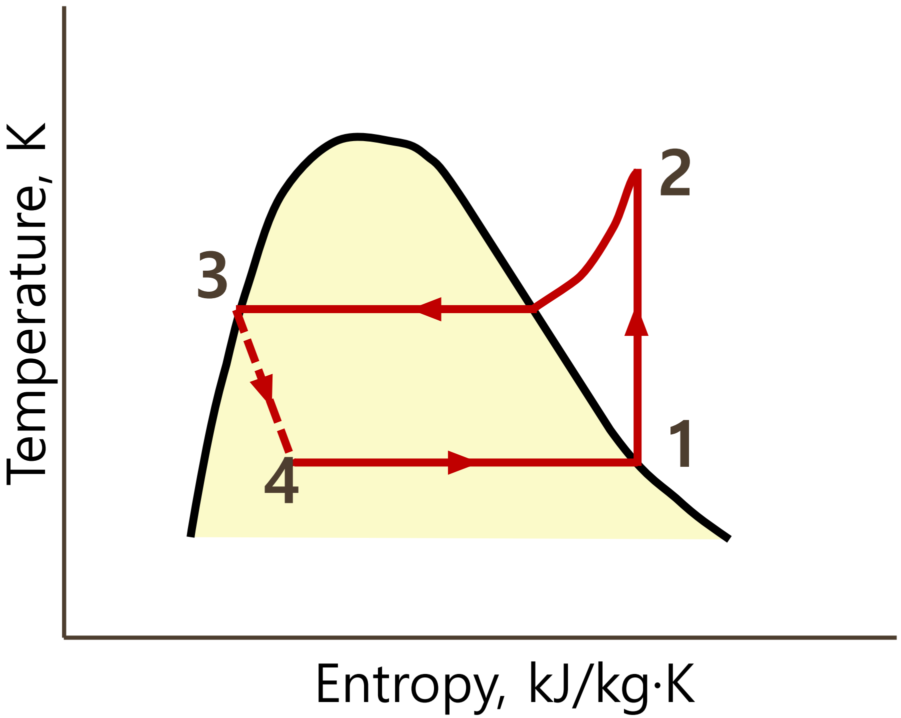
Expansion Process



- **3-4 Process (Expansion)**

Irreversible expansion at constant enthalpy from saturated liquid to the evaporator pressure

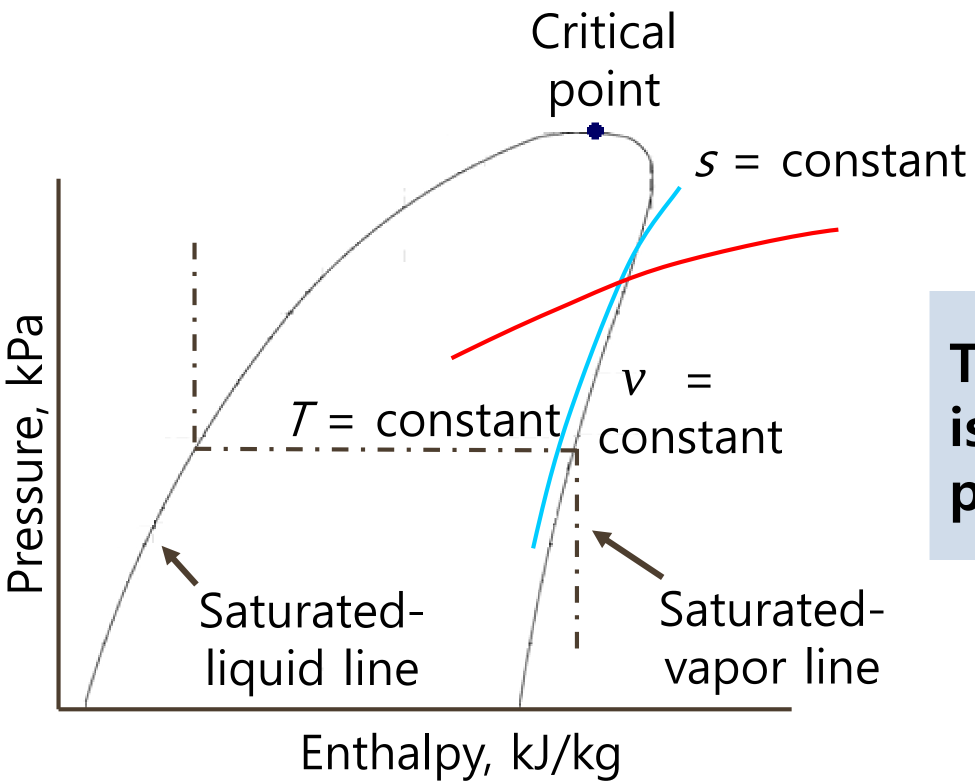
Evaporation Process



- **4-1 Process (Evaporation)**

Reversible addition of heat at constant pressure causing evaporation to saturated vapor

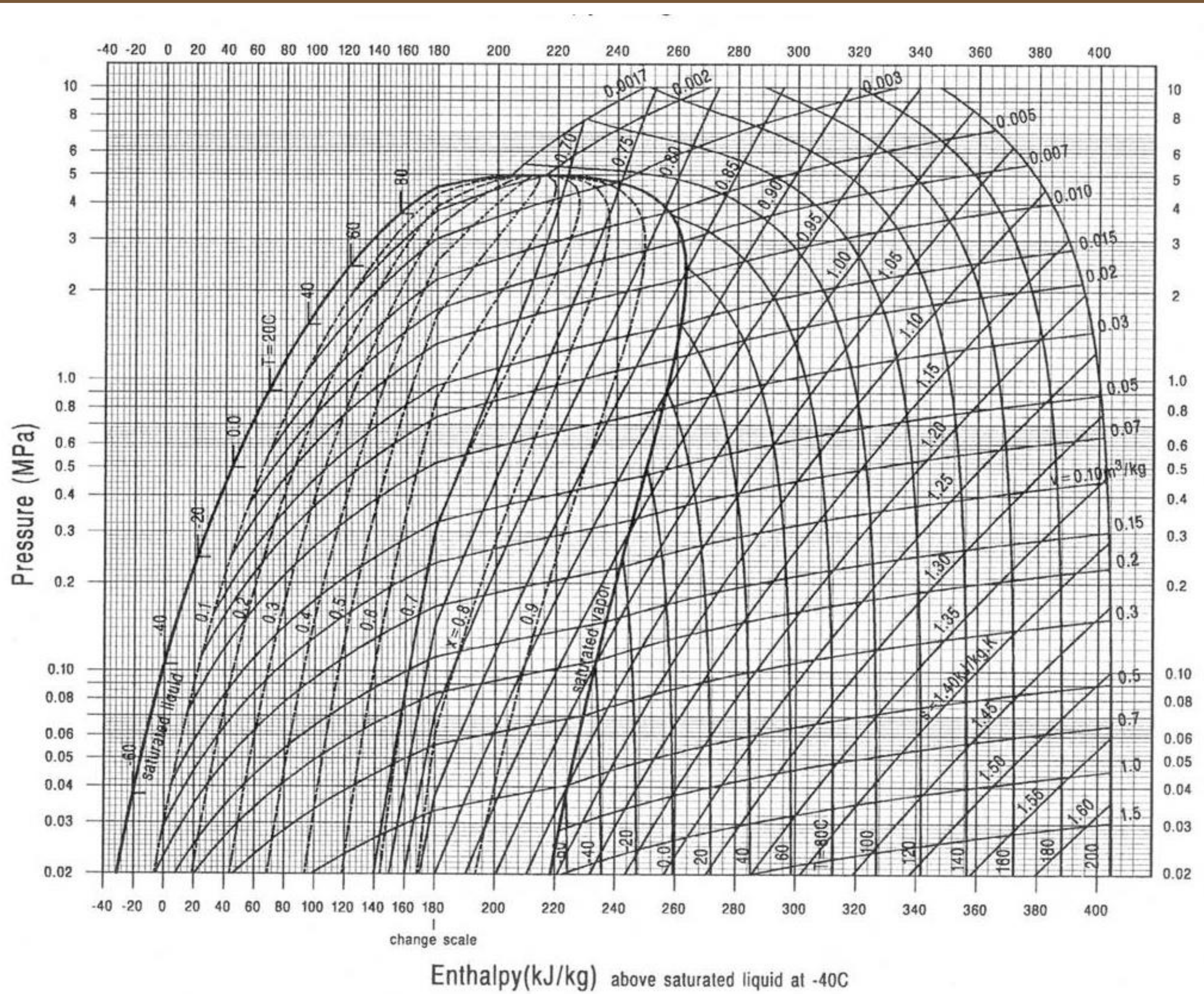
P-h Diagram of Refrigerant



The pressure- enthalpy diagram is the usual graphic means of presenting refrigerant properties.

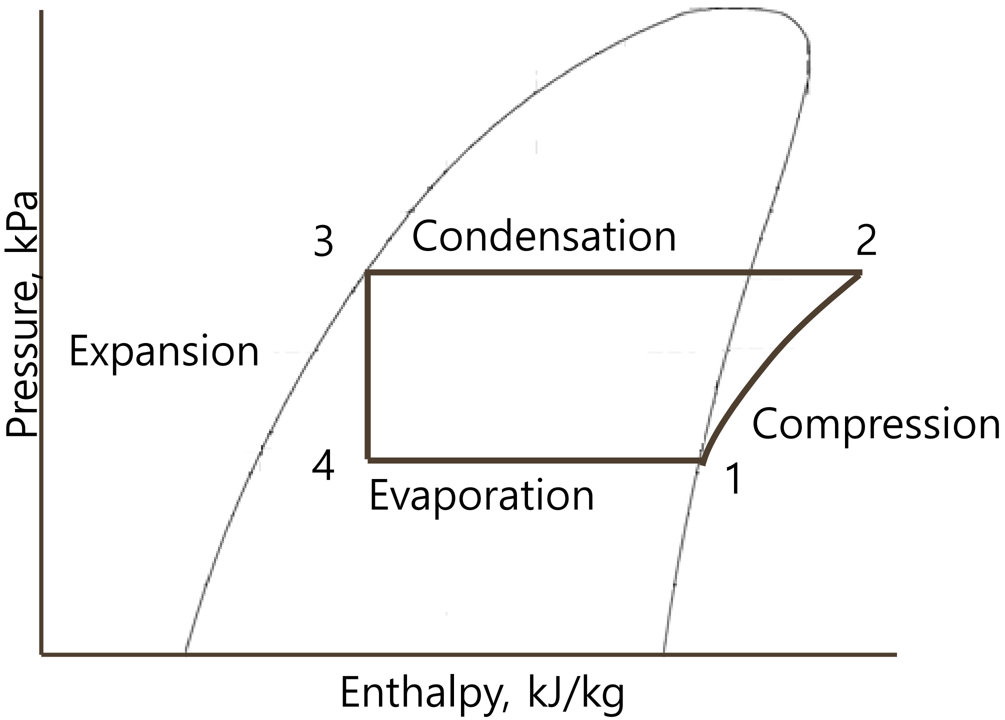
Standard Vapor-Compression Cycle

Actual P-h Diagram of R22



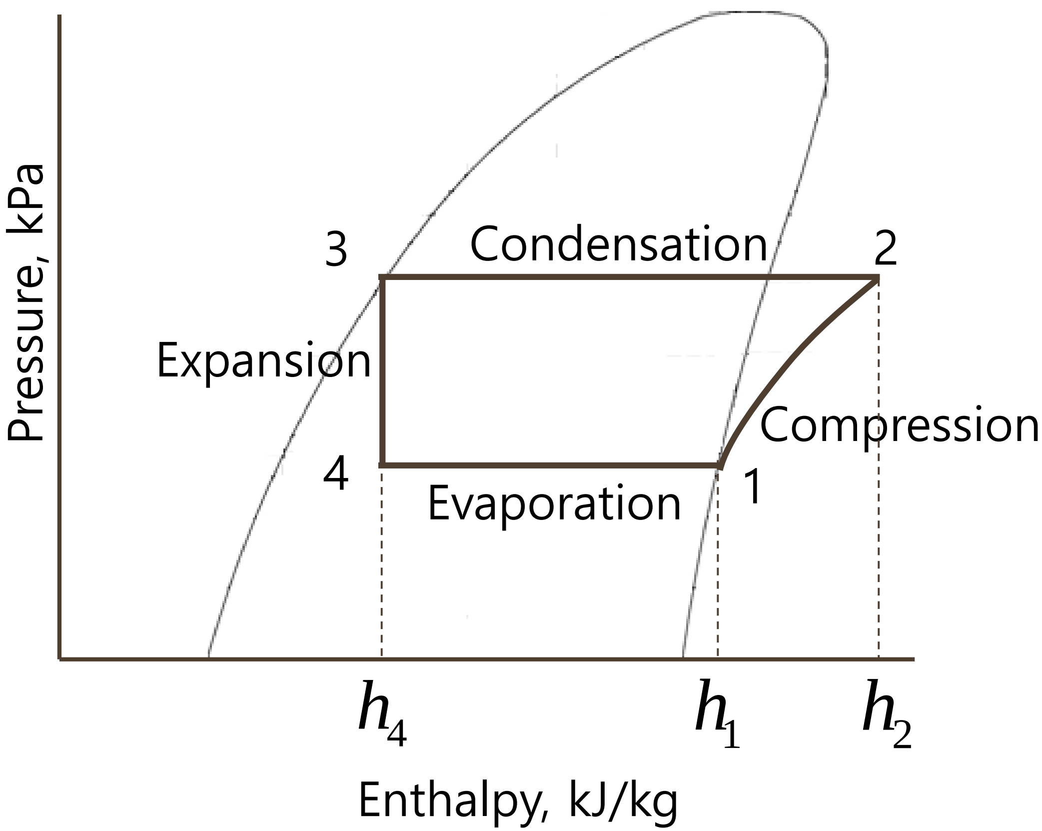
Standard Vapor-Compression Cycle

Cycle on the Pressure-Enthalpy Diagram



In refrigeration practice, the enthalpy is one of the most important properties sought, and the pressure can usually be determined most easily.

Coefficient of Performance (COP)



The work of compression

$= h_2 - h_1$

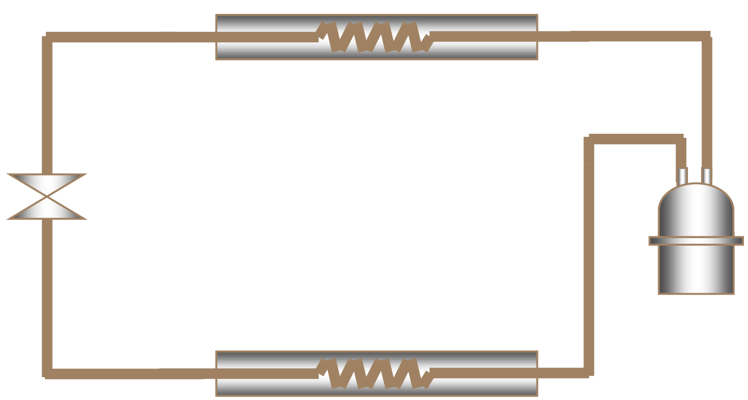
The refrigerating effect

$= h_1 - h_4$

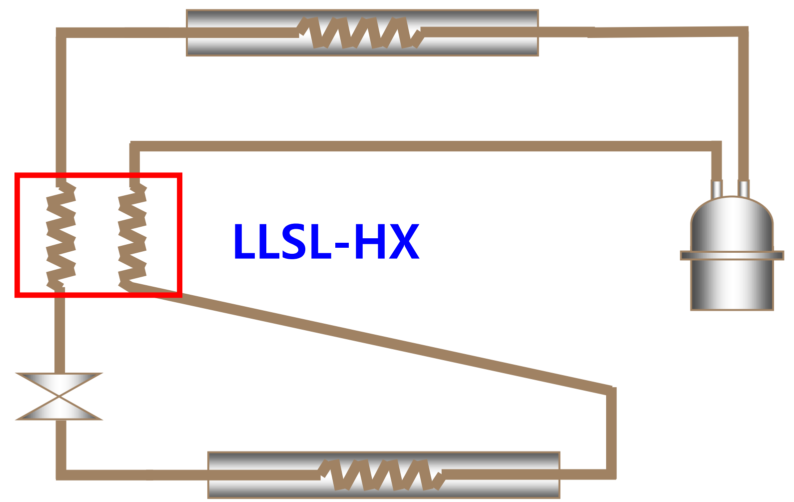
$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

Liquid Line – Suction Line Heat Exchanger

Liquid Line - Suction Line Heat Exchanger



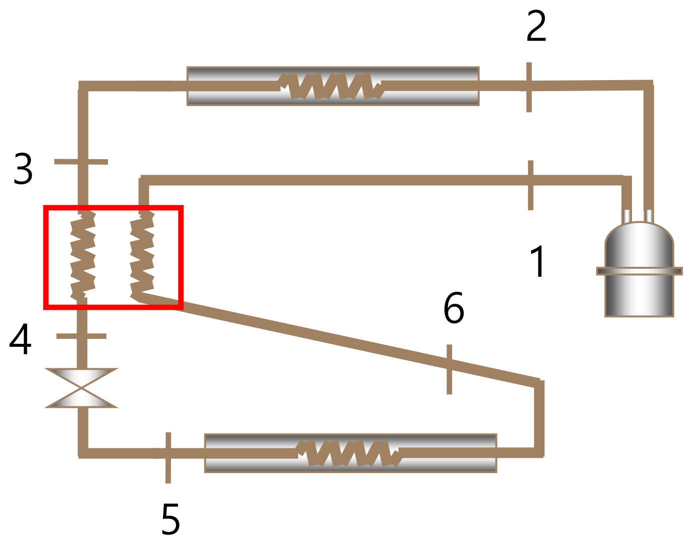
Normal cycle

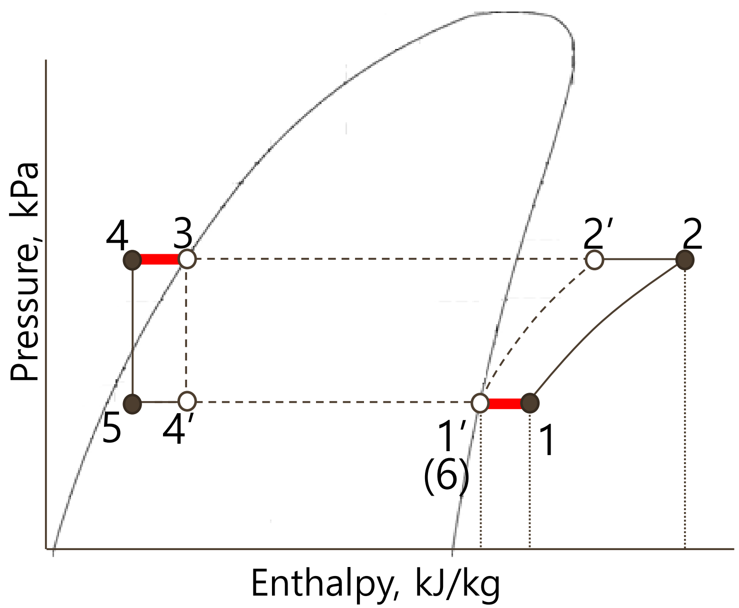


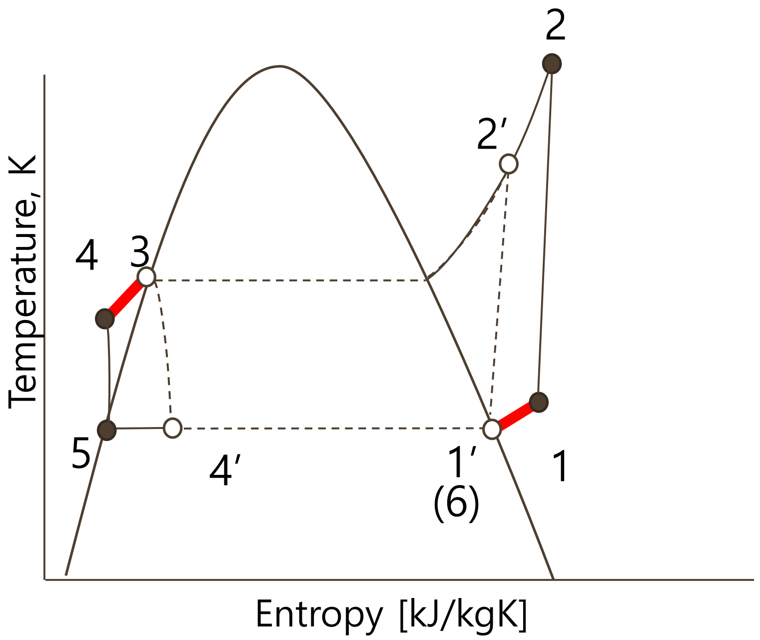
Liquid line – suction line
heat exchange cycle

Liquid Line – Suction Line Heat Exchanger

Schematic and Graph







Advantages

1. Superheating of the vapor leaving the evaporator
2. Sub-cooling of the liquid leaving the condenser
3. Increased refrigeration effect

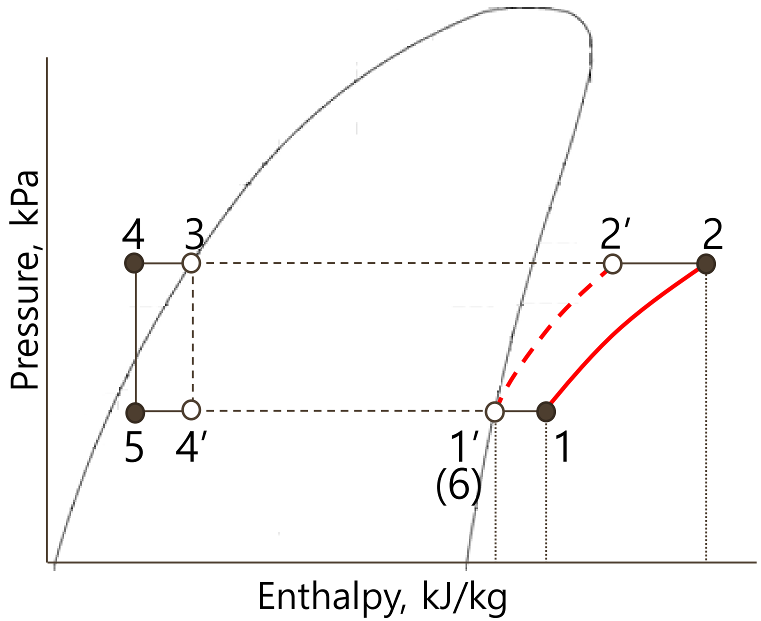
$$\dot{Q} = \dot{m} \cdot \Delta h$$

(*h* = refrigeration effect)

Liquid Line – Suction Line Heat Exchanger

Disadvantages

1. Increase compressor work



$$\dot{w}' = h_{2'} - h_{1'}$$

$$\dot{w} = h_2 - h_1$$

2. Additional cost of heat exchanger

Question and Answer Session