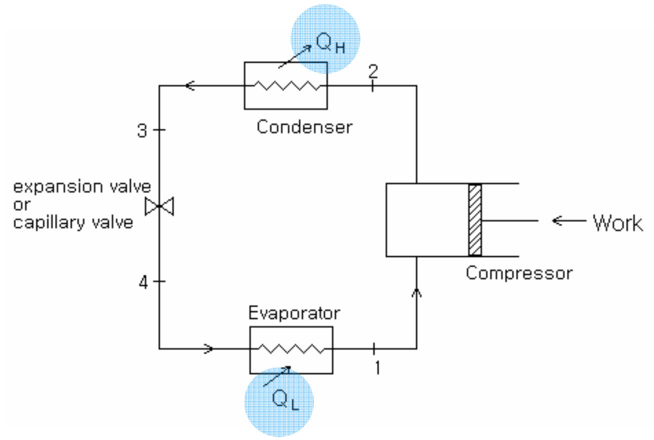
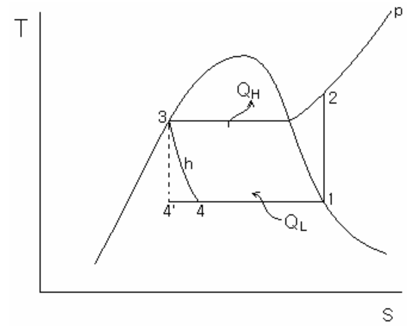
Chapter 10 Refrigeration cycle (냉동사이클)

- Steam vapor – Compression refrigeration cycle (2개의 상에 걸친 냉매)





<u>working fluid</u>: steam again

Refrigeration: seek q_L
Heat Pump: seek q_H

1-2: Sat vap undergoes an isentropic compression
2-3: Heat is rejected at constant p
3-4: Adiabatic throttling process
4-1: Working fluid is evaporated at constant p

1-2-3-4'= Identically reverse of Rankine except, we use expansion valve(3-4) that is irreversible.

At state 3, saturated liquid 상태이므로 turbine을 이용할 경우에 실제 얻은 일이 매우 작다. 그러므로 값비싼 장치는 이용하는 것 보다 단순 압력 강하 장치인 throttling device를 사용 (valve or capillary tube)

⇒이는 등 엔탈피 과정.

	1st	2nd
Comp	$w_c = h_2 - h_1$	$s_2 = s_1$
Condenser	$q_H = h_2 - h_3$	
Valve	$h_4 = h_3$	
Evaporator	$q_L = h_1 - h_4$	

Coefficient of performance 성능계수 (Recall)

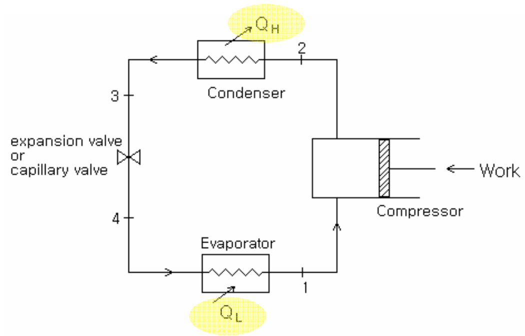
<u>Refrigerator</u> $\beta = \dfrac{q_L}{w_c} = \dfrac{h_1 - h_4}{h_2 - h_1}$ <u>Heat pump</u> $\beta = \dfrac{q_H}{w_c} = \dfrac{h_2 - h_3}{h_2 - h_1}$

냉동사이클 (Refrigerator)

열기관 사이클을 역으로 작동시킨 것으로 생각할 수 있다.

열펌프 (Heat Pump)

냉동사이클의 방열부 열 (Q_H) 을 난방 등에 사용하는 사이클



- Example 10-1
  Consider a ref. Cycle with Ammonia (NH3) as a working fluid.
  Find q_L, w_c, β. Given $T_1 = -15°C$ $T_2 = 40°C$

1-2: $w_c = h_2 - h_1$

@1) since sat vapor

$$T_1 = -15°C,\ p_1 = 0.2365 MPa,\ h_1 = 1425.7\,kJ/kg$$
$$v_1 = v_{g1} = 0.5093\,m^3/kg$$
$$s_1 = s_{g1} = 5.5453\,kJ/kg$$

@2) superheated

$$T_2 = 40°C,\ s_2 = s_1 = 5.54\,kJ/kg.K$$
$$p_2 = 548.4\,kPa,\ h_2 = 1536.7\,kJ/kg$$

@3) sat liquid

$$p_3 = p_2 = 548.5\,kPa,\ T_2 = 6.71°C$$
$$h_3 = 212.24\,kJ/kg$$

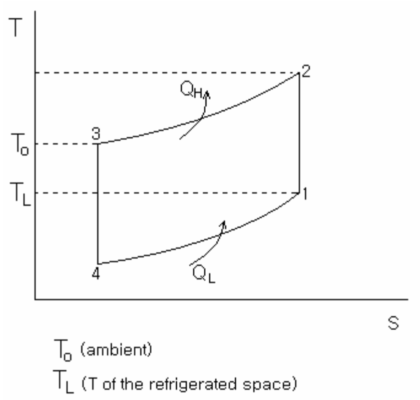
@4)

$$h_4 = h_3 = 212.24\,kJ/kg,\ p_4 = 0.2365\,MPa$$

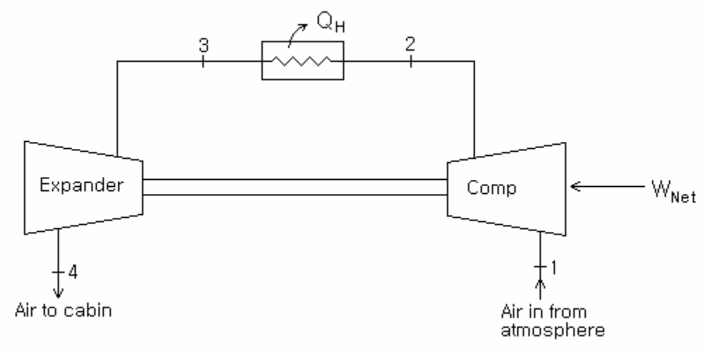
$$\therefore w_c = h_2 - h_1 = 1536.7 - 1425.7 = 111.0\,kJ/kg$$
$$q_L = h_1 - h_4 = 1213.15\,kJ/kg$$

$$CoP_{(R)} = \frac{1213.5}{111.0} = 10.9$$ 냉동기 성능계수

- Air-Standard Refrigeration Cycle (단일상에서의 기체-냉매)
  Often used as aircraft cooling systems.
  Reverse of the Brayton cycle.



In practice, this cycle is used to cool aircraft in an open cycle.



Upon leaving the expander, the cool air is blown directly into the cabin, thus providing cooling effect where needed.

- Homework (due ?)

  10-1,
  10-3,
  10-6,
  10-10

Chapter 11 Thermodynamic Relations

Thus far, we have talked about several thermodynamic properties.

$p,\ v,\ \rho,\ T,\ m,\ e,\ h,\ s,\ c_p,\ c_v ...$

F (Helmholtz free energy), f (per unit mass)
G (Gibbs' free energy), g

<u>Two Important Relations</u>

Consider a variable z that is a continuous function of x and y.

$$z = f(x, y)$$

$$dz = \left(\frac{\partial z}{\partial x}\right)_y dx + \left(\frac{\partial z}{\partial y}\right)_x dy$$

It is convenient to rewrite this as

$$dz = M\,dx + N\,dy \quad \text{--------------------(*)}$$

The physical significance of the partial derivatives can be understood from $p - v - T$ diagram (surface) of the superheated vapor.

$$(x, y, z) \rightarrow (p, v, T)$$

e.g. Evaluate the partial derivatives along a constant-temperature line,

$$\left(\frac{\partial p}{\partial v}\right)_T$$

In (*), if x, y and z are all point functions (i.e. quantities that depend only on the state and are independent of the path) the differentials are exact differentials. That is

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y \quad \text{--------------------------(1)}$$

The second important relations follow. Consider

$$x = f(y, z)$$

and $dx = \left.\frac{\partial x}{\partial y}\right|_z dy + \left.\frac{\partial x}{\partial z}\right|_y dz$ (a)

Similarly, $y = f(x, z)$ then

$$dy = \left(\frac{\partial y}{\partial x}\right)_z dx + \left(\frac{\partial y}{\partial z}\right)_x dz \quad \text{(b)}$$

Sub (b) → (a) we have

$$dx = \left(\frac{\partial x}{\partial y}\right)_z \left[\left.\frac{\partial y}{\partial x}\right|_z dx + \left.\frac{\partial y}{\partial z}\right|_x dz\right] + \left.\frac{\partial x}{\partial z}\right|_y dz$$

$$= \left.\frac{\partial x}{\partial y}\right|_z \left.\frac{\partial y}{\partial x}\right|_z dx + \left[\left.\frac{\partial x}{\partial y}\right|_z \left.\frac{\partial y}{\partial z}\right|_x + \left.\frac{\partial x}{\partial z}\right|_y\right] dz$$

Two possible cases.

If $dz = 0,\ dx \neq 0$, then

$$\left.\frac{\partial x}{\partial y}\right|_z \left.\frac{\partial y}{\partial x}\right|_z = 1$$

If $dx = 0,\ dz \neq 0$, then

$$\left.\frac{\partial x}{\partial y}\right|_z \left.\frac{\partial y}{\partial z}\right|_x + \left.\frac{\partial x}{\partial z}\right|_y = 0$$

or

$$\left.\frac{\partial x}{\partial y}\right|_z \left.\frac{\partial y}{\partial z}\right|_x \left.\frac{\partial z}{\partial x}\right|_y = -1 \qquad \text{--------------------(2)}$$

2 개의 성질을 알고 제 3의 성질을 구할 때 쓴다.

- Maxwell Relations

  Four equations relating the properties p, v, T, s

  Recall what we already derived,

$$du = T\,ds - p\,dv \qquad (3)$$

$$dh = T\,ds + v\,dp \qquad (h = u + pv) \qquad (4)$$

The remaining two are derived from the definition of the Helmholtz function, f.

$$f = u - Ts$$

$$so\ df = du - T\,ds - s\,dT$$

Sub (3) into above

$$df = -p\,dv - s\,dT \qquad (5)$$

Similarly, using Gibb's energy

$$g = h - Ts$$

$$dg = dh - T\,ds - s\,dT$$

Sub (4) into above gives

$$dg = v\,dp - s\,dT \qquad (6)$$

Since eqns (3), (4), (5), (6) are relations involving properties, we conclude that these are exact differentials and thus, are of the general form.

$$dz = M\,dx + N\,dy$$

Since $\left.\dfrac{\partial M}{\partial y}\right|_x = \left.\dfrac{\partial N}{\partial s}\right|_v$

From (3) we have

$$\left.\frac{\partial T}{\partial v}\right|_s = -\left.\frac{\partial p}{\partial s}\right|_v$$

From (4) we have

$$\left.\frac{\partial T}{\partial p}\right|_s = \left.\frac{\partial v}{\partial s}\right|_p$$

From (5) we have

$$\left.\frac{\partial p}{\partial T}\right|_v = \left.\frac{\partial s}{\partial v}\right|_T$$

From (6) we have

$$\left.\frac{\partial v}{\partial T}\right|_p = -\left.\frac{\partial s}{\partial p}\right|_T$$

Maxwell's relations for simple compressible system

- Note p, T, v can be measured experimentally but s cannot be measured experimentally.
- By using the Maxwell Relations, we can determine changes in entropy from quantities that can be measured, (i.e. p, T, v).
- There are some additional useful relations from (3) -> (6)

$$\left.\frac{\partial u}{\partial s}\right|_v = T\ , \qquad \left.\frac{\partial u}{\partial v}\right|_s = -p$$

$$\left.\frac{\partial h}{\partial s}\right|_p = T\ , \qquad \left.\frac{\partial h}{\partial p}\right|_s = v$$

$$\left.\frac{\partial f}{\partial v}\right|_T = -p\ , \qquad \left.\frac{\partial f}{\partial T}\right|_v = -s$$

$$\left.\frac{\partial g}{\partial p}\right|_T = v\ , \qquad \left.\frac{\partial g}{\partial T}\right|_p = -s$$