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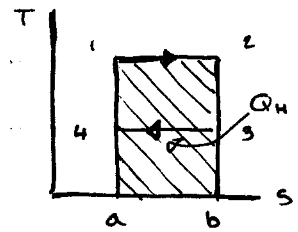
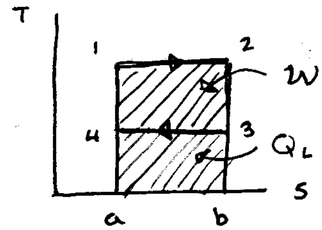
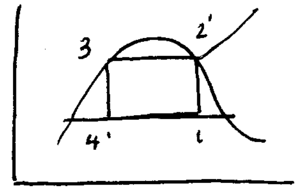
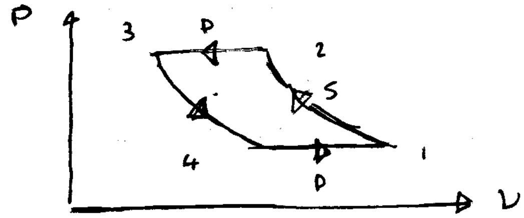
# Refrigeration Systems

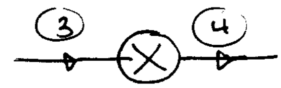


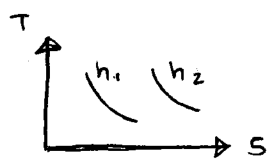



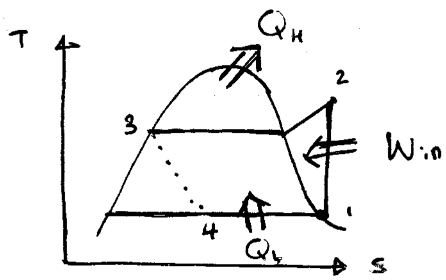

For 3 to 4:




$$q_{c.v.} + (h_i + V_i^2/2 + gz_i) = w_{c.v.} + (h_e + V_e^2/2 + gz_e)$$

$$h_i = h_e$$




Performance of refrigeration system is given in terms of coefficient of performance.

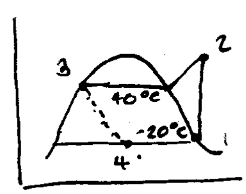
$$\beta = q_L / w_c$$

heat pump system: $\beta' = q_H / w_c$

Example: Consider an ideal refrigeration cycle that uses R-134a as the working fluid. The temperature of the refrigerant in the evaporator is $-20°C$ ... etc.

$$\beta = \frac{Q_L}{w_c}$$

$$w = h_2 - h_1$$




2 ↘

$\omega = h_2 - h_1$

Sat. vapour, $T = 20°C$ } $h_1 = 386.08$ kJ/kg, $s_1 = 1.7395$ kJ/kg.K

$s_1 = s_2 = 1.7395$ kJ/kg.K

$P_2 = P_3 = P_g @ T_3 = 1017$ kPa (sat. liquid @ 3)

thus, $h_2 = 428.4$ kJ/kg (by interpolation)

$T_2 = 47.7$ °C

$\omega_c = (428.4 - 386.08) = 42.3$ kJ/kg

$q_L = h_1 - h_4$

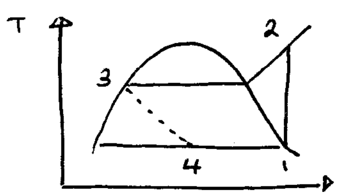
where $h_4 = h_3 = 256.5$ kJ/kg

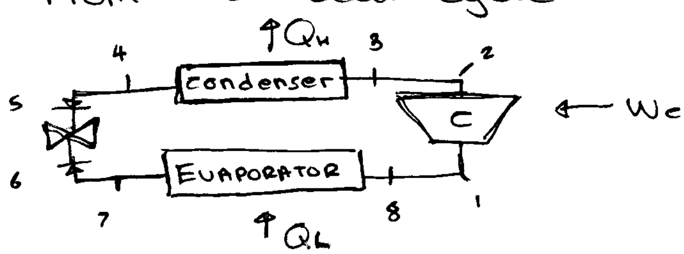
$q_L = (386.08) - (256.5) = 129.6$ kJ/kg

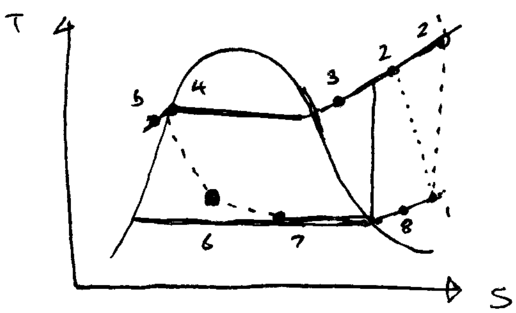
$\beta = q_L / \omega_c = \frac{129.6}{42.3} = 3.064$

Ref. capacity $= q_L \times \dot{m} = 129.6 \times 0.03 = 3.89$ kW

Deviation of the actual vapour-compression refrigeration cycle from the ideal cycle.



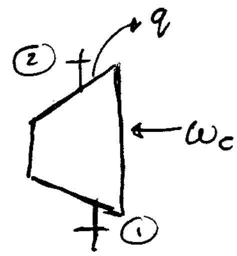
(9.71)

**Example** "A refrigeration cycle utilizes R-134a..."

$P_1 = 125$ kPa  $T_1 = -10$ °C
$P_2 = 1.2$ MPa  $T_2 = 100$ °C
$P_3 = 1.19$ MPa  $T_3 = 80$ °C
$P_4 = 1.16$ MPa  $T_4 = 45$ °C
$P_5 = 1.15$ MPa  $T_5 = 40$ °C
$P_6 = P_7 = 140$ kPa  $x_6 = x_7$
$x_6 = x_7$  $T_8 = -20$ °C
$P_8 = 130$ kPa

} Determine COP of the cycle

$\beta = q_L / w_c$




Energy eq'n:

$q + h_1 = h_2 + w_c$

$\Rightarrow w_c = h_1 - h_2 + q$

$w_c = 394.4 - 480.9 + (-4)$  { $h_1 = 394.4$ kJ/kg, $h_2 = 480.9$ kJ/kg

$w_c = -90.5$ kJ/kg

$q_L = h_8 - h_7$  { $h_8 = 386.6$ kJ/kg, $h_7 = h_5 = 256.4$ kJ/kg

where $h_6 = h_5 = h_7$

$q_L = 386.6 - 256.4 = 130.2$ kJ/kg

$\beta = q_L / w_c = 130.2 / 90.5 = 1.44$

↳ multi-cycle refrigeration cycle.

from 8th edition

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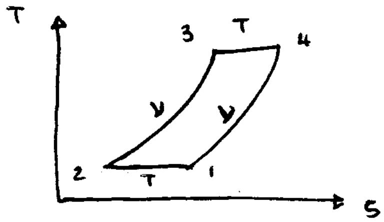
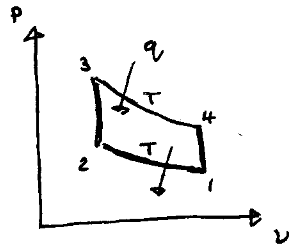




$w_{1\to2}$ $q_{1\to2}$

$\begin{cases} P = \alpha / v \\ v = \alpha / P \end{cases}$

$T_1 = T_2 = 25°C$

$P_1 = 100$ kPa

$CR = v_1/v_2 = 6$

$T_3 = T_4 = 1100°C$

Ideal gas law $\Rightarrow$ $P_2 = P_1(v_1/v_2) = 100(6) = 600$

$w_{1\to2} = \int_1^2 \frac{\alpha}{P} dP = \alpha \int_1^2 \frac{dP}{P} = \alpha(\ln P|_1^2)$

$w = \int_1^2 P dv = \int_1^2 \frac{\alpha}{v} dv = \alpha \int_1^2 \frac{dv}{v} = RT \ln v|_1^2$

$w_{1\to2} = RT(\ln v_2 - \ln v_1) = -RT(\ln v_1 - \ln v_2) = -RT \ln\left(\frac{v_1}{v_2}\right)$

$w_{1\to2} = -(0.287)(298.2)\ln(6) = -153.3$ kJ/kg

$V_2 = V_3 \Rightarrow P_3 = P_2\left(\frac{T_3}{T_2}\right) = 600\left(\frac{1373.2}{298.2}\right) = 2763$ kPa

$q_{2\to3} = u_3 - u_2 = C_v(T_3 - T_2) = 0.717(1373.2 - 298.1)$
$= 770.8$ kJ/kg

$w_{3\to4} = RT \ln\left(\frac{V_4}{V_3}\right) = 0.287(1373.2\text{ K})\ln(6) = 706.1$ kJ/kg

$w_{net} = w_{3\to4} - w_{1\to2} = 706.1 - 153.3 = 552.8$ kJ/kg

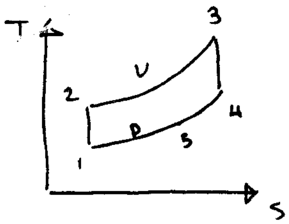
$\eta = \frac{w_{net}}{q_{3-4}}$ $\quad \eta_{no\ regen.} = \frac{w_{net}}{q_{2-3} + q_{3-4}} \Rightarrow \frac{(552.8)}{(770.8) + (706.1)}$

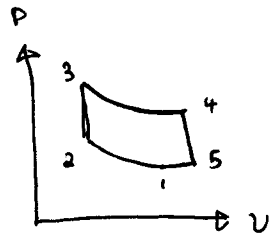
$\eta_{no,reg} = 0.374$ or $37.4\%$

$\eta_{reg} = \frac{w_{net}}{q_{3-4}} = \frac{552.8}{706.1} = 0.783$ or $78.3\%$

→ from 8th edition

10-114




$P_1 = 150$ kPa

$T_1 = 300$ K

$v_1/v_2 = 9$ $\quad v_4/v_3 = 14$

$P_4 = 250$ kPa

$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = 300(9)^{0.4} = 722.5$ K

$P_2 = P_1\left(\frac{v_1}{v_2}\right)^{k} = 150(9)^{1.4} = 3951$ kPa

(k = 1.4)

$P_3 = \left(\frac{v_4}{v_3}\right)^k P_4 = (14)^{1.4}(250) = 10058$ kPa

$T_3 = T_2\left(\frac{P_3}{P_2}\right) = (722.5)\left(\frac{10058}{3251}\right) = 2235.3$ K

$q_H = c_v(T_3 - T_2) = 0.717(2235.3 - 722.5) = 1085$ kJ/kg

Otto, Atkinson, Miller, etc.

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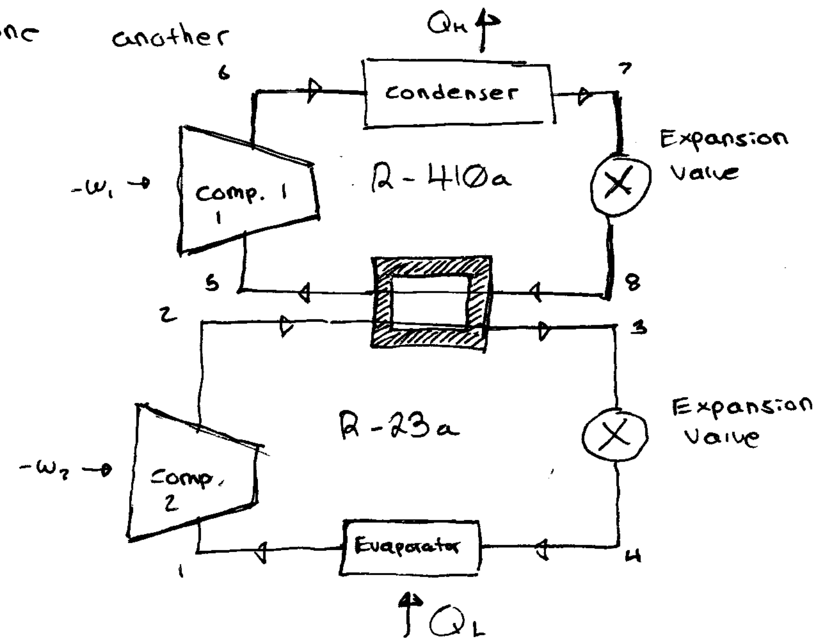
Refrigeration Cycle Configurations

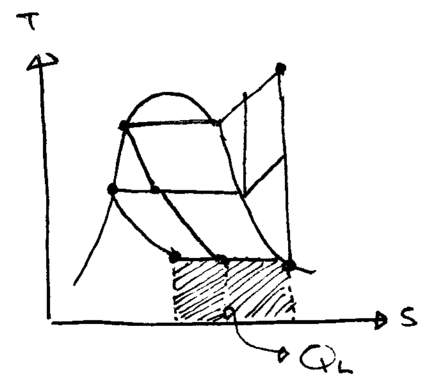
Two-stage compression w/ dual loops

- can be used when the temperature between the compressor stages is too low to use a two-stage compressor w/ intercooling.
- lowest temp. compressor handles a smaller volume, so has the largest specific work.

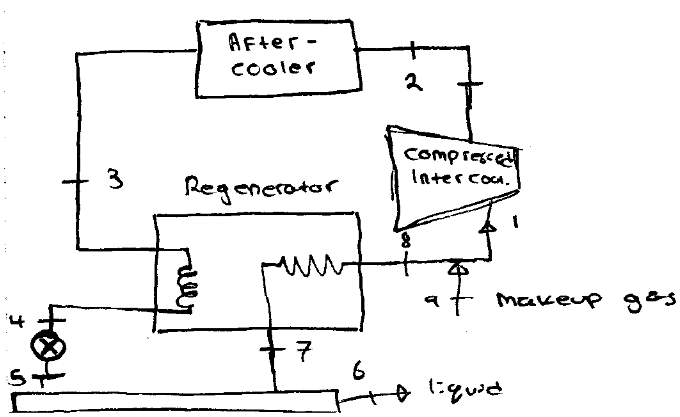
Cascade refrigeration System

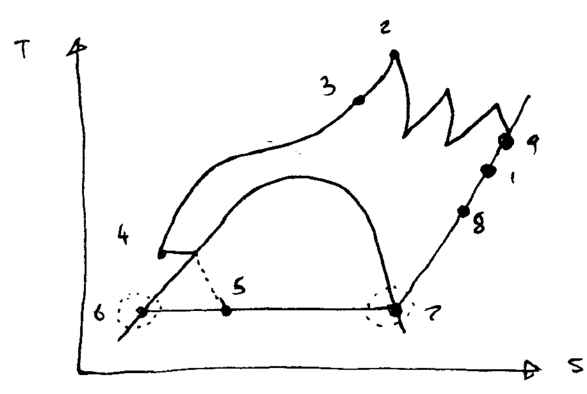
- temperature difference may be so large that two different refrigeration cycles must be used with two different substances stacking, on-top of one another



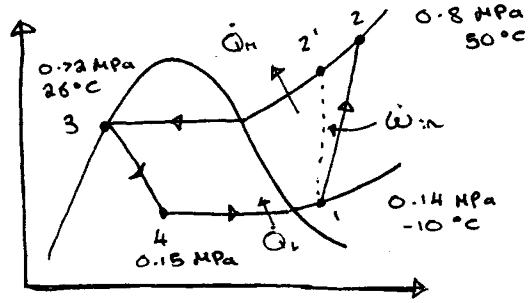




A Linde-Hampson System for liquefaction of gases



## Example




$P_1 = 0.14$ MPa, $T_1 = -10$ °C $\}$ $h_1 = 394.126$ kJ/kg

$P_3 = 0.72$ MPa, $T_3 = 26$ °C $\}$ $h_3 = h_4$, $h_3 \cong 235$ kJ/kg

$$\dot{Q}_L = (0.05)(394.126 - 235) = 8 \text{ kJ/s}$$

$$\dot{W}_c = \dot{m}(h_2 - h_1)$$

$P_2 = 0.8$ MPa, $T_2 = 50$ °C $\}$ $h_2 = 435.11$ kJ/kg

$$\dot{W}_c = 0.05(435.11 - 394.126) = 2.05 \text{ kW}$$

$$COP = \beta = \frac{\dot{Q}_L}{\dot{W}_c} = \frac{8}{2.05} = 3.9$$

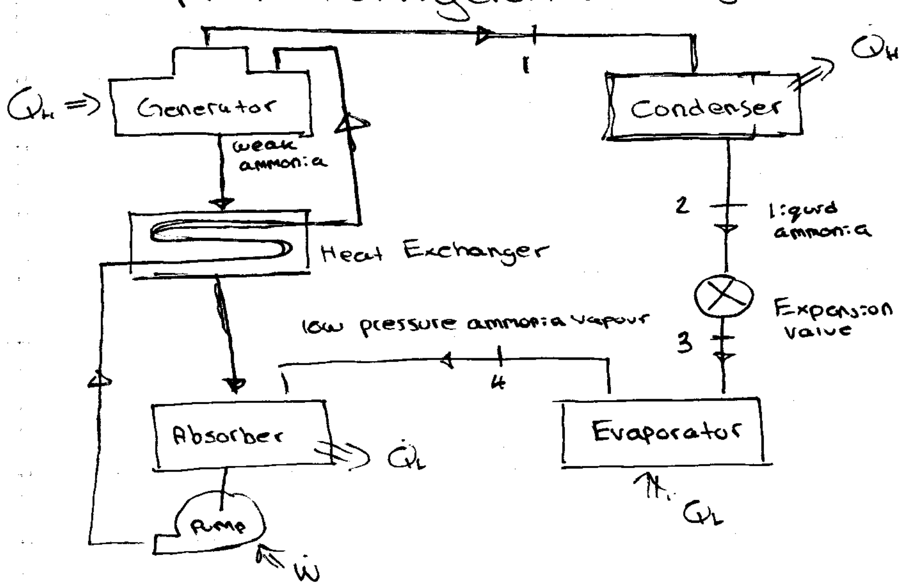
$$\eta_{comp} = \frac{\dot{W}_s}{\dot{W}_{ac}} = \frac{\dot{m}(h_{2s} - h_1)}{\dot{m}(h_{2a} - h_1)}$$

$S_2 = S_1$ (isentropic process)

$S_2 = S_1 = 1.7532$ kJ/kg.K, $P = 0.8$ MPa $\rightarrow$ $h_{2s} \cong 425$ kJ/kg

$$\eta_{comp} = \frac{425 - 394.126}{435.11 - 394.126} = 0.75 \text{ or } 75\%$$

## Absorption Refrigeration Cycle




$$\dot{W}_{in} = \dot{W}_p + \eta_{HE}\dot{Q}_H$$

$$\dot{Q}_L = COP\,\dot{W}_{in} = COP(\dot{W}_p + \eta_{HE}\dot{Q}_H)$$

$$COP' = \beta_{absorp\ ref} = \frac{\dot{Q}_L}{\dot{Q}_H} = COP(\eta_{HE} + \dot{W}_p/\dot{Q}_H)$$