ملخصات مدار

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Temperature:

$$T(K) = T(^\circ C) + 273.15 \quad 278$$

$$T(R) = T(^\circ F) + 459.67 \quad 460$$

$$T(R) = 1.8\,T(K)$$

$$T(^\circ F) = 1.8\,T(^\circ C) + 32$$

$$\Delta T(K) = \Delta T(^\circ C)$$

$$\Delta T(^\circ F) = 1.8\,\Delta T(^\circ C)$$

1R | 1K | 1.8°F | 1.8R

Pressure:

$$P_{gauge} = P_{abs} - P_{atm}$$

$$P_{abs} = P_{gauge} + P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$

$$P_{below} = P_{above} + \underbrace{\rho g h}_{\text{spe. weight}}$$

or $P = P_{atm} + \rho g h$

Chapter 2:-

$$e_{mech} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

$$\dot{E}_{mech} = \dot{m}\,(e_{mech})$$

$$\Delta \dot{E}_{mech} = \dot{m}\,\Delta e_{mech}$$

$$Q = \int_1^2 \dot{q}\,dt$$

↳ varies with time ↳ Q(t)

1

① Q_{in}, sys (q), $W_{done\ by\ the\ system}$

boundary Work

$$W_b = \int_{V_1}^{V_2} P\,dV = \text{area under a P-V diagram}$$

↳ P(V)

① Polytropic process:

$$P = CV^{-n}$$

$$W_b = \int_1^2 P\,dV = \int_1^2 CV^{-n}\,dV = \frac{P_2V_2 - P_1V_1}{1-n}$$

polytropic

② polytropic and ideal gas

$$W_b = \frac{mR(T_2 - T_1)}{1-n}$$

③ isothermal $n=1$ or mRT

$$W_b = \int_{V_1}^{V_2} \frac{C}{V}\,dV = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$$

④ isobaric : P = constant

$$W_b = P\int_{V_1}^{V_2} dV = P\Delta V$$

ideal gases only:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n} = \left(\frac{V_1}{V_2}\right)^{(n-1)}$$

Shaft work: $W_{sh} = \tau(2\pi n)$ or $W_{sh} = \dot{m}\,W_{kg}$

Electrical work: $W_{ele} = VN = \frac{\text{energy}}{\text{ele charge}}$

or $W_{ele} = VI$ current

or $W_{ele} = V\int_1^2 I\,dt$

$W_{spring} = \frac{1}{2}K(x_2^2 - x_1^2)$ or $= \int_{x_1}^{x_2} Kx\,dx$

$W_{\text{elastic solid bars}} = F_s = \int_1^2 \sigma_n \cdot A \, dx$

$\Rightarrow F = \sigma_s 2b \Rightarrow W_s = \sigma_s 2b \Delta x$

$W_{\text{stretching of a liquid film}}$

$W_s = \sigma_s dA = \sigma_s \Delta A$

* The largest source of air pollution is Motor vehicles (HC, NO_x, CO)
  - Volatile organic compound

* Ground level ozone, which is the primary component of smog, forms when HC and NO_x react in the presence of sunlight on hot days. (~~diesel~~ vehicles)

* sulfuric acid and nitric acid are formed when sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight. (electric power plants and vehicles)

* greenhouse gases: ① CO_2 ② water vapor ③ trace amounts of other gases like methane and N_2O

* NO_x and HC cause smog.

* 1st law: during an adiabatic, closed system process: $\Delta E = W_{net}$

$E_{in} - E_{out} = Q_{in} - Q_{out} + W_{in} - W_{out} + E_{mass,in} - E_{mass,out}$

ΔE

(2)

$E_{in} - E_{out} = \underbrace{\Delta E}_{\text{change in KE, PE, U}}$

(change in Q, W, E_{mass})

Efficiency: (P/P) Q/(Q)

$\eta = \frac{\text{Energy delivered from the machine}}{\text{Energy supplied to the machine}}$

$\eta_{combustion} = \frac{Q}{HV}$ ← Higher or lower heating value

Furnaces-

cars and jet engines

$HHV = LHV + n \Delta \hat{H}_v (H_2O, 25°C)$

$= 44.013 \text{ kJ/mole}$ (or L)

$= 18.934 \text{ Btu/lbmole}$

$\eta_{overall\ (power\ plant)} = \eta_{combustion} \cdot \eta_{generator} \cdot \eta_{thermal}$

$= \frac{\dot{W}_{net,electrical}}{HHV \text{ in net}}$

(*) Mechanical η:

$\eta_{mech} = \frac{\Delta E_{mech,out}}{\Delta E_{mech,in}} = 1 - \frac{\Delta E_{loss}}{\Delta E_{mech,in}}$

or $\eta_{mech} = \frac{\Delta E_{fluid}}{\Delta E_{mech,in}} = \frac{\frac{1}{2}V^2 \dot{m}}{\dot{W}_{shaft,in}}$

(2)

Mech. eff.

$$\eta_{turbin} = \frac{\Delta \dot{E}_{mech,out}}{\Delta \dot{E}_{fluid,in}} = \frac{\dot{W}_{shaft,out}}{|\Delta \dot{E}_{fluid,in}|}$$

$$\eta_{pump} = \frac{\Delta \dot{E}_{fluid,out}}{\Delta \dot{E}_{mech,in}} = \frac{\Delta \dot{E}_{fluid,out}}{\dot{W}_{shaft,in}}$$

$$\eta_{generator} = \frac{\dot{W}_{ele,out}}{\Delta \dot{E}_{mech,in}}$$

$$\eta_{Motor} = \frac{\Delta \dot{E}_{mech,out}}{\dot{W}_{ele,in}}$$

$$\eta_{motor-pump} = \frac{\Delta \dot{E}_{fluid,in}}{\dot{W}_{elect,in}}$$

$$\eta_{turbine-gen} = \frac{\dot{W}_{ele,out}}{\Delta \dot{E}_{fluid,in}}$$

: مهم جداً ***

cost of utilized energy = $\frac{\text{cost of E input}}{\text{efficiency}}$

Simple ~~paybac~~ payback period:

$$= \frac{\text{Excess initial Cost}}{\text{Annual cost savings}}$$

Power generation potential: ***

$$\dot{W}_{max} = \dot{m}\, e_{mech}$$

***

$$\dot{m} = \rho V A$$

$\dot{V}$ ($\dot{Q}$)

chapter 4:

$W_{net,out} = Q_{net,in}$ } Energy balance on a cycle

or $\dot{W}_{net,out} = \dot{Q}_{net,in}$

on a closed sys.:

$\Delta E = Q - W$ or $Q_{in-out} + W_{in-out}$

KE PE U

or $\frac{dE}{dt} = \dot{Q} - \dot{W}$

Power cycles:

$$W_{cycle} = Q_{in} - Q_{out}$$

Refrigeration and heat pump cycle

$$W_{cycle} = Q_{out} - Q_{in}$$

For a constant pressure expansion or compression process:

$$\Delta H = \Delta U + W_b = Q - W_{other}$$

From the E balance:

$$dU = dQ - dW_b - dW_s$$

general 1st equ for mech. reversible closed system (σ_s ...)

$\Rightarrow d(nU) = dQ - P\,d(nV)$

(*) For constant V ($W_b = 0$)

$d(nU) = dQ \Rightarrow$ $\boxed{n\Delta U = Q}$

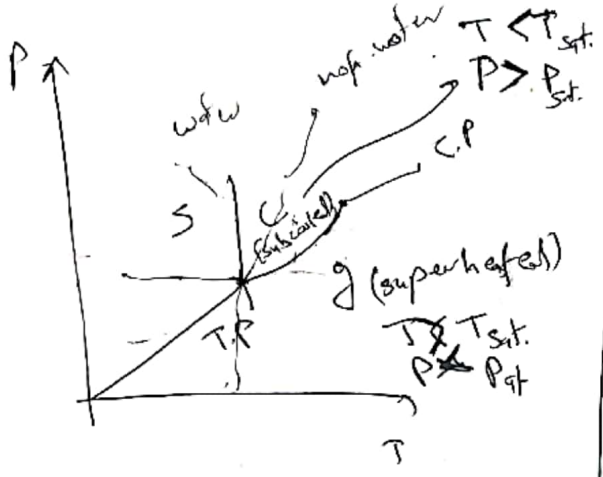
(*) constant P ($W_b \neq 0$)

$d(nU) = dQ - P\,d(nV)$

$dQ = d(nU) + P\,d(nV)$

dnH

$dQ = dnH \Rightarrow$ $\boxed{\Delta Q = n\Delta H}$



$P_v = RT$

$PV = nR_u T$ or $PV = mRT$

or $P\bar{V} = R_u T$

for 2 different states:

$$\frac{P_1 V_1}{T} = \frac{P_2 V_2}{T_2}$$

ideal gas works well at low density: $\rho = \frac{PM}{RT}$ or $\frac{P}{RT}$

Antoine equation:

$$\log_{10} P^* = A - \frac{B}{T + C}$$

Calgusius — Clapeyron eqn.

$$\ln P^* = -\frac{\Delta \hat{H}^v}{RT} + B$$

$$z = \frac{Pv}{RT}, \quad T_r = \frac{T}{T_c}, \quad P_r = \frac{P}{P_c}$$

$$V_r = \frac{V_{actual}}{V_{critical}} = \frac{V_{actual}}{RT_{cr}/P_{cr}}$$

$x = \frac{m_{vapor}}{m_{total}}$ " $1 - x$ gives moisture content"

Van der Waal's eqn: (2)

$$\left(P + \frac{a}{\bar{v}^2}\right)(\bar{v} - b) = RT$$

$$a = \frac{27 R^2 T_{cr}^2}{64 P_{cr}}, \quad b = \frac{RT_{cr}}{8 P_{cr}}$$

$$y_{avg} = y_f + x y_{fg}$$

$$x = \frac{y_{avg} - y_f}{y_{fg}}$$

or $y_{avg} = x \cdot y_g + (1 - x) y_f$

Beattie-Bridgeman Eqn: (5)

$$P = \frac{R_u T}{\bar{v}^2}\left(1 - \frac{c}{\bar{v} T^3}\right)(\bar{v} + B) - \frac{A}{\bar{v}^2}$$

$$A = A_0\left(1 - \frac{a}{\bar{v}}\right), \quad B = B_0\left(1 - \frac{b}{\bar{v}}\right)$$

Compressed liquid:

$y \simeq y_{f@T}$ ~ v, u, s, h

a more accurate relation for h

$$h \simeq h_{f@} + v_{f@T}(P - P_{sat\,@T})$$

* Benedict-Webb-Rubin: (8)

Virial Eqn of state:

$$\frac{P\hat{v}}{RT} = 1 + \frac{B}{\hat{v}}$$

Chapter 3:

(1) at low pressure: $Pv = RT$

(2) two phase region: Vander Vals:

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT$$

(3) at moderate pressure, virial eqn:

$$\frac{P\hat{V}}{RT} = 1 + \frac{B}{\hat{V}}$$

(4) Liquid Region $= PV = ZRT$

For liquids and solids:

$$C_p = C_v = C$$

$$\Delta u = \int_1^2 C(T)\,dT = C_{avg}(T_2 - T_1)$$

$$\Delta h = \Delta u + V\Delta P$$

chapter 4:

boundry work:

[1] General: $W_b = \int_{V_1}^{V_2} P\,dV$

[2] Isobaric: $W_b = P(V_2 - V_1)$

[3] polytropic: $\frac{P_2V_2 - V_1P_1}{1-n}$ $\quad n \neq 1$

[4] Isothermal $(n=1) = W_b = P_1V_1\ln\left(\frac{V_2}{V_1}\right)$ or $mRT\ln\left(\frac{V_2}{V_1}\right)$

Chapter 5: Energy analysis of unsteady processes

unsteady $\frac{dE}{dt} \neq 0$

therefore: $Q_{net} + W_{net} + \sum m\theta_{net} = m_{e_2} - m_{e_1}$

$\theta = h + ke + pe$

$e = u + ke + pe$

and that's H_{eT}.

$\sum_{in} m\theta - \sum_{out} m\theta$

Energy balance for a closed sys.:

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

for constant pressure process, $W_b + \Delta U = \Delta H$ (closed system)

$$Q - W_{other} = \Delta H + \Delta KE + \Delta PE$$

$$\Delta u = u_2 - u_1 = \int_{T_1}^{T_2} C_v(T)\,dT = C_{v\,avg}(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = \int_{T_1}^{T_2} C_p(T)\,dT = C_{p\,avg}(T_2 - T_1)$$

} for ideal gases

also for ideal gases:

$C_p = C_v + R$

$$K = \frac{C_p}{C_v}$$

Thermodynamics:

The second law of Thermodynamics

Heat Engines:

$$W_{net,out} = W_{out} - W_{in}$$
$$= Q_{in} - Q_{out}$$
$$= Q_H - Q_L \quad \text{"Heat Engine only"}$$

$$\eta_{HE} = \frac{W_{net,H}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

[*] Kelvin-Planck Statement: It's impossible for any heat engine that operates on a cycle to gain heat from a high Temp. source and produces the same amount of work. ($Q_L = 0$, $\eta = 1$ - impossible)

[R] Clasius Statement:
→ It's impossible to construct a device that operates on a cycle and produces no effect other than the transfer of heat from lower T body to higher T body
($W_{net,in} = 0$, impossible)

[*] any device that violates the Kelvin-Planck statement also violates the Clasius statement, and vice versa.

Refrigerators:

$$W_{net,in} = Q_{out} - Q_{in} = Q_H - Q_L$$

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{1}{\frac{Q_H}{Q_L} - 1}$$

↳ can be greater than 1

Heat pumps:

$$W_{net,in} = Q_{out} - Q_{in} = Q_H - Q_L$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

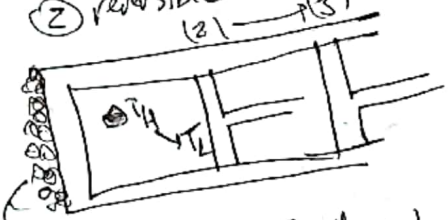
$$COP_{HP} = COP_R + 1$$

Energy Efficiency rating (EER) = 3.412 COP_R

Carnot cycle: a heat engine that operates in a completely reversible manner. process in the carnot cycle are:

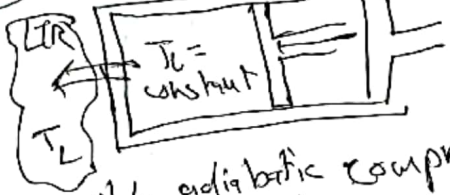
(1) reversible Isothermal expansion

(2) reversible adiabatic expansion

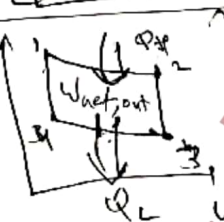


insulation

(3) reversible Isothermal compression



(4) reversible adiabatic compression:



reversed refrigeration

The Carnot Principles:

① $\eta_{irrev} > \eta_{rev}$ is a false statement

② for two reversible heat engines having the same reservoirs $\eta_1 \overset{must}{=} \eta_2$

$$\left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L} \sim abs.$$ (ترز)

ME and R

Therefore, for Karnot heat engines only

$$\eta_{th,rev} = 1 - \frac{Q_H}{Q_L} = 1 - \frac{T_L}{T_H}$$

$$\eta_{th} \begin{cases} > \eta_{carnot} & \text{impossible} \\ = \eta_{carnot} & \text{reversible} \\ < \eta_{carnot} & \text{(actual) irrev.} \end{cases}$$

$$COP_R \begin{cases} > COP_{R,rev} & \text{impossible} \\ < COP_{R,rev} & \text{irreversible} \\ = COP_{R,rev} & \text{reversible} \end{cases}$$

$$COP_{R,rev} = \frac{1}{T_H/T_L - 1}, \quad COP_{HP,rev} = \frac{1}{1 - \frac{T_L}{T_L}}$$

Ideal gas temp scale ل تون هو

$$\delta q = du + \delta w \quad 1^{st} \text{ law}$$

$$\Rightarrow \delta q = c_{v_0}\, dT + p\, dv$$

$$\Rightarrow \boxed{\delta q = c_{v_0}\, dT + \frac{RT}{v}\, dv}$$

processes ال في استخدم

carnot cycles ال

adiabatic (T=const) isothermal و ال شو

$Q = 0$ ثابتة

⑧ (7)

Chapter 7: Entropy (Closed Sys!)

Clausius Inequality: $\oint \frac{\partial Q}{T} \leq 0$ (abs T of the boundary)

$$\oint \frac{\partial Q}{T} = \int_1^2 \frac{\partial Q}{T} + \int_2^3 \frac{\partial Q}{T} + \int_3^4 \frac{\partial Q}{T} + \int_4^1 \frac{\partial Q}{T}$$

$$= \frac{Q_H}{T_H} + 0 - \frac{Q_L}{T_L} + 0$$

(isothermal rev.)

$$= \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 1 \text{ for rev. } \left(\frac{T_H}{T_L} = \frac{Q_H}{Q_L}\right)$$

$\oint \frac{\partial Q}{T} = 0$

for irrev: $\oint \frac{\partial Q}{T} < 0$

$\oint \frac{\partial Q}{T}$	rev (or $\int_{rev}$)	irrev
Heat Engine	$=0$	<0
Refrig & HP	$=0$	<0

2nd law of Thermodynamics for closed system: $S_2 - S_1 = \int_1^2 \frac{\partial Q}{T} + S_{gen}$

$S_{gen} \geq 0$

rev. $= 0$

irrev. > 0

The increase of entropy principle:

(*) for an isolated system (or adiabatic)

$$\Delta S = \int_0 \frac{\partial Q}{T} + S_{gen} = S_{gen}$$

(*) we can make any system as an isolated system by combining it with its surroundings:

$$S_{gen} = \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr}$$

Entropy generation during heat transfer

$$S_{gen} = \Delta S_{tot} = \Delta S_{sys} + \sum \Delta S_{surr} \geq 0$$

$$= (S_2 - S_1) + \frac{Q_{surr,net}}{T_{surr}}$$

$$Q_{surr,net} = -Q_{in,sys} = Q_{out,sys}$$

(*) S_{gen} for closed system with const. temperature surroundings T_{surr}

$$S_{gen} = \Delta S_{sys} + \sum \Delta S_{surr}$$

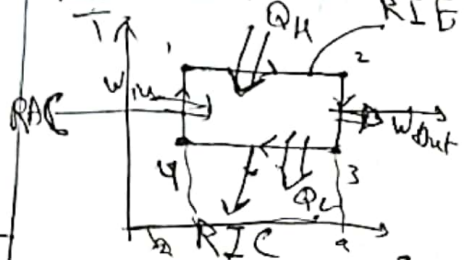
$$= (S_2 - S_1) + \frac{Q_{surr}}{T_{surr}}$$

$$S_{gen} = (S_2 - S_1) - \frac{Q_{sys}}{T_{surr}} \geq 0$$

(*) $\int ds = \int \frac{\partial Q_{int,rev}}{T} \Rightarrow \partial Q_{int,rev} = \int T ds$

or $Q_{int,rev}$ = area under the T-S curve. (reversible P.)

(*) T-S for a carnot HE:



$$Q_H = \int_1^2 T ds = T_H (S_2 - S_1) \quad (1,2,a,b)$$

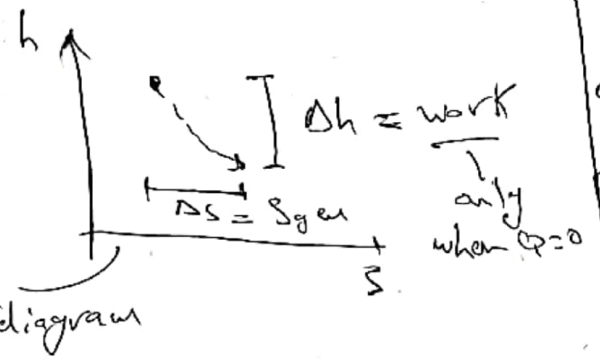
(isothermal)

$$Q_L = \int_3^4 T ds = T_L (S_2 - S_1) \quad (3,4,a,b)$$

$$W_{net} = Q_H - Q_L = T_H (S_2 - S_1) - T_L (S_2 - S_1)$$

(*) Isentropic ($\Delta S = 0$) for example: adiabatic and reversible.

h-S diagram: for adiabatic processes:



Tds Equations (Gibbs equations)

"simple comp. substance"

$\partial Q = du + P dv$ ← boundary work

$Tds = du + Pdv \Rightarrow \boxed{ds = \frac{du}{T} + \frac{Pdv}{T}}$ 1st eqn

$dh = du + dp.v + v.dp \Rightarrow \boxed{Tds = dh - vdp}$ 2nd eqn.

Entropy of liquids and solids

since $dv \simeq 0 \Rightarrow Tds = du$ & $ds = \frac{du}{T}$

$\Rightarrow ds = \frac{C_{avg}\,dT}{T} = \boxed{C_{avg} \ln\left(\frac{T_2}{T_1}\right)}$

$\therefore s_2 - s_1 = \int_1^2 \frac{C_{avg}\,dT}{T} = C_{avg} \ln\left(\frac{T_2}{T_1}\right)$

for an isentropic process:

$s_2 - s_1 = 0$ or $s_2 = s_1 \Rightarrow \boxed{T_1 = T_2}$ ** only for incompressible substances

Entropy Change of Ideal Gas

Tds relations: $PV = RT$

(1) $ds = \frac{du}{T} + \frac{Pdv}{T} = \frac{C_v dT}{T} + \frac{RT}{V}\frac{dv}{T}$

$\boxed{ds = \frac{C_v dT}{T} + R\frac{dv}{v}}$

(2) $ds = \frac{dh}{T} - \frac{v\,dp}{T} = \boxed{\frac{C_p dT}{T} - \frac{R\,dp}{P}}$

This integration is complex when $C(T)$ so we have two ways to get through it:

(1) Assume C_{avg}:

① $\boxed{\Delta s = C_{avg,v} \ln\frac{T_2}{T_1} + R \ln\frac{v_2}{v_1}}$ (A=2)

② $\boxed{\Delta s = C_{avg,p} \ln\frac{T_2}{T_1} - R \ln\frac{P_2}{P_1}}$

(2) Use tables !!! $\Delta s = s_2 - s_1$

$\boxed{\Delta s = s_2^\circ - s_1^\circ + R \ln\frac{v_2}{v_1}} \quad ---①$

$\boxed{\Delta s = s_2^\circ - s_1^\circ - R \ln\frac{P_2}{P_1}} \quad ---②$

from A-17 (18)! $s^\circ = \int_0^T \frac{C_p(T)\,dT}{dT}$

Isentropic process for ideal gases

$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1}$, $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$

$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{k}$

$Tv^{k-1} = C$ $\quad TP^{(k-1)/k} = C$

$Pv^k = C$

1st, 2nd and 3rd isentropic relations (**) assuming constant specific heats

Entropy balance for open systems:

$$\frac{dS_{CV}}{dt} = \dot{S}_{gen} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \sum \frac{\dot{Q}_K}{T_K}$$

- $\frac{dS_{CV}}{dt}$: The rate of entropy change
- $\sum \dot{m}_i s_i$: entropy transferred by mass
- $\sum \frac{\dot{Q}_K}{T_K}$: entropy transfer by heat

(*) for a steady state flow process:

$$\frac{dS_{CV}}{dt} = 0$$

(K) for single stream steady flow devices.

$$\frac{dS_{CV}}{dt} = 0, \quad \text{entropy transfered by mass} = \dot{m}(s_i - s_e)$$

$$\dot{S}_{gen} = \dot{m}(s_e - s_i) - \sum \frac{\dot{Q}_K}{T_K}$$

(K) for adiabatic single stream devices:

$$s_e = s_i + s_{gen} \geq s_i$$

The Principle of The Increase of Entropy

$$\frac{dS_{net}}{dt} = \frac{dS_{C.V.}}{dt} + \frac{dS_{surr}}{dt}$$

$$= \sum \dot{S}_{gen} \geq 0$$

$$\Delta S_{net} = \Delta S_{C.V.} + \Delta S_{surr}$$

$$= (m_2 s_2 - m_1 s_1) = \frac{-Q_{C.V.}}{T_0} + \sum m_e s_e - \sum m_i s_i$$

(D)

The Transient process (unsteady):

$$\frac{d}{dt}(ms)_{C.V.} = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \sum \frac{\dot{Q}}{T} + \dot{S}_{gen}$$

$$\Downarrow \int_0^t \sim dt$$

$$(m_2 s_2 - m_1 s_1)_{C.V.} = \sum m_i s_i - \sum m_e s_e + \int_0^t \sum \frac{\dot{Q}_{C.V.}}{T} dt + S_{gen}$$

(**)

Calculation of the Ideal work.

$$-Q = T_0 \Delta(\sum \dot{m} s)_{FS}$$

T_0 of the surr.

$$\dot{W}_{ideal} = \Delta\left[\left(h + \frac{1}{2}v^2 + zg\right)\dot{m}\right]_{FS} - T_0 \Delta(\sum \dot{m} s)_{FS}$$

$\frac{1}{2}v^2 + zg$ can be neglected

or per unit mass $\dot{W}_{ideal} = \Delta H - T_0 \Delta S$

when W_{ideal} is positive

$$\eta_t(\text{work required}) = \frac{\dot{W}_{ideal}}{\dot{W}_{FS}}$$

$\dot{W}_{in} - \dot{W}_{out} > 0$ — done on the sys — actual

when W_{ideal} is -ve (work producing devices)

$$\eta_t(\text{work produced}) = \frac{\dot{W}_s}{\dot{W}_{ideal}}$$

Lost Work

$W_{lost} = W_s - W_{ideal} \Rightarrow \dot{W}_{lost} = \dot{W}_{ideal} - \dot{W}$

or $\dot{W}_{lost} = T_o \Delta(S_{in}|_{fs} - \dot{Q}$

T_{surr}

(*) for the case of a single surrounding

Temp. T_s /

$\dot{W}_{lost} = T_o \dot{S}_G$

S_{gen}

(*) $W_{rev} \geq W_{act}$

(*) work producing device:

→ reversible produces more

work consuming device:

→ reversible consumes less

The Reversible Steady-State Process

from the first law, and the 2nd law:

(if the process is reversible and adiabatic)

$T\Delta s = dh - vdP \Rightarrow h_{ei} = \int_i^e v dP$

$\Rightarrow w = (h_i - h_e) + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)$

steady flow work

$$w = -\int_i^e v dP + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)$$

This eqn is valid for any reversible, steady state process without the restriction that it be either adiabatic or isothermal.

(*) if the device involves no work, ($w = 0$) → Bernoulli equation:

$v(P_2 - P_1) + \frac{V_i^2 - V_e^2}{2} + g(z_2 - z_1) = 0$

When KE and PE are negligible:

$w = -\int_1^2 v dP$

(*) The larger the specific volume, the greater the work produced or consumed by a steady state device.

(*) Minimizing The Compressor Work ($\int v dP$)

Isentropic (adiabatic rev.) ($PV^K = C$)

$W_{comp,in} = \frac{KR(T_2 - T_1)}{K-1} = \frac{KRT_1}{K-1}\left[\left(\frac{P_2}{P_1}\right)^{(K-1)/K} - 1\right]$

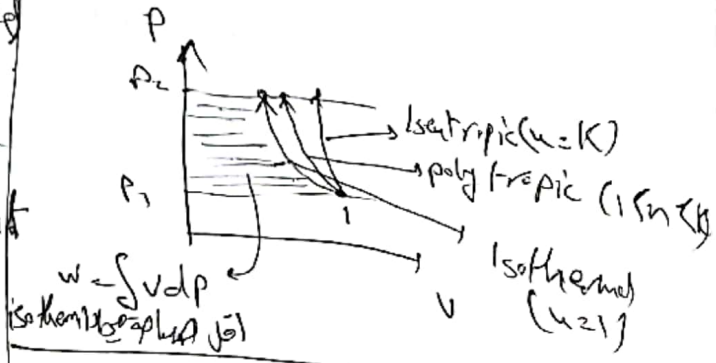
polytropic ($PV^n = const.$)

$W_{comp,in} = \frac{nR(T_2 - T_1)}{n-1} = \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$

Isothermal ($PV = C$)

$W_{comp,in} = RT \ln \frac{P_2}{P_1}$

(*) Isentropic requires the maximum work and Isothermal requires the minimum.



Multistage Compression with Intercooling

(*) Ideally, the cooling process takes place at constant pressure and the gas is cooled to the initial Temp (T_1) at each intercooler.

$$W_{comp,in} = \frac{nRT_1}{n-1}\left[\left(\frac{P_x}{P_1}\right)^{(n-1)/n} - 1\right] + \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_x}\right)^{(n-1)/n} - 1\right]$$

$$= W_{comp\ I,in} + W_{comp\ II,in}$$

$$P_x = (P_1 P_2)^{1/2} \quad \text{or} \quad \frac{P_x}{P_1} = \frac{P_2}{P_x}$$

must be correct to minimize W_{comp}.

Isentropic Efficiencies of SF Devices

$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{W_a}{W_s}$$

$$\eta_T = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

→ Is a measure of the deviation of actual process from idealized ones.

Isentropic Efficiencies of Compressors and Pumps

$$\eta_c = \frac{W_s}{W_a} = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}}$$

$$\eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$ KE & PE are negligible

$$\eta_p = \frac{W_s}{W_a} = \frac{v(P_2 - P_1)}{h_{2a} - h_1}$$ (Pump)

η_c = rev. Isothermal / actual Isothermal efficiency

Isentropic Eff. of nozzles

$$\eta_n = \frac{\text{Actual KE at nozzle exit}}{\text{Isentropic KE at nozzle exit}}$$

$$\eta_n = \frac{V_{2a}^2}{V_{2s}^2}$$

(*) If the inlet velocity of the fluid is small relative to the exit velocity, the energy balance is:

$$h_1 = h_{2a} + \frac{V_{2a}^2}{2}$$

Then $$\eta_n = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

Vapor Power Cycles

(*) Thermodynamic cycles can be divided into two general categories:

1. power cycles (HE)
2. refrigeration cycles (or HP)

Ideal cycle ⇒ Internally reversible

Reversible cycle ⇒ totaly "

remember that: $\eta_T = \frac{\dot W_{in}}{\dot Q_H}$ (T_H ...)

or $\eta_{carnot\ HE} = 1 - \frac{T_L}{T_H}$

Work in HE

- shaft Work
- Boundary work

for a reversible, SS_f Process, $KE, PE = 0$

$$\boxed{W_s = -\int v\,dP}$$

per mass

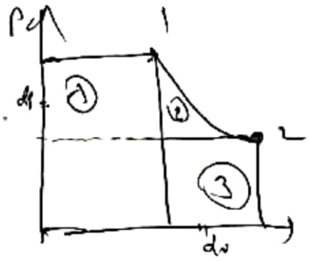
(*) for a rev., involving a simple comp. substance:

$$w_b = \int P\,dv$$

per mass

$W_s = v\,dp = ① + ②$

$W_b = ③ + ②$



(*) In power cycles involving only shaft work like the carnot cycle:

$$W_{net} = -\int_1^2 v\,dp - \int_3^4 v\,dp$$

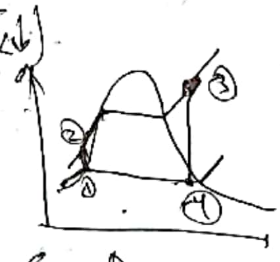
pump — Turbine

$$\int_1^2 v\,dp \overset{Avg}{<} \int_4^3 v\,dp \text{ Avg}$$

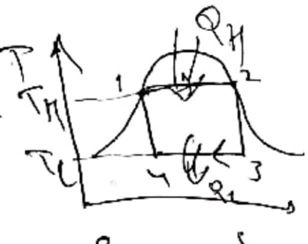
(*) If four-process cycle, with a piston cylinder system:

$$W_n = \int_1^2 P\,dv + \int_2^3 P\,dv + \int_3^4 P\,dv + \int_4^1 P\,dv$$

expansion ⇒ W_b (+ve), comp ⇒ W_b (−ve)

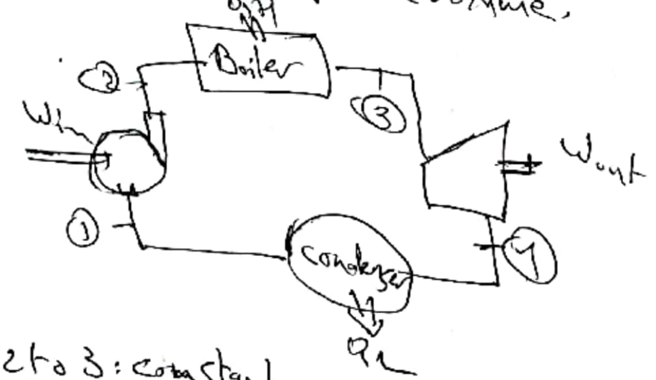


for Rankine cycle



for carnot cycle

Rankine Cycle: The ideal four steady state cycle, utilizing a phase change between vapor and liquid to maximize the difference in specific volume.



2 to 3: constant pressure, consists of 3 sections:
1. subcooled → sat. temp
2. vaporization at T_{sat} const
3. superheating vapor

3 to 4: Isentropic expansion

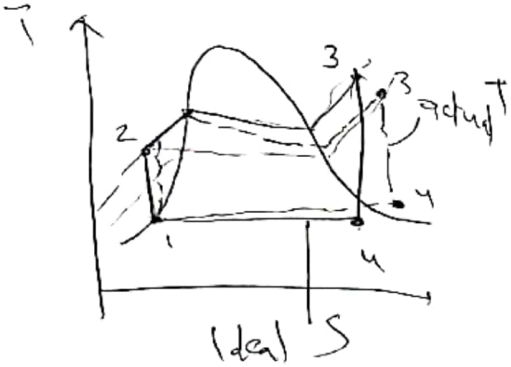
4 to 1: constant pressure, constant T process produce sat. liq at ④

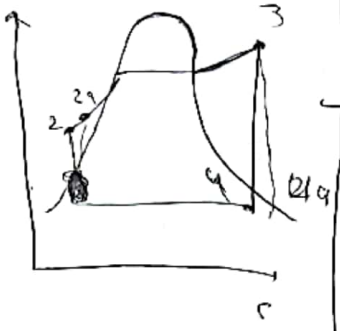
1 to 2: Isentropic, produces subcooled liquid

$$\boxed{W_{pump} = h_2 - h_1 = \int_1^2 v\,dP}$$

Deviation for Rankine cycle

(*) Fluid friction and heat loss to the surr. are the two common sources of irrev.s





Ideal Rankine cycle

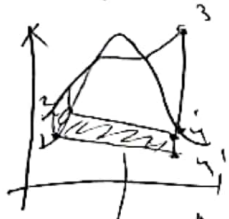
$$\eta_p = \frac{w_s}{w_q} = \frac{h_1 - h_{2s}}{h_1 - h_{2s}}$$

$$\eta_T = \frac{w_q}{w_s} = \frac{h_3 - h_{4q}}{h_3 - h_{4s}}$$

(*) Increasing the eff. of Rankine Cycles

In general: $\eta_{th} \uparrow \Leftrightarrow \uparrow T_H \Leftrightarrow \downarrow T_L$

(1) lowering the condenser Pressure ($\downarrow T_L$)



side effect: lowering the condenser pressure increases The moisture content of the steam at the final stages of the turbine

- Area $\uparrow$, $w_{rev,out} \uparrow$

(2) Superheating the steam to high Temp.

(3) Increasing the boiler pressure (moisture content $\uparrow$ (undesirable)

This side effect can be corrected by reheating the steam.

Summary: The quality of steam leaving the turbine is:

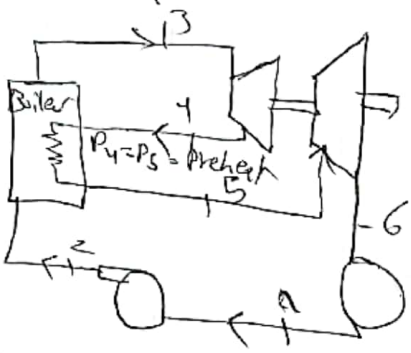
- Increased by superheating the steam
- Decreased by lowering the pump P.
- " " increasing the pressure during heat addition.

The Ideal Reheat Rankine Cycle

To avoid (*) in step (3) of increasing η:

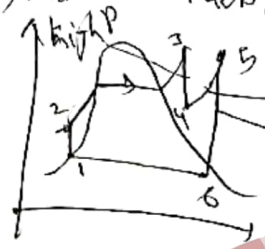
(i) superheating the steam to very high Temp. before it enters the turbine

(ii) Expand the steam in the Turbine in two stages and reheat it in between.



$q_{in} = q_{primary} + q_{reheat}$

$w_{turb,out} = w_{turb,1} + w_{turb,2}$

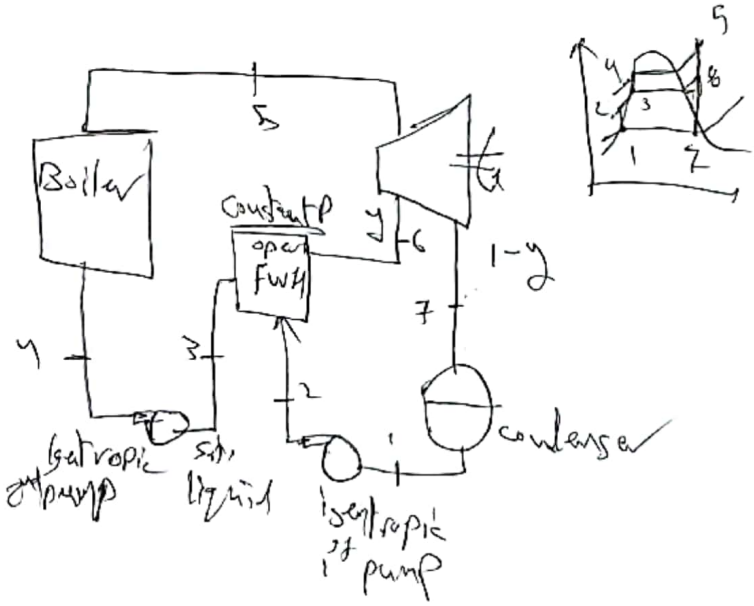


The Ideal Regenerative Rankine Cycle:

(*) Yet another way to increase the efficiency of a Rankine cycle ($T_{avg} \uparrow \Rightarrow \eta \uparrow$)

(*) used by Extracting hot water(steam) from the turbine and mixing it by (F W H) or feed water heater which acts as a mixing chamber

(*) The mixture leaves the FWH as a Sat. liquid



$q_{in} = h_5 - h_4$

$q_{out} = (1-y)(h_2 - h_1)$ *

$w_{turb,out} = (1-y)(h_6 - h_7) + (h_5 - h_6)$ K

$w_{pump,in} = (1-y)\, w_{pumpI,in} + w_{pumpII,in}$

where

$y = \dot{m}_6 / \dot{m}_5$

$w_{pumpI,in} = v_1 (P_{2\varepsilon} - P_1)$ $\quad w_{pump_{II}} = v_3 (P_4 - P_3)$

(6)

Refrigeration and Heat Pump Cycles

$COP_R = \dfrac{\text{Diesred output}}{\text{required input}} = \dfrac{\dot{Q}_L}{\dot{W}_{net,in}}$

$COP_{HP} = \dfrac{\dot{Q}_H}{\dot{W}_{net,in}}$

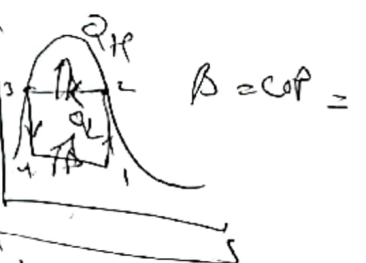
$COP_{HP} = COP_R + 1$ (+ve)

(*) The cooling capacity of a refrigeration system ($\dot{Q}_L$) is often expressed in terms of tons of refrigeration

1 ton of refri. $\equiv 211 \frac{KJ}{min}$ or $200 \frac{BTU}{min}$

The reversed Carnot Cycle

(*) 2 isothermal, 2 isentropic



$\beta = COP = \dfrac{\dot{Q}_H}{\dot{W}_{in,net}} = \dfrac{T_L}{T_H - T_L}$

$\dot{W}_{net,in} = \dot{Q}_H - \dot{Q}_L$

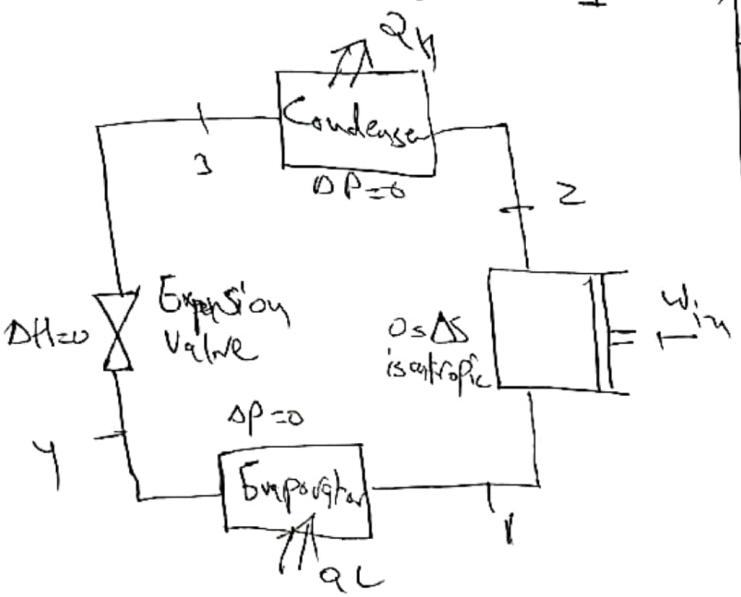
$COP_{R,carnot} = \dfrac{1}{T_H/T_L - 1}$

$COP_{HP,carnot} = \dfrac{1}{1 - T_L/T_H}$

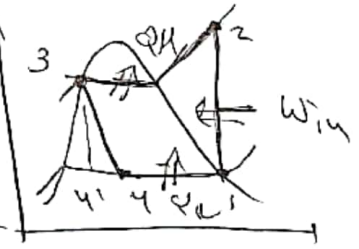
$COP \uparrow$ as $|T_L - T_H| \downarrow$

(*) Carnot Refrigerator has the highest COP

The Ideal Vapor Compression Refrigeration Systems (IVCRS)



(*) all are internally reversible except the valve.



$$\frac{\dot{Q}_{in}}{\dot{m}} = h_1 - h_4 \;,\; \frac{W_c}{\dot{m}} = h_2 - h_1$$

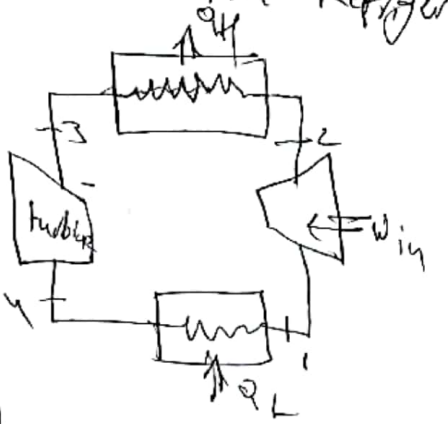
$$\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3 \;,\; h_4 = h_3$$

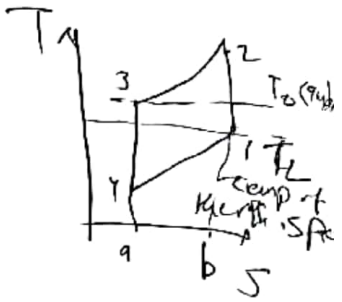
$$COP_R = \frac{q_L}{W_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{HP} = \frac{h_2 - h_3}{h_2 - h_1}$$

(*) two important parameters that were need to consider in the selection of a refrigerant : T_H and T_L

Air Standard Refrigeration Cycle

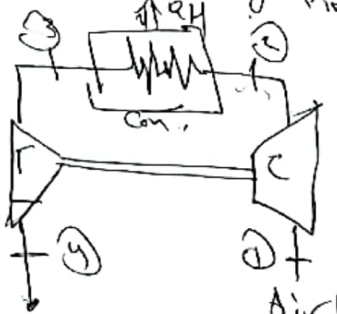


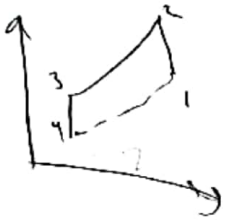


$$COP_R = \frac{q_L}{W_{net,in}} = \frac{q_L}{W_{comp,in} - W_{turb,out}}$$

$$= \frac{\dot{Q}_{in}/\dot{m}}{\dot{W}_{c,in} - \dot{W}_{t,in}} = \frac{(h_1 - h_4)}{(h_2 - h_1) - (h_3 - h_4)}$$

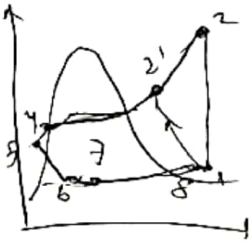
(*) The reversed Brayton cycle, can be used for refrigeration





(*) For gas cycle COP ↓, but they involve simple compon...

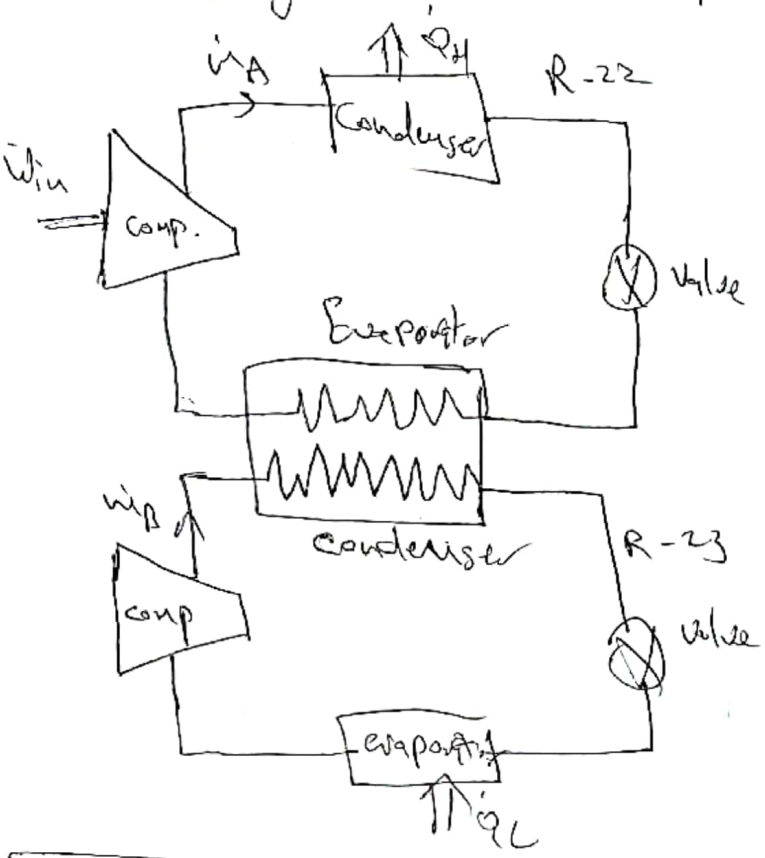
Deviation from Vapor-Compression RS.



$$\eta_c = \frac{(\dot{W}_c/\dot{m})_s}{(\dot{W}_c/\dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

Combined cycles: (cascade system)

- used when there is a difference between the ambient Temp. and the refrigerated space's Temp.



$$\frac{\dot{m}_A}{\dot{m}_B} = \frac{h_2 - h_3}{h_5 - h_8}$$

from: $\dot{m}_A(h_5 - h_8) = \dot{m}_A(h_2 - h_3)$

$$COP_{R,cascade} = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{\dot{m}_B(h_1 - h_4)}{\dot{m}_A(h_6 - h_5) + \dot{m}_B(h_2 - h_1)}$$

$$= \frac{\dot{Q}_{in}}{\dot{W}_{cA} + \dot{W}_{cB}}$$

Finally