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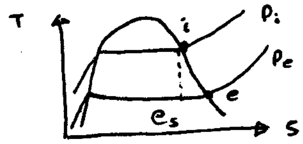
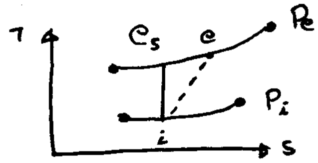
Efficiency of a turbine

$$\eta_{turbine} = \frac{w}{w_s} = \frac{h_i - h_e}{h_i - h_{es}}$$



Efficiency of compressor / pump

$$\eta_{comp} = \frac{w_s}{w} = \frac{h_i - h_{es}}{h_i - h_e}$$



Efficiency of a cooled compressor

$$\eta_{cooled\ pump} = \frac{w_T}{w}$$

The work input, for which is w_T, compared to the larger work w required for the real compressor.

$\boxed{\text{Example}}$ (7.12 from textbook)

$P_i = 100$ kPa $\quad$ $P_e = 150$ kPa $\quad$ $\eta_{comp} = 70\%$

$T_i = 300$ K $\quad$ air is an ideal gas

where $\eta_{comp} = \frac{w_s}{w} \Rightarrow \frac{h_i - h_{es}}{h_i - h_e} = \frac{C_p(T_i - T_{es})}{C_p(T_i - T_e)}$

$$\eta = \frac{T_i - T_{es}}{T_i - T_e}$$

From table

For isentropic : $\frac{T_{es}}{T_i} = \left(\frac{P_e}{P_i}\right)^{K-1/K}$ $\quad$ isentropic relation between T and P

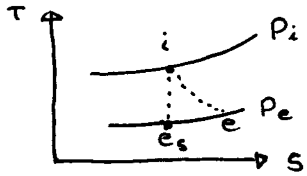
$$T_{es} = T_i\left(\frac{P_e}{P_i}\right)^{K-1/K} = (300)\left(\frac{150}{100}\right)E\left(\frac{1.4-1}{1}\right) \Rightarrow T_{es} = 336.9\text{ K}$$

$$0.7 = \frac{300 - 336.9}{300 - T_e} \Rightarrow \boxed{T_e = 352.8\text{ K}}$$

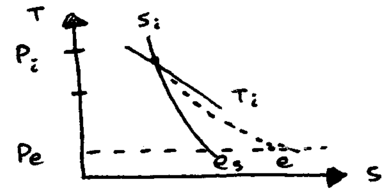
Actual work $= C_p(T_i - T_e) = (1.004)(300 - 352.8)$

$$\boxed{w = -53\text{ kJ/kg}}$$

The nozzle efficiency :



$$\eta_{nozzle} \; \frac{V_e^2/2}{V_{es}^2/2}$$



$\boxed{\text{Example}}$ (From textbook) → 8th edition question

$V_e = 500$ m/s

$\eta_{nozzle} = 0.88$

$$(0.88) = \frac{(500^2/2)}{(V_{es}^2/2)} \Rightarrow V_{es} = 533 \text{ m/s}$$

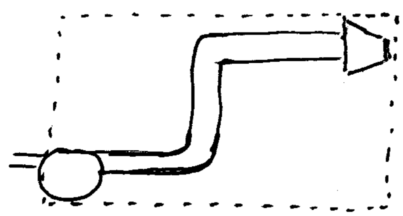
$\boxed{\text{Example}}$ (From textbook) → 8th edition? 7.134

"An emergency drain pump..."

0.1 m³/s liquid water at 15°C, 10 m vertically up, velocity of 20 m/s

Nozzle, pump, pipe have combined efficiency (isentropic) of 60%.

- How much power needed to [illegible]ve the pump?



Energy eq'n :

$$\dot m_i(h_i + V_i^2/2 + z_i g) + \cancel{\dot Q_{c.v.}} = \dot m_e(h_e + V_e^2/2 + z_e g) + \dot W_{c.v.}$$

$$\dot m_i = \dot m_e = \dot m$$

$$\dot W_{c.v.} = \dot m_i(h_i + V_i^2/2 + g z_i) - \dot m_e(h_e + V_e^2/2 + g z_e)$$

$$\dot W_{c.v.} = \dot m\left(h_i - h_e + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)\right)$$

$\dot V = 0.1 \text{ m}^3/\text{s}$ $\quad v = V/m = \dot V/\dot m \Rightarrow \dot m = \dot V/v$

From table @ 15°C

$\dot m = 0.1/0.001001$

$\dot m = 99.9$ kg/s

Using: $\left(\left(w = -\int v\,dp \Rightarrow v\int dp = v(P_i - P_e)\right)\right)$

$$\dot W_{c.v.} = 99.9\left[(v(P_i - P_e)) + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)\right]$$

$w = v\int dp$ for liquid

$$\dot W_{c.v.} = 99.9\left[v(0) + \frac{0 - 20^2}{2}\left(\frac{1}{1000}\right) + 9.81(0 - 10)\left(\frac{1}{1000}\right)\right]$$

$\boxed{\dot W_{c.v.} = -29.8 \text{ kW}}$ (isentropic)

$$\eta_{pump} = \frac{\dot{W}_{c.v.s}}{\dot{W}_{cv}} \Rightarrow \dot{W}_{c.v} = \frac{\dot{W}_{cv.s}}{\eta_{pump}} = \frac{-29.8}{0.6}$$

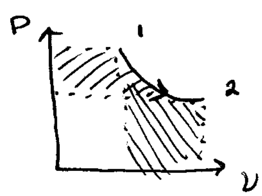
$$\dot{W}_{c.v} = -50 \text{ kW}$$

Power Systems

For a reversible, steady-state process involving negligible kinetic and potential energy changes, shaft work per unit mass:

$$w = -\int v\,dP$$

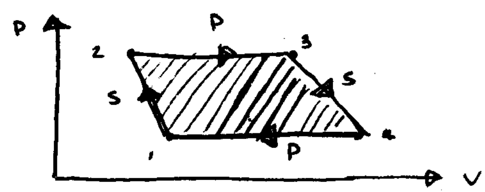
For a reversible process involving a simple compressible substance the movement work per unit mass $w = \int P\,dv$



Four Processes Power Systems

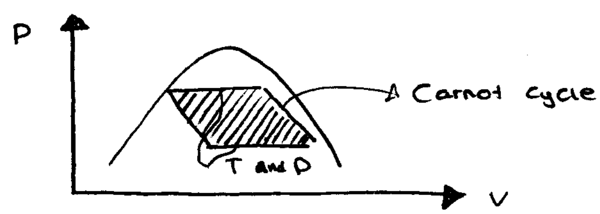
Assumptions :

- each process is internally reversible
- negligible KE/PE



net work output for this system

$$w_{net} = -\int_1^2 v\,dP + 0 - \int_3^4 v\,dP + 0 = \int_1^2 v\,dP + \int_4^3 v\,dP$$

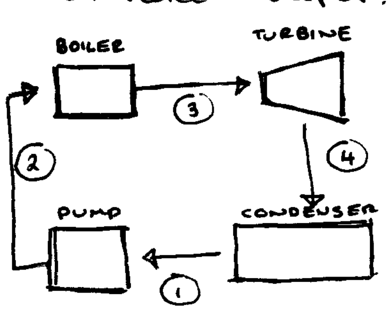


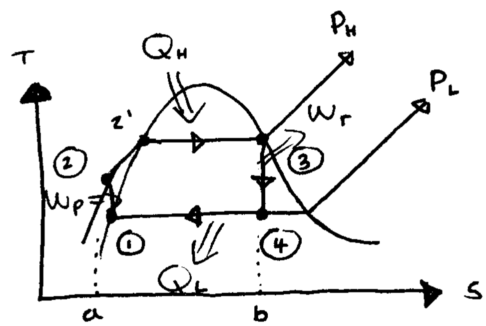
In a cylinder/piston system involving boundary-movement work:

$$w_{net} = \int_1^2 P\,dv + \int_2^3 P\,dv + \int_3^4 P\,dv + \int_4^1 P\,dv$$

The Rankine Cycle

- idealized four steady-state process cycle, in which (1) is sat. liquid, and (3) is either S.H. vapor or saturated vapor.





(1) → (2) : Reversible adiabetic pumping process in pump

(2) → (3) : Const. pressure heat transfer in boiler

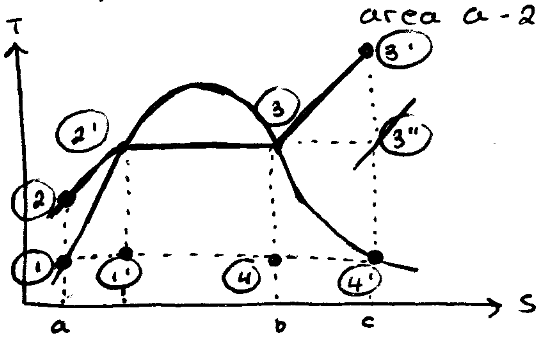
(3) → (4) : revers. adiabetic expansion in the turbine

(4) → (1) : Const. pressure trans. of heat

@ (4) : liquid + vapour

@ (1) : just liquid

$$\eta_{th} = \frac{W_{net}}{q_H} \Rightarrow \frac{\text{area } 1-2-2'-3-4-1}{\text{area } a-2-2'-3-b-a}$$

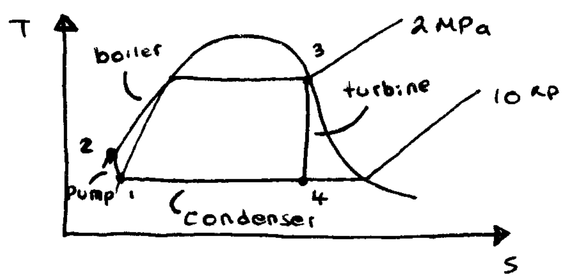


Why not select carnot?
- the pumping process
- Superheating the vapour

→ Rankine cycle has lower efficiency than a carnot cycle

1' → Great difficulties in designing a pump that handles a mixture of liquid and vapour.

$\boxed{\text{Example}}$ (From textbook, 9.1)



$$\omega_p = -\int_1^2 v\,dP = -v\int_1^2 dP = -v(P_2 - P_1)$$

$v_p|_{P=10kP} = 0.00101$

$\omega_p = -0.00101(2000-10) = = -2 \text{ kJ/kg}$

$h_1 = h_f|_{P=10kPa} = 191.8 \text{ kJ/kg}$

$$\cancel{\dot{Q}_{c.v.}} + \dot{m}_i(h_i + \cancel{ke} + \cancel{pe}) = \dot{W}_{c.v.} + \dot{m}_e(h_e + \cancel{ke} + \cancel{pe})$$

$h_i = \omega_p + h_e \rightarrow \omega_p = h_i - h_e$

From energy eq'n: $\omega_p = h_1 - h_2$

$h_2 = h_1 - \omega_p \Rightarrow 191.8 - (-2) = 193.8 \text{ kJ/kg}$

Boiler: $q_H = h_3 - h_2$ $\qquad h_3 = h_g|_{2MPa} = 2799.5 \text{ kJ/kg}$

$q_H = 2799.5 - 193.8 = 2605.7 \text{ kJ/kg}$

Turbine: $w_T = h_3 - h_4$

$(s_3 = s_4)$

↳ $s_g|_{2MPa} = 6.3409 = s_f|_{10kPa} + x_4\, s_{fg}|_{10kPa}$

cont'd ...

$s_f = 0.6493$, $s_{fg} = 7.5009$ } $x_4 = 0.7488$

$h_4 = h_f|_{10kPa} + x_4 h_{fg}|_{10kPa}$

$h_4 = 191.8 + 0.7588(2392.8) = 2007.5$ kJ/kg

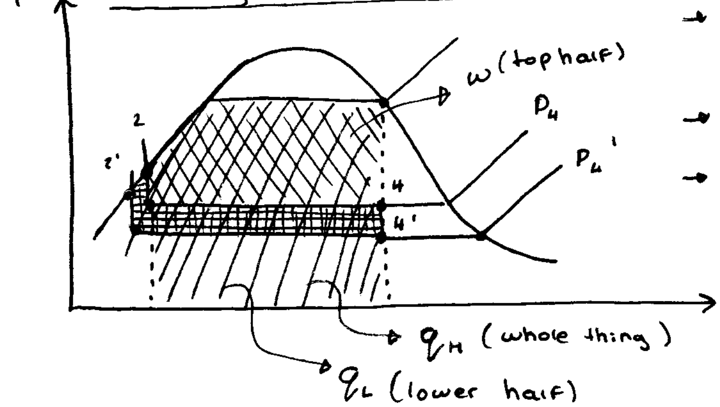
$w_T = 2799.5$ kJ/kg $- 2007.5$ kJ/kg $= 792$ kJ/kg

Condenser : $q_L = h_4 - h_1 = 2007.5 - 191.8 = 1815.7$ kJ/kg

$$\eta = \frac{w_{net}}{q_H} \Rightarrow \frac{w_T - w_P}{q_H} = \frac{q_H - q_L}{q_H} = \boxed{30.3\ \%}$$

Effect of Pressure and Temperature of the Rankine Cycle

Lowering the back pressure:



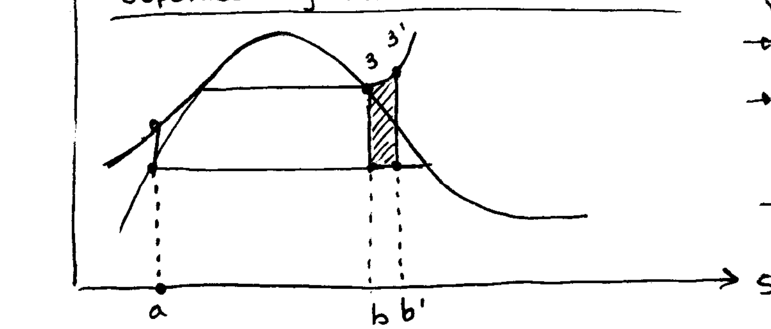
NOTE:

→ Increase in efficiency

→ Decrease in turbine efficiency

→ Erosion of the turbine blades

Superheating the steam in boiler:

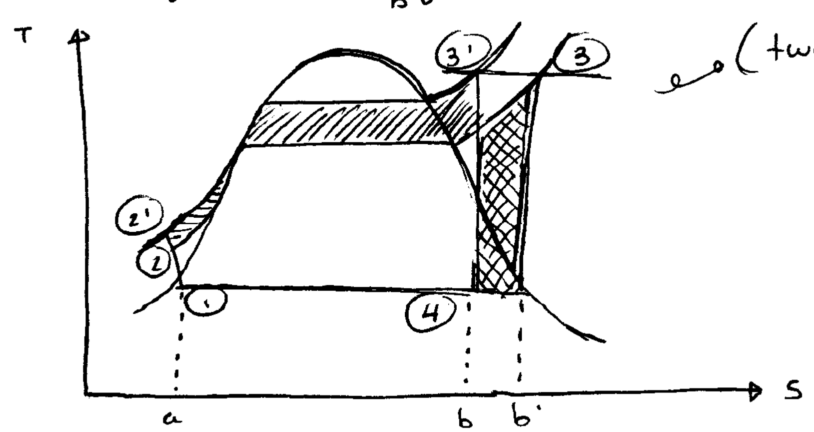


NOTE:

→ increase in efficiency

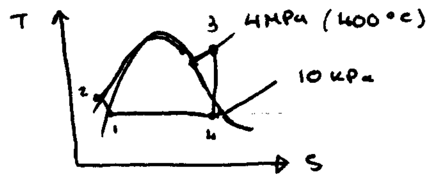
→ the quality of steam inc.

→ average temp. increased



(two turbines)

$\boxed{\text{Example}}$ (From textbook 9-2)



Pump : $w_p = -v(P_2 - P_1)$

$= -0.001001(4000-10)$

$w_p = -4 \text{ kJ/kg}$

$w_p = h_1 - h_2 \Rightarrow h_2 = h_1 - w_p \Rightarrow 191.8 - (-4) = 195.8 \text{ kJ/kg}$

$h_3 \Big|_{\substack{T = 400°C \\ P = 4\,MPa}} = 321.6 \text{ kJ/kg}$

Boiler: $q_H = h_3 - h_2 = 3213.6 - 195.85 = 3017.8 \text{ kJ/kg}$

$S_3 = S_4$; $x_4 = 0.8159$

$h_4 = h_f + x_4 h_{fg} = 2144.1 \text{ kJ/kg}$

$w_T = h_3 - h_4 = 3213.6 - 2144.1 = 1069.5 \text{ kJ/kg}$

$q_H = h_4 - h_1 = 1952.3$

$\eta = \dfrac{w_{net}}{q_H} =$