CH. SEVEN EXERGY

[Moran & Shapiro way of doing things]

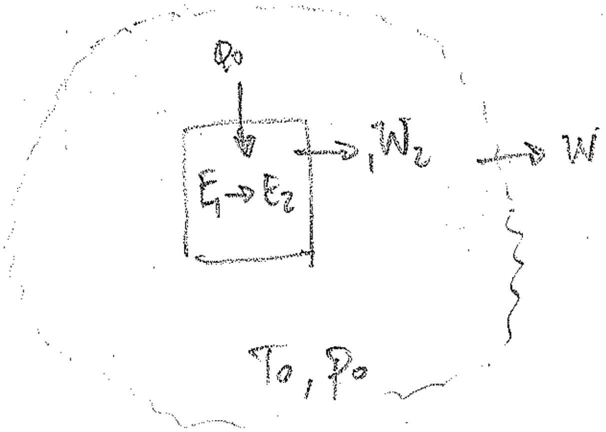
$\mathsf{E} \equiv$ Exergy

Φ or Ψ in your notes

$$\mathsf{E} = (E - U_0) + p_0(V - V_0) - T_0(S - S_0)$$

$$E = U + KE + PE$$

Consider Closed System in surroundings



First Law: (applied to combined system) $\cancelto{0}{Q} = \Delta E + W$

$$\Delta E = \Delta E_{sys} + \Delta E_{surr}$$

Process proceeds to dead state $\Rightarrow$

$$\Delta E_{sys} = \cancelto{U_0}{E_{sys,2}} - \cancelto{E}{E_{sys,1}}$$

$$\Delta E_{surr} = U_{surr,2} + \cancelto{0}{KE_2} + \cancelto{0}{PE_2} - U_{surr,1} - \cancelto{0}{KE_1} - \cancelto{0}{PE_1}$$

$$= \Delta U_{surr}$$

So,

$$\Delta E = (U_0 - E) + \Delta U_{surr}.$$

Recall TdS Eq.: $\quad TdS = dU + pdV$

For the surroundings ... $\quad T = T_0 = \text{const.}$

$p = p_0 = \text{const.}$

$$T_o \Delta S_{surr} = \Delta U_{surr.} + p_o \Delta V_{surr}$$

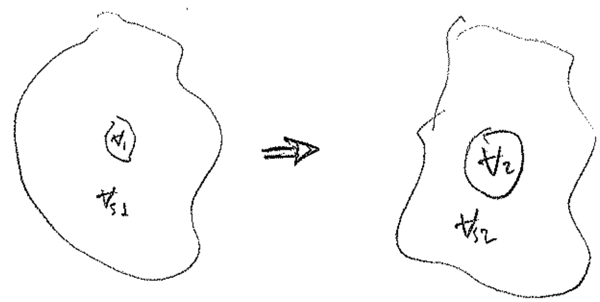
Solve for ΔU_{surr}, insert into ΔE ...

$$\Delta E = (U_o - E) + T_o \Delta S_{surr} - p_o \Delta V_{surr}$$

Insert back into First Law ...

$$W = -\Delta E = (E - U_o) - T_o \Delta S_{surr} + p_o \Delta V_{surr}$$

Note ΔV of surroundings ...



$$\Delta V_{surr} = V_{s2} - V_{s1}$$

$$\Delta V_{sys} = V_2 - V_1$$

& $$V_1 + V_{s1} = V_2 + V_{s2}$$

$$V_{s2} - V_{s1} = V_1 - V_2$$

$$\Delta V_{surr} = -\Delta V_{sys}$$

$V_o \equiv$ volume of sys. @ dead state

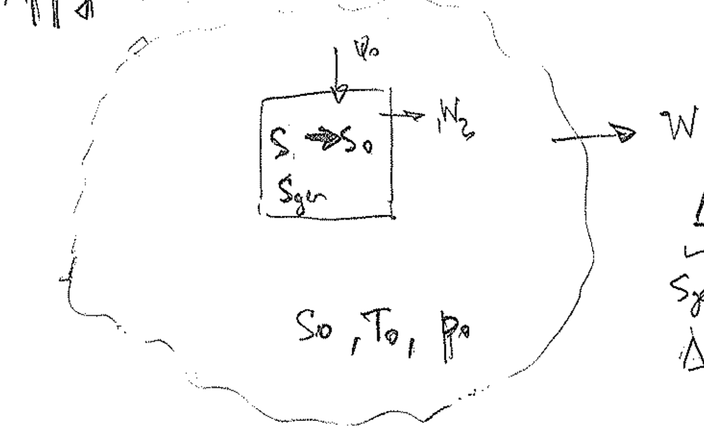
$V \equiv$ volume of sys. initially

$$\Delta V_{surr} = -(V_o - V) = V - V_o$$

So ...

$$W = (E - U_o) - T_o \Delta S_{surr} + p_o (V - V_o)$$

Apply Second Law to Control Mass ...



$$\underbrace{\Delta S}_{S_{gen}} = \underbrace{\Delta S_{sys}}_{S_o - S} + \Delta S_{surr}$$

$$\Delta S_{surr} = S_{gen} + (S - S_o)$$

So ...

$$W = \underbrace{(E - U_o) - T_o(S - S_o) + p_o(\forall - \forall_o)}_{\text{Exergy}} - \underbrace{T_o S_{gen}}_{\text{lost work}}$$

Exergy
property of the system
for specified surroundings

lost work
${}_1I_2 \equiv$ irreversibility
depends on process

For closed system ... able to exchange heat w/ reservoir

$$\Delta E = \int_1^2 \delta Q - {}_1W_2$$

$$-T_o \times \left[\Delta S = \int_1^2 \frac{\delta Q}{T_b} + S_{gen} \right] \quad 2^{nd} \text{ Law}$$

$$\Delta E - T_o \Delta S = \int_1^2 \delta Q - {}_1W_2 - T_o \int_1^2 \frac{\delta Q}{T_b} - T_o S_{gen}$$

temp @ boundary!

Note: $\Phi_2 = E_2 = E_2 - U_0 - T_0(S_2 - S_0) + p_0(\forall_2 - \forall_0)$

$\Phi_1 = E_1 = E_1 - U_0 - T_0(S_1 - S_0) + p_0(\forall_1 - \forall_0)$

$$\Phi_2 - \Phi_1 = \underbrace{E_2 - E_1}_{\Delta E} - T_0(\underbrace{S_2 - S_1}_{\Delta S}) + p_0(\forall_2 - \forall_1)$$

or $$\Delta E = \Phi_2 - \Phi_1 + T_0 \Delta S - p_0 \Delta \forall$$

so...

$$\Phi_2 - \Phi_1 + \cancel{T_0 \Delta S} - p_0 \Delta\forall - \cancel{T_0 \Delta S} = \int_1^2 \delta Q - {}_1W_2 - T_0 \int_1^2 \frac{\delta Q}{T} - T_0 S_{gen}$$

$$\Phi_2 - \Phi_1 = \underbrace{\int_1^2 \delta Q - T_0 \int_1^2 \frac{\delta Q}{T_b}} \underbrace{- {}_1W_2 + p_0 \Delta\forall} - T_0 S_{gen}$$

$$\underbrace{\int_1^2 \left(1 - \frac{T_0}{T_b}\right) \delta Q}_{\text{effective heat trans.}} - \underbrace{\left[{}_1W_2 - p_0 \Delta\forall\right]}_{\text{useful work}} - \underbrace{T_0 S_{gen}}_{\text{lost work due to irreversibilities}}$$

Note, if heat trans. occurs @ const. temp. at boundary T_b ...

$$\int_1^2 \left(1 - \frac{T_0}{T_b}\right) \delta Q = \left(1 - \frac{T_0}{T_b}\right) \underbrace{Q_b}_{\text{all heat trans @ boundary}} \equiv Q_{eff.}$$

"from previous notes"

So ...

$$\boxed{\begin{aligned} \Delta\Phi &= \Delta\Phi_Q + \Delta\Phi_W + \Delta\Phi_d \\ \Delta\Phi_Q &= Q_{eff} && \text{[effective heat trans.]} \\ \Delta\Phi_W &= -W = {}_1W_2 - p_0\Delta V && \text{[-useful work]} \\ \Delta\Phi_d &= -T_0 S_{gen} && \text{[-lost work]} \end{aligned}}$$

① $\Delta\Phi_Q$ = exergy change due to heat trans.
"$Q_{eff} > 0$ means increase in Φ"

② $\Delta\Phi_W$ = exergy change due to work
"$W < 0$ means increase in Φ"

③ $\Delta\Phi_d$ = exergy destruction
"$T_0 S_{gen} = {}_1I_2 > 0$ means decrease in Φ" always is!

Specific Version: $\boxed{\Delta\phi = \Delta\phi_Q + \Delta\phi_W + \Delta\phi_d}$

Recall:

$${}_1W_2^{rev} = \Phi_1 - \Phi_2 = -\Delta\Phi = -\Delta\Phi_Q - \Delta\Phi_W - \cancel{\Delta\Phi_d}$$

0 (reversible

Derived Eq. for $\dot{W}_{cv}$ ... (w/ heat exchange w/ reservoir R)

$$\dot{W}_{cv} = \dot{W}_{cv}^{rev} - \underbrace{T_o \dot{S}_{gen}}_{\text{lost work rate}}$$

$$\dot{W}_{cv} = \sum \dot{m}_i \psi_i - \sum \dot{m}_e \psi_e + \dot{Q}_R \left[1 - \frac{T_o}{T_R}\right] - T_o \dot{S}_{gen}$$

At Steady-State, 1 inlet / 1 exit ...

$$\psi_e - \psi_i = \underbrace{q_R \left[1 - \frac{T_o}{T_R}\right]}_{\Delta\psi_Q} \underbrace{- w_{cv}}_{\Delta\psi_W} \underbrace{- T_o \dot{s}_{gen}}_{\Delta\psi_d}$$

$$\Delta\psi = \Delta\psi_Q + \Delta\psi_W + \Delta\psi_d$$

$$\Delta\psi_Q = q_R \left[1 - \frac{T_o}{T_R}\right] = q_{eff}$$

$q_{eff} > 0 \Rightarrow \psi$ increases

$$\Delta\psi_W = -w_{cv}$$

$w_{cv} < 0 \Rightarrow \psi$ increases compressor pump

$w_{cv} > 0 \Rightarrow \psi$ decreases power output.

Exergy Destruction

$$\Delta\psi_d = -T_o s_{gen} = -i_{cv}$$

$i_{cv} \overset{\text{always!}}{>} 0 \Rightarrow \psi$ decreases "due to irreversibilities"