Exergy Destruction & Balance

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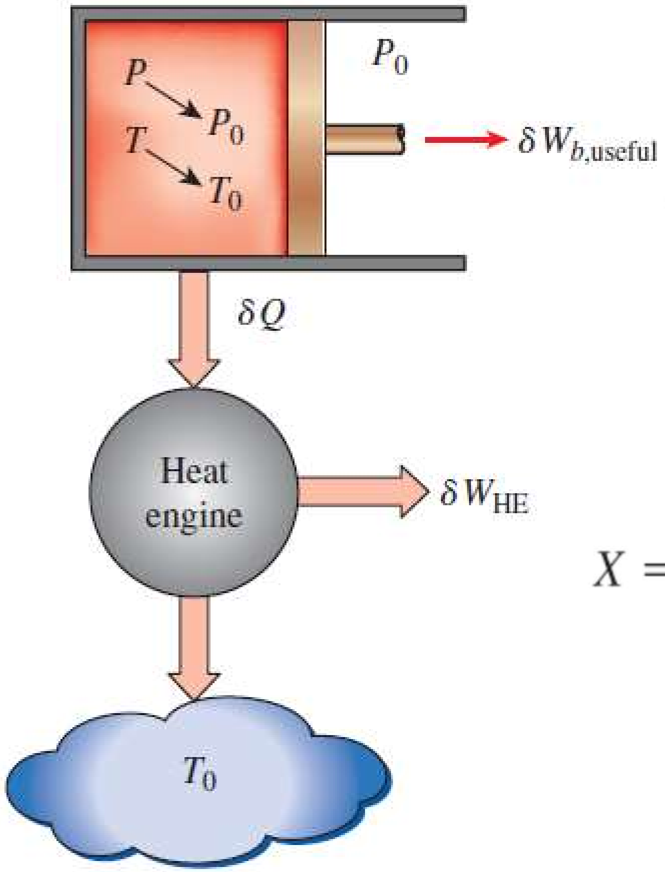
Previously: Exergy of closed & flow systems



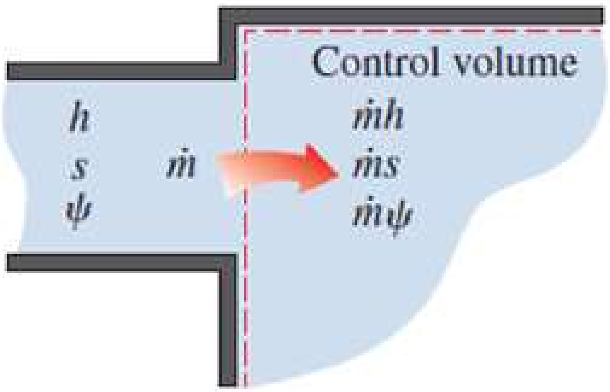
$$\delta W = P\,dV = (P - P_0)\,dV + P_0\,dV = \delta W_{b,\text{useful}} + P_0\,dV$$

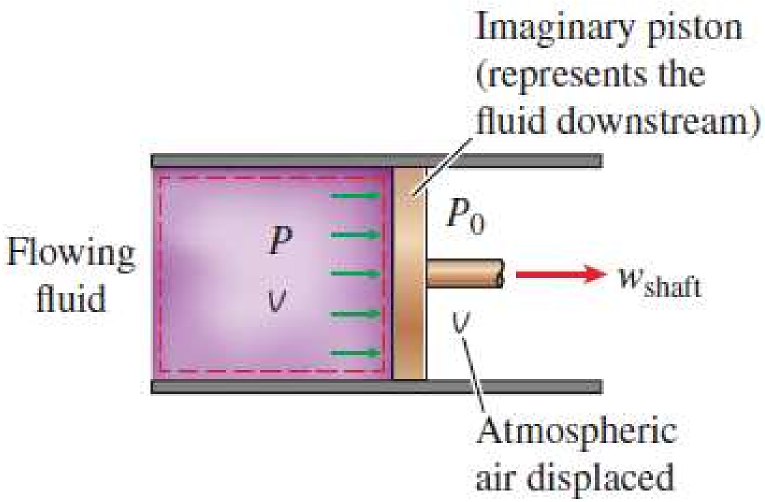
$$\delta W_{\text{HE}} = \left(1 - \frac{T_0}{T}\right)\delta Q = \delta Q - \frac{T_0}{T}\delta Q = \delta Q - (-T_0\,dS) \rightarrow$$

$$\delta Q = \delta W_{\text{HE}} - T_0\,dS$$

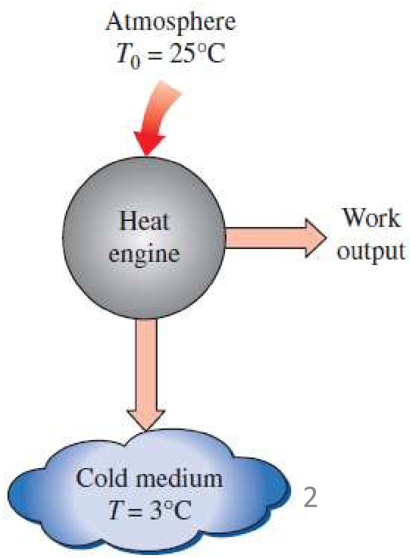
$$\delta W_{\text{total useful}} = \delta W_{\text{HE}} + \delta W_{b,\text{useful}} = -dU - P_0\,dV + T_0\,dS$$

$$X = (U - U_0) + P_0(V - V_0) - T_0(S - S_0) + m\frac{V^2}{2} + mgz$$



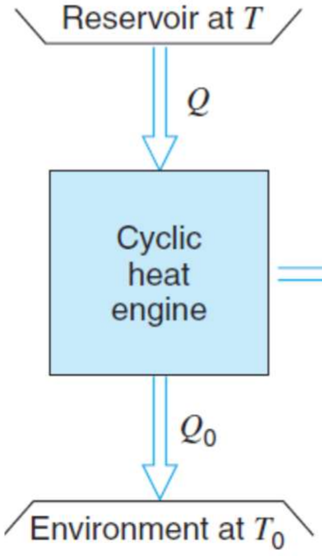


$$Pv = P_0 v + w_{\text{shaft}}$$



Figs-TD: Cengel & Boles

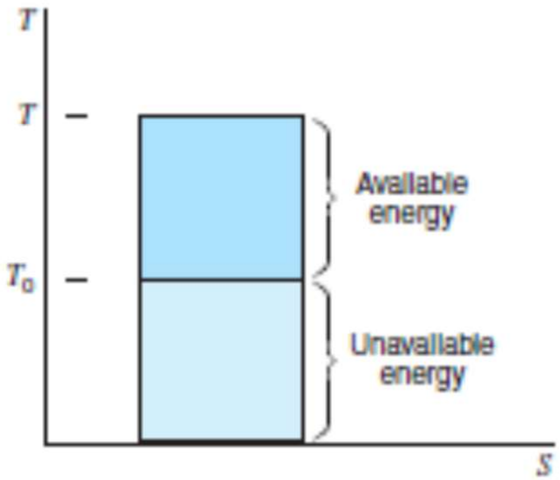
Entropy, Available & Unavailable Energy

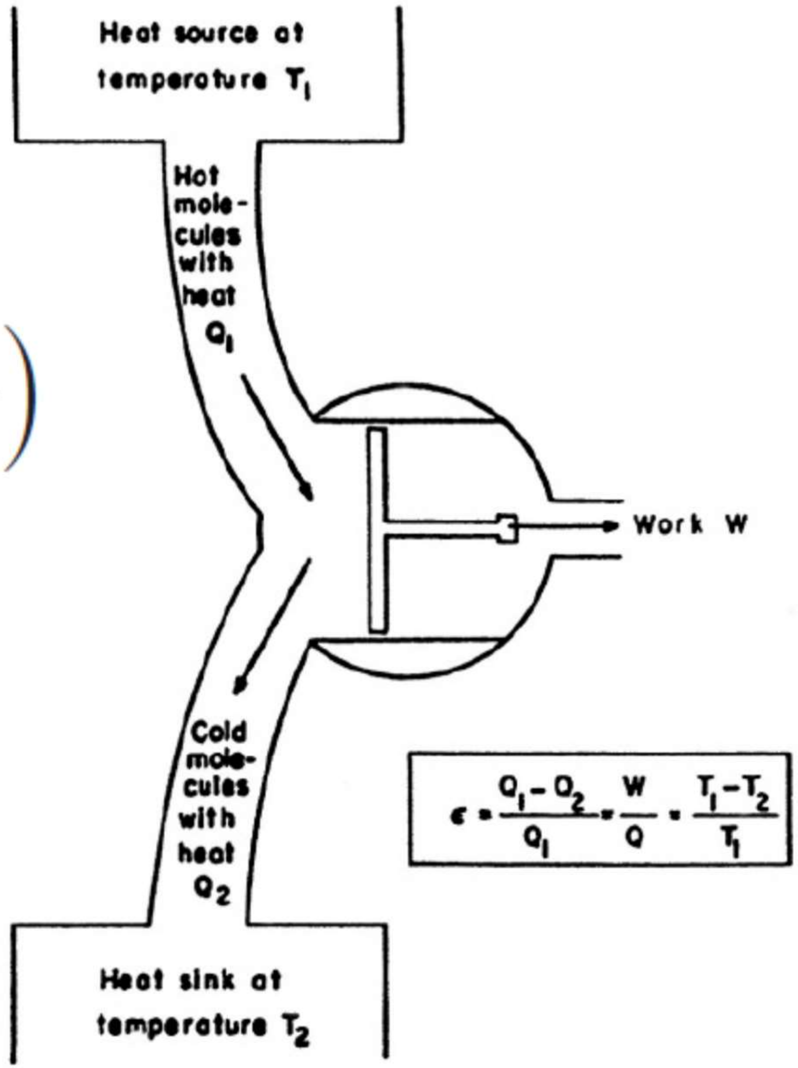


Energy: $W_{\text{rev HE}} = Q - Q_0$

Entropy: $0 = \dfrac{Q}{T} - \dfrac{Q_0}{T_0}$

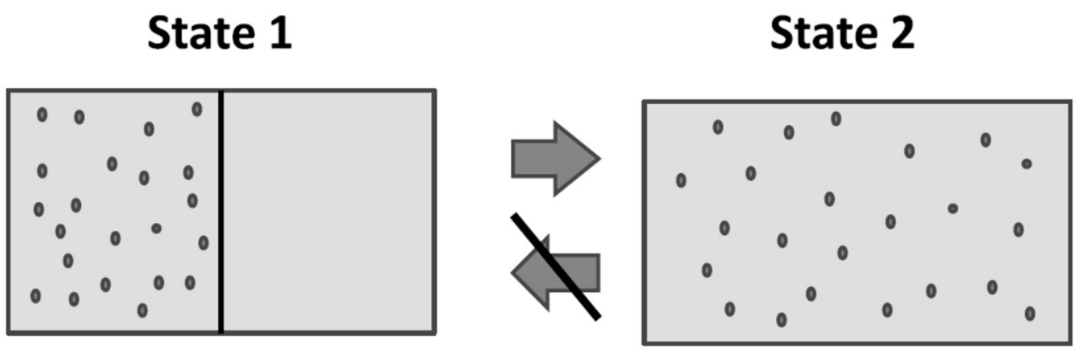
$$\Phi_{QT} = W_{\text{rev HE}} = Q\left(1 - \frac{T_0}{T}\right)$$

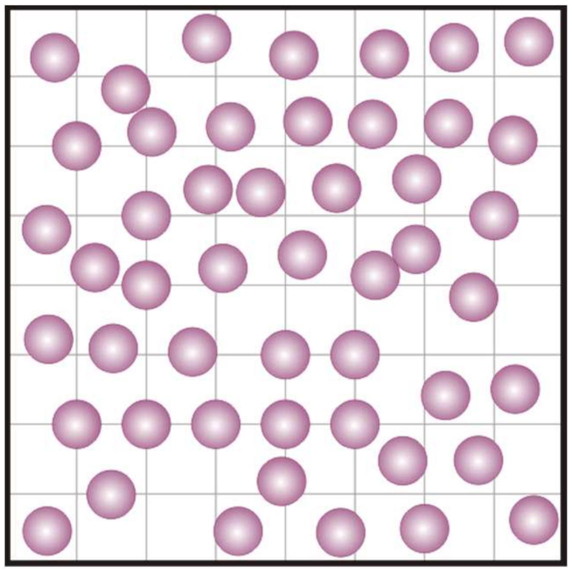




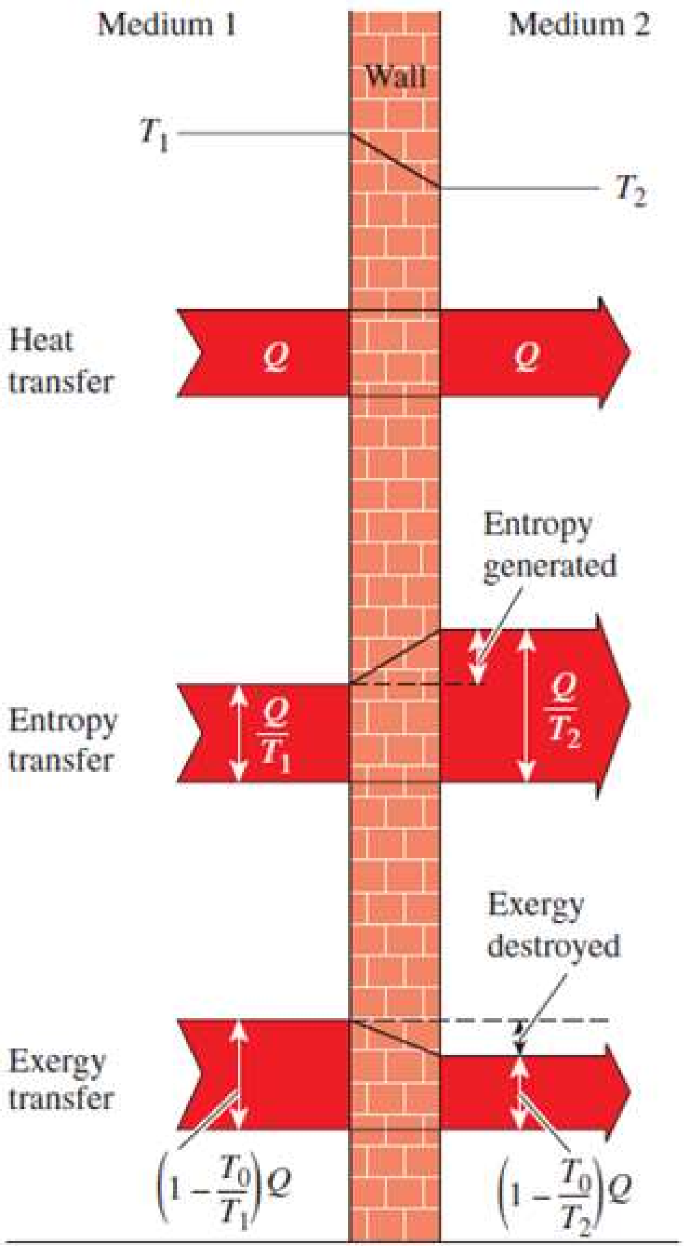
Figs-TD-Borgnakke & Sonntag; Modern Electrochemistry 2B, Bockris & Reddy

Entropy & Entropy Generation





S=KlnΩ



Figs-FOP-Shankar; TD-Cengel & Boles

Entropy & Exergy in an Isolated system

Energy balance: $$\cancelto{0}{E_{in}} - \cancelto{0}{E_{out}} = \Delta E_{system} \rightarrow 0 = E_2 - E_1$$

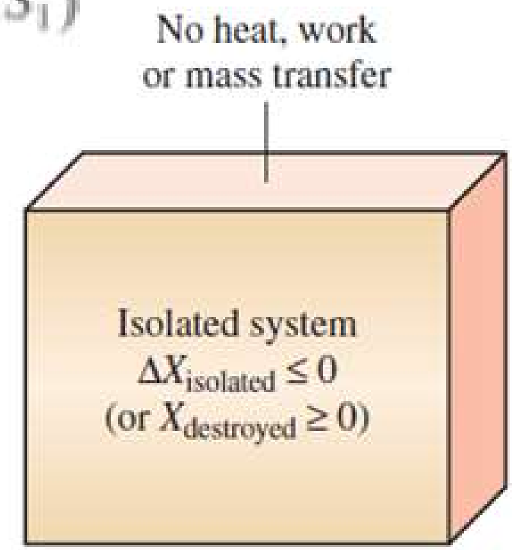
Entropy balance: $$\cancelto{0}{S_{in}} - \cancelto{0}{S_{out}} + S_{gen} = \Delta S_{system} \rightarrow S_{gen} = S_2 - S_1$$

$$-T_0 S_{gen} = E_2 - E_1 - T_0(S_2 - S_1)$$

$$X_2 - X_1 = (E_2 - E_1) + P_0\cancelto{0}{(V_2 - V_1)} - T_0(S_2 - S_1)$$
$$= (E_2 - E_1) - T_0(S_2 - S_1)$$

$$-T_0 S_{gen} = X_2 - X_1 \leq 0$$

$$\Delta X_{isolated} = (X_2 - X_1)_{isolated} \leq 0$$



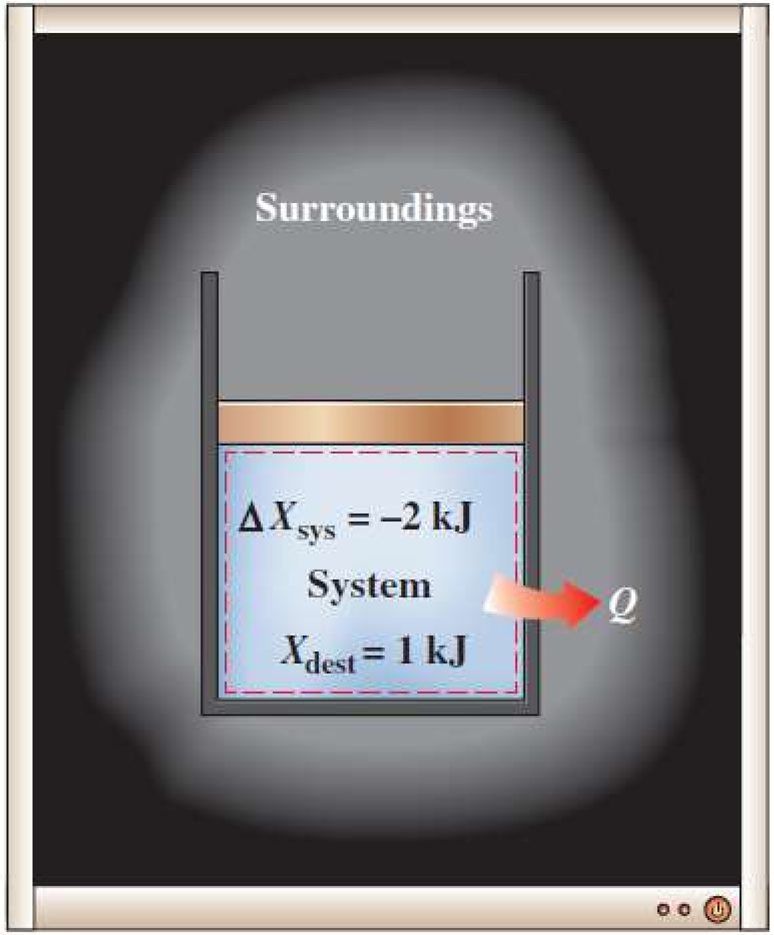
Decrease of exergy principle-"The exergy of an isolated system during a process always decreases or, in the limiting case of a reversible process, remains constant."

Figs-TD: Cengel & Boles

Exergy Destruction

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} \geq 0$$

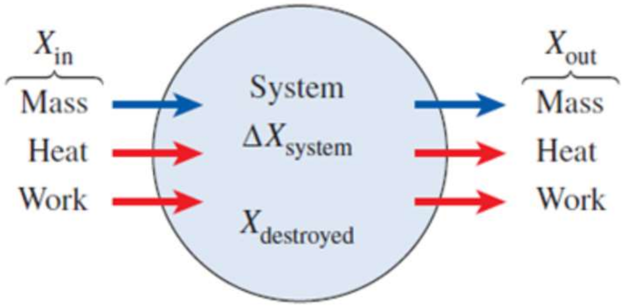
$$X_{\text{destroyed}} \begin{cases} > 0 & \text{Irreversible process} \\ = 0 & \text{Reversible process} \\ < 0 & \text{Impossible process} \end{cases}$$



Figs-TD: Cengel & Boles

Exergy balance for a closed system

$$\begin{pmatrix}\text{Total}\\ \text{exergy}\\ \text{entering}\end{pmatrix} - \begin{pmatrix}\text{Total}\\ \text{exergy}\\ \text{leaving}\end{pmatrix} - \begin{pmatrix}\text{Total}\\ \text{exergy}\\ \text{destroyed}\end{pmatrix} = \begin{pmatrix}\text{Change in the}\\ \text{total exergy}\\ \text{of the system}\end{pmatrix}$$



General:

$$\underbrace{X_{\text{in}} - X_{\text{out}}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} \quad \underbrace{-\, X_{\text{destroyed}}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_{\text{system}}}_{\substack{\text{Change}\\ \text{in exergy}}} \qquad \text{(kJ)}$$

General, rate form:

$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} \quad \underbrace{-\, \dot{X}_{\text{destroyed}}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{dX_{\text{system}}/dt}_{\substack{\text{Rate of change}\\ \text{in exergy}}} \qquad \text{(kW)}$$

$$\dot{X}_{\text{heat}} = (1 - T_0/T)\dot{Q},\ \dot{X}_{\text{work}} = \dot{W}_{\text{useful}},\ \text{and}\ \dot{X}_{\text{mass}} = \dot{m}\psi$$

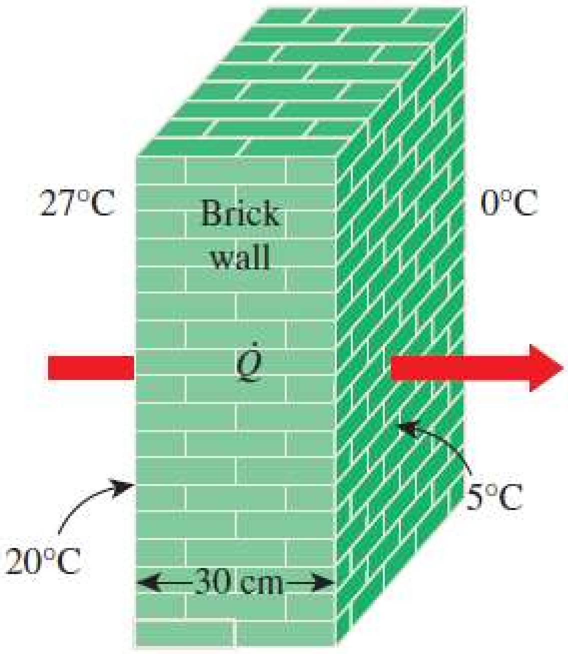
General, unit-mass basis:

$$(x_{\text{in}} - x_{\text{out}}) - x_{\text{destroyed}} = \Delta x_{\text{system}} \qquad \text{(kJ/kg)}$$

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} \quad \text{or} \quad \dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}}$$

Figs-TD: Cengel & Boles

Exergy Destruction in Heat Conduction



$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{\text{destroyed}}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{dX_{\text{system}}/dt^{\nearrow 0\text{ (steady)}}}_{\substack{\text{Rate of change}\\ \text{in exergy}}} = 0$$

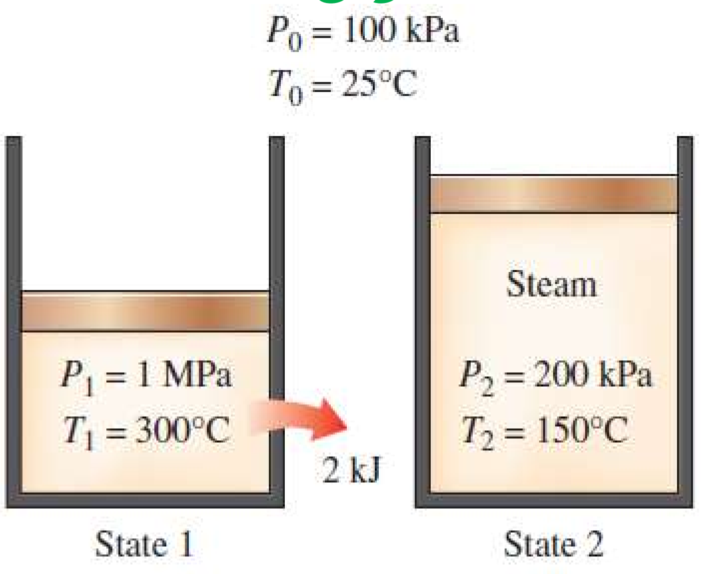
$$\dot{Q}\left(1 - \frac{T_0}{T}\right)_{\text{in}} - \dot{Q}\left(1 - \frac{T_0}{T}\right)_{\text{out}} - \dot{X}_{\text{destroyed}} = 0$$

$$(1035\text{ W})\left(1 - \frac{273\text{ K}}{293\text{ K}}\right) - (1035\text{ W})\left(1 - \frac{273\text{ K}}{278\text{ K}}\right) - \dot{X}_{\text{destroyed}} = 0$$

$$\dot{X}_{\text{destroyed}} = \mathbf{52.0\ W}$$

Figs-TD: Cengel & Boles

Exergy Destruction in Steam Expansion



$$X_1 = m[(u_1 - u_0) - T_0(s_1 - s_0) + P_0(v_1 - v_0)]$$

$$X_2 = m[(u_2 - u_0) - T_0(s_2 - s_0) + P_0(v_2 - v_0)]$$

$$\Delta X = X_2 - X_1$$

$$W_u = W - W_{\text{surr}} = W_{b,\text{out}} - P_0(V_2 - V_1) = W_{b,\text{out}} - P_0 m(v_2 - v_1)$$

$$\eta_{\text{II}} = \frac{\text{Exergy recovered}}{\text{Exergy expended}} = \frac{W_u}{X_1 - X_2}$$

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = T_0\left[m(s_2 - s_1) + \frac{Q_{\text{surr}}}{T_0}\right]$$

Figs-TD: Cengel & Boles

What's next?

- Exergy balance in open system/control volume