Quantifying Exergy Changes

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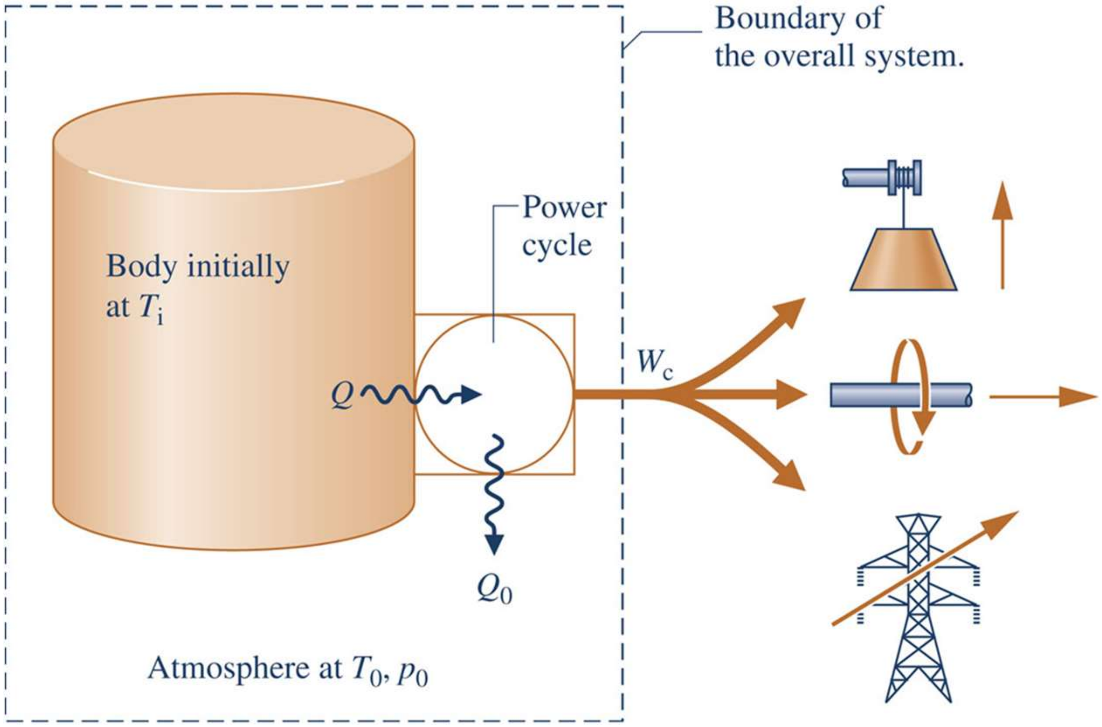
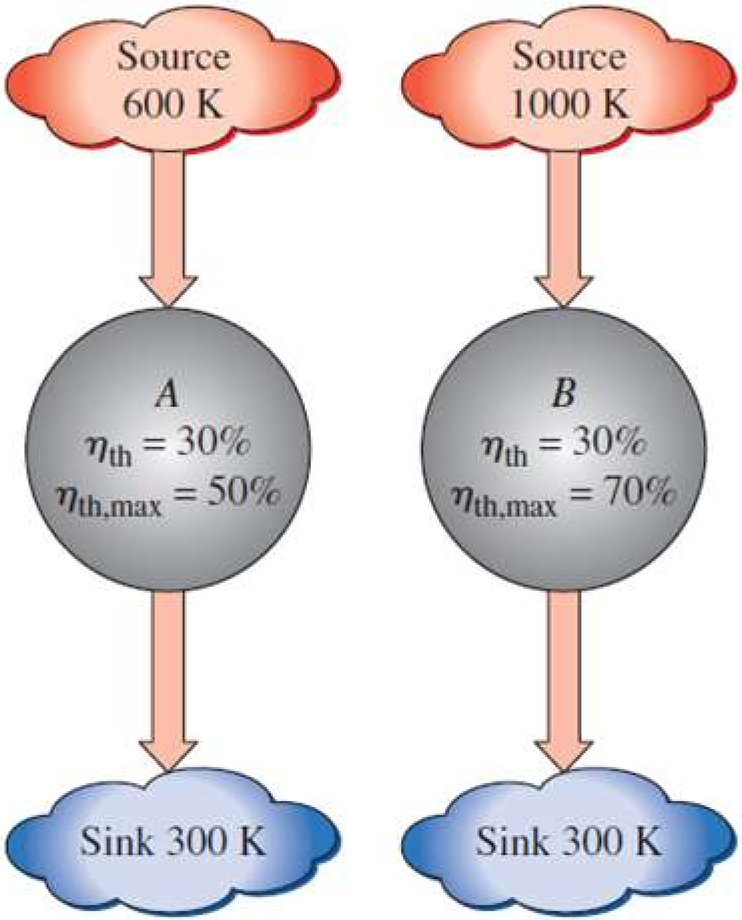
Previously: Best way to utilize energy resources?





$$\eta_{II} = \frac{\text{Exergy recovered}}{\text{Exergy expended}} = 1 - \frac{\text{Exergy destroyed}}{\text{Exergy expended}}$$

Figs-TD: Cengel & Boles; Moran, Shapiro, Boettner & Bailey

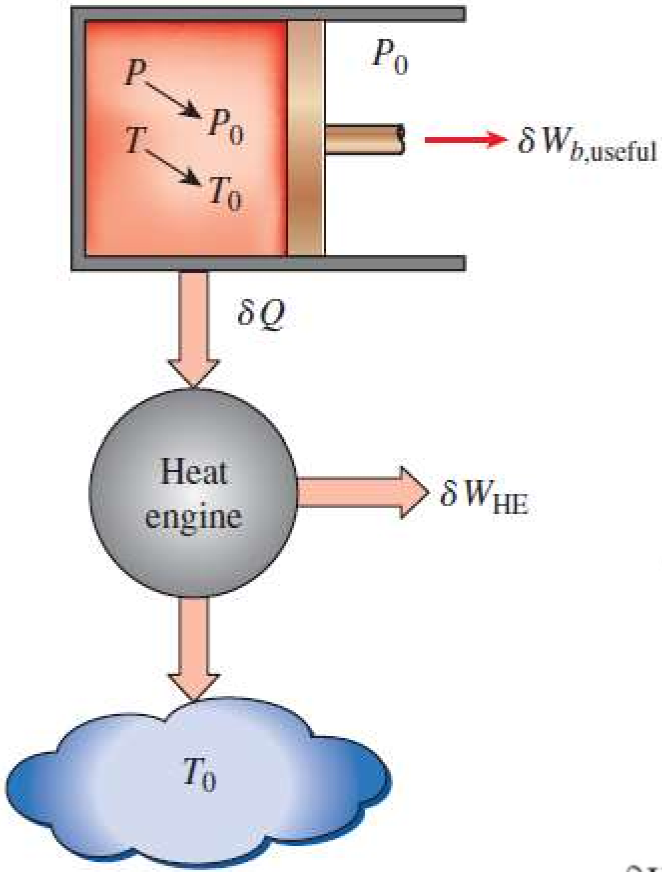
Some general features of exergy

- "Combination property": Involves both system and surrounding
- Extensive state property that is not conserved

$$\mathrm{E} = (U - U_0) + p_0(V - V_0) - T_0(S - S_0) + \mathrm{KE} + \mathrm{PE}$$

$$\mathrm{E}_2 - \mathrm{E}_1 = (U_2 - U_1) + p_0(V_2 - V_1) - T_0(S_2 - S_1) + (\mathrm{KE}_2 - \mathrm{KE}_1) + (\mathrm{PE}_2 - \mathrm{PE}_1)$$

Exergy of a fixed mass



$$\underbrace{\delta E_{\text{in}} - \delta E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$-\delta Q - \delta W = dU$$

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

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

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

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

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

Figs-TD: Cengel & Boles

Exergy changes in a closed system

$$\phi = (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$
$$= (e - e_0) + P_0(v - v_0) - T_0(s - s_0)$$

$$\Delta\phi = \phi_2 - \phi_1 = (u_2 - u_1) + P_0(v_2 - v_1) - T_0(s_2 - s_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

$$= (e_2 - e_1) + P_0(v_2 - v_1) - T_0(s_2 - s_1)$$

$$\Delta X = X_2 - X_1 = m(\phi_2 - \phi_1) = (E_2 - E_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)$$

$$= (U_2 - U_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1) + m\frac{V_2^2 - V_1^2}{2} + mg(z_2 - z_1)$$

$$X_{\text{system}} = \int \phi \, \delta m = \int_V \phi\rho \, dV$$

Figs-TD: Cengel & Boles

Exergy can be zero but never negative

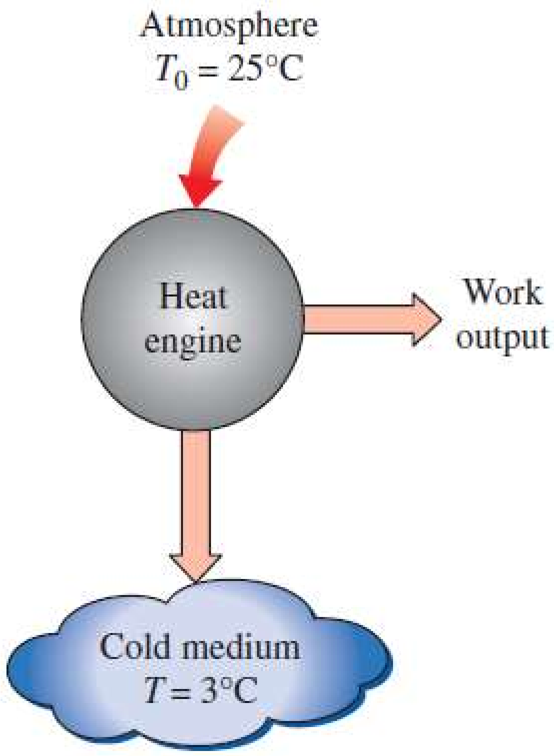
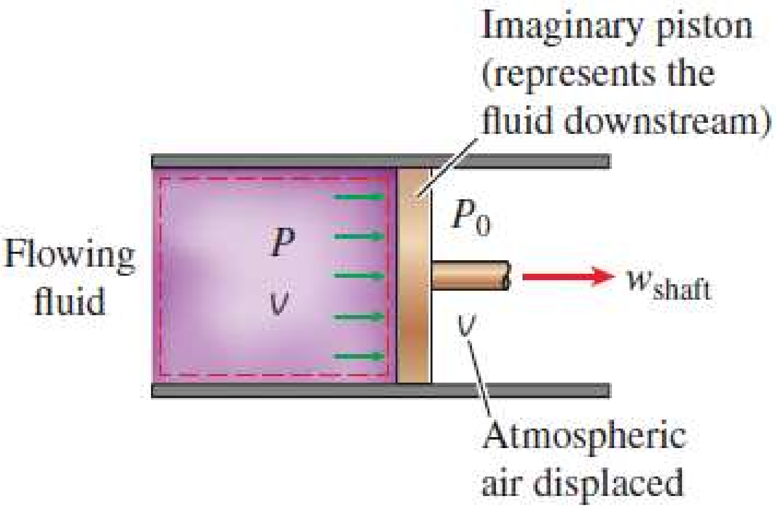


Fig-TD: Cengel & Boles

Exergy of flow system



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

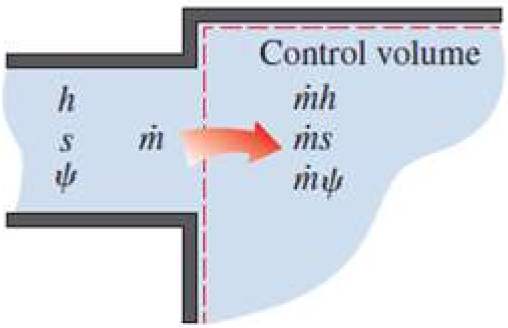
$$x_{flow} = Pv - P_0 v = (P - P_0)v$$

$$x_{flowing\ fluid} = x_{nonflowing\ fluid} + x_{flow}$$

$$= (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz + (P - P_0)v$$

$$= (u + Pv) - (u_0 + P_0 v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

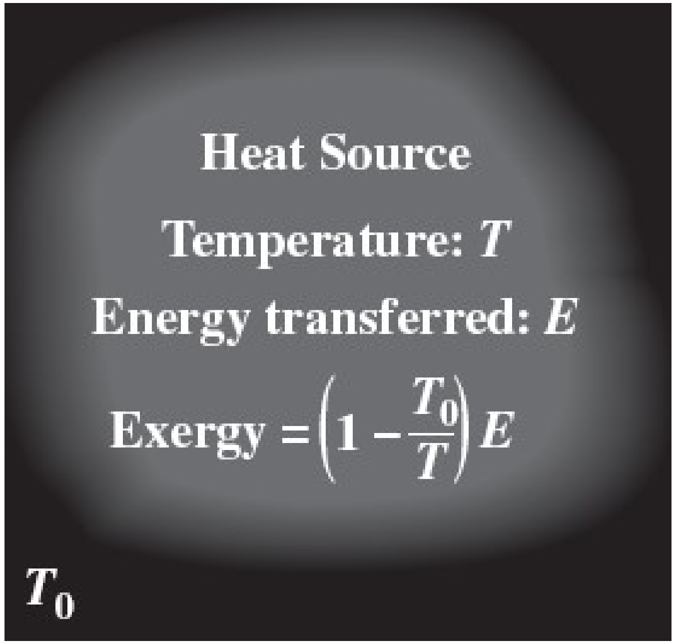
$$= (h - h_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$



$$\Delta\psi = \psi_2 - \psi_1 = (h_2 - h_1) + T_0(s_2 - s_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

Figs-TD: Cengel & Boles

Exergy of heat transfer



$$X_{\text{heat}} = \int \left(1 - \frac{T_0}{T}\right) \delta Q$$

Figs-TD: Cengel & Boles

What's next?

- Exergy destruction, balance & 2^{nd} law efficiency