Work and 1st Law notes

Work, W = all energy transferred across boundary, EXCEPT heat

BOUNDARY WORK

Boundary Work = $W_b = \int PdV$ (kJ)

Special cases:

Isobaric: $w = P(v_2 - v_1)$ (kJ/kg)

Isochoric: $w = 0$

Isothermal, ideal gas ($Pv = C$): $w = RT\ln\left(\frac{v_2}{v_1}\right) = RT\ln\left(\frac{P_1}{P_2}\right) = P_1V_1\ln\left(\frac{v_2}{v_1}\right)$ (kJ/kg)

Polytropic, gas ($Pv^n = C$): $w = \frac{P_2v_2 - P_1v_1}{(1-n)}$ (kJ/kg)

FIRST LAW

ENERGY PROPERTIES

Internal Energy, U and enthalpy, H

Ideal gases

$u_2 - u_1 = C_V*(T_2-T_1)$ (kJ/kg)

$h_2 - h_1 = C_P*(T_2-T_1)$ (kJ/kg)

Ideal liquids: $C_V = C_P$ and $h_2 - h_1 = u_2 - u_1$

Water/steam and refrigerant: Use tables A-4 – A-6 and A-11 – A-13.

Closed System

General: $\mathbf{Q - W = \Delta U}$

Sign convention: Work done by (out of) system (+). Heat into system (+).

Special Cases

Isobaric expansion with only boundary work	$Q - W_b = \Delta U$ OR $Q = \Delta H$
Adiabatic process:	$-W = \Delta U$
Passive process (no work):	$Q = \Delta U$
Adiabatic and passive (e.g. calorimeter):	$0 = \Delta U$
Cycle ($\Delta U = 0$):	$Q_{net} = W_{net}$

Open systems at STEADY STATE

$$\dot{Q} - \dot{W} = \sum_e \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e \right) - \sum_i \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i \right) \quad \text{(kw)}$$

Special Cases

one inlet (1) and one outlet (2)

$$\dot{Q} - \dot{W} = \dot{m}\left(h_2 - h_1 + \frac{\left(V_2^2 - V_1^2\right)}{2000} + g(z_2 - z_1)\right) \qquad \text{(kw)}$$

where units of h are kJ/kg, *V* are m/s and z is km

neglecting potential energy changes (nozzles, diffusers)

$$\dot{Q} - \dot{W} = \dot{m}\left(h_2 - h_1 + \frac{\left(V_2^2 - V_1^2\right)}{2000}\right) \qquad \text{(kw)}$$

Stationary - ke and pe changes neglected: (often turbines, compressors).

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) \qquad \text{(kw)}$$

Adiabatic and passive, no heat or work (often heat exchangers, mixers)

$$0 = \sum_e \dot{m}_e(h_e) - \sum_i \dot{m}_i(h_i) \qquad \text{(kw)}$$

adiabatic throttling valve: $h_2 = h_1$

Cycle:

$$\dot{Q}_{net} = \dot{W}_{net} \qquad \text{(kw)}$$

mass flow rate, $\dot{m}$:

Conservation of mass at steady-state: $\sum_i \dot{m}_i = \sum_e \dot{m}_e$

$\dot{m} = \rho V A = \rho \dot{V} = \frac{\dot{V}}{v}$ where *V* = velocity, *v* = spec. vol., $\dot{V}$ = vol. flow rate

Individual control volume devices – see handout on web page.

Problem Solution Rubric:

1. Write the 1^{st} law for the appropriate system.
2. Modify 1^{st} law for special cases
3. Calculate energy properties (internal energy, enthalpy) using specific heat and temperature or tables.
4. Find mass terms, if necessary, using ideal gas law and/or open system relations for $\dot{m}$.