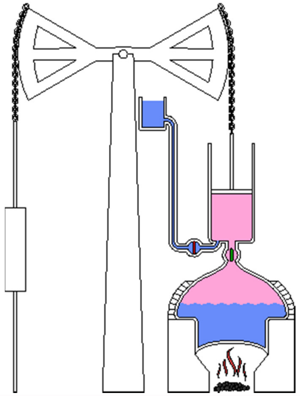
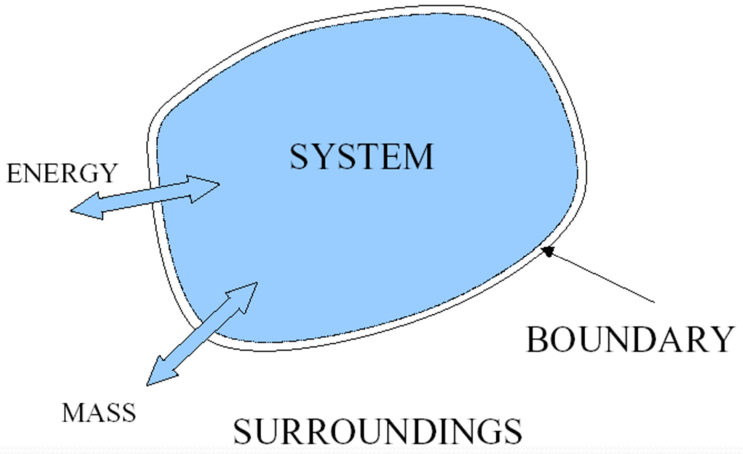
CHAPTER 7

ENERGY BALANCES



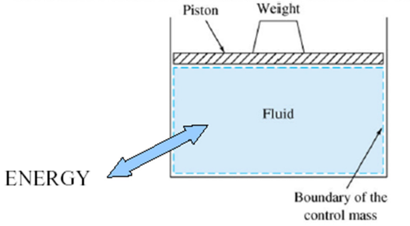
SYSTEM

It is a three-dimensional region of space or an amount of matter, bounded by an arbitrary (real or imaginary) surface

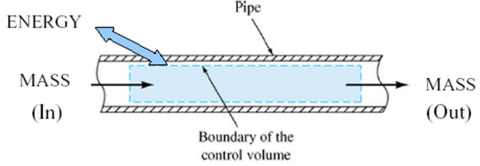


SYSTEM

CLOSED: Mass is not transferred across the boundaries



OPEN: Mass can be transferred across any of the boundaries



SIGN CONVENTION

ENERGY IN = POSITIVE MASS IN = POSITIVE	ENERGY OUT = NEGATIVE MASS OUT = NEGATIVE

7.1-7.2 Energy & 1st Law of Thermodynamics

* What is energy?

* Forms of Energy

- Kinetic energy (KE) $KE = \frac{1}{2} mV^2$

- Potential energy (PE) $PE = mgz$

- Internal energy (U)

* Total Energy , E = KE + PE + U

Change in kinetic energy:

$$\Delta KE = KE_2 - KE_1 = \frac{1}{2}m(V_2^2 - V_1^2)$$

Change in potential energy:

$$\Delta PE = PE_2 - PE_1 = mg(z_2 - z_1)$$

Change in potential energy:

$$\Delta U = U_2 - U_1$$

Note: Δ means "change" and is always calculated as "final value minus initial value"

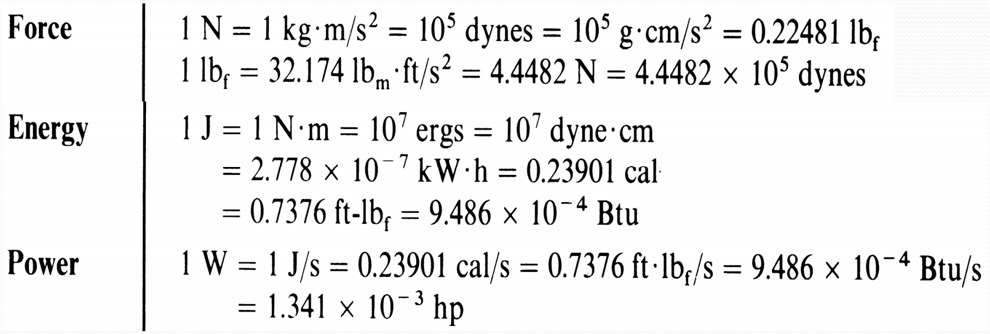
How energy can be **transferred** between a system and its surroundings?

- ✓ Heat – energy that flows as a result of temperature difference between a system and its surrounding ; *heat is defined positive when it is transferred to the system from the surroundings*.
- ✓ Work – energy that flows in response to any driving force other than a temperature difference; *work is defined positive when it is done by the system on the surroundings.*

Types of Work

- ✓ **Flow work (W_{fl})** - energy carried across the boundaries of a system with the mass flowing across the boundaries (i.e. internal, kinetic & potential energy)
- ✓ **Shaft work (W_s)** - energy in transition across the boundaries of a system due to a driving force other than temperature, and not associated with mass flow (an example would be mechanical work due to a piston, pump or compressor)

Energy – Conversion Units



Force	$1\ N = 1\ kg\cdot m/s^2 = 10^5\ dynes = 10^5\ g\cdot cm/s^2 = 0.22481\ lb_f$ $1\ lb_f = 32.174\ lb_m\cdot ft/s^2 = 4.4482\ N = 4.4482 \times 10^5\ dynes$
Energy	$1\ J = 1\ N\cdot m = 10^7\ ergs = 10^7\ dyne\cdot cm$ $= 2.778 \times 10^{-7}\ kW\cdot h = 0.23901\ cal$ $= 0.7376\ ft\text{-}lb_f = 9.486 \times 10^{-4}\ Btu$
Power	$1\ W = 1\ J/s = 0.23901\ cal/s = 0.7376\ ft\cdot lb_f/s = 9.486 \times 10^{-4}\ Btu/s$ $= 1.341 \times 10^{-3}\ hp$

Reference Points

Recall…

1. E is always measured relative to reference point!
   - ✓ Reference plane for PE
   - ✓ Reference frame for KE
   - ✓ Reference state for $\hat{U}$ or $\hat{H}$ (i.e. usually, but not necessarily $\hat{U}$ or $\hat{H} = 0$)

And…

1. Changes in E are important, not total values of E
2. ΔE depends only on beginning and end states
3. Q and W depend on process path (could get to the same end state with different combinations of Q and W)

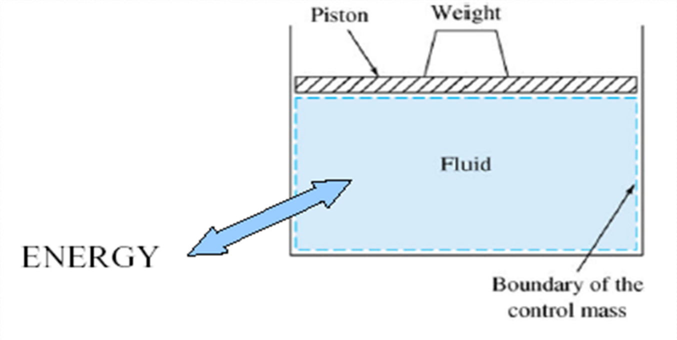
General Balance Equation

- A balance on conserved quantity (i.e. mass, energy, momentum) in a process system may be written as:

Input + generation - output - consumption

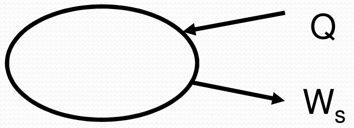
= accumulation

7.3 Energy Balance on Closed Systems



- How do you describe a closed system control volume?
- What effect does this have on the mass and energy balances?

- ➢ There is no mass transfer into a closed system
- ➢ The only way energy can get into or out of a closed system is by heat transfer or work



a. Heat transfer (Q):

b. Work (Ws):

Note: * Work is any boundary interaction that is not heat (mechanical, electrical, magnetic, etc.)

First Law of Thermodynamics

- Energy can neither be created nor destroyed ; It can only change forms

$$\text{Input} + \cancelto{0}{\text{generation}} - \text{output} - \cancelto{0}{\text{consumption}}$$

$$= \text{accumulation}$$

$$\therefore \ \textbf{Input} - \textbf{output} = \textbf{accumulation}$$

Closed System

- In a closed system,
  - ✓ no mass crosses the boundary, hence the input & output terms are eliminated
  - ✓ energy can be transferred across the boundary as heat & work, hence the accumulation term may be defined as the change in total energy in the system, i.e.

$$\begin{pmatrix}\text{Final total Energy}\\ \text{in the System}\end{pmatrix} - \begin{pmatrix}\text{Initial Total Energy}\\ \text{in the System}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{system energy}\end{pmatrix}$$

$$E_f \qquad - \qquad E_i \qquad \qquad Q - W_S$$

$$E = KE + PE + U$$

$$\Delta E = E_f - E_i$$

$$\Delta E = Q - W_s$$

Q = heat transferred to the system
W_s = work done by the system

$$\Delta E = \Delta KE + \Delta PE + \Delta U$$

$$\Delta KE + \Delta PE + \Delta U = Q - W_s$$

$$\Delta E = \Delta U + \Delta PE + \Delta KE = Q - W$$

Note: $Q = \sum_i Q_i$ (Summation of all heat transfer across system boundary)

$W_s = \sum_i W_{s,i}$ (Summation of all work across system boundary)

For a closed system what is ΔE equal to?

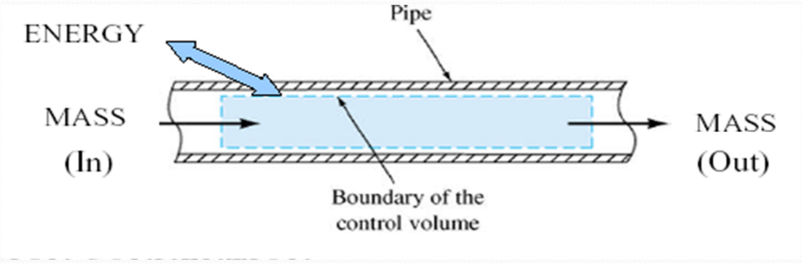
$$\Delta E = \Delta \mathrm{KE} + \Delta \mathrm{PE} + \Delta \mathrm{U} = Q - W_s$$

- Is it steady state ? (if yes, ΔE = 0)
- Is it adiabatic? (if yes, Q = 0)
- Are there moving parts, e.g. do the walls move? (if no, W_s = 0)
- Is the *system* moving? (if no, ΔKE = 0)
- Is there a change in elevation of the *system*? (if no, ΔPE = 0)
- Does temperature, phase, chemical composition change, or pressure change less than a few atmospheres ? (if no to all, ΔU = 0)

Example 1

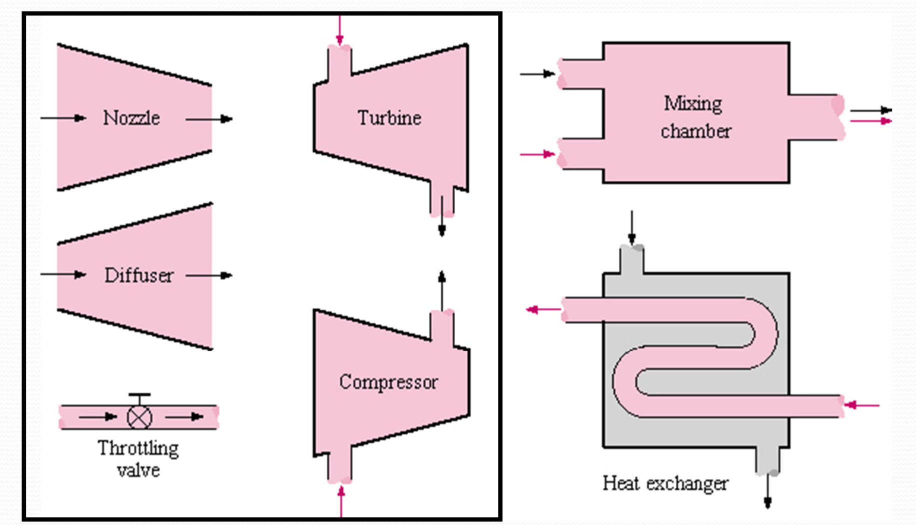
A closed system of mass 5 kg undergoes a process in which there is work of magnitude 9 kJ to the system from the surroundings. The elevation of the system increases by 700 m during the process. The specific internal energy of the system decreases by 6 kJ/kg and there is no change in kinetic energy of the system. The acceleration of gravity is constant at g=9.6 m/s^2. Determine the heat transfer, in kJ.

7.4 Energy Balances on Open Systems



- How are open systems control volumes different from closed systems?
- What effect does this have on the energy balance?

Some common open system steady flow devices



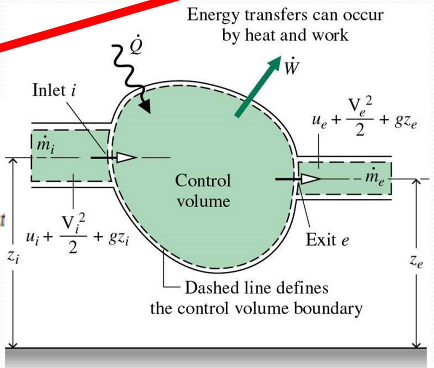
Only one in and one out

Application of First Law - Conservation of energy for a control volume

$$\begin{bmatrix}\text{time rate of change}\\ \text{of the energy}\\ \text{contained within}\\ \text{the control volume at}\\ \text{time t}\end{bmatrix} = \begin{bmatrix}\text{net rate at which}\\ \text{energy is being}\\ \text{transferred in}\\ \text{by heat transfer}\\ \text{at time t}\end{bmatrix} - \begin{bmatrix}\text{net rate at which}\\ \text{energy is being}\\ \text{transferred out}\\ \text{by work at}\\ \text{time t}\end{bmatrix} + \begin{bmatrix}\text{net rate of energy}\\ \text{transfer into the}\\ \text{control volume}\\ \text{accompanying}\\ \text{mass flow } \dot{m}\end{bmatrix}_{\dot{m}}$$

$$\frac{\partial E_{cv}}{\partial t} = \dot{Q} - \dot{W} + \Delta\dot{E}_{cv}$$

$$\Delta E_{cv} = [U + KE + PE]_{in} - [U + KE + PE]_{out}$$



General Energy Balances on Open Systems at Steady State

$$\frac{\partial E_{cv}}{\partial t} = 0 \quad \text{hence,} \quad \Delta\dot{E}_{CV} = \dot{Q} - \dot{W}$$

$$\underset{\dot{E}_{out}}{\begin{pmatrix}\text{Total Energy}\\ \text{Leaving the System}\end{pmatrix}} - \underset{\dot{E}_{in}}{\begin{pmatrix}\text{Total Energy}\\ \text{Entering the System}\end{pmatrix}} = \underset{\dot{Q}-\dot{W}}{\begin{pmatrix}\text{Change in the total}\\ \text{system energy}\end{pmatrix}}$$

$$\Delta\dot{E} = \dot{E}_{out} - \dot{E}_{in}$$

$$\Delta\dot{E} = \dot{Q} - \dot{W}$$

$$\Delta\dot{E} = \Delta KE + \Delta PE + \Delta U$$

$$\Delta KE + \Delta PE + \Delta U = \dot{Q} - \dot{W}$$

$$\Delta U + \Delta KE + \Delta PE = \dot{Q} - \dot{W}$$

$$\Delta U = \dot{m}\left(\hat{U}_f - \hat{U}_i\right)$$

$$\Delta KE = \frac{1}{2}\dot{m}\left(v_f^2 - v_i^2\right)$$

$$\Delta PE = \dot{m}g\left(z_f - z_i\right)$$

$$\dot{m} = \dot{m}_f = \dot{m}_i$$

$$\dot{m}\Delta\left(\hat{U} + \frac{v^2}{2} + gz\right) = \dot{Q} - \dot{W}$$

7.4a Types of Work

Recall …. How energy can be transferred across boundaries of

a closed system ?

an open system?