



G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

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Nandikotkur Road, Venkayapalli, Kurnool – 518452

Department of Mechanical Engineering

***Bridge Course
On
Thermal Engineering-II***

G.PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY
Pasupula (V), Nandikotkur Road, Venkayapalli, Kurnool

Department of Mechanical Engineering
BRIDGE COURSE FOR THE SUBJECT “THERMAL ENGINEERING-II”

Class: III B.Tech-I Sem – Mechanical Engineering

Microscopic: tracking the movement of matter and energy on a particle by particle basis

Macroscopic: use the conservation equations (energy and mass) to track movement of matter and energy on an average over a fixed domain (referred to as classical thermodynamics)

Energy

- the total energy of the system per unit mass is denoted as e and is given as

$$e = E/m \text{ (kJ/kg)}$$

- if we neglect the contributions of magnetic, electric, nuclear energy, we can write the total energy as

$$E = U + KE + PE = U + mV^2/2 + mgz$$

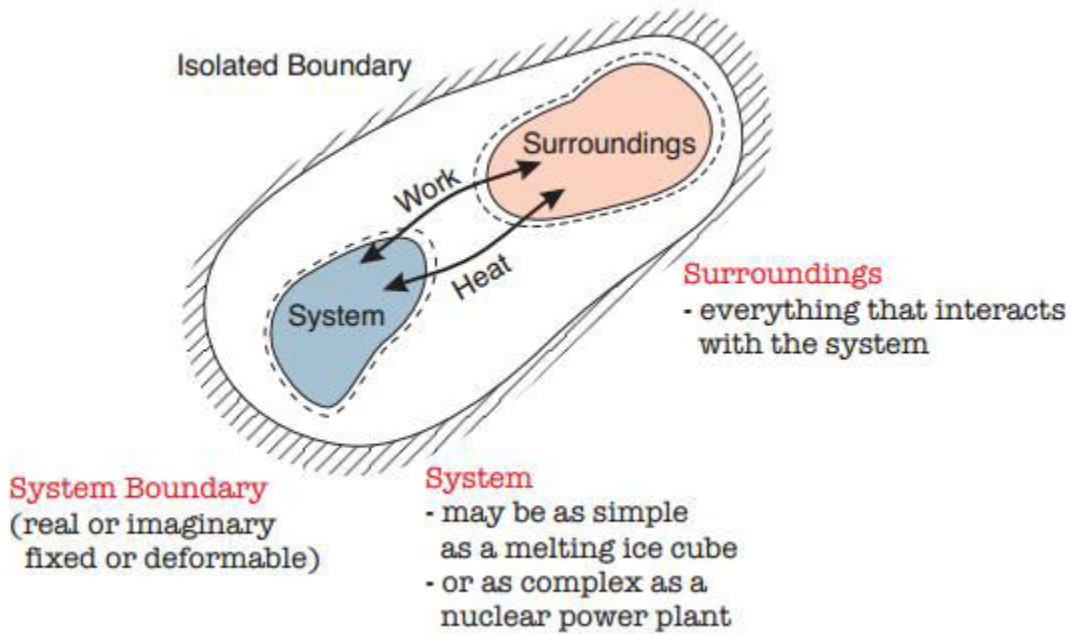
Dimensions and Units

SI: International System

- SI is the preferred because it is logical (base 10) and needs no correction factors
- unit convention:

Parameter	Units	Symbol
length, L	meters	m
mass, m	kilograms	kg
time, t	seconds	s
temperature, T	kelvin	K
velocity, V	meter per second, $\equiv L/t$	m/s
acceleration, a	meter per second squared $\equiv L/t^2$	m/s^2
force, F	newton, $\equiv m \cdot L/t^2$	N
energy, E	joule $\equiv m \cdot L^2/t^2$	J

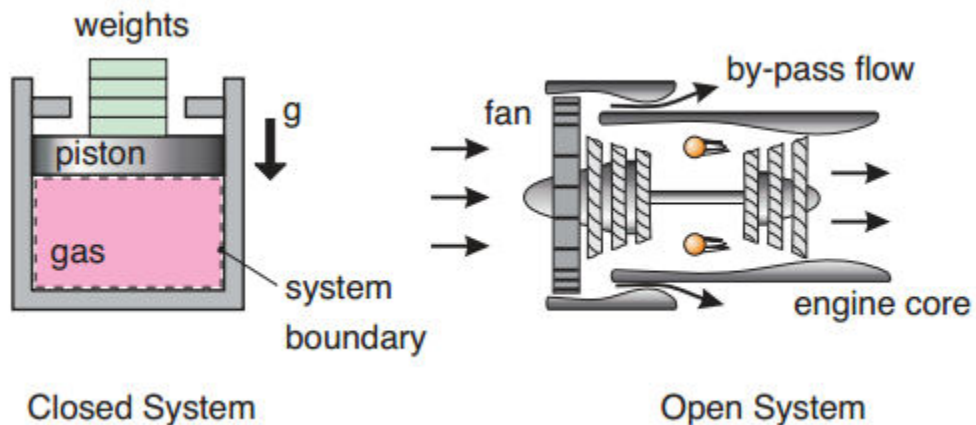
Thermodynamic Systems



SYSTEM:

Closed System: composed of a control (or fixed) mass where heat and work can cross the boundary but no mass crosses the boundary.

Open System: composed of a control volume (or region in space) where heat, work, and mass can cross the boundary or the control surface.



WORK & HEAT TRANSFER:

- work and heat transfer are NOT properties → they are the forms that energy takes to cross the system boundary

Thermodynamic Properties of Systems

Basic Definitions

Thermodynamic Property: Any observable or measurable characteristic of a system. Any mathematical combination of the measurable characteristics of a system

Intensive Properties: Properties which are independent of the size (or mass) of the system

- they are not additive $\Rightarrow X_{A+B} \neq X_A + X_B$
- examples include: pressure, temperature, and density

Extensive Properties: Properties which are dependent of the size (or mass) of the system

- they are additive $\Rightarrow X_{A+B} = X_A + X_B$
- examples include: volume, energy, entropy and surface area

Specific Properties: Extensive properties expressed per unit mass to make them intensive properties

- specific property (intensive) \rightarrow extensive property/mass

Measurable Properties

- P, V, T, and m are important because they are measurable quantities. Many other thermodynamic quantities can only be calculated and used in calculations when they are related to P, V, T, and m
- Pressure (P) and Temperature (T) are easily measured intensive properties.

Note: They are not always independent of one another.

- Volume (V) and mass (m) are easily measured extensive properties.

Pressure

- Pressure = Force/Area ; $\rightarrow \text{N/m}^2 = \text{Pa}$
- in fluids, this is pressure (normal component of force per unit area)
- in solids, this is stress

Thermodynamic Processes

- the process is any change from one equilibrium state to another. (If the end state = initial state, then the process is a cycle)
- the process path is a series intermediate states through which a system passes during the process (we very seldom care what the process path is)
- processes are categorized based on how the properties behave:
 - isobaric (P = constant)
 - isothermal (T = constant)
 - isochoric or isometric (V = constant)

- isentropic ($s = \text{constant}$)
- isenthalpic ($h = \text{constant}$)
- adiabatic (no heat transfer)

Stored Energy

- how is energy stored in matter?

$$\text{Stored Energy} = E = KE + PE + U$$

- **Kinetic Energy:** Energy due to motion of the matter with respect to an external reference frame ($KE = mV^2/2$)
- **Potential Energy:** Energy due to the position of the matter in a force field (gravitational, magnetic, electric). It also includes energy stored due to elastic forces and surface tension ($PE = mgz$)
- **Internal Energy** = microscopic forms of energy, U
 - forms of the energy in the matter due to its internal structure (independent of external reference frames)

Transit Energy

Heat

- transit form of energy that occurs when there is ΔT (a temperature gradient)
- notation - Q (kJ), q (kJ/kg), \dot{Q} (kW), \dot{q} (kW/kg)

Work

- transit form of energy that occur due to all other driving forces
- notation - W (kJ), w (kJ/kg), \dot{W} (kW), \dot{w} (kW/kg)

Phases of Pure Substances

- a pure substance may exist in different phases, where a phase is considered to be a physically uniform
- 3 principal phases:

Solids:

- strong molecular bonds
- molecules form a fixed (but vibrating) structure (lattice)

Liquids:

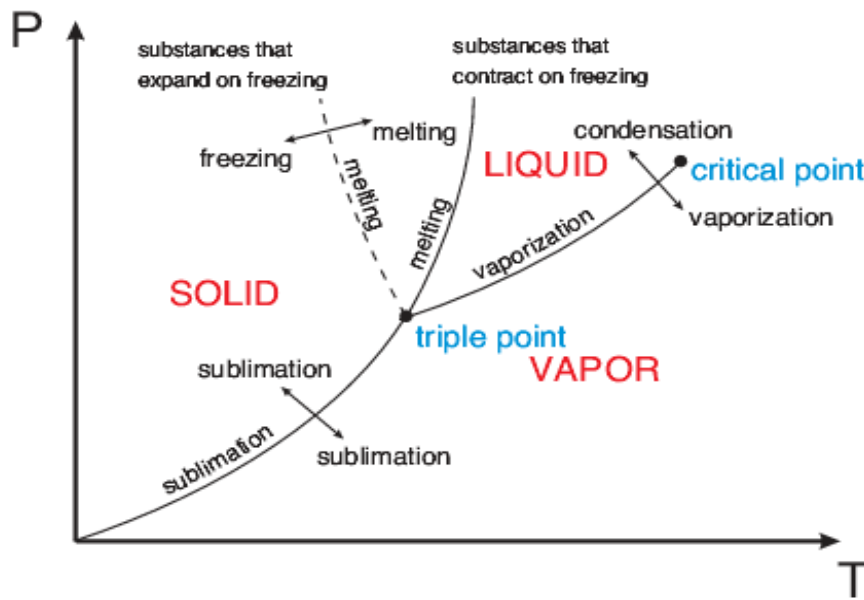
- molecules are no longer in a fixed position relative to one another
- molecules float about each other

Gases:

- there is no molecular order intermolecular forces ≈ 0

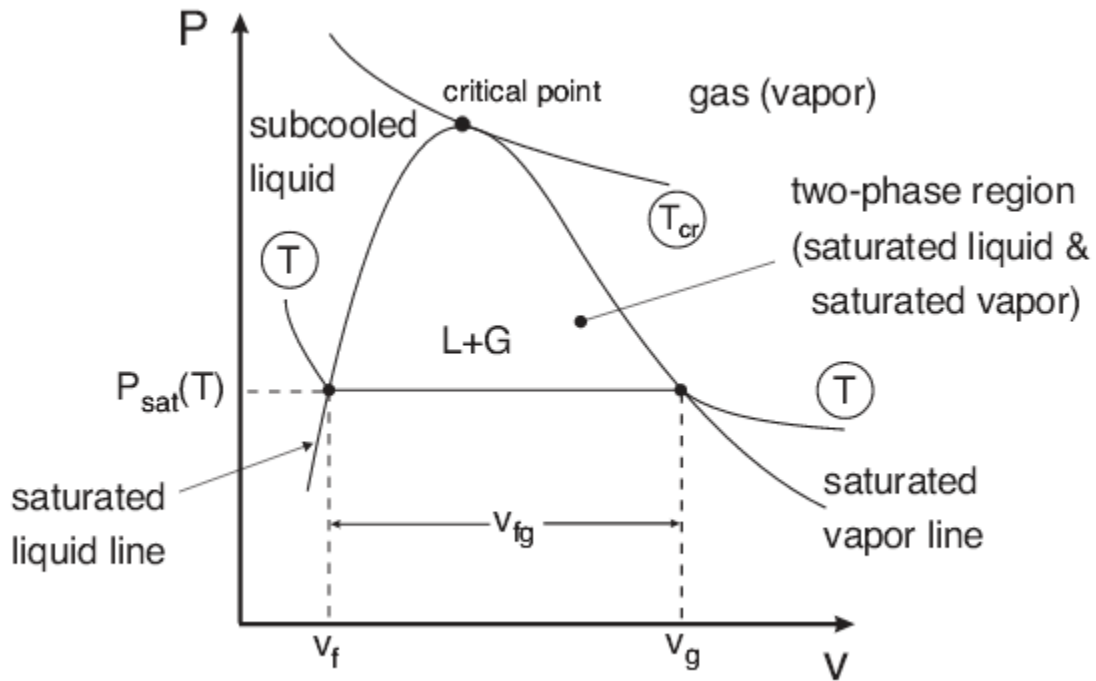
Behavior of Pure Substances (Phase Change Processes)

- **Critical Point:** liquid and vapor phases are not distinguishable
- **Triple point:** liquid, solid, and vapor phases can exist together



The Vapor Dome

general shape of a P-v diagram for a pure substance.



Specific volume: v_f, v_g And $v_{fg} = v_g - v_f$

Internal Energy: u_f, u_g And $u_{fg} = u_g - u_f$

Specific Enthalpy: h_f, h_g And $h_{fg} = h_g - h_f$

Specific Entropy: S_f, S_g And $S_{fg} = S_g - S_f$

in the two phase region, pressure and temperature cannot be specified independently

$$P_{\text{Sat}} = P(T_{\text{sat}}) \Leftrightarrow T_{\text{Sat}} = T(P_{\text{sat}})$$

this only holds true under the vapor dome in the two-phase region.

Ideal Gases

- gases that adhere to a pressure, temperature, volume relationship

$$Pv = RT \quad \text{or} \quad PV = mRT$$

referred to as ideal gases

-where R is the gas constant for the specified gas of interest ($R = R_u/M$)

$R_u =$ Universal gas constant, $\equiv 8.314 \text{ kJ}/(\text{kmol} \cdot \text{K})$

$M =$ molecular weight (or molar mass) of the gas

Real Gases

- experience shows that real gases obey the following equation closely:

$$Pv = ZRT \quad (\text{T and P are in absolute terms})$$

– this equation is used to find the third quantity when two others are known

– Z is the compressibility factor

– Note: $R_{\text{air}} = 0.287 \text{ kJ}/\text{kg} \cdot \text{K}$, $R_{\text{H}_2} = 4.124 \text{ kJ}/\text{kg} \cdot \text{K}$

Specific Heats:

Ideal Gases

- for any gas whose equation of state is exactly

$$Pv = RT$$

the specific internal energy depends only on temperature

$$u = u(T)$$

- the specific enthalpy is given by

$$h = u + Pv$$

where

$$h(T) = u(T) + RT$$

Note: Since $u = u(T)$, and R is a constant, enthalpy is only a function of temperature.

- for an ideal gas

$$C_v = du/dT \Rightarrow C_v = C_v(T) \text{ only}$$

$$C_p = dh/dT \Rightarrow C_p = C_p(T) \text{ only}$$

From the equation for enthalpy,

$$RT = h(T) - u(T)$$

If we differentiate with respect to T

$$R = dh/dT - du/dT$$

Control Mass (Closed System)

A thermodynamic analysis of a system can be performed on a fixed amount of matter known as a control mass or over a region of space, known as a control volume.

Conservation of Mass

Conservation of Mass, which states that mass cannot be created or destroyed, is implicitly satisfied by the definition of a control mass.

Conservation of Energy

The first law of thermodynamics states:

Energy cannot be created or destroyed it can only change forms.

- energy transformation is accomplished through energy transfer as work and/or heat. Work and heat are the forms that energy can take in order to be transferred across the system boundary.
- the first law leads to the principle of Conservation of Energy where we can stipulate the energy content of an isolated system is constant.

energy entering – energy leaving = change of energy within the system

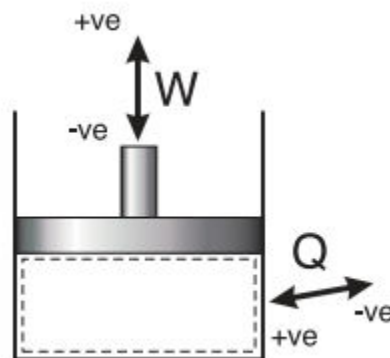
Sign Convention

There are many potential sign conventions that can be used.

Cengel Approach

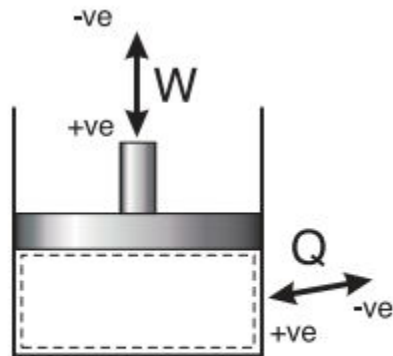
Heat Transfer: heat transfer to a system is positive and heat transfer from a system is negative.

Work Transfer: work done by a system is positive and work done on a system is negative.



Culham Approach

Anything directed into the system is positive, anything directed out of the system is negative



Forms of Energy Transfer

Work Versus Heat

- Work is macroscopically organized energy transfer.
- Heat is microscopically disorganized energy transfer.

Heat Energy

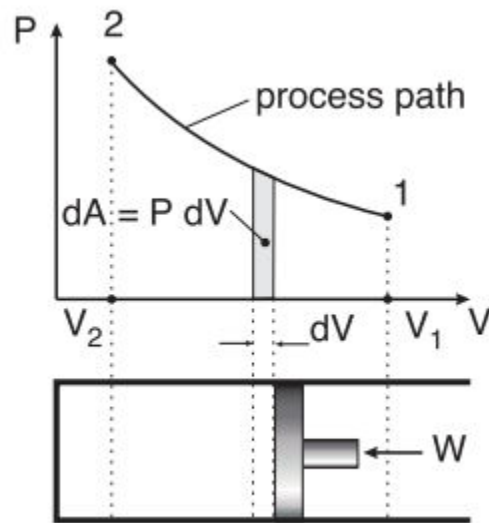
- Notation:
 - Q (kJ) amount of heat transfer
 - \dot{Q} (kW) rate of heat transfer (power)
 - q (kJ/kg) - heat transfer per unit mass
 - \dot{q} (kW/kg) - power per unit mass
- modes of heat transfer:
 - conduction: diffusion of heat in a stationary medium
 - convection: it is common to include convective heat transfer in traditional heat transfer analysis. However, it is considered mass transfer in thermodynamics.
 - radiation: heat transfer by photons or electromagnetic waves

Work Energy

- Notation:
 - W (kJ) amount of work transfer
 - \dot{W} (kW) power
 - w (kJ/kg) - work per unit mass
 - \dot{w} (kW/kg) - power per unit mass
- work transfer mechanisms in general, are a force acting over a distance Mechanical Work
- force (which generally varies) times displacement

$$W_{12} = \int_1^2 F ds$$

Moving Boundary Work



- compression in a piston/cylinder, where A is the piston cross sectional area (frictionless)
- the area under the process curve on a $P - V$ diagram is proportional to $\int_1^2 P dv$
- the work is:
 - +ve for compression
 - -ve for expansion
- sometimes called $P dV$ work or compression /expansion work

$$W_{12} = -\int_1^2 F ds = -\int_1^2 P \cdot A ds = -\int_1^2 P dV$$

Polytropic Process: where $P V^n = C$

- examples of polytropic processes include:

Isobaric process: if $n = 0$ then $P = C$ and we have a constant pressure process

Isothermal process: if $n = 1$ then from the ideal gas equation $P V = RT$ and $P V$ is only a function of temperature

Isometric process: if $n \rightarrow \infty$ then $P^{1/n} V = C^{1/n}$ and we have a constant volume process

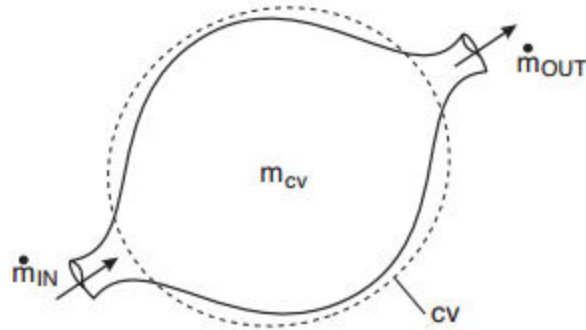
Iisentropic process: if $n = k = C_p/C_v$ then we have an isentropic process

Control Volume (Open System)

The major difference between a Control Mass and and Control Volume is that mass crosses the system boundary of a control volume.

CONSERVATION OF MASS:

Unlike a control mass approach, the control volume approach does not implicitly satisfy conservation of mass, therefore we must make sure that mass is neither created nor destroyed in our process.

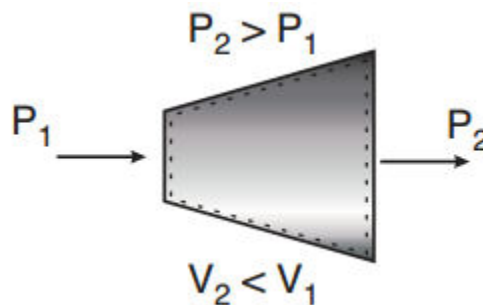


$$\left\{ \begin{array}{l} \text{rate of increase} \\ \text{of mass within} \\ \text{the CV} \end{array} \right\} = \left\{ \begin{array}{l} \text{net rate of} \\ \text{mass flow} \\ \text{IN} \end{array} \right\} - \left\{ \begin{array}{l} \text{net rate of} \\ \text{mass flow} \\ \text{OUT} \end{array} \right\}$$

$$\frac{d}{dt}(m_{CV}) = \dot{m}_{IN} - \dot{m}_{OUT}$$

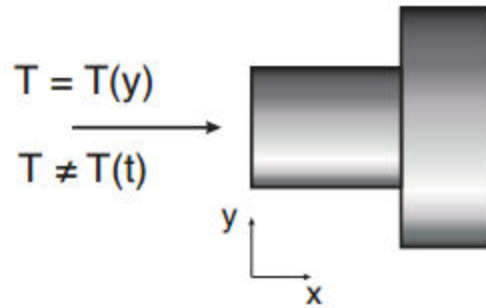
Some Practical Assumptions for Control Volumes

Steady State Process: The properties of the material inside the control volume do not change with time. For example



Diffuser: P changes inside the control volume, but the pressure at each point does not change with time.

Steady Flow Process: The properties of the material crossing the control surface do not change with time. For example



Inlet Pipe: T at the inlet may be different at different locations, but temperature at each boundary point does not change with time.

The steadiness refers to variation with respect to time

- if the process is not steady, it is unsteady or transient
- often steady flow implies both steady flow and steady state