

# **Engineering Thermodynamics**

**Basics of Thermodynamics  
Chapter-1**

# Definition

- Thermodynamics: 'Thermo' means 'Heat energy' and 'Dynamics' means 'conversion' or 'transformation'. Concisely, thermodynamics deals with conversion of energy from one form to another.
- The main forms of energy of interest in thermodynamics are:

**heat** and **work**

- Work is the form of energy useful in displacement of a body:

$$\text{Work} = \text{Force} \times \text{Distance (Joules)}$$

- Heat is the form of energy transferred due to temperature gradient between two bodies

$$\text{Heat} = \text{Mass} \times \text{Specific} \times \text{Temperature difference (Joules)}$$

# Applications of Engineering Thermodynamics

- Thermodynamic is used to design various systems using fluid properties to cause energy transformation. For example, design of heat engines, refrigeration machines, air conditioning systems.

## Fluid Properties:

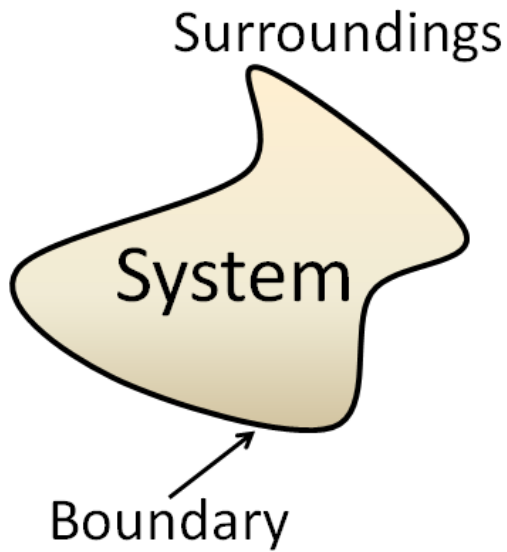
- Density
- Specific heat capacity
- Temperature
- Internal energy
- Entropy
- Enthalpy
- Pressure
- Specific volume
- Mass

# The Language of Thermodynamics

Translate the concepts which are developed in the lab into mathematical form?

## Definitions:

- Universe: Represents all measured space, not convenient!
- System: The part of the Universe that we choose to study
- Surroundings: The rest of the Universe
- Boundary: The surface dividing the System from the Surrounding, real or imaginary



# Thermodynamic Systems

## Systems can be:

- Open: Mass and Energy can transfer between the System and the Surroundings
- Closed: Energy can transfer between the System and the Surroundings, but NOT mass
- Isolated: Neither Mass nor Energy can transfer between the System and the Surroundings

# How to Describe a System?

The substance contained within a system can be characterized by its properties, such as P, T, V, n, M, ...

Properties can be divided into:

- **Extensive**: directly proportional to the amount of material in the system: Volume (V), Mass (M)
- **Intensive**: value independent of the amount of material: T
  - For a one-component system (pure substance) extensive properties can be made intensive by dividing by the number of moles:
    - $v = V/n$ ;  $v = \text{molar volume}$
    - $u = U/n$ ;  $s = S/n$ ;  $h = H/n$ ;  $g = G/n$

# Thermodynamic State of a System

Condition in which we find the system at any given time.

- In this figure, the system does not undergo any change.
  - All properties can be measured throughout the system.
  - The condition of the system is completely described i.e. state 1.
- Now remove some weights.
  - If the value of even one property changes, then:
  - the state will change to a different one (state 2).

Thus, two systems comprised of the same substance whose intensive properties have identical values are in the same state

# Process

Any change from one state to another, where at least some of the properties change, is called a process. In most of the processes, one thermodynamic property is held constant. Some of these processes are:

Process	Property held constant
isobaric	Pressure
isothermal	temperature
isochoric	volume
isentropic	entropy (see Chapter 3)

## Isobaric Process ( $P=\text{Constant}$ )

- We can understand the concept of a constant pressure process by considering the figure below. The force exerted by the water on the face of the piston has to equal the force due to the combined weight of the piston and the bricks. If the combined weight of the piston and bricks is constant, then  $F$  is constant and the pressure is constant even when the water is heated.

# Equilibrium

- Refers to a condition in which the state neither changes with time nor has the tendency to spontaneously change i.e. no driving force for change. Any system subject to **net fluxes** cannot be in equilibrium.

## To be at equilibrium:

The system has to be at **thermal** ( $T_{sys}=T_{surr}$ ), **mechanical** ( $P_{sys}=P_{surr}$ ), **phase** (the mass of two phases, e.g., ice and liquid water) and **chemical reaction** (no tendency to react) equilibrium.

### Phase Equilibrium: A Dynamic Process

At  $P^{sat}$  the vaporization rate becomes equal to the condensation rate.  $P^{sat}$  is an exponential function of temperature.

## State Postulate

As noted earlier, the state of a system is described by its intensive properties. But by experience not all properties must be known before the state is specified. Once a sufficient number of properties are known, the state is specified and all other properties are known. The number of properties required to fix the state of a system containing a pure substance is given by the State Postulate:

*If we have a **system** of pure substance, its thermodynamic state and, therefore all its **intensive** thermodynamic properties can be determined from **two** independent intensive properties.*

- We call the two intensive properties we select to constrain the state the independent variables. All other properties are then dependent variables. For example Molar Volume ( $m^3/mol$ ):

$$v = v(T, P)$$

# Phase Rule

- **Gibbs Phase Rule**

The degree of freedom which is the number of independent, intensive properties needed to constrain the properties in a given phase can be found by the **Gibb's phase rule**:

$$f = m - \pi + 2$$

Where:

$m$ =number of components

$\pi$ =number of phases

$f$ =number of intensive parameters to completely determine the system

**Read page 16 of the text book for more info.**

# Phase Diagrams- $PvT$ Surface for Pure Substances

Graphical depictions of the relation between  $P$ ,  $v$ , and  $T$ .

[Virtual pvT diagram](#)

<http://www.wisc-online.com/objects/ViewObject.aspx?ID=GCH6304>

# P-v Surface

- Critical Properties:

Appendix A

$$\left(\frac{\partial P}{\partial v}\right)_{T_c} = 0$$

$$\left(\frac{\partial^2 P}{\partial v^2}\right)_{T_c} = 0$$

Liquid Phase: Volume change is small as pressure decreases

Pressure ( $P^{sat}$ ) remains constant as  $P$  and  $T$  are no longer independent

# Thermodynamic Property Tables

- If two independent intensive properties of a pure substance is specified the state of the system is constrained. In this case any other properties can be identified.
- The thermodynamic properties of common substances have been tabulated. For examples in Appendix B the properties of water is tabulated (steam Tables) at different temperatures and pressures.

**TABLE B.1 Saturated Water: Temperature Table**

$T$ °C	$P$ kPa, MPa	$\hat{v}_l$ m <sup>3</sup> /kg	$\hat{v}_v$ m <sup>3</sup> /kg	$\hat{u}_l$ kJ/kg	$\Delta\hat{u}_{lv}$ kJ/kg	$\hat{u}_v$ kJ/kg	$\hat{h}_l$ kJ/kg	$\Delta\hat{h}_{lv}$ kJ/kg	$\hat{h}_v$ kJ/kg	$\hat{s}_l$ kJ/kg K	$\Delta\hat{s}_{lv}$ kJ/kg K	$\hat{s}_v$ kJ/kg K
0.01	0.6113	0.001000	206.132	0.00	2375.3	2375.3	0.00	2501.3	2501.3	0.0000	9.1562	9.1562
5	0.8721	0.001000	147.118	20.97	2361.3	2382.2	20.98	2489.6	2510.5	0.0761	8.9496	9.0257
10	1.2276	0.001000	106.377	41.99	2347.2	2389.2	41.99	2477.7	2519.7	0.1510	8.7498	8.9007
15	1.7051	0.001001	77.925	62.98	2333.1	2396.0	62.98	2465.9	2528.9	0.2245	8.5569	8.7813
20	2.3385	0.001002	57.790	83.94	2319.0	2402.9	83.94	2454.1	2538.1	0.2966	8.3706	8.6671
25	3.1691	0.001003	43.359	104.86	2304.9	2409.8	104.87	2442.3	2547.2	0.3673	8.1905	8.5579
30	4.2461	0.001004	32.893	125.77	2290.8	2416.6	125.77	2430.5	2556.2	0.4369	8.0164	8.4533
35	5.6280	0.001006	25.216	146.65	2276.7	2423.4	146.66	2418.6	2565.3	0.5052	7.8478	8.3530
40	7.3837	0.001008	19.523	167.53	2262.6	2430.1	167.54	2406.7	2574.3	0.5724	7.6845	8.2569
45	9.5934	0.001010	15.258	188.41	2248.4	2436.8	188.42	2394.8	2583.2	0.6386	7.5261	8.1647

# Thermodynamic Property Tables

## Interpolation:

TABLE B.1 Saturated Water: Temperature Table

$T$ °C	$P$ kPa, MPa	$\hat{v}_l$ m <sup>3</sup> /kg	$\hat{v}_c$ m <sup>3</sup> /kg	$\hat{u}_l$ kJ/kg	$\Delta\hat{u}_{lc}$ kJ/kg	$\hat{u}_c$ kJ/kg	$\hat{h}_l$ kJ/kg	$\Delta\hat{h}_{lc}$ kJ/kg	$\hat{h}_c$ kJ/kg	$\hat{s}_l$ kJ/kg K	$\Delta\hat{s}_{lc}$ kJ/kg K	$\hat{s}_c$ kJ/kg K
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$$y = y_{low} + (y_{high} - y_{low}) \left( \frac{x - x_{low}}{x_{high} - x_{low}} \right)$$

## Read Example 1.2

# The Ideal Gas

**Equation of State:** an equation that relates the measured properties  $T$ ,  $P$ , and  $v$ . The simplest is the ideal gas law:

$$PV=nRT \text{ or } Pv=RT$$

*Assumptions:*

1. Gas molecules are infinitesimally small, hard, and round spheres
2. Molecules occupy negligible volume
3. Exert forces upon each other only through collisions

# Assignment:

Problems 1.6, 1.14, 1.19 from the text book.