Chapter 1 - Introduction and Preliminaries

Lecture 1
Sections 1.1-1.6, 3.13

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
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Convention

- The following scheme will be used within our notes:
  1. **Bold** words are definitions
  2. *Italic* words or letters represent variables
  3. <u>Underline</u> words or phrases represent a law, theorem and/or hypothesis
  4. Bracketed [ ] symbols are units
  5. Blue words or phrases (except in summaries) are hyperlinks - click them!
- Each section (number and title) is displayed on the right navigation pane, following our text, and is hyperlinked within the PDF
- Important equations will be $\boxed{\text{boxed}}$

Outline

- Each lecture will have the following format:
  - A title slide listing the sections covered from the text
  - A “Student Learning Objectives” slide listing the key concepts covered in the lecture
  - Conceptual material with corresponding examples following the learning objectives
  - A summary of the the “Student Learning Objectives” at the end of each lecture
  - A list of suggested problems from the text covering the material presented in the lecture

Student Learning Objectives

At the end of the lecture, students should be able to:

- Understand what comprises a system
- Construct a control volume through prescribing a control surface; open or closed, a control mass or an isolated system
- Differentiate between a macroscopic and microscopic view point
- Understand and identify phases, states and properties
- Differentiate between intensive and extensive properties
- Identify three common processes and how they relate to cycles
- Calculate density and specific volume
- Understand the concept of the Conservation of Mass

Overview

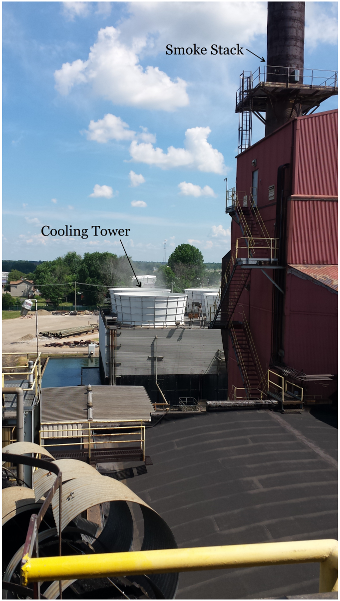
- Thermodynamics is the science of energy and entropy, both storage and conversion
- As engineers, we are interested in converting thermal energy (i.e. heat) into mechanical energy (i.e. kinetic energy) and minimizing the penalty for such conversion (entropy production), such as in developing internal combustion engines
- Thermodynamics dictates every possible action within our universe - these actions are governed by the Zeroth, First, Second and Third laws
- In this course, we are going to focus on phase transformations and **processes** - the act of going from an initial state to a final state of thermodynamic equilibrium - and how they relate to devices

Control Surface and Volume

- When analyzing a **system**, which can be a single device or a combination of many devices that contain a quantity of matter, taken in a macroscopic view point - we need to define a region of interest
- We isolate the region of interest using a **control surface** (C.S.) - a boundary that separates a system and its surroundings
- All devices that contain matter within the control surface are known as a **control volume** (C.$\forall$.)

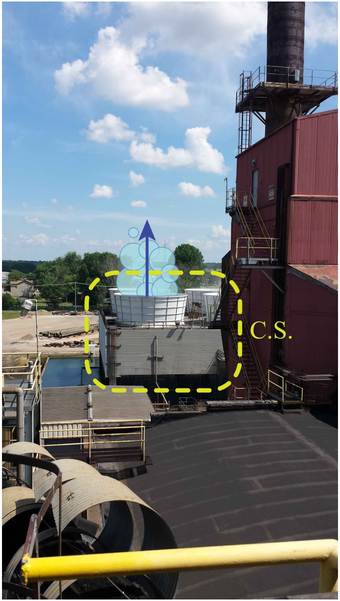
C.S. and C.∀.

- Consider this coal-fired power plant in Orville Ohio.
- If we were interested in analyzing the cooling tower, how would we draw a C.S. to encompass the proper C.∀.?



Open and Closed C.S.

- Is this C.S. stationary or moving?
- A **closed system** does not allow mass to cross the C.S.
- An **open system** allows mass to cross the C.S.
- Is our system open or closed?



Control Mass and Isolated System

- There are particular C.∀. for which no mass transfer takes place across the C.S. - this is referred to as a **control mass** (C.M.) - it contains the same amount of matter at all times
- Therefore, a C.M. is a closed system by default
- If there exists a C.M. where no work or heat crosses the C.S., the system is referred to as an **isolated system**
- Therefore, a C.S. defines a C.∀., in which there may or may not be mass flow into or out of the system - if there is no mass flow, then the C.∀. is a C.M. - furthermore, if no work or heat crosses the C.S. of the C.M., the system is isolated

Macroscopic vs. Microscopic Viewpoints

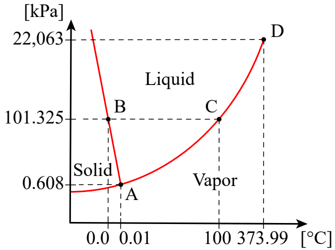
- We do not want to analyze our system **microscopically** - as is done in statistical thermodynamics - where the contribution of each individual molecule to our system properties is considered, and is mathematically cumbersome and computationally prohibitive
- We evaluate our system **macroscopically** - the consideration of the total, time-averaged effects of all the molecules within our system
- For the macroscopic view point to be valid, we must obey the **continuum assumption** - the volume of interest is much larger than the molecular dimensions of our system, and the volume is treated as homogeneous and continuous

Working Fluids

- Water is an amazing working fluid - it is abundant, cheap, has the capacity to store large amounts of energy, and changes phase at relatively low temperatures
- A **phase** is a quantity of matter that is uniform throughout (i.e. water as a solid, liquid or vapor)
- Steam, which is the vapor phase of water, is used to power steam turbines, the backbone of land-based power generation

Phases

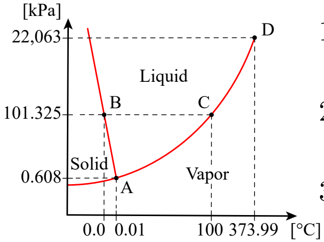
- A phase diagram is used to describe the phase of a substance, based upon two independent properties
- The solid, liquid and vapor phases are defined as the regions constrained by the phase boundaries (red lines)



- Multiple phases can exist simultaneously (solid-liquid, solid-vapor, liquid-vapor and solid-liquid-vapor)
- We will discuss more about phases and phase diagrams in Lecture 3

Example #1

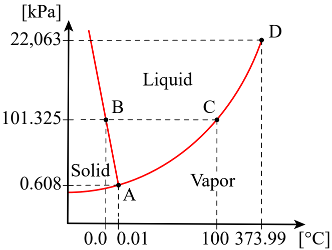
- Given the phase diagram of water below, determine which phase the water is existing in based upon prescribed T and P values:



1. P=500 [kPa], T=50 °C
2. P=0.01 [kPa], T=200 °C
3. P=25 [kPa], T=-20 °C

State and Properties

- For a given phase, a substance exits at a unique T and P, i.e. a unique **state**
- A **state** is described by observable, macroscopic **properties**



- A **property** of a substance is a thing such as mass, temperature (T), pressure (P), volume ($\forall$) and density (ρ), used to define a state
- Typically we need two, independent properties to define a state - three if on a phase boundary
- States will be denoted by integers, i.e. 1, 2, 3, etc. for closed systems, and circled numbers, i.e. 1, 2, 3, etc., for open systems

Thermodynamic Properties

- Observable, macroscopic properties falls under two classifications:
- **Intensive** properties are independent of the mass of the system (e.g. temperature, pressure, density)
- **Extensive** properties are dependent on the mass of the system (e.g. mass, volume, energy)

Example #2

- Given the following list of properties, determine if they are intensive or extensive

(a) Temperature
(b) Thermal conductivity
(c) Density
(d) Thermal diffusivity
(e) Total energy
(f) Kinematic viscosity
(g) Volume
(h) Specific Heat Capacity
(i) Magnetic permeability
(j) Coefficient of thermal expansion

Thermodynamic Equilibrium

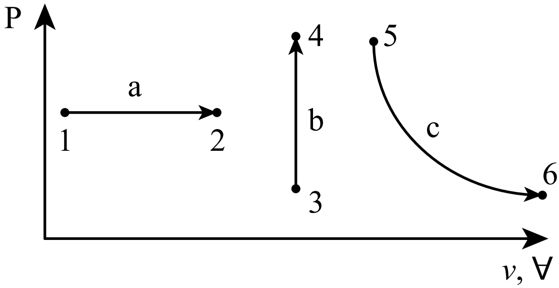
- When we refer to properties of a substance and of the system, we imply the value of the property has significance for the entire system, and this implies equilibrium
- If we are in **thermal equilibrium**, the temperature is the same throughout the entire system, and we may speak of temperature as a property
- If we are in **mechanical equilibrium**, the pressure is uniform throughout the system and we may speak of pressure as a property
- The system is in **thermodynamic equilibrium** when it is in equilibrium regarding all possible changes of state (thermal, mechanical, chemical)

Processes and Cycles

- Whenever at least one property of a system changed, a change in state has occurred
- The path of succession of states through which the system passes is a **process**, denoted by letters a, b, c, etc.
- To provide properties at each state, the system has to be in equilibrium, but for continually changing states, we assume the transition from one to another is done in a **quasi-equilibrium process**
- When a system in a given initial state goes through a number of different changes of state or processes and returns to its initial state, the system has undergone a **cycle**

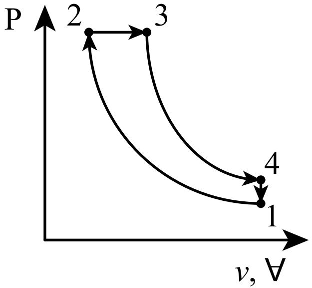
Processes

- There are three common processes:
  (a) **Isobaric process** (P=c) - pressure is invariant during change of state
  (b) **Isochoric process** ($\forall$=c) - volume is invariant during change of state
  (c) **Isothermal process** (T=c) - temperature is invariant during change of state



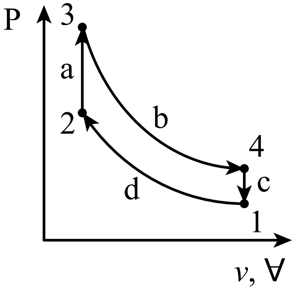
Cycles

- A cycle is a series of processes, that progresses from an initial state through various intermediate states, back to the initial state
- Let us consider an idealized diesel cycle below



Example #3

- Given the following $P-\nu$ diagram of an idealized Otto cycle, identify each of the processes:



(a) Process a:

(b) Process b:

(c) Process c:

(d) Process d:

Specific Volume and Density

- **Specific volume** (ν) is the volume per unit mass of a substance [m^3/kg]

$$\boxed{\nu = \frac{\forall}{m}}$$

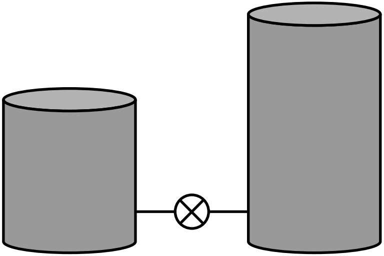
- Under our continuum assumption, it is the mass per smallest unit volume such that our mass is uniformly distributed throughout
- **Density** (ρ) is mass per unit volume [kg/m^3], or the reciprocal of ν

$$\boxed{\rho = \frac{m}{\forall} = \frac{1}{\nu}}$$

- These intensive properties allow us to construct $T - \nu$ and $P - \nu$ diagrams

Example #4

- Tank 1 has 1 [kg] of air and a volume of 0.5 [m^3]. Tank 2 has a volume of 0.75 [m^3] and a density of 0.85 [kg/m^3]. When the valve is opened, determine
  1. The final density
  2. The final specific volume



Example #4

- Solution:

Conservation of Mass - Closed System

- The **Conservation of Mass**, also known as the continuity equation, states that the mass of a system must remain constant over time, i.e. cannot be created or destroyed

- If a C.M. (i.e. closed system), the mass within our system cannot change regardless to changes of volume

$$\boxed{\frac{d\,m}{dt} = \frac{d}{dt}\int \rho\, d\forall = 0}$$

Conservation of Mass - Open System

- If an open system, the mass entering must equal the mass exiting, or the time-rate-of-change of mass within the system must equal the difference between mass flow in and mass out

$$\boxed{\frac{dm}{dt} = \dot{m}_{\text{in}} - \dot{m}_{\text{out}}}$$

- $\dot{m}$ represents a **mass flow rate**, [kg/s]
- A positive value of the time-rate-of-change of mass indicates the system is accumulating mass
- A negative value of the time-rate-of-change of mass indicates the system is dissipating mass

Student Learning Objectives

At the end of the lecture, students should be able to:

- Understand what comprises a system
  - A system is a region, device, or combination of devices of interest.
- Construct a control volume through prescribing a control surface; open or closed, a control mass or an isolated system
  - A control surface (C.S.) defines a control volume (C.∀.). A system where mass does not enter or exit the C.∀. is a closed system, and by default, a control mass (C.M.). If no quantity of work or heat crosses the C.S. of a C.M., it is an isolated system. A system where mass does enter or exit the C.∀. is an open system.

Student Learning Objectives

- Differentiate between a macroscopic and microscopic view point
  - A microscopic view considers the interaction of every discrete molecule or particle within the system. A macroscopic view considers the volume- and time-averaged contributions of all molecules or particles within a system when determining a property.
  - We will not follow the path of Boltzmann and Ehrenfest in the study of statistical thermodynamic.

Student Learning Objectives

- Understand and identify phases, states and properties
  - Phases characterize whether our substance is a solid, liquid, or vapor. States are unique regions of a phase described by two, independent properties (three if on phase boundary). A property is a measurable quantity (intensive or extensive) used to define a state.
- Differentiate between intensive and extensive properties
  - Intensive properties are independent of the mass of the system, whereas extensive properties are dependent on the mass of the system.

Student Learning Objectives

- Identify three common processes and how they relate to cycles
  - Three common processes are isobaric (P=c), isochoric ($\forall$=c), and isothermal (T=c). Processes, when connect in succession, can create cycles.
- Calculate density and specific volume
  - Density is the mass per unit volume. Specific volume is the reciprocal of density.

Student Learning Objectives

- Understand the concept of the Conservation of Mass
  - Mass can neither be created nor destroyed. For a closed system, the mass remains invariant with respect to time and any changes to the system properties. For an open system, the time-rate-of-change of mass must equal the difference between the mass flow into and out of the system.

Suggested Problems

- 1.1, 1.2, 1.3, 1.22, 1.25, 1.37, 1.38, 1.40