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B-KUL-Z55337
Applied Thermodynamics

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Adapted from: Y.A. Cengel, M. A. Boles, Thermodynamics – An Engineering Approach (5th Edition)

Introduction

- Thermodynamics can be defined as the science of *energy.*
- More precisely: *Therme* (**heat**) and *Dynamis* (**motion**)

=> **Study of the conversion between heat and work**

- A fundamental law: Conservation of energy (first law of thermodynamics)
- Second law of thermodynamics: energy is characterized by « quality ». Transformation go in the direction of a degradation of energy quality

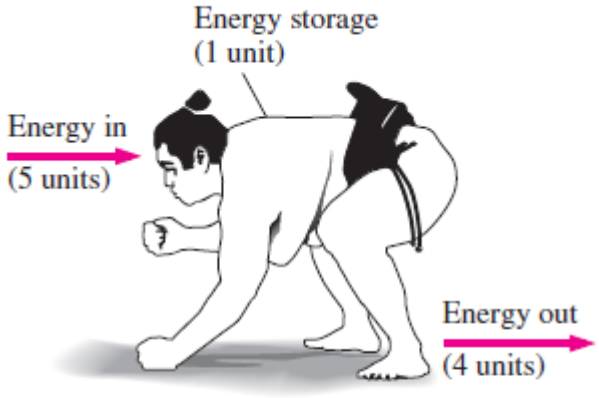

FIGURE 1–2

Conservation of energy principle for the human body.

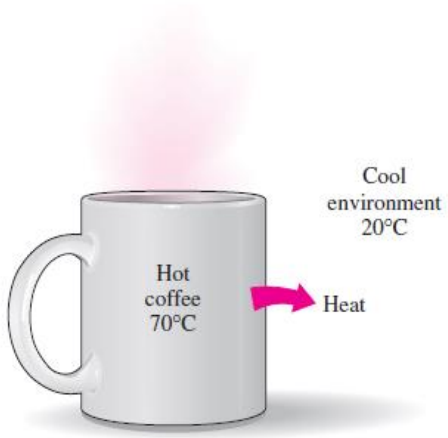

FIGURE 1–3

Heat flows in the direction of decreasing temperature.

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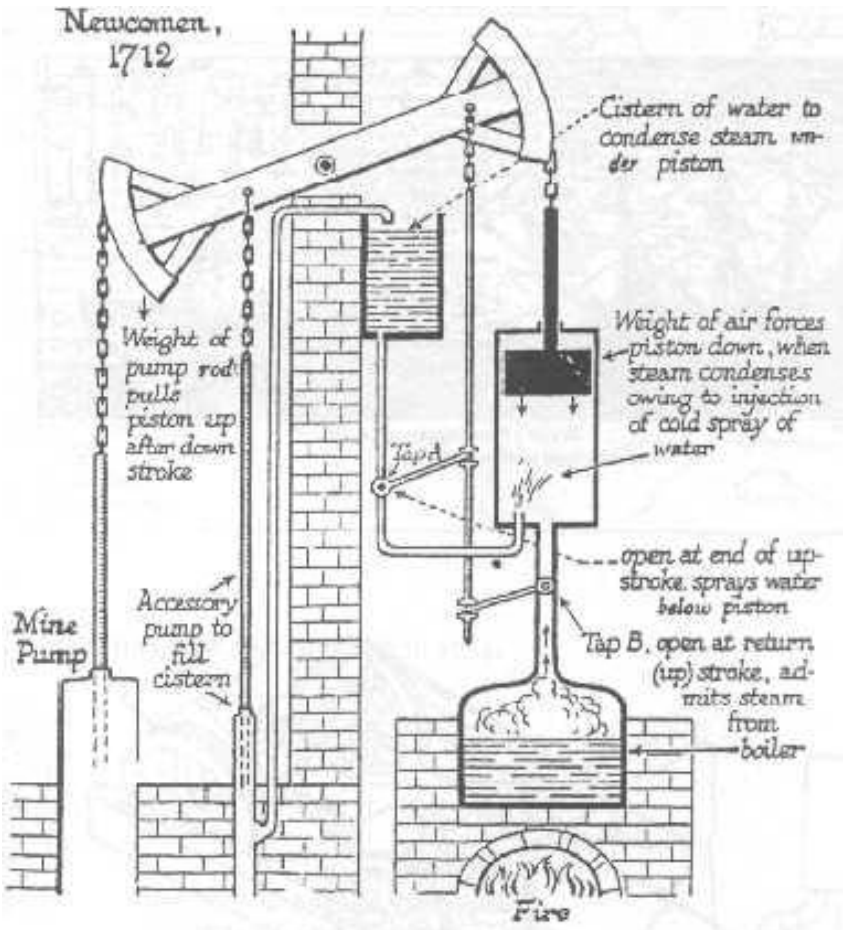
Introduction

- The science of thermodynamics appeared with the first steam engines (Savery, 1697 and Newcomen, 1712)
- The first and the second laws appear around 1850 (William Rankine, Rudolph Clausius, and Lord Kelvin (William Thomson)),
- 1er syllabus of Thermodynamique by Rankine in 1859
- Engineering thermodynamics (macroscopic) and not statistical thermodynamics



DIAGRAMMATIC VIEW OF NEWCOMEN'S ATMOSPHERIC OR FIRE ENGINE (1712)

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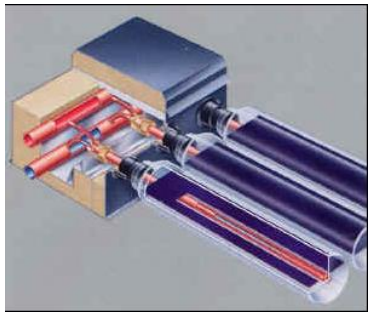
Applications of thermodynamics

- Thermal confort
- HVAC systems
- Cogeneration
- Power plants
- Engines

Source: INNOVA



Chapter 1

Basic concepts

Thermodynamics has a unique vocabulary associated with it. Precise definition of basic concepts forms a sound foundation for the development of a science and prevents possible misunderstandings.

Units

- English system vs. Metric system, or International System (« SI », système international)
- In this class, we use the SI system!

TABLE 1–1

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

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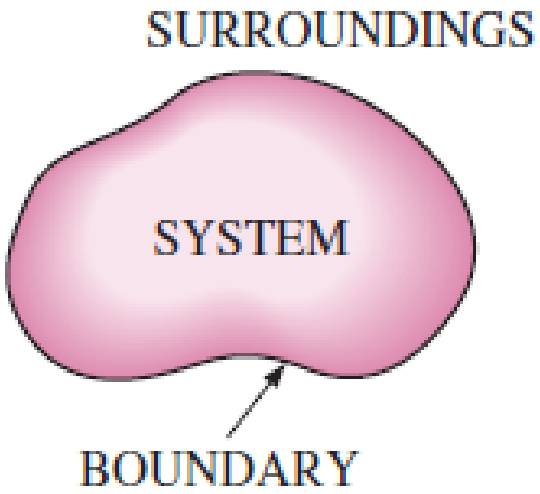
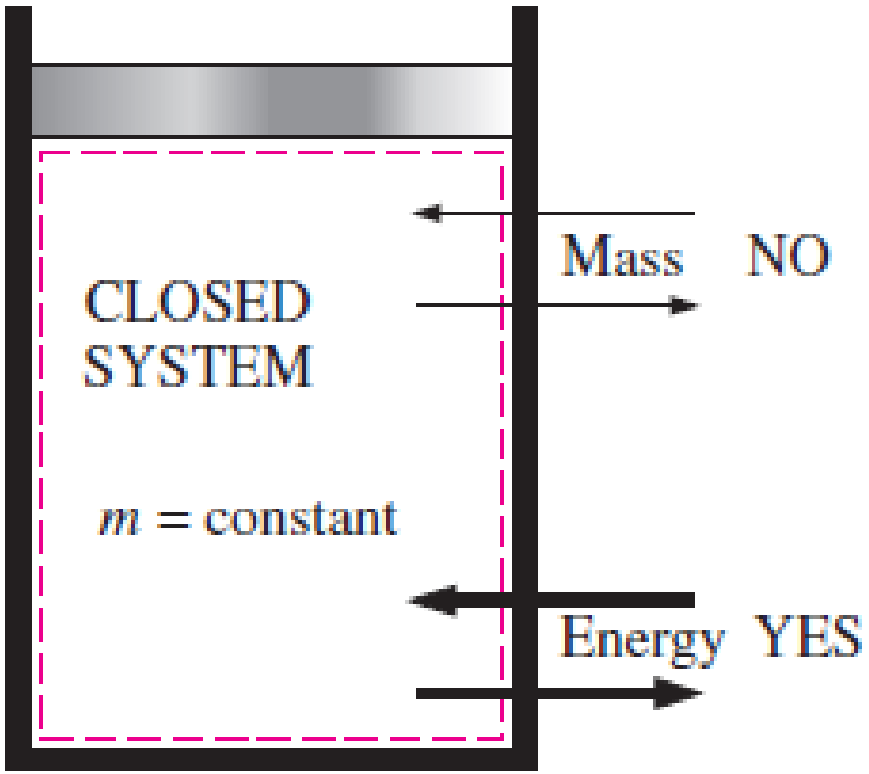
Systems and control volumes

- Thermodynamics focuses on the energy exchanges between a system and its surroundings
- System = *a quantity of matter or a region in space chosen for study*
- Surroundings = mass or region outside the system
- System + surroundings = universe
- Boundary = contact surface shared by both the system and the surroundings
  - Real or fictitious
  - Fixed or movable
  - Zero thickness



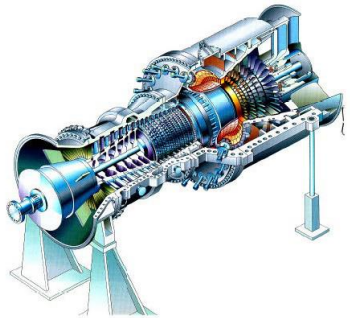
Systems and control volumes

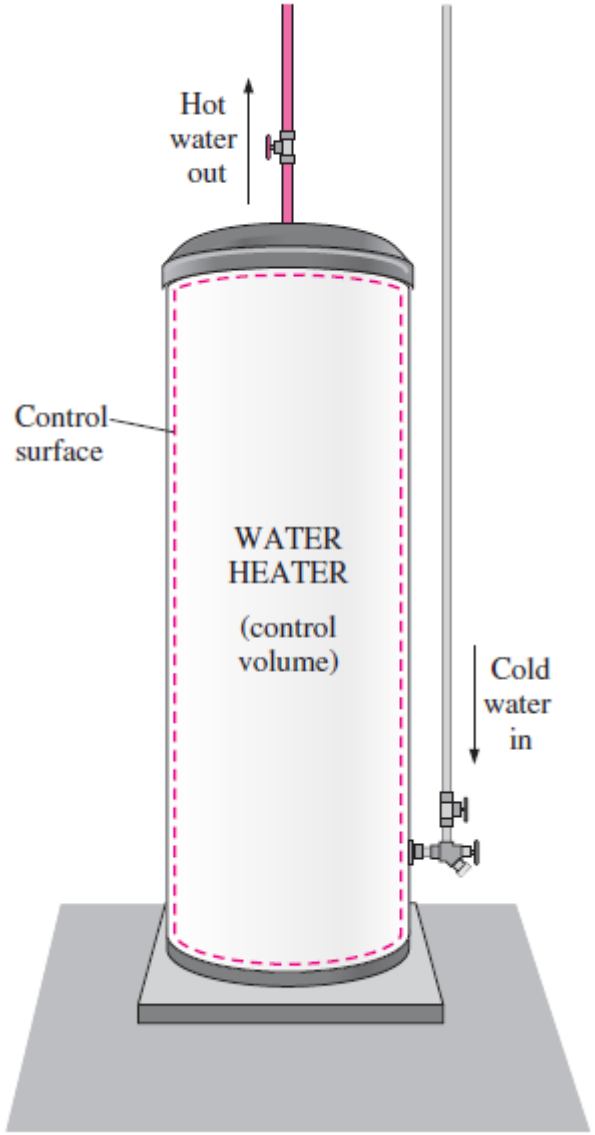
- **Closed system (or control mass)**
  - Fixed amount of mass
  - No mass can cross the boundary
  - Energy in the form of heat or work can cross the boundary
  - If no energy is exchanged**:** **isolated system**
  - Example: mass of gas enclose in piston-cylinder system:



Systems and control volumes

- Open system (or control volume):
  - Selected region of space
  - Both mass and energy can cross the boundary
  - The choice of the boundary is arbitrary





Frontière imaginaire

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Properties of a system

- Property = characteristics of a system
- Examples?
- intensives/extensives properties:
  - Intensives:
    - independent of the mass of the system (temperature, pressure, density)
    - Lower case (except T et sometimes P)
  - Extensives:
    - Depend on the size of the system (mass, volume), proportionality relationship
    - Capital letters (except m)
- Specific variable/property = intensive variable per unit of mass (for example: specific volume v=V/m)

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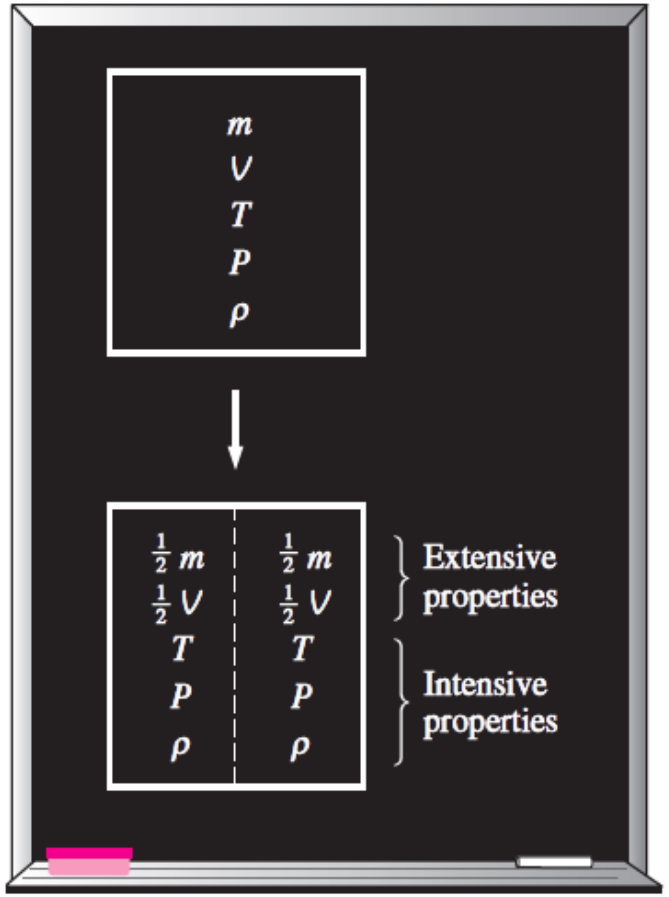
Properties of a system

Intensive or extensive property?



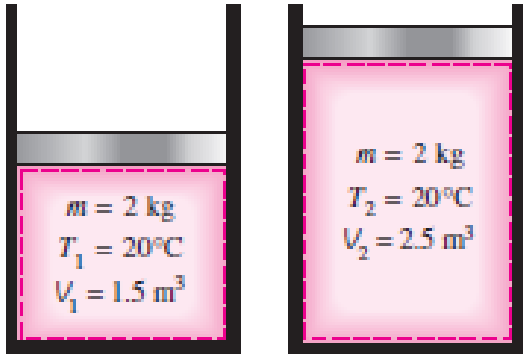
If we divide the system into two equal parts with an imaginary partition, each part will have the same value of intensive properties as the original system, but half the value of the extensive properties

State of a system

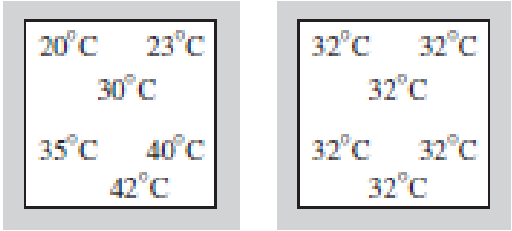
- In a system without any transformation, the system properties allow defining the state.

  => If a property varies, the state changes to a different one!
- Equilibrium state: no unbalanced potentials (or driving forces) within the system.
- Three conditions must be satisfied:
  - No energy exchange within the system.
  - No exchange between the system and its surrounding.
  - The system is stable in case of external pertubation (comes back to the initial state if the pertubation is removed).

- A system in equilibrium does not change when isolated from the surroundings.



(a) State 1 (b) State 2

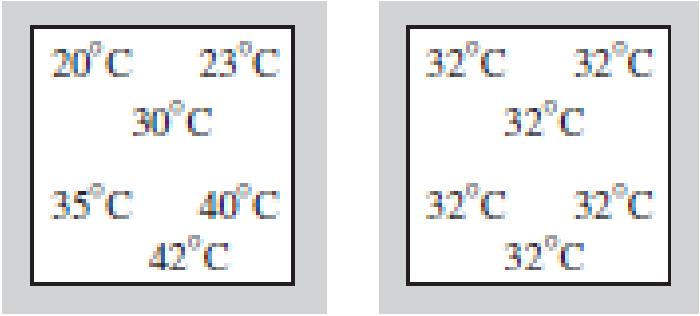


(a) Before (b) After

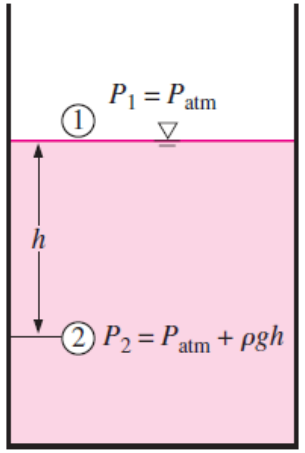
State of a system

Different types of equilibrium:

- Thermal equilibrium: uniform temperature within the system (=> no heat flow)
- Mechanical equilibrium: The pressure does not vary in time (! But it can vary in space, e.g. because of gravitational effects)
- Phase equilibrium: the mass of each phase does not vary in titme
- Chemical equilibrium: the chemical composition does not vary in time.



(a) Before (b) After



State postulate

- It is not necessary to specify all the properties to define the state of system
- State postulate:

  The state of a simple compressible system* is completely specified by two independent, intensive properties.

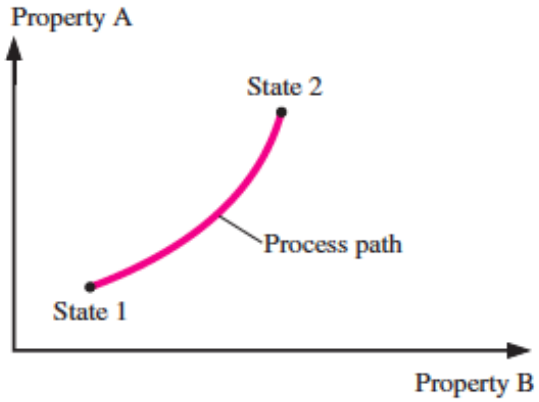
* simple compressible system: absence of electrical, magnetic, gravitational, motion, and surface tension effects

Two properties are independent if one property can be varied while the other one is held constant.

Counter example: T and p in a two-phase system

Processes and cycles

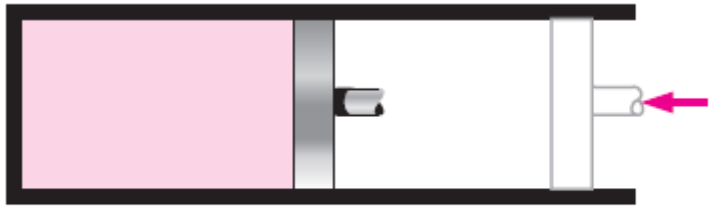
- **Process** = change that a system undergoes from one equilibrium state to another
- **Path of a process** = the series of states through which a system passes during a process
- To completely describe a process, the following must be specified:
  - The initial and the final states
  - The path
  - The interactions with the surroundings



Processes and cycles

Quasi-static process (or quasi-static equilibrium): the system remains infinitesimally close to an equilibrium state at all times. It is sufficiently slow to allow the system to adjust itself internally so that properties in one part of the system do not change faster than in other parts.

(*a*) Slow compression (quasi-equilibrium)



(*b*) Very fast compression (nonquasi-equilibrium)

Example of the piston-cylinder system:

- If the device is compressed suddenly, compressed suddenly, the molecules near the face of the piston will not have enough time to escape and they will have to pile up in a small region in front of the piston, thus creating a high-pressure region there.
- If the piston is moved slowly, the molecules will have sufficient time to redistribute and there will not be a molecule pileup in front of the piston. As a result, the pressure inside the cylinder will always be nearly uniform and will rise at the same rate at all locations.

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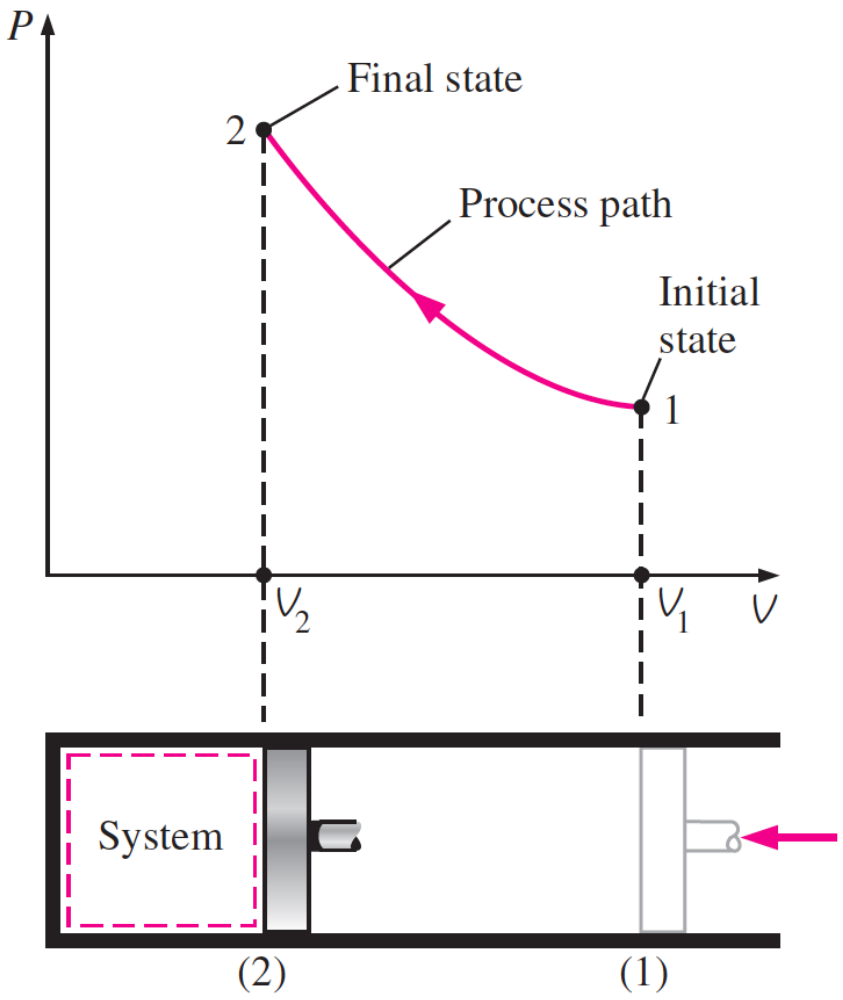
Processes: example of a compression



Processes and cycles

- Quasi-static process:
  - Close to reversible process.
- Reversible process:
  - Idealized process (not a true representation)
  - However, many processes closely approximate it
- Interesting for engineers:
  - Easy to analyse
  - Ideal, maximum performance case (for example: in the case of an expansion in a turbine, case in which the most work is delivered)
- Other types of processes:
  - Isothermal process
  - Isobaric process
  - Isochoric process
- **Cycle**: it returns to its initial state at the end of the process (initial state = final state)

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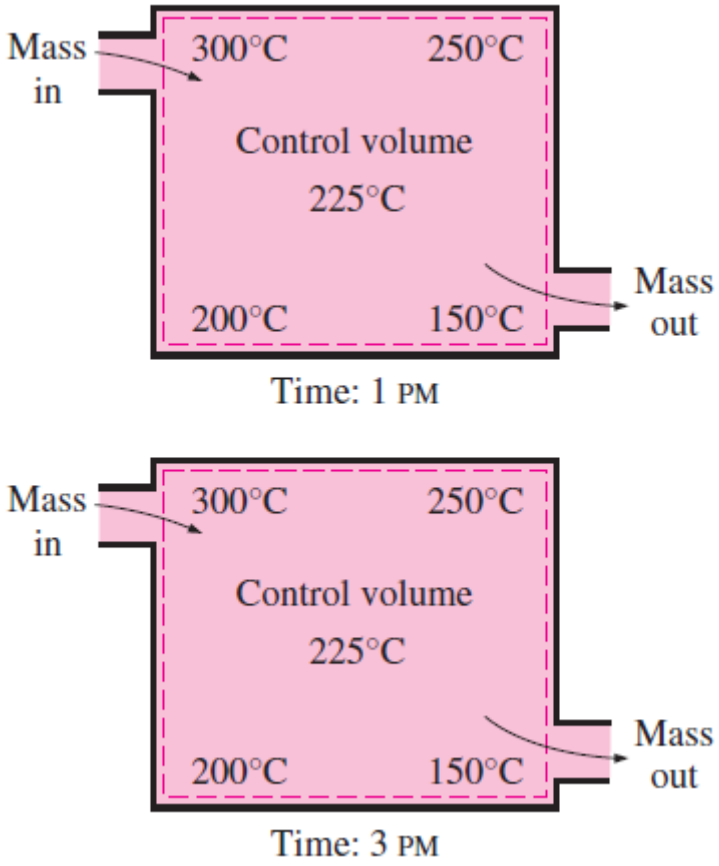
Processes and cycles

- **Steady-flow (or steady-state) process**: no change in time

- Conditions:
  - In a particular location of the control volume, the properties do not change in time
  - The total volume and energy of the control volume do not change in time
  - Examples: compressors, turbines after some time of operation



Temperature scales

- All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water, which are also called the ice point and the steam point, respectively.
  - **Celsius scale**: Ice point 0°C. Steam point:100°
  - **Fahrenheit scale**: Ice point 32°F. Steam point: 212°F

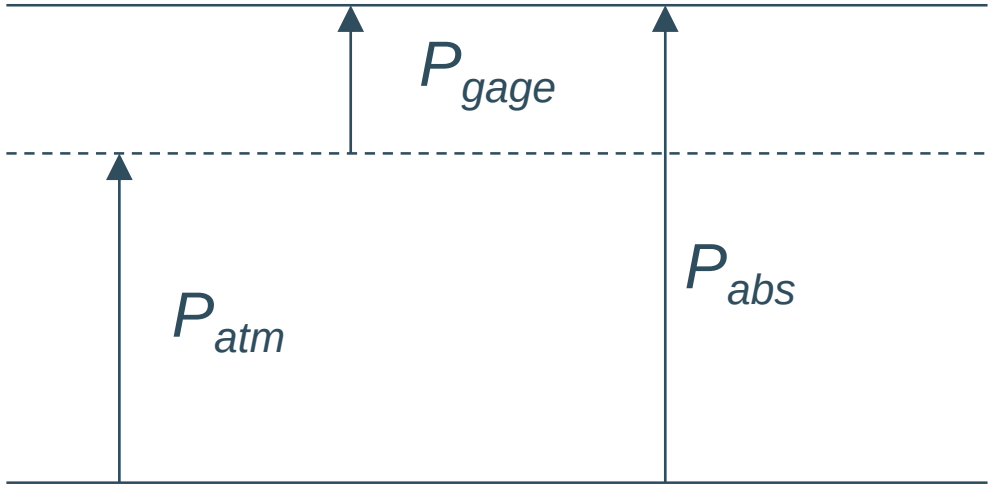
- Temperature scale independent of the properties of any substance? => **Thermodynamic temperature**
  - Kelvin scale: The lowest temperature is absolute zero, or 0 K
  - Rankine scale: idem

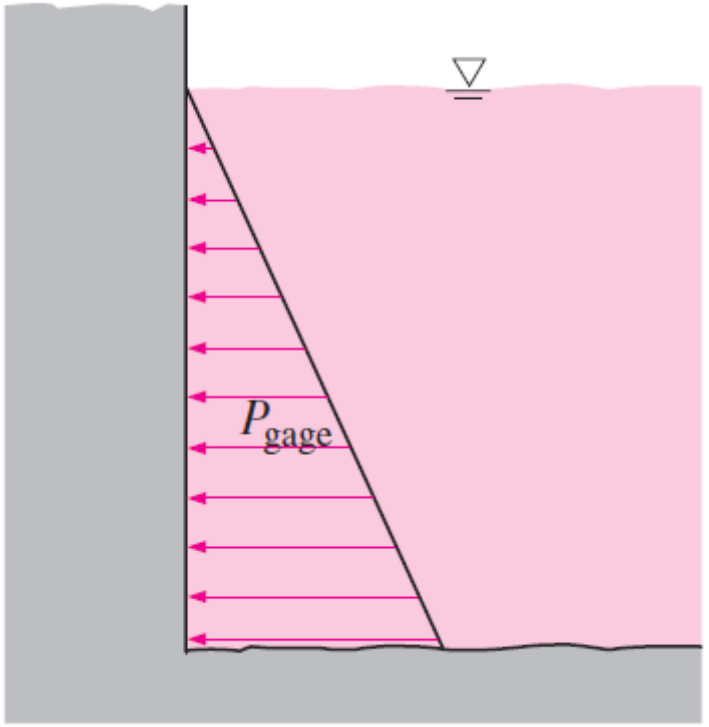
Pressure

- **Pression**: normal force by unit of surface
- 1 Pa = 1 N/m^2

  1 bar = 10^5 Pa = 0.1 MPa = 100 kPa

  1 atm = 101325 Pa
- Absolute pressure is measured by reference to vacuum
- Gage pressure is measured by reference to atmospheric pressure





$$\Delta P = P_2 - P_1 = \rho g \, \Delta z = \gamma_s \, \Delta z$$

Exercises in EES

1–82 Solve this system of three equations with three unknowns using EES:

$$2x - y + z = 5$$

$$3x^2 + 2y = z + 2$$

$$xy + 2z = 8$$

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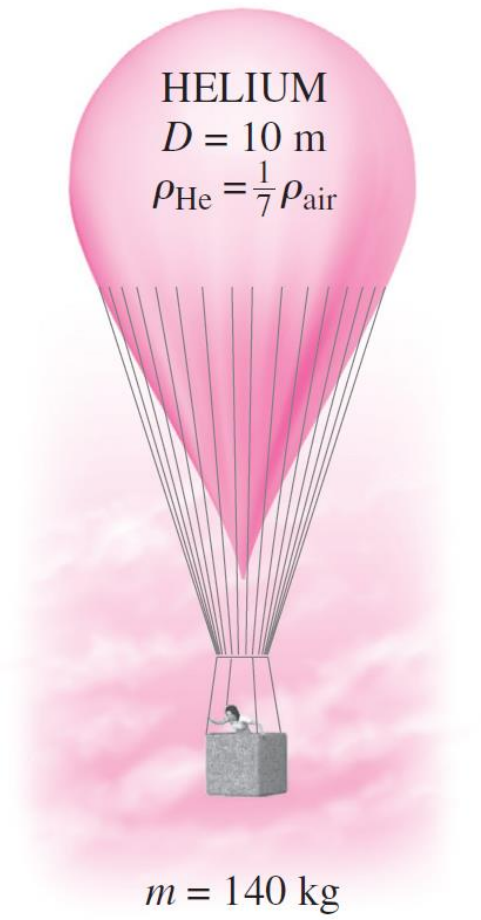
Exercises in EES

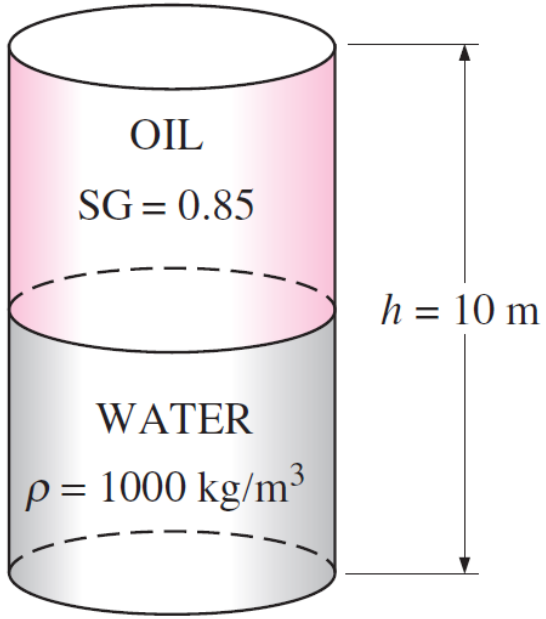
1–101 Balloons are often filled with helium gas because it weighs only about one-seventh of what air weighs under identical conditions. The buoyancy force, which can be expressed as $F_b = \rho_{air} g V_{balloon}$, will push the balloon upward. If the balloon has a diameter of 10 m and carries two people, 70 kg each, determine the acceleration of the balloon when it is first released. Assume the density of air is $\rho = 1.16$ kg/m^3, and neglect the weight of the ropes and the cage. *Answer:* 16.5 m/s^2



Exercises in EES

1–106 The lower half of a 10-m-high cylindrical container is filled with water (ρ = 1000 kg/m^3) and the upper half with oil that has a specific gravity of 0.85. Determine the pressure difference between the top and bottom of the cylinder.

Answer: 90.7 kPa



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