Thermodynamics

Introduction:

Thermodynamics did not emerge as a science until the construction of the first successful atmospheric steam engines in England by Thomas Savery in 1697 and Thomas Newcomen in 1712. These engines were very slow and inefficient, but they opened the way for the development of a new science. The first and second laws of thermodynamics emerged simultaneously in the 1850s. The term thermodynamics was first used in a publication by Lord Kelvin in 1849. The first thermodynamic textbook was written in 1859 by William Rankine, a professor at the University of Glasgow.

Thermodynamics:

Thermodynamics can be defined as the science of energy. The name thermodynamics stems from the Greek words **thermo** (**heat**) and **dynamic** (**power**).

Today the same name is broadly interpreted to include all aspects of energy and energy transformations, including power generation, refrigeration, and relationships among the properties of matter.

Conservation of energy principle: it simply states that during an interaction, energy can change from one form to another but the total amount of energy remains constant. That is, **energy cannot be created or destroyed.**

The first law of thermodynamics: is simply an expression of the conservation of energy principle, and it asserts that energy is a thermodynamic property.

The second law of thermodynamics:

It asserts that energy has quality as well as quantity, and actual processes occur in the direction of decreasing quality of energy. For example, a cup of hot coffee left on a table eventually cools, but a cup of cool coffee in the same room never gets hot by itself as shown in figure (1)

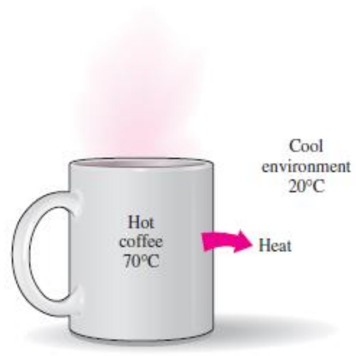


Figure (1) Heat flows in the direction of decreasing temperature.

Application Areas of Thermodynamics:

Thermodynamics is commonly encountered in many engineering systems. Some examples include:

- The refrigerator.
- The heating and air-conditioning systems.
- The humidifier.
- The pressure cooker.
- The water heater.
- Automotive engines.
- Airplanes.
- Wind turbines.
- The computer and the TV.
- Solar collectors.
- Jet engines
- Conventional or nuclear power plants.

Figure (2) shows Some application area of thermodynamics.

Power plants

Airplanes

Solar collector

Wind turbines

Figure (2) shows Some application area of thermodynamics

Thermodynamics system:

A system: is defined as a quantity of matter or a region in space chosen for study.

Surroundings: is the mass or region outside the system.

Boundary: is the real or imaginary surface that separates the system from its surroundings.

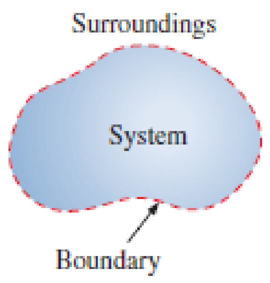
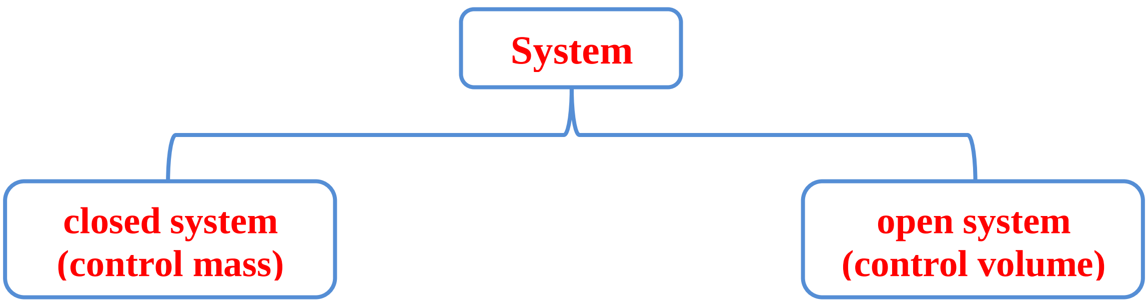


Figure (3) illustrate system, surroundings, and boundary

The boundary of a system can be fixed or movable. Note that the boundary is the contact surface shared by both the system and the surroundings. Mathematically speaking, the boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space. *These terms (system, surrounding, and boundary) are illustrated in figure (3).*

- Systems may be considered to be (***closed***) or (***open***).



Closed system: (also known as a control mass) consists of a fixed amount of mass, and no mass can cross its boundary. That is, no mass can enter or leave a closed system, But energy, in the form of (heat or work), can cross the boundary, as shown in Figure (4).

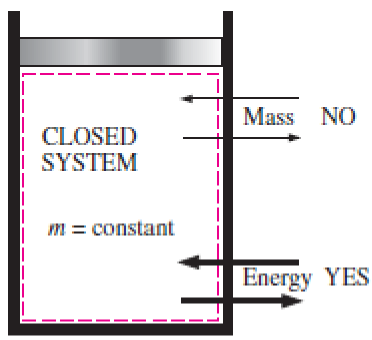


Figure (4) Closed system

Open system: (also known as a control volume), it usually encloses a device that involves mass flow such as *a compressor, turbine, or nozzle*. Flow through these devices is best studied by selecting the region within the device as the control volume. Both mass and energy can cross the boundary of a control volume. Figure (5) illustrate an open system (a control volume) with one inlet and one exit.

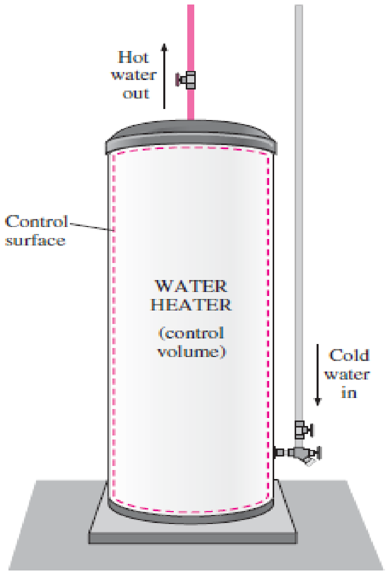


Figure (5) open system

The boundaries of a control volume are called a control surface, and they can be real or imaginary. In the case of a nozzle, the inner surface of the nozzle forms the real part of the boundary, and the entrance and exit areas form the imaginary part, since there are no physical surfaces there figure (6). *A control volume can be fixed in size and shape, as in the case of a nozzle, or it may involve a moving boundary, as shown in figure* (7). *Most control volumes, however, have fixed boundaries and thus do not involve any moving boundaries.*

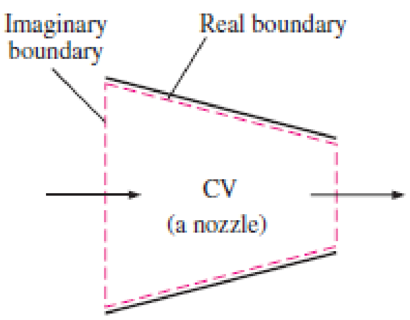


Figure (6) A control volume with real and imaginary boundaries

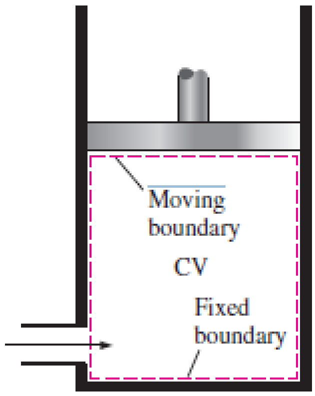


Figure (7) A control volume with fixed andmoving boundaries

- If, as a special case, even energy is not allowed to cross the boundary, that system is called an **isolated system**.

Macroscopic and Microscopic of Thermodynamics:

Systems can be studied from *a macroscopic* or *a microscopic* point of view.

The macroscopic approach: *is concerned with the gross or overall behavior*. This is sometimes called (*classical thermodynamics*).

No model of the structure of matter at the molecular, atomic, and subatomic levels is directly used in classical thermodynamics. Although the behavior of systems is affected by molecular structure, classical thermodynamics allows important aspects of system behavior to be evaluated from observations of the overall system.

The microscopic approach: known as (*statistical thermodynamics*), is concerned directly with the structure of matter.

The objective of statistical thermodynamics is to characterize by statistical means the average behavior of the particles making up a system of interest and relate this information to the observed macroscopic behavior of the system.

For applications involving lasers, plasmas, high speed gas flows, chemical kinetics, very low temperatures (cryogenics), and others, the methods of statistical thermodynamics are essential.

Properties of a system:

Any characteristic of a system is called a (**property**). Some familiar properties are pressure P, temperature T, volume V, and mass m. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation.

Properties are considered to be either (**intensive**) or (**extensive**).

Properties

Intensive properties: those that are independent of the mass of a system, such as temperature, pressure, and density.

Extensive properties: those that are dependent of the mass of a system , such as volume

- *Generally*, *uppercase letters* are used to denote **(extensive properties)** (with mass m being a major exception), and *lowercase letters* are used for **(intensive properties)** (with pressure P and temperature T being the obvious exceptions).

- Extensive properties per unit mass are called **(specific properties)**.

  Some examples of specific properties are:

  - specific volume $\left(v = \dfrac{V}{m}\right)$
  - specific total energy $\left(e = \dfrac{E}{m}\right)$

Density and specific gravity:

Density: is defined as mass per unit volume.

$$\boxed{Density\,(\rho) = \frac{m}{V} \qquad (\mathrm{kg/m^3})}$$

The *reciprocal* of density is **the specific volume** (v) , which is defined as volume per unit mass. That is:

$$\boxed{v = \frac{V}{m} = \frac{1}{\rho}}$$

Specific gravity or (relative density): is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4 °C, for which $\rho_{H_2O} = 1000$ kg/m^3).

$$\boxed{\text{Specific gravity (SG)} = \frac{\rho}{\rho_{H_2O}}}$$

- *Note that the specific gravity of a substance is a dimensionless quantity.*

Specific weight: the weight of a unit volume of a substance

$$\boxed{\text{Specific weight } (\gamma_s) = \rho g}$$

Where:(g) *is the gravitational acceleration*

State and Equilibrium:

State: at an instant of time a given state, all the properties of a system have fixed values.

If the value of even one property changes, the state will change to a different one. In Figure (8) *a system is shown at two different states.*

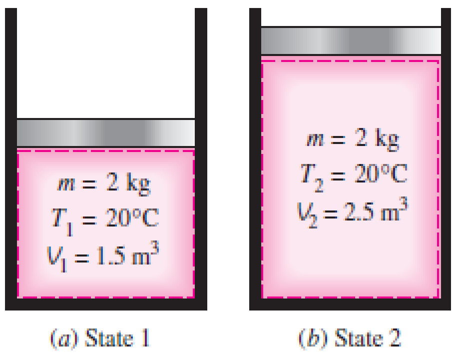


Figure (8) A system at two different states

Equilibrium: The word equilibrium implies a state of balance. In an equilibrium state there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

There are many types of equilibrium:

Thermal equilibrium:
a system is in thermal equilibrium if the temperature is the same throughout the entire system, as shown in Figure (9). That is, the system involves no temperature differential, which is the driving force for heat flow.

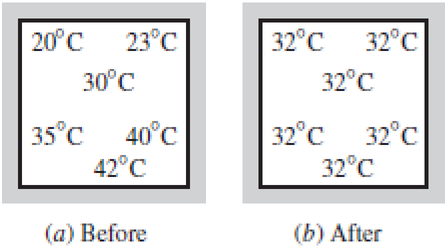


Figure (9) A closed system reaching thermal equilibrium.

Mechanical equilibrium: Mechanical equilibrium is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time.

Chemical equilibrium: a system is in chemical equilibrium if its chemical composition does not change with time, that is, no chemical reactions occur.

Phase equilibrium: If a system involves two phases, it is in phase equilibrium when the mass of each phase reaches an equilibrium level and stays there.

Processes and Cycles:

process: Any change that a system undergoes from one equilibrium state to another.

Path of the process: the series of states through which a system passes during a process

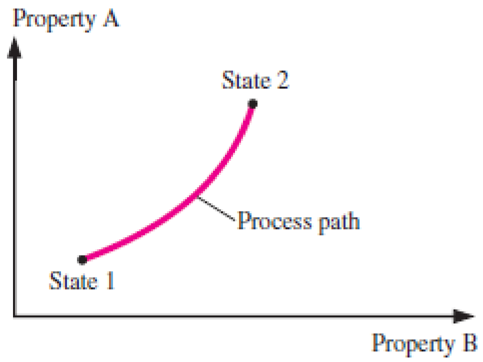


Figure (10) A process between states 1 and 2 and the process path.

Figure (10) *illustrate A process between states 1 and 2 and the process path.*

Adiabatic process: A process during which there is no heat transfer, as shown in figure (11)

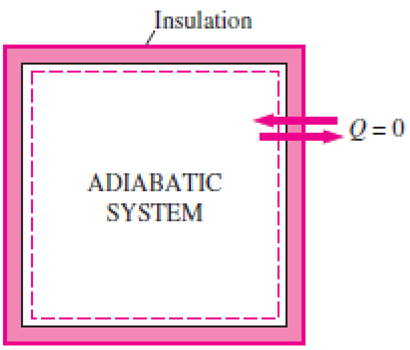


Figure (11) During an adiabatic process, a system exchanges no heat with its surroundings

- **Isothermal process:** is a process during which the temperature (T) remains constant.
- **Isobaric process:** is a process during which the pressure (P) remains constant.
- **Isochoric (or isometric) process:** is a process during which the specific volume (v) remains constant.

Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes. Some common properties that are used as coordinates are temperature T, pressure P, and volume V (or specific volume v).

Figure (12) shows the *P-V* diagram of a compression process of a gas.

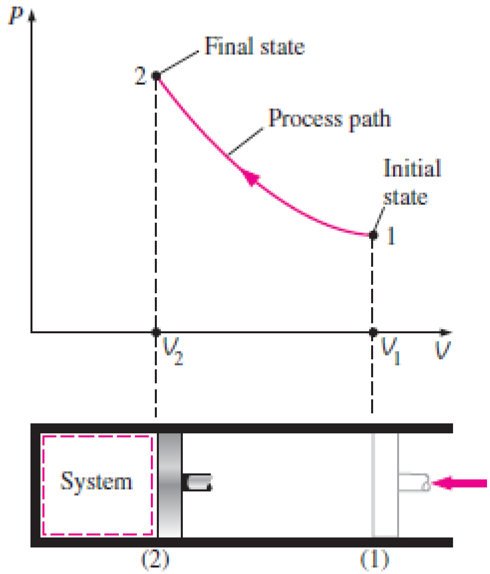


Figure (12) The *P-V* diagram of a compression process.

Cycle: A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical, as shown in figure (13)

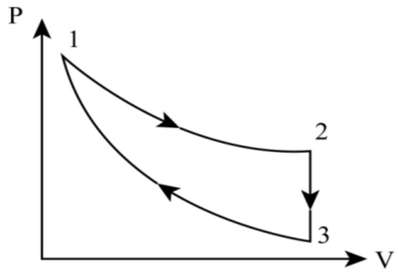


Figure (13) shown cycle in thermodynamics

Point and path functions:

Point function: These are variables whose values can be determined at any given point in a system based on its current properties *such as* (*volume, pressure, and temperature*), and are not affected by the path the system took to reach that state.

Path function: These are variables that depend on the path a system takes to get from one state to another, such as (*heat and work*).

The steady flow process:

The term steady implies no change with time. The opposite of steady is unsteady, or transient. The term uniform, however, implies no change with location over a specified region.

Steady-flow process: *which can be defined as a process during which a fluid flows through a control volume steadily, as shown in figure* (14).

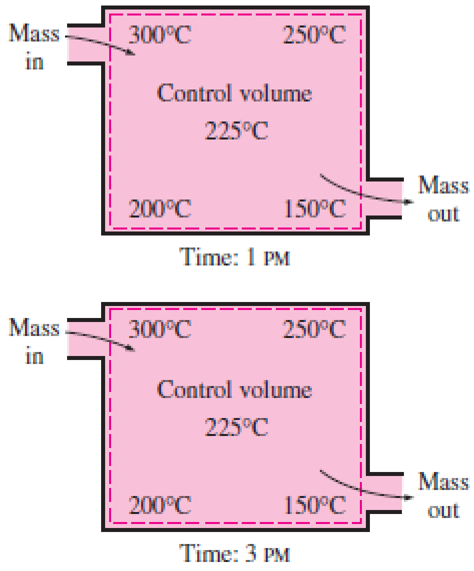


Figure (14) During a steady-flow process, fluid properties within the control volume may change with position but not with time

Temperature:

Temperature can be defined as a measure of hotness or coldness. thermometer is used to measure temperature. The temperature scales used are the Celsius scale, the Fahrenheit scale, Kelvin scale, and Rankine scale

Where:

$$\boxed{T(K) = T(^{o}C) + 273.15}$$

$$\boxed{T(R) = T(^{o}F) + 459.67}$$

$$\boxed{T(R) = 1.8T(K)}$$

$$\boxed{T(^{o}F) = 1.8T(^{o}C) + 32}$$

When a body is brought into contact with another body that is at a different temperature, heat is transferred from the body at higher temperature to the one at lower temperature until both bodies attain the same temperature as shown in the figure (15). At that point, the heat transfer stops, and the two bodies are said to have reached thermal equilibrium. The equality of temperature is the only requirement for thermal equilibrium.

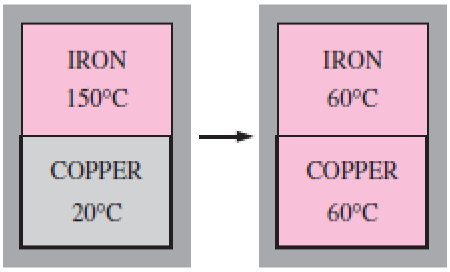


Figure (15) Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure

The zeroth law of thermodynamics:

The zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.

It was named the zeroth law since it should have preceded the first and the second laws of thermodynamics.