Thermodynamics

ESO201A

Lecture #1

Thermodynamics and Energy

Thermodynamics can be defined as the science of energy. Although everybody has a feeling of what energy is, it is difficult to give a precise definition for it. Energy can be viewed as the ability to cause changes.

The name thermodynamics stems from the Greek words therme (heat) and dynamis (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.

One of the most fundamental laws of nature is the 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. A rock falling off a cliff, for example, picks up speed as a result of its potential energy being converted to kinetic energy.

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 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. The high temperature energy of the coffee is degraded (transformed into a less useful form at a lower temperature) once it is transferred to the surrounding air.

It is well-known that a substance consists of a large number of particles called molecules. The properties of the substance naturally depend on the behaviour of these particles. For example, the pressure of a gas in a container is the result of momentum transfer between the molecules and the walls of the container. However, one does not need to know the behaviour of the gas particles to determine the pressure in the container. It would be sufficient to attach a pressure gauge to the container. The macroscopic approach to the study of thermodynamics that does not require a knowledge of the behaviour of individual particles is called classical thermodynamics. It provides a direct and easy way to the solution of engineering problems. A more elaborate approach, based on the average behaviour of large groups of individual particles, is called statistical thermodynamics. This microscopic approach is rather involved and is used in this text only in the supporting role.

Application Areas of Thermodynamics

Thermodynamics is commonly encountered in many engineering systems and other aspects of life.

Human body

The first law of thermodynamics forms the backbone of the diet industry:
A person who has a greater energy input (food) than energy output (exercise) will gain weight (store energy in the form of fat), and a person who has a smaller energy input than output will lose weight.
The change in the energy content of a body or any other system is equal to the difference between the energy input and the energy output, and the energy balance is expressed as $E_{in} - E_{out} = \Delta E$.

The heart is constantly pumping blood to all parts of the human body, various energy conversions occur in trillions of body cells, and the body heat generated is constantly rejected to the environment. The human comfort is closely tied to the rate of this metabolic heat rejection. We try to control this heat transfer rate by adjusting our clothing to the environmental conditions.

Ordinary Household

Many ordinary household utensils and appliances are designed, in whole or in part, by using the principles of thermodynamics. Some examples include the electric or gas range, the heating and air-conditioning systems, the refrigerator, the pressure cooker, the water heater, the iron, and even the computer and the TV.

Engineering Systems

On a larger scale, thermodynamics plays a major part in the design and analysis of automotive engines, rockets, jet engines, and conventional or nuclear power plants, solar collectors, and the design of vehicles from ordinary cars to aeroplanes.

Systems and Control Volumes

A system is defined as a quantity of matter or a region in space chosen for study. The mass or region outside the system is called the surroundings. The real or imaginary surface that separates the system from its surroundings is called the boundary (Fig. 1.1). 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.

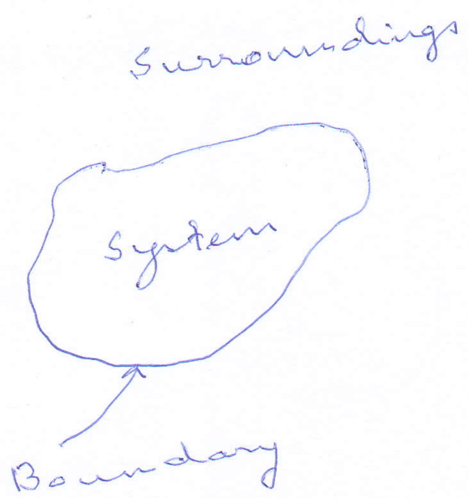

Fig. 1.1 System, surroundings, and boundary

Systems may be considered to be closed or open, depending on whether a fixed mass or a fixed volume in space is chosen for study. A closed system (also known as control mass or just system when the context makes it clear) 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, as shown in Fig. 1.2. But energy, in the form of heat or work, can cross the boundary; and the volume of the closed system does not have to be fixed. If, as a special case, even energy is not allowed to cross the boundary, that system is called an isolated system.

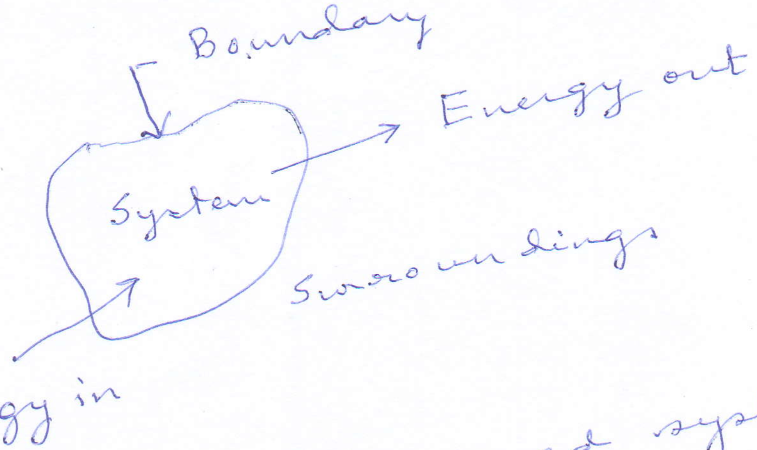

Fig. 1.2 A closed system
(No mass transfer)

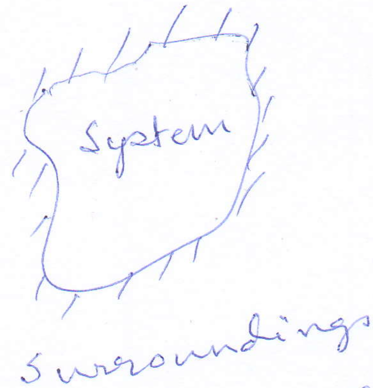

Fig. 1.3 An isolated system
(no mass or energy transfer)

The isolated system is one in which there is no interaction between the system and the surroundings. It is of fixed mass or energy, and there is no mass or energy transfer across the system boundary.

Consider the piston-cylinder device shown in Fig. 1.4. Let us say that we would like to find out what happens to the enclosed gas when it is heated. Since we are focusing our attention on the gas, it is our system. The inner surface of the piston and the cylinder form the boundary, and since no mass is crossing this boundary, and part of the boundary (inner surface of the piston, in this case) may move. Everything outside the gas, including the piston and the cylinder, is the surroundings.

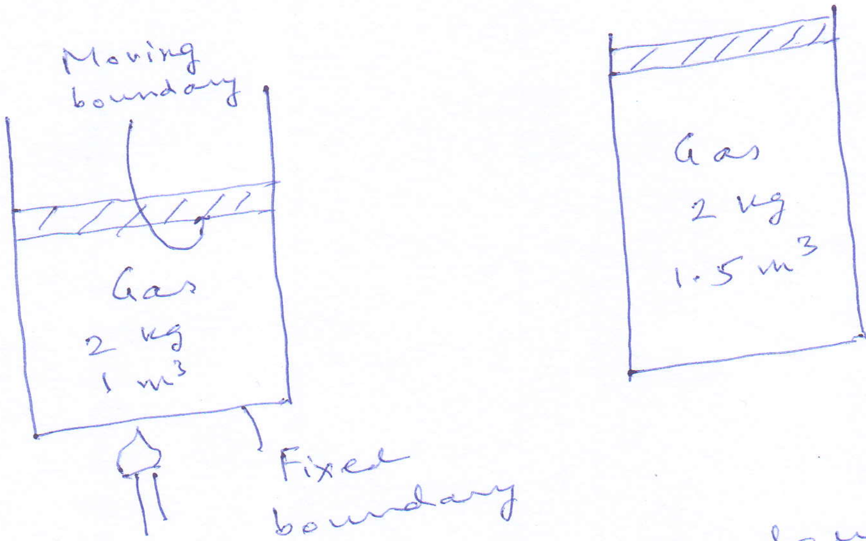

Fig. 1.4 A closed system with a moving boundary

An open system or a control volume, as it is often called, is a properly selected system in space. It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle. Both mass or energy can cross the boundary of a control volume.

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 (Fig. 1.5).

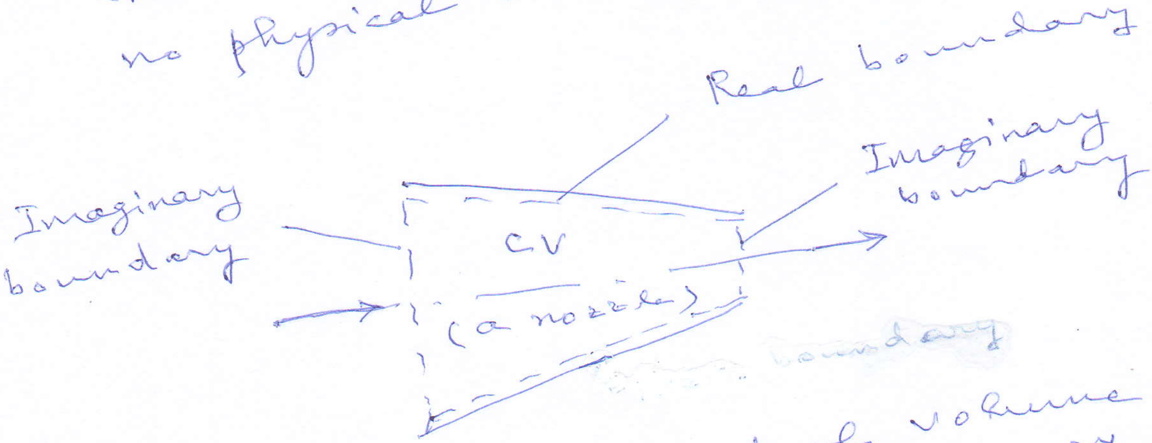

Fig. 1.5 A control volume with a real and imaginary boundaries

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 Fig. 1.6.

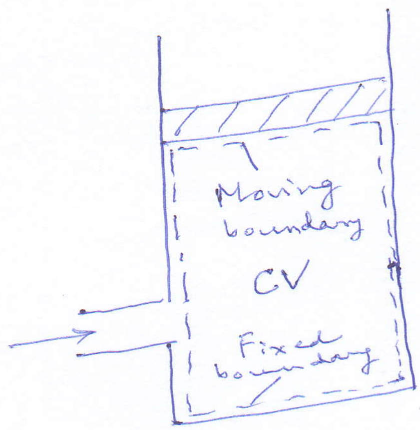

Fig. 1.6 A control volume with fixed and moving boundaries

As an example of an open system, consider the water heater shown in Fig. 1.7. Let us say that we would like to determine how much heat we must transfer to the water in the tank in order to supply a steady stream of hot water. Since the hot water will leave the tank and be replaced by cold water, it is not convenient to choose a fixed mass as our system for the analysis. Instead, we can concentrate our attention on the volume formed by the interior surfaces of the tank and consider the hot and cold water streams as mass leaving and entering the control volume. The interior surfaces of the tank form the control surface for this case, and mass is crossing the control surface at two locations.

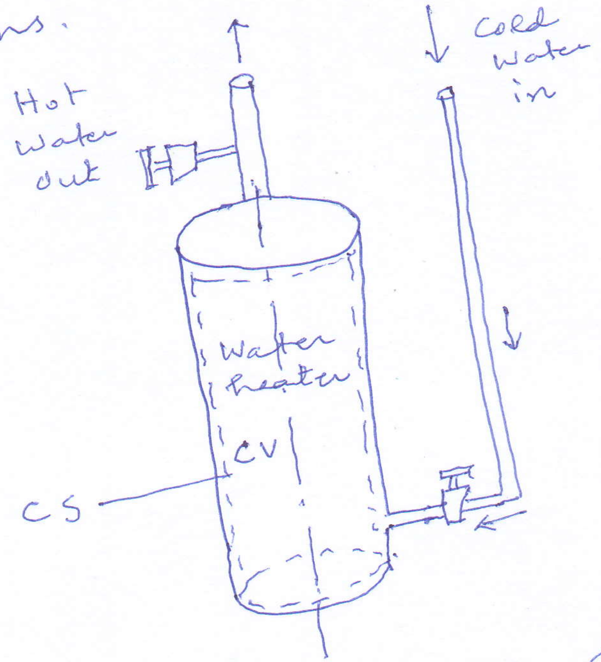

Fig. 1.7 An open system (CV) with one inlet and one exit