Module

1

Lecture
2

Thermodynamics

Basic Concepts of Thermodynamics

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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.
- The change in the value of any property for a cyclic process is zero.
- For example $\oint dP = 0$, $\oint dV = 0$, $\oint dT = 0$

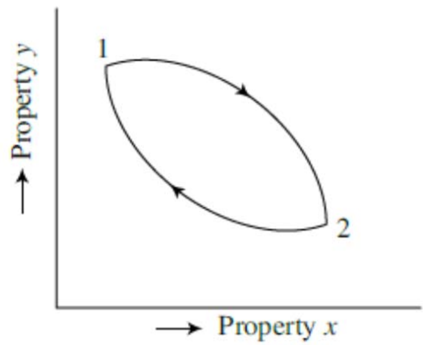


Fig. 1.8: Cycle

- e.g. Carnot cycle, Rankine cycle, Otto cycle, Diesel cycle, Dual cycle etc.

Energy Transfer By Work

- Mechanical work is defined as the product of a force F and the displacement caused by the force when both are measured in the same direction.
- The expression for differential quantity of work δW resulting from differential displacement ds is given by

$$\delta W = F\,ds$$

- Work is a scalar quantity.
- The total work for a finite displacement is obtained from the integration of *Fds*.
- The basic unit of work in the SI system is the Newton-metre (N-m) called the Joule (J). We shall use the more conventional kilojoule (kJ) which is 10^3 N-m.

In thermodynamics, work transfer is considered as occurring between the system and the surroundings. Work is said to be done by a system if the sole effect on the surroundings can be reduced to the raising of a load. The weight may not actually be raised, but the net effect external on the system would be raising of a weight.

Let us consider the battery and motor as a system as in Fig. 1.9. The motor is driving a fan. The system is doing work on surroundings.

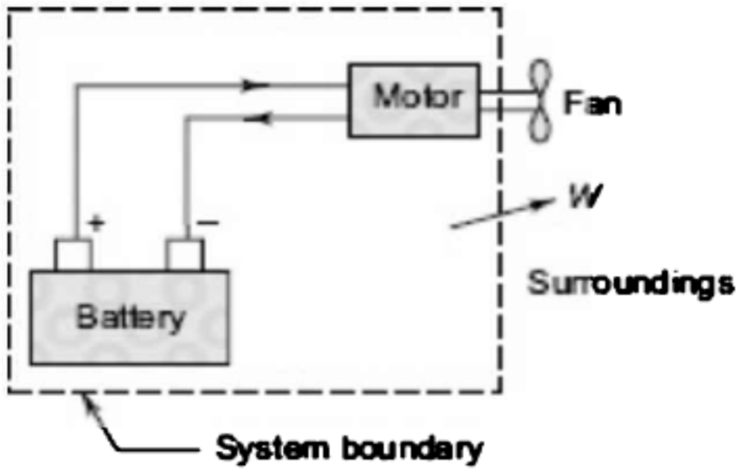


Fig. 1.9: Battery-motor system driving a fan

- When the fan is replaced by a pulley and a weight as shown in Fig. 1.10, the weight may be raised with pulley driven by the motor. The sole effect on the things external to the system is then the raising of a weight.

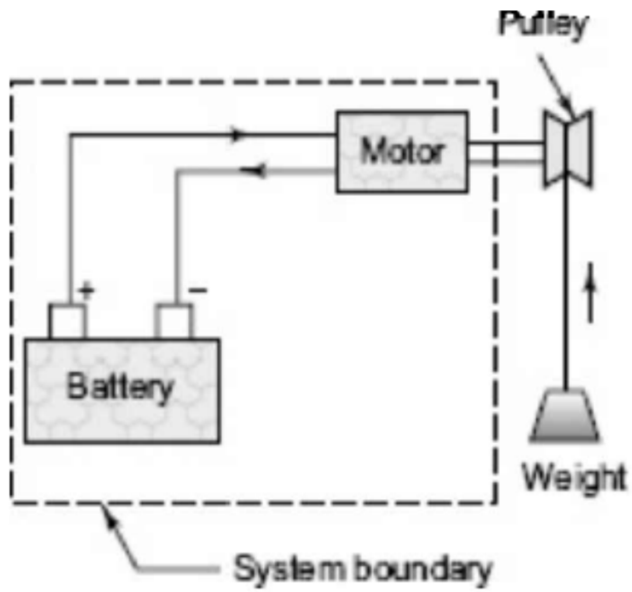
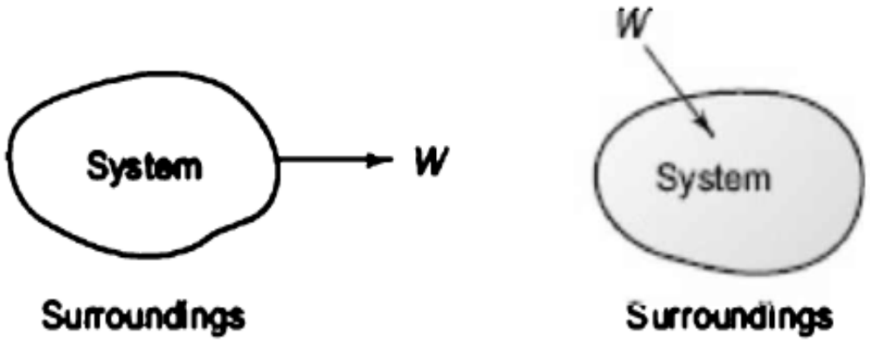


Fig. 1.10: Work transfer from a system

Sign Convention:



(a) *W* is positive (b) *W* is negative

Path Function and Point Function:

The magnitude of a path function depends on the path followed during a process as well as on the end states. On the other hand, the magnitude of a point function depends only on the end states. Path functions are designated by the symbol δ.

- The value of *W* depends on the details of the interactions taking place between the system and surroundings during a process and not just the initial and final states of the system.
- It follows that **work is not a property** of the system or the surroundings.

- The differential of work, δW, is said to be *inexact* because, in general, the following integral cannot be evaluated without specifying the details of the process.

$$\int_1^2 \delta W = W$$

- On the other hand, the differential of a property is said to be *exact* because the change in a property between two particular states depends in no way on the details of the process linking the two states. For example, the change in volume between two states can be determined by integrating the differential dV, without regard for the details of the process, as follows

$$\int_{V1}^{V2} dV = V2 - V1$$

where V_1 is the volume *at* state 1 and V_2 is the volume *at* state 2. The differential of every property is exact. Exact differentials are written using the symbol *d*.

P–dV Work or Displacement Work or Moving Boundary Work

- Let the gas in the cylinder be a system as shown in Fig. 1.10 having initially the pressure P1 and volume V1. The inner surfaces of the piston and the cylinder form the boundary. The piston is the only boundary which moves due to gas pressure. Let the piston moves out to a new position 2, where the pressure and volume are P2 and V2 respectively.
- At any intermediate point in the travel of the piston, let the pressure be P and volume be V. When the piston moves an infinitesimal distance *dl* and if A be the area of the piston, the force acting on the piston $F = PA$ and the infinitesimal amount of work done by the gas on the piston.

$$\delta W = F.dl = PA.dl = P.dV$$

where, $dV = A\,dl = Infinitesimal\ displacement\ volume.$

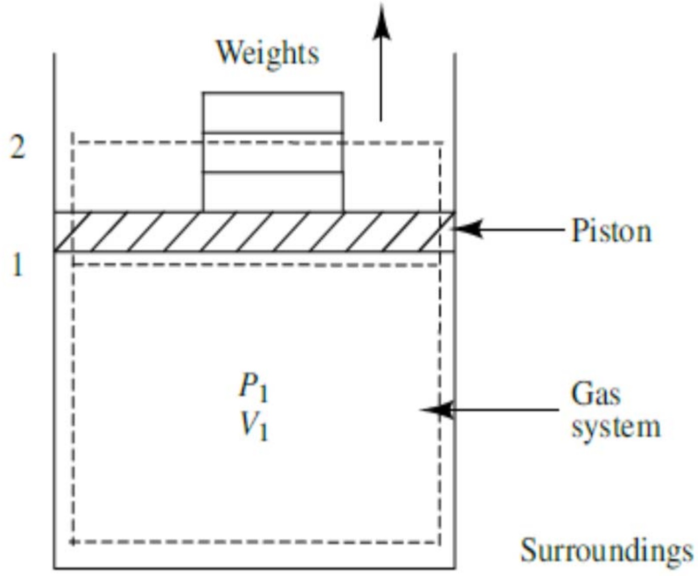


Fig. 1.10: Cylinder-piston Assembly

- When the piston moves out from position 1 to 2 with the volume changing from V1 to V2 , the amount of work W done by the system will be

$$W_{1-2} = \int_{V1}^{V2} P\, dV$$

- This integral can be evaluated only if we know the functional relationship between P and V during the process.

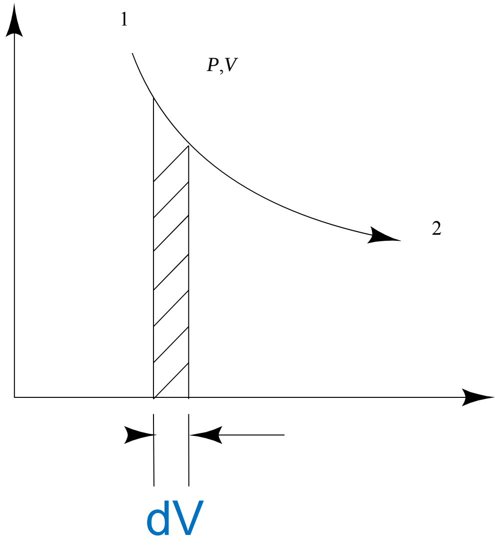


Fig. 1.11: P–V diagram for a quasi-equilibrium expansion process

The area under the process curve on a P–V diagram is equal in magnitude to the work done during a quasi-equilibrium expansion or compression process of a closed system.

P–dV Work or Displacement Work or Moving Boundary Work for Different Quasi-static Processes

Most of the cycles or processes that are normally encountered in thermodynamics analysis of systems can be identified by any one or a combination of the following processes

a) Constant Pressure process (Isobaric or Isopiestic process)

$$W_{1-2} = \int_{v1}^{v2} Pdv = P(v_2 - v_1)$$

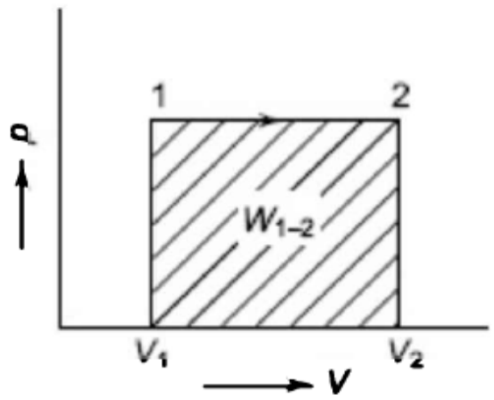


Fig. 1.12: Constant pressure process

b) Constant volume process (Isochoric process)

$$W_{1-2} = \int P\,dv = 0$$

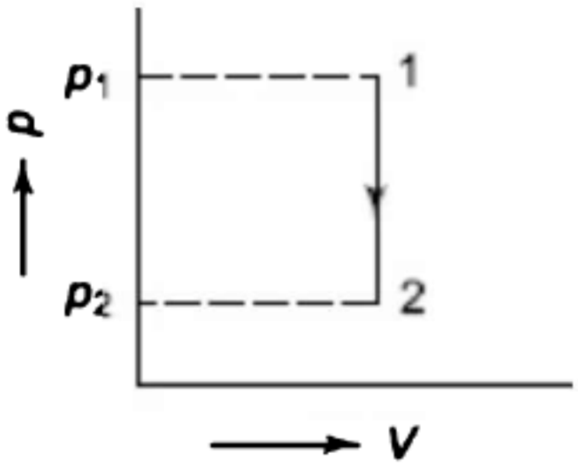


Fig. 1.13: Constant volume process

c) Hyperbolic Process:

Hyperbolic process is one for which the quantity Pv =constant.

$$W_{1-2} = \int_{v1}^{v2} P dv = \int_{v1}^{v2} \frac{C}{v} dv$$

Where Pv = C = $P_1 v_1 = P_2 v_2$

Integrating above Eq. and substituting the constant, C, we get

$$W_{1-2} = C ln\frac{v_2}{v_1} = P_1 v_1 ln\frac{v_2}{v_1} = P_2 v_2 ln\frac{v_2}{v_1}$$

Note: For an ideal gas the hyperbolic process becomes an isothermal process.

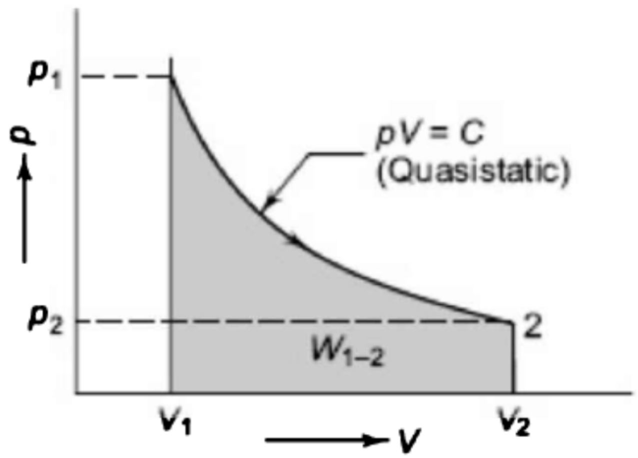


Fig. 1.13: Process in which Pv=constant

d) Polytropic Process:

- When a gas undergoes a process in which energy is transferred as heat, the process frequently occurs in such a manner that a plot of ln P versus lnv yields a straight line. For such a process, pressure and volume are related by Pv^n = constant, where n is the polytropic index of expansion or compression. Such processes are called polytropic processes. Polytropic index n may be of any value from -∞ to +∞, depending on the particular process. The work done is expressed by

$$W_{1-2} = \int_{v1}^{v2} Pdv = \int_{v1}^{v2} \frac{C}{v} dv$$

$$= C\frac{v_2^{-n+1} - v_1^{-n+1}}{1-n} = \frac{Cv_1^{-n+1} - Cv_2^{-n+1}}{n-1}$$

For a polytropic process between states 1 and 2, the functional relationship between pressure and volume can be expressed as

$$P_1 v_1^n = P_2 v_2^n = C$$

Substituting the constant value C

$$W_{1-2} = \frac{P_1 v_1^n v_1^{-n+1} - P_2 v_2^n v_2^{-n+1}}{n-1}$$

$$W_{1-2} = \frac{P_1 v_1 - P_2 v_2}{n-1} = \frac{P_1 v_1}{n-1}\left[1 - \frac{P_2 v_2}{P_1 v_1}\right] = \frac{P_1 v_1}{n-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{n-1/n}\right]$$

This expression is valid for all values for n except n = 1.

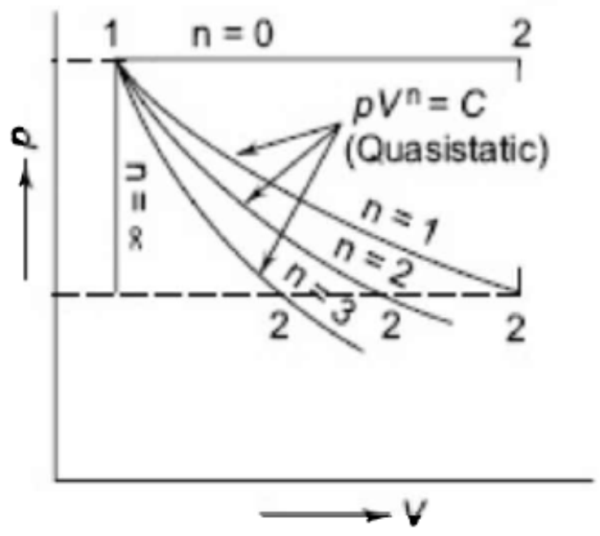


Fig. 1.14: Process in which $Pv^n = constant$

WORK TRANSFER: It not a property of a system

Let the system be taken from the state 1 to the state 2 by different quasi-equilibrium paths such as 1-a-2, 1-b-2 or 1-c-2 (Fig. 1.15). Since the area under the curve on the process diagrams represents the quasi-equilibrium work done and the area under the curve is different for different paths, so the work done is different for each path. The work done in a process depends not only on the initial and final states, but also the path followed by a system during a change of state, i.e., work transfer is a path function and not a property of a system.

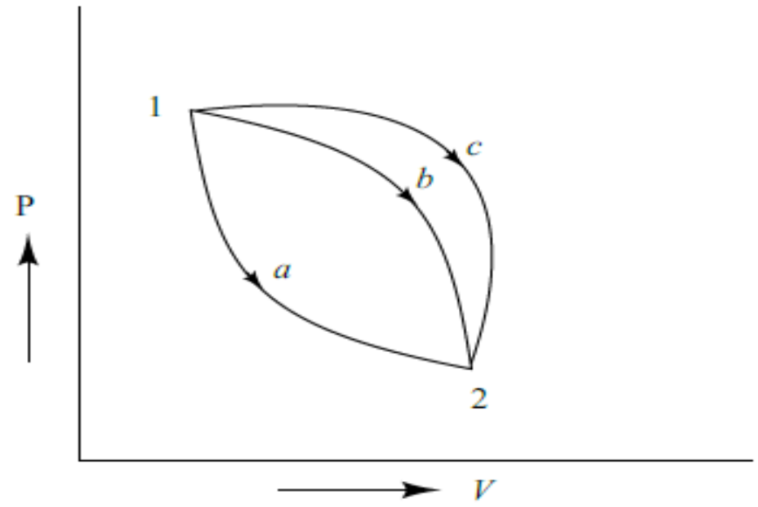


Fig. 1.15: Work transfer

OTHER MODES OF WORK:

a) Shaft Work

Energy transmission with a rotating shaft is very common in engineering practices (Fig. 1.14). Often the torque **T** applied to the shaft is constant, which means that the force *F* applied is also constant. For a specified constant torque, the work done during *n* revolutions is determined as follows: a force *F* acting through a moment arm *r* generates a torque **T** of (Fig. 1.14)

$$T = F\,r \rightarrow F = \frac{T}{r}$$

- This force acts through a distance *s*, which is related to the radius *r* by

$$s = (2\pi r)n$$

Then the shaft work is determined from

$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi r n) = 2\pi n T$$

- The power transmitted through the shaft is the shaft work done per unit time, which can be expressed as

$$\dot{W}_{sh} = 2\pi\dot{n}T$$

where $\dot{n}$ is the number of revolutions per unit time.

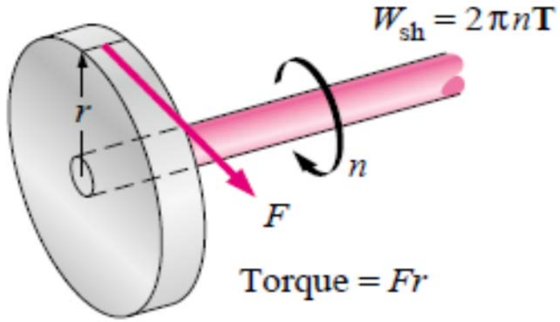
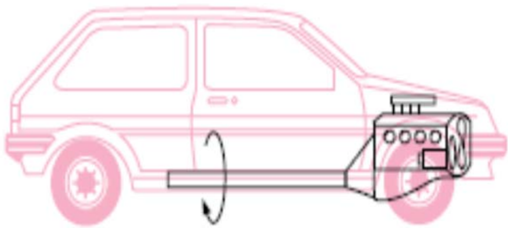
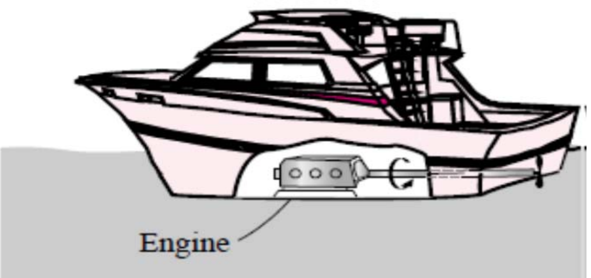


Fig. 1.14: Shaft work is proportional to the torque applied and the number of revolutions of the shaft.



BOAT



b) Electric Power

A system shown in Fig. 1.15 consists of an electrolytic cell. The cell is connected to an external circuit through which an electric current, *i*, is flowing. The current is driven by the electrical potential difference V existing across the terminals labelled a and b.

- The rate of energy transfer by work, or the power, is

$$W_{electrical} = Vi$$

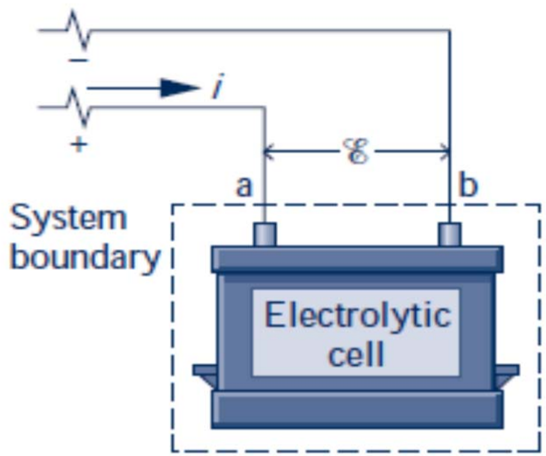


Fig. 1.15: Electrical Power

c) Spring Work

- It is common knowledge that when a force is applied on a spring, the length of the spring changes (Fig. 1.16). When the length of the spring changes by a differential amount *dx* under the influence of a force *F*, the work done is

$$\delta W_{spring} = F\,dx$$

To determine the total spring work, we need to know a functional relationship between *F* and *x*. For linear elastic springs, the displacement *x* is proportional to the force applied (Fig. 1.6).

That is, $F = k\,x$, where *k* is the spring constant and has the unit kN/m.

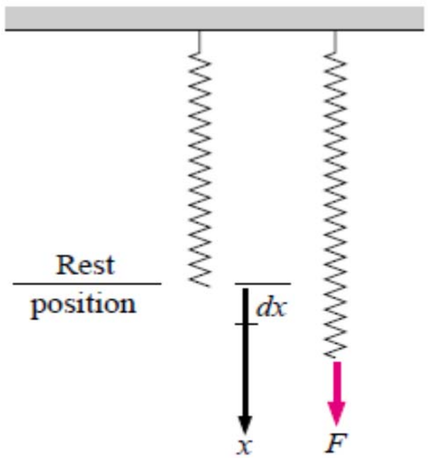


Fig. 1.16: Elongation of a spring under influence of a force

The displacement *x* is measured from the undisturbed position of the spring (that is, $x = 0$ when $F = 0$). Substituting the F and integrating yield

$$W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$$

- where $x1$ and $x2$ are the initial and the final displacements of the spring respectively, measured from the undisturbed position of the spring.

d) Flow Work

Unlike closed systems, control volumes involve mass flow across their boundaries, and some work is required to push the mass into or out of the control volume. This work is known as the **flow work,** or **flow energy,** and is necessary for maintaining a continuous flow through a control volume.

- To obtain a relation for flow work, consider a fluid element of volume *V* as shown in Fig. 1.17.

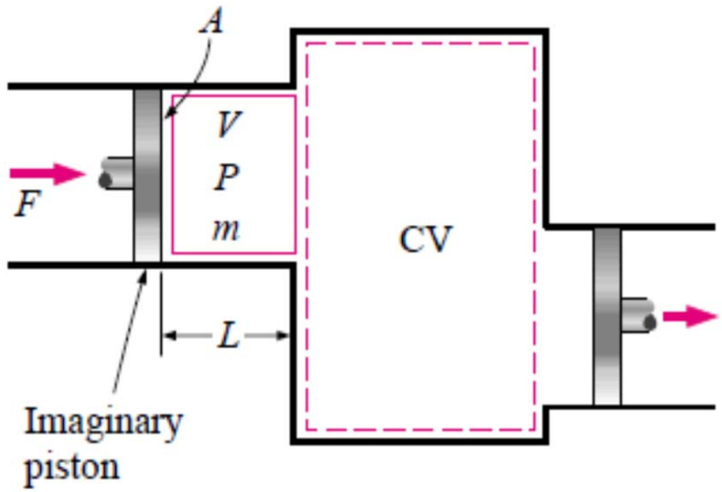


Fig. 1.17: Schematic for flow work.

The fluid immediately upstream will force this fluid element to enter the control volume; thus, it can be regarded as an imaginary piston. The fluid element can be chosen to be sufficiently small so that it has uniform properties throughout.

- If the fluid pressure is *P* and the cross-sectional area of the fluid element is *A* (Fig. 1.17), the force applied on the fluid element by the imaginary piston is

$$F = P\,A$$

- To push the entire fluid element into the control volume, this force must act through a distance *L*. Thus, the work done in pushing the fluid element across the boundary (i.e., the flow work) is

$$W_{flow} = FL = PAL = PV$$

- The flow work per unit mass is obtained by dividing both sides of this equation by the mass of the fluid element:

$$w_{flow} = Pv$$

- The flow work relation is the same whether the fluid is pushed into or out of the control volume (Fig. 1.17). It is interesting that unlike other work quantities, flow work is expressed in terms of properties. In fact, it is the product of two properties of the fluid. For that reason, it is viewed as a *combination property* (like enthalpy).

Thank You