ENGINEERING THERMODYNAMICS
AMEC06
B. Tech III Semester (BT23)
MECHANICAL ENGINEERING

Course Objective

Students will try to learn:

- The fundamental knowledge on concepts of physics and chemistry for obtaining the axiomatic principles using thermodynamic co-ordinates.
- The thermodynamic disorderness in the real time physical systems like external/internal heat engines, heat pumps to get the measure of performance characteristics.
- The performance characteristics of open and closed systems of thermodynamic cycles for effective delineation of real time applications.
- The thermodynamic cycles such as power and refrigerant cycles to yield alternative solutions to conserve the environment.

Course Outcome

CO 1	**Recall** the basic concepts of thermodynamic properties and working principles of energy conversions in physical systems by laws of thermodynamics.	Remember
CO 2	**Summarize** the equivalence of two statements of second law of thermodynamics and the entropy concepts for typical engineering problems.	Understand
CO 3	**Explain** the properties of pure substances and steam to emit relevant inlet and exit conditions of thermodynamic work bearing systems.	Understand
CO 4	**Apply** the significance of partial pressure and temperature to table the performance parameters of ideal gas mixtures.	Apply
CO 5	**Identify** the properties of air conditioning systems by practicing psychrometry chart and property tables.	Apply
CO 6	**Illustrate** the working of various air standard cycles and work out to get the performance characteristics.	Understand

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Basic Definition

Fundamental Concepts and Definitions

Thermodynamics:

- It is the science of the relations between Heat and Work and the properties of the systems.
- Thermodynamics is a branch of science, phenomena of energy and related properties of matter, especially of laws of transformation of heat into other forms of energy and vice versa.

Fundamental Concepts and Definitions

Thermodynamics:

- Thermodynamics is an axiomatic science which deals with the relations among heat, work and properties of system which are in equilibrium. It describes state and changes in state of physical systems.

System:

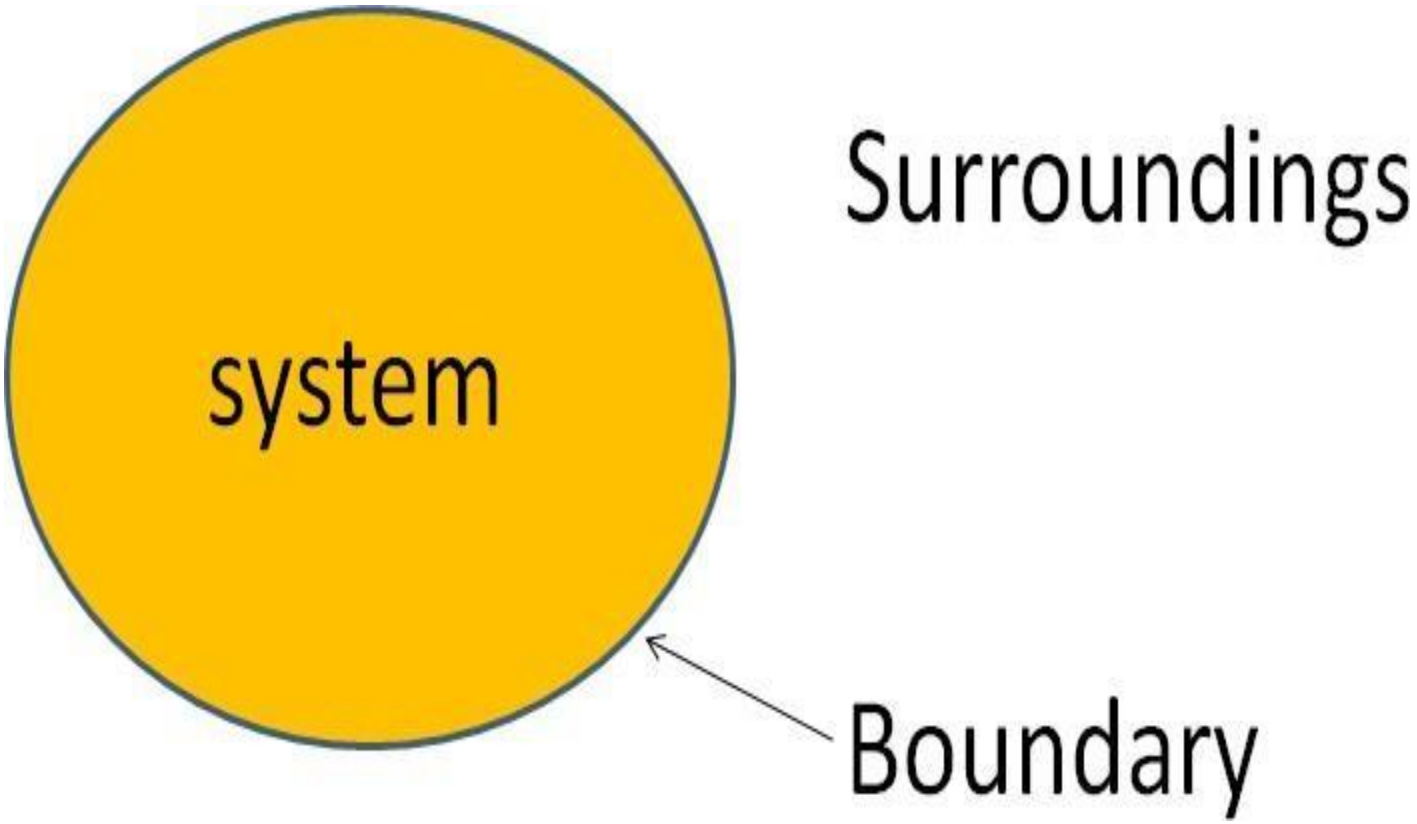
- A thermodynamic system is defined as a quantity of matter or a region in space which is selected for the study.

Surroundings:

- The mass or region outside the system is called surroundings.

Boundary:

- The real or imaginary surfaces which separates the system and surroundings is called boundary. The real or imaginary surfaces which separates the system and surroundings is called boundary.


system
Surroundings
Boundary

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Microscopic and Macroscopic View

Microscopic View or Study:

- The approach considers that the system is made up of a very large number of discrete particles known as molecules. These molecules have different velocities are energies. The values of these energies are constantly changing with time. This approach to thermodynamics, which is concerned directly with the structure of the matter, is known as statistical thermodynamics.
- The behavior of the system is found by using statistical methods, as the number of molecules is very large. So advanced statistical and mathematical methods are needed to explain the changes in the system.
- The properties like velocity, momentum, impulse, kinetic energy and instruments cannot easily measure force of impact etc. that describe the molecule.
- Large numbers of variables are needed to describe a system. So the approach is complicated.

Macroscopic View or Study

Macroscopic View or Study:

- In this approach a certain quantity of matter is considered without taking into account the events occurring at molecular level. In other words this approach to thermodynamics is concerned with gross or overall behavior. This is known as classical thermodynamics.
- The analysis of macroscopic system requires simple mathematical formula.
- The value of the properties of the system are their average values. For examples consider a sample of gas in a closed container. The pressure of the gas is the average value of the pressure exerted by millions of individual molecules.
- In order to describe a system only a few properties are needed.

Difference Between Micro and Macroscopic View

S.No	Macroscopic Approach	Microscopic Approach
1	In this approach a certain quantity of matter is considered without taking into account the events occurring at molecular level.	**The matter is consideredto be comprised of a large number of tiny particles known as molecules, which moves randomly in chaotic fashion. The effect of molecular motion is considered.**
2	Analysis is concerned with overall behavior of the system.	**The Knowledge of the structure of matter is essential in analyzing the behavior of the system.**
3	This approach is used in the study of classical thermodynamics.	**This approach is used in the study of statistical thermodynamics.**
4	A few properties are required to describe the system.	**Large numbers of variables are required to describe the system.**
5	The properties like pressure, temperature, etc. needed to describe the system, can be easily measured.	**The properties like velocity, momentum, kinetic energy, etc. needed to describe the system, cannot be measured easily.**
6	**The properties of the system are their average values.**	**The properties are defined for each molecule individually.**

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State

The thermodynamic state of a system is defined by specifying values of a set of measurable properties sufficient to determine all other properties. For fluid systems, typical properties are pressure, volume and temperature. More complex systems may require the specification of more unusual properties. As an example, the state of an electric battery requires the specification of the amount of electric charge it contains.

Property

- Properties may be extensive or intensive.
- Intensive properties: The properties which are independent of the mass of thesystem.

For example: Temperature, pressure and density are the intensive properties.

- Extensive properties: The properties which depend on the size or extent of the system are called extensive properties.

For example: Total mass, total volume and total momentum.

Process and Cycle

Process:

When the system undergoes change from one thermodynamic state to final state due change in properties like temperature, pressure, volume etc, the system is said to have undergone thermodynamic process.

- Various types of thermodynamic processes are: isothermal process, adiabatic process, isochoric process, isobaric process and reversible process.

Cycle:

- Thermodynamic cycle refers to any closed system that undergoes various changes due to temperature, pressure, and volume, however, its final and initial state are equal. This cycle is important as it allows for the continuous process of a moving piston seen in heat engines and the expansion/compression of the working fluid in refrigerators, for example. Without the cyclical process, a car wouldn't be able to continuously move when fuel is added, or a refrigerator would not be able to stay cold. Visually, any thermodynamic cycle will appear as a closed loop on a pressure volume diagram.

Examples: Otto cycle, Diesel Cycle, Brayton Cycle etc.

Reversibility

- Reversibility, in thermodynamics, a characteristic of certain processes (changes of a system from an initial state to a final state spontaneously or as a result of interactions with other systems) that can be reversed, and the system restored to its initial state, without leaving net effects in any of the systems involved.

An example of a reversible process would be a single swing of a frictionless pendulum from one of its extreme positions to the other. The swing of a real pendulum is irreversible because a small amount of the mechanical energy of the pendulum would be expended in performing work against frictional forces, and restoration of the pendulum to its exact starting position would require the supply of an equivalent amount of energy from a second system, such as a compressed spring in which an irreversible change of state would occur.

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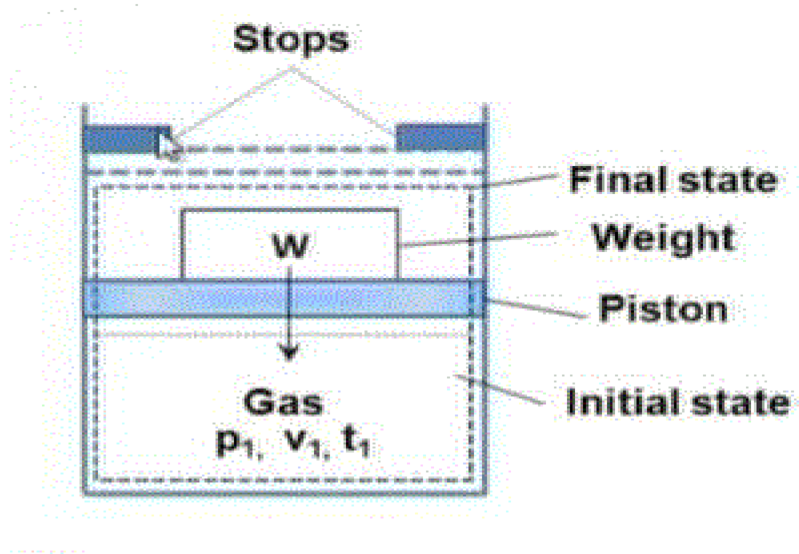
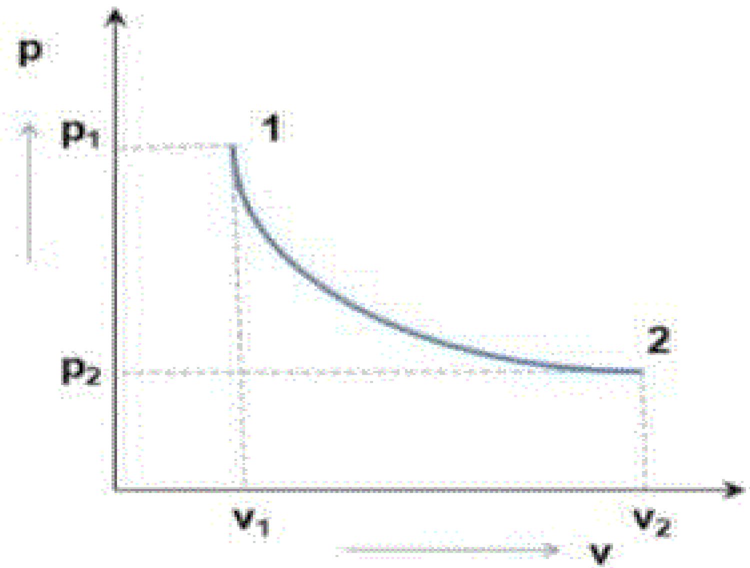
Quasi static process

- When a process is processing in such a way that system will be remained infinitesimally close with equilibrium state at each time, such process will be termed as quasi static process or quasi equilibrium process.

- In simple words, we can say that if system is going under a thermodynamic process through succession of thermodynamic states and each state is equilibrium state then the process will be termed as quasi static process.

Quasi static process





We will see one example for understanding the quasi static process, but let us consider one simple example for better understanding of quasi static process. If a person is coming down from roof to ground floor with the help of ladder steps then it could be considered as quasi static process. But if he jumps from roof to ground floor then it will not be a quasi static process.

Weight placed over the piston is just balancing the force which is exerted in upward direction by gas. If we remove the weight from the piston, system will have unbalanced force and piston will move in upward direction due to force acting over the piston in upward direction by the gas.

Irreversible Process

- The irreversible process is also called the natural process because all the processes occurring in nature are irreversible processes. The natural process occurs due to the finite gradient between the two states of the system. For instance, heat flow between two bodies occurs due to the temperature gradient between the two bodies; this is in fact the natural flow of heat. Similarly, water flows from high level to low level, current moves from high potential to low potential, etc.
- In the irreversible process the initial state of the system and surroundings cannot be restored from the final state.

Irreversible Process

- During the irreversible process the various states of the system on the path of change from initial state to final state are not in equilibrium with each other.
- During the irreversible process the entropy of the system increases decisively and it cannot be reduced back to its initial value.
- The phenomenon of a system undergoing irreversible process is called as irreversibility.

Causes of Irreversibility

- Friction: Friction is invariably present in real systems. It causes irreversibility in the process as work done does not show an equivalent rise in the kinetic or potential energy of the system. The fraction of energy wasted due to frictional effects leads to deviation from reversible states.
- Free expansion: Free expansion refers to the expansion of unresisted type such as expansion in a vacuum. During this unresisted expansion the work interaction is zero, and without the expense of any work, it is not possible to restore initial states. Thus, free expansion is irreversible.

Causes of Irrevesibility

- Heat transfer through a finite temperature difference: Heat transfer occurs only when there exists temperature difference between bodies undergoing heat transfer. During heat transfer, if heat addition is carried out in a finite number of steps then after every step the new state shall be a non-equilibrium state.

- Non equilibrium during the process: Irreversibilities are introduced due to lack of thermodynamic equilibrium during the process. Non-equilibrium may be due to mechanical inequilibrium, chemical inequilibrium, thermal inequilibrium, electrical inequilibrium, etc. and irreversibility is called mechanical irreversibility, chemical irreversibility, thermal irreversibility, electrical irreversibility respectively. Factors discussed above are also causing non-equilibrium during the process and therefore make process irreversible.

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Flow Work

Flow work The flow work, significant only in a flow process or an open system, represents the energy transferred across the system boundary as a result of the energy imparted to the fluid by a pump, blower or compressor to make the fluid flow across the control volume. Flow work is analogous to displacement work. Let p be the fluid pressure in the plane of the imaginary piston, which acts in a direction normal to it (Fig. 3.16). The work done on this imaginary piston by the external pressure as the piston moves forward is given by

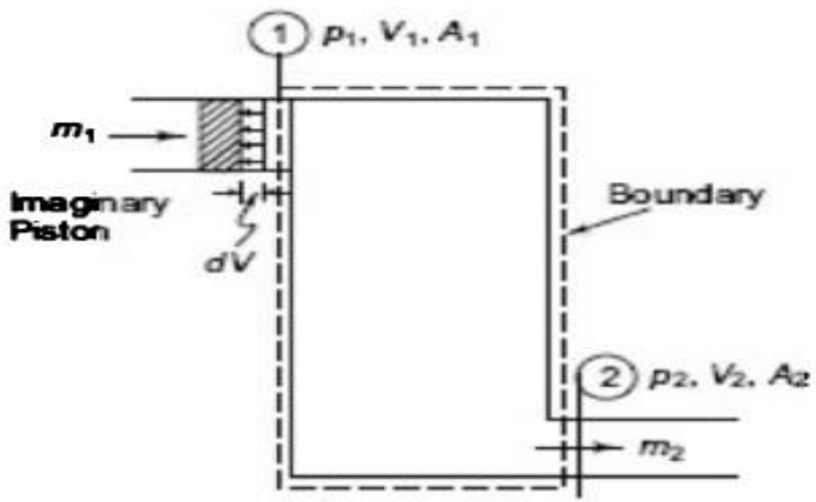

Fig. 3.16 *Flow work*

$$đW_{\text{flow}} = p\,dV, \qquad (3.16)$$

Problems

Example 4.1 A stationary mass of gas is compressed without friction from an initial state of 0.3 m^3 and 0.105 MPa to a final state of 0.15 m^3 and 0.105 MPa, the pressure remaining constant during the process. There is a transfer of 37.6 kJ of heat from the gas during the process. How much does the internal energy of the gas change?

Solution First law for a stationary system in a process gives

$$Q = \Delta U + W$$

or

$$Q_{1-2} = U_2 - U_1 + W_{1-2} \tag{1}$$

Here

$$W_{1-2} = \int_{V_1}^{V_2} p dV = p(V_2 - V_1)$$

$$= 0.105\ (0.15 - 0.30)\ \text{MJ} = -\ 15.75\ \text{kJ}$$

$$Q_{1-2} = -\ 37.6\ \text{kJ}$$

$\therefore$ Substituting in Eq. (1)

$$-\ 37.6\ \ \text{kJ} = U_2 - U_1 - 15.75\ \text{kJ}$$

$\therefore$

$$U_2 - U_1 = \mathbf{-\ 21.85\ kJ}$$

The internal energy of the gas decreases by 21.85 kJ in the process.

Problems

A system undergoes a process 1–2 in which it absorbs 200 kJ energy as heat while it does 100 kJ of work. Then it follows the path 2–3 in which it rejects 50 kJ energy as heat, when 80 kJ work is done on it. If it is required to restore the system to state-1 through an adiabatic path, calculate the work and heat interactions along the adiabatic. Also calculate the net work and heat interactions.

Solution: Application of the first law of thermodynamics to the process 1–2 gives

$$U_2 - U_1 = Q_{12} - W_{12}$$

$$= 200 - 100 = 100 \text{ kJ}$$

Similarly

$$U_3 - U_2 = Q_{23} - W_{23}$$

$$= -50 - (-80) = 30 \text{ kJ}$$

For the complete cycle, $\Delta U = 0$

or

$$(U_2 - U_1) + (U_3 - U_2) + (U_1 - U_3) = 0$$

Problems

or $$100 + 30 + (U_1 - U_3) = 0$$

or $$U_1 - U_3 = -130 \text{ kJ}$$

The process 3–1 is desired to be adiabatic. Therefore $Q_{31} = 0$. **Ans.**
The first law of thermodynamics for the process 3–1 gives

$$U_1 - U_3 = Q_{31} - W_{31}$$

or $$-130 = 0 - W_{31}$$

Therefore, work done during adiabatic process $= 130$ kJ **Ans.**

Net work is given by

$$W_{net} = \oint \delta W$$

$$= W_{12} + W_{23} + W_{31}$$

$$= 100 + (-80) + 130 = 150 \text{ kJ}$$ **Ans.**

We know that for a cyclic process

$$\oint \delta Q = \oint \delta W = 150 \text{ kJ}$$

Therefore, net heat interaction $= 150$ kJ **Ans.**

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Principles of Thermometry

- Thermometry is the science and practice of temperature measurement. Any measurable change in a thermometric probe (e.g. the dilatation of a liquid in a capillary tube, variation of electrical resistance of a conductor, of refractive index of a transparent material, and so on) can be used to mark temperature levels, that should later be calibrated against an internationally agreed unit if the measure is to be related to other thermodynamic variables.

- Thermometry is sometimes split in metrological studies in two subfields: contact thermometry and noncontact thermometry. As there can never be complete thermal uniformity at large, thermometry is always associated to a heat transfer problem with some space-time coordinates of measurement, given rise to time-series plots and temperature maps.

Constant Volume Gas Thermometer

(i) Constant Volume Gas Thermometers

This thermometer consists of a capillary tube (C), which connects thermometer bulb with a *U*-tube manometer. A small amount of helium gas is contained in the bulb '*B*'. The left limb of manometer is kept open to atmosphere and can be moved vertically and mercury level on the right limb can be adjusted so that it just touches lip '*L*' of the capillary. The pressure of the gas in the bulb is used as a thermometric property and is given by

$$P = P_{atm} + \rho_m h$$

where, P_{atm} = Atmospheric pressure

ρ_m = density of mercury

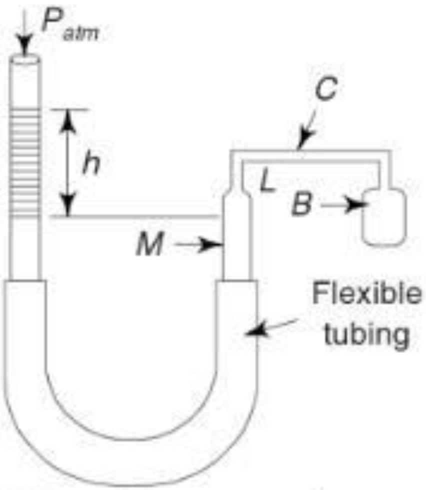


Fig. 1.14 Constant volume gas thermometer

When the bulb is brought in contact with the system whose temperature is to be measured, it comes in thermal equilibrium with the system. The gas in the bulb will be heated and expanded, pushes the mercury column downward on the right limb. This rises mercury column on the left limb. The flexible limb is then adjusted so that the mercury again touches the lip '*L*'. The difference in mercury level '*h*' is recorded and the pressure '*P*' of the gas in the bulb is estimated. Since the gas volume in the bulb is constant, from ideal gas equation we can write,

$$\Delta T = \frac{V}{R} \Delta P \qquad (\because PV = mRT)$$

Constant Volume Gas Thermometer

($\because$ V is constant, R is constant)

$$\Delta T \propto \Delta P$$

i.e. the temperature rise is proportional to pressure rise.

Since for an ideal gas at constant volume, $T \propto P$

$$\frac{T}{Ttp} = \frac{P}{Ptp}$$

$$T = 273.16 \ \frac{P}{Ptp}$$

Ttp: Triple point temperature of water

or

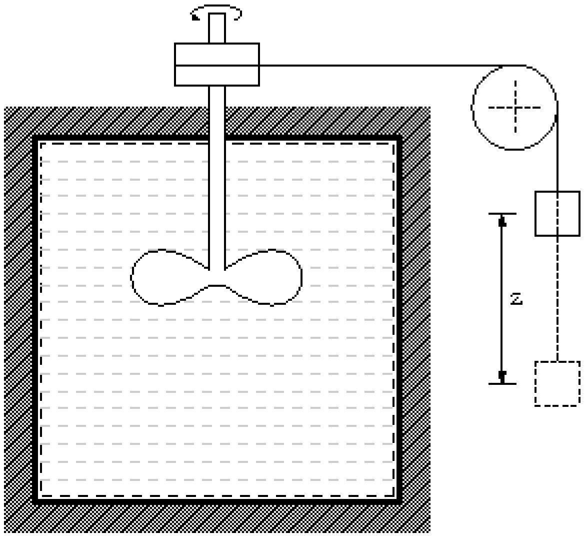
$$T = 273.16 \ \lim_{Ptp \to 0} \left[\frac{P}{Ptp} \right]$$

Temperature Scale

Scales of Temperature:

- There are three temperature scales in use Fahrenheit, Celsius and Kelvin. Fahrenheit temperature scale is a scale based on 32 for the freezing point of water and 212 for the boiling point of water, the interval between the two being divided into 180 parts.
- The conversion formula for a temperature that is expressed on the Celsius (C) scale to its Fahrenheit (F) representation is: $F = 9/5C + 32$.
- Celsius temperature scale also called centigrade temperature scale, is the scale based on 0 for the freezing point of water and 100 for the boiling point of water.
- Kelvin temperature scale is the base unit of thermodynamic temperature measurement in the International System (SI) of measurement. It is defined as 1/ 273.16 of the triple point (equilibrium among the solid, liquid, and gaseous phases) of pure water.

Joules Experiment



James P. Joule carried out his famous experiment; he placed known amounts of water, oil, and mercury in an insulated container and agitated the fluid with a rotating stirrer. The amounts of work done on the fluid by the stirrer were accurately measured, and the temperature changes of the fluid were carefully noted. He found for each fluid that a fixed amount of work was required per unit mass for every degree of temperature rise caused by the stirring, and that the original temperature of the fluid could be restored by the transfer of heat through simple contact with a cooler object. In this experiment you can conclude there is a relationship between heat and work or in other word heat is a form of energy.

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Heat and Work

Heat:

- It is the energy in transition between the system and the surroundings by virtue of the difference in temperature Heat is energy transferred from one system to another solely by reason of a temperature difference between the systems.
- Heat exists only as it crosses the boundary of a system and the direction of heat transfer is from higher temperature to lower temperature. For thermodynamics sign convention, heat transferred to a system is positive; Heat transferred from a system is negative.

Work:

- Thermodynamic definition of work: Positive work is done by a system when the sole effect external to the system could be reduced to the rise of a weight.
- Work done by the system is positive and work done on the system is negative.

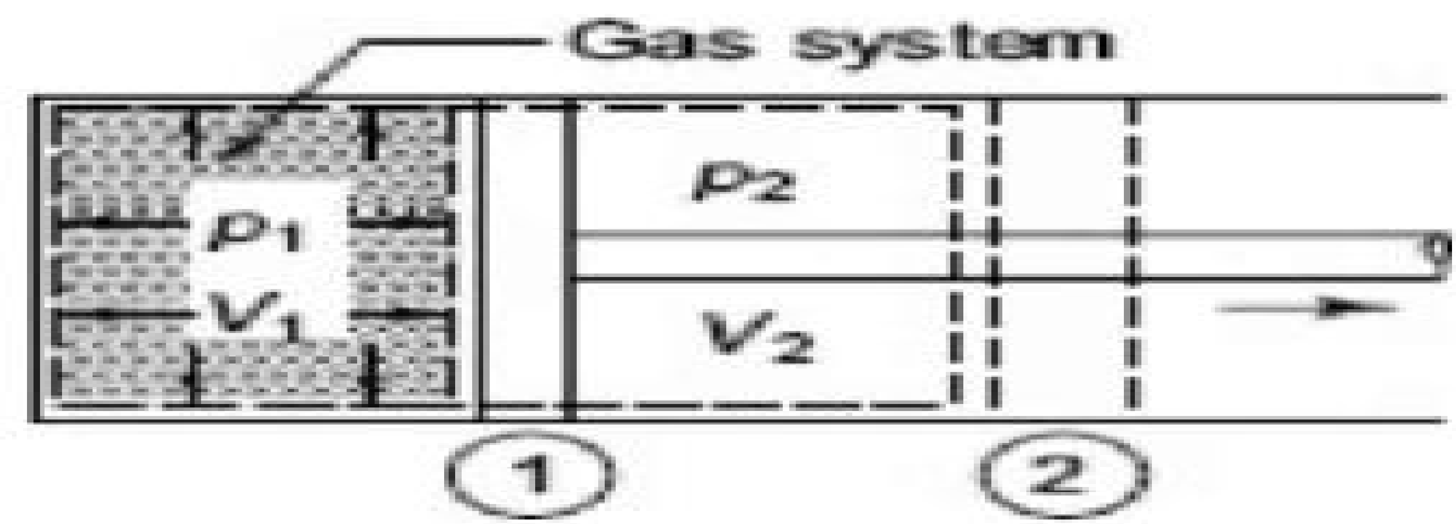
Types of work interaction

- Expansion and compression work (displacement work)
- Work of a reversible chemical cell
- Work in stretching of a liquid surface
- Work done on elastic solids
- Work of polarization and magnetization

Displacement Work

pdV-WORK OR DISPLACEMENT WORK

Let the gas in the cylinder (Fig. 3.4) be a system having initially the pressure p_1 and volume V_1. The system is in thermodynamic equilibrium, the state of which is described by the coordinates p_1, V_1. The piston is



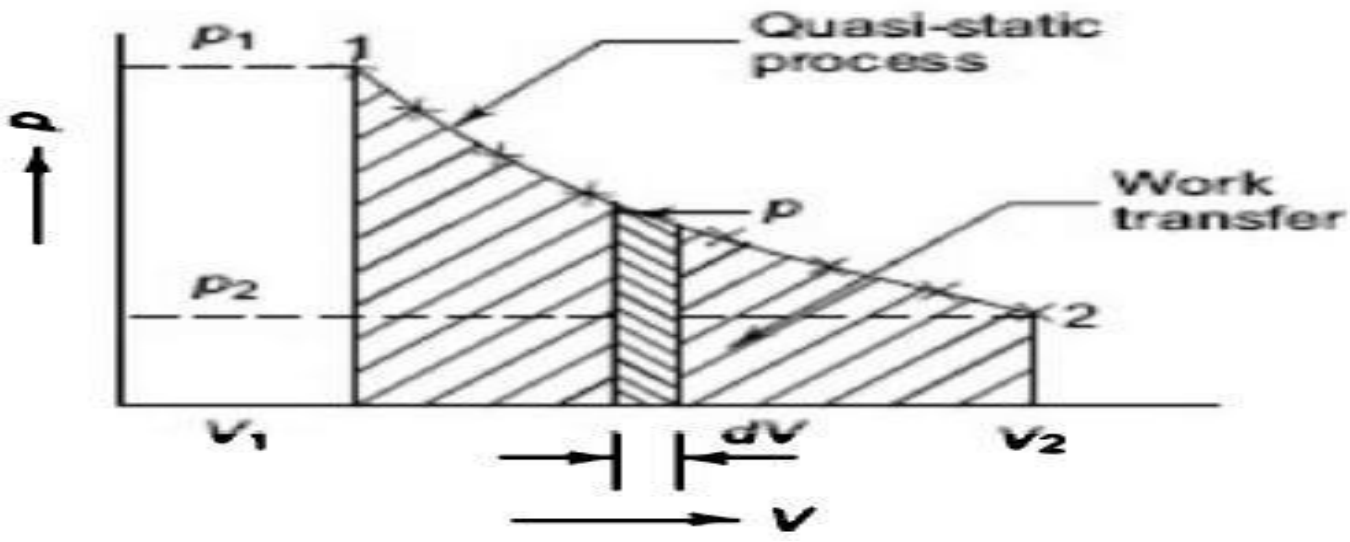
pdV work

- The infinitesimal amount of work done by the gas on the system is

$$dW\text{-}F.dl\text{-}padl\text{-}pdV$$

- The amount of work done by the system will be

$$W_{1\text{-}2} = \int_{v1}^{v2} pdV$$



Shaft Work

2. Shaft work When a shaft, taken as the system (Fig. 3.14a), is rotated by a motor, there is work transfer into the system. This is because the shaft can rotate a pulley which can raise a weight. If T is the torque applied to the shaft and $d\theta$ is the angular displacement of the shaft, the shaft work is

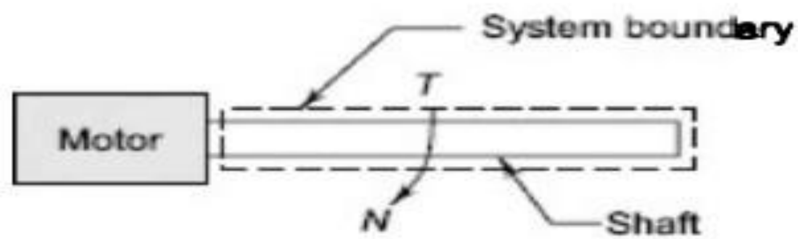


Fig. 3.14(A) *Shaft work*

$$W - \int_1^2 T d\theta \qquad (3.14\,a)$$

and the shaft power is

$$W \quad \int_1^2 T \frac{d\theta}{d\tau} \quad T\omega \qquad (3.15\,b)$$

where ω is the angular velocity and T is considered a constant in this

Flow Work

Flow work The flow work, significant only in a flow process or an open system, represents the energy transferred across the system boundary as a result of the energy imparted to the fluid by a pump, blower or compressor to make the fluid flow across the control volume. Flow work is analogous to displacement work. Let p be the fluid pressure in the plane of the imaginary piston, which acts in a direction normal to it (Fig. 3.16). The work done on this imaginary piston by the external pressure as the piston moves forward is given by

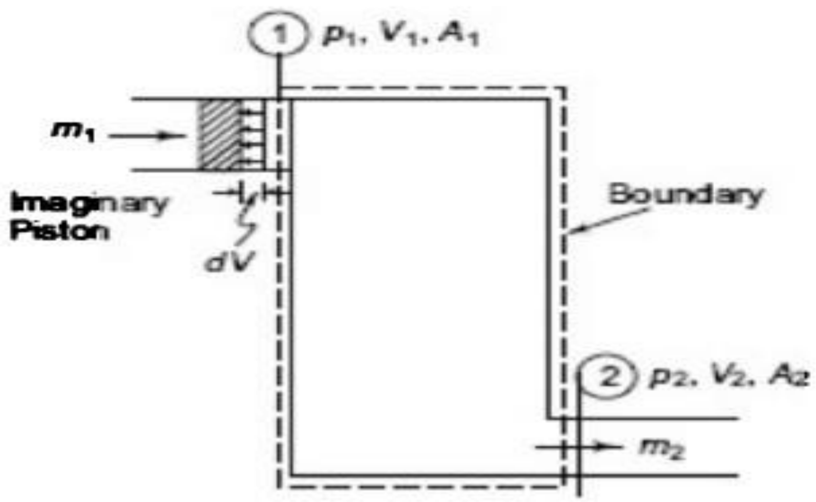


Fig. 3.16 *Flow work*

$$đW_{\text{flow}} = p\,dV, \tag{3.16}$$

Point and Path functions

- Point function does not depend on the history (or path) of the system. It only depends on the state of the system.

Examples of point functions are: temperature, pressure, density, mass, volume, enthalpy, entropy, internal energy etc.

- Path function depends on history of the system (or path by which system arrived at a given state).

Examples for path functions are work and heat.

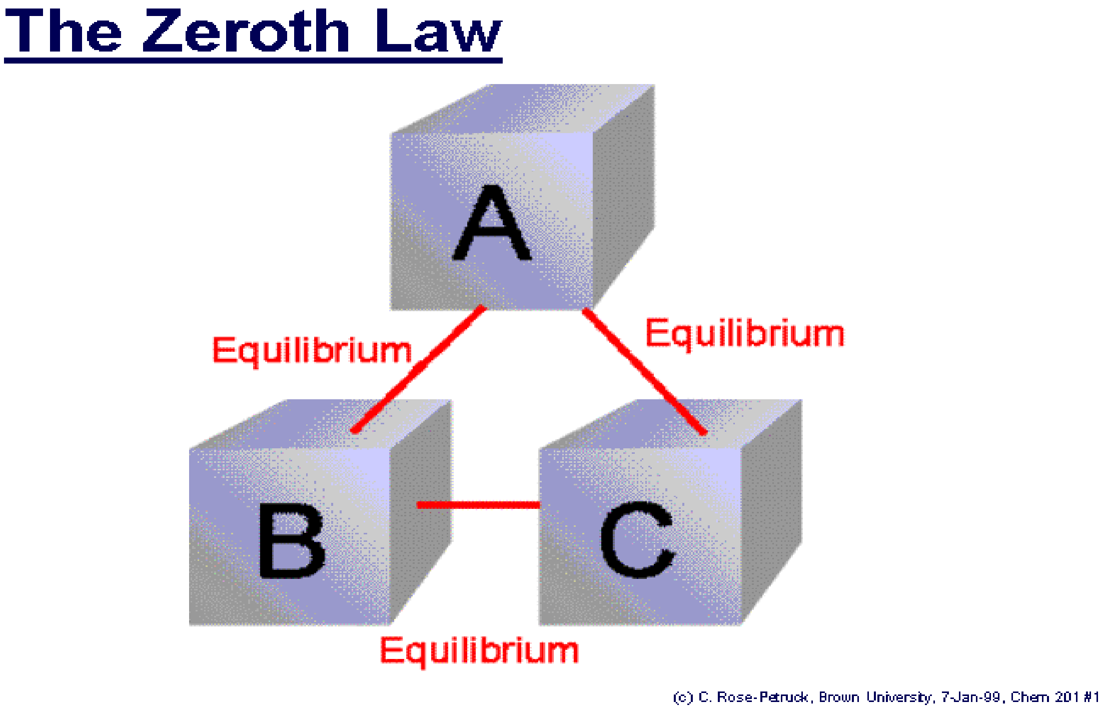
- Path functions are not properties of the system, while point functions are properties of the system.
- Change in point function can be obtained by from the initial and final values of the function, whereas path has to defined in order to evaluate path functions.

Zeroth Law of Thermodynamics

- The Thermodynamics Zeroth Law states that if two systems are at the same time in thermal equilibrium with a third system, they are in equilibrium with each other.

- If an object with a higher temperature comes in contact with an object of lower temperature, it will transfer heat to the lower temperature object. The objects will approach the same temperature and in the absence of loss to other objects, they will maintain a single constant temperature. Therefore, thermal equilibrium is attained.

Zeroth Law



If objects ‘A’ and ‘C’ are in thermal equilibrium with ‘B’, then object ‘A’ is in thermal equilibrium with object ‘C’. Practically this means are at the same temperature and it forms the basis for comparison of temperatures.
If a=b; b=c theall three objects n a=c

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First Law of Thermodynamics

- During a thermodynamic cycle, a cyclic process the systems undergoes, the cyclic integral of heat added is equal to integral of work done. The first law equation can also be written in the form,

$$§(dQ – dW) = 0$$

- Equation dU = dQ – dW is a corollary to the first law of thermodynamics. It shows that there exists a property internal energy (U) of the system, such that a change in its value is equal to the difference in heat entering and work leaving the system.
- The First law of thermodynamics states that energy is neither created nor destroyed. Thus the total energy of the universe is a constant. However, energy can certainly be transferred from one form to another form.
- The 1st law of thermodynamics can be mathematically stated as follows:

$$§dQ = §dW$$

Corollary 1:

- There exists property of closed system; the change in value of this property during the process is given by the difference between heat supplied and work done.

$$dU = dQ - dW$$

- Here E is property of system and is called as total energy that includes internal energy, kinetic energy, potential energy, electrical energy, magnetic energy, chemical energy, etc.

Corollary 2:

- For the isolated system, heat and work both interactions are absent ($d\,Q = 0$, $d\,W = 0$) and E = constant. Energy can neither be created nor be destroyed; but, it can be converted from one form to other.

Corollary 3:

- A perpetual motion machine of first kind is almost impossible.

PMM1

Perpetual Motion Machine of First Kind (PMM1):

- A hypothetical machine which can produce useful work *without any source* or which can produce more energy than consumed. It violates the first law of Thermodynamics. Perpetual Motion Machine 1 (PMM1) is a machine that violates first law of thermodynamics. First law of thermodynamics states that energy can be neither created or nor destroyed. A perpetual motion machine 1 violates the law by creating energy. All processes in universe comply with first and second law of thermodynamics. Therefore PPM1 does not and can never exist.

e.g.: An electric heater that consumes 1KW of electricity cannot produce more than 1KW heat.

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Steady flow energy equation

- Virtually all the practical systems involve flow of mass across the boundary separating the system and the surroundings. Whether it be a steam turbine or a gas turbine or a compressor or an automobile engine there exists flow of gases/gas mixtures into and out of the system. So we must know how the first Law of thermodynamics can be applied to an open system.
- The fluid entering the system will have its own internal, kinetic and potential energies.
- Let u1 be the specific internal energy of the fluid entering C_1 be the velocity of the fluid while entering Z_1 be the potential energy of the fluid while entering Similarly let u_2, C_2 and Z_2 be respective entities while leaving.

Application f First Law

APPLICATION OF FIRST LAW TO STEADY FLOW PROCESS

Steady Flow Energy Equation (S.F.E.E.)

In many practical problems, the rate at which the fluid flows through a machine or piece of apparatus is constant. This type of flow is called *steady flow*.

Assumptions :

The following *assumptions* are made in the system analysis :

(*i*) The mass flow through the system remains constant.

(*ii*) Fluid is uniform in composition.

(*iii*) The only interaction between the system and surroundings are work and heat.

(*iv*) The state of fluid at any point remains constant with time.

(*v*) In the analysis only potential, kinetic and flow energies are considered.

SFEE

The steady flow equation can be expressed as follows :

$$u_1 + \frac{C_1^2}{2} + Z_1 g + p_1 v_1 + Q = u_2 + \frac{C_2^2}{2} + Z_2 g + p_2 v_2 + W \qquad \text{...(4.45)}$$

$$(u_1 + p_1 v_1) + \frac{C_1^2}{2} + Z_1 g + Q = (u_2 + p_2 v_2) + \frac{C_2^2}{2} + Z_2 g + W$$

$$h_1 + \frac{C_1^2}{2} + Z_1 g + Q = h_2 + \frac{C_2^2}{2} + Z_2 g + W \qquad [\because \ h = u + pv]$$

If Z_1 and Z_2 are neglected, we get

$$h_1 + \frac{C_1^2}{2} + Q = h_2 + \frac{C_2^2}{2} + W \qquad \text{...[4.45 (a)]}$$

where, Q = Heat supplied (or entering the boundary) per kg of fluid,

W = Work done by (or work coming out of the boundary) 1 kg of fluid,

C = Velocity of fluid ,

Z = Height above datum,

p = Pressure of the fluid,

u = Internal energy per kg of fluid, and

pv = Energy required for 1 kg of fluid.

This equation is applicable to any medium in any steady flow. It is applicable not only to rotary machines such as centrifugal fans, pumps and compressors but also to reciprocating machines such as steam engines.

Application of SFEE

ENGINEERING APPLICATIONS OF STEADY FLOW ENERGY EQUATION (S.F.E.E.)

. Water Turbine

Refer to Fig. 4.32. In a water turbine, water is supplied from a height. The potential energy of water is converted into kinetic energy when it enters into the turbine and part of it is converted into useful work which is used to generate electricity.

Considering centre of turbine shaft as *datum*, the energy equation can be written as follows :

$$\left(u_1 + p_1 v_1 + Z_1 g + \frac{C_1^{\,2}}{2}\right) + Q = \left(u_2 + p_2 v_2 + Z_2 g + \frac{C_2^{\,2}}{2}\right) + W$$

In this case,

$$Q = 0$$

$$\Delta u = u_2 - u_1 = 0$$

$$\therefore \quad v_1 = v_2 = v$$

$$Z_2 = 0$$

$$\left(p_1 v + Z_1 g + \frac{C_1^{\,2}}{2}\right) = \left(p_2 v + Z_2 g + \frac{C_2^{\,2}}{2}\right) + W$$

ENGINEERING THERMODYNAMICS
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Water Turbine

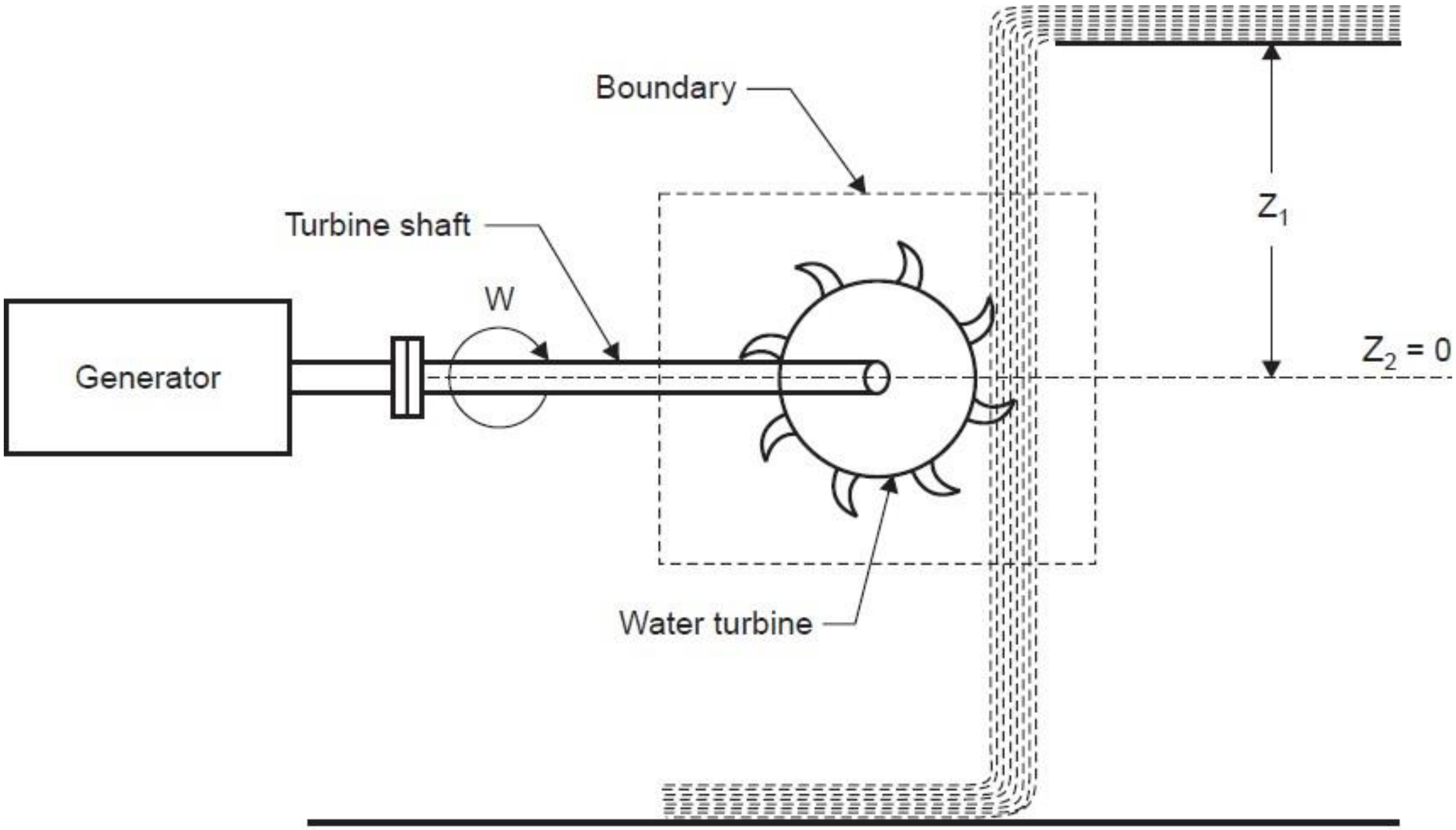

Fig. 4.32. Water turbine.

Steam Turbine

Steam or Gas Turbine

In a steam or gas turbine steam or gas is passed through the turbine and part of its energy is converted into work in the turbine. This output of the turbine runs a generator to produce electricity as shown in Fig. 4.33. The steam or gas leaves the turbine at lower pressure or temperature.

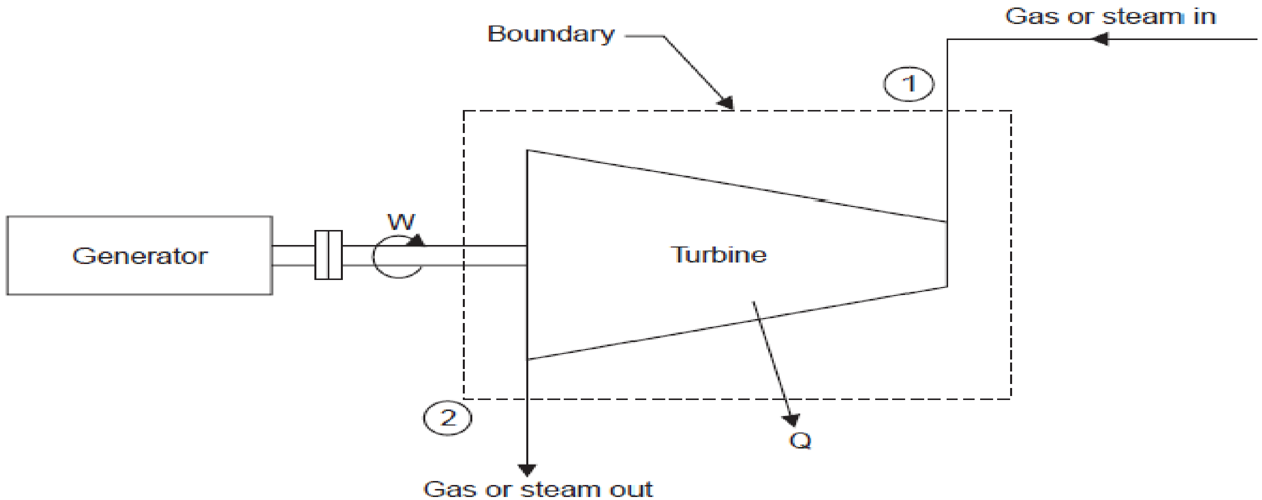

Fig. 4.33. Steam or gas turbine.

Applying energy equation to the system.

Here, $Z_1 = Z_2$ (*i.e.*, $\Delta Z = 0$)

$$h_1 + \frac{C_1^2}{2} - Q = h_2 + \frac{C_2^2}{2} + W \qquad \text{...(4.55)}$$

The sign of Q is *negative* because heat is *rejected* (or comes out of the boundary).

The sign of W is *positive* because work is done by the system (or work comes out of the boundary).

Reciprocating Compressor

Reciprocating Compressor

Refer Fig. 4.36. The reciprocating compressor draws in air from atmosphere and supplies at a considerable higher pressure in small quantities (compared with centrifugal compressor). The reciprocating compressor can be considered as steady flow system *provided the control volume includes the receiver which reduces the fluctuations of flow considerably.*

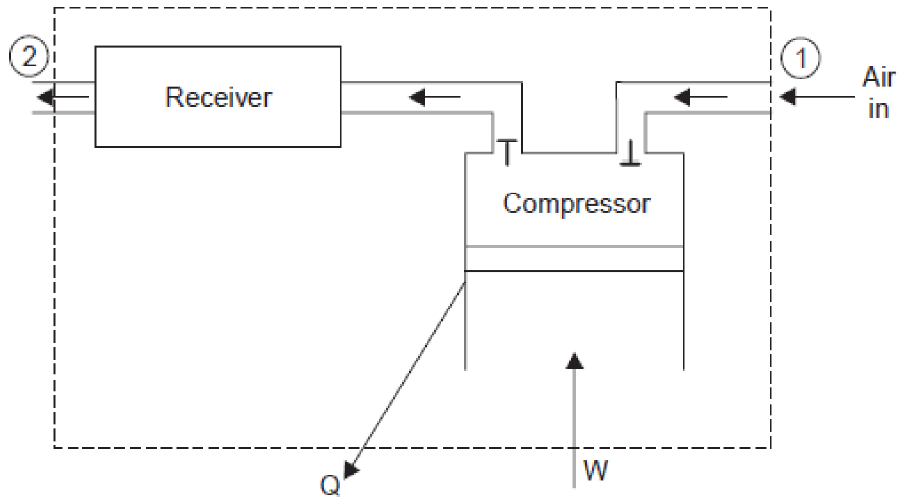

Fig. 4.36. Reciprocating compressor.

Applying energy equation to the system, we have :

$\Delta PE = 0$ and $\Delta KE = 0$ since these changes are negligible compared with other energies.

$$\therefore \qquad h_1 - Q = h_2 - W \qquad \text{...(4.58)}$$

Boiler

Boiler

A boiler transfers heat to the incoming water and generates the steam. The system is shown in Fig. 4.37.

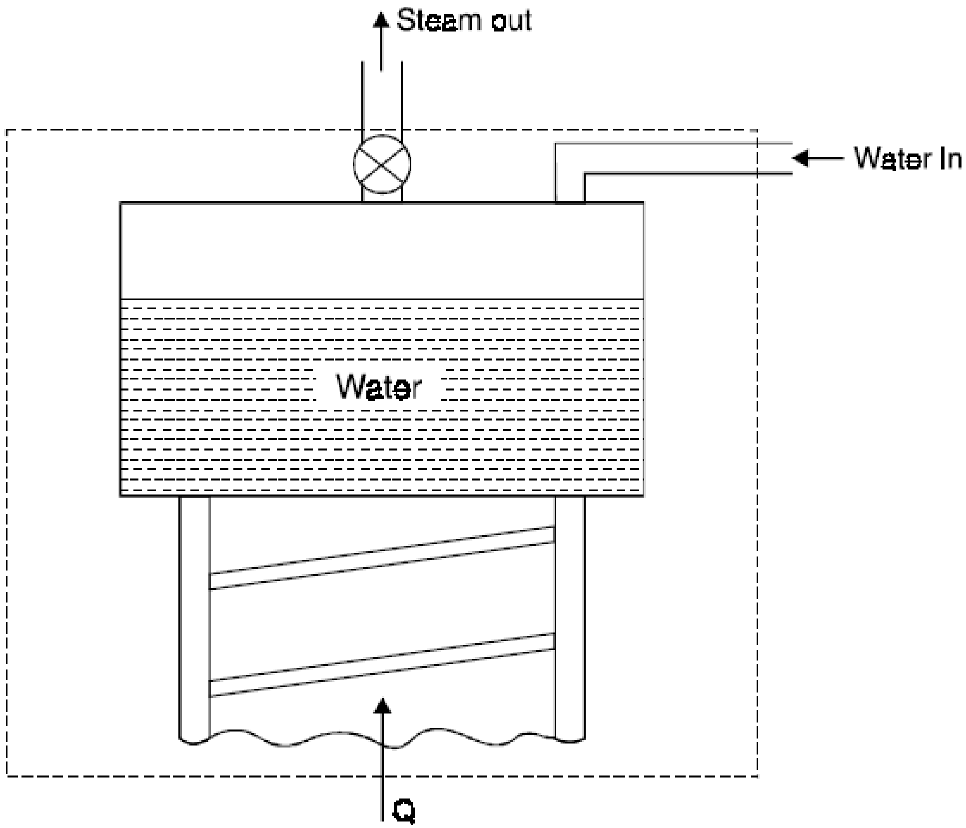

Fig. 4.37. Boiler