Velammal Institute of Technology, Panchetti
Department of Mechanical Engineering

ME8351- ENGINEERING THERMODYNAMICS
Focused question

UNIT I BASIC CONCEPTS AND FIRST LAW

PART –A

1. Define the term thermal engineering.

Ans: Thermal engineering is the science that deals with the energy transfer to practical applications such as energy transfer power generation, refrigeration, gas compression and its effect on the properties of working substance.

2. What is meant by thermodynamic system? How do you classify it? (MU – Oct'99, Apr'2000: BRU – Apr'96; MSU – Apr'96)

Ans: Thermodynamic system is defined as the any space or matter or group of matter where the energy transfer or energy conversions are studied.

It may be classified into three types.

(a) Open system
(b) Closed system
(c) Isolated system

3. What is meant by closed system? Give an example.(BNU – Nov'95)

Ans: When a system has only heat and work transfer, but there is no mass transfer, it is called as closed system.

Example: Piston and cylinder arrangement.

4. Define a open system, Give an example.

Ans: When a system has both mass and energy transfer it is called as open system.
Example: Air Compressor.

6. Define an isolated system

Ans: Isolated system is not affected by surroundings. There is no heat, work and mass transfer take place. In this system total energy remains constant. Example: Entire Universe

7. Define: Specific heat capacity at constant pressure. (MU – Oct'99)

Ans: It isdefined as the amount of heat energy required to raise or lower the temperature of unit mass of the substance through one degree when the pressure kept constant. It is denoted by C_p.

8. Define: Specific heat capacity at constant volume.

Ans: it is defined as the amount of heat energy required to raise or lower the temperature of unit mass of the substance through one degree when volume kept constant.

9. What is meant by surroundings?
Ans: Any other matter out side the system boundary is called as surroundings.

10. What is boundary?
Ans: System and surroundings are separated by an imaginary line is called boundary.

11. What is meant by thermodynamic property? (MU – Apr'2001; BRU – Nov'96; BNU – Nov'94)

Ans: Thermodynamic property is any characteristic of a substance which is used to identify the state of the system and can be measured, when the system remains in an equilibrium state.

12. How do you classify the property?
Ans: Thermodynamic property can be classified into two types.

1. Intensive or Intrinsic and
2. Extensive and Extrinsic property.

13. Define Intensive and Extensive properties. (MU – Oct'96,98; MKU – Apr'96)

Ans: The properties which are independent on the mass of the system is called intensive properties.
e.g., Pressure, Temperature, Specific Volume etc.,

The properties which are dependent on the mass of the system is called extensive properties. e.g., Total energy, Total volume, weight etc.

15. What do you understand by equilibrium of a system?

Ans: When a system remains in equilibrium state, it should not undergo any charges to its own accord.

16. What is meant by thermodynamic equilibrium? (MU – Apr'98; MSU – Apr'96)

Ans: When a system is in thermodynamic equilibrium, it should satisfy the following three conditions.

(a) Mechanical Equilibrium :- Pressure remains constant
(b) Thermal equilibrium :- Temperature remains constant
(c) Chemical equilibrium : There is no chemical reaction.

17. State the First law of thermodynamics (MU – Apr'95)

Ans:First of thermodynamics states that when system undergoes a cyclic process the net heat transfer is equal to work transfer.

18. Define: PMM of first kind

Ans: PMM of first kind delivers work continuously without any input. It violates first law of thermodynamics, It is impossible to construct an engine working with this principle.

19. Define the term process (MKU – Nov'96)

Ans: It is defined as the change of state undergone by a gas due to energy flow.

20. Define the term Cycle: (MKU – Nov'96)

Ans: When a system undergoes a series of processes and return to its initial condition, it is known as cycle.

21. What is meant by open and closed cycle.
Ans: In a closed cycle, the same working substance will recirculate again and again.

In a open cycle, the same working substance will be exhausted to the surroundings after expansion.

22. What is meant by reversible and irreversible process. (MU – Apr'2001; BNU – Nov'94)

Ans: A process is said to be reversible, it should trace the same path in the reverse direction when the process is reversed. It is possible only when the system passes through a continuous series of equilibrium state.

If a system does not pass through continuous equilibrium state, then the process is said to be irreversible.

23. What is meant by Point and Path function? (Mu – Oct'2000; MKU – Nov'94)

Ans: The quantities which is independent on the process or path followed by the system is known as point functions.Example: Pressure, volume, temperature, etc.,

The quantities which are dependent on the process or path followed by the system is known as path functions.

Example: Heat transfer, work transfer.

24. What is Quasi – Static process? (MU – Oct'98, Apr'2000 & 2001; BNU – Nov'95)

Ans: The process is said to be quasi – static, it should proceed infinitesimally slow and follows continuous series of equilibrium states. Therefore, the quasi static, it should proceed infinitesimally slow and follows continuous series of equilibrium states. Therefore, the quasi static process may be an reversible process.

25. Explain Zeroth Law of thermodynamics? (MU – Nov'94, Apr'2001; BRU – Apr'96)

Ans: Zeroth law of thermodynamics states that when two systems are separately in thermal equilibrium with a third system, then they themselves are in thermal equilibrium with each other.

26. Define the term enthalpy? (MU – Oct'99)

Ans: The Combination of internal energy and flow energy is known as enthalpy of the system. It may also be defined as the total heat of the substance.

Mathematically, enthalpy (H) = U + pv KJ)

Where, U – internal energy
p – pressure
v – volume
In terms of C_p& T → $H = mC_p (T_2-T_1)K$

27. Define the term internal energy (MKU – Apr'96)

Ans: Internal energy of a gas is the energy stored in a gas due to its molecular interactions.

It is also defined as the energy possessed by a gas at a given temperature.

28. What is meant by thermodynamic work?

Ans: It is the work done by the system when the energy transferred across the boundary of the system. It is mainly due to intensive property difference between the system and surroundings.

29. Define Heat.

Ans: Heat is the energy crossing the boundary due to the temperature difference between the system and surroundings.

Ans: Energy can neither be created nor destroyed, but it can be transferred from one form to another.

32. Define entropy of a pure substance. (MU – Oct'2000; MKU – Nov'96; BRU – Nov'95)

Ans: Entropy is an important thermodynamic property, which increases with addition of heat and decreases with its removal. Entropy is a function of temperature only. It is an unavailability of energy during energy transfer.

30. Give the general gas energy equations. (MU – Apr'95 & 98)

Ans: $dH = dE + dW$.

33. Define an isentropic process. (MU – Oct'99)

Ans: Isentropic process is also called as reversible adiabatic process. It is a process which follows the law of $pV^y = C$ is known as isentropic process. During this process entropy remains constant and no heat enters or leaves the gas.

34. Explain the throttling process.

Ans: When a gas or vapour expands and flows through an aperture of small size, the process is called as throttling process.

35. Work done in a free expansion process is _____ (MU – Apr'97)

Ans: Zero

36. Define free expansion process.

Ans: When a gas expands suddenly into a vacuum through a large orifice is known as free expansion process.

37. Which property is constant during throttling? (MU – Oct'98, Oct'2000)

Ans: Enthalpy

38. If in the equation $PV^n = C$, the value of n = then the process is called _____

Ans: Constant Volume process

39. The polytropic index (n) is given by _____ (MU – Apr'95 & 96)

Ans: n = log (P2/P1)/ log (V1/V2)

40. Work transfer is equal to heat transfer in case of _____ process.MU – Nov'94)

Ans: Isothermal process.

41. Write down the characteristic gas equation.

Ans: Characteristic gas equation is PV = mRT

Where,

p =Pressure V=Volume R = Characteristic gas constant T = Temperature.

42. What is meant by steady flow process? (BNU – Nov'96)

Ans: During the process the rate of flow of mass and energy across the boundary remains constant, is known as steady flow process.

43. What is the difference between steady flow and non – flow process?

Ans: During the steady flow process the rate of flow of mass and energy across the boundary remains constant.

In case of non – flow across the system and boundary.

PART –B

1. Explain Concept of continuum, comparison of microscopic and macroscopic approach.

Concept of continuum:

In microscopic approach the substance is assumed to be continuously distributed, ignoring the space between the molecules. This is known as continuum hypothesis.

Since the matter is treated as continuous, the density at a point can be defined as

$$\rho = \lim_{v \to v'} \left(\frac{m}{v} \right)$$

Where v' is the smallest volume for which a definite value of the ratio exists. Below the limiting value of v', the fluctuation in average density will be high and a definite value for the ratio becomes impossible, with the *mean free path** of the molecules approaching the order of magnitude of the dimension of the vessel.

Macroscopic (or) classical approach

- Macroscopic thermodynamics is only concerned with the effects of the action of many molecules and these effects can be perceived by human senses.
- In a macroscopic approach, a certain quantity of matter is considered, without events occurring at molecular level being taken into account.

Microscopic (or) statistical approach

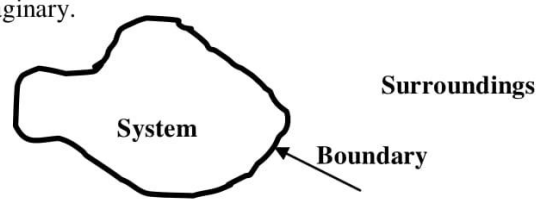
- In this matter is composed of my raids of molecules.
- If it is a gas, each molecule at a given instant has a certain position, velocity, and energy and for each molecule these change very frequently as a result of collisions. The behaviour of gas is described by summing up the behavior of each molecule.

2. Explain the term System and their types.

A Thermodynamic **system** is defined as a quantity of matter or a region in space whose behavior is being investigated.

Everything external to the system is defined as **surroundings**. In its usual context, the term surroundings are restricted to the regions in the immediate vicinity which has a detectable influence on the system.

Boundary is the surface which separates the system from its surroundings. It may be fixed or moving and real or imaginary.

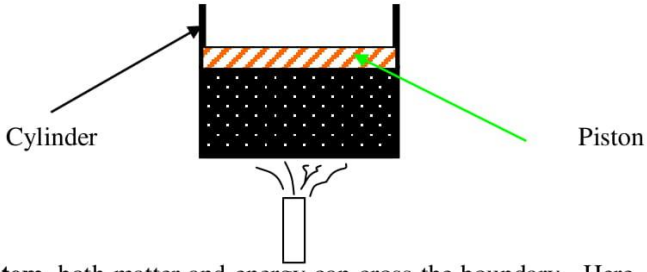


Types of Thermodynamic Systems

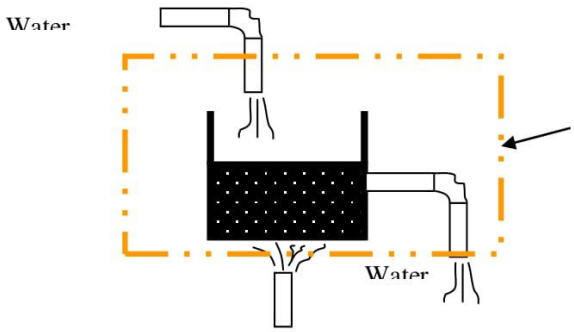
There are three types of thermodynamic systems:

a) Closed System b) Open System and c) Isolated System

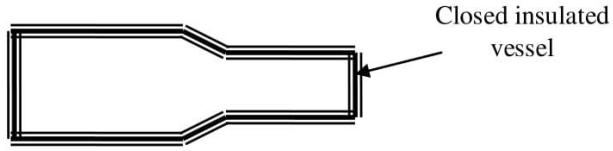
In **closed system**, attention is focused on a fixed mass. Energy in the form of heat and work can cross the boundary of the system. But there is no mass flow across the boundary. Hence, the possibility of change in volume is always there in the closed systems.



In **open system**, both matter and energy can cross the boundary. Here, the behaviour of a fixed region in space called control volume is investigated and hence, there is no change in volume. The surface of the control volume is known as control surface.



A system that exchanges neither energy nor matter with its surroundings is known as an **isolated system.**

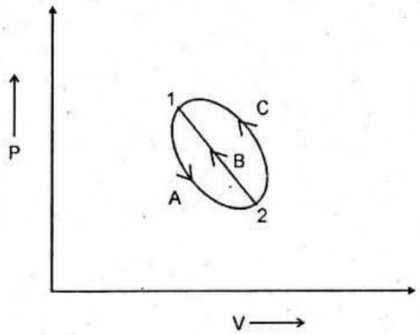


3. Define internal energy and prove that it is a point function.

Internal energy:

Internal energy is defined as the heat energy stored in the gas at a given temperature.

Consider a system changing from state 1 to state 2 by following the Path A but the system returns to the original state by the two different paths namely B and C as shown Figure.



As per the first law of thermodynamics, for the Path A

$Q_a = W_a + \Delta U_a$

For Path C, $Q_C = W_C + \Delta U_C$

For the cycle l–A–2–B–l, we know that

$$\oint W = \oint Q$$

$$W_A + W_B = Q_A + Q_B$$

$$\Rightarrow Q_A - W_A = W_B - Q_B \Rightarrow \Delta U_A = -\Delta_B \quad \ldots (1)$$

For Path B, $Q_B = W_B + \Delta U_B$

Similarly,

For the cycle 1−A−2−C−1, we know that $\oint W = \oint Q$

$$W_A + W_C = Q_A + Q_C \Rightarrow Q_A - W_A = W_C - Q_C$$

$$\Rightarrow \Delta U_A = -\Delta U_C \quad \ldots (2)$$

From equation (1) and (2), we can write
$\Delta U_B = \Delta U_C$.
If indicates that the change is internal energy is constant between two states irrespective of the path followed by the system. Hence, the internal energy is a property of the system.

4. Define 'processes and 'cycle' with one example each. Explain some process

It is defined as to change of state undergone by a gas due to energy flow.
Example: Constant Volume Process, Adiabatic Process etc.
Cycle: When a system undergoes a series of process and return to its initial condition, it is known as cycle.
Example: Air Standard Cycle, Vapour Power Cycle etc.

Constant Pressure Process (Isobaric Process)

Figure 2.5 shows a piston cylinder arrangement containing a fluid. Let the fluid expands such that the pressure of the fluid remains constant throughout the process. Figure 2.6 shows the process in a p-V diagram.

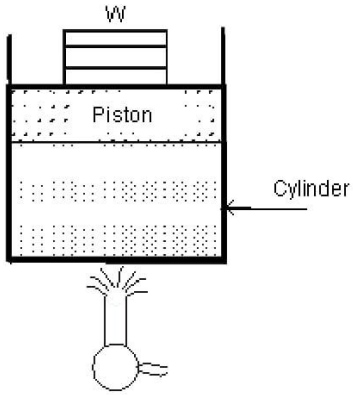


Figure 2.5

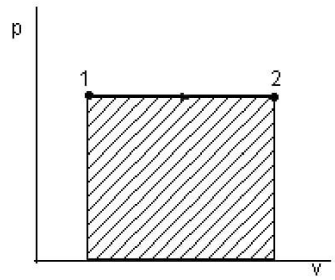


Figure 2.6

The mathematical expression for displacement work can be obtained as follows:

$$W = p\,(V_2 - V_1)$$

This expression shows that the area under a curve in a p-V diagram gives work done in the process.

Constant volume process (Isochoric Process)

Consider a gas contained in a rigid vessel being heated. Since there is no change in volume, the displacement work is zero.

Hyperbolic process

Let the product of pressure and volume remains constant at all the intermediate states of a process. In the p-V diagram it will be a hyperbola as shown in the below figure.

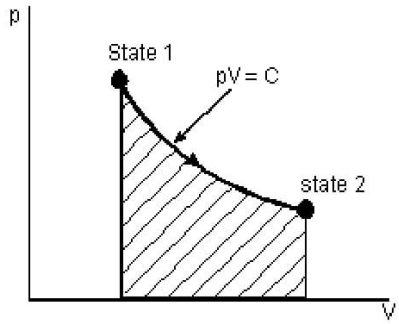


Figure 2.7

$$_1W_2 = \int_1^2 pdV$$

$$= \int_1^2 CdV \text{ where C=pV}$$

$$= C\int_1^2 \frac{1}{V}dV$$

$$= C \ln (V_2/V_1)$$

$$= p_1V_1\ln (V_2/V_1) \text{ (or) } p_2V_2\ln (V_2/V_1)$$

For Ideal gases when temperature remains constant, pV will be constant i.e., isothermal process are hyperbolic processes for an ideal gas.

Polytrophic Process

Any process can be represented by the general form pV^n =constant. Based on the valve of **n**, the process differs as given below; for other values of n, the process is known as polytrophic process. Figure shows the polytrophic process of various possible polytrophic indexes 'n' on p-V coordinates. Expression for displacements work for a polytrophic process can be obtained as follows:

$$_1W_2 = \int_1^2 pdV$$

$$= \int_1^2 \frac{C}{V^n}dV \quad \text{where } C = pV^n$$

$$= C\int_1^2 V^{-n}dV$$

$$= C\left[\frac{V^{-n+1}}{-n+1}\right]_1^2$$

$$= \left[\frac{CV_2^{-n+1} - CV_1^{-n+1}}{-n+1}\right]_1^2$$

$$= \left[\frac{p_2V_2^{\,n}V_2^{-n+1} - p_1V_1^{\,n}V_1^{-n+1}}{-n+1}\right] \qquad \text{since } C = p_1V_1^{\,n} = p_2V^n{}_2$$

$$= \left[\frac{p_2V_2 - p_1V_1}{-n+1}\right]$$

5. Quasi-static, reversible and irreversible processes.

Quasi-static process:

In thermodynamics, a quasi-static process is a thermodynamic process that happens "infinitely slowly". No real process is quasi-static, but such processes can be approximated by performing them very slowly.

Any reversible process is necessarily a quasi-static one.

Reversible process:

The process in which the system and surroundings can be restored to the initial state from the final state without producing any changes in the thermodynamics properties of the universe is called a reversible process.

Irreversible process:

In the irreversible process the initial state of the system and surroundings cannot be restored from the final state.

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.

Identify any four reasons for the irreversibility in a process.

The reasons for irreversibility in a process is
(1) Lack of equilibrium. (2) Heat transfer through a finite temperature difference. (3) Lack of Pressure equilibrium within the interior of the system. (4) Free expansion. (5) Dissipative effects.

6. Explain the term Heat and work transfer, definition and comparison, sign convention.

Heat: Heat is defined as the energy crossing the boundary of a system due to the temperature difference between system and surrounding.

Thermodynamic work: It is the work done by the system when the energy transferred across the boundary of the system. It is mainly due to intensive property difference between the system and surrounding.

Flow work is significant only in a flow process or an open system; represents the energy transferred across the system boundary as result of 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

$$\boxed{dw_{flow} = P\,dV.}$$

Sign convention for work:

The work output from any system is taken as positive work.

Examples: Heat engines, turbine etc.

The work supplied to the system is taken as negative work.

Example: Compressor, Fans, heat pump

Sign convention for heat:

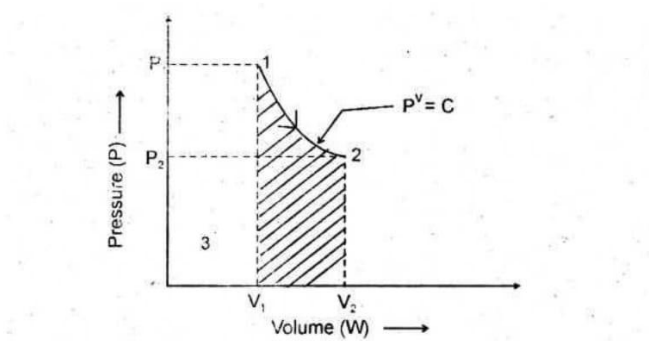
Heat given into a system is positive

Heat coming out of the system is negative

7. Derive the expression for the work transfer in an isothermal process.

Work transfer for an isothermal process:

In the process, the temperature of working substance remains constant pressure decreases are value increases. Hence, there is no change in Temperature. There is no change in internal energy and enthalpy because both the internals energy and enthalpy are function of temperature.



Isothermal process is very slow process so that the temperature is maintained constantly during the process.

Relation between P, V and T

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Here, $T_1 = T_2 \;\therefore\; P_1V_1 = P_2V_2 \Rightarrow \boxed{\frac{P_1}{P_2} = \frac{V_2}{V_1}}$

Work done (W)

For any Process

$$W = \int_1^2 P \cdot dV \qquad \ldots (1)$$

Characteristic gas equation is $; \frac{PV}{T} = C.$

Here, T = constant

PV = constant

$P^V = c,$

$$P_1V_1 = P_1V_2 \; ; P = \frac{C}{V}.$$

Substituting the value of P in equation (1)

$$W = \int_1^2 \frac{C}{V} dV = C \int_1^2 \frac{dV}{V} = C \cdot [ln\ V]_1^2 = C \cdot \ln \left[\frac{V_2}{V_1}\right]$$

$$W = PV \ln \left[\frac{V_2}{V_1}\right] \quad [\because \; C = P^V]$$

W = PV In [V2/ V1] = mRT In [V2 / v1]kJ.

8. Discuss briefly about application of closed and open systems.

Application based up on the open system
Apply steady flow energy equation for a boiler

Boiler

A boiler is a device which is used to generate high-pressure steam by supplying heat to the water. In this system, heat energy is stored in the steam. Therefore, internal energy (u) exists and flow energy (pv) exits due to movement of water. But there is no work is done by the system potential energy (gz) and kinetic energy (c2/2) is very small. So we can neglect it. Therefore; Z1 = Z2; C1 =C2; W=0

Applying the above conditions in SFEE, we get

Q=h2 - h1 k j

Apply steady flow energy equation for a Condenser

Condenser

A condenser is a device used to condense a hot steam in to water by using coolant. The main function of the condenser is to transfer heat steam to coolant .In this system there no work done, change in kinetic and potential energies. (i.e. =w=0, z1 = z2; c1 =c2).

Applying steady floe energy equation in the system, it may written as

h1 + q = h2

q = h 2 - h1 k j

Air Compressor

Air compressor is a device used to compress air at high pressure . The input for this compressor is atmospheric pressure . It is classified into two types

Rotary compressor

Reciprocating Compressor

Rotary Compressor

It is the one of the type of compressor which compresses air at high pressure by using rotors. It supply large of quantity of air at moderate pressure.

In this compressor,

There is no heat transfer(q = 0)

There is no change in potential and kinetic energies(z1 =z2; c1 = c2)

Then the steady floe energy equation is written as

h1 =h2 - W

h2-h1= w J / KG

This shows that the work done increase due to increase in enthalpy. A negative sign show that work is done the system.

Reciprocating Compressor

It produce very small quantity of air with very high pressure .Large area is made to contract with surrounding for producing small quantity of air when compared to rotary compressor .Hence ,the heat transfer is more

In the system the potential and kinetic energies are negligible (z 1=z2) and (c1 = c2)

The steady flow energy equation in the system is

h1 -q = h2 - w (-w is work done on the system)

w = q+(h2 - h1) J/KG

-q indicates the heat rejection to the surrounding

TURBINE

Turbine is a device which convert potential energy of working fluid into mechanical work . The turbine is fully insulated . Therefore , there is no heat transfer(q = 0). In the turbine the expansion of working fluid us treated as reversible isentropic . The change in potential and kinetic energy is negligible . Therefore Z1 = Z2 and C1 =C2

Applying the steady flow energy equation in above equation the above equation can be written as

h1 =h2 + W

Work output W= h1 - h2 J/KG

9. State that steady flow energy equation for a nozzle. State the assumptions made.

Nozzle is a device which increases the velocity or kinetic energy of the working substances at constant pressure drop In this system,

(1) There is no work done by the system (W = 0).

(2) There is no heat transfer taking place (Q = 0).

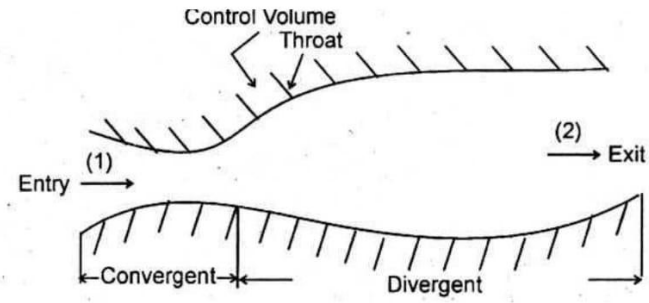
(3) There is no potential energy ($Z_1 = Z_2$).

Apply steady flow energy equation to this system.

$$\frac{C_1^2}{2} + h_1 = \frac{C_2^2}{2} + h_2.$$

$$\frac{C_2^2}{2} + \frac{C_1^2}{2} = h_1 - h_2.$$

This equation shows that increase in kinetic energy will result decrease in enthalpy.



From above equation it may be rewritten by

$$C_2^2 - C_1^2 = 2(h_1 - h_2)$$

$$\text{Final velocity, } C_2 = \sqrt{2(h_1 - h_2) + C_1^2}\ m/s$$

Since, initial velocity C_1 is very small, we can neglect it,

$$\boxed{C_2 = \sqrt{2(h_1 - h_2)}}.$$

The expansion of the fluid in a nozzle is treated as reversible adiabatic (or) isentropic.

$$C_2 = \sqrt{2 \times C_P(T_1 - T_2) + C_1^2} \qquad \boxed{\therefore\ h = C_P \Delta T}$$

$$C_2 = \sqrt{2 \times C_P \times \left[T_1 - T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}\right] + C_1^2}$$

For isentropic process

$$\therefore\ T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}} \times T_1$$

Final Velocity

$$C_2 = \sqrt{2 \times C_P \times T_1 \left[1 - \left[\frac{P_2}{P_1}\right]^{\frac{\gamma - 1}{\gamma}}\right] + C_1^2}.$$

10. Explain the Steady and unsteady flow processes.

When a flow process is satisfying the following conditions, it is known as a steady flow process.

1. The mass and energy content of the control volume remains constant with time.
2. The state and energy of the fluid at inlet, at the exit and at every point within the control volume are time independent.
3. The rate of energy transfer in the form of work and heat across the control surface is constant with time.

Therefore for a steady flow process

$$\sum m_{in} = \sum m_{out}$$

Also

$$[\Delta E_{CV}] = 0$$

$$[\dot{Q} - \dot{W}] + \sum_{in} m_{in}\left[h + \frac{C^2}{2} + Zg\right] - \sum_{out} m_{out}\left[h + \frac{C^2}{2} + Zg\right] = 0$$

For problem of single inlet stream and single outlet stream

$$[\dot{Q} - \dot{W}] = \dot{m}\left[(h_2 - h_1) + \left(\frac{C_2^{\,2} - C_1^{\,2}}{2}\right) + (Z_2 - Z_1)g\right]$$

This equation is commonly known as steady flow energy equation (SFEE).

Unsteady flow process:

Many processes of engineering interest involve unsteady flow, where energy and mass content of the control volume increase or decrease.

Examples for such conditions are:

1) Filling closed tanks with a gas or liquid.
2) Discharge from closed vessels.
3) Fluid flow in reciprocating equipment's during an individual cycle.

To develop a mathematical model for the analysis of such systems the following assumptions are made.

1) The control volume remains constant relative to the coordinate frame.

2) The state of the mass within the control volume may change with time, but at any instant of time the state is uniform throughout the entire control volume.

3) The state of the mass crossing each of the areas of flow on the control surface is constant with time although the mass flow rates may be time varying.

Unlike in steady flow system, duration of observation Δt plays an important role in transient analysis. Let mass of the working fluid within the control volume before and after the observation be m_1 and m_2 respectively. Applying mass balance we get,

$$(m_2 - m_1)_{CV} = \Sigma m_i - \Sigma m_0$$

Where Σm_i is the mass entered the control volume during the interval Δt seconds.

Σm_0 is the mass left the control volume during the interval Δt seconds.

By applying energy balance we get,

$$[Q_{cv} - W_{cv}] + \sum_{in} m_{in}\left[h + \frac{C^2}{2} + Zg\right] - \sum_{out} m_{out}\left[h + \frac{C^2}{2} + Zg\right] = \Delta E_{cv}$$

Where E_{CV} is the change in energy content of the control volume in Δt seconds

Q_{CV} is the heat energy entered into the control volume in Δt seconds.

W_{CV} is the work energy left the control volume in Δt seconds.

h_i & h_0 are specific enthalpy of the inlet and outlet streams respectively.

$Z_i g$ & $Z_0 g$ are the potential energy of inlet and outlet streams respectively.