1

Basic Concept and First Law of Thermodynamics

1.1. Introduction

Thermodynamic is the systematic and formulated knowledge which deals with transformation of energy of all kinds from one form to another. It can make an effort to convert heat into work, Also, it has tendency to change and attain equilibrium between the system and surrounding. The transformation of the energy either chemical or physical takes place in the system with certain restrictions. These restrictions are called laws of thermodynamics.

Thermodynamics deals with three phases of theoretical chemistry. These phases are

(*i*) Experimental

(*ii*) The fundamental laws

(*iii*) Prediction of properties

The experimental phases involves with determination of equilibrium state and its relations. These relations are made used by the chemical kinetics to determine the rate of any chemical reactions. The fundamental laws of thermodynamics has been given the mathematical form which can be conveniently used by any one for any purpose. Chemical Engineering Thermodynamics is mainly concerned with heat, work and properties of the system. The prediction of properties of the system is done with the help of micro and macro analysis.

The basic principles of thermodynamics are utilized by Chemical Engineers, Mechanical Engineers, Metallurgists and Chemists for different types of applications. Hence, it is an evident from the fact that thermodynamics has wide scope.

Thermodynamics analysis has certain limitations. For example, it cannot predicts the rate of any chemical process. The rate of any chemical process may be represented as

$$\text{Rate} = \frac{\text{Driving force}}{\text{Resistance}} \qquad \text{...(1.1)}$$

In this case, the driving force may be determined by thermodynamics principle but not the resistance. Hence, it is the limitations of thermodynamics. In similar way, the mechanism of any chemical process do not come under the juridiction of thermodynamics principles, however complicated is the chemical process.

1.2. Basic Concept

The basic concept of Chemical Engineering Thermodynamics involves following important terms:

1.2.1. System

The definite boundary in which some process occurs is called system. For example, generation of steam in a boiler may be consider as the system.

1.2.2. Surroundings

The things which are not included inside the boundary is called surroundings. For example, space all around of a reaction vessel may be consider as the surroundings.

1.2.3. Process

A process is one in which a system undergoes series of exhanges in a state. For example, heating of water in a kettle.

1.2.4. Closed System

The system in which no mass transfer but energy transfer may takes place is called closed system. For example, the refrigerant unit as a whole.

1.2.5. Open System

The system in which mass as well as energy transfer can takes place is called open system. For example, each unit of refrigerator.

1.2.6. State

State of a system is its condition which charaterized by a definite member of co-ordinates can be evaluated quantitatively.

1.2.7. Properties

The co-ordinates which fix-up the state of the system is called properties. It is the observable characteristics of a particular kind of material. For example, pressure, volume, density etc.

1.2.8. Intensive Properties

The properties which do not depends on the quantity of the material making up of the system are called intesive properties. For example, temperature, pressure etc.

1.2.9. Extensive Properties

The properties which depend on the quantity of the material making up of the system are called extensive properties. For example, volume, internal energy, enthalpy etc.

1.2.10. State Function

A state function is a function which depends only on the state of the system and is independent of the history of the system. Its differential is exact.

1.2.11. Path Function

A path function is a function which depends upon the sequence of processes the system undergoes. Its differential is not exact.

1.2.12. Equilibrium State

Equilibrium state may be defined as a state where there is no tendency for a change. It is a static condition of the system. Mechanical equilibrium, chemical equilibrium and thermal equilibrium are some examples of equilibrium state.

1.2.13. Mechanical Equilibrium

A system is said to be in a state of mechanical equilibrium, if the forces acting on the system are balanced.

1.2.14. Chemical Equilibrium

A system is said to be in a state of chemical equilibrium, if the composition of the system does not vary with time.

1.2.15. Thermal Equilibrium

A system is said to be in a state of thermal equilibrium, if there is no temperature variation from point to point in a system.

1.2.16. Thermometric Properties

The properties which changes in value as a function of temperature are called thermometric properties. For example, length of liquid column in a capillary of thermometer.

1.2.17. Fixed Point

The state of an arbitrarily chosen standard system which is easily reproducible is called fixed point. For example, temperature at the tripple point of water.

1.2.18. Macro State

A system is said to be in macro state, if it is large enough to be visible by naked eye. For example, sugar crystal.

1.2.19. Micro State

A system is said to be in micro state, if it is so small that not to be visible by naked eye. For example, molecule of water.

1.2.20. Heat

It is the feeling of hotness. For example, one can feel the hotness during the summer.

1.2.21. Temperature

It is the degree of hotness. For example, we find our body temperature using doctor's thermometer in degree.

1.2.22. Work

It is the product of the force exerted on the sytem and the distance moved by the system due to the applied force on it. It may be represented by the equation.

$$W = F.\, dL \qquad \text{...(1.1)}$$

where W = Amount of work done, J
F = Force applied, N
dL = Distance moved, m

1.2.23. Static Pressure

Pressure read by any pressure measuring instrument without disturbing the flow is called static pressure.

1.2.24. Dynamic Pressure

It is the pressure associated with the system due to moving of fluid. It may be represented by the equation

$$p_d = \frac{1}{2}(\rho u^2) \qquad \text{...(1.2)}$$

where p_d = Dynamic pressure, N/m^2
ρ = Density of the fluid, kg/m^3
u = Velocity of moving fluid, m/s

1.2.25. Cyclic Process

A system is said to be cyclic process if it can be restored to its original state during the course of changes.

1.3. Phase Rule

A rule which relate the possible number of phases, constituents and degree of freedom of a chemical system is called phase rule. Mathematically, it may be expressed as

$$P + F = C + 2 \qquad \text{...(1.3)}$$

where P = Number of phases
F = Degree of freedom
C = Number of component

Phase rule provides the theoretical foundation based in thermodynamics for characterizing the chemical state of a system. It helps in predicting the equilibrium relations of the phases present as a function of physical condition such as pressure and temperature.

1.4. Zeroth Law of Thermodynamics

If two systems are in thermal equilibrium with a third one, then the systems in talk are in thermal equilibrium with each other. For example, consider the Fig. 1.1.

If A is in equilibrium with C and B is also in equilibrium with C. Then, A and B are in equilibrium with each other.

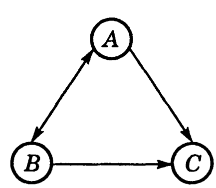


Fig. 1.1. Equilibrium system.

1.5. Heat Reservoir

A heat reservoir is a system from which a large finite quantity of heat energy can be extracted or to which a large finite quantity of heat energy can be added without changing its temperature. A simple heat reservoir system is shown in Fig. 1.2.

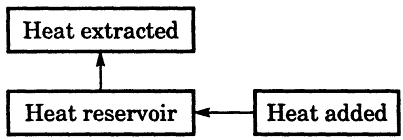


Fig. 1.2. Heat reservoir system.

1.6. Heat Engine

Heat engine is a thermodynamic system. It operates in cycle. It receives a net amount of heat and delivers a net amount of work. The working fluid undergoes a series of processes constituting the heat engine cycle. The performance of heat engine is indicated by its thermal efficiency. It may be expressed as

$$\eta = \frac{W_{net}}{Q_1} \quad ...(1.4)$$

where $W_{net} = Q_2 - Q_1$ ...(1.5)

η = Thermal efficiency

W_{net} = Net work done

Q_2 = Amount of work done equivalent to heat transfer at step 2

Q_1 = Amount of work done equivalent to heat transfer at step 1

1.7. Reversible Process

A process is said to be reversible if it can be restored to their original condition by reversing the direction of interaction. For example, process of conversion of water into ice and ice into water.

1.8. Irreversible Process

A process is said to be irreversible if it cannot be restored to their original condition by reversing the direction of interaction. For example, process of burning of fuel.

1.9. Homogeneous System

A homogeneous system is one whose properties remains uniform throughout. For example, sugar dissolved in water.

1.10. Heterogeneous System

A heterogeneous system is one in which more than one phase exists. For example, slurry of calcium carbonate.

1.11. Internal Energy

Energy possessed by the body by virtue of translation and cancel it rotation of molecule is called internal energy. It is denoted by U. Its unit is J/kg.

1.12. Kinetic Energy

Energy possessed by the body by virtue of its motion is called kinetic eneryg. It is denoted by E_k. It may be expressed as

$$\Delta E_k = \frac{1}{2}(u_2^2 - u_1^2) \quad ...(1.6)$$

where ΔE_k = Change in kinetic energy, J/kg

u_1 = Initial velocity, m/s

u_2 = Final velocity, m/s

1.13. Potential Energy

Energy possessed by the body by virtue of its position is called potential energy. It is denoted by E_p. It may be expressed as

$$\Delta E_p = g(z_2 - z_1) \quad ...(1.7)$$

where ΔE_p = Change in potential energy, J/kg

g = Acceleration due to gravity, m/s^2

z_1 = Initial position, m

z_2 = Final position, m

1.14. Enthalpy

The total heat content of the system is called enthalpy. It is denoted by H. It may be expressed as

$$H = U + PV \quad ...(1.8)$$

where H = Enthalpy, J/kg

U = Internal energy, J/kg

P = Absolute pressure, N/m^2

V = Specific volume, m^3/kg

In differential form the equation (1.8) may be written as

$$dH = dU + d(PV)$$

$$dH = dU + PdV + VdP \quad ...(1.9)$$

But $$TdS = dU + PdV \quad \text{...(1.10)}$$

Substituting equation (1.10) in equation (1.9), we get

$$dH = TdS + VdP \quad \text{...(1.11)}$$

1.15. Thermodynamics

Thermodynamics is the science which deals with the transformation of energy of the relation between heat, work and properties of the system.

1.16. First Law of Thermodynamics

First law of thermodynamics in general deals with law of conservation of energy. It may be stated as "Energy neither can be created nor it can be destroyed, whenever it disappear in one form its reappear in some other form and hence the total amount of energy remains constant".

Any change in the state of the system will cause corresponding changes in the surrounding as well. So, first law for process is applied both to system and surroundings. It may be expressed as

$$\Delta(\text{Energy of the system}) + \Delta(\text{Energy of the surroundings}) = 0 \quad \text{...(1.12)}$$

1.16.1. First Law of Thermodynamics for Cyclic Process

The first law for cyclic process may be defined as "whenever a system undergoes a cyclic change, however complex the system may be, the algebraic sum of the work transfer is equal to the algebraic sum of energy transfer as heat." Therefore, the work delivered in this process is equal to zero. It may be expressed as

$$\oint (dQ - dW) = 0 \quad \text{...(1.13)}$$

1.16.2. First Law of Thermodynamics for Non-flow (Closed) System

If the boundary of the system does not permit the mass transfer but may permit the energy transfer between the system and surrounding, then the system is said to be non-flow (closed) system. In this case of the system the mass is necessarily be constant. For such a system and surrounding the energy is transferred to or from it as heat and work. It may be represented as

$$\Delta U = Q - W \quad \text{...(1.14)}$$

where ΔU = Change in internal energy, J/kg

Q = Amount of heat transferred, J/s

W = Amount of work done, J/kg

1.16.3. Formulation of First Law of Thermodynamics for Non-Flow (Closed) System

First law of thermodynamics may be stated as "Energy neither can be created nor it can be destroyed, whenever it disappear in one form its reapper in some other form and hence the total amount of energy remains unchange."

The first law applies to the system and surroundings together and not in general to the system alone. In its more basic form the first law may be written as

$$\Delta(\text{Energy of the system}) + \Delta(\text{Energy of the surroundings}) = 0 \quad \text{...(1.15)}$$

Change in energy of the system may be possible in various form such as internal energy, kinetic energy and potential energy. Likewise, the change in energy of the surroundings are heat and work. The usual sign convention is to regard a quantity of heat as positive when it is transferred to the system from the surroundings. On the other hand, a quantity of work usually regarded as positive when work is done by the system on the surroundings. Thus, equation (1.15) may be written as

$$\Delta(\text{Internal Energy}) + \Delta(\text{Kinetic Energy}) + \Delta(\text{Potential Energy}) = \text{Heat} \pm \text{Work} \quad \text{...(1.16)}$$

$$\Delta U + \Delta E_K + \Delta E_P = Q \pm W \quad \text{...(1.17)}$$

where $\Delta U = U_2 - U_1$ ...(1.18)

= Change in internal energy, J/kg

U_2 = Internal energy at position 2, J/kg

U_1 = Internal energy at position 1, J/kg

$\Delta E_K = (u_2^2 - u_1^2)/2$ ...(1.19)

= Change in kinetic energy, J/kg

u_2 = Velocity at position 2, m/s

u_1 = Velocity at position 1, m/s

$\Delta E_P = g(Z_2 - Z_1)$ ...(1.20)

= Change in potential energy, J/kg

g = Acceleration due to gravity, m/s^2

Z_2 = Elevation at position 2, m

Z_1 = Elevation at position 1, m

Q = Amount of heat transferred, J/s

W = Amount of work done, J/kg

Change in kinetic energy and change in potential energy are negligible compared to change in internal energy. Hence, kinetic energy and potential energy may be neglected. Therefore, equation (1.17) may be modified as

$$\Delta U = Q - W \quad \text{...(1.21)}$$

This equation is called first law of thermodynamics in finite form. Consider the closed system shown in Fig. 1.3.

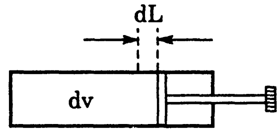


Fig. 1.3. Closed system.

The equation (1.21) may be written in differential form as

$$dU = dQ - dW \qquad ...(1.22)$$

This equation is called first law of thermodynamics in differential form. From the definition of work, we know that

$$dW = F.dL \qquad ...(1.23)$$

where dW = Differential work done, J/kg

$F = PA$

= Applied force, N

P = Absolute pressure, N/m^2

A = Area, m^2

dL = Differential distance moved, m

$$dL = \frac{dV}{A} \qquad ...(1.24)$$

dV = Differential volume, m^3

Substituting equation (1.24) in equation (1.23), we get

$$dW = PdV \qquad ...(1.25)$$

Substituting equation (1.25) in equation (1.22), we get

$$dU = dQ - PdV \qquad ...(1.26)$$

But,

$$dS = dQ/T$$

$$dQ = TdS \qquad ...(1.27)$$

Substituting, equation (1.27) in equation (1.26), we get

$$dU = TdS - PdV \qquad ...(1.28)$$

This equation is called first law of thermodynamics in converted differential form.

1.16.4. First Law of Thermodynamics for Flow (Open) System

If the boundary of the system does permit the mass transfer as well as energy transfer between the system and surrounding, then the system is said to be flow (open) system. In this case of the system the mass is not necessarily be constant. For such a system and surrounding the change in enthalpy depends on energy transfered to or from it as heat and shaft work. It may be represented as

$$\Delta H = Q - W_s \qquad ...(1.29)$$

where $\Delta H = H_2 - H_1 \qquad ...(1.30)$

= change in enthalpy, J/kg

H_2 = Enthalpy at position 2, J/kg

H_1 = Enthalpy at position 1, J/kg
Q = Amount of heat transferred, J/s
W_S = Shaft work, J/kg

1.16.5. Formulation of First Law of Thermodynamics for Flow (Open) System

A steady state flow system is shown in Fig. 1.4.

Consider a unit mass of fluid is entering the system at section-1 with pressure P_1, velocity u_1, temperature T_1 and elevation Z_1 and going out from the section-2 with pressure P_2, velocity u_2, temperature T_2 and elevation Z_2.

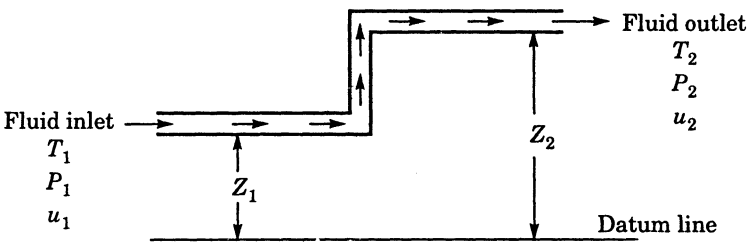


Fig. 1.4. Steady state flow process.

The energy of the unit mass of fluid may undergo the changes in all forms taken into accounts that are internal energy, kinetic energy and potential energy. In this process work done 'W' represents all the work done by the unit mass of fluid which is equal to the algebraic sum of the shaft work and the work done at the inlet and outlet of the system. It may be represented as

$$W = W_S - P_1V_1 + P_2V_2 \quad \text{...(1.31)}$$

Substituting equation (1.31) in equation (1.17), we get

$$\Delta U + \Delta E_K + \Delta E_P = Q - (W_S - P_1V_1 + P_2V_2)$$
$$\Delta U + \Delta E_K + \Delta E_P = Q - W_S + P_1V_1 - P_2V_2$$
$$\Delta U + \Delta E_K + \Delta E_P = Q - W_S - (P_2V_2 - P_1V_1)$$
$$\Delta U + \Delta E_K + \Delta E_P = Q - W_S - \Delta PV$$
$$\Delta U + \Delta PV + \Delta E_K + \Delta E_P = Q - W_S$$
$$\Delta(U + PV) + \Delta E_K + \Delta E_P = Q - W_S \quad \text{...(1.32)}$$

But, $$H = U + PV \quad \text{...(1.33)}$$

Substituting equation (1.33) in equation (1.32), we get

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S \quad \text{...(1.34)}$$

Change in kinetic energy and change in potential energy are negligible compared to change in internal energy. Hence, kinetic energy and potential energy may be neglected. Therefore, equation (1.34) may be written as

$$\Delta H = Q - W_S \qquad \text{...(1.35)}$$

where ΔH = Change in enthalpy, J/kg

Q = Amount of heat transfered, J/s

W_S = Shaft work, J/kg

1.17. Heat Capacity

The amount of heat required to raise the temperature of a given mass of any material by 1°C is called heat capacity. In general, it may be represented as

$$dQ = m\, C_p\, dT \qquad \text{...(1.36)}$$

where dQ = Differential amount of heat transfer, J/s

m = Mass of material, kg

C_p = Specific heat, J/kg °C

dT = Differential temperature change, °C

Heat capacity is of the two types

(*i*) Specific heat at constant pressure

(*ii*) Specific heat at constant volume

1.17.1. Formulation of Specific Heat at Constant Pressure

From the 1st law of thermodynamics, we know that

$$dU = dQ - dW \qquad \text{...(1.37)}$$

From equation (1.36), we have

$$dQ = m\, C_p\, dT$$

Considering, $m = 1$ (mole)

$$dQ = C_p\, dT \qquad \text{...(1.38)}$$

From equation (1.25), we have

$$dW = PdV \qquad \text{...(1.25)}$$

Substituting equation (1.38) and (1.25) in equation (1.37), we get

$$dU = C_p\, dT - PdV$$

$$dU + pdV = C_p\, dT \qquad \text{...(1.39)}$$

Pressure, P is constant. Hence, equation (1.39) may be written as

$$dU + d(PV) = C_p\, dT$$

$$d(U + PV) = C_p\, dT$$

But, $H = U + PV$

$$dH = C_p\, dT$$

$$C_P = \left(\frac{\partial H}{\partial T}\right)_P \qquad \text{...(1.40)}$$

This is the equation for specific heat at constant pressure.

1.17.2. Formulation of Specific Heat at Constant Volume

From the 1st law of thermodynamics, we know that

$$dU = dQ - dW \qquad ...(1.41)$$

From the equation (1.25), we have

$$dW = PdV$$

Volume, V is constant.

$$dW = 0 \qquad ...(1.42)$$

Substituting, equation (1.42) in equation (1.41), we get

$$dU = dQ \qquad ...(1.43)$$

From the definition of heat capacity at constant volume, we have

$$dQ = mC_V\,dT \qquad ...(1.44)$$

Considering, m = 1 mole

$$dQ = C_V\,dT \qquad ...(1.45)$$

Substituting equation (1.45) in equation (1.43), we get

$$dU = C_V\,dT$$

$$C_V = \left(\frac{\partial U}{\partial T}\right)_V \qquad ...(1.46)$$

Example 1.1. *20 kg of water are vaporized at constant temperature of 100°C and 1 atm pressure. The heat added to the system is 2257 kJ / kg. The specific volume of liquid and vapor are 1.04×10^{-3} and 167.2×10^{-2} m^3/kg respectively. Find ΔU.*

Solution. We know that

$$W = P\Delta V$$

$$W = P(V_2 - V_1)$$

$$W = 1 \times 10^5\,(167.2 \times 10^{-2} - 1.04 \times 10^{-3})$$

$$W = 1.67096 \times 10^2 \text{ kJ/kg}$$

$$\Delta U = Q - W$$

$$\Delta U = 2257 - 167.096$$

$$\Delta U = 2089.904 \text{ kJ/kg}$$

For 20 kg of water

$$\Delta U = 41{,}798.08 \text{ kJ.} \quad \textbf{Ans.}$$

Example 1.2. *20 kg of water are vaporized at constant temperature of 100°C and 1 atm pressure. The heat added to the system is 2257 kJ / kg. The specific volume of liquid and vapor are 1.04×10^{-3} and 167.2×10^{-2} m^3/kg respectively. Find ΔH.*

Solution. We know that

$$\Delta H = \Delta U + \Delta(PV)$$

$$\Delta H = \Delta U + P(\Delta V)$$
$$= \Delta U + P(V_2 - V_1) \quad ...(1.47)$$

From the example 1.1, we have

$$\Delta U = 2089.904 \text{ kJ/kg}$$
$$P = 1 \times 10^5 \text{ N/m}^2$$
$$V_2 = 167.2 \times 10^{-2} \text{ m}^3\text{/kg}$$
$$V_1 = 1.04 \times 10^{-3} \text{ m}^3\text{/kg}$$

Substituting above values in equation (1.47), we get

$$\Delta H = 2089.904 + 1 \times 10^5$$
$$(167.2 \times 10^{-2} - 1.04 \times 10^{-3}) \times 10^{-3}$$
$$\Delta H = 2257 \text{ kJ/kg}$$

For 20 kg of water

$\Delta H = 45{,}140$ kJ. **Ans.**

Example 1.3. *A certain battery is charged by applying a current of 40 A and 12 V for 45 min. time period. During the charging process the battery loses 211 kJ of heat to the surroundings. How much does the change in internal energy of the battery during the 45 min. time period?*

Solution. The process is non flow. For non flow process

$$\Delta U = Q - W \quad ...(1.48)$$

where ΔU = Change in internal energy, kJ

Q = Amount of heat transfer, kJ

W = Work done, kJ

$W = VI$, Watts

$V = 12$ volt

$I = 40$ A

$W = 12 \times 40$ J/s

$W = 480 \times (45 \times 60) \times 10^{-3}$ kJ

$W = 1296$ kJ

Work done on the system. Hence, W is negative. During the charging process battery loses heat. Hence, Q is negative.

$$\Delta U = -211 - 1296$$

$\Delta U = -1507$ kJ. **Ans.**

Example 1.4. *A turbine operating under steady conditions receives 5000 kg of steam per hour. The steam enters the turbine at a velocity of 50 m/s, at an elevation of 5 m and specific enthalpy of 2750 kJ/kg. It leaves the turbine at a velocity of 10 m/s, at an elevation of 1m and specific enthalpy of 2250 kJ/kg. Heat losses for the turbine to surroundings amounts to 16580 kJ/hr. Determine the h.p. output of the turbine.*

Solution. It is a flow system.

Mass flowrate of steam = 5000 kg/hr

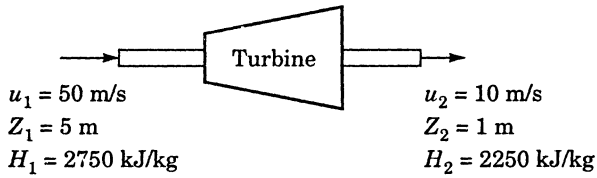


Fig. 1.5. Steam turbine.

$$Q = 16580 \text{ kJ/hr}$$

$$\text{h.p.} = ?$$

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S \quad \text{...(1.49)}$$

$$(2250 - 2750) \times 10^3 + \frac{1}{2}(10^2 - 50^2) + 9.81(1 - 5) = -(16580 \times 10^3/5000) - W_S$$

$$-500 \times 10^3 - 1200 - 39.24 = -3316 - W_S$$

$$W_S = -3316 + 500 \times 10^3 + 1200 + 39.24$$

$$W_S = 497923.24 \text{ J/kg}$$

$$W_S = (497923.24) \times (5000/3600) \text{ J/s}$$

$$W_S = 691560.06 \text{ watts}$$

$$\text{h.p.} = (691560.06)/745.5$$

$$\text{h.p.} = 927.6$$

Output of the turbine = 928 hp. **Ans.**

Example 1.5. *The turbine of a jet engine received a steady flow of gas at a pressure of 720×10^3 N/m^2, at a temperature of 870°C and at a velocity of 160 m/s. It discharges the gases at a pressure of 215×10^3 N/m^2, at a temperature of 625°C and at a velocity of 300 m/s. Evaluate the output of the turbine in h.p. The process may be assumed adiabatic. The enthalpy data is as follows.* $H_1 = 1000$ *kJ/kg and* $H_2 = 719$ *kJ/kg.*

Solution. It is a flow system.

Assume mass flow rate of gas = 1 kg/s

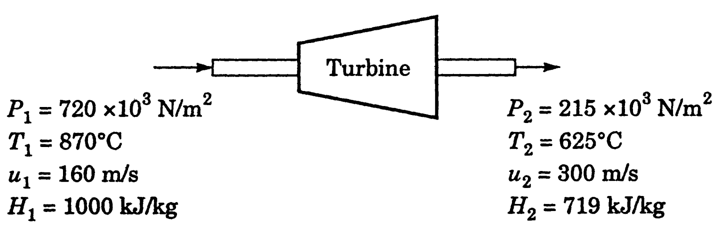


Fig 1.6. Steam turbine.

Assume that the process is adiabatic

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(719 - 1000) \times 10^3 + \frac{1}{2}(300^2 - 160^2) + 0 = 0 - W_S$$

$$-281 \times 10^3 + 32{,}200 + 0 = -W_S$$

$$W_S = 281 \times 10^3 - 32{,}200$$

$$W_S = 248800 \text{ J/kg}$$

$$W_S = 248800 \times 1 \text{ Watts}$$

$$W_S = 248800 \text{ Watts}$$

$$\text{h.p.} = 333.7$$

Output of the turbine = 334 hp. **Ans.**

Example 1.6. *A gas turbine receives gas at an enthalpy of 800 kJ/kg and at a velocity of 100 m/s. The gas leaves the turbine at an enthalpy of 380 kJ/kg and at a velocity of 150 m/s. Heat lost to surroundings from the gas is 36 kJ/s. If the rate of gas flow is 1.0 kg/s, find the power developed by the turbine.*

Solution. It is a flow system.

Mass flow rate of gas = 1.0 kg/s

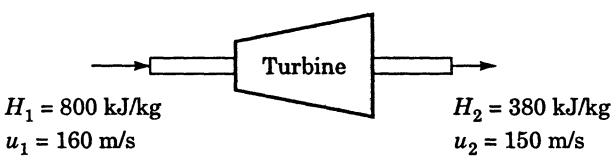


Fig. 1.7. Gas turbine.

$$Q = -36 \text{ kJ/s}$$

$$\text{hp} = ?$$

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(380 - 800) \times 10^3 + \frac{1}{2}(150^2 - 100^2) + 0 = \frac{-(36 \times 10^3)}{1} - W_S$$

$$-420 \times 10^3 + 6250 + 0 = -36000 - W_S$$

$$W_S = -36000 + 420 \times 10^3 - 6250$$

$$W_S = 377750 \text{ J/kg}$$

$$W_S = 377750 \times 1 \text{ J/S}$$

$$W_S = 377750 \text{ Watts}$$

h.p. = (377750)/745.5

h.p. = 506.7

Power developed by the turbine is 507 hp. **Ans.**

Example 1.7. *At entry to the reciprocating compressor of a refrigerator, the refrigerant F-12 has pressure and temperature of 200 × 10^3 N/m^2 and − 10°C respectively. At the exit from the compressor the F-12 has 900 × 10^3 N/m^2 and 55°C. The flow is steady. Evaluate the external work in J/kg of the F-12. Assume the compressor to be adiabatic and changes in K.E. and P.E. to be negligible. The enthalpy of F-12 at the entry and extreme condition is H_1 = 180 × 10^3 J/kg and H_2 = 215 × 10^3 J/kg respectively.*

Solution. It is a flow system.

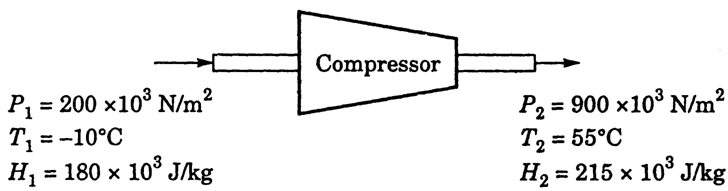


Fig. 1.8. Reciprocating compressor.

Assume that the compressor is at adiabatic condition.

Kinetic energy is negligible.

Potential energy is negligible.

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(215 - 180) \times 10^3 + 0 + 0 = 0 - W_S$$

$$35 \times 10^3 + 0 + 0 = - W_S$$

$$W_S = - 35 \times 10^3 \text{ J/kg}$$

The external work of compressor = − 35,000 J/kg. **Ans.**

Example 1.8. *In a gas turbine the flow rate of air is 4 kg/s. The velocity and enthalpy of air at the entrance are 250 m/s and 6000 kJ/kg respectively. At the exit velocity is 170 m/s and enthalpy is 400 kJ/kg. As the air passes through the turbine a loss of heat equal to 40 kJ/s occurs. Find the horse power developed by the turbine.*

Solution. It is a flow system.

Mass flow rate of air = 4 kg/s.

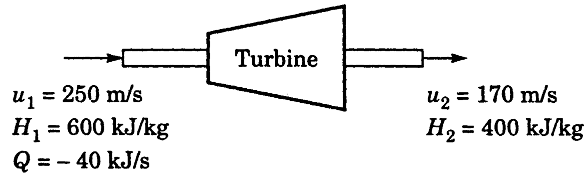


Fig. 1.9. Gas turbine.

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(400 - 600) \times 10^3 + \frac{1}{2}(170^2 - 250^2) + 0 = \frac{-(40 \times 10^3)}{4} - W_S$$

$$-200 \times 10^3 - 16800 + 0 = -10000 - W_S$$

$$W_S = -10000 + 200 \times 10^3 + 16800$$

$$W_S = 206800 \text{ J/kg}$$

$$W_S = 206800 \times 4 \text{ J/s}$$

$$W_S = 827200 \text{ Watts}$$

$$\text{h.p.} = (827200)/745.5$$

$$\text{h.p.} = 1109.59$$

Horse power developed by the turbine = 1110 h.p. **Ans.**

Example 1.9. *Water at 90°C is pumped from a storage tank 1 to a storage tank 2, 15 m above by a 1.5 h.p. motor. 150 kcal/s of heat is extracted from this water in a heat exanger. If the water flow rate is 180 kg/min., what is the temperature of water delivered in the second tank? Take data from steam tables.* *(Mangalore University, 1991)*

Solution. It is a flow system.

Mass flow rate of air = 180 kg/min.

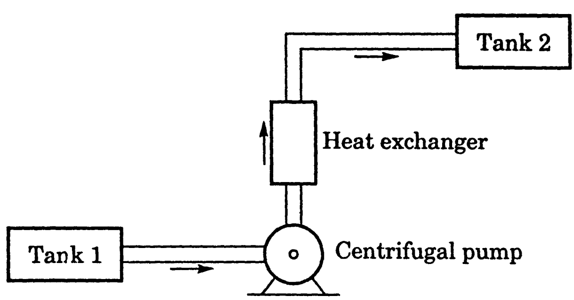


Fig. 1.10. Pumping of water from storage tank.

$T_1 = 90°C$ $\quad\quad$ $T_2 = ?$

$z_1 = 0$ m $\quad\quad$ $z_2 = 15$ m

$W_S = 1.5$ h.p.

$Q = -\ 150$ kcal/s

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(H_2 - H_1) + 0 + 9.81\ (15 - 0) = -\ (150 \times 10^3 \times 4.187)/3 - (1.5 \times 745.5)/3$$

$$(H_2 - H_1) + 147.15 = -\ 209350 - 372.75$$

$$(H_2 - H_1) = -\ 209350 - 372.75 - 147.15$$

$$(H_2 - H_1) = -\ 209869.9 \text{ J/kg} \quad \quad ...(1.50)$$

From the steam table at 90°C

$$H_1 = 376.9 \times 10^3 \text{ J/kg}$$

Substituting above value in equation (1.50), we get

$$H_2 - 376900 = -\ 209869.9$$

$$H_2 = -\ 209869.9 + 376900$$

$$H_2 = 167030.1 \text{ J/kg}$$

From the steam table corresponding value of $H_2 = 167030.1$ J/kg, the temperature is 39.88°C.

The temperature of water delivered in the second tank is 40°C. **Ans.**

Example 1.10. *A steam turbine received 500 kg steam per hour at 24.5 bars and 45°C, at a velocity of 50 m/s and an elevation of 4.5 m. Heat transfer from the turbine to the surrounding is 3141 kJ/hr. Steam leaves the turbine dry saturated at 1.5 bars, at a velocity of 130 m/s and an elevation of 1.5 m. Determine the h.p. developed by the turbine.*

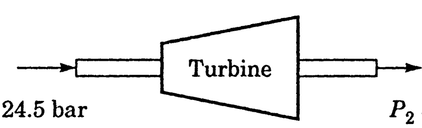
Data (from steam table):

At 24.5 bar; 450°C $\quad\quad$ $H_1 = 3351.76\ kJ/kg$

At 1.5 bar; Dry saturated $\quad\quad$ $H_2 = 2682.58\ kJ/kg$

Solution. It is a flow system.

Mass flow rate of steam = 500 kg/hr.



$P_1 = 24.5$ bar	$P_2 = 1.5$ bar
$T_1 = 450°C$	$T_2 =$ Dry saturated
$u_1 = 50$ m/s	$u_2 = 130$ m/s
$z_1 = 4.5$ m	$Z_2 = 1.5$ m
$H_1 = 3351.76$ kJ/kg	$H_2 = 2682.58$ kJ/kg
$Q = -3141$ kJ/hr	

Fig. 1.11. Steam turbine.

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(2682.58 - 3351.76) \times 10^3 + \frac{1}{2}(130^2 - 50^2)$$

$$+ 9.81(1.5 - 4.5) = -(3141 \times 10^3)/500 - W_S$$

$$-669.18 \times 10^3 - 7200 - 29.43 = -6282 - W_S$$

$$W_S = -6282 + 669.18 \times 10^3 - 7200 + 29.43$$

$$W_S = 655727.43 \text{ J/kg}$$

$$W_S = 655727.43 \times (500/3600) \text{ J/s}$$

$$W_S = 91073.25 \text{ Watts}$$

$$\text{h.p.} = 91073.25/745.5$$

$$\text{h.p.} = 122.16$$

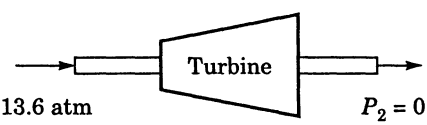
Power developed by the turbine = 122 h.p. **Ans.**

Example 1.11. *Steam at 13.6 absolute pressure and 316°C (state-1) enters a turbine through standard 76 mm diameter pipe line with a velocity of 3 m/s. The exit from the turbine is carried through a standard 254 mm diameter pipe line and is at 0.272 atm absolute pressure and 71°C (state-2). Data is given as:*

$H_1 = 30.82 \times 10^5$ J/kg	$H_2 = 26.33 \times 10^5$ J/kg
$V_1 = 0.191$ m³/kg	$V_2 = 5.75$ m³/kg

Assume there is no heat loss. Find the power output of the turbine.

Solution. It is a flow system.



$P_1 = 13.6$ atm	$P_2 = 0.272$ atm
$T_1 = 316$°C	$T_2 = 71$°C
$H_1 = 30.82 \times 10^5$ J/kg	$H_2 = 26.33 \times 10^5$ J/kg
$V_1 = 0.191$ m^3/kg	$V_2 = 5.75$ m^3/kg
$u_1 = 3$ m/s	$u_2 = ?$
$d_1 = 76$ mm	$d_2 = 254$ mm

Fig. 1.12. Steam turbine.

From continuity equation, we have

$$a_1 \cdot u_1 = a_2 \cdot u_2 \quad ...(1.51)$$

$$(\pi \cdot d_1^2/4) \cdot u_1 = (\pi \cdot d_2^2/4) \cdot u_2 \quad ...(1.52)$$

$$u_2 = u_1 \cdot (d_1^2/d_2^2)$$

$$u_2 = 3 \times (76^2/254^2)$$

$$u_2 = 0.268 \text{ m/s}$$

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$(26.33 - 30.82) \times 10^5 + \frac{1}{2}(0.268^2 - 3^2) + 0 = 0 - W_S$$

$$-4.49 \times 10^5 - 4.46 + 0 = 0 - W_S$$

$$W_S = 4.49 \times 10^5 + 4.46$$

$$W_S = 449004.46 \text{ J/kg}$$

Mass flow rate of steam $= (u_1/v_1) \times a_1$

$= (3/0.191) \times \pi \times (76 \times 10^{-3})^2/4$

$= 0.071$ kg/s

$$W_S = 449004.46 \times 0.071 \text{ J/s}$$

$$W_S = 31879.32 \text{ Watts}$$

$$\text{h.p.} = 31879.32/745.5$$

$$\text{h.p.} = 42.76$$

Power output of the turbine = 43 h.p. **Ans.**

Example 1.12. *Air flows steadily at the rate of 0.4 kg / s through an air compressor. The air enters the compressor at a verlocity of 6 m / s, pressure 1.02 kg / cm² and specific volume of 0.845 m³ / kg. It leaves the compressor at a velocity of 3.5 m / s, pressure 7.4 kg / cm² and specific volume of 0.162 m³ / kg. The internal energy of the fluid leaving is 21 kcal / kg greater than that of the air entering. Cooling water in the compressor jacket absorbs heat from the air at the rate of 15 kcal / s. Calculate the power required to run the compressor.*

Solution. It is a flow system.

Mass flow rate of air = 0.4 kg/s.

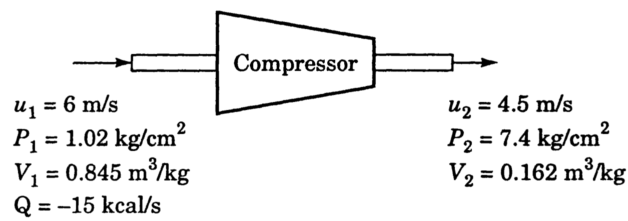


Fig. 1.13. Air compressor.

Internal energy of the fluid is 21 kcal/kg greater than that of the air entering the compressor.

$$U_2 = U_1 + 21$$

$$U_2 - U_1 = 21$$

$$\Delta U = 21 \text{ kcal/kg} \quad \text{...(1.53)}$$

For steady state flow process, we know that

$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S \quad \text{...(1.54)}$$

But, $$\Delta H = \Delta U + \Delta(PV) \quad \text{...(1.55)}$$

Substituting equation (1.55) in equation (1.54), we get

$$\Delta U + \Delta(PV) + \Delta E_K + \Delta E_P = Q - W_S$$

$$\Delta U + (P_2V_2 - P_1V_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$

$$21 \times 10^3 \times 4.187 + (7.4 \times 0.162 - 1.02 \times 0.85) \times 10^4 \times 9.81$$

$$+ \frac{1}{2}(4.5^2 - 6^2) + 0 = -(15 \times 10^3 \times 4.187)/0.4 - W_S$$

$$87.93 \times 10^3 + 3.31 \times 10^4 - 7.88 + 0 = -157.01 \times 10^3 - W_S$$

$$W_S = -157.01 \times 10^3 - 87.93 \times 10^3 - 3.31 \times 10^4 + 7.88$$

$$W_S = -278032.12 \text{ J/kg}$$

$$W_S = -278032.12 \times 0.4 \text{ J/s}$$

$$W_S = -111212.85 \text{ Watts}$$

$$\text{h.p.} = 111212.85/745.5$$

$$\text{h.p.} = 149$$

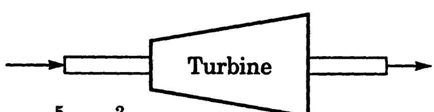
Power required to run the compressor = 149 h.p. **Ans.**

Example 1.13. *Compute the horse power developed by a turbine from the data given below:*

	Pressure *(N/m²)*	*Temperature* *(°C)*	*Velocity* *(m/s)*	*Diameter of pipe* *(cm)*	*Elevation* *(m)*
Inlet	20.65×10^5	425	4.5	10	3
Outlet	0.40×10^5	92	–	21	Datum level

Assume no heat loss.

Solution. It is a flow system.



$P_1 = 20.65 \times 10^5$ N/m² $\quad$ $P_2 = 0.40 \times 10^5$ N/m²

$T_1 = 425°C$ $\quad$ $T_2 = 92°C$

$u_1 = 4.5$ m/s $\quad$ $u_2 = ?$

$d_1 = 10$ cm $\quad$ $d_2 = 21$ cm

$z_1 = 3$ m $\quad$ $Z_2 = 0$ m

Fig. 1.14. Steam turbine.

From the steam table we get enthalpy of superheated steam

$H_1 = 3302.95$ kJ/kg $\qquad H_2 = 2668.36$ kJ/kg

From the continuity equation, we have

$$a_1 \cdot u_1 = a_2 \cdot u_2$$

$$(\pi \,.\, d_1^2/4) \,.\, u_1 = (\pi \,.\, d_2^2/4) \,.\, u_2$$
$$u_2 = u_1 \,.\, (d_1^2/d_2^2)$$
$$u_2 = 4.5 \times (10^2/21^2)$$
$$u_2 = 1.02 \text{ m/s}$$
$$\Delta H + \Delta E_K + \Delta E_P = Q - W_S$$
$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_S$$
$$(2668.36 - 3302.95) \times 10^3 + \frac{1}{2}(1.02^2 - 4.5^2) + 9.81(0 - 3)$$
$$= 0 - W_S$$
$$-634.59 \times 10^3 - 9.61 - 29.43 = 0 - W_S$$
$$W_S = 634.59 \times 10^3 + 9.61 + 29.43$$
$$W_S = 634629.04 \text{ J/kg}$$

From the steam table we get specific volume of super-heated steam

$$V_1 = 0.157 \text{ m}^3\text{/kg}$$
$$V_2 = 4.25 \text{ m}^3\text{/kg}$$

$$\text{Mass flow rate of steam} = (u_1/v_1) \times a_1$$
$$= (4.5/0.157) \times \pi \times (10 \times 10^{-2})^2/4$$
$$= 0.225 \text{ kg/s}$$
$$W_S = 634629.04 \times 0.225 \text{ J/s}$$
$$W_S = 142791.53 \text{ Watts}$$
$$\text{h.p.} = 142791.53/745.5$$
$$\text{h.p.} = 191.54$$

Power developed by the turbine = 192 h.p. **Ans.**

Example 1.14. *A turbine operating adiabatically is fed with steam at 350°C and 8.0 MPa at the rate of 1000 kg/hr. Process steam saturated at 0.5 MPa is withdrawn from an intermediate location of the turbine at the rate of 300 kg/hr and the remaining steam leaves the turbine saturated at 0.1 MPa. What is the power output of the turbine?*

Solution. It is a flow system.

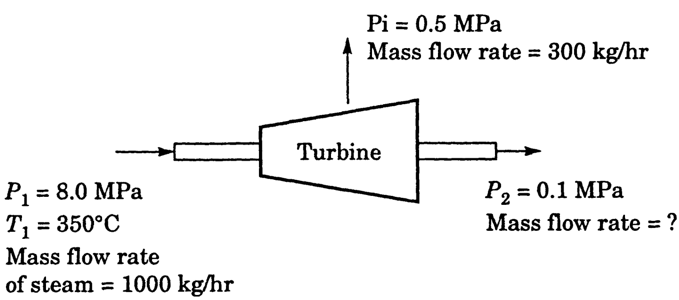


Fig. 1.15. Steam turbine.

Mass flow rate of stream = 1000 kg/hr

From the steam table we get enthalpy of super-heated steam

$H_1 = 3162.57$ kJ/kg $\quad H_i = 2746.6$ kJ/kg $\quad H_2 = 2673.7$ kJ/kg

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + 0 + 0 = 0 - W_s$$

$$(519886 - 878492) = -W_s$$

$$-358606 = -W_s$$

$$W_s = 358606 \text{ watts}$$

$$\text{h.p.} = 358606/745.5$$

$$\text{h.p.} = 481.02$$

Power output of the turbine = 481 hp. **Ans.**

Example 1.15. *A trial run on a steam turbine power plant gave the following results.*

Entrance to boiler (water)	*Exit of turbine (steam)*
$u_1 = 5.5$ *m/s*	$u_2 = 26$ *m/s*
$H_1 = 860$ *kJ/kg*	$H_2 = 2680$ *kJ/kg*
$z_1 = 4.2$ *m*	$z_2 = 0$ *m*

Mass flow rate = 3600 kg/hr

Determine the power developed by the turbine if the heat added to the system is 2100 kJ/s.

Solution. It is a flow system.

Mass flow rate = 3600 kg/hr

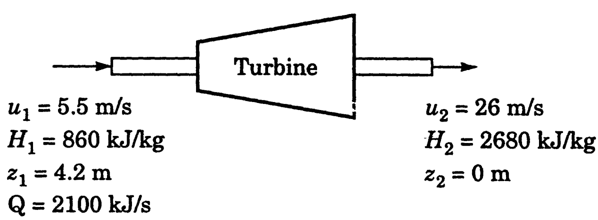


Fig. 1.16. Steam turbine.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$(2680 - 860) \times 10^3 + \frac{1}{2}(26^2 - 5.5^2) + 9.81(0 - 4.2) = (2100 \times 10^3/1) - W_s$$

$$1820 \times 10^3 + 645.8 - 41.2 = 2100 \times 10^3 - W_s$$

$$W_s = 2100 \times 10^3 - 1820 \times 10^3 - 645.8 + 41.2$$

$$W_s = 279395.4 \text{ J/kg}$$

$$W_s = 279395.4 \times \left(\frac{3600}{3600}\right)$$

$$W_s = 279395.4 \text{ J/s}$$

$$\text{h.p.} = 374.7$$

Power developed by the turbine = 375 h.p. **Ans.**

Example 1.16. *A flow process is under the following conditions of operation.*

	At the entrance	*At the exit*
Enthalpy	*1863135 J/kg*	*232892 J/kg*
Velocity	*24 m/s*	*15 m/s*
Elevation	*23 m*	*......*

Heat is transferred to the system at the rate of 52750 J/s. What is the work done by the system when the elevation at the exit is 3 m.

Solution. It is a flow system.

Assume, mass flow rate = 1 kg/s.

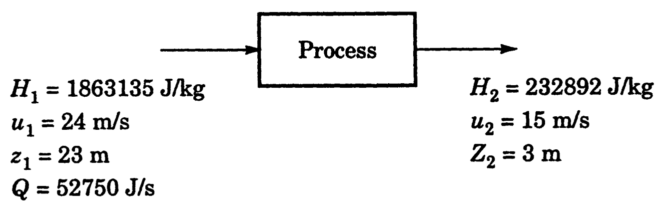


Fig. 1.17. Flow process.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$(232892 - 1863135) + \frac{1}{2}(15^2 - 24^2) + 9.81(3 - 23) = 52750 - W_s$$

$$-1630243 - 293 - 196 = 52750 - W_s$$

$$W_s = 52750 + 1630243 + 293 + 196$$

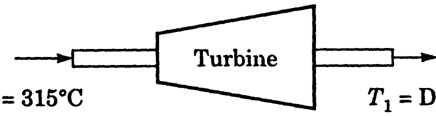
$$W_s = 1683482 \text{ J/kg}$$

Work done by the system is 1683482 J/kg. **Ans.**

Example 1.17. *Steam flows through a small steam turbine at a rate of 1.25 kg/s entering at 315°C and 13.6 atm. It leaves the turbine at dry saturated and 1.36 atm. The steam enters at 76 m/s at a point 1.8 m above the discharge and leaves at 43 m/s. Calculate the shaft work output in h.p. assuming the device is adiabatic.*

Solution. It is a flow system.

Mass flow rate = 1.25 kg/s



$T_1 = 315°C$	T_1 = Dry saturated
$P_1 = 13.6$ atm	$P_2 = 1.36$ atm
$u_1 = 76$ m/s	$u_2 = 43$ m/s
$z_1 = 1.8$ m	$z_2 = 0$ m
$Q = 0$ (Adiabatic)	

Fig. 1.18. Steam turbine.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$(2732 - 3076) \times 10^3 + \frac{1}{2}(43^2 - 76^2) + 9.81(0 - 1.8) = 0 - W_s$$

$$-344 \times 10^3 - 1964 - 17.5 = -W_s$$

$$W_s = 344 \times 10^3 + 1964 + 17.6$$

$$W_s = 345981.6 \text{ J/kg}$$

$$W_s = 345981.6 \times 1.25 \text{ J/s}$$

$$W_s = 432477 \text{ watts}$$

$$\text{h.p.} = 580.1$$

Shaft work output is 580 h.p. **Ans.**

Example 1.18. *A 100 mm diameter vertical cylinder closed system contain a combustible mixture at a temperature of 15°C. The piston is free to move and its mass is such that the mixture pressure is 240×10^3 N/m². The upper surface of the system is exposed to the atmosphere. The mixture is ignited and the reaction is allowed to proceed. As the reaction proceeds, the piston move slowly upward and heat is transferred to the surrounding. When the reaction is completed the temperature of the content reduced to the initial temperature. During the process it is found that the piston has moved upward a net distance of 85 mm and the magnitude of heat transfer within the surrounding is 4 kJ. Evaluate the increase in energy of the content of the cylinder.*

Solution. It is a non flow system.

Changes in kinetic energy and potential energies are negligible.

$$\Delta U + \Delta E_k + \Delta E_p = Q - W \quad ...(1.56)$$

$$\Delta U + \Delta E_k + \Delta E_p = Q - P\Delta V \quad ...(1.57)$$

$$\Delta U + \Delta E_k + \Delta E_p = Q - P \times (\pi d^2/4) \times h \quad ...(1.58)$$

$$\Delta U + 0 + 0 = -4 \times 10^{-3} - (1 \times 10^{5}) \times \pi \times ((100 \times 10^{-3})^2/4) \times 85 \times 10^{-3}$$

$$\Delta U = -4000 - 66.75$$

$$\Delta U = -4066.75 \text{ J}$$

Increase in internal energy of the content of the cylinder is 4066.75 J. **Ans.**

Example 1.19. *Water is flowing in a horizontal duct which is insulated. The inlet area and velocity are respectively 9 cm² and 16 m/s. The exit area is 36 cm². Determine the change in specific enthalpy of water from inlet to exit.* *(GATE Exam. 2000)*

Solution. It is a flow process.

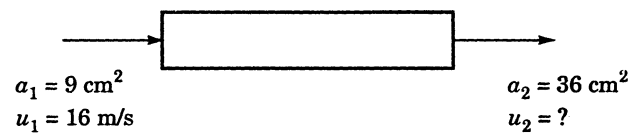


Fig. 1.19. Horizontal duct.

From continuity equation, we have

$$a_1 \cdot u_1 = a_2 \cdot u_2$$

$$u_2 = u_1 \times (a_1/a_2)$$

$$u_2 = 16 \times (9/36)$$

$$u_2 = 4 \text{ m/s}$$

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$\Delta H + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$\Delta H + \frac{1}{2}(4^2 - 16^2) + 0 = 0 - 0$$

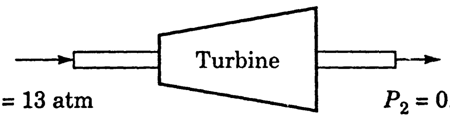
$$\Delta H - 120 + 0 = 0 - 0$$

$$\Delta H = 120 \text{ J/kg}$$

Change in specific enthalpy of water from inlet to exit is 120 J/kg. **Ans.**

Example 1.20. *Steam at 13 atm and 300°C (state 1) enters a turbine through a standard 7.6 cm dimeter pipe line with a velocity of 5 m/s. The exit from the turbine is carried through a standard 25.4 cm diameter pipe line and is at 0.275 atm and 70°C (state 2). What is the power output of the turbine in h.p. Assume no heat loss.*

Solution. It is a flow system.



$P_1 = 13$ atm　　　　　　　　$P_2 = 0.275$ atm
$T_1 = 300°C$　　　　　　　　$T_2 = 70°C$
$d_1 = 7.6$ cm　　　　　　　　$d_2 = 25.4$ cm
$u_1 = 5$ m/s　　　　　　　　$u_2 = ?$

Fig. 1.20. Steam turbine.

From continuity equation, we have

$$a_1 \cdot u_1 = a_2 \cdot u_2$$
$$u_2 = u_1 \times (a_1/a_2)$$
$$u_2 = 5 \times (\pi \times (7.6 \times 10^{-2})^2/4)/(\pi \times (25.4 \times 10^{-2})^2/4)$$
$$u_2 = 5 \times (7.6 \times 10^{-2})^2/(25.4 \times 10^{-2})^2$$
$$u_2 = 0.45 \text{ m/s}$$
$$\Delta U + \Delta E_k + \Delta E_p = Q - W_s$$
$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$
$$(2627 - 3044) \times 10^3 + \frac{1}{2}(0.45^2 - 5^2) + 0 = 0 - W_s$$
$$-417 \times 10^3 - 12.4 + 0 = 0 - W_s$$
$$W_s = 417 \times 10^3 + 12.4$$
$$W_s = 417012.4 \text{ J/kg}$$

Mass flow rate of steam $= (u_1/v_1) \times a_1$

$$= (5/0.196) \times \pi \times (7.6 \times 10^{-2})^2/4$$
$$= 0.116 \text{ kg/s}$$
$$W_s = 417012.4 \times 0.116 \text{ J/s}$$
$$W_s = 48373 \text{ watts}$$
$$\text{h.p.} = 64.88$$

The power output of the turbine is 65 h.p. **Ans.**

Example 1.21. *Water flow through a horizontal coil heated by steam condensing on the outside. If the inlet pressure and temperature of water are 2 atm and 70°C and that of at the exit 1 atm and 105°C, calculated the heat added to the coil per kg of water. The entering velocity is 1.5 m/s and that of leaving is 150 m/s.*

Data: $H_1 = 297868$ *J/kg*　　$H_2 = 2688503$ *J/kg*

Solution. It is a flow system.

$P_1 = 2$ atm	$P_2 = 1$ atm
$T_1 = 70°C$	$T_2 = 105°C$
$u_1 = 1.5$ m/s	$u_2 = 150$ m/s
$Q = ?$	$H_2 = 2688503$ J/kg
$H_1 = 297868$ J/kg	

Fig. 1.21. Horizontal coil.

$$\Delta U + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$(2688503 - 297868) + \frac{1}{2}(150^2 - 1.5^2) + 0 = Q - 0$$

$$2390635 + 11249 + 0 = Q - 0$$

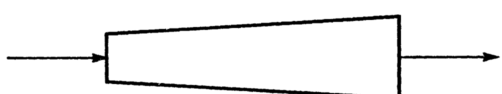
$$Q = 2390635 + 11249$$

$$Q = 2401884 \text{ J/kg}$$

Heat added to the coil = 2401884 J/kg. **Ans.**

Example 1.22. *Water is flowing in straight horizontal insulated pipe of 25 mm inner diamter. There is no device present for adding or removing energy as work. The upstream velocity is 12 m/s. The water flows into a section where the diameter is suddenly increased. What is the change in enthalpy of the water if the downstream diameter is 50 mm. If it is 100 mm what is the maximum enthalpy change for a sudden enlargement in the pipe?*

Solution. It is a flow system.



$d_1 = 25$ mm	$d_2 = 50$ mm
$u_1 = 12$ m/s	$u_2 = ?$
$Q = 0$	$d_2 = 100$ mm
$W_s = 0$	$u_2 = ?$

Fig. 1.22. Horizontal pipe.

From the continuity equation, we have

$$a_1 \,.\, u_1 = a_2 \,.\, u_2$$

$$u_2 = u_1 \times (a_1/a_2)$$

$$u_2 = 12 \times (25^2/50^2)$$

$$u_2 = 3 \text{ m/s}$$

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$\Delta H + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$\Delta H + \frac{1}{2}(3^2 - 12^2) + 0 = 0 - 0$$

$$\Delta H - 67.5 + 0 = 0$$

$$\Delta H = 67.5 \text{ J/kg.} \quad \textbf{Ans.}$$

From the continuity equation, we have

$$a_1 \cdot u_1 = a_2 \cdot u_2$$

$$u_2 = u_1 \times (a_1/a_2)$$

$$u_2 = 12 \times (25^2/100^2)$$

$$u_2 = 0.75 \text{ m/s}$$

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$\Delta H + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

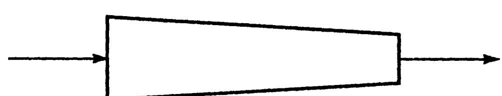
$$\Delta H + \frac{1}{2}(0.75^2 - 12^2) + 0 = 0 - 0$$

$$\Delta H - 71.72 = 0$$

$$\Delta H = 71.72 \text{ J/kg.} \quad \textbf{Ans.}$$

Example 1.23. *Steam flows at steady state through a converging insulated nozzle 250 mm long and with an inlet diameter of 50 mm. At the nozzle entrance (state-1) the temperature and pressure are 312°C and 6.8 atm and the velocity is 30 m/s. At the nozzle exit (state-2), the steam temperature and pressure are 230°C and 3.4 atm. The enthalpy values are H_1 = 3092 kJ/kg and H_2 = 2929 kJ/kg. What is the velocity of the steam at the nozzle exit and what is the exit diameter?*

Solution. It is a flow system.



$d_1 = 50$ mm	$d_2 = ?$
$T_1 = 312$°C	$T_2 = 230$°C
$P_1 = 6.8$ atm	$P_2 = 3.4$ atm
$u_1 = 30$ m/s	$u_2 = ?$
$H_1 = 3092$ kJ/kg	$H_2 = 2929$ kJ/kg
$l = 250$ mm	

Fig. 1.23. Converging nozzle.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$(2929 - 3092) \times 10^3 + \frac{1}{2}(u_2^2 - 30^2) + 0 = 0 - 0$$

$$-163 \times 10^3 + \frac{1}{2}(u_2^2 - 30^2) + 0 = 0$$

$$\frac{1}{2}(u_2^2 - 30^2) = 163 \times 10^3$$

$$u_2^2 - 30^2 = 163000 \times 2$$

$$u_2^2 - 900 = 326000$$

$$u_2^2 = 326000 + 900$$

$$u_2^2 = 326900$$

$$u_2 = 572 \text{ m/s}$$

The velocity of the steam at the nozzle exit is 572 m/s. **Ans.**

From the continuity equation, we have

$$a_1 . u_1 = a_2 . u_2$$

$$(\pi \times d_1^2/4) \times u_1 = (\pi \times d_2^2/4) \times u_2$$

$$d_2^2 = d_1^2 \times (u_1/u_2)$$

$$d_2^2 = (50)^2 \times (30/572)$$

$$d_2^2 = 131$$

$$d_2 = 11.45 \text{ mm}$$

The exit diameter of the nozzle is 11.45 mm. **Ans.**

Example 1.24. *A fluid has a velocity of 220 cm / s when entering a piece of apparatus. With what velocity must the fluid leave the apparatus so that the difference in entering and leaving kinetic energy is equivalent to 1 J / kg of the fluid?* *(GATE Exam., 2000)*

Solution. It is a flow system.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$\Delta H + \frac{1}{2}(u_2^2 - u_1^2) + 0 = 0 - 0$$

$$1 + \frac{1}{2}(u_2^2 - 2.2^2) + 0 = 0$$

$$u_2 = 1.685 \text{ m/s}$$

The fluid must leave the apparatus with a velocity 1.685 m/s. **Ans.**

Example 1.25. *The potential energy of a body of mass 30 kg is 4.5 kJ. Calculate the height of the body from the ground.*

Solution. $\Delta E_p = mg(z_2 - z_1)$

$$4.5 \times 10^3 = 30 \times 9.81(z_2 - 0)$$

$$(z_2 - 0) = 4.5 \times 10^3/(30 \times 9.81)$$
$$z_2 = 15.29 \text{ m}$$

The height of the body from the ground is 15.29 m. **Ans.**

Example 1.26. *If the body of the mass 30 kg is moving at a velocity of 60 m / s, what is its kinetic energy?*

Solution. $E_K = \frac{1}{2} mV^2$

$$E_K = \frac{1}{2} \times 30 \times 60^2$$
$$E_K = 54000 \text{ J}$$

The kinetic energy of the body is 54 kJ. **Ans.**

Example 1.27. *A Santro car having a mass of 1300 kg is moving with a speed of 100 km / hr. What is the kinetic energy of the car?*

Solution. $E_K = \frac{1}{2} m \times V^2$

$$E_K = \frac{1}{2} \times 1300\ (100 \times 10^3/3600)^2$$
$$E_K = 501623.46 \text{ J}$$
$$E_K = 501.6 \text{ kJ}$$

The kinetic energy of the car is 501.6 kJ. **Ans.**

Example 1.28. *A man whose weight is 75 kg takes 3 min. for climbing up a staircase. What is the power developed in him, if the staircase is made up of 21 stairs each 0.15 m in height?*

Solution. $E_P = m \times g \times z$

$$E_p = 70 \times 9.81 \times (21 \times 0.15)$$
$$E_p = 2163.105 \text{ J}$$
$$E_p = 2163.10 \text{ J}/(3 \times 60) \text{ Watts}$$
$$E_p = 12.02 \text{ watts}$$

The power developed in man is 12.02 watts. **Ans.**

Example 1.29. *Liquid water at 100°C and 1 atm has internal energy 418700 J / kg. What is the enthalpy? The specific volume of liquid water at these conditions is 1.045×10^{-3} m³ / kg.*

Solution. $H = U + PV$

$$H = 418700 + 1 \times 10^5 \times (1.045 \times 10^{-3})$$
$$H = 418700 + 104.5$$
$$H = 418804.5 \text{ J/kg}$$
$$H = 418.8 \text{ kJ/kg}$$

Enthalpy of liquid water is 418.8 kJ/kg. **Ans.**

Example 1.30. *10 kg of water are vapourized at constant temperature of 100°C and 1 atm pressure. The heat added to the system* *is 2257 kJ/kg. The specific volumes of liquid and vapor are* 1.04×10^{-3} *and* 167.2×10^{-2} m^3/kg *respectively. Find* ΔU, ΔH *and* ΔS.

Solution. $\Delta U = Q - W$

$$\Delta U = Q - P\Delta V$$

$$\Delta U = Q - P(V_2 - V_1)$$

$$\Delta U = 2257 \times 10^3 - 1 \times 10^5 (167.2 \times 10^{-2} - 1.04 \times 10^{-3})$$

$$\Delta U = 2257 \times 10^3 - 167096$$

$$\Delta U = 2089904 \text{ J/kg}$$

$$\Delta U = 2089904 \times 10 \text{ J}$$

$$\Delta U = 20899.04 \text{ kJ} \quad \textbf{Ans.}$$

$$\Delta H = \Delta U + \Delta(PV)$$

$$\Delta H = \Delta U + P(V_2 - V_1)$$

$$\Delta H = 2089904 + 1 \times 10^5 (167.2 \times 10^{-2} - 1.04 \times 10^{-3})$$

$$\Delta H = 2089904 + 167096$$

$$\Delta H = 2257000 \text{ J/kg}$$

$$\Delta H = 2257000 \times 10 \text{ J}$$

$$\Delta H = 22570 \text{ kJ.} \quad \textbf{Ans.}$$

$$\Delta S = \frac{Q}{T}$$

$$\Delta S = \frac{2257 \times 10^3}{373}$$

$$\Delta S = 6050.94$$

$$\Delta S = 6050.94 \times 10 \text{ J/K}$$

$$\Delta S = 60.51 \text{ kJ/K} \quad \textbf{Ans.}$$

Example 1.31. *A system consisting of some fluid is stirred in a tank. The work done on the system by the stirrer is of the order of 1.5 h.p. Heat generated because of the stirring is dissipated through the surroundings. If this heat transfer is 845 kcal/hr, determine the change in internal energy.*

Solution. $\Delta U = Q - W$

$$\Delta U = -845 \times 10^3 \times 4.187 + 1.5 \times 745.5 \times 3600$$

$$\Delta U = -3538015 + 4025700$$

$$\Delta U = 487685 \text{ J/hr} \quad \textbf{Ans.}$$

Example 1.32. *Steel wool contain in a cylinder at atmospheric pressure of pure Oxygen. The cylinder is fitted with frictionless piston which maintains the Oxygen pressure at 1 atmosphere. The iron in the steel wool reacts with* O_2 *to form* Fe_2O_3. *Heat is removed from the process so as to keep the temperature constant at 25°C. Calculate* ΔU *for the process for the reaction of 2 kgmol of iron.*

Solution. Chemical reaction

$$2Fe(s) + \frac{3}{2}\,O_2(g) \rightarrow Fe_2O_3(s)$$

$$\Delta U = Q - W \qquad \text{...(1.59)}$$

$$\Delta U = Q - P\Delta V$$

$$\Delta U = Q - (n_2 - n_1)\,RT \qquad \text{...(1.60)}$$

From the S.I. Data book, we have

$$Q = 830500 \text{ J}$$

$$(n_2 - n_1) = 3/2 \text{ kgmol}$$

$$R = 8314 \text{ J/kg mol K}$$

$$T = 298 \text{ K}$$

Substituting above values in equation (1.60), we get

$$\Delta U = -\,830500 - \frac{3}{2} \times 8314 \times 298$$

$$\Delta U = -\,830500 - 3716358$$

$$\Delta U = -\,4546858 \text{ J}$$

$$\Delta U = 4546.85 \text{ kJ}$$

Change in internal energy for the reaction of 2 kg mol of iron is 4546.85 kJ. **Ans.**

Example 1.33. *A stationary mass of gas is compressed without friction from an initial state of 0.4 m^3 and 0.105 MPa to a final state of 0.2 m^3 and 0.105 MPa, the pressure remaining constant during the process. There is a transfer of 37.5 kJ of heat from the gas during the process. How much does the internal energy of the gas change?*

Solution. It is a non flow process

$$\Delta U = Q - W$$

$$\Delta U = Q - \Delta(PV)$$

$$\Delta U = Q - P\Delta V$$

$$\Delta U = Q - P(V_2 - V_1)$$

$$\Delta U = -\,37.5 \times 10^3 - (1.036 \times 10^5)\,(0.2 - 0.4)$$

$$\Delta U = -\,37.5 \times 10^3 + 20720$$

$$\Delta U = -\,16780 \text{ J}$$

The internal energy of the gas change is – 16.78 kJ. **Ans.**

Example 1.34. *In a thermal power plant, superheated steam at 30.58 atm and 300°C enters an adiabatic turbine and leaves as steam of quality 0.85 at 45°C. The steam enters the turbine with a velocity of 10 m / s at an elevation of 11 m above the ground and leaves the turbine with a velocity of 45 m / s at an elevation of 5 m above the ground. If the flow rate of steam through the turbine is 1 kg / s, determine the power output of the turbine.*

Solution. It is a flow system.

Flow rate of steam = 1 kg/s

$P_1 = 30.58$ atm $P_2 = 5.096$ atm

$T_1 = 300°C$ $T_2 = 45°C$

$u_1 = 10$ m/s $u_2 = 45$ m/s

$Z_1 = 11$ m $Z_2 = 5$ m

Fig. 1.24. Thermal power plant.

Quality steam of 0.85, the steam pressure is 5.096 atm

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$(H_2 - H_1) + \frac{1}{2}(u_2^2 - u_1^2) + g(z_2 - z_1) = Q - W_s$$

$$(2625.2 - 2995.1) \times 10^3 + \frac{1}{2}(45^2 - 10^2) + 9.81\,(5 - 11) = 0 - W_s$$

$$-369.9 \times 10^3 + 962.5 - 58.86 = -W_s$$

$$W_s = 369.9 \times 10^3 - 962.5 + 58.86$$

$$W_s = 368996.36 \text{ J/kg}$$

$$W_s = 368996.36 \times 1 \text{ J/s}$$

$$\text{h.p.} = 368996.36/745.5$$

$$\text{h.p.} = 495$$

Power output of the turbine is 495 h.p. **Ans.**

Example 1.35. *Compute the work given out during a process if the internal energy of the system changes by 90000 J and the heat flow is – 35,000 J.*

Solution. It is a non flow system

$$\Delta U = Q - W$$

$$90{,}000 = -35{,}000 - W$$

$$W = -35000 - 90000$$

$$W = -125000 \text{ J}$$

$$W = -125 \text{ kJ}$$

Work given out during the process is – 125 kJ. **Ans.**

Example 1.36. *During a reversible process at constant pressure of 2 atm and 200°C useful energy equal to 274.68 kJ was given out by the system. As a result of this process 5 g mol are produced. Find ΔU for this process.*

Solution. It is a non flow process.

$$\Delta U = Q - W$$

$$\Delta U = Q - PV$$

$$\Delta U = Q - nRT \qquad ...(1.61)$$

$$\Delta U = -274.68 \times 10^3 - 5 \times 8.314 \times 373$$

$$\Delta U = -274680 - 15505.61$$

$$\Delta U = -290185.61 \text{ J.} \quad \textbf{Ans.}$$

Example 1.37. *It has been suggested that the bottom of a water falls should be hotter than the top. What temperature difference would you expect in the case of water fall having a height of 60 m.*

Data: $C_p = 4.2\ kJ/kg\ K$

Assume there is no kinetic energy.

Solution. It is a flow system.

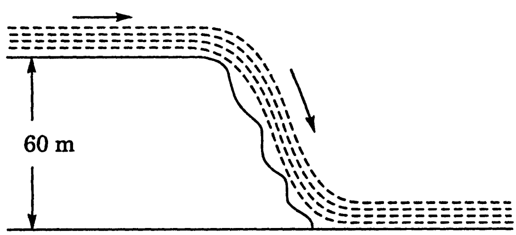


Fig. 1.25. Water fall.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$mC_p (T_2 - T_1) + 0 + g(z_2 - z_1) = 0 - 0$$

$$1 \times 4.2 \times 10^3 \times (T_2 - T_1) + 9.81(0 - 60) = 0$$

$$4.2 \times 10^3 \times (T_2 - T_1) - 9.81 \times 60 = 0$$

$$4.2 \times 10^3 \times (T_2 - T_1) = 9.81 \times 60$$

$$4200 \times (T_2 - T_1) = 588.6$$

$$(T_2 - T_1) = 588.6/4200$$

$$(T_2 - T_1) = 0.14 \text{ K}$$

The temperature difference expected in the case of water fall is 0.14 K. **Ans.**

Example 1.38. *20 peoples attained a cocktail party in a small room which measure 7 × 8 × 3 m³. Each person after drinking gives up about 125 J/s. Assuming that the room is completely sealed and insulated. Calculate the air temperature rise occuring in 15 minutes. Assume that each person occupies a volume of 0.7 m³ and initially the pressure and temperature are 1 atm and 25°C respectively.*

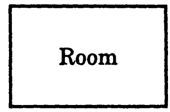
Data: $C_V = 20.78\ kJ/kg\ mol\ .\ K$

Solution. It is a non flow process. The volume of the room is constant.

$T_1 = 25°C$

$V_1 = 154\ m^3$

$C_v = 20.78$ kJ/kgmol K



$T_2 = ?$

Fig. 1.26. Insulated room.

Volume of air present in the room

$$= 7 \times 8 \times 3 - 20 \times 0.7$$
$$= 154\ m^3$$
$$\Delta U = Q - W$$

The room is completely sealed and insulated. Hence, amount of heat transferred, $Q = 0$

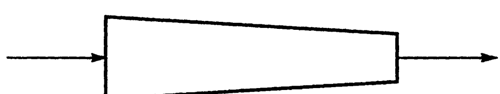
$$\Delta U = -W = mC_v (T_2 - T_1) \qquad ...(1.62)$$
$$\Delta U = mC_v (T_2 - T_1)$$
$$20 \times 125 \times 15 \times 60 = \left(\frac{154}{22.4}\right) \times \left(\frac{273}{273 + 25}\right) \times (20.78 \times 10^3)(T_2 - T_1)$$
$$(T_2 - T_1) = 17.2\ K. \quad \textbf{Ans.}$$

Example 1.39. *An ideal gas is flowing in steady state through a horizontal tube which has non conducting walls. No heat is added nor any shaft work is done. The cross-sectional area of the tube changes with length and this causes the velocity to change. Derive an expression relating the temperature and velocity of the gas.*

If N_2 at 150°C flows past one section of the tube at a velocity of 15 m/s, what will be its temperature at another section where the velocity is 365 m/s?

Data: C_{PN_2} = 1.0416 kJ/kg K. (*Kanpur University, 1978*)

Solution. It is a flow system.



$T_1 = 150°C$ $\qquad$ $T_2 = ?$

$u_1 = 15$ m/s $\qquad$ $u_2 = 365$ m/s

Fig. 1.27. Horizontal tube.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$
$$\Delta H + \Delta E_k + 0 = 0 - 0$$
$$mC_p (T_2 - T_1) + \frac{1}{2} m (u_2^2 - u_1^2) + 0 = 0$$
$$C_p (T_2 - T_1) = -\frac{1}{2}(u_2^2 - u_1^2)$$

$$C_p (T_2 - T_1) = \frac{1}{2} (u_1^2 - u_2^2)$$

$$(T_2 - T_1) = (u_1^2 - u_2^2)/2C_p$$

$$T_2 = T_1 + (u_1^2 - u_2^2)/2C_p \qquad ...(1.63)$$

$$T_2 = 423 + (15^2 - 365^2)/(2 \times 1.0416 \times 10^3)$$

$$T_2 = 423 + (225 - 133225)/2083.2$$

$$T_2 = 423 - 63.85$$

$T_2 = 359.15$ K. **Ans.**

Example 1.40. *The properties of O_2 gas may be expressed over a restricted range by the relation*

$$PV = 260T + 71 \times 10^3 \text{ and}$$

$$T = 1.52U - 273$$

where, P is in N/m^2 and V is in m^3/kg. Calculate C_p and C_v for 1 kg of O_2 at a pressure of 600×10^3 N/m^2 and temperature 280°C contained in a rigid vessel.

Solution. From the specific heat at constant pressure, we have

$$C_p = \left(\frac{\partial H}{\partial T}\right)_P \qquad ...(1.64)$$

From the definition of enthalpy, we know that

$$H = U + PV \qquad ...(1.65)$$

From the given relations, we have

$$PV = 260T + 71 \times 10^3 \qquad ...(1.66)$$

$$T = 1.52U - 273 \qquad ...(1.67)$$

$$U = 0.66T + 179.6 \qquad ...(1.68)$$

Substituting equation (1.68) and (1.66) in equation (1.65), we get

$$H = 0.66T + 179.6 + 260T + 71 \times 10^3$$

$$H = 260.66\,T + 71179.6 \qquad ...(1.69)$$

Differentiating equation (1.69) w.r.t. 'T' at constant 'P', we get

$$\left(\frac{\partial H}{\partial T}\right)_P = 260.66 + 0$$

$C_p = 260.66$ J/kg K. **Ans.**

From the specific heat at constant volume, we have

$$C_v = \left(\frac{\partial H}{\partial T}\right)_V \qquad ...(1.70)$$

From the equation (1.168), we have

$$U = 0.66T + 179.6 \qquad ...(1.68)$$

Differentiating equation (1.68) w.r.t. 'T' at constant 'V', we get

$$\left(\frac{\partial H}{\partial T}\right)_V = 0.66 + 0$$

$$C_V = 0.66 \text{ J/kg K.} \quad \textbf{Ans.}$$

Example 1.41. *A gas expands from an initial volume of 0.2 m^3 to a final volume of 0.4 m^3 in a reversible steady flow process. During the process, the pressure varies with the volume as*

$$P = 5 \times 10^6 V + 7 \times 10^4$$

where, P is in N/m^2 and V is in m^3. The inlet line is 4 m below the outlet line and the gas enters with a negligible velocity. The internal energy of the gas decreases by 30 kJ during the process. Determine the heat transferred.

Solution. It is a non flow process.

$$\Delta U + \Delta E_k + \Delta E_p = Q - \dot{W}$$

$$\Delta U + \Delta E_k + \Delta E_p = Q - \Delta(PV)$$

$$\Delta U + \Delta E_k + g(z_2 - z_1) = Q - (P_2V_2 - P_1V_1) \qquad ...(1.71)$$

$$-30 \times 10^3 + 0 + 9.81\,(4 - 0) = Q - (20.7 \times 10^5 \times 0.4 - 10.7 \times 10^5 \times 0.2)$$

$$-30 \times 10^3 + 0 + 39.24 = Q - (828000 - 214000)$$

$$-30 \times 10^3 + 39.24 = Q - 614000$$

$$Q = 584039 \text{ J.} \quad \textbf{Ans.}$$

Example 1.42. *Oil flows at a rate of 1800 kg/min. from an open reservoir at a height of 410 m to another reservoir at the ground. Heat is supplie to the oil on its way at the rate 1800 kJ/min. and work is supplied by a 1 h.p. pump. Take the mean specific heat of oil to be 3.5 kJ/kg K. Calculate the temperature change of the oil.*

Solution. It is a flow process.

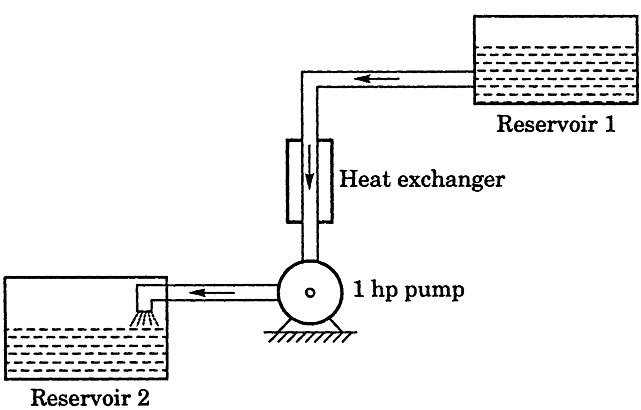


Fig. 1.28. Pumping of oil from Reservoir 1 to Reservoir 2.

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$C_p (T_2 - T_1) + 0 + g(z_2 - z_1) = Q - 1\ W_s$$

$$3.5 \times 10^3 (T_2 - T_1) + 0 + 9.81 (0 - 410) = 1800 \times 10^3/1800 - 1 \times 745.5/30$$

$$3.5 \times 10^3(T_2 - T_1) - 4022.1 = 1000 - 24.85$$

$$3.5 \times 10^3(T_2 - T_1) = 1000 - 24.85 + 4022.1$$

$$3.5 \times 10^3 (T_2 - T_1) = 4997.25$$

$$(T_2 - T_1) = 4997.25/3.5 \times 10^3$$

$$(T_2 - T_1) = 1.43 \text{ K.} \quad \textbf{Ans.}$$

Example 1.43. *An insulated rigid vessel contains air at 5 atm and 102°C. The volume of the vessel is 1 m^3. Air may be assumed to behave as an ideal gas. The specific heat C_V of air is 0.7176 kJ/kg K. The temperature of the air is increased by a rotating paddle wheel. Calculate the work done to raise the temperature of the air to 150°C.*

Solution. It is a non flow system.

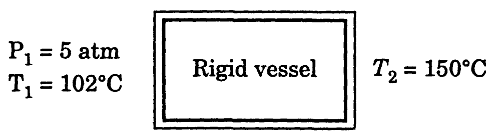


Fig. 1.29. Insulated rigid vessel.

$$\Delta U + \Delta E_k + \Delta E_p = Q - W$$

$$mC_V (T_2 - T_1) + 0 + 0 = 0 - W$$

$$\frac{1 \times 5 \times 10^5}{8.314 \times 375} \times \frac{0.7176 \times 10^3}{29} \times (423 - 375) = -W$$

$$190.48 = -W$$

$$W = -190.48 \text{ kJ}$$

Workdone to raise the temperature of the air to 150°C is – 190.48 kJ.

Ans.

Example 1.44. *Saturated water and saturated steam are mixed under adiabatic conditions with a water to steam mass ratio 1:15. If mixing is carried out under steady state conditions at constant pressure, calculate the enthalpy of mixture from the data given below:*

Pressure	*Enthalpy*
Saturated water at 20 atm	*917221 J/kg*
Saturated steam at 20 atm	*2801223 J/kg*

Solution.

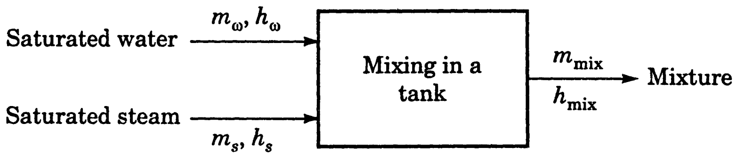


Fig. 1.30. Mixing of saturated water and steam.

$$m_w \cdot h_w + m_s \cdot h_s = m_{\text{mix}} \cdot h_{\text{mix}}$$
$$h_{\text{mix}} = (m_w \cdot h_w + m_s \cdot h_s)/m_{\text{mix}}$$
$$h_{\text{mix}} = [(1) \times (917221) + (15) \times (2801223)]/(1 + 15)$$
$$h_{\text{mix}} = (917221 + 42018345)/16$$
$$h_{\text{mix}} = 2683473 \text{ J/kg}$$

Enthalpy of mixture is 2683473 J/kg. **Ans.**

Example 1.45. *A house hold refrigerator is loaded with fresh food and closed. Consider the whole refrigerator and contents as a system. The machine uses 1 kwh of electrical energy in cooling the food and internal energy of the system decreases by 1250 kcal as the temperature drops. Find the magnitude and the sign of heat transfer for the process and justify your answer.* (*Bangalore University, 1990*)

Solution. It is a non flow process.

$$\Delta U = Q - W$$
$$-1250 = Q - 860$$
$$Q = -1250 + 860$$
$$Q = -390 \text{ kcal/hr}$$
$$Q = -453 \text{ watts}$$

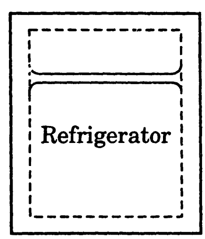


Fig. 1.31. Refrigerator.

The internal energy of the system decreases by – 453 watts as cooling is effected in the refrigerator.

Example 1.46. *On a warm summer day, a housewife decides to beat the heat by closing the doors and windows in the kitchen and opening the refrigerator door. Initially she feels cool and refreshed, but after a while the effect begins to wear off. Evaluate the situation, as it relates to the first law of thermodynamics, considering the room including the refrigerator as the system.*

Solution. It is a non flow process.

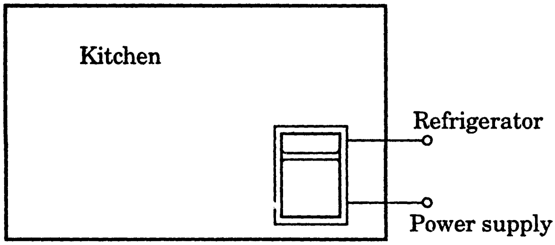


Fig. 1.32. Kitchen.

Assume that the kitchen wall, window and door are non conducting. Therefore, amount of heat transfer, $Q = 0$. Hence, on a warm summer day when the housewife, opened the refrigerator door, the temperature of the air in the room falls. Now, considering the kitchen including the refrigerator as the system.

$$\Delta U = Q - W$$
$$\Delta U = 0 - W$$
$$\Delta U = -W$$

The power supply is given to the refrigerator for its operation. Hence, work is done on the system and W is negative. This results in an increase of temperature of the air. Hence, as soon as the refrigerator door is opened, initially she feels cool and refreshed but after a while the effect gradually begins to wear off.

Example 1.47. *2.5 kg of liquid having a constant specific heat of 2.4 kJ/kg°C is stirred in a well insulated tank causing the temperature to raise by 10°C. Find ΔU and W for the process.*

Solution. It is a non flow process.

$$\Delta U = mc_v \, \Delta T \qquad ...(1.73)$$
$$\Delta U = 2.5 \times 2.4 \times 10$$
$$\Delta U = 60 \text{ kJ.} \quad \textbf{Ans.}$$
$$\Delta U = Q - W$$
$$60 = 0 - W$$
$$W = -60 \text{ kJ.} \quad \textbf{Ans.}$$

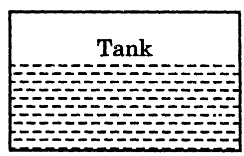


Fig. 1.33. Insulated tank.

Example 1.48. *A system undergoes a process during which the temperature changes from 200°C to 450°C. The internal energy of the system is given by*

$$U = 13.5 + 0.8T$$

where, T is in °C. During the process the work done per degree rise in temperature is $\dfrac{dW}{dt} = 0.5$ *kJ/°C. Determine the heat transfer during the process.*

Solution. It is a non flow process.

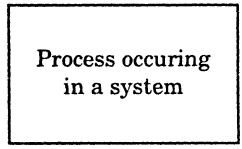


Fig. 1.34. System undergoing a process.

$$\frac{dW}{dT} = 0.5$$

$$dW = 0.5\,dT$$

$$W = \int_{200}^{450} 0.5\,dT$$

$$W = 0.5\,(450 - 200)$$

$$W = 125 \text{ kJ}$$

$$U = 13.5 + 0.8T$$

$$U_1 = 13.5 + 0.8 \times 200$$

$$U_1 = 173.5 \text{ kJ}$$

$$U_2 = 13.5 + 0.8 \times 450$$

$$U_2 = 373.5 \text{ kJ}$$

$$U_2 - U_1 = 373.5 - 173.5$$

$$U_2 - U_1 = 200 \text{ kJ}$$

$$\Delta U = 200 \text{ kJ}$$

$$\Delta U = Q - W$$

$$200 = Q - 125$$

$$Q = 200 + 125$$

$$Q = 325 \text{ kJ}. \quad \textbf{Ans.}$$

1.18. Flow Calorimeter

It is a device used to measure the heat content of the flowing fluid. A typical flow calorimeter is shown in Fig. 1.35. It consists of a constant temperature bath and a heater.

Let us consider a constant temperature bath containing a circular coil through which the test fluid is pumped. The bath is filled up with ice cool water, ice and a little salt to maintain the temperature of the bath at 0°C.

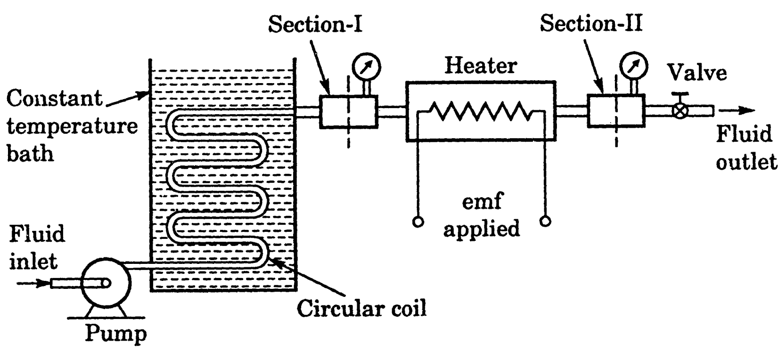


Fig. 1.35. Flow Calorimeter.

The test fluid enters at section-I and moves out from the section-II. The kinetic energy and potential energy of the flowing fluids are negligible and no shaft work is accomplished. The temperature of the test fluid is maintained at 0°C at section-I.

At this point, the heat is added to the fluid using a electric resistance heater. The rate of heat input to the fluid is determined from the resistance of the heater and the amount of current passing through it. The measurement of rate of heat input and the rate of flow of fluid gives the value of enthalpy between the two sections. The values of enthalpy of test fluid for various conditions at section-II may be calculated by the equation

$$\Delta H = Q - W_s$$
$$H_2 - H_1 = Q - W_s$$
$$H_2 - H_1 = Q - 0$$
$$H_2 - H_1 = Q$$
$$H_2 = H_1 + Q \qquad ...(1.74)$$

where H_2 = Enthalpy of fluid at section-II, J/kg

H_1 = Enthalpy of fluid at section-I, J/kg

Q = Amount of heat added to the fluid, J/kg

H_2 values depends on Q as well as H_1. The conditions of the fluid at section-I is always remain constant, because of the reason that the test fluid is at 0°C and the pressure varies from run to run. However, the pressure has a negligible effect on the properties of the fluid, unless it reached a very high pressure. Hence, setting the value of $H_1 = 0$, the equation (1.74) may be modified as

$$H_2 = Q \qquad ...(1.75)$$

The results may be recorded along with corresponding values of temperature 'T' and pressure 'P' existing at section-II for a large number of runs. In addition, measurement of specific volume 'V' and specific entropy 'S' may be made for the same conditions.

In this way, compiling of properties of the test fluid over the entire useful range of conditions are called thermodynamic properties. If this test is carried out for water and the properties are compilied over the entire useful range of conditions, then it is known as steam Table.

Example 1.49. *For a flow calorimeter with water as the test fluid the following data are obtained. Flow rate of water* 4.12×10^{-3} *kg/s,* $T_1 = 0°C$, $T_2 = 300°C$, $P_2 = 2.95$ *atm and the rate of heat addition from the resistance heater is 12780 watts. It is observed that the water is completely vaporized in the process. Calculate the enthalpy of steam at 300°C and 2.95 atm pressure for liquid water at 0°C.*

Solution. It is a flow calorimeter system.

$$H_2 = H_1 + Q$$

$$H_2 = 0 + 12780/(4.12 \times 10^{-3})$$

$$H_2 = 3101.94 \text{ kJ/kg.} \quad \textbf{Ans.}$$

REVIEW QUESTIONS

1.1. Define thermodynamics.

1.2. Discuss in detail the scope of thermodynamics.

1.3. Define system and surrounding.

1.4. Differentiate between system and surrounding.

1.5. Define open system and closed system.

1.6. Differentiate between open system and closed system.

1.7. What is the process of thermodynamics? Give suitable examples.

1.8. Define the state of a system.

1.9. Define the properties of the system.

1.10. Define intensive and extensive properties.

1.11. Differentiate between intensive and extensive properties. Give suitable examples.

1.12. Define state function.

1.13. Define path function.

1.14. What is equilibrium state?

1.15. Define mechanical equilibrium. Give suitable examples.

1.16. Define chemical equilibrium. Give suitable examples.

1.17. Define thermal equilibrium. Give suitable examples.

1.18. Explain the term thermometric properties.

1.19. Define fixed point of a state. Give suitable examples.

1.20. Define macro and micro state of thermodynamics. Give suitable examples.

1.21. Differentiate between macro and micro state.

1.22. Define heat. Give suitable examples.

1.23. Define temperature. Give suitable examples.

1.24. Define work. Give suitable examples.

1.25. Define static pressure.

1.26. Define dynamic pressure.

1.27. Define cyclic process. Give suitable example.

1.28. Define and explain the phase rule with suitable example.

1.29. Define zeroth law of thermodynamics with suitable examples.

1.30. Define heat engine. Give suitable example.

1.31. Define heat reservoir. Give suitable example.

1.32. Differentiate between heat engine and heat reservoir.

1.33. Define reversible process. Give suitable example.

1.34. Define irreversible process. Give suitable example.

1.35. Differentiate between reversible and irreversible process.

1.36. Define homogeneous system. Give suitable examples.

1.37. Define heterogeneous system. Give suitable examples.

1.38. Differentiate between homogeneous and heterogeneous system.

1.39. What is the general statemenet of first law of thermodynamics?

1.40. Exaplain the first law of thermodynamics for cyclic process.

1.41. Explain the first law of thermodynamics for non flow (closed) system.

1.42. Explain the first law of thermodynamics for flow (open) system.

1.43. Formulate the first law of thermodynamics for non flow (closed) system.

1.44. Formulate the first law of thermodynamics for flow (open) system.

1.45. Elaborate on sign convention used in first law of thermodynamics.

1.46. Define heat capacity.

1.47. Formulate the equation for specific heat at constant pressure.

1.48. Formulate the equation for specific heat at constant volume.

1.49. What are the forms of energy which change in system.

1.50. What are the energies in transit?

1.51. Define enthalpy and formulate the equation for the same.

1.52. Define thermodynamics property. Give example.

1.53. What is the role of thermodynamics in energy consumption?

1.54. Define specific heat.

1.55. Distinguish between Reversible and Irreversible processes. What are the salient characteristics of a reversible process? Are all real process reversible?

1.56. Show that the work done on or by a closed system undergoing a reversible adiabatic change is a point function.

(Jadavpur University, 1975)

1.57. What is thermodynamics properties? Explain how the thermodynamics properties of a fluid is determined using a flow calorimeter.

1.58. What is meant by entrance work in flow system?

EXERCISES

1.1. 15 kg of water are vaporized at constant temporature of 100°C and 1 atm pressure. The heat added to the system is 2257 kJ/kg. The specific volume of liquid and vapour are 1.04×10^{-3} and 167.2×10^{-2} m^3/kg respectively. Find ΔU.

1.2. 5 kg of water is vaporized at constant temperature of 100°C and 1 atm pressure. The heat added to the system is 2257 kJ/kg. The specific volume of liquid and vapour are 1.04×10^{-3} and 167.2×10^{-2} m^3/kg respectively. Find ΔH.

1.3. A certain battery is charged by applying a current of 30 A and 9 V for 40 min. time period. During the charging process the battery loses 210 kJ of heat to the surroundings. How much does the change in internal energy of the battery during the 40 min. time periods?

1.4. Show that energy balances for steady state flow process for open system is given by

$$\Delta H + \Delta E_K + \Delta E_p = Q - W_s.$$

1.5. A turbine operating under steady state conditions receives 5000 kg steam per hour. The steam enters at a velocity of 3000 m/min., at an elevation of 5 m and specific enthalpy 2750 kJ/kg. It leaves the turbine at a velocity of 600 m/min., an elevation of 1 m and specific enthalpy 2250 kJ/kg. Heat losses from the turbine to surroundings amouents to 16,580 kJ/hr. Determine the h.p. output of the turbine.

Note: 1 h.p. = 745.5 W.

1.6. The turbine of a jet engine received a steady flow of gas at a pressure of 720×10^3 N/m^2, at a temperature of 870°C and at a velocity of 180 m/s. It discharges the gases at a pressure of 215×10^3 N/m^2, at a temperature of 625°C and at a velocity of 320 m/s. Evaluate the output of the turbine in h.p. The process may be assumed iadiabatic. The enthalpy datas are as follows:

$$H_1 = 1000 \text{ kJ/kg}, \quad H_2 = 719 \text{ kJ/kg}.$$

1.7. A gas turbine receives gas at an enthalpy of 850 kJ/kg and at a velocity of 100 m/s. The gas leaves the turbine at an enthalpy of 450 kJ/kg and at a velocity of 180 m/s. Heat lost to the surroundings from the gas is 42 kJ/s. If the rate of gas flow is 1.2 kg/s, calculate the power developed by the turbine.

1.8. At entry to the reciprocating compressor of a refrigerator, the refrigerant F-12 has pressure and temperature of 200×10^3 N/m^2 and – 10°C respectively. At the exit from the compressor the F-12 has 900 $\times 10^3$ N/m^2 and 55°C. The flow is steady. Evaluate the external work in J/kg of the F-12. Assume the compressor to be adiabatic and changes in K.E. and P.E. to be negligible. The enthalpy of F-12 at the entry and extreme condition is $H_1 = 183 \times 10^3$ J/kg and $H_2 = 214 \times 10^3$ J/kg respectively.

1.9. A turbine operating under steady conditions receives 6000 kg/hr of steam. The steam enters the turbine at a velocity of 3000 m/min., an elevation of 5 m and specific enthalpy of 2800 kJ/kg. It leaves the turbine at a velocity of 600 m/min., an elevation of 1 m and specific enthalpy of 2200 kJ/kg. Calculate the energy converted into work.

1.10. Water at 90°C is pumped from a storage tank 1 to a storage tank 2, 13 m above by a 1.2 h.p. motor, 627 kJ/min. of heat is extracted from the water using a heat exchanger. If the flow rate is 180 kg/min., what is the temperature of water delivered in the second tank? Take data from steam table.

1.11. A steam turbine received 560 kg steam per hour at 24.5 atm and 45°C, at a velocity of 50 m/s and an elevation of 4.5 m. Heat transfer from the turbine to the surrounding is 3000 kJ/hr. Steam leaves the turbine dry saturated at 1.5 atm, at a velocity of 130 m/s and an elevation of 1.2 m. Determine the power develped by the turbine in h.p. Take data from steam table.

1.12. Steam at 13.5 atm absolute pressure and 315°C (state-1) enter a turbine through standard 76 mm diameter pipe line with a velocity of 5 m/s.

The exit from the turbine is carried through a standard 254 mm diameter pipe line and is at 0.217 atm absolute pressure and 70°C (state-2).

Data is given as:

$H_1 = 30.80 \times 10^5$ J/kg $\qquad H_2 = 26.30 \times 10^5$ J/kg

$V_1 = 0.190$ m³/kg $\qquad V_2 = 5.74$ m³/kg

Assume there is no heat loss. Find the power output of the turbine.

1.13. Air flows steadily at the rate of 0.5 kg/s through an air compressor. The air enter the compressor at a velocity of 5 m/s, pressure 1.05 kg/cm² and specific volume of 0.85 m³/kg. It leaves the compressor at a velocity of 3.5 m/s, pressure 7.5 kg/cm² and specific volume of 0.163 m³/kg. The internal energy of the fluid leaving is 21 kcal/kg greater than that of the air entering. Cooling water in the compressor jacket absorbs heat from the air at the rate of 16 kcal/s. Calculate the h.p. required to run the compressor.

1.14. Compute the horse power developed by a turbine from the data given below:

	Pressure (*N/m²*)	*Temperature* (*°C*)	*Velocity* (*m/s*)	*Diameter of pipe* (*cm*)	*Elevation* (*m*)
Inlet	20×10^5	420	5	2.54	3.5
Outlet	0.35×10^5	90	—	5.08	Datum Level

Assume no heat loss.

1.15. Air flows steadily at the rate of 22.68 kg/min. through an air compressor entering at velocity of 6.1 m/s, pressure 1.02 kg/cm² and specific volume of 0.845 m³/kg. It leaves the compressor at velocity of 4.6 m/s, pressure 7.2 kg/cm² and specific volume of 0.163 m³/kg. The internal energy of the fluid leaving is 21.1 kcal/kg greater than that of the air entering. Cooling water in the compressor jacket absorbs heat from the air at the rate of 882 kcal/min.

(*i*) Calculate the h.p. required to run the compressor

(*ii*) Determine the ratio of inlet pipe diameter to outlet pipe diameter.

1.16. A turbine operating adiabatically is fed with steam at 420°C and 8.5 MPa at the rate of 1000 kg/hr. Process steam saturated at 0.6 MPa is withdrawn from an intermediate location of the turbine at the rate of 300 kg/hr and the remaining steam leaves the turbine saturated at 0.15 MPa. What is the power output of the turbine?

1.17. A trial run on a steam turbine power plant gave the following results:

Entrance to turbine $\qquad$ *Exit of turbine*

$u_1 = 6.5$ m/s $\qquad u_2 = 25$ m/s

$H_1 = 950$ kJ/kg $\qquad H_2 = 2750$ kJ/kg

$z_1 = 5.2$ m $\qquad z_2 =$ Datum level

Mass flow rate = 3600 kg/hr

Determine the power developed by the turbine if the heat added to the system is 2500 kJ/s.

1.18. A flow process is under the following conditions of operation:

	At the entrance	*At the exit*
Enthalpy:	16,65,130 J/kg	2,50,890 J/kg
Velocity:	25 m/s	10 m/s
Elevation:	20 m	......

Heat is transferred to the system at the rate of 50,000 J/s. What is the work done by the system, when the elevation at the exit is 5 m?

1.19. Steam flows through a small steam turbine at a rate of 1.2 kg/s entering at 312°C and 13.5 atm. It leaves the turbine at dry saturated and 1.5 atm. The steam enters at 75 m/s at a point 5 m above the discharge and leaves at 35 m/s. Calcuate the shaft work output in horse power assuming the device is adiabatic.

1.20. Air is compressed reversibly and adiabatically from 1 atm and 16°C to 5 atm according to the relation $PV^{1/2} = C$. Changes in the kinetic and potential energies are negligible. Compute the work done in compressing the air for the follwing cases.

(*i*) Non flow process

(*ii*) Steady state flow process

1.21. Calculate ΔU and ΔH in J for 1 kg of water as it vaporized at a constant temperature 100°C and pressure of 1 atm. The specific volume of liquid water and steam at this condition are 0.00104 and 1.673 m^3/kg respectively. For this changes 2256.9 kJ of heat is added to liquid water.

1.22. A Maruti Suzuki car having a mass of 1500 kg is moving with a speed of 70 km/hr. What is the kinetic energy of the car?

1.23. 5 kg of water is vapourized at constant temperature of 100°C and 1 atm pressure. The heat added to the system is 2250 kJ/kg. The specific volume of liquid and vapour are 0.00104 and 1.672 m^3/kg respectively. Find ΔU, ΔH and ΔS.

1.24. A woman whose weight is 60 kg takes 3.5 min. for climbing up a staircase. What is the power developed in her, if the staircase is made up of 25 stair each 0.13 m in height?

1.25. If a motor bike of mass 100 kg is moving at a velocity of 100 km/hr, what is its kinetic energy?

1.26. The potential energy of a body of mass 20 kg is 6.5 kJ. Calculate the height of the body from the ground.

1.27. A fluid has a velocity of 210 cm/s, when entering a piece of apparatus. With what velocity must the fluid leave the apparatus so that the difference in entering and leaving kinetic energy is equivalent to 1 J/kg of the fluid?

1.28. During a reversible process at constant pressure of 2 atm and 210°C useful energy of 277 kJ was given out by the system. As a result of this process 5 gmol is produced. Find ΔU for this process.

1.29. Steam flows at steady state through a converging insulated nozzle 280 mm long and with a inlet diameter of 76 mm. At the nozzle entrance (state 1) the temperature and pressure are 300°C and 6.5 atm and the velocity is 40 m/s. At the nozzle exit (state 2), the steam temperature and pressure are 220°C and 3.2 atm. The enthalpy values are H_1 = 3045 kJ/kg and H_2 = 2825 kJ/kg. What is the velocity of the steam at the nozzle exit and what is the exit diameter?

1.30. Water is flowing in a straight horizontal insulated pipe of 18 mm inner diameter. There is no device present for adding or removing energy as work. The upstream velocity is 15 m/s. The water flows a section where the diameter is suddenly increased. What is the change in enthalpy of the water if the downstream diameter is 57 mm. If it is 100 mm what is the maximum enthalpy change for a sudden enlargement in the pipe?

1.31. A system consisting of some fluid is stirred in a tank. The work done on the system by the stirrer is of the order of 2.5 h.p. Heat generated because of the stirring is dissipated through the surroundings. If this heat transfer is 900 kcal/hr, determine the change in internal energy.

1.32. Steel wool contains in a cylinder at atmosphuric pressure of pure Oxygen. The cylinder is fitted with friction less piston which maintains the Oxygen pressure at 1 atm. The iron in the steel wool reacts with Oxygen to form Fe_2O_3. Heat is removed from the process so as to keep the temperature constant at 30°C. Calculate the ΔU of the process for the reaction of 10 kg mol of iron. (Take data from S.I. data book.)

1.33. How much difference in elevation will result in change in potential energy equivalent to 1 J/kg of the substance considered?

1.34. What are C_p and C_v? Derive the equation for the same.

1.35. A turbine operating under steady conditions receives 5000 kg of steam per hour. The steam enters the turbine at a velocity of 3000 m/min., at an elevation of 5 m and specific enthalpy of 2777 kJ/kg. It leaves the turbine at a velocity of 600 m/min., at an elevation of 1 m and specific enthalpy of 2252 kJ/kg. Heat losses for the turbine to surroundings amounts to 16,680 kJ/hr. Determine the h.p. output of the turbine.

1.36. A stationary mass of gas is compressed without friction from an initial state of 0.5 m^3 and 1 atm to a final state of 0.3 m^3 and 1 atm, the pressure remaining constant during the process. There is a transfer of 45.2 kJ of heat from the gas during the process. Calculate the change in internal energy of the gas.

1.37. In a thermal power plant, superheated steam at 25 atm and 250°C enters an adiabatic turbine and leaves as steam of quality 0.85 at 50°C. The steam enters the turbine with a velocity of 15 m/s at an elevation of 13 m above the ground and leaves the turbine with a velcity of 10 m/s at an elevation of 5 m above the ground. If the flow rate of steam through the turbine is 1.5 kg/s, determine the power output of the turbine.

1.38. Show that for a steady state flow process

$$\Delta H + \frac{\Delta u^2}{2} + g\Delta z = Q - W_s$$

where all terms have their usual significance.

1.39. In a gas turbine the flow rate of air is 4 kg/s. The velocity and enthalpy of air at the entrance are 230 m/s and 6000 kJ/kg respectively. At exit the velocity is 170 m/s and the enthalpy is 4000 kJ/kg. As the air passes through the turbine a loss of heat equal to 40 kJ/s occurs. Calculate the horse power developed by the turbine.

1.40. A gas turbine receives gas at an enthalpy of 800 kJ/kg and a velocity of 120 m/s. The gas leaves the turbine at an enthalpy of 385 kJ/kg and a velocity of 180 m/s. Heat lost to surroundings from the gas is 38 kJ/s. If the rate of gas flow is 10 kg/s, find the power developed by the turbine.

1.41. Iron reacts with hydrochloric acid at 300 K according to the reaction

$$FeS(s) + 2HCl(aq) \longrightarrow FeCl_2(aq) + H_2(g)$$

Determine the work done when 0.1 kg iron reacts with HCl in

(*i*) Closed vessel

(*ii*) Open vessel.

1.42. During a reversible process at constant pressure of 3 atm and 220°C useful energy equal to 285 kJ was given out by the system. As a result of this process 5.2 g mol is produced. Find ΔU for this process.

1.43. It has been suggested that the bottom of a water fall should be hotter than the top. What temperature difference would you expect in the case of water fall having a height of 45 m. Assume there is no kinetic energy.

Data: $C_p = 4.2$ kJ/kg K.

1.44. 30 people attained a cocktail party in a small room which measures $7 \times 8 \times 3$ m^3. Each person after drinking gives up about 130 J/s. Assuming that the room is completely sealed and insulated. Calculate the room temperature after 25 min. of the incident. Assume that each person occupies a volume of 0.71 m^3 and initially the pressure and temperature are 1 atm and 25°C respectively.

Data: $C_{v(\text{air})} = 0.7176$ kJ/kg K.

1.45. A gas expands from an initial volume of 0.3 m^3 to a final volume of 0.5 m^3 in a reversible steady flow process. During the process, the pressure varies with the volume as

$$P = 5.2 \times 10^6\, V + 7.2 \times 10^4$$

where, P is in N/m^2 and V is in m^3. The inlet line is 4.2 m below the outlet line and the gas enters with a negligible velocity. The internal energy of the gas decreases by 30.2 kJ during the process. Determine the heat transferred.

1.46. Oil flows at a rate of 1500 kg/min. from an open reservoir at a height of 350 m to another reservoir at the ground level. Heat is supplied to the oil on its way at the rate 1800 kJ/min. and work is supplied by 1.2 h.p. pump. Take the mean specific heat of oil to be 3.45 kJ/kg K. Calculate the change in temperature of the coil.

1.47. During a process the temperature of the system rises from 100°C to 200°C. Heat transfer per degree rise in temperature reached during the process is given by

$$\frac{dQ}{dT} = 1004 \text{ J/K}.$$

The work done by the system per degree rise in temperature at each temperature reached is given by

$$\frac{dw}{dT} = (1 - 0.03T)\ 4184 \text{ J/K.}$$

Calculate the change in the internal energy of the system during the process. *(Andhra University, 1979)*

1.48. The latent heat of vapourisation of water at 1 atm is 2259.74 kJ/kg and the volume change from 0.01045 m^3/kg to 1.67525 m^3/kg. What is the change in internal energy due to evaporation?

(Andhra University, 1977)

1.49. Derive the mathematical expression of the first law for a steady state flow process and deduce the expression for a flow calorimeter.

1.50. Determine the energy transport required to increase the temperature of 5 kg of air from 20°C to 80°C. Assume the air is stationary and behave as an ideal gas with constant specific heats.

1.51. A system consisting of some fluid is stirred in a tank. The work done on the system by the stirrer is of the order of 5 h.p. Heat generated because of stirring is dissipated through surroundings. If this heat transfer is 3556.4 kJ/hr., determine the change in internal energy.

1.52. Determine the energy transport necessary to decrease the temperature of 6 kg of methane from 350°C to 30°C. Assume the methane is stationary and behaves as an ideal gas with constant specific heats.