# SSC-JE

Staff Selection Commission

# Junior Engineer

## Mechanical Engineering

### Conventional Solved Questions

Previous Years Solved Papers of
Exams held between 2007–2021

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**SSC-Junior Engineer : Mechanical Engineering Previous Year Conventional Solved Papers**



First Edition: 2016

Second Edition: 2018

Third Edition: 2019

Fourth Edition: 2020

Fifth Edition : 2021

**Sixth Edition: 2022**

# Preface

**B. Singh** (Ex. IES)

**Staff Selection Commission-Junior Engineer** has always been preferred by Engineers due to job stability. SSC-Junior Engineer examination is conducted every year. MADE EASY team has deeply analyzed the previous exam papers and observed that a good percentage of questions are repetitive in nature, therefore it is advisable to solve previous years papers before a candidate takes the exam.

The SSC JE exam is conducted in two stages as shown in table given below.

| Papers | Subject | Maximum Marks | Duration |
|---|---|---|---|
| **Stage 1:**<br>Paper-I : Objective type | (i) General Intelligence & Reasoning<br>(ii) General Awareness<br>(iii) General Engineering : Mechanical | 50 Marks<br>50 Marks<br>100 Marks | 2 hours |
| **Stage 2:**<br>Paper-II Conventional Type | General Engineering : Mechanical | 300 Marks | 2 hours |
| **Note:** In Paper-I, every question carry one mark and there is negative marking of ¼ marks for every wrong answer. Candidates shortlisted in Stage 1 are called for Stage 2. On the basis of combined score in Stage 1 and Stage 2, final merit list gets prepared. | | | |

In the fourth edition, the book has been thoroughly revised and Reasoning-Aptitude section is also added. MADE EASY has taken due care to provide complete solution with accuracy. Apart from Staff Selection Commission-Junior Engineer, this book is also useful for Public Sector Examinations and other competitive examinations for engineering graduates.

I have true desire to serve student community by providing good source of study and quality guidance. I hope this book will prove as an important tool to succeed in SSC-JE and other competitive exams. Any suggestion from the readers for improvement of this book is most welcome.

With Best Wishes

**B. Singh**

CMD, MADE EASY

# Syllabus of Engineering Subjects

***(For Conventional Type Papers)***

# Mechanical Engineering

**Theory of Machines and Machine Design:** Concept of simple machine, Four bar linkage and link motion, Flywheels and fluctuation of energy, Power transmission by belts – V-belts and Flat belts, Clutches – Plate and Conical clutch, Gears – Type of gears, gear profile and gear ratio calculation, Governors – Principles and classification, Riveted joint, Cams, Bearings, Friction in collars and pivots.

**Engineering Mechanics and Strength of Materials:** Equilibrium of Forces, Law of motion, Friction, Concepts of stress and strain, Elastic limit and elastic constants, Bending moments and shear force diagram, Stress in composite bars, Torsion of circular shafts, Buckling of columns – Euler's and Rankin's theories, Thin walled pressure vessels

**Thermal Engineering:** Properties of Pure Substances : p-v & P-T diagrams of pure substance like H2O, Introduction of steam table with respect to steam generation process; definition of saturation, wet & superheated status. Definition of dryness fraction of steam, degree of superheat of steam. h-s chart of steam (Mollier's Chart).
1st Law of Thermodynamics : Definition of stored energy & internal energy, 1st Law of Thermodynamics for cyclic process, Non Flow Energy Equation, Flow Energy & Definition of Enthalpy, Conditions for Steady State Steady Flow; Steady State Steady Flow Energy Equation.
2nd Law of Thermodynamics : Definition of Sink, Source Reservoir of Heat, Heat Engine, Heat Pump & Refrigerator; Thermal Efficiency of Heat Engines & co-efficient of performance of Refrigerators, Kelvin – Planck & Clausius Statements of 2nd Law of Thermodynamics, Absolute or Thermodynamic Scale of temperature, Clausius Integral, Entropy, Entropy change calculation for ideal gas processes. Carnot Cycle & Carnot Efficiency, PMM-2; definition & its impossibility.

**Air standard Cycles for IC engines :** Otto cycle; plot on P-V, T-S Planes; Thermal Efficiency, Diesel Cycle; Plot on P-V, T-S planes; Thermal efficiency. IC Engine Performance, IC Engine Combustion, IC Engine Cooling & Lubrication.

**Rankine cycle of steam :** Simple Rankine cycle plot on P-V, T-S, h-s planes, Rankine cycle efficiency with & without pump work. Boilers; Classification; Specification; Fittings & Accessories : Fire Tube & Water Tube Boilers. Air Compressors & their cycles; Refrigeration cycles; Principle of a Refrigeration Plant; Nozzles & Steam Turbines

**Fluid Mechanics & Machinery:** Properties & Classification of Fluids : ideal & real fluids, Newton's law of viscosity, Newtonian and Non-Newtonian fluids, compressible and incompressible fluids. Fluid Statics : Pressure at a point. Measurement of Fluid Pressure : Manometers, U-tube, Inclined tube. Fluid Kinematics : Stream line, laminar & turbulent flow, external & internal flow, continuity equation. Dynamics of ideal fluids : Bernoulli's equation, Total head; Velocity head; Pressure head; Application of Bernoulli's equitation. Measurement of Flow rate Basic Principles : Venturimeter, Pilot tube, Orifice meter. Hydraulic Turbines: Classifications, Principles. Centrifugal Pumps : Classifications, Principles, Performance.

**Production Engineering:** Classification of Steels : mild steal & alloy steel, Heat treatment of steel, Welding – Arc Welding, Gas Welding, Resistance Welding, Special Welding Techniques i.e. TIG, MIG, etc. (Brazing & Soldering), Welding Defects & Testing; NDT, Foundry & Casting – methods, defects, different casting processes, Forging, Extrusion, etc, Metal cutting principles, cutting tools, Basic Principles of machining with (i) Lathe (ii) Milling (iii) Drilling (iv) Shaping (v) Grinding, Machines, tools & manufacturing processes.

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# SSC-JE

## Conventional Solved Papers (Paper-II)

## Mechanical Engineering

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CHAPTER 1

Paper - II : Conventional

# Thermodynamics

## 1. Basic Concepts & Zeroth Law of Thermodynamics

**1.1** The gas in system received heat which causes expansion against at a constant pressure of 2 bar. An agitator in the system is driven by an electric motor. Using 100 W for 4 kJ of heat supplied the volume increase of the system in 30 sec is 0.06 $m^3$. Estimate net change in the energy of the system.

[SSC-JE 27.03.2011 : 15 Marks]

**Solution:**

Pressure, $p$ = 2 bar = 200 kPa, Rating of motor = 100 W

Heat supplied, $Q$ = 4 kJ, Duration of heat supply = 30 s

Volume increase of the system, $\Delta V$ = 0.06 $m^3$

Displacement work done of gas = $\int p\,dV$ = 200 × 0.06 = 12 kJ (positive work)

Work done by motor = 100 × 30 = 3 kJ (negative work)

Net work done by the system on the surroundings,

$$W = 12 - 3 = 9 \text{ kJ}$$

As per 1st law of thermodynamics:

$$Q_s = W + \Delta U$$

$$\Delta U = Q_s - W = 4 - 9 = -5 \text{ kJ}$$

The –ve sign indicates that energy of the system decreases

**1.2** Define the following:

(i) Reversible and irreversible process

(ii) External and internal irreversibility

(iii) Intensive and extensive properties

[SSC-JE 29.04.2018 : 15 Marks]

**Solution:**

(i) Reversible and Irreversible process

- Reversible Process: An object is said to undergo a reversible process if at any time during the process both the object and the surroundings with which it interacts can be brought back to their initial states.

  It is a process that can be reversed without leaving any trace on the surroundings. That is, both the system and the surroundings are returned to their initial states at the end of the reverse process. This is possible only if the net heat and net work exchange between the system and the surroundings is zero for the combined process.

- Irreversible Process: An object is said to undergo an irreversible process if the process is reversed then both the object and the surroundings with which it interacts can not be brought back to their initial states.

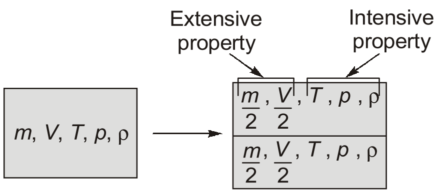
  A process which is not reversible is always known as irreversible process.

(ii) External and internal irreversibility:

- **External Irreversibility:** A process is called externally irreversible if no reversibility occur outside the system boundaries during the process. If heat transfer occurs between a reservoir and a system with some finite temperature difference then the process is called externally irreversible process and this irreversibility known as external irreversibility.
- **Internal Irreversibility:** A process is called internally irreversible if no reversibilities occur within the boundaries of the system during the process. During an internally irreversible process, a system proceed through a single process with high driving force and heat dissipation takes place.

(iii) Intensive and extensive properties:

- **Intensive properties:** A property is said to be intensive properties if it is independent on the mass of the system. Some examples of intensive properties are temperature, pressure and density.
- **Extensive properties:** A property is said to be extensive property if it is dependent on the mass of the system. Some examples of extensive properties are total mass, total volume and total momentum. An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.

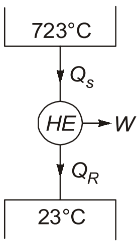



## 2. Energy and Energy Interactions

**2.1** A cyclic heat engine operates between a source temperature of 723°C and sink temperature of 23°C. What is the least rate of heat rejection per kW net output of the engine? Also show the block diagram.

[SSC-JE 26.05.2013 : 15 Marks]

**Solution:**




Source temperature, $T_1 = 723°C = 996\text{ K}$

Sink temperature, $T_2 = 23°C = 296\text{ K}$

$$\eta_{Carnot} = 1 - \frac{T_2}{T_1} = 1 - \frac{296}{996} = 0.7028$$

$$\frac{W}{Q_s} = 0.7028 \text{ or } Q_s = 1.423 \text{ kW}$$

$$W = Q_s - Q_R$$

or, $Q_R = Q_s - W = 1.423 - 1 = 0.423$ kW (least rate)

**2.2** A mixture of gases expands at constant pressure from 1 MPa, 0.03 $m^3$ to 0.06 $m^3$ with 90 kJ heat transfer to the system. There is no work other than 'work done' on a piston. Find the change in internal energy of the mixture.

[SSC-JE 18.01.2015 : 15 Marks]

**Solution:**

$$\text{Work transfer, } \Delta W = \int p\, dV = 1 \times 10^3 \times (0.06 - 0.03) = 30 \text{ kJ}$$

$$\text{Heat supplied, } Q_s = 90 \text{ kJ}$$

As per first law of thermodynamics

$$Q_s = \Delta U + W$$

or, $$\Delta U = Q_s - W = 90 - 30 = 60 \text{ kJ}$$

## 3. First Law of Thermodynamics

**3.1** 3 kg of an ideal gas is compressed adiabatically, from $P_1$ = 1 kgf/cm$^2$, $T_1$ = 20°C to a final pressure of 4 kgf/cm$^2$ calculate

(i) Initial volume (ii) Final volume

(iii) Final temperature (iv) Work performed

(v) Heat transfer from the system

[Take g = 9.81 m/s$^2$] [SSC-JE 27.03.2011 : 15 Marks]

**Solution:**

Mass of an ideal gas, $m$ = 3 kg; Initial pressure, $P_1$ = 1 kgf/cm$^2$ = 0.98 × 10$^5$ N/m$^2$

Initial temperature, $T_1$ = 20°C = 273 + 20 = 293 K; Final pressure, $P_2$ = 4 kgf/cm$^2$ = 3.92 × 10$^5$ N/m$^2$

• Let us assume air as an ideal gas

$c_p$ = 1.005 kJ/kgK $c_v$ = 0.718 kJ/kgK

$$R = c_p - c_v = 0.287 \text{ kJ/kgK}$$

From ideal gas law, $P_1V_1 = mRT_1$

$$V_1 = \frac{mRT_1}{P_1} = \frac{3 \times 287 \times 293}{0.98 \times 10^5} = 2.574 \text{ m}^3$$

$$P_1V_1^\gamma = P_2V_2^\gamma$$

$$V_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} V_1 = \left(\frac{1}{4}\right)^{\frac{1}{1.4}} \times 2.574 = 0.956 \text{ m}^3$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 293 \times (4)^{\frac{0.4}{1.4}} = 435.4 \text{ K}$$

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{(0.98 \times 10^5 \times 2.574 - 3.92 \times 10^5 \times 0.956)}{(1.4 - 1)} = -306.25 \text{ kJ}$$

$$\text{Change in internal energy, } \Delta U = m\, c_v (T_2 - T_1) = 3 \times 0.718\, (435.4 - 293) = 306.73 \text{ kJ}$$

$$\text{Heat transferred, } Q_{1-2} = \Delta U + W_{1-2} = 306.73 - 306.25 = 0.48 \text{ kJ}$$ [In adiabatic process, $Q_{1\text{-}2}$=0]

**3.2** 0.3 kg of Nitrogen gas at 100 kPa and 40°C is contained in a cylinder. The piston is moved compressing Nitrogen until the pressure of 1 MPa and temperature become 160°C. The work done during the process is 30 kJ. Calculate the heat transferred from Nitrogen to the surrounding. $c_v$ for Nitrogen 0.75 kJ/kg-K. [SSC-JE 08.04.2012 : 15 Marks]

**Solution:**

Given, $m$ = 0.3 kg; $p_1$ = 100 kPa; $T_1$ = 40°C = 313 K

$p_2$ = 1 MPa; $T_2$ = 160°C = 433 K; $W_{1-2}$ = –30 kJ; $c_v$ = 0.75 kJ/kgK

Change in internal energy, $dU = mc_V(T_2 - T_1) = 0.3 \times 0.75\,(433 - 313) = 27$ kJ

Applying first law for process,

$$Q_{1-2} = dU + W_{1-2} = 27 - 30 = -3 \text{ kJ}$$

Hence, the negative sign shows that the heat transferred from nitrogen to the surrounding.

**3.3** A system receives 50 kJ of heat while expanding with volume change of 0.14 $m^3$ against an atmosphere of $1.2 \times 10^5$ N/$m^2$. A mass of 90 kg in the surroundings is also lifted through a distance of 5.5 m.

(i) Calculate the change in energy of the system.

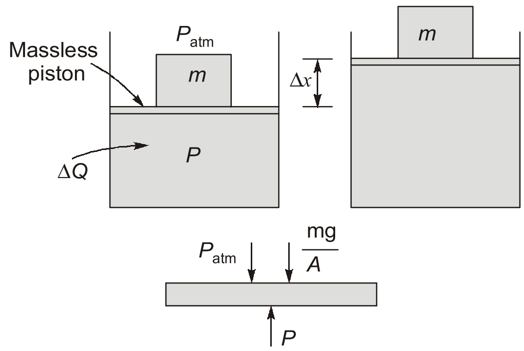
(ii) The system is returned to its initial volume by an adiabatic process which requires 110 kJ of work. Find the change in energy of the system.

(iii) For the combined processes of (i) and (ii), calculate the change in energy of the system.

[SSC-JE 30.07.2017 : 15 Marks]

**Solution:**

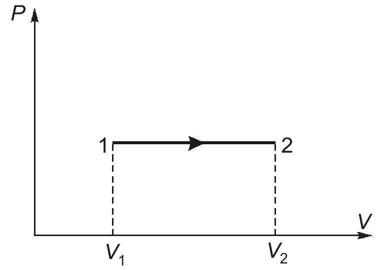
Given: $P_{atm} = 1.2 \times 10^5$ N/$m^2$, $m = 90$ kg, $\Delta Q = +50$ kJ, $\Delta V = 0.14$ $m^3$, $\Delta x = 5.5$ m




$$A = \text{Area of position}$$

(i)
$$\Delta V = A\,\Delta x$$
$$A = \frac{\Delta V}{\Delta x} = \frac{0.14}{5.5} = 0.02545 \text{ m}^2$$
$$P = P_{atm} + \frac{mg}{A}$$
$$= 1.2 \times 10^5 + \frac{90 \times 9.8}{0.02545}$$
$$= 1.54 \times 10^5 \text{ N/m}^2$$

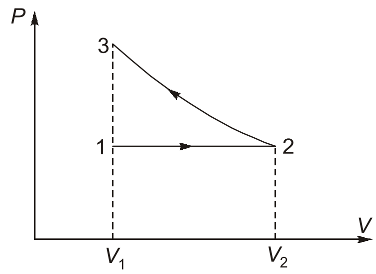
Now, assuming the expansion process as isobaric




$$W_{1-2} = P\Delta V$$
$$= (1.54 \times 10^5) \times 0.14$$
$$= 21.652 \times 10^3 \text{ J}$$
$$W_{1-2} = 21.65 \text{ kJ}$$

Using 1st law of thermodynamics

$$Q = \Delta U + W_{1-2}$$
$$\Delta U = Q - W_{1-2} = 50 - 21.65$$
$$\Rightarrow \quad (\Delta U)_{1-2} = 28.35 \text{ kJ}$$




(ii) Now, the system returns to its initial volume by an adiabatic process

$$W_{2-3} = -110 \text{ kJ}$$
$$(\Delta Q)_{2-3} = 0 \quad [\because \text{Adiabatic}]$$
$$\Delta Q = \Delta U + W$$
$$0 = (\Delta U)_{2-3} + (-110)$$
$$(\Delta U)_{2-3} = 110 \text{ kJ}$$

(iii) Total change in energy for the combined process,

$$(\Delta U)_{Total} = (\Delta U)_{1-2} + (\Delta U)_{2-3} = 28.35 + 110 = 138.35 \text{ kJ}$$

**3.4** Volume of 0.1 $m^3$ of an ideal gas at 300 K and 1 bar is compressed adiabatically to 8 bar. It is then cooled at constant volume and further expanded isothermally so as to reach the condition from where it started. Determine:

(i) Pressure at the end of constant volume cooling

(ii) Change in internal energy during constant volume process.

(iii) Net work done and heat transferred during the cycle.

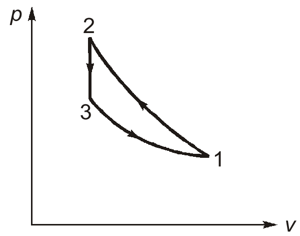
Take $c_p = 14.3$ kJ/kgK and $c_v = 10.2$ kJ/kgK.

[SSC-JE 29.04.2018 : 15 Marks]

**Solution:**

Given: $V_1 = 0.1\ m^3$, $T_1 = 300$ K, $P_1 = 1$ bar, $P_2 = 8$ bar


$$c_p = 14.3 \text{ kJ/kgK},\ c_v = 10.2 \text{ kJ/kgK}$$




**(i)** Process 1–2:

$$\gamma = \frac{c_p}{c_v} = \frac{14.3}{10.2} = 1.402$$

$$Pv^\gamma = \text{constant}$$

$$P_1 v_1^\gamma = P_2 v_2^\gamma$$

$$P_1 v_1^\gamma = P_2 v_2^\gamma$$

$$1 \times (0.1)^{1.402} = 8 \times (V_2)^{1.402}$$

$$V_2 = 0.0227\ m^3$$

$$m_1 = m_2$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{1 \times 0.1}{300} = \frac{8 \times 0.0227}{T_2}$$

$$T_2 = 544.8 \text{ K}$$

Now, process 2–3: $V_2 = V_3$

$$\frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$\frac{8}{544.8} = \frac{P_3}{300}$$

$$P_3 = 4.405 \text{ bar}$$

**(ii)** Process 2–3:

Change in internal energy

$$\Delta U = mc_v(T_3 - T_2) \quad \text{...(i)}$$

Mass, $$m = \frac{P_1 V_1}{RT_1} \quad \text{...(ii)}$$

$$R = c_p - c_v = 14.3 - 10.2 = 4.1 \text{ kJ/kgK}$$

From equation (ii), $$m = \frac{1 \times 10^5 \times 0.1}{4.1 \times 10^3 \times 300} = 0.00813 \text{ kg}$$

Now from equation (i), $$\Delta U = 0.00813 \times 10.2\,(300 - 544.8)$$

$$= -20.3 \text{ kJ} = 20.3 \text{ kJ (decrease in internal energy)}$$

**(iii)** Net work done, $$W_{net} = W_{12} + W_{23} + W_{31} \quad \text{...(iii)}$$

Work done in process 1–2:

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{1 \times 100 \times 0.1 - 8 \times 100 \times 0.0227}{1.402 - 1}$$

$$= -20.298 \text{ kJ} = 20.298 \text{ kJ} \quad \text{(work done on the system)}$$

Work done in process 2–3,

$$W_{2-3} = 0 \quad \text{(constant volume process)}$$

Workdone in process 3–1,

$$W_{3-1} = P_1V_1 \ln\left(\frac{V_1}{V_3}\right) = 1\times 100\times 0.1\times \ln\left(\frac{0.1}{0.0227}\right)$$

$= 14.828$ kJ (work, done by the system)

Now, $W_{net}$ from equation (iii),

$$W_{net} = W_{1-2} + W_{2-3} + W_{3-1} = -20.298 + 0 + 14.828 = -5.47 \text{ kJ}$$

$= 5.47$ kJ (Net work done on the system)

For a cycle, $Q_{net} = W_{net}$

Net heat transfer, $Q_{net} = -5.47 \text{ kJ} = 5.47 \text{ kJ}$ (Net heat transfer from the system)

**3.5** A fluid system undergoes a non-flow frictionless process following the pressure volume relation as $p = (5/V) + 1.5$ where $p$ is in bar and V is in m$^3$. During the process the volume changes from 0.15 m$^3$ to 0.05 m$^3$ and the system rejects 45 kJ of heat. Determine:

(i) Change in internal energy

(ii) Change in enthalpy.

[SSC-JE 29.12.2019 : 15 Marks]

**Solution:**

Given: Non-flow process (Frictionless)

$P = \frac{5}{V} + 1.5$, $V_i = 0.15$ m$^3$, $V_f = 0.05$ m$^3$, $Q = -45$ kJ (Rejected)

$$W = \int_i^f Pdv = \int_i^f \left(\frac{5}{V} + 1.5\right)\times 10^5 dV$$

$$= \int_{0.15}^{0.05} \left(\frac{5}{V} + 1.5\right) dV \times 10^5 \text{ Joule}$$

$$= \left[5\ln\left(\frac{V_f}{V_i}\right) + 1.5(V_f - V_i)\right]_{0.15}^{0.05} \times 10^5 \text{ Joule}$$

$$= \left[5\ln\left(\frac{0.05}{0.15}\right) + 1.5(0.05 - 0.15)\right]\times 10^5$$

$$= -5.643 \times 10^5 \text{ J} = -564.3 \text{ kJ}$$

Applying 1$^{st}$ law energy equation,

(i) Internal energy, $\Delta Q = \Delta U + \Delta W$

$$-45 = \Delta U - 564.3$$

$$\Delta U = 519.3 \text{ kJ}$$

(ii) Enthalpy ($\Delta H$), $\Delta H = H_2 - H_1 = (U_2 - P_2V_2) - (U_1 - P_1V_1)$

$$= (U_2 - U_1) + (P_2V_2 - P_1V_1)$$

$$P = \frac{5}{V} + 1.5$$

$$P_1 = \frac{5}{V_1} + 1.5 = \frac{5}{0.15} + 1.5 = 34.83 \text{ bar}$$

$$P_2 = \frac{5}{V_2} + 1.5 = \frac{5}{0.05} + 1.5 = 101.5 \text{ bar}$$

$$\Delta H = 519.3 + (101.5 \times 10^2 \times 0.05 - 34.84 \times 10^2 \times 0.15)$$

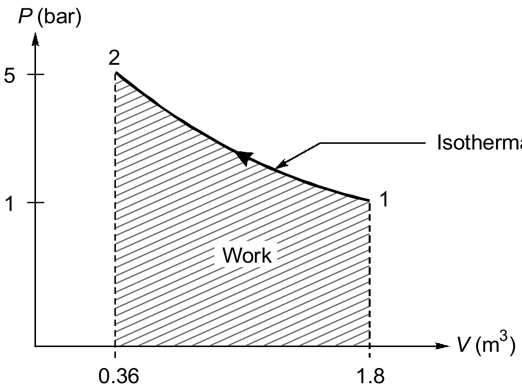
$$= 504.2 \text{ kJ}$$

**3.6** Air enters a compressor at $10^5$ Pa and 25°C having volume of 1.8 $m^3$/kg and is compressed to $5 \times 10^5$ Pa isothermally. Determine:

1. Work done;
2. Change in internal energy; and
3. Heat transferred.

[SSC-JE 21.03.2021 : 15 Marks]

**Solution:**




Initial state:

$$P_1 = 10^5 \text{ Pa} = 100 \text{ kPa}; \; T_1 = 25°\text{C} = 298 \text{ K}$$
$$v_1 = 1.8 \text{ m}^3/\text{kg}$$

Final state: $P_2 = 5 \times 10^5 \text{ Pa} = 500 \text{ kPa}$

Process is isothermal:

(i) Work done:
$$W = P_1 v_1 \ln\left(\frac{V_2}{V_1}\right) = P_1 v_1 \ln\left(\frac{P_1}{P_2}\right)$$
$$= 100 \times 1.8 \times \ln\left(\frac{100}{500}\right) = -289.7 \text{ kJ/kg}$$ (–ve shows that work is input)

(ii) Change in internal energy:

Since it is isothermal process so, $\Delta U = 0$

(iii) Heat transfer, from Ist law,

$$Q = \Delta U + W$$
$$Q = W \qquad [\because \delta U = 0]$$
$$Q = -289.7 \text{ kJ/kg}$$ (–ve show that heat is lost to surrounding)

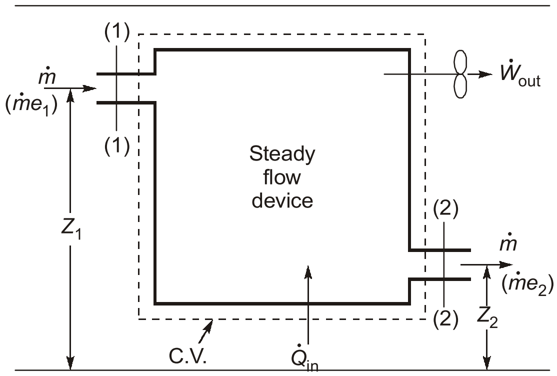
**3.7** Write down the general energy equation for steady flow system and simplify when applied for the following systems:

(i) Centrifugal water pump,
(ii) Reciprocating air compressor,
(iii) Steam nozzle,
(iv) Steam turbine

[SSC-JE 26.09.2021 : 15 Marks]

**Solution:**

General energy equation for steady flow system:




Consider a device in which flow rates at inlet and outlet is same.

**Writing mass balance:**

$$\dot{m}_{in} - \dot{m}_{out} = \left(\frac{dm}{dt}\right)_{CV}$$

Since, $\dot{m}_{in} = \dot{m}_{out} \Rightarrow \left(\frac{dm}{dt}\right)_{CV} = 0$ and $m_{CV}$ = Constant

**Writing energy balance:**

Since it is steady flow device, so properties do not change with time.

$$\dot{E}_{in} - \dot{E}_{out} = \left(\frac{dE}{dt}\right)_{CV}$$

Since, $E_{CV}$ = Constant

$\therefore$ $\dot{E}_{in} = \dot{E}_{out}$

$$\dot{m}\left(u_1 + \frac{V_1^2}{2} + gz_1 + P_1v_1\right) + \dot{Q}_{in} = \dot{m}\left(u_2 + \frac{V_2^2}{2} + gz_2 + P_2v_2\right) + \dot{W}_{out}$$

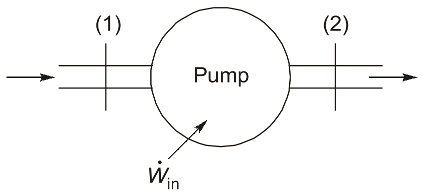
Where, $P_1v_1$ = Flow work

$$h_1 + \frac{V_1^2}{2} + gz_1 + \frac{\dot{Q}_{in}}{\dot{m}} = h_2 + \frac{V_2^2}{2} + gz_2 + \frac{\dot{W}_{out}}{\dot{m}} \qquad [h = U + Pv]$$

This is the general energy equation for steady flow system (or SFEE).

Applying SFEE for

**(i) Centrifugal water pump**




$$u_1 + P_1v_1 + \frac{V_1^2}{2} + gz_1 + \frac{\dot{Q}_{in}}{\dot{m}} = u_2 + P_2v_2 + \frac{V_2^2}{2} + gz_2 + \frac{\dot{W}_{out}}{\dot{m}}$$

**Assumptions:**

1. Negligible heat transfer
2. Neglecting changes in kinetic and potential energies.
3. Incompressible fluid
4. Process is almost isothermal

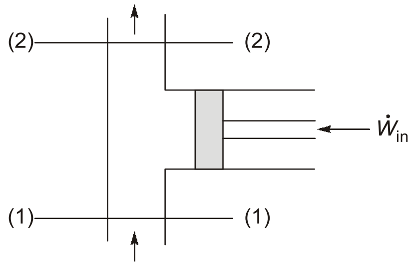
SFEE reduces to

$$P_1v_1 = P_2v_2 - \frac{\dot{W}_{in}}{\dot{m}}$$

[As, $v_1 = v_2 = v$, due to incompressible fluid] or, $$\frac{\dot{W}_{in}}{\dot{m}} = v(P_2 - P_1)$$

or, $$\dot{W}_{in} = \dot{V}(P_2 - P_1)$$

(ii) Reciprocating air compressor:




Assumptions:

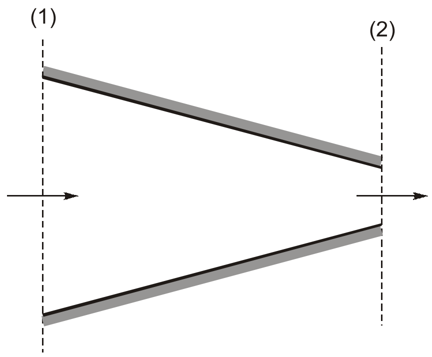
1. Neglecting changes in kinetic and potential energies
2. Negligible heat transfer

SFEE reduces to

$$h_1 = h_2 - \frac{\dot{W}_{in}}{\dot{m}}$$

∴ $$\dot{W}_{in} = \dot{m}(h_2 - h_1)$$

(iii) Steam Nozzle




In nozzle, $$\dot{W}_{out} = 0$$
$$\dot{Q}_{in} = 0$$

Assumption:

1. Change in potential energy is negligible

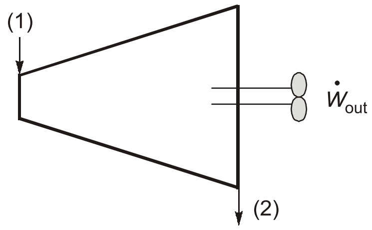
So, SFEE reduces to

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

∴ $$\frac{V_2^2 - V_1^2}{2} = h_1 - h_2, \text{ when } V_2 >> V_1 \text{ then } V_2 = \sqrt{2(h_1 - h_2)}$$

In nozzle the velocity of steam is increased at the cost of enthalpy.

(iv) Steam turbine



Assumptions:

1. Changes in Kinetic and potential energies are neglected.
2. Body is insulated

SFEE reduces to,

$$h_1 = h_2 + \frac{\dot{W}_{out}}{\dot{m}}$$

The function of turbine is to produce shaft work at the cost of enthalpy.

## 4. Open System Analysis by First Law

**4.1** The properties of a certain fluid are related as follows:

$u = 196 + 0.718T$ $\quad pv = 0.287(T + 273)$

where, $u$ is the specific internal energy (kJ/kg), $T$ is in °C, $p$ is pressure and $v$ is specific volume ($m^3$/kg). For this fluid, find $c_v$ and $c_p$.

[SSC-JE 18.01.2015 : 15 Marks]

**Solution:**

$$u = 196 + 0.718T = 196 + 0.718\,(T - 273)$$
$$= 196 + 0.718T - 196.014$$
$$u = 0.718T - 0.014$$
$$c_v = \left(\frac{du}{dT}\right)_v = 0.718 \text{ kJ/kgK}$$
$$h = u + pv = 196 + 0.718T + 0.287\,(T + 273)$$
$$= 0.718T - 0.014 + 0.287T$$
$$h = 1.005T - 0.014$$
$$\left(\frac{\partial h}{\partial T}\right)_p = c_P = 1.005 \text{ kJ/kg K}$$

**4.2** With the assumptions, derive the Steady Flow Energy Equation (SFEE).

[SSC-JE 30.07.2017 : 15 Marks]

**Solution:**

Steady flow means that the rate of flow of mass and energy through the control surface are constant i.e. properties are not varying with respect to time. Therefore mass at the entry of control volume and at the exit of control volume is same.

Let,

$\dot{m}$ = Mass flow rate at entry and exit

$h$ = Specific enthalpy

$u$ = Specific internal energy

KE = Kinetic energy = $\frac{1}{2}mC^2$

PE = Potential energy = $mgz$

$v$ = Specific volume

$P$ = Pressure

$PV$ = Flow work

z = Height from datum

(1) & (2) = Inlet and outlet section