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(2001-2021)

Mechanical Engineering

Paper-II

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Mechanical Engineering : Indian Forest Service Main Examination: (Paper-II)

First Edition: 2017
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Fifth Edition: 2021

Sixth Edition: 2022

Preface

B. Singh (Ex. IES)

Our country has a vast forest cover of near about 25% of geographical area and if man doesn't learn to treat trees with respect, man will become extinct; Death of forest is end of our life. Scientific management and judicial exploitation of forest becomes first task for sustainable development.

Engineer is one such profession which has an inbuilt word "Engineer – skillful arrangement" and hence IFS is one of the most talked about jobs among engineers to contribute their knowledge and skills for the arrangement and management for sustainable development

In order to reach to the estimable position of Divisional Forest Officer (DFO), one needs to take an arduous journey of Indian Forest Service Examination. Focused approach and strong determination are the pre-requisites for this journey. Besides this, a good book also comes in the list of essential commodity of this odyssey.

I feel extremely glad to launch the revised edition of such a book which will not only make Indian Forest Service Examination plain sailing, but also with 100% clarity in concepts.

MADE EASY team has prepared this book with utmost care and thorough study of all previous years' papers of Indian Forest Service Examination. The book aims to provide complete solution to all previous years' questions with accuracy.

On doing a detailed analysis of previous years' Indian Forest Service Examination question papers, it came to light that a good percentage of questions have been asked in Engineering Services, Indian Forest Services and State Services exams. Hence, this book is a one stop shop for all Indian Forest Service Examination, CSE, ESE and other competitive exam aspirants.

I would like to acknowledge efforts of entire MADE EASY team who worked day and night to solve previous years' papers in a limited time frame and I hope this book will prove to be an essential tool to succeed in competitive exams and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

With Best Wishes

B. Singh

CMD, MADE EASY Group

Previous Years Solved Papers

Indian Forest Service Main Examination

Mechanical Engineering

Paper-II

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■■■

1 Thermodynamics

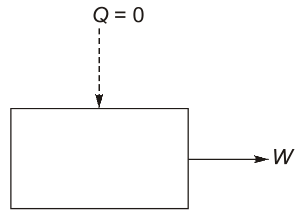
1. Basic Concepts, Heat and Work

1.1 **Explain why PMMK I and PMMKII devices are not practicable. (Perpetual Motion Machine Kind)**
[IFS (Mains) 2002 : 10 Marks]

Solution:

The first law states the principle of conservation of energy. Energy is neither created nor destroyed, but only gets transformed from one form to another. There can be no machine which would continuously supply mechanical work without some other form of energy disappearing simultaneously.

Such fictitious machine is called a perpetual motion machine of the first kind or in brief PMMI. A PMMI is thus impossible. The converse of the above statement is also true. There can be no machine which would continuously consume work without some other form of energy appearing simultaneously.

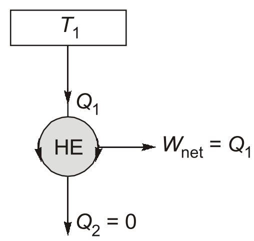


PMM I

The Kelvin Planck statement of second law states: It is impossible for a heat engine to produce a net work in a complete cycle if it exchanges heat only with single reservoir i.e. not rejecting any heat with lower temperature ($Q_2 = 0$).

Thus, $$\eta = 1 - \frac{Q_2}{Q_1}$$

and if $Q_2 = 0$ (i.e. $W_{net} = Q_1$ or $\eta = 100\%$) the heat engine will produce net work in a complete cycle by exchanging heat with only one reservoir, thus violating the Kelvin-Planck statement. Such a heat engine is called a perpetual motion machine of the second kind, PMMII. A PMMII is thus impossible.



PMM II

1.2 **State the Zeroth law of thermodynamics and highlight its significance.**
[IFS (Mains) 2013 : 5 Marks]

Solution:

When a body A is in thermal equilibrium with a body B, and also separately with a body C, than B and C will be in thermal equilibrium with each other. This is known as Zeroth law of Thermodynamics. It is the basis of temperature measurement.

Significance:

1. It has wide applications in thermometry.
2. If a body C is a thermometer and it is used to measure temperatures of A and B. And if it shows both the readings as same, then (C) is infect showing its own temperature.

1.3 **For an isothermal process, show that:**

$$\int_1^2 pdV = -\int_1^2 Vdp$$

[IFS (Mains) 2013 : 5 Marks]

Solution:

For an isothermal process, to prove:

$$\int_1^2 PdV = -\int_1^2 VdP$$

Isothermal process is defined as, $PV = \text{Constant} = C$

Differentiating both sides, we get,

$$PdV + VdP = 0$$

or $$PdV = -VdP$$

When system undergoes change in state from state (1) to state (2).

$$\int_1^2 PdV = -\int_1^2 VdP$$

1.4 The readings of two thermometers *A* and *B* agree at ice point and steam point as 0°C and 100°C. The two temperature readings are related by the following expression:

$$t_A = a + bt_B + ct_B^2$$

where *a*, *b* and *c* are constants. In a constant temperature bath, the temperature are shown as 51°C on thermometer *A* and 50°C on thermometer *B*. Determine the reading on thermometer *B* when the thermometer *A* reads 65°C. Can you comment which of the two thermometers is correct?

[IFS (Mains) 2016 : 20 Marks]

Solution:

Given: $t_A = a + bt_B + ct_B^2$

As the reading of two thermometers *A* and *B* agree at ice point (0°C) and steam point (100°C).

When $t_A = 0°\text{C}$, t_B is also 0°C

$$= a + bt_B + ct_B^2$$

$$0 = a + b(0) + c(0)^2$$

$$a = 0$$

So, $$t_A = bt_B + ct_B^2$$

when, $t_A = 100°\text{C}$, t_B is also 100°C

$$100 = b(100) + c(100)^2$$

$$b + (100)c = 1 \quad \text{... (i)}$$

when, $t_B = 50°\text{C}$, $t_A = 51°\text{C}$

$$t_A = bt_B + ct_B^2$$

$$51 = (50)b + (50)^2 c \quad \text{... (ii)}$$

From equations (i) and (ii), we get $b = 1.04$

$$c = -4 \times 10^{-4}$$

$\therefore$ $$t_A = 1.04\, t_B - 4 \times 10^{-4}\, t_B^2$$

when, t_A reads 65°C $$65 = 1.04 t_B - 4 \times 10^{-4}\, t_B^2$$

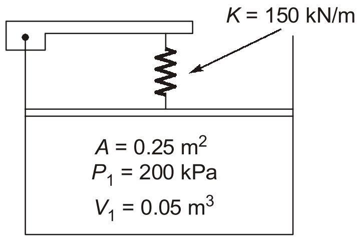
or $$t_B = 64.07°\text{C}$$

None of the two thermometers are ideal. So we cannot comment on to which is more correct.

1.5 A piston-cylinder device contains 0.05 m^3 of a gas initially at 200 kPa. At this state, a linear spring that has a spring constant of 150 kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas, causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross- sectional area of the piston is 0.25 m^2, determine:

(i) the final pressure inside the cylinder,

(ii) the total work done by the gas.



[(IFS Mains) 2017 : 10 Marks]

Solution:

Assumptions:

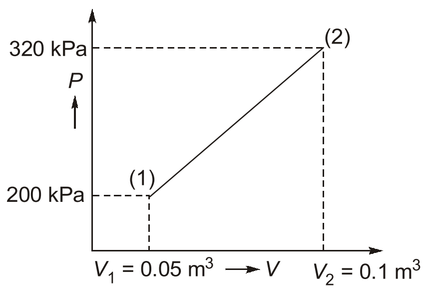
1. Mass conserved in the process.
2. Surrounding conditions are not altered in the process.

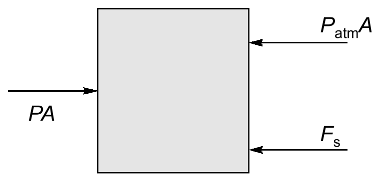
$$\text{Initial volume } (V_1) = 0.05 \text{ m}^3,$$

$$\text{Initial pressure } (P_1) = 200 \text{ kPa},$$

$$\text{Spring constant (k)} = 150 \text{ kN/m, Area } A = 0.25 \text{ m}^2.$$

Let the final pressure and volume inside the cylinder be P_2 and V_2 respectively.





At any state, $PA = P_{atm}A + F_s$

For initial state, $F_s = 0$

$P_1 = P_{atm} = 200$ kPa

and $P_2 A = P_1 A + F_s$

or, $P_2 = P_1 + \dfrac{kx}{A}$

⇒ P = $F(x)$ (linear variations)

where, $x = \dfrac{V_2 - V_1}{A} = \dfrac{2V_1 - V_1}{A} = \dfrac{V_1}{A} = \dfrac{0.05}{0.25} = 0.2$ m

$$P_2 = 200 + \frac{150 \times 0.2}{0.25} = 200 + 120 = 320 \text{ kPa}$$

$$\text{Total work done by the gas, } W = \int_{x_1}^{x_2} PAdx = \int_1^2 PdV = \text{Area under curve 1–2}$$

$$W_{1-2} = \int_{x_1}^{x_2} (P_{atm}A + kx)dx = 200 \times 0.25 \times 0.2 + \frac{1}{2} \times 150 \times 0.2^2 = 13 \text{ kJ}$$

or, W_{1-2} = area under curve 1–2 = $\dfrac{1}{2}[200 + 320] \times 0.2 \times 0.25 = 13$ kJ

1.6 **A non-flow quasi-static process occurs for which $P = (-3V + 16)$ bar, where V is the volume in m^3. What is the work done when V changes from $2 m^3$ to $6 m^3$?**

[(IFS Mains) 2019 : 8 Marks]

Solution:

Given, $P = (-3V + 16)$ bar; $V_1 = 2\ m^3$; $V_2 = 6\ m^3$

Work done in non-flow process,

$$W = \int PdV = \int_{V_1}^{V_2} (-3V + 16)dV = \left[\frac{-3V^2}{2} + 16V\right]_2^6$$

$$= \frac{-3}{2}(6^2 - 2^2) + 16(6-2) = -1.5 \times 32 + 16 \times 4$$

$$= 16 \text{ bar} - m^3 = 16 \times 10^5 \text{ N-m}$$

Workdone, $W = 1600$ kJ

1.7 **What is the reversible adiabatic work for a steady flow system when KE and PE changes are negligible? How is it different from a closed stationary system?**

[(IFS Mains) 2020 : 8 Marks]

Solution:

For a flow system at steady state

From (SFEE)

$$\dot{m}\left[h_1 + \frac{V_1^2}{2000} + gz_1\right] + \dot{Q} = \dot{m}\left[h_2 + \frac{V_2^2}{2000} + gz_2\right] + \dot{W}$$

Since, $\Delta PE = 0 = \Delta KE$

$\dot{Q} = 0$ (adiabatic process)

$$\Rightarrow \quad \dot{m}(h_1 - h_2) = \dot{W} \quad \text{...(i)}$$

For a closed stationary system

From 1st law of thermodynamics

$$\underbrace{\Delta Q}_{0 \text{ (Adiabatic)}} = \Delta u + \Delta W$$

$$\Rightarrow \quad \dot{W} = (u_1 - u_2) \quad \text{...(ii)}$$

Hence, comparing (i) and (ii), we see that the terms are different w.r.t. enthalpy and internal energy that is to say that the flow work term is absent in closed system.

2. First Law of Thermodynamics

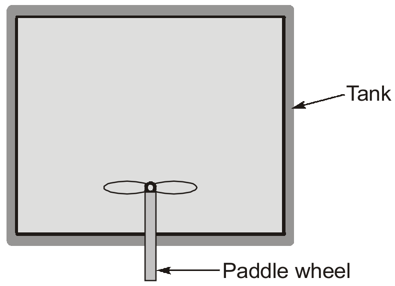
2.1 **An insulated rigid chamber of 2.5 m^3 capacity contains air at 25°C and 250 kPa. A paddle wheel inserted in the chamber does 900 kJ of work on the air.**

Assuming constant specific heats, calculate the entropy increase during the process.

Take $c = 0.717$ kJ/kg-K and $R = 0.287$ kJ/kg-K.

[IFS (Mains) 2001 : 10 Marks]

Solution:



Given: Volume, V = 2.5 m^3, T = 25°C = 298 K,

P = 250 kPa, Work done by paddle wheel, W_{Paddle} = 900 kJ

As the chamber is insulated one, the paddle wheel work will increase the internal energy of the liquid.

$$dQ = dU + dW$$

$$dQ = 0,$$

and $dW = -900$ kJ (Work is done on the system)

$$dU = 900 \text{ kJ}$$

$$mc_V(T_2 - T_1) = 900 \text{ kJ}$$

Also, $PV = mRT$

$$m = \frac{250\times10^3\times2.5}{287\times298} = 7.3 \text{ kg}$$

$$7.3\times0.717\times(T_2 - 298) = 900$$

$$T_2 = 469.76 \text{ K}$$

$$(\Delta S)_{system} = \text{Entropy increase of system} = \left[mc_V \ln\frac{T_2}{T_1} + mR\ln\frac{V_2}{V_1}\right]$$

For ideal gas:

$[V_2 = V_1] \Rightarrow$ For constant volume process.

$$= \int_{T_1}^{T_2}\frac{mc_v dT}{T} = mc_v \ln\left(\frac{T_2}{T_1}\right) = 7.3\times0.717\times\ln\left(\frac{469.76}{298}\right) = 2.382 \text{ kJ/K}$$

2.2 (i) An ideal gas is heated at constant volume until its temperature is 3 times the original temperature, then it is expanded isothermally till is reaches its original pressure, the gas is then restored to its original state. Determine the expression of net work done.

(ii) 300 kJ/s of heat is supplied at a constant fixed temperature of 290°C to a heat engine. The heat rejection takes place at 8.5°C. The following results were obtained:

I. 215 kJ/s of heat is rejected

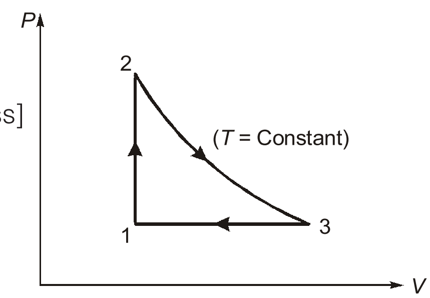
II. 150 kJ/s of heat is rejected

III. 75 kJ/s of heat is rejected

Using Clausius inequality which of the results report a reversible cycle of irreversible cycle, or impossible result?

[IFS (Mains) 2003 : 5 + 5 = 10 Marks]

Solution:



(i) Given: $T_2 = 3T_1$, $T_2 = T_3 = 3T_1$

$$W_{1\text{-}2} = 0 \text{ [Constant volume process]}$$

$$W_{2\text{-}3} = P_2V_2\ln\left(\frac{P_2}{P_3}\right)$$

$$P_2 = 3P_1 \text{ and } P_1 = P_3$$

$$\frac{P_2}{P_3} = 3$$

$$W_{2\text{-}3} = P_2V_2 \ln(3) = 1.098\, P_2V_2$$
$$= 1.098\, mRT_2$$
$$W_{3\text{-}1} = P_1(V_3 - V_1) = mR(T_3 - T_1)$$
$$= mR(3T_1 - T_1) = 2mRT_1 = \frac{2mRT_2}{3} = 0.66\, mRT_2$$
$$W_{net} = W_{1\text{-}2} + W_{2\text{-}3} + W_{3\text{-}1} = 0 + 1.098\, mRT_2 - 0.66\, mRT_2 = 0.438\, mRT_2$$
$$W_{net} = 1.314\, mRT_1$$

(ii) Given: $Q_1 = 300$ kJ/s, $T_1 = 290°C = 563$ K, $T_2 = 8.5°C = 281.5$ K

Clausius Inequality says, $= \oint \frac{dQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2}$

Case I: $T_1 = 563$ K, $T_2 = 281.5$ K

When $W_2 = 215$ kJ/s

$$\oint \frac{đQ}{T} = \frac{300}{563} - \frac{215}{281.5} = -0.23$$

As $\oint \frac{đQ}{T} < 0$ (Cycle is possible and irreversible)

Case II:

When $Q_2 = 150$ kJ/s

$$\oint \frac{đQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} = \frac{300}{563} - \frac{150}{281.5} = 0$$ (Cycle is reversible)

Case III:

When, $Q_2 = 75$ kJ/s

$$\oint \frac{đQ}{T} = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} = \frac{300}{563} - \frac{75}{281.5} = 0.266$$

As $\oint \frac{đQ}{T} > 0$ (Cycle is impossible)

2.3 In a closed system, dry saturated steam at 100 bar expands isothermally and reversibly to a pressure of 10 bar. Calculate the heat supplied and work done per kg of steam during the process.

[IFS (Mains) 2004 : 20 Marks]

Solution:

Give: $P_1 = 100$ bar (dry saturated steam), $P_2 = 10$ bar

Expansion is isothermal and reversible,

From steam table,

At $P_1 = 100$ bar (saturated steam)

$T_1 = 311.06$ °C

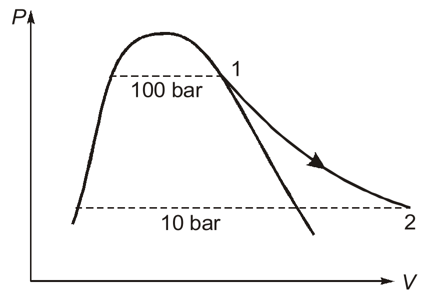
$u_1 = 2544.4$ kJ/kg

$h_1 = 2724.7$ kJ/kg

$v_1 = v_g = 0.018026$ m^3/kg

As the expansion process is isothermal.

$$T_1 = T_2 = 311.06°C$$



and $P_2 = 10$ bar

$T_{sat} = 179.91°C$

$\because (T_2 > T_{sat}) \rightarrow$ (It is in superheated state)

From steam table,

At, $T_{300°C}$, $u_{300°C} = 2793.2$ kJ/kg

At, $T_{350°C}$, $u_{350°C} = 2875.2$ kJ/kg

Using linear interpolation, method,

$$u_2 - 2793.2 = \frac{2875.2 - 2793.2}{350 - 300}(311.06 - 300)$$

$$u_2 = 2811.3384 \text{ kJ/kg}$$

Similarly,
$$(v_2 - 0.25794) = \frac{0.28247 - 0.25794}{350 - 300}(311.06 - 300)$$

$$v_2 = 0.2633 \text{ m}^3/\text{kg}$$

$$\text{Work done per kg, } w = P_1 v_1 \ln\left(\frac{P_1}{P_2}\right) = (100 \times 10^5) \times (0.018026) \ln\left(\frac{100}{10}\right) = 415.063 \text{ kJ/kg}$$

and
$$u_2 - u_1 = 2811.3384 - 2544.4 = 266.9384 \text{ kJ/kg}$$

$$\text{Heat supplied per kg, } Q = (u_2 - u_1) + w = 266.9384 + 415.063 = 682.0014 \text{ kJ/kg}$$

2.4 (i) An inventor claims to have developed an engine which draws 1000 kJ of heat energy per cycle each from two thermal reservoirs at temperatures 1500 K and 900 K and rejects 1600 kJ of heat energy per cycle to a thermal reservoir at 300 K while performing 400 kJ per cycle of work. Examine the validity of the claim using first law of thermodynamics and inequality of Clausius.

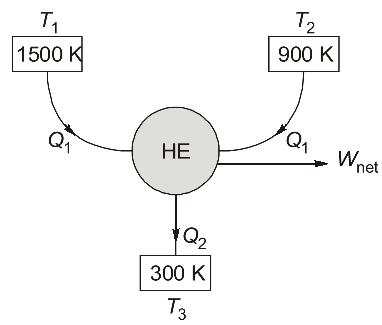
(ii) Using appropriate T-ds relations, show that the slope of the constant volume line is higher than that of a constant pressure line passing through a given state represented on a temperature-entropy diagram for a perfect gas. Sketch the temperature-entropy diagram.

[IFS (Mains) 2006 : 5 + 5 = 10 Marks]

Solution:

(i) Given: $Q_1 = 1000$ kJ, $Q_2 = 1600$ kJ

Work, $W_{given} = 400$ kJ (Given)



Using 1st law of thermodynamics, work produced in a cycle

$$\oint_c đQ = \oint_c đW$$

$$W_{net} = 2Q_1 - Q_2$$
$$= 2 \times 1000 - 1600 = 400 \text{ kJ} = W \text{(given)}$$

It satisfy the 1st law of thermodynamics.

According to clausius inequality.

$$\oint \frac{\delta Q}{T} = \frac{Q_1}{T_1} + \frac{Q_1}{T_2} - \frac{Q_2}{T_3} = \frac{1000}{1500} + \frac{1000}{900} - \frac{1600}{300} = 0.66 + 1.11 - 5.33$$
$$= -3.5633$$

As
$$\oint \frac{\delta Q}{T} < 0$$

[The cycle is possible and irreversible in nature]

(ii) Using Tds relations, $$Tds = c_V dT + T\left(\frac{\partial P}{\partial T}\right)_V dV$$

At constant volume, $dV = 0$

$$(Tds)_V = (c_V dT)_V$$

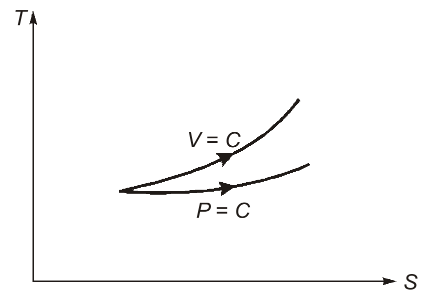
$$\left(\frac{\partial T}{\partial s}\right)_V = \frac{T}{c_V}$$

Similarly, $$Tds = c_P dT - T\left(\frac{\partial V}{\partial T}\right)_P dP$$

At constant pressure, $dP = 0$

$$\left(\frac{\partial T}{\partial s}\right)_P = \frac{T}{c_P}$$

As ($c_P > c_V$ or $\gamma > 1$) $$\left(\frac{\partial T}{\partial s}\right)_V > \left(\frac{\partial T}{\partial s}\right)_P$$

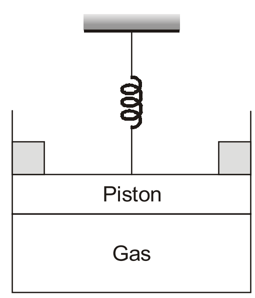


The slope of constant volume line is higher than that of constant pressure line passing through a given state represented on a temperature - entropy diagram.

2.5 A closed cylinder of 0.25 m diameter is fitted with a light frictionless piston. The piston is retained in position by a catch in the cylinder wall and the volume on one side of the piston contains air at a pressure of 750 kN/m^2. The volume on the other side of the piston is evacuated. A helical spring is mounted co-axially with the cylinder in this evacuated space to give a force of 120 N on the piston in this position. The catch is released and the piston travels along the cylinder until it comes to rest after a stroke of 1.2 m. The piston is then held in its position of maximum travel by a ratchet mechanism. The spring force increases linearly with the piston displacement to a final value of 5 kN. Calculate the work done by the compressed air on the piston.

[IFS (Mains) 2008 : 15 Marks]

Solution:



Assumptions:

1. Only conservative forces
2. No leakage
3. Insulated piston.

Given: $d = 0.25$ m, A_P = Area of piston = $\frac{\pi}{4}d^2$, $A_P = \frac{\pi}{4}(0.25)^2 = 0.049$ m^2

Initial Position $$(P_g)_1 = 750 \text{ kN/m}^2$$

$$(F_g)_1 = (P_g)_1 \times A_P = 750 \times 0.049 = 36.79 \text{ kN}$$

x_1 is initial compression of spring

$$kx_1 = f_{S1} = 120 \text{ N}$$

Final position: Let x_2 be the final compression in spring.

$$x_2 - x_1 = 1.2 \text{ m} \quad \text{(Given)}$$

$$kx_2 = f_{S2} = 5 \text{ kN} = 5000 \text{ N}$$

Since, $$x_2 - x_1 = 1.2$$

$$\frac{5000}{k} - \frac{120}{k} = 1.2$$

$$k = \text{Spring stiffness} = 4066.67 \text{ N/m}$$

and $$kx_1 = 120$$

$$x_1 = \frac{120}{4066.67} = 0.029 \text{ m}$$

and $$kx_2 = 5000 \text{ N}$$

$$x_2 = \frac{5000}{4066.67} = 1.229 \text{ m}$$

Neglecting piston weight and friction.

So, work done by the compressed air on the piston,

$$W = F_S dx = \int_{x_1}^{x_2} kx\,dx$$

$$= k\frac{x^2}{2}\Bigg|_{x_1}^{x_2} = \frac{k}{2}(x_2^2 - x_1^2) = \frac{4066.67}{2}\left[1.229^2 - 0.029^2\right] = 3.07 \text{ kJ}$$

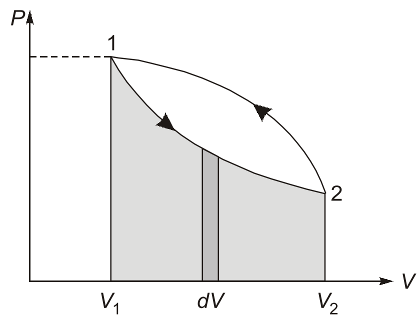
2.6 Consequent upon first law of thermodynamics, show that the heat is a path function.

[IFS (Mains) 2010 : 7 Marks]

Solution:

The amount of work (W) done by the system when it undergoes change in state from (i) to (ii) in a reversible process in closed system is given as

$$W_{1\text{-}2} = \int_{V_1}^{V_2} PdV$$



Thus the magnitude of the work done is given by the area under the path 1-2. Since the area under each curve represents the work for each process, the amount of work involved in each case is not a function of the end states of the process, and thus it depends on the path the system follows in going from state 1 to state 2. For this reason work is called a path function.

According to first law of thermodynamics,

$$dU = \delta Q - \delta W$$

Consider a system undergoes a cyclic process. Its initial and final states are same. And as internal energy is a property of system ($U_1 - U_1$) or ($dU = 0$).

$$\Rightarrow \quad \oint_c đQ = \oint_c đW$$

As work transfer is a path function. The heat transfer (δQ) like (δW), also depends on the process and is path-dependent and not a property.

2.7 In a system executing a non-flow process the work and heat per degree change of temperature are given by $\frac{dW}{dT}$ = 200 W - s/°C and $\frac{dQ}{dT}$ = 160 J/°C

What will be the change in internal energy of the system when its temperature changes from T_1 = 55°C to T_2 = 95°C?

[IFS (Mains) 2013 : 5 Marks]

Solution:

Given: $$\frac{dW}{dT} = 200 \text{ W-s/°C} = 200 \text{ J/°C}$$

$$\frac{dQ}{dT} = 160 \text{ J/°C}$$

Let dU be the change in internal energy of system when temperature changes from T_1 = 55°C to T_2 = 95°C. For a non-flow process.

$$dQ = dU + dW$$

or

$$\frac{dQ}{dT} = \frac{dU}{dT} + \frac{dW}{dT}$$

$$\frac{dU}{dT} = \frac{dQ}{dT} - \frac{dW}{dT} = 160 - 200 = -40 \text{ J/°C} = -40 \text{ J/°C}$$

or

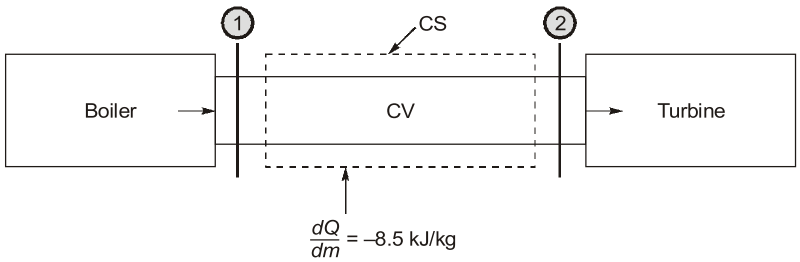
$$\int_{U_1}^{U_2} dU = -40 \int_{T_1}^{T_2} dT$$

$$U_2 - U_1 = \Delta U = -40\,(T_2 - T_1) = -40\,(95 - 55) = -1600 \text{ J}$$

2.8 In a steam power station, steam flows steadily through a 0.2 m diameter pipeline from the boiler to the turbine. At the boiler end, the steam conditions are found to be
p = 4 MPa, t = 400°C, h = 3213.6 kJ/kg and v = 0.073 m^3/kg.
At the turbine end, the conditions are found to be
p = 3.5 MPa, t = 392 °C, h = 3202.6 kJ/kg and v = 0.084 m^3/kg.
There is a heat loss of 8.5 kJ/kg from the pipeline. Calculate the steam flow rate.

[IFS (Mains) 2014 : 15 Marks]

Solution:



Steady flow energy equation for the control volume can be written as

$$h_1 + \frac{V_1^2}{2} + Z_1 g + \frac{\delta Q}{dm} = h_2 + \frac{V_2^2}{2} + Z_2 g + \frac{\delta W_x}{dm}$$

Also,

$$\frac{A_1 V_2}{v_1} = \frac{A_2 V_2}{v_2}$$

$$V_2 = \frac{A_1 V_1}{v_1} \cdot \frac{v_2}{A_2} = \frac{v_2}{v_1} \cdot V_1 = \frac{0.084}{0.073} V_1 = 1.15 V_1$$

and $\frac{\delta W_x}{dm} = 0$, neglecting potential energy change.

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

$$\left(\frac{V_2^2 - V_1^2}{2}\right) \times 10^{-3} = (h_1 - h_2) + \frac{\delta Q}{dm} = (3213.6 - 3202.6) + (-8.5) = 2.5 \text{ kJ/kg}$$

$$\frac{V_1^2 (1.15^2 - 1^2) \times 10^{-3}}{2} = 2.5$$

$$V_1^2\,(1.15^2 - 1^2) = 5000$$

$$V_1^2 = 15503.875$$

$$V_1 = 124.51 \text{ m/s}$$

$$\text{Mass flow rate } (\dot{m}) = \frac{A_1V_1}{v_1} = \frac{\frac{\pi}{4}(0.2)^2 \times 124.51}{0.073}$$

$$\dot{m} = 53.55 \text{ kg/sec}$$

2.9 **Helium contained in a cylinder with piston expands according to the law PV$^{1.2}$ = C from 20 m^3, 5 bar, 220 K to a pressure of 2 bar. Calculate the work done and heat transfer during the process. For helium molecular weight = 4.0, C_p = 5.2 kJ/kg K and γ = 1.66 [IFS (Mains) 2015 : 10 Marks]**

Solution:

Given: PV^n = Constant (n = 1.2), V_1 = 20 m^2, P_1 = 5 bar, T_1 = 220 K, P_2 = 2 bar, molecule weight, M = 4, c_p = 5.2 kJ/kg-K, γ = 1.6

$$P_1V_1^{1.2} = P_2V_2^{1.2}$$

$$5(20)^{1.2} = 2(V_2)^{1.2}$$

$$\left(\frac{V_2}{20}\right)^{1.2} = 2.5$$

$$V_2 = 42.9 \text{ m}^3$$

$$\text{Work done} = \left(\frac{P_1V_1 - P_2V_2}{n-1}\right) = \frac{(5\times10^5\times20)-(2\times10^5\times42.9)}{1.2-1} = 7100 \text{ kJ}$$

Also,

$$R = \frac{\bar{R}}{m} = \frac{8.3146\times10^3}{4} = 2078.65 \text{ (J/kg-K)}$$

$$c_p - c_v = R$$

$$c_v = c_p - R = 5.2 - 2.078 = 3.12 \text{ kJ/kg-K}$$

Also,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{2}{5}\right)^{\frac{1.2-1}{1.2}}$$

$$T_2 = 188.85 \text{ K}$$

$$\text{Change in internal energy, } \Delta U = U_2 - U_1 = mc_V(T_2 - T_1)$$

and

$$m = \frac{PV}{RT} = \left(\frac{5\times10^5\times20}{2078.65\times220}\right) = 21.86 \text{ kg}$$

$$\Delta U = 21.86 \times 3.12 \times (188.85 - 220) = -2125.24 \text{ kJ}$$

$$Q = \text{Heat transfer during the process}$$

$$Q = \Delta U + W = -2125.24 + 7100 = 4974.75 \text{ kJ}$$

2.10 **Air flows at the rate of 0.5 kg/s through an air compressor, entering at 7 m/s velocity, 10 kPa pressure and 0.95 m^3/kg specific volume and leaving at a velocity of 5 m/s, pressure 700 kPa and specific volume 0.19 m^3/kg. The internal energy of the air leaving is 90 kJ/kg less than that at entry. Cooling water in the compressor jackets absorbs 58 kW of heat. Compute the rate of shaft work input to the air and also calculate the ratio of inlet pipe to outlet pipe diameter.**

[IFS (Mains) 2015 : 10 Marks]