CLASS TEST

S.No. : 01 JP_ME_05092023

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MECHANICAL ENGINEERING

THERMODYNAMICS

Duration : 1:00 hr. **Maximum Marks : 50**

Read the following instructions carefully

1. This question paper contains **30** objective questions. **Q.1-10** carry one mark each and **Q.11-30** carry two marks each.
2. Answer all the questions.
3. Questions must be answered on Objective Response Sheet (**ORS**) by darkening the appropriate bubble (marked **A**, **B**, **C**, **D**) using HB pencil against the question number. Each question has only one correct answer. In case you wish to change an answer, erase the old answer completely using a good soft eraser.
4. There will be **NEGATIVE** marking. For each wrong answer **1/3rd** of the full marks of the question will be deducted. More than one answer marked against a question will be deemed as an incorrect response and will be negatively marked.
5. Write your name & Roll No. at the specified locations on the right half of the **ORS**.
6. No charts or tables will be provided in the examination hall.
7. Choose the **Closest** numerical answer among the choices given.
8. If a candidate gives more than one answer, it will be treated as a **wrong answer** even if one of the given answers happens to be correct and there will be same penalty as above to that questions.
9. If a question is left blank, i.e., no answer is given by the candidate, there will be **no penalty** for that question.

DO NOT OPEN THIS TEST BOOKLET UNTIL YOU ARE ASKED TO DO SO

Q. No. 1 to Q. No. 10 carry 1 mark each

Q.1 In two new temperature scale (°x) and (°y) the boiling and freezing points of water at 1 atm are 50°x, 200°x, 100°y and 50°y respectively. At what temperature both scales show same number reading?

(a) 90.5°x (b) 87.5°x
(c) 102.5°x (d) 0°x

Q.2 Which of the following are intensive properties?

1. Thermal conductivity
2. Temperature
3. Density
4. Potential energy
5. Pressure
6. Viscosity
7. Kinetic energy

Select the correct answer using the codes given below:

(a) 1, 2, 4, 5 and 6 (b) 3, 4, 6 and 7
(c) 1, 2, 3, 5 and 6 (d) 2, 3, 5 and 6

Q.3 Specific heat for polytropic process (c_{poly}) is

(a) $c_v\left(\frac{\gamma-1}{n-1}\right)$ (b) $c_v\left(\frac{n-1}{\gamma-1}\right)$

(c) $c_v\left(\frac{\gamma-n}{\gamma-1}\right)$ (d) $c_v\left(\frac{\gamma-n}{1-n}\right)$

Q.4 Which one of the following pair of equations describes an irreversible refrigeration system?

(a) $\oint \delta Q < 0$ and $\oint \frac{\delta Q}{T} > 0$

(b) $\oint \delta Q < 0$ and $\oint \frac{\delta Q}{T} < 0$

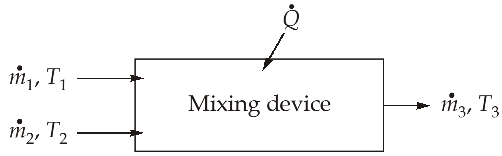
(c) $\oint \delta Q > 0$ and $\oint \frac{\delta Q}{T} < 0$

(d) $\oint \delta Q > 0$ and $\oint \frac{\delta Q}{T} > 0$

Q.5 If a pure substance contained in a rigid vessel passed through the critical state on heating, its initial state should be

(a) Wet steam
(b) Saturated water
(c) Saturated steam
(d) Subcooled water

Q.6 Two mass streams of the same ideal gas are mixed in a steady-flow chamber while receiving energy by heat transfer from the surroundings as shown in the figure below. The mixing process takes place at constant pressure with no work and negligible changes in kinetic and potential energies. Assume the gas has constant specific heats.



What will be the expression for the final temperature of the mixture in terms of the rate heat transfer to the mixing chamber and the inlet and exit mass flow rates?

(a) $T_3 = \frac{\dot{m}_3}{\dot{m}_1}T_1 + \frac{\dot{m}_3}{\dot{m}_2}T_2 - \frac{\dot{Q}}{\dot{m}_3 c_p}$

(b) $T_3 = \frac{\dot{m}_3}{\dot{m}_1}T_1 + \frac{\dot{m}_3}{\dot{m}_2}T_2 + \frac{\dot{Q}}{\dot{m}_3 c_p}$

(c) $T_3 = \frac{\dot{m}_1}{\dot{m}_3}T_1 + \frac{\dot{m}_2}{\dot{m}_3}T_2 - \frac{\dot{Q}}{\dot{m}_3 c_p}$

(d) $T_3 = \frac{\dot{m}_1}{\dot{m}_3}T_1 + \frac{\dot{m}_2}{\dot{m}_3}T_2 + \frac{\dot{Q}}{\dot{m}_3 c_p}$

Q.7 Consider the following statements regarding a mixture of saturated-liquid and saturated-vapor states of a pure substance.

1. In a saturation state, the pressure and temperature are not independent properties.
2. Two independent properties, such as pressure and specific volume or pressure and quality, are required to specify a saturation mixture state of a pure substance.

Which of the following statement(s) is/are correct?

(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) None of them

Q.8 Which of the following statement is false?
(a) The change in availability of an open system is equal to change in Gibbs function of system at constant room temperature.
(b) The change in availability of closed system is equal to change in Helmholtz function at given room temperature.
(c) Gibbs function is useful in evaluating the availability of systems in which chemical reaction occurs.
(d) Gibbs function $(G) = H - TS$ and Helmholtz function $(F) = U - TS$ is applicable for open and closed system respectively.

Q.9 A real gas when throttled during compression, its temperature will always increase when
(a) it is throttled in a region where isentropic curve in T-P diagram have positive slope.
(b) it is throttled in a region where isentropic curve in T-P diagram have zero slope.
(c) it is throttled above maximum inversion temperature.
(d) it is throttled in cooling region.

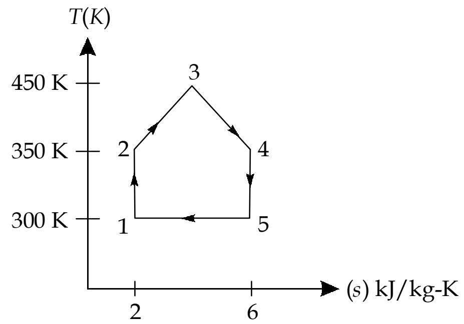
Q.10 **Statement (I):** The deviation from ideal-gas behaviour at a given temperature and pressure can accurately be accounted for by the introduction of a correction factor called the compressibility factor (z).
Statement (II): In air-conditioning applications, the water vapour in the air can be treated as an ideal gas with essentially no error since the pressure of the water vapour is very low.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

Q. No. 11 to Q. No. 30 carry 2 marks each

Q.11 Consider the following statements regarding enthalpy:
1. It is equal to $(u + pv)$.
2. It is measure of total heat content of a system.
3. For steady flow through an insulated horizontal varying diameter pipe, enthalpy remains constant.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

Q.12 Efficiency of a cycle shown below will be



(a) 20% (b) 25%
(c) 40% (d) 55%

Q.13 Two reversible engines are working in series with intermediate temperature as 327°C have same efficiency. If the lowest temperature is 500 K then the highest temperature of engine is
(a) 800°C (b) 800 K
(c) 720°C (d) 720 K

Q.14 In an air compressor air enters at a mass flow rate of 0.5 kg/s with a temperature of 25°C and leaves it at 175°C. Velocities of air at inlet and exit are 5 m/s and 2 m/s respectively. If heat loss from compressor is 10 kW then what is the power input to compressor?
(a) 95 kW (b) 85.4 kW
(c) 77 kW (d) 66.5 kW

Q.15 A heat engine with an efficiency of 50% is used to drive a refrigerator. The heat input to the heat engine is half of the sum of heat rejected by the heat engine and refrigerator. The COP of refrigerator will be
(a) 2 (b) 3
(c) 4 (d) 2.5

Q.16 Consider the following statements:

1. A gas cools upon expansion only when its Joule-Thompson coefficient is negative in the temperature range of expansion.
2. For both open and closed system, the isothermal work expression is same.
3. A liquid expands upon freezing when the slope of its fusion curve on pressure temperature diagram is negative.

Which of the above statements are correct?

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) All of these

Q.17 Match **List-I** with **List-II** and select the correct answer using the codes given below:

List-I	**List-II**
A. du	**1.** $\frac{Tv\beta^2}{k_t}$
B. dh	**2.** $\frac{1}{c_p}\left[T\left(\frac{\partial v}{\partial T}\right)_P - v\right]$
C. μ	**3.** $c_v dT + \left[T\left(\frac{\partial P}{\partial T}\right)_v - P\right]dv$
D. $c_p - c_v$	**4.** $c_P dT + \left[v - T\left(\frac{\partial v}{\partial T}\right)_P\right]dP$

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	3	4	1	2

Q.18 An imaginary engine having thermal efficiency 70 percent, receives heat and does work on a slowly moving piston at such rates that the cycle of operation of 1 kg of working fluid can be represented as a circle on a P–V diagram where 1 cm = 200 kPa and 1 cm = 0.2 m^3/kg. The heat rejected by the engine in the cycle is 1200 kJ/kg. What is the diameter of the circle on P–V diagram?

(a) 8.24 cm (b) 7.14 cm
(c) 9.44 cm (d) 10.74 cm

Q.19 Helium contained in a cylinder at ambient conditions, 100 kPa, 20°C, is compressed in a reversible isothermal process to 600 kPa, after which the gas is expanded back to 100 kPa in a reversible adiabatic process. What will be the net work per kilogram of helium required?

[Take γ = 1.66]

(a) 309.23 kJ/kg
(b) 128.29 kJ/kg
(c) 618.83 kJ/kg
(d) 920.31 kJ/kg

Q.20 In SAIL plant, it is required to melt iron at the rate of 2.1 kg/s from 30°C to 1850°C. The melting point of iron is 1555°C, latent heat is 295 kJ/kg. The specific heat in solid and liquid states are 0.50 kJ/kgK and 0.51 kJ/kgK respectively. Take density of iron to be 7100 kg/m^3 and electric furnace efficiency to be 90%. What is the rating of the electric furnace?

(a) 2.5 kW
(b) 2.8 kW
(c) 2.5 MW
(d) 2.8 MW

Q.21 A real gas follows the following relation:

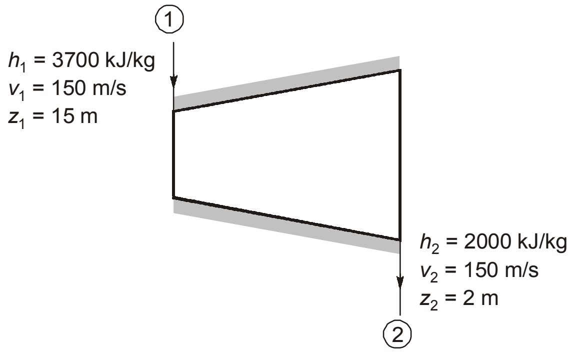
$$\left(P + \frac{a}{V^2}\right)(V - b) = mRT$$

Where P is pressure in kPa, V is volume in m^3 and m is mass of gas in kg (a and b are constants). If the system goes isothermally from 1 m^3 to 10 m^3 at a temperature of 293 K, then what will be the work done by the system?

Use the values, a = 155 kNm^4, $b = 0.98 \times 10^{-2}$ m^3, m = 10 kg and R = 0.287 kJ/kgK

(a) 2204 kJ
(b) 1804 kJ
(c) 1733.33 kJ
(d) 1656 kJ

Q.22 The inlet and outlet conditions of steam for an adiabatic steam turbine are indicated below:



If the power produced by the turbine is 70 MW, the mass flow rate of steam through turbine is

(a) 20.5 kg/s (b) 17.8 kg/s
(c) 41.2 kg/s (d) 57.9 kg/s

Q.23 Three bodies at initial temperatures of 200 K, 250 K and 540 K. What is the maximum amount of work that can be extracted in a process in which these bodies are brought to a final common temperature? Each of these bodies satisfy equation $U = CT$, where C is heat capacity, U is the internal energy. (Take C = 8.4 kJ/K)

(a) 960 kJ (b) 1090 kJ
(c) 657 kJ (d) 756 kJ

Q.24 A piston cylinder device contains 0.05 m^3 of 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. After heat is supplied to the gas, the piston rises and spring compresses such that the volume inside the cylinder doubles. If the cross sectional area of piston is 0.25 m^2 then the total work done by the gas will be

(a) 8 kJ (b) 3 kJ
(c) 10 kJ (d) 13 kJ

Q.25 An insulated 8 m^3 rigid tank contains air at 600 kPa and 400 K. A valve connected to the tank is now opened, and air is allowed to escape until the pressure inside drops to 200 kPa. The air temperature during the process is maintained constant by an electric resistance heater placed in tank, then the electrical energy supplied to air during this process will be

[At 400 K, h = 400.98 kJ/kg and u = 286.16 kJ/kg]

(a) 1.333 kWh (b) 0.889 kWh
(c) 0.444 kWh (d) 1.778 kWh

Q.26 The work that can be obtained from air that is compressed to a pressure P_1 at constant temperature to when surrounding temperature and pressure are T_0 and P_0 respectively, in a rigid tank is

(a) $RT_0\left[\ln\left(\frac{P_1}{P_0}\right)+\frac{P_0}{P_1}-1\right]$

(b) $RT_1\left[\ln\left(\frac{P_1}{P_0}\right)-1\right]$

(c) $RT_0\left[\ln\left(\frac{P_1}{P_0}\right)+\frac{T_0}{T_1}-1\right]$

(d) $RT_1\left[\ln\left(\frac{T_1}{T_0}\right)+\frac{T_0}{T_1}-1\right]$

Q.27 Air is throttled from 50°C and 800 kPa to a pressure of 200 kPa at a rate of 0.5 kg/s in an environment at 25°C. The change in kinetic energy is negligible and no heat transfer occurs during the process. What is the power waisted during the process?

(a) 0 (b) 236 kW
(c) 118 kW (d) 59 kW

Q.28 In a test of a water-Jacketed compressor, the shaft work required is 90 kN-m/kg of air compressed. During compression increase in enthalpy of air is 30 kJ/kg of air and increase in enthalpy of circulating cooling water is 40 kJ/kg of air. The change in velocity is negligible. The amount of heat lost to the atmosphere from the compressor per kg of air is

(a) 80 kJ (b) 120 kJ
(c) 40 kJ (d) 20 kJ

Directions for Q.29 to Q.30

Each of the next items consists of two statements, one labelled as the 'Statement (I)' and the other as 'Statement (II)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I).

(c) Statement (I) is true but Statement (II) is false.

(d) Statement (I) is false but Statement (II) is true.

Q.29 **Statement (I):** Through one point, there can pass only one reversible adiabatic.

Statement (II): Two constant property lines cannot intersect each other.

Q.30 **Statement (I):** For both equilibrium and non-equilibrium system, the state of a pure substance of given mass can be fixed by specifying two independent intensive properties.

Statement (II): Temperature and specific volume are always independent properties.

■■■■

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THERMODYNAMICS

MECHANICAL ENGINEERING

Date of Test : 05/09/2023

ANSWER KEY

1.	(b)	7.	(c)	13.	(d)	19.	(c)	25.	(b)
2.	(c)	8.	(b)	14.	(b)	20.	(d)	26.	(a)
3.	(d)	9.	(c)	15.	(a)	21.	(b)	27.	(d)
4.	(b)	10.	(b)	16.	(b)	22.	(c)	28.	(d)
5.	(a)	11.	(b)	17.	(c)	23.	(d)	29.	(a)
6.	(d)	12.	(b)	18.	(c)	24.	(d)	30.	(d)

DETAILED EXPLANATIONS

1. (b)

Linear interpolation,

°x	°y
50	100
200	50
x	y

$$\frac{x-200}{50-200} = \frac{y-50}{100-50}$$

For $x = y$

$$\frac{x-200}{-150} = \frac{x-50}{50}$$

$\Rightarrow$ $x = 87.5°x$

2. (c)

An intensive property is a property of matter that depends only on the type of matter in a sample and independent of mass of matter. Example : Temperature, density, solubility, conductivity, viscosity, pressure, etc.

3. (d)

$$c_{poly} = c_v\left(\frac{\gamma - n}{1-n}\right)$$

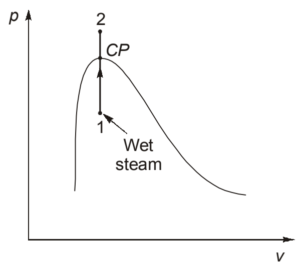
4. (b)

For irreversible system, Clausius inequality

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

and refrigerator $\oint \delta Q < 0$.

5. (a)

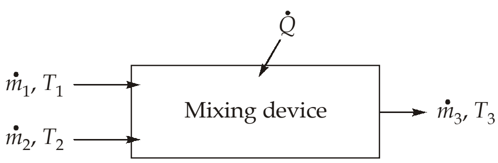


Constant volume heat addition process passing through critical point.

6. (d)

Mixing takes place at constant pressure.

From steady flow energy equation



$$\dot{m}_1(h_1) + \dot{m}_2(h_2) + \dot{Q} = \dot{m}_3(h_3) + W$$

$$\dot{m}_3(c_P T_3) = \dot{m}_1(c_P T_1) + \dot{m}_2(c_P T_2) + \dot{Q}$$

$$T_3 = \frac{\dot{m}_1}{\dot{m}_3}(T_1) + \frac{\dot{m}_2}{\dot{m}_3}(T_2) + \frac{\dot{Q}}{m_3 c_P}$$

7. **(c)**

To understand the significance of the term independent property, consider the saturated-liquid and saturated-vapor states of a pure substance. These two states have the same pressure and the same temperature, but they are definitely not the same state. In a saturation state, therefore, pressure and temperature are not independent properties. Two independent properties, such as pressure and specific volume or pressure and quality, are required to specify a saturation state of a pure substance.

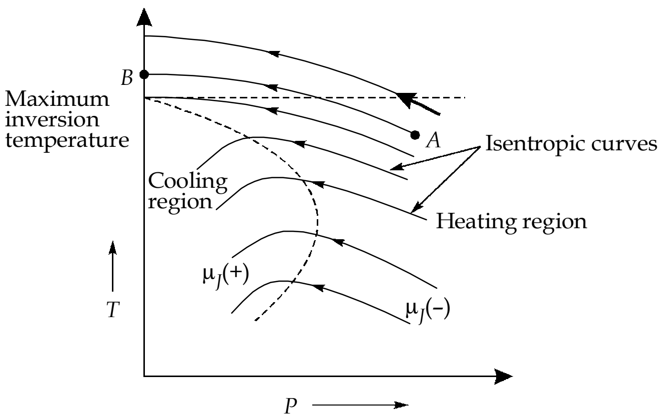
8. **(b)**

The change in availability of closed system is not equal to change in Helmholtz function at given room temperature.

The change in availability of closed system

$$\phi_1 - \phi_2 = (u_1 + P_oV_1 - T_oS_1) - (u_2 + P_oV_2 - T_oS_2)$$

9. **(c)**



As gas is throttled above maximum inversion temperature (curve AB and above) then the temperature of gas keeps on increasing.

10. **(b)**

Real gases deviate from the ideal gas behaviour and this deviation at given temperature and pressure can be accurately accounted by introducing a correct factor called the compressibility factor (z),

$$z = \frac{V_{actual}}{V_{ideal}}$$

11. **(b)**

For steady flow through an insulated horizontal constant diameter pipe, enthalpy remains constant but not for varying diameter.

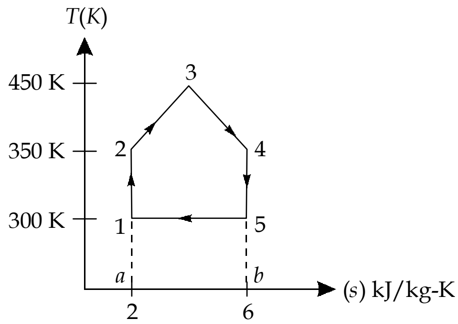
Because when diameter of pipe change corresponding to that pressure will also change for same mass flow rate and hence flow work changes.

12. (b)

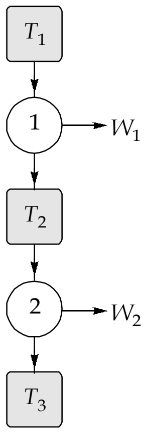
$$\eta = \frac{\text{Work}}{Q_{\text{supply}}} = \frac{ar(1-2-3-4-5-1)}{ar(a-2-3-4-b-a)}$$

$$= \frac{\frac{1}{2}\times 100\times 4 + 50\times 4}{\frac{1}{2}\times 100\times 4 + 350\times 4}$$

$$= \frac{400}{1600} = \frac{1}{4} = 25\%$$



13. (d)



For series combination with same efficiency,

$$T_2^2 = T_1 \times T_3$$

$$(327 + 273)^2 = T_1 \times 500$$

$$T_1 = \frac{600^2}{500} = 720 \text{ K}$$

14. (b)

$$\dot{m} = 0.5 \text{ kg/s}, T_1 = 25°\text{C}, T_2 = 175°\text{C}, V_1 = 5 \text{ m/s}, V_2 = 2 \text{ m/s}$$

Considering compressor as system,

From first law,

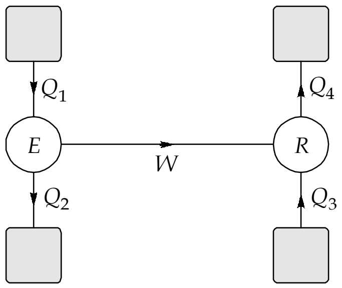
$$\dot{E}_{in} - \dot{E}_{out} = \left(\frac{dE}{dt}\right)_{system}^{\nearrow 0} \quad (\because \text{ Steady flow})$$

$$\text{Work input, } \dot{W} = \dot{m}(h_2 - h_1) + \frac{\dot{m}}{2000}\left(V_2^2 - V_1^2\right) + \dot{Q}$$

$$= 0.5(1.005)(175-25) + \frac{0.5}{2000}\left(2^2 - 5^2\right) + 10$$

$$= 85.36 \text{ kJ}$$

15. (a)



Given: $\eta_E = 0.5$

Also $$Q_1 = \frac{1}{2}(Q_2 + Q_4)$$

$$W = \eta Q_1 = 0.5Q_1$$

$\Rightarrow$ $$Q_2 = Q_1 - W = 0.5Q_1$$

$\Rightarrow$ $$Q_4 = 2Q_1 - Q_2 = 1.5Q_1$$

$$(\text{COP})_R = \frac{Q_3}{Q_4 - Q_3} = \frac{Q_4 - W}{W}$$

$$= \frac{Q_4}{W} - 1 = \frac{1.5Q_1}{0.5Q_1} - 1 = 3 - 1 = 2$$

16. (b)

- A gas cools upon expansion, when its Joule-Thomson coefficient is positive in the temperature range of expansion.
- For achieving the effect of cooling by Joule-Kelvin expansion, the initial temperature of the gas must be below the point where the inversion curve intersect the temperature axis, i.e. below the maximum inversion temperature.

17. (c)

- $$du = c_v dT + \left[T\left(\frac{\partial P}{dT}\right)_v - P\right]dv$$
- $$dh = c_P dT + \left[v - T\left(\frac{dv}{dT}\right)_P\right]dP$$
- $$c_p - c_v = -T\left(\frac{\partial v}{\partial T}\right)_P^2 \left(\frac{\partial v}{\partial T}\right)_T = \frac{Tv\beta^2}{k_t}$$
- $$\mu = \left(\frac{\partial T}{\partial P}\right)_h = \frac{1}{c_p}\left[T\left(\frac{\partial v}{\partial T}\right)_P - v\right]$$

18. (c)

Given data:

$$\text{Cycle efficiency} = \eta = 0.7$$
$$\text{Heat rejected} = Q_R = 1200 \text{ kJ/kg}$$
$$\text{Heat added} = Q_A$$

$$\eta = \frac{Q_A - Q_R}{Q_A} = 1 - \frac{Q_R}{Q_A}$$

$$\Rightarrow \quad 0.7 = 1 - \frac{1200}{Q_A}$$

$$\Rightarrow \quad \frac{1200}{Q_A} = 0.3$$

$$\Rightarrow \quad Q_A = 4000 \text{ kJ/kg}$$
$$W = Q_A - Q_R = 2800 \text{ kJ/kg}$$

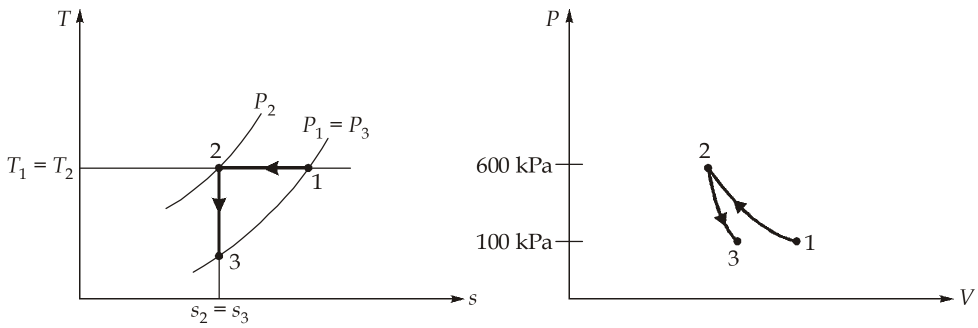
From the scale given

$$1 \text{ cm}^2 = 200 \times 0.2 = 40 \text{ kJ/kg}$$
$$\text{Area of circle} \times 1 \text{ cm}^2 = W$$

$$\Rightarrow \quad \text{Area of circle} = \frac{2800}{40} = 70 \text{ cm}^2$$

$$\frac{\pi}{4}d^2 = 70 \text{ cm}^2$$
$$d = 9.44 \text{ cm}$$

19. (c)



The adiabatic reversible expansion of ideal gas and constant specific heat, (k = 1.66)

$$T_3 = T_2\left(\frac{P_3}{P_2}\right)^{\frac{k-1}{k}}$$

$$= 293\left(\frac{100}{600}\right)^{0.4} = 143.089 \text{ K}$$

The isothermal process has work done on the system.

$$W_{12} = -RT_1 \ln\left(\frac{P_2}{P_1}\right) = -\frac{8.314}{4} \times 293 \times \ln\left(\frac{600}{100}\right) = -1091.18 \text{ kJ/kg}$$

For process 2-3,

$$Q = \Delta U + W$$
$$W_{23} = -(U_3 - U_2) = (U_2 - U_3) \quad ; \quad Q_{23} = 0 \text{ [adiabatic]}$$

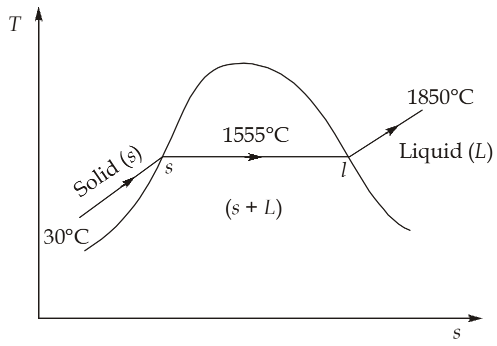
$$c_v = \frac{R}{(\gamma - 1)} = \frac{\left(\frac{8.315}{4}\right)}{(1.66 - 1)} = 3.149$$

$$W_{23} = c_v (T_2 - T_3) = 3.149(293 - 143) = 472.35 \text{ kJ/kg}$$

The net work is,

$$W_{NET} = -1091.18 + 472.35 = -618.83 \text{ kJ/kg}$$

20. (d)



$$\text{Heat required, } q = (c_p)_s (T_m - T_i) + \text{Latent heat} + (c_p)_l (T_f - T_m)$$

$$= 0.50 \times (1555 - 30) + 295 + 0.51(1850 - 1555) = 1207.95 \text{ kJ/kg}$$

$$\therefore \quad \text{furnace rating} = \frac{\dot{m}q}{\eta} = \frac{2.1 \times 1207.95}{0.90} = 2818.55 \text{ kW} = 2.818 \text{ MW}$$

21. (b)

For a constant temperature process,

$$P = \frac{mRT}{V - b} - \frac{a}{V^2}$$

$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{mRT}{V - b} dV - \int_{V_1}^{V_2} \frac{a}{V^2} dV$$

$$W = mRT \ln\left(\frac{V_2 - b}{V_1 - b}\right) + a\left(\frac{1}{V_2} - \frac{1}{V_1}\right)$$

Putting the values of m = 10 kg, R = 0.287 kJ/kgK

T = 293 K, V_2 = 10 m^3, V_1 = 1 m^3, a = 155 kNm^4 and b = 0.0098 m^3, we get

$$W = 10 \times 0.287 \times 293 \ln\left(\frac{10 - 0.0098}{1 - 0.0098}\right) + 155\left(\frac{1}{10} - \frac{1}{1}\right)$$

$$= 1804.22 \text{ kJ}$$

22. (c)

Applying steady flow energy equation,

$$m\left(h_1 + \frac{v_1^2}{2} + gz_1\right) + Q = m\left(h_2 + \frac{v_2^2}{2} + gz_2\right) + W$$

For adiabatic flow, $Q = 0$,

$$\Rightarrow \quad m\left(h_1 + \frac{v_1^2}{2000} + \frac{gz_1}{1000}\right) = m\left(h_2 + \frac{v_2^2}{2000} + \frac{gz_2}{1000}\right) + W$$

$$\Rightarrow m\left(h_1 - h_2 + \frac{v_1^2 - v_2^2}{2000} + \frac{g(z_1 - z_2)}{1000}\right) = 70000$$

$$\Rightarrow \quad m\left(3700 - 2000 + \frac{150^2 - 150^2}{2000} + \frac{9.81}{1000}(15-2)\right) = 70000$$

$$\Rightarrow \quad m = 41.2 \text{ kg/s}$$

23. (d)

Let the final common temperature of 3 reservoirs be T_f

Given: $U = CT$

$$\Rightarrow \quad dU = CdT$$

Now, $$dS = \frac{CdT}{T}$$

$$\Rightarrow \quad \Delta S = C\ln\frac{T_f}{T_i}$$

T_i = Initial temperature

For maximum work, $\Sigma\Delta S = 0$

$$\Rightarrow \quad \Delta S_1 + \Delta S_2 + \Delta S_3 = 0$$

$$\Rightarrow \quad C\ln\frac{T_f}{200} + C\ln\frac{T_f}{250} + C\ln\frac{T_f}{540} = 0$$

$$\Rightarrow \quad T_f^3 = 200 \times 250 \times 540$$

$$\Rightarrow \quad T_f = 300\,\text{K}$$

$$W_{max} = -[\Delta U_1 + \Delta U_2 + \Delta U_3] = -\left[C\left[T_f - T_1\right] + C\left[T_f - T_2\right] + C\left[T_f - T_3\right]\right]$$

$$= -[8.4(300-200) + 8.4(300-250) + 8.4(300-540)]$$

$$\Rightarrow \quad W_{max} = 756 \text{ kJ}$$

24. (d)

Given: $V_1 = 0.05 \text{ m}^3$

Now, enclosed volume at final state is

$$V_2 = 2V_1 = 0.1 \text{ m}^3$$

$\therefore$ Displacement of piston, $x = \dfrac{\Delta V}{A} = \dfrac{0.05}{0.25} = 0.2 \text{ m}$

Force applied by linear spring at final state,

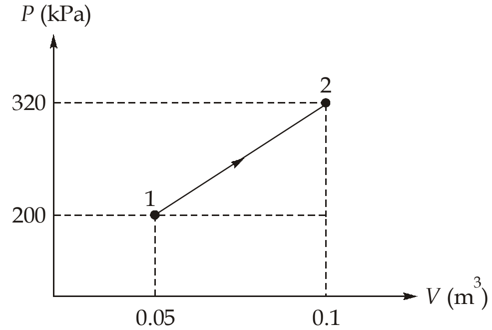
$$F_{spring} = kx = 150 \times 0.2 = 30 \text{ kN}$$

Additional pressure applied by spring,

$$P = \frac{F_{spring}}{A} = \frac{30}{0.25} = 120 \text{ kPa}$$

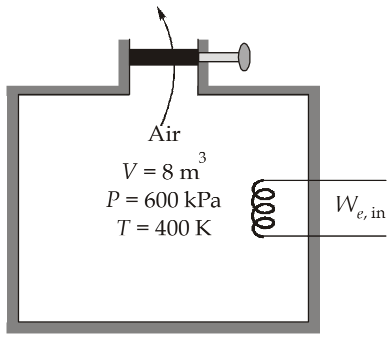
Without the spring, pressure of gas would remain constant at 200 kPa but under the effect of spring, pressure rises linearly from 200 kPa to (200 + 120) = 320 kPa.

Now, total work done by gas = Area under the process (1-2)



$$W = \text{Area} = \left(\frac{200+320}{2}\right)(0.1-0.05)\text{ kJ} = 13 \text{ kJ}$$

25. (b)



$$m_1 = \frac{P_1V_1}{RT_1} = \frac{600\times 8}{0.287\times 400} = 41.81 \text{ kg}$$

$$m_2 = \frac{P_2V_2}{RT_2} = \frac{200\times 8}{0.287\times 400} = 13.94 \text{ kg}$$

At 400 K, $h_e = 400.98$ kJ/kg and $u_1 = u_2 = 286.16$ kJ/kg

Mass balance:

$$m_{in} - m_{out} = \Delta m_{system}$$

$\Rightarrow$ $m_e = m_1 - m_2 = 41.81 - 13.94 = 27.87$ kg

Energy balance:

$$E_{in} - E_{out} = \Delta E_{system}$$

$$W_{e,in} - m_e h_e = m_2u_2 - m_1u_1 \quad \text{(Since } Q \cong \text{KE} \cong \text{PE} \cong 0)$$

$$m_e h_e + m_2u_2 - m_1u_1 = W_{e,in}$$

$$W_{e,in} = m_e h_e + u(m_2 - m_1) \quad (\because\ u = u_1 = u_2)$$

$$= m_e h_e + u(-m_e)$$

$$W_{e,in} = m_e(h_e - u)$$

$$= 27.87 \times (400.98 - 286.16) \text{ kJ}$$

$$= 27.87 \times 114.82 \text{ kJ}$$

$$= 3200.03 \text{ kJ}$$

$$= 0.889 \text{ kWh} \quad [\because 1 \text{ kWh} = 3600 \text{ kJ}]$$

26. (a)

Work potential = Exergy (non-flow) = $\phi_1 - \phi_0$

$$= [(u_1 - u_0) + P_0(V_1 - V_0) - T_0(S_1 - S_0)]$$

Here, $u_1 = u_0$ as $T_1 = T_0$

and, $$P_0(V_1 - V_0) = P_0\left(\frac{RT_1}{P_1} - \frac{RT_0}{P_0}\right) = RT_0\left(\frac{P_0}{P_1} - 1\right)$$

and, $$T_0(S_1 - S_0) = T_0\left(c_p \ln\left(\frac{T_1}{T_0}\right) - R\ln\left(\frac{P_1}{P_0}\right)\right) = -RT_0 \ln\left(\frac{P_1}{P_0}\right)$$

$\Rightarrow$ $$\phi = RT_0\left[\ln\left(\frac{P_1}{P_0}\right) + \frac{P_0}{P_1} - 1\right]$$

27. (d)

T_0 = 25 + 273 = 298, T_1 = 50°C = 273 + 50 = 323 K, P_1 = 800 kPa, m = 0.5 kg/s, P_2 = 200 kPa

Assuming air as ideal gas and for throttling,

$$h_1 = h_2$$

$\Rightarrow$ $$T_1 = T_2$$

So, $$\Delta S = c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

$$= 0 - 0.287\ln\left(\frac{1}{4}\right) = 0.287\ln 4 = 0.287 \times 2 \times 0.693$$

Power waisted, $I = mT_0\Delta S$ = 0.5 × 298 × 0.287 × 2 × 0.693

= 59.28 kW

28. (d)

$$W = (\Delta h)_{\text{air}} + (\Delta h)_{\text{water}} + Q$$

$$90 = 30 + 40 + Q$$

$$Q = 20 \text{ kJ/kg}$$

29. (a)

A reversible adiabatic process is the one where entropy (which is a property) of a system remains constant.

30. (d)

The state of a pure substance of given mass can be fixed by specifying two independent intensive properties, provided the system is in equilibrium. There may be any number of independent intensive properties for defining non-equilibrium system.

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