**Thermodynamics (MEL2020)**
**Indian Institute of Technology Jodhpur**

**End Examination – Part 1 (Short answers)** Date: 25th April 2022
**Maximum points: 25 points** **Instructions:** **Time: 10:00 to 10:45 AM**

- Each question carries **1 point**
- Write down your **final short answers** in clean A4 sheet.
- All questions are compulsory
- Please upload the part 1 scanned document before **10.50 AM**
- No late Submission are allowed (leads to zero marks)
- Q (1 to 5) answer the correct option
- Q (6-25) write the final short answer

**Write down only correct option for the question given below**

1. Irreversibility of thermodynamic process occurs only by (write correct statement numbers)
   1. heat transfer across the boundary
   2. Frictional effects
   3. Unrestrained expansion
   4. Mixing of two dissimilar pure substances

   a) 2 only
   b) 1 and 2 only
   c) 3 and 4 only
   d) 3 only
   e) 4 only
   f) 2 only
   g) 2, 3 and 4 only
   h) 1, 2, 3 and 4

2. Keeping the limitations imposed by the second-law of thermodynamics in mind, choose the wrong statement below:
   a) A heat engine cannot have a thermal efficiency of 100%.
   b) For all reversible processes, the second-law efficiency is 100%.
   c) The second-law efficiency of a heat engine cannot be greater than its thermal efficiency.
   d) The second-law efficiency of a process is 100% if no entropy is generated during that process

3. For the two paths, one reversible and one irreversible, to change the state of the system from same initial point to same final point for both the paths,
   a) Q, W are same
   b) $\Delta U$ is same
   c) $\Delta U$ is not same
   d) $\Delta U$ is can be different
   e) $\Delta U$, Q, W are same
   f) $\Delta U$, Q are different

4. Exergy for a closed system can be,
   a) Negative
   b) Negative or zero
   c) Positive or zero
   d) always negative
   e) -3
   f) Positive or negative
   g) -1

5. Which of the following assumptions are inherent in Clausius-Clapeyron equation?
   a) Specific molar volume of the liquid is very small compared to specific molar volume of the gas and as a result can be neglected.
   b) Saturated vapor obeys ideal gas law.
   c) The molar heat of vaporization is independent of temperature.
   d) All of these
   e) None of these

**Write down only final short answer for the question given below**

6. For a pure substance, write the Maxwell's relation obtained from the fundamental property relation: $dU = TdS - pdV$

7. A 3-$m^3$ rigid tank contains nitrogen gas at 500 kPa and 300 K. Now heat is transferred to the nitrogen in the tank and the pressure of nitrogen rises to 800 kPa. The work done (in kJ) during this process is

8. 1 $m^3$ of an ideal gas at 500 K 1000 kPa expands reversibly to 5 times its initial volume in an insulated container. If the specific heat capacity (at constant pressure) of the gas is 21 J/mol K, the final temperature (in K) will be

9. Air is contained in a variable-load piston-cylinder device equipped with a paddle wheel. Initially, air is at 500 kPa and 27°C. The paddle wheel is now turned by an external electric motor until 30 kJ/kg of work has been transferred to air. During this process, heat is transferred to maintain a constant air temperature while allowing the gas volume to triple. Calculate the required amount of heat transfer (in kJ/kg).

10. Electrical power is to be generated in a hydroelectric power plant that receives water at a rate of 85 $m^3/s$ from an elevation of 65 m using a turbine generator with an efficiency of 70 percent. When frictional losses in piping are disregarded, the electric power output (in MW) of this plant is

11. Steam enters a diffuser steadily at 0.5 MPa, 300°C, and 122 m/s at a rate of 4 kg/s. The inlet area (in $cm^2$) of the diffuser is

**TABLE A–6**

Superheated water

| T °C | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg·K | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg·K | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg·K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P = 0.50 MPa (151.83°C) | | | | P = 0.60 MPa (158.83°C) | | | | P = 0.80 MPa (170.41°C) | | | |
| Sat. | 0.37483 | 2560.7 | 2748.1 | 6.8207 | 0.31560 | 2566.8 | 2756.2 | 6.7593 | 0.24035 | 2576.0 | 2768.3 | 6.6616 |
| 200 | 0.42503 | 2643.3 | 2855.8 | 7.0610 | 0.35212 | 2639.4 | 2850.6 | 6.9683 | 0.26088 | 2631.1 | 2839.8 | 6.8177 |
| 250 | 0.47443 | 2723.8 | 2961.0 | 7.2725 | 0.39390 | 2721.2 | 2957.6 | 7.1833 | 0.29321 | 2715.9 | 2950.4 | 7.0402 |
| 300 | 0.52261 | 2803.3 | 3064.6 | 7.4614 | 0.43442 | 2801.4 | 3062.0 | 7.3740 | 0.32416 | 2797.5 | 3056.9 | 7.2345 |
| 350 | 0.57015 | 2883.0 | 3168.1 | 7.6346 | 0.47428 | 2881.6 | 3166.1 | 7.5481 | 0.35442 | 2878.6 | 3162.2 | 7.4107 |
| 400 | 0.61731 | 2963.7 | 3272.4 | 7.7956 | 0.51374 | 2962.5 | 3270.8 | 7.7097 | 0.38429 | 2960.2 | 3267.7 | 7.5735 |
| 500 | 0.71095 | 3129.0 | 3484.5 | 8.0893 | 0.59200 | 3128.2 | 3483.4 | 8.0041 | 0.44332 | 3126.6 | 3481.3 | 7.8692 |
| 600 | 0.80409 | 3300.4 | 3702.5 | 8.3544 | 0.66976 | 3299.8 | 3701.7 | 8.2695 | 0.50186 | 3298.7 | 3700.1 | 8.1354 |
| 700 | 0.89696 | 3478.6 | 3927.0 | 8.5978 | 0.74725 | 3478.1 | 3926.4 | 8.5132 | 0.56011 | 3477.2 | 3925.3 | 8.3794 |
| 800 | 0.98966 | 3663.6 | 4158.4 | 8.8240 | 0.82457 | 3663.2 | 4157.9 | 8.7395 | 0.61820 | 3662.5 | 4157.0 | 8.6061 |
| 900 | 1.08227 | 3855.4 | 4396.6 | 9.0362 | 0.90179 | 3855.1 | 4396.2 | 8.9518 | 0.67619 | 3854.5 | 4395.5 | 8.8185 |
| 1000 | 1.17480 | 4054.0 | 4641.4 | 9.2364 | 0.97893 | 4053.8 | 4641.1 | 9.1521 | 0.73411 | 4053.3 | 4640.5 | 9.0189 |
| 1100 | 1.26728 | 4259.0 | 4892.6 | 9.4263 | 1.05603 | 4258.8 | 4892.4 | 9.3420 | 0.79197 | 4258.3 | 4891.9 | 9.2090 |
| 1200 | 1.35972 | 4470.0 | 5149.8 | 9.6071 | 1.13309 | 4469.8 | 5149.6 | 9.5229 | 0.84980 | 4469.4 | 5149.3 | 9.3898 |
| 1300 | 1.45214 | 4686.6 | 5412.6 | 9.7797 | 1.21012 | 4686.4 | 5412.5 | 9.6955 | 0.90761 | 4686.1 | 5412.2 | 9.5625 |

12. The specific heat at constant volume for an ideal gas is given by $C_v = 0.7 + (2.7 \text{ X } 10^{-4})T$ (kJ/kg.K) where **T** is in kelvin. The change in the internal energy (in kJ/kg) for this ideal gas undergoing a process in which the temperature changes from 27 to 127°C is most nearly

13. Draw the correct T-ν diagram if steam at $\nu_1 = 0.005\text{m}^3/\text{kg}$ is heated to $\nu_2 = 0.5\text{m}^3/\text{kg}$ while maintaining P = 500 kPa. The dots are states 1 and 2 with 1 being on the left.

**TABLE A–5**

Saturated water—Pressure table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg·K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
| 175 | 116.04 | 0.001057 | 1.0037 | 486.82 | 2037.7 | 2524.5 | 487.01 | 2213.1 | 2700.2 | 1.4850 | 5.6865 | 7.1716 |
| 200 | 120.21 | 0.001061 | 0.88578 | 504.50 | 2024.6 | 2529.1 | 504.71 | 2201.6 | 2706.3 | 1.5302 | 5.5968 | 7.1270 |
| 225 | 123.97 | 0.001064 | 0.79329 | 520.47 | 2012.7 | 2533.2 | 520.71 | 2191.0 | 2711.7 | 1.5706 | 5.5171 | 7.0877 |
| 250 | 127.41 | 0.001067 | 0.71873 | 535.08 | 2001.8 | 2536.8 | 535.35 | 2181.2 | 2716.5 | 1.6072 | 5.4453 | 7.0525 |
| 275 | 130.58 | 0.001070 | 0.65732 | 548.57 | 1991.6 | 2540.1 | 548.86 | 2172.0 | 2720.9 | 1.6408 | 5.3800 | 7.0207 |
| 300 | 133.52 | 0.001073 | 0.60582 | 561.11 | 1982.1 | 2543.2 | 561.43 | 2163.5 | 2724.9 | 1.6717 | 5.3200 | 6.9917 |
| 325 | 136.27 | 0.001076 | 0.56199 | 572.84 | 1973.1 | 2545.9 | 573.19 | 2155.4 | 2728.6 | 1.7005 | 5.2645 | 6.9650 |
| 350 | 138.86 | 0.001079 | 0.52422 | 583.89 | 1964.6 | 2548.5 | 584.26 | 2147.7 | 2732.0 | 1.7274 | 5.2128 | 6.9402 |
| 375 | 141.30 | 0.001081 | 0.49133 | 594.32 | 1956.6 | 2550.9 | 594.73 | 2140.4 | 2735.1 | 1.7526 | 5.1645 | 6.9171 |
| 400 | 143.61 | 0.001084 | 0.46242 | 604.22 | 1948.9 | 2553.1 | 604.66 | 2133.4 | 2738.1 | 1.7765 | 5.1191 | 6.8955 |
| 450 | 147.90 | 0.001088 | 0.41392 | 622.65 | 1934.5 | 2557.1 | 623.14 | 2120.3 | 2743.4 | 1.8205 | 5.0356 | 6.8561 |
| 500 | 151.83 | 0.001093 | 0.37483 | 639.54 | 1921.2 | 2560.7 | 640.09 | 2108.0 | 2748.1 | 1.8604 | 4.9603 | 6.8207 |
| 550 | 155.46 | 0.001097 | 0.34261 | 655.16 | 1908.8 | 2563.9 | 655.77 | 2096.6 | 2752.4 | 1.8970 | 4.8916 | 6.7886 |
| 600 | 158.83 | 0.001101 | 0.31560 | 669.72 | 1897.1 | 2566.8 | 670.38 | 2085.8 | 2756.2 | 1.9308 | 4.8285 | 6.7593 |
| 650 | 161.98 | 0.001104 | 0.29260 | 683.37 | 1886.1 | 2569.4 | 684.08 | 2075.5 | 2759.6 | 1.9623 | 4.7699 | 6.7322 |
| 700 | 164.95 | 0.001108 | 0.27278 | 696.23 | 1875.6 | 2571.8 | 697.00 | 2065.8 | 2762.8 | 1.9918 | 4.7153 | 6.7071 |
| 750 | 167.75 | 0.001111 | 0.25552 | 708.40 | 1865.6 | 2574.0 | 709.24 | 2056.4 | 2765.7 | 2.0195 | 4.6642 | 6.6837 |

14. Carbon dioxide contained in a piston-cylinder device is compressed from 0.3 to 0.1 $\text{m}^3$. During the process, the pressure and volume are related by $P = av^{-2}$, where $a = 8 \text{ kPa-m}^6$. Calculate the boundary work done (in kJ) on the carbon dioxide during this process.

15. Find the quality of steam at 120$^o$C if the vapour occupies 1000L and the liquid occupies 2L.

**TABLE A–4**

Saturated water—Temperature table

| | | Specific volume, $m^3/kg$ | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg·K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp., $T$ °C | Sat. press., $P_{sat}$ kPa | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
| 100 | 101.42 | 0.001043 | 1.6720 | 419.06 | 2087.0 | 2506.0 | 419.17 | 2256.4 | 2675.6 | 1.3072 | 6.0470 | 7.3542 |
| 105 | 120.90 | 0.001047 | 1.4186 | 440.15 | 2071.8 | 2511.9 | 440.28 | 2243.1 | 2683.4 | 1.3634 | 5.9319 | 7.2952 |
| 110 | 143.38 | 0.001052 | 1.2094 | 461.27 | 2056.4 | 2517.7 | 461.42 | 2229.7 | 2691.1 | 1.4188 | 5.8193 | 7.2382 |
| 115 | 169.18 | 0.001056 | 1.0360 | 482.42 | 2040.9 | 2523.3 | 482.59 | 2216.0 | 2698.6 | 1.4737 | 5.7092 | 7.1829 |
| 120 | 198.67 | 0.001060 | 0.89133 | 503.60 | 2025.3 | 2528.9 | 503.81 | 2202.1 | 2706.0 | 1.5279 | 5.6013 | 7.1292 |

16. A room is heated with a 1500 W electric heater. How much power (in W) can be saved if a heat pump with a COP of 3.0 is used instead?

17. High pressure steam is expanded adiabatically and reversibly through a well insulated turbine which produces some shaft work. If the enthalpy change and entropy change across the turbine are represented by $\Delta H$ and $\Delta S$, respectively, for this process then choose the correct statement from the given below
    a) $\Delta H = 0$ and $\Delta S = 0$
    b) $\Delta H = 0$ and $\Delta S \neq 0$
    c) $\Delta H \neq 0$ and $\Delta S = 0$
    d) $\Delta H \neq 0$ and $\Delta S \neq 0$

18. Steam undergoes isentropic expansion from in a turbine from 5000 kPa and 400 °C (entropy 6.65 kJ/kg.K) to 150 kPa (entropy of saturated liquid = 1.4336 kJ/kg.K and entropy of saturated vapour = 7.2234 kJ/kg.K). The exit condition of steam is

19. A heat engine operates at 75% of the maximum possible efficiency. The ratio of the heat source temperature (in K) to the heat sink (in K) is 5/3. The fraction of the heat supplied that is converted to work is

20. A heat engine receives heat from a source at 1500 K at a rate of 600 kJ/s and rejects the waste heat to a sink at 300 K. If the power output of the engine is 400 kW, the second law efficiency of this heat engine is

21. Steam at 1000 bar and 300 K undergoes Joule-Thomson expansion to 1 atm. What would be the temperature (in K) of steam after expansion? Assume steam to be an ideal gas.

22. An insulated rigid tank contains 0.9 kg of air at 150 kPa and 20°C. A paddle wheel inside the tank is now rotated by an external power source until the temperature in the tank rises to 55°C. If the surrounding air is at $T_0$ = 20°C, determine the exergy destroyed ($X_{dest}$) (in kJ). Assume air as an ideal gas, $C_v$ of air is 0.718 kJ/kg K.

23. Steam is condensed at a constant temperature of 30°C as it flows through the condenser of a power plant by rejecting heat at a rate of 55 MW. The rate of entropy change of steam (in MW/K) as it flows through the condenser is

24. Using the Maxwell relations, determine $\left(\frac{\partial S}{\partial P}\right)_T$ , for a gas whose equation of state is given by : P (v - b) = RT.

25. The weight placed on the steam exhaust port of a domestic pressure cocker never allows the pressure to build up above 200 kPa inside the cooker. Determine the temperature (in Kssssss) at which water boils in the pressure cooker. The latent heat of vaporization of water is 2256.94 kJ/Kg at 100 $^{o}$C and P=101.325 kPa. Assume that no other data is available.

**************************End of the question paper** ****************************