ESO201A Thermodynamics
Instructor: Jishnu Bhattacharya
Quiz 2
Total points: 40

Date: 8th April 2023,
Venue: As per the shared sitting plan
Allotted time: 50 minutes (8:00 – 8:50 AM)

Important instructions:

You must write your **name**, **roll number** and **section**, and put your **signature** in the space given below.

Be careful, all questions have negative marking.

Please use the space mentioned as "**Rough Work**" in the question paper for calculations, if required.

Name:

Signature:

Roll no.:

Section:

(Total points = 10 × 4 = 40 points). Write the correct option **(A, B, C, D or E)** for the following questions. +4 points for the correct answer and **-1 point for the wrong answer**. 0 points for the unanswered question.

Take air properties wherever required: c_v = 0.718 kJ/kg-K, c_p = 1.005 kJ/kg-K, R = 0.287 kJ/kg-K, k = 1.4. Assume ideal gas with constant specific heats.

#	Question	A/B/C/D/E
1.	Air at 1 bar and 25°C is compressed adiabatically to 2 bar and 50°C in a closed system. Which of the following statements is correct? (a) The process is isochoric (b) The process is possible but irreversible (c) The process is possible and reversible (d) The process is impossible (e) The process is isentropic	**D**
2.	In a gas turbine power plant, the inlet and outlet pressures of the compressor is 1 bar and 20 bar, respectively. The thermal efficiency (in %) of the corresponding ideal Brayton cycle with air as the working fluid is: (a) 69.8 (b) 57.5 (c) 28.6 (d) 88.2 (e) 39.3	**B**

3.	Consider steady flow of air through an insulated nozzle. The temperature of air at the inlet and outlet are 320 K and 305 K, respectively. The inlet velocity is negligible. The elevation of inlet and outlet is the same. The outlet velocity (in m/s) is: (a) 173.6 (b) 122.8 (c) 5.5 (d) 146.8 (e) 92.8	**A**
4.	Air enters a pipe at 1 bar and flows isothermally (at 300 K), adiabatically and steadily at the rate of 1 kg/s. Due to pipe friction, the pressure drop between the inlet and outlet of the pipe is 7% of the pressure at the inlet. For environment temperature of 300 K, the rate of exergy destruction (in kW) in the pipe section is: (a) 15.63 (b) 2.08 (c) 6.25 (d) 21.77 (e) 9.38	**C**
5.	Air is compressed steadily and adiabatically from 290 K and 90 kPa to 473 K and 400 kPa. The isentropic efficiency (in %) of the compressor is: (a) 93.8 (b) 33.2 (c) 77.5 (d) 84.2 (e) 65.5	**D**
6.	A steady 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 (in %) of this heat engine is: (a) 80.0 (b) 33.3 (c) 66.7 (d) 50.0 (e) 83.3	**E**
7.	Air is expanded from $v_1 = 1\ m^3/kg$ and $T_1 = 300$ K to $v_2 = 5\ m^3/kg$ and $T_2 = 600$ K. What is the change in the entropy ($s_2 - s_1$) of air in this process (in kJ/kg-K)? (a) 0.498 (b) 0.235 (c) 0.960 (d) 0.036	**C**

	(e) 1.609	
8.	If the environment conditions are 100 kPa and 300 K, the exergy (in kJ/kg) of stagnant air at zero elevation and at 1 MPa and 300 K is: (a) 120.76 (b) 206.73 (c) 8.61 (d) 198.20 (e) 86.10	**A**
9.	An ideal Diesel cycle has heat input of 750 kJ/kg to the cycle. Use air as the working fluid. If the temperature of air at the end of compression stroke is 650 K, the temperature (in K) of air at the end of heat addition process is: (a) 1963.2 (b) 1396.3 (c) 1044.6 (d) 1694.6 (e) 1230.5	**B**
10.	During a constant-volume heat-addition process, 287.2 kJ/kg of heat is transferred to air from a source at 2000 K. Environment temperature is 300 K. During this process the change in entropy of air ($s_2 - s_1$) is 0.6084 kJ/kg-K. The exergy destruction (in kJ/kg) during this process (1-2) is: (a) 225.5 (b) 43.1 (c) 182.4 (d) 212.4 (e) 139.4	**E**

Rough Work:

1. Entropy balance on the closed system:
   $s_{in} - s_{out} + s_{gen} = s_2 - s_1$, here $s_{in} = 0$, $s_{out} = 0$ (adiabatic closed system).
   $s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} = 1.005\ln\frac{323}{298} - 0.287\ln\frac{2}{1} = -0.118\,\frac{kJ}{kg-K}$
   $s_{gen} = -0.118\,\frac{kJ}{kg-K}$ (negative s_{gen} is not possible)
2. Thermal efficiency of ideal Brayton cycle:
   $\eta_{th} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}} = 1 - \frac{1}{\left(\frac{20}{1}\right)^{\frac{1.4-1}{1.4}}} = 0.575$
3. Energy balance on nozzle:
   $h_1 = h_2 + \frac{1}{2}V_2^2 \rightarrow V_2 = \sqrt{2c_p(T_1 - T_2)} = \sqrt{2 \times 1005(320 - 315)} = 173.6\,\frac{m}{s}$
4. For steady flow, single stream, adiabatic system:

$\dot{S}_{gen} = \dot{m}(s_e - s_i) = 1\left(c_p \ln\frac{T_e}{T_i} - R\ln\frac{P_e}{P_i}\right) = -0.287\ln\frac{93}{100} = 0.02083\ \frac{kW}{K}$

$\dot{X}_{des} = T_0\dot{S}_{gen} = 300 \times 0.2083 = 6.25\ kW$

5. For isentropic compression:

$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = \left(\frac{400}{90}\right)^{\frac{1.4-1}{1.4}} = 1.531 \rightarrow T_{2s} = 444.1\ K\ (T_1 = 290\ K)$

$\eta_C = \frac{T_{2s}-T_1}{T_2-T_1} = \frac{444.1-290}{473-290} = 0.842$

6. For heat engines:

$\eta_{II} = \frac{\eta_{th}}{\eta_{th,rev}} = \frac{\dot{W}_{out}/\dot{q}_{in}}{1-T_L/T_H} = \frac{400/600}{1-300/1500} = 0.833$

7. For ideal gas with constant specific heats:

$s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} = 0.718\ln\frac{600}{300} + 0.287\ln\frac{5}{1} = 0.960\frac{kJ}{kg-K}$

8. Exergy for closed system per unit mass:

$\emptyset = (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$

$V = 0, z = 0, u = u_0(as\ T = T_0)$

$\emptyset = P_0(v - v_0) - T_0(s - s_0) = P_0\left(\frac{RT}{P} - \frac{RT_0}{P_0}\right) - T_0\left(c_p\ln\frac{T}{T_0} - R\ln\frac{P}{P_0}\right) = RT_0\left(\frac{P_0}{P} - 1 + \ln\frac{P}{P_0}\right) = 0.287 \times 300\left(\frac{100}{1000} - 1 + \ln\frac{1000}{100}\right) = 120.76\frac{kJ}{kg}$

9. Constant pressure heat addition process:

$q_{in} = c_p(T_3 - T_2) \rightarrow 750 = 1.005(T_3 - 650) \rightarrow T_3 = 1396.3\ K$

10. Entropy balance on the extended system:

$s_{in} - s_{out} + s_{gen} = s_2 - s_1$, $s_{in} = q_{in}/T_{source} = 287.2/2000 = 0.1436$ kJ/kg-K, $s_{out} = 0$

$s_2 - s_1 = 0.6084\frac{kJ}{kg-K}$

$s_{gen} = 0.6084 - 0.1436 = 0.4648\ \frac{kJ}{kg-K}$

$x_{des} = T_0 s_{gen} = 300 \times 0.4648 = 139.4\frac{kJ}{kg}$