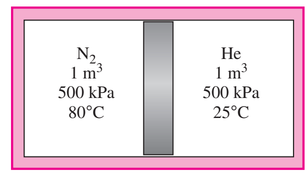
4 November 2019

CHE 260F – Thermodynamics and Heat Transfer

Mid-Term Exam – 2019

You have 110 minutes to do the following five problems. You may use any type of non-communicating calculator. All questions are worth equal marks.

1) Consider a well-insulated horizontal rigid cylinder that is divided into two compartments by a piston that is free to move but does not allow gas to leak past it. Initially one side of the piston contains 1 m^3 of nitrogen gas at 500 kPa and 80°C while the other side contains 1 m^3 of helium gas at 500 kPa and 25°C. Thermal and mechanical equilibrium are established in the cylinder as a result of heat transfer through the piston while it moves freely. Determine the final equilibrium temperature and the final volume of each gas.



2) A piston–cylinder device contains helium gas initially at 100 kPa, 10°C, and 0.2 m^3. The helium is now compressed in a polytropic process (PV^n = constant) to 700 kPa and 290°C. Determine the heat loss or gain during this process.

3) Steam enters a nozzle at 400°C and 800 kPa with a velocity of 10 m/s and leaves at 300°C and 200 kPa while losing heat through the nozzle wall at a rate of 25 kW. For an inlet area of 800 cm^2, determine the exit velocity and the nozzle exit area.

4) Hot combustion gases enter the nozzle of a turbojet engine at 260 kPa, 747°C, and 80 m/s, and they exit at a pressure of 85 kPa. Assuming an isentropic efficiency of 92% and treating the combustion gases as air, determine (*a*) the exit velocity and (*b*) the exit temperature.

5) Steam enters a turbine operating at steady state at 3.5 MPa, 600°C with a mass flow rate of 125 kg/minute and exits as saturated vapour at 20 kPa. The turbine produces power at a rate of 2 MW while losing heat from its surface to the surroundings air at 27°C. Kinetic and potential energy changes can be ignored. Determine (a) the rate of heat transfer (b) the rate of entropy generation.

Gas Properties

Gas	R	c_v	c_p
Air	0.2870 kJ/kgK	0.718 kJ/kgK	1.005 kJ/kgK
Nitrogen	0.2968 kJ/kgK	0.743 kJ/kgK	1.040 kJ/kgK
Helium	2.0769 kJ/kgK	3.1156 kJ/kgK	5.1925 kJ/kgK

Ideal gas equation

$PV = NR_uT$ $\quad R_u$ =8.314 kJ/kmol K

$PV = mRT$ $\quad R=R_u/M$

Boundary Work

$$W_{12} = -\int_{V_1}^{V_2} P\,dV$$

For a constant pressure process

$$W_{12} = P_1(V_1 - V_2) = P_1V_1 - P_2V_2$$

For a polytropic process $PV^n = C$

$$W_{12} = P_1V_1 \ln\frac{V_1}{V_2} = P_2V_2 \ln\frac{V_1}{V_2} \quad \text{for } n=1$$

$$W_{12} = \frac{P_2V_2 - P_1V_1}{n-1} \quad \text{for } n \neq 1$$

Flow work per unit mass of fluid

$w_{\text{flow}} = Pv$

Enthalpy $h = u + Pv$

Specific heats

$$c_v(T) \equiv \left(\frac{\partial u}{\partial T}\right)_v \text{ and } c_p(T) \equiv \left(\frac{\partial h}{\partial T}\right)_P$$

For an ideal gas

$$c_p = c_v + R$$

$$\Delta u = u_2 - u_1 = c_{v,avg}(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = c_{p,avg}(T_2 - T_1)$$

Specific heat ratio $\gamma = \dfrac{c_p}{c_v} = \dfrac{\overline{c_p}}{\overline{c_v}}$

For a control volume

$$\dot{m} = \frac{AV}{v}$$

$$\dot{Q} + \dot{W} = \dot{m}\left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

Gibbs equation

$$ds = \frac{1}{T}du + \frac{P}{T}dv$$

For a liquid or solid

$$\Delta s = s_2 - s_1 = c_{avg}\int_{T_1}^{T_2}\frac{dT}{T} = c_{avg}\ln\frac{T_2}{T_1}$$

For an ideal gas

$$\Delta s = s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}$$

$$\Delta s = s_2 - s_1 = c_v \ln\frac{P_2}{P_1} + c_p \ln\frac{v_2}{v_1}$$

$$\Delta s = s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

Isentropic turbine efficiency

$$\eta_t = \frac{w_t}{w_{t,s}} = \frac{h_2 - h_1}{h_{2s} - h_1}.$$

Isentropic nozzle efficiency,

$$\eta_{nozzle} = \frac{\mathbf{V}_2^2}{\mathbf{V}_{2s}^2}.$$

Isentropic compressor or pump efficiency,

$$\eta_c = \frac{w_{c,s}}{w_c} = \frac{h_{2s} - h_1}{h_2 - h_1}.$$

For an isentropic process in an ideal gas

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{(\gamma-1)};\quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma};$$

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{\gamma};\quad Pv^{\gamma}=\text{constant}$$

For a saturated liquid-vapour mixture

$$x = \frac{\text{mass of vapour}}{\text{mass of mixture}} = \frac{m_g}{m}$$

$$u = \frac{m_g}{m}u_g + \frac{m_f}{m}u_f = xu_g + (1-x)u_f$$

$$h = \frac{m_g}{m}h_g + \frac{m_f}{m}h_f = xh_g + (1-x)h_f$$

$$s = \frac{m_g}{m}s_g + \frac{m_f}{m}s_f = xs_g + (1-x)s_f$$