1 November 2018

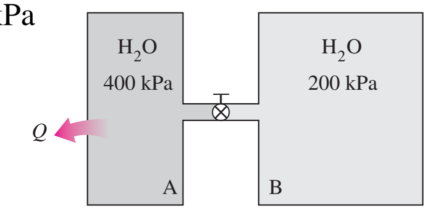
CHE 260F – Thermodynamics and Heat Transfer

Mid-Term Exam – 2018

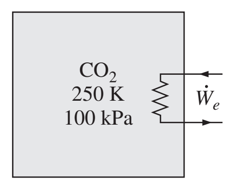
You have 110 minutes to do the following five problems. You may use any type of non-communicating calculator. All questions are worth equal marks.

1) A piston–cylinder device contains helium gas initially at 150 kPa, 20°C, and 0.5 m^3. The helium is now compressed in a polytropic process (PV^n= constant) to 400 kPa and 140°C. Determine the heat loss or gain during this process.
Assume that for helium R = 2.0769 kJ/kgK and c_v = 3.1156 kJ/kgK

2) Two rigid tanks are connected by a valve. Tank A contains 0.2 m^3 of water at 400 kPa and 80 percent quality. Tank B contains 0.5 m^3 of water at 200 kPa and 250°C. The valve is now opened, and the two tanks allowed to lose heat until the system reaches thermal equilibrium with the surrounding air at 25°C. Determine the amount of heat transfer during this process.



3) A 0.8 m^3 rigid tank contains carbon dioxide (CO_2) gas at 250 K and 100 kPa. A 500-W electric resistance heater placed in the tank is now turned on and kept on for 40 min after which the pressure of CO_2 is measured to be 175 kPa. Assuming the surroundings to be at 300 K and using constant specific heats, determine (*a*) the final temperature of CO_2, (*b*) the net amount of heat transfer from the tank, and (*c*) the entropy generation during this process.
Assume that for CO_2: R = 0.1889 kJ/kgK, c_p = 0.895 kJ/kgK, c_v = 0.706 kJ/kgK.



4) Air enters a nozzle steadily at 280 kPa and 77°C with a velocity of 50 m/s and exits at 85 kPa and 320 m/s. The heat losses from the nozzle (per kilogram of air flowing through the nozzle) to the surrounding atmosphere at 20°C are estimated to be 3.2 kJ/kg. Determine: (*a*) the exit air temperature and (*b*) the entropy generated per kilogram of airflow.
Assume that for air: R = 0.2870 kJ/kgK, c_p = 1.005 kJ/kgK, c_v = 0.718 kJ/kgK.

5) Steam enters an adiabatic turbine steadily at 3.5 MPa, 500°C, and 45 m/s, and leaves at 100 kPa and 75 m/s. If the measured power output of the turbine is 5 MW and the isentropic efficiency is 77%, determine the mass flow rate of steam.

Ideal gas equation

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

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

Boundary Work

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

Flow work per unit mass of fluid

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

First law $Q + W = \Delta E$

Enthalpy $h = u + Pv$

Specific heats

$c_v(T) \equiv \left(\frac{\partial u}{\partial T}\right)_v$ 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 $\gamma = \frac{c_p}{c_v} = \frac{\overline{c}_p}{\overline{c}_v}$

For a liquid or solid

$\Delta h = h_2 - h_1 = c(T_2 - T_1) + v(P_2 - P_1)$

For a control volume

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

Second Law

$dS_{\text{isolated}} > 0$ not in equilibrium

$dS_{\text{isolated}} = 0$ at equilibrium

$$T \equiv \left(\frac{\partial U}{\partial S}\right)_{m,V}$$

$$\frac{P}{T} \equiv \left(\frac{\partial S}{\partial V}\right)_{m,U}$$

Gibbs equation

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

Entropy change

$$dS = \left(\frac{\delta Q_{rev}}{T}\right)$$

$$\Delta S = S_2 - S_1 = \int_1^2 \left(\frac{\delta Q_{irr}}{T}\right) + S_{gen}$$

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

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

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

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

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

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

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

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

$$h = h_f + x(h_g - h_f) = h_f + xh_{fg}$$

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