*6 October 2022*

# CHE 260 – Thermodynamics and Heat Transfer

## Quiz 1 – 2022

*You have 60 minutes to do the following three problems. You may use the aid sheet provided and any type of non-communicating calculator.*

1) A piston/cylinder assembly has 0.5 kg of air initially at 2000 kPa, 1000 K as shown in Fig. 1. The external pressure ($P_0$) and the mass of the piston ($m_P$) are constant. When the piston rests on the stops the volume in the cylinder $V_{min}$ = 0.03 m$^3$. The air now cools to 400 K by heat transfer to the surroundings. Find the final volume and pressure of the air (does it hit the stops?) and the work and heat transfer in the process. Show the process on a *P*-*V* diagram.

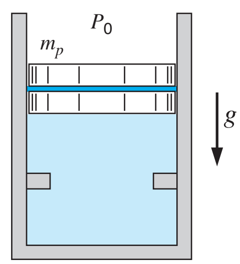


Figure 1 (35 Marks)

2) A piston-cylinder assembly contains 0.2 L of air at 90 kPa and 20°C as shown in Fig. 2. The air is compressed in a quasi-equilibrium polytropic process in which $Pv^{1.25}$=constant to a final volume that is 1/6 of the initial volume. Determine the final temperature and pressure and the work done and heat transferred during this process.

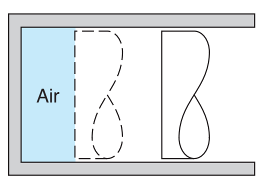


Figure 2 (30 Marks)

3) Two steady flows of air enter a control volume, as shown in Fig. 3. One is a 0.025 kg/s flow at 350 kPa, 150°C, state 1, and the other enters at 450 kPa, 15°C, state 2. A single flow exits at 100 kPa, −40°C, state 3. The control volume rejects 1 kW heat to the surroundings and produces 4 kW of power output. Neglect kinetic and potential energy changes and determine the mass flow rate at state 2.

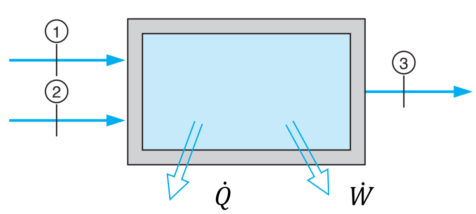


Figure 3 (35 Marks)

**Ideal gas equation**

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

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

**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**

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

**Spring Work**

$$W_{\text{spring}} = \int_{x_1}^{x_2} F dx = \int_{x_1}^{x_2} Kx dx = \frac{1}{2}K(x_2^2 - x_1^2)$$

**First law** $Q + W = \Delta E$

**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 liquid or solid**

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

**For a control volume**

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

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

| | Air | | |
|---|---|---|---|
| Temp (K) | $c_p$ (kJ/kgK) | $c_v$ (kJ/kgK) | $\gamma = c_p/c_v$ |
| 250 | 1.003 | 0.716 | 1.401 |
| 300 | 1.005 | 0.718 | 1.400 |
| 350 | 1.008 | 0.721 | 1.398 |
| 400 | 1.013 | 0.726 | 1.395 |
| 450 | 1.020 | 0.733 | 1.391 |
| 500 | 1.029 | 0.742 | 1.387 |
| 550 | 1.040 | 0.753 | 1.381 |
| 600 | 1.051 | 0.764 | 1.376 |
| 650 | 1.063 | 0.776 | 1.370 |
| 700 | 1.075 | 0.788 | 1.364 |
| 750 | 1.087 | 0.800 | 1.359 |
| 800 | 1.099 | 0.812 | 1.354 |
| 900 | 1.121 | 0.834 | 1.344 |
| 1000 | 1.142 | 0.855 | 1.336 |

| Gas | $R$ (kJ/kgK) | $c_p$ (kJ/kg K) | $c_v$ (kJ/kg K) |
|---|---|---|---|
| He | 2.07703 | 5.1926 | 3.1156 |
| Ar | 0.20813 | 0.5203 | 0.3122 |
| $H_2$ | 4.12418 | 14.2091 | 10.0849 |
| CO | 0.29683 | 1.0413 | 0.7445 |
| $N_2$ | 0.29680 | 1.0416 | 0.7448 |
| $O_2$ | 0.25983 | 0.9216 | 0.6618 |
| $H_2O$ | 0.46152 | 1.8723 | 1.4108 |
| $CO_2$ | 0.18892 | 0.8418 | 0.6529 |
| $NH_3$ | 0.48819 | 2.1300 | 1.6418 |
| Air | 0.2870 | 1.0035 | 0.7165 |