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MM 209: THERMODYNAMICS : 2017-18: FALL

Tutorial 2 **Date:5/08/2017**

1. Ten litres of a monoatomic perfect gas at 25 ^{o}C and 10 atm pressure are expanded to a final pressure of 1 atm. The molar heat capacity of the gas at constant volume, C_V, is 3/2 R and is independent of temperature. Calculate the word one, the heat absorbed, and the change in U in H for the gas if the process is carried out (1) isothermally and reversible, and (2) adiabatically and reversible.

(a) The isothermal reversible expansion. The state of the gas moves from *a* to *b* along the 298 degrees isotherm. As, along any isotherm, the product *PV* is constant,

$$V_b = \frac{P_a V_a}{P_b} = \frac{10 \times 10}{1} = 100 \text{ liters}$$

For an ideal gas undergoing an isothermal process, ΔU=0 and hence, from the First Law,

$$q = w = \int_a^b PdV = nRT\int_a^b \frac{dV}{V} = 4.09 \times 8.3144 \times 298 \times \ln \frac{100}{10} \text{ joules}$$
$$= 23.3 \text{ kilojoules}$$

Thus in passing from the state *a* to the state *b* along the 298 degree isotherm, the system performs 23.3 kilojoules of work and absorbs 23.3 kilojoules of heat from the constant-temperature surroundings.

As, for an ideal gas, H is a function only of temperature, then $\Delta H_{(a\to b)}=0$; that is,

$$\Delta H_{(a\to b)} = \Delta U_{(a\to b)} + (P_b V_b - P_a V_a) = (P_b V_b - P_a V_a)$$
$$= nRT_b - nRT_a = nR(T_b - T_a) = 0$$

(b) The reversible adiabatic expansion. If the adiabatic expansion is carried out reversibly, then during the process the state of the system is, at all time, given by PV^{γ}=constant, and the final state is the point c in the diagram. The volume V_C is obtained from $P_a V_a^{\gamma} = P_c V_c^{\gamma}$ as

$$V_c = \left(\frac{10 \times 10^{5/3}}{1}\right)^{3/5} = 39.8 \text{ liters}$$

and

$$T_c = \frac{P_c V_c}{nR} = \frac{1 \times 39.8}{4.09 \times 0.08206} = 119 \text{ degrees}$$

The point c thus lies on the 119 degree isotherm. As the process is adiabatic, q=0 and hence

$$\Delta U_{(a\to c)} = -w = \int_a^c nc_v dT = nc_v(T_c - T_a)$$
$$= 4.09 \times 1.5 \times 8.3144 \times (119 - 298) \text{ joules}$$
$$= -9.13 \text{ kilojoules}$$

The work done by the system as a result of the process equals the decrease in the internal energy of the system=9.13 kilojoules.

2. Given that μ=1.11K/atm for CO_2, calculate the value of its isothermal Joule Thomson coefficient. The specific heat of CO2 is 37.11J/K . mol. Calculate the energy that must be supplied as heat to maintain constant temperature when 12 moles of CO2 flows through a throttle in an isothermal Joule-Thomson experiment and the pressure drop is 55 atm.

The isothermal Joule–Thomson coefficient is

$$\left(\frac{\partial H_m}{\partial p}\right)_T = -\mu C_{p,m} = -(1.11 \text{ K atm}^{-1}) \times (37.11 \text{ J K}^{-1}\text{mol}^{-1}) = \boxed{-41.2 \text{ J atm}^{-1}\text{mol}^{-1}}$$

If this coefficient is constant in an isothermal Joule–Thomson experiment, then the heat that must be supplied to maintain constant temperature is ΔH in the following relationship

$$\frac{\Delta H/n}{\Delta p} = -41.2 \text{ J atm}^{-1}\text{mol}^{-1} \quad \text{so} \quad \Delta H = -(41.2 \text{ J atm}^{-1}\text{mol}^{-1})n\Delta p$$

$$\Delta H = -(41.2 \text{ J atm}^{-1}\text{mol}^{-1}) \times (12.0 \text{ mol}) \times (-55 \text{ atm}) = \boxed{27.\bar{2} \times 10^3 \text{ J}}$$

3. During steady state operation, a gearbox receives 60kW through the input shaft and delivers the power through the output shaft. For the geatbox as the system, the rate of energy transfer by convection is

$$dQ = -hA(T_b - T_f)$$

where h = 0.171 kW/m^2. K is the heat transfer coefficient, A = 1.0 m^2 is the outer surface area of the gearbox, T_b = 300 K (27 ^oC) is the temperature at the outer surface, and T_f = 293 K (20 ^oC) is the temperature of the surrounding air away from the immediate vicinity of the gearbox. For the geatbox, evaluate the heat transfer rate and the power delivered through the output shaft, each in kW.

Analysis: Using the given expression for $\dot{Q}$ together with known data, the rate of energy transfer by heat is

1
$$\begin{aligned}\dot{Q} &= -\text{hA}(T_b - T_f)\\ &= -\left(0.171\frac{\text{kW}}{\text{m}^2\cdot\text{K}}\right)(1.0\ \text{m}^2)(300 - 293)\ \text{K}\\ &= -1.2\ \text{kW}\end{aligned}$$

The minus sign for $\dot{Q}$ signals that energy is carried *out* of the gearbox by heat transfer.

The energy rate balance, Eq. 2.37, reduces at steady state to

2
$$\cancel{\frac{dE}{dt}}^{0} = \dot{Q} - \dot{W} \qquad \text{or} \qquad \dot{W} = \dot{Q}$$

The symbol $\dot{W}$ represents the *net* power from the system. The net power is the sum of $\dot{W}_1$ and the output power $\dot{W}_2$

$$\dot{W} = \dot{W}_1 + \dot{W}_2$$

With this expression for $\dot{W}$, the energy rate balance becomes

$$\dot{W}_1 + \dot{W}_2 = \dot{Q}$$

Solving for $\dot{W}_2$, inserting $\dot{Q} = -1.2$ kW, and $\dot{W}_1 = -60$ kW, where the minus sign is required because the inpu shaft brings energy *into* the system, we have

3
$$\begin{aligned}\dot{W}_2 &= \dot{Q} - \dot{W}_1\\ &= (-1.2\ \text{kW}) - (-60\ \text{kW})\\ &= +58.8\ \text{kW}\end{aligned}$$

4 The positive sign for $\dot{W}_2$ indicates that energy is transferred from the system through the output shaft, a expected.