Answer Key

Problem Set

1 to 4

$P_1 = 100\ kPa$ $\quad P = C$

$T_1 = 300\ k$ $\quad T_2 = 620\ k$

a) Work

$$W_{NF} = mR(T_2 - T_1)$$

$$\frac{W_{NF}}{m} = (0.287\ kJ/kg\text{-}k)(620 - 300)k$$

$$\frac{W_{NF}}{m} = 91.84\ kJ/kg$$

b) Heat required

$$Q = mC_p \Delta T$$

$$\frac{Q}{m} = (1.0062\ kJ/kg\text{-}k)(620 - 300)k$$

$$\frac{Q}{m} = 321.984\ kJ/kg$$

c) $\Delta U = mC_v \Delta T$

$$\frac{\Delta U}{m} = (0.7186\ kJ/kg\text{-}k)(620 - 300)k$$

$$\frac{\Delta U}{m} = 229.952\ kJ/kg$$

d) $\Delta S = mC_p \ln \frac{T_2}{T_1}$

$$\frac{\Delta S}{m} = (1.0062\ kJ/kg\text{-}k) \ln \left(\frac{620\ k}{300\ k}\right)$$

$$\frac{\Delta S}{m} = 0.7304\ kJ/kg\text{-}k$$

5 to 8

$V_1 = 1500\ L = 1.5\ m^3$

$P_1 = 450\ kPa$ $\quad P = C$

$t_1 = 320°C$ $\quad t_2 = 530°C$

Ref. $R = 0.280\ kJ/kg\text{-}K$

$C_p = 1.0\ kJ/kg\text{-}K$

a) $P_1V_1 = mRT_1$

$(450\ kPa)(1.5\ m^3) = m(0.280\ kJ/kg\text{-}K)(320+273)K$

$m = 3.9661\ kg$

b) $\frac{V_1}{V_2} = \frac{T_1}{T_2}$

$\frac{1.5\ m^3}{V_2} = \frac{593\ K}{803\ K}$

$V_2 = 2.0312\ m^3$

c) $\Delta U = mC_v(T_2 - T_1)$

$R = C_p - C_v$

$0.280\ kJ/kg\text{-}K = 1.0\ kJ/kg\text{-}K - C_v$

$C_v = 0.720\ kJ/kg\text{-}K$

$\Delta U = (3.9661\ kg)(0.720\ kJ/kg\text{-}K)(803 - 593)K$

$\Delta U = 599.6743\ kJ$

$\Delta H = mC_p(T_2 - T_1)$

$= (3.9661\ kg)(1.0062\ kJ/kg\text{-}K)(803 - 593)K$

$\Delta H = 838.0449\ kJ$

d) $W_{NF} = mR(T_2 - T_1)$

$= (3.9661\ kg)(0.280\ kJ/kg\text{-}K)(803 - 593)K$

$W_{NF} = 233.2067\ kJ$

9 to 11

Nitrogen

$P_1 = P_2 = 1.2\ kPa$ $\quad P = C$

$\bar{v}_1 = 1.80\ m^3/kg$ $\quad \bar{v}_2 = 0.76\ m^3/kg$

$m = 2.20\ kgs$

a) $W_{NF} = P(V_2 - V_1)$; $\bar{v} = \frac{V}{m}$

$V = \bar{v} m$

$= mP(\bar{v}_2 - \bar{v}_1)$

$= (2.20\ kg)\left(1.20\ \frac{kN}{m^2}\right)(0.76 - 1.80)\ m^3/kg$

$W_{NF} = -2.7456\ kJ$

b) $\Delta S = mC_p \ln \frac{V_2}{V_1}$

$= (2.20\ kg)\left(1.0399\ \frac{kJ}{kg\text{-}k}\right) \ln \left(\frac{0.76\ m^3/kg}{1.80\ m^3/kg}\right)$

$\Delta S = -1.9726\ kJ/k$

c) $\Delta H = mC_p(T_2 - T_1)$

$W_{NF} = mR(T_2 - T_1)$

$(T_2 - T_1) = \frac{W_{NF}}{mR}$

$\Delta H = mC_p\left(\frac{W_{NF}}{mR}\right) = \left(1.0399\ \frac{kJ}{kg\text{-}k}\right)\left(\frac{-2.7456\ kJ}{0.2968\ \frac{kJ}{kg\text{-}k}}\right)$

$\Delta H = -9.6198\ kJ$

$\Delta U = mC_v(T_2 - T_1) = mC_v\left(\frac{W_{NF}}{mR}\right) = \left(0.7431\ \frac{kJ}{kg\text{-}k}\right)\left(\frac{-2.7456\ kJ}{0.2968\ \frac{kJ}{kg\text{-}k}}\right)$

$\Delta U = -6.8742\ kJ$

12 to 13

$Q = 1200 \text{ kJ/kg}$ $V = C$

$T_2 = 650 \text{ k}$

a) $Q = m C_v (T_2 - T_1)$

$1200 \text{ kJ/kg} = (5 \text{ kg})(0.7186 \text{ kJ/kg-k})(650 - T_1)\text{k}$

$T_1 = 316.0173 \text{ k}$

b) $\frac{P_1}{P_2} = \frac{T_1}{T_2}$

$\frac{300 \text{ kPa}}{P_2} = \frac{316.0173 \text{ k}}{650 \text{ k}}$

$P_2 = 617.0549 \text{ kPa}$

Nitrogen

$t_1 = 85°F$

$t_2 = 300°F$

$m = 0.12\ lbm$

a) $Q = m C_v (T_2 - T_1)$

$C_v = \left(0.7431\ \frac{kJ}{kg\text{-}K}\right)$

$= (0.12\ lbm)\left(0.1775\ \frac{Btu}{lbm\text{-}°R}\right)(300 - 85)°R$

$Q = 4.5795\ Btu$

$M = 32\ kg/kgmol$

$V = 2$

$t_1 = 220°C$

$t_2 = 800°C$

$\Delta u = 170\ kJ/kg$

$\Delta H = mC_p(T_2 - T_1)$

$R = \frac{\bar{R}}{M} = \frac{8.314\ kJ/kg\text{-}K}{32\ kg/kgmol} = 0.2598\ kJ/kg\text{-}K$

$R = C_p - C_v$

$\Delta u = mC_v(T_2 - T_1)$

$170\ kJ/kg = C_v(800 - 220)\ K$

$C_v = 0.2931\ kJ/kg\text{-}K$

$0.2898\ kJ/kg\text{-}K = C_p - 0.2931\ kJ/kg\text{-}K$

$C_p = 0.5529\ kJ/kg\text{-}K$

$\frac{\Delta H}{m} = (0.5529\ kJ/kg\text{-}K)(800 - 220)K$

$\boxed{\frac{\Delta H}{m} = 320.682\ kJ/kg}$

$\frac{\Delta S}{m} = mC_v \ln\left(\frac{T_2}{T_1}\right)$

$\frac{\Delta S}{m} = (0.2931\ kJ/kg\text{-}K)\ln\left(\frac{800°K}{220°K}\right)$

$\boxed{\frac{\Delta S}{m} = 0.3784\ kJ/kg\text{-}K}$

$T_1 = 300\ K$

$P_1 = 100\ kPa \quad T = ?C \quad P_2 = 400\ kPa$

$m = 2\ kg$

$$W_{out} = m R T_1 \ln\left(\frac{P_1}{P_2}\right)$$

$$= (2\ kg)\left(0.287\ \frac{kJ}{kg\text{-}K}\right)(300\ K)\ln\left(\frac{100\ kPa}{400\ kPa}\right)$$

$$W_{out} = -238.7199\ kJ$$

17 to 19

$T_1 = 320\ k$

$P_1 = 520\ kPa$ $\quad T = C \quad$ $P_2 = 100\ kPa$

$V_1 = 0.010\ m^3$

$$P_1 V_1 = m R T_1$$

$$(520\ kPa)(0.010\ m^3) = m\left(0.287\ \frac{kJ}{kg \cdot K}\right)(320\ K)$$

$$m = 0.05662\ kg$$

$$\frac{P_1}{P_2} = \frac{V_2}{V_1}$$

$$\frac{520\ kPa}{100\ kPa} = \frac{V_2}{0.010\ m^3}$$

$$V_2 = 0.052\ m^3$$

$$V_2 = 52\ L$$

$$W_{out} = P_1 V_1 \ln \frac{V_2}{V_1} = (520\ kPa)(0.010\ m^3) \ln\left(\frac{52\ L}{10\ L}\right)$$

$$W_{out} = 8.5730\ kJ$$

$Q = 10\ kJ$

$m = 0.5\ kg$ of nitrogen

$P_1 = 440\ kPa$

$T_1 = T_2 = 400\ K$

$$Q = W_{NF} = mRT_1 \ln \frac{P_1}{P_2}$$

$$10\ kJ = (0.5\ kg)\left(0.2968\ \frac{kJ}{kg\text{-}K}\right)(400\ K) \ln \frac{P_1}{P_2}$$

$$\ln \frac{P_1}{P_2} = 0.16846$$

$$\frac{440\ kPa}{P_2} = e^{0.16846}$$

$$P_2 = 371.7833\ kPa$$

21 to 22

$P_1 = 920\ kPa$

$T_1 = 800\ K \quad (S=C)$

$V_1 = 0.13\ m^3$

$W_{NF} = 130\ kJ$

$P_1 V_1 = mRT_1$

$(920\ kPa)(0.13\ m^3) = m(0.287\ kJ/kg\text{-}K)(800)\ K$

$m = 0.5209\ kg$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$W_{NF} = \frac{mR(T_2 - T_1)}{1-k}$$

$$130\ kJ = \frac{(0.5209\ kg)(0.287\ kJ/kg\text{-}K)(T_2 - 800\ K)}{1-1.4}$$

$T_2 = 452.1699\ K$

$$\frac{452.1699\ K}{800\ K} = \left(\frac{P_2}{920\ kPa}\right)^{\frac{1.4-1}{1.4}}$$

$P_2 = 124.8903\ kPa$

$P_1 = 100\ kPa$ (S=C) $P_2 = 560\ kPa$ Helium

$V_1 = 0.24\ m^3$

$$W_{NF} = \frac{(P_2V_2 - P_1V_1)}{1-k}$$

$$\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = \left(\frac{V_1}{V_2}\right)^{k-1}$$

$$\left(\frac{560\ kPa}{100\ kPa}\right)^{\frac{1}{1.666}} = \frac{0.24 m^3}{V_2}$$

$$V_2 = 0.08533\ m^3$$

$$W_{NF} = \frac{(560\ kPa)(0.08533\ m^3) - (100\ kPa)(0.24\ m^3)}{1-1.666}$$

$$W_{NF} = -35.7129\ kJ$$

$m = 1\ kg$ ethane C_2H_6

$t_1 = 1100°C$

$t_2 = 38°C$

$$W_{NF} = \frac{mR(T_2 - T_1)}{1 - k} =$$

$$W_{NF} = \frac{(1\ kg)(0.2765\ kJ/kg\text{-}K)(38 - 1100)K}{1 - 1.187}$$

$$W_{NF} = 1570.2034\ kJ$$

25 to 26

$Q = 300\ kJ \quad (PV^n = c)$

$n = 1.2$

$\Delta H = mC_p \Delta T$

$Q = mC_n \Delta T$

$m\Delta T = \frac{Q}{C_n}$; $C_n = C_v\left(\frac{k-n}{1-n}\right)$

$= (0.7186\ kJ/kg\text{-}k)\left[\frac{1.4-1.2}{1-1.2}\right]$

$C_n = -0.7186\ kJ/kg\text{-}k$

$\Delta H = \frac{Q}{C_n} C_p = \frac{(300\ kJ)(1.0062\ kJ/kg\text{-}k)}{(-0.7186\ kJ/kg\text{-}k)}$

$\Delta H = -420.0668\ kJ$

$\Delta U = mC_v \Delta T$

$\Delta U = \frac{Q C_v}{C_n} = \frac{(300\ kJ)(0.7186\ kJ/kg\text{-}k)}{(-0.7186\ kJ/kg\text{-}k)}$

$\Delta U = -300\ kJ$

$W_{NF} = \frac{mR\Delta T}{1-n}$

$= \frac{RQ}{C_n(1-n)} = \frac{(0.287\ kJ/kg\text{-}k)(300\ kJ)}{(-0.7186\ kJ/kg\text{-}k)(1-1.2)}$

$W_{NF} = 599.0815\ kJ$

27 to 28

$P_1 = 900\ kPa$
$T_1 = 1500\ K$
$v_1 = 98\ m/s$

$PV^{1.3} = C$

$P_2 = 180\ kPa$
$T_2 = ?$
$v_2 = 175\ m/s$
$W_{SF} = 45000\ kW$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\frac{T_2}{1500\ K} = \left(\frac{180\ kPa}{900\ kPa}\right)^{\frac{0.3}{1.3}}$$

$$T_2 = 1034.64\ K$$

From: $Q = W_{SF} + \Delta H + \Delta KE$

for mass flow rate of nitrogen

$$W_{SF} = n\left[\frac{mR(T_2 - T_1)}{1-n}\right]$$

$$4500\ \frac{kJ}{s} = 1.3\left[\frac{\dot{m}\left(0.2968\ \frac{kJ}{kg\cdot K}\right)(1034.64 - 1500)K}{1 - 1.399}\right]$$

$$\dot{m} = 75.1861\ kg/s$$

$$\Delta H = \dot{m} C_p (T_2 - T_1)$$

$$= \left(75.1861\ \frac{kg}{s}\right)\left(1.0799\ \frac{kJ}{kg\cdot K}\right)(1034.64 - 1500)K$$

$$\Delta H = -36384.64\ kJ/s$$

$$\Delta KE = \frac{1}{2}\frac{m}{g_c}\left(v_2^2 - v_1^2\right)$$

$$\Delta KE = \frac{1}{2}\frac{(75.1861\ kg/s)}{\left(1\ \frac{kg\cdot m}{N\cdot s^2}\right)}\left(175^2 - 98^2\right)m^2/s^2$$

$$\Delta KE = 790.24\ kJ/s$$

$$Q = [45000 + (-36384.64) + 790.24]\ kJ/s$$

$$Q = 9405.6\ kJ/s$$

29 to 31

$P_1 = 3800\ kPa$ $\quad PV^{1.3} = C$ $\quad P_2 = 120\ kPa$

$V_1 = 0.75\ m^3$

$$W_{NF} = \frac{P_2V_2 - P_1V_1}{1-n}$$

$$\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} = \frac{V_1}{V_2}$$

$$\left(\frac{120\ kPa}{3800\ kPa}\right)^{1/1.3} = \frac{0.75\ m^3}{V_2}$$

$$V_2 = 10.6997\ m^3$$

$$W_{NF} = \frac{(120\ kPa)(10.6997\ m^3) - (3800\ kPa)(0.75\ m^3)}{1-1.3}$$

$$W_{NF} = 5220.12\ kJ$$

$$Q = mC_n(T_2 - T_1)$$

$$W_{NF} = \frac{mR(T_2 - T_1)}{1-n}$$

$$m(T_2 - T_1) = \frac{(1-n)W_{NF}}{R}$$

$$Q = \frac{C_n(1-n)W_{NF}}{R}$$

$$= \frac{(-3.8042\ kJ/kg\text{-}K)(1-1.3)(5220.12\ kJ)}{(2.077\ kJ/kg\text{-}K)}$$

$$Q = 2868.3265\ kJ$$

$$C_n = C_v\left[\frac{k-n}{1-n}\right]$$

$$= 3.1182\ kJ/kg\text{-}K\left[\frac{1.666 - 1.3}{1-1.3}\right]$$

$$C_n = -3.8042\ kJ/kg\text{-}K$$

$$\Delta S = mC_n \ln\left[\frac{P_2}{P_1}\right]^{\frac{n-1}{n}}$$

$$\frac{\Delta S}{m} = (-3.8042\ kJ/kg\text{-}K)\ln\left[\frac{120\ kPa}{3800\ kPa}\right]^{\frac{1.3-1}{1.3}}$$

$$\boxed{\frac{\Delta S}{m} = 3.0334\ kJ/kg\text{-}K}$$