Chapter 2 - Section A - Mathcad Solutions

2.1 (a) $M_{wt} := 35 \cdot kg$ $g := 9.8 \cdot \frac{m}{s^2}$ $\Delta z := 5 \cdot m$

$Work := M_{wt} \cdot g \cdot \Delta z$ $Work = 1.715\,kJ$ **Ans.**

(b) $\Delta U_{total} := Work$ $\Delta U_{total} = 1.715\,kJ$ **Ans.**

(c) By Eqs. (2.14) and (2.21): $dU + d(PV) = C_P \cdot dT$

Since P is constant, this can be written:

$$M_{H2O} \cdot C_P \cdot dT = M_{H2O} \cdot dU + M_{H2O} \cdot P \cdot dV$$

Take Cp and V constant and integrate: $M_{H2O} \cdot C_P \cdot (t_2 - t_1) = U_{total}$

$t_1 := 20 \cdot degC$ $C_P := 4.18 \cdot \frac{kJ}{kg \cdot degC}$ $M_{H2O} := 30 \cdot kg$

$t_2 := t_1 + \frac{\Delta U_{total}}{M_{H2O} \cdot C_P}$ $t_2 = 20.014\,degC$ **Ans.**

(d) For the restoration process, the change in internal energy is equal but of opposite sign to that of the initial process. Thus

$Q := -\Delta U_{total}$ $Q = -1.715\,kJ$ **Ans.**

(e) In all cases the total internal energy change of the universe is zero.

2.2 Similar to Pb. 2.1 with mass of water = 30 kg.

Answers are:

(a) W = 1.715 kJ

(b) Internal energy change of the water = 1.429 kJ

(c) Final temp. = 20.014 deg C

(d) Q = -1.715 kJ

2.4 **The electric power supplied to the motor must equal the work done by the motor plus the heat generated by the motor.**

$i := 9.7\text{amp}$ $\quad$ $E := 110\text{V}$ $\quad$ $Wdot_{mech} := 1.25\text{hp}$

$Wdot_{elect} := i \cdot E$ $\quad$ $Wdot_{elect} = 1.067 \times 10^3\,\text{W}$

$Qdot := Wdot_{elect} - Wdot_{mech}$ $\quad$ $Qdot = 134.875\,\text{W}$ **Ans.**

2.5 **Eq. (2.3):** $\Delta U^t = Q + W$

Step 1 to 2: $\Delta Ut_{12} := -200\text{J}$ $\quad$ $W_{12} := -6000\text{J}$

$Q_{12} := \Delta Ut_{12} - W_{12}$ $\quad$ $Q_{12} = 5.8 \times 10^3\,\text{J}$ **Ans.**

Step 3 to 4: $Q_{34} := -800\text{J}$ $\quad$ $W_{34} := 300\text{J}$

$\Delta Ut_{34} := Q_{34} + W_{34}$ $\quad$ $\Delta Ut_{34} = -500\,\text{J}$ **Ans.**

Step 1 to 2 to 3 to 4 to 1: Since ΔU^t **is a state function,** ΔU^t **for a series of steps that leads back to the initial state must be zero. Therefore, the sum of the** ΔU^t **values for all of the steps must sum to zero.**

$\Delta Ut_{41} := 4700\text{J}$ $\quad$ $\Delta Ut_{23} := -\Delta Ut_{12} - \Delta Ut_{34} - \quad Ut_{41}$

$\Delta Ut_{23} = -4000\,\text{J}$ **Ans.**

Step 2 to 3: $\Delta Ut_{23} = -4 \times 10^3\,\text{J}$ $\quad$ $Q_{23} := -3800\text{J}$

$W_{23} := \Delta Ut_{23} - Q_{23}$ $\quad$ $W_{23} = -200\,\text{J}$ **Ans.**

For a series of steps, the total work done is the sum of the work done for each step.

$W_{12341} := -1400\text{J}$

$W_{41} := W_{12341} - W_{12} - W_{23} - W_{34}$ $\quad W_{41} = 4.5 \times 10^3\,J$ **Ans.**

Step 4 to 1: $\Delta Ut_{41} := 4700J$ $\quad W_{41} = 4.5 \times 10^3\,J$

$Q_{41} := \Delta Ut_{41} - W_{41}$ $\quad Q_{41} = 200\,J$ **Ans.**

Note: $Q_{12341} = -W_{12341}$

2.11 The enthalpy change of the water = work done.

$M := 20 \cdot kg$ $\quad C_P := 4.18 \cdot \frac{kJ}{kg \cdot degC}$ $\quad \Delta t := 10 \cdot degC$

$Wdot := 0.25 \cdot kW$ $\quad \Delta\tau := \frac{M \cdot C_P \cdot \Delta t}{Wdot}$ $\quad \Delta\tau = 0.929\,hr$ **Ans.**

2.12 $Q := 7.5 \cdot kJ$ $\quad \Delta U := -12 \cdot kJ$ $\quad W := \Delta U - Q$

$W = -19.5\,kJ$ **Ans.**

$\Delta U := -12 \cdot kJ$ $\quad Q := \Delta U$ $\quad Q = -12\,kJ$ **Ans.**

2.13 Subscripts: c, casting; w, water; t, tank. Then

$m_c \cdot \Delta U_c + m_w \cdot \Delta U_w + m_t \cdot \Delta U_t = 0$

Let C represent specific heat, $\quad C = C_P = C_V$

Then by Eq. (2.18)

$m_c \cdot C_c \cdot \Delta t_c + m_w \cdot C_w \cdot \Delta t_w + m_t \cdot C_t \cdot \Delta t_t = 0$

$m_c := 2 \cdot kg$ $\quad m_w := 40 \cdot kg$ $\quad m_t := 5 \cdot kg$

$C_c := 0.50 \cdot \frac{kJ}{kg \cdot degC}$ $\quad C_t := 0.5 \cdot \frac{kJ}{kg \cdot degC}$ $\quad C_w := 4.18 \cdot \frac{kJ}{kg \cdot degC}$

$t_c := 500 \cdot degC$ $\quad t_1 := 25 \cdot degC$ $\quad t_2 := 30 \cdot degC$ **(guess)**

Given $\quad -m_c \cdot C_c \cdot (t_2 - t_c) = (m_w \cdot C_w + m_t \cdot C_t) \cdot (t_2 - t_1)$

$t_2 := Find(t_2)$ $\quad t_2 = 27.78\,degC$ **Ans.**

2.15 $mass := 1 \cdot kg$ $C_V := 4.18 \frac{kJ}{kg \cdot K}$

(a) $\Delta T := 1K$ $\Delta Ut := mass \cdot C_V \cdot \Delta T$ $\Delta Ut = 4.18\,kJ$ **Ans.**

(b) $g := 9.8 \frac{m}{s^2}$ $\Delta E_P := \Delta Ut$

$\Delta z := \frac{\Delta E_P}{mass \cdot g}$ $\Delta z = 426.531\,m$ **Ans.**

(c) $\Delta E_K := \Delta Ut$ $u := \sqrt{\frac{\Delta E_K}{\frac{1}{2} \cdot mass}}$ $u = 91.433 \frac{m}{s}$ **Ans.**

2.17 $\Delta z := 50m$ $\rho := 1000 \frac{kg}{m^3}$ $u := 5 \frac{m}{s}$

$D := 2m$ $A := \frac{\pi}{4} D^2$ $A = 3.142\,m^2$

$mdot := \rho \cdot u \cdot A$ $mdot = 1.571 \times 10^4 \frac{kg}{s}$

$Wdot := mdot \cdot g \cdot \Delta z$ $Wdot = 7.697 \times 10^3\,kW$ **Ans.**

2.18 (a) $U_1 := 762.0 \cdot \frac{kJ}{kg}$ $P_1 := 1002.7 \cdot kPa$ $V_1 := 1.128 \cdot \frac{cm^3}{gm}$

$H_1 := U_1 + P_1 \cdot V_1$ $H_1 = 763.131 \frac{kJ}{kg}$ **Ans.**

(b) $U_2 := 2784.4 \cdot \frac{kJ}{kg}$ $P_2 := 1500 \cdot kPa$ $V_2 := 169.7 \cdot \frac{cm^3}{gm}$

$H_2 := U_2 + P_2 \cdot V_2$ $\Delta U := U_2 - U_1$ $\Delta H := H_2 - H_1$

$\Delta U = 2022.4 \frac{kJ}{kg}$ **Ans.** $\Delta H = 2275.8 \frac{kJ}{kg}$ **Ans.**

2.22 $D_1 := 2.5cm$ $u_1 := 2\frac{m}{s}$ $D_2 := 5cm$

(a) **For an incompressible fluid, ρ=constant. By a mass balance, mdot = constant = $u_1A_1\rho = u_2A_2\rho$.**

$u_2 := u_1 \cdot \left(\frac{D_1}{D_2}\right)^2$ $u_2 = 0.5\frac{m}{s}$ **Ans.**

(b) $\Delta E_K := \frac{1}{2}u_2^{\ 2} - \frac{1}{2}u_1^{\ 2}$ $\Delta E_K = -1.875\frac{J}{kg}$ **Ans.**

2.23 **Energy balance:** $mdot_3 \cdot H_3 - (mdot_1 \cdot H_1 + mdot_2 \cdot H_2) = Qdot$

Mass balance: $mdot_3 - mdot_1 - mdot_2 = 0$

Therefore: $mdot_1 \cdot (H_3 - H_1) + mdot_2 \cdot (H_3 - H_2) = Qdot$

or $mdot \cdot C_p \cdot (T_3 - T_1) + mdot_2 \cdot C_P \cdot (T_3 - T_2) = Qdot$

$$T_3 \cdot C_P \cdot (mdot_1 + mdot_2) = Qdot + mdot_1 \cdot C_P \cdot T_1 + mdot_2 \cdot C_P \cdot T_2$$

$mdot_1 := 1.0\frac{kg}{s}$ $T_1 := 25degC$ $mdot_2 := 0.8\frac{kg}{s}$ $T_2 := 75degC$

$Qdot := -30\frac{kJ}{s}$ $C_P := 4.18\frac{kJ}{kg \cdot K}$

$T_3 := \frac{Qdot + mdot_1 \cdot C_P \cdot T_1 + mdot_2 \cdot C_P \cdot T_2}{(mdot_1 + mdot_2) \cdot C_P}$ $T_3 = 43.235\,degC$ **Ans.**

2.25 By Eq. (2.32a): $\Delta H + \frac{\Delta u^2}{2} = 0$ $\Delta H = C_P \cdot \Delta T$

By continuity, incompressibility $u_2 = u_1 \cdot \frac{A_1}{A_2}$ $C_P := 4.18 \cdot \frac{kJ}{kg \cdot degC}$

$$\Delta u^2 = u_1^2\cdot\left[\left(\frac{A_1}{A_2}\right)^2 - 1\right] \qquad \Delta u^2 = u_1^2\cdot\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]$$

SI units: $u_1 := 14\cdot\frac{m}{s}$ $\quad D_1 := 2.5\cdot cm$ $\quad D_2 := 3.8\cdot cm$

$$\Delta T := \frac{u_1^2}{2\cdot C_P}\cdot\left[1 - \left(\frac{D_1}{D_2}\right)^4\right] \qquad \Delta T = 0.019\,degC \qquad \textbf{Ans.}$$

$D_2 := 7.5cm$

$$\Delta T := \frac{u_1^2}{2\cdot C_P}\cdot\left[1 - \left(\frac{D_1}{D_2}\right)^4\right] \qquad \Delta T = 0.023\,degC \qquad \textbf{Ans.}$$

Maximum T change occurrs for infinite D2:

$D_2 := \infty\cdot cm$

$$\Delta T := \frac{u_1^2}{2\cdot C_P}\cdot\left[1 - \left(\frac{D_1}{D_2}\right)^4\right] \qquad \Delta T = 0.023\,degC \qquad \textbf{Ans.}$$

2.26 $T_1 := 300K$ $\quad T_2 := 520K$ $\quad u_1 := 10\frac{m}{s}$ $\quad u_2 := 3.5\frac{m}{s}$ $\quad molwt := 29\frac{kg}{kmol}$

$Wsdot := 98.8kW$ $\quad ndot := 50\frac{kmol}{hr}$ $\quad C_P := \frac{7}{2}\cdot R$

$$\Delta H := C_P\cdot\left(T_2 - T_1\right) \qquad \Delta H = 6.402\times 10^3\,\frac{kJ}{kmol}$$

By Eq. (2.30):

$$Qdot := \left[\Delta H + \left(\frac{u_2^2}{2} - \frac{u_1^2}{2}\right)\cdot molwt\right]\cdot ndot - Wsdot \qquad Qdot = -9.904\,kW \qquad \textbf{Ans.}$$

2.27 By Eq. (2.32b):

$$\Delta H = -\frac{\Delta u^2}{2\cdot g_c} \qquad \textbf{also} \qquad \frac{V_2}{V_1} = \frac{T_2}{T_1}\cdot\frac{P_1}{P_2}$$

By continuity, constant area

$$u_2 = u_1\cdot\frac{V_2}{V_1} \qquad u_2 = u_1\cdot\frac{T_2}{T_1}\cdot\frac{P_1}{P_2} \qquad \Delta u^2 = u_2^2 - u_1^2$$

$$\Delta u^2 = u_1^2 \cdot \left[\left(\frac{T_2}{T_1} \cdot \frac{P_1}{P_2} \right)^2 - 1 \right] \qquad \Delta H = C_P \cdot \Delta T = \frac{7}{2} \cdot R \cdot (T_2 - T_1)$$

$P_1 := 100 \cdot psi$ $\quad P_2 := 20 \cdot psi$ $\quad u_1 := 20 \cdot \frac{ft}{s}$ $\quad T_1 := 579.67 \cdot rankine$

$R = 3.407 \frac{ft \cdot lb_f}{mol \cdot rankine}$ $\quad molwt := 28 \frac{gm}{mol}$

$T_2 := 578 \cdot rankine$ **(guess)**

Given $\quad \frac{7}{2} \cdot R \cdot (T_2 - T_1) = -\frac{u_1^2}{2} \cdot \left[\left(\frac{T_2}{T_1} \cdot \frac{P_1}{P_2} \right)^2 - 1 \right] \cdot molwt$

$T_2 := Find(T_2)$ $\quad T_2 = 578.9\,rankine$ **Ans.**

$(119.15 \cdot degF)$

2.28 $u_1 := 3 \cdot \frac{m}{s}$ $\quad u_2 := 200 \cdot \frac{m}{s}$ $\quad H_1 := 334.9 \cdot \frac{kJ}{kg}$ $\quad H_2 := 2726.5 \cdot \frac{kJ}{kg}$

By Eq. (2.32a): $\quad Q := H_2 - H_1 + \frac{u_2^2 - u_1^2}{2}$ $\quad Q = 2411.6 \frac{kJ}{kg}$ **Ans.**

2.29 $u_1 := 30 \cdot \frac{m}{s}$ $\quad H_1 := 3112.5 \cdot \frac{kJ}{kg}$ $\quad H_2 := 2945.7 \cdot \frac{kJ}{kg}$

$u_2 := 500 \cdot \frac{m}{s}$ **(guess)**

By Eq. (2.32a): Given $\quad H_2 - H_1 = \frac{u_1^2 - u_2^2}{2}$ $\quad u_2 := Find(u_2)$

$u_2 = 578.36 \frac{m}{s}$ **Ans.**

$D_1 := 5 \cdot cm$ $\quad V_1 := 388.61 \cdot \frac{cm^3}{gm}$ $\quad V_2 := 667.75 \cdot \frac{cm^3}{gm}$

Continuity: $D_2 := D_1 \cdot \sqrt{\frac{u_1 \cdot V_2}{u_2 \cdot V_1}}$ $D_2 = 1.493\,\text{cm}$ **Ans.**

2.30 (a) $t_1 := 30 \cdot \text{degC}$ $t_2 := 250 \cdot \text{degC}$ $n := 3 \cdot \text{mol}$

$C_V := 20.8 \cdot \frac{\text{J}}{\text{mol} \cdot \text{degC}}$

By Eq. (2.19): $Q := n \cdot C_V \cdot (t_2 - t_1)$ $Q = 13.728\,\text{kJ}$ **Ans.**

Take into account the heat capacity of the vessel; then

$m_v := 100 \cdot \text{kg}$ $c_v := 0.5 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{degC}}$

$Q := (m_v \cdot c_v + n \cdot C_V) \cdot (t_2 - t_1)$ $Q = 11014\,\text{kJ}$ **Ans.**

(b) $t_1 := 200 \cdot \text{degC}$ $t_2 := 40 \cdot \text{degC}$ $n := 4 \cdot \text{mol}$

$C_P := 29.1 \cdot \frac{\text{joule}}{\text{mol} \cdot \text{degC}}$

By Eq. (2.23): $Q := n \cdot C_P \cdot (t_2 - t_1)$ $Q = -18.62\,\text{kJ}$ **Ans.**

2.31 (a) $t_1 := 70 \cdot \text{degF}$ $t_2 := 350 \cdot \text{degF}$ $n := 3 \cdot \text{mol}$

$C_V := 5 \cdot \frac{\text{BTU}}{\text{mol} \cdot \text{degF}}$ **By Eq. (2.19):**

$Q := n \cdot C_V \cdot (t_2 - t_1)$ $Q = 4200\,\text{BTU}$ **Ans.**

Take account of the heat capacity of the vessel:

$m_v := 200 \cdot \text{lb}_m$ $c_v := 0.12 \cdot \frac{\text{BTU}}{\text{lb}_m \cdot \text{degF}}$

$Q := (m_v \cdot c_v + n \cdot C_V) \cdot (t_2 - t_1)$ $Q = 10920\,\text{BTU}$ **Ans.**

(b) $t_1 := 400 \cdot \text{degF}$ $t_2 := 150 \cdot \text{degF}$ $n := 4 \cdot \text{mol}$

$C_P := 7 \cdot \frac{BTU}{mol \cdot degF}$

By Eq. (2.23):

$Q := n \cdot C_P \cdot (t_2 - t_1)$ $\quad Q = -7000\,BTU$ **Ans.**

2.33 $H_1 := 1322.6 \cdot \frac{BTU}{lb_m}$ $\quad H_2 := 1148.6 \cdot \frac{BTU}{lb_m}$ $\quad u_1 := 10 \cdot \frac{ft}{s}$

$V_1 := 3.058 \cdot \frac{ft^3}{lb_m}$ $\quad V_2 := 78.14 \cdot \frac{ft^3}{lb_m}$ $\quad D_1 := 3 \cdot in$ $\quad D_2 := 10 \cdot in$

$$mdot := \frac{\frac{\pi}{4} \cdot D_1^2 \cdot u_1}{V_1} \qquad mdot = 3.463 \times 10^4 \frac{lb}{sec}$$

$$u_2 := mdot \cdot \frac{V_2}{\frac{\pi}{4} \cdot D_2^2} \qquad u_2 = 22.997 \frac{ft}{sec}$$

Eq. (2.32a): $W_s := H_2 - H_1 + \frac{u_2^2 - u_1^2}{2}$ $\quad W_s = -173.99 \frac{BTU}{lb}$

$Wdot := -W_s \cdot mdot$ $\quad Wdot = 39.52\,hp$ **Ans.**

2.34 $H_1 := 307 \cdot \frac{BTU}{lb_m}$ $\quad H_2 := 330 \cdot \frac{BTU}{lb_m}$ $\quad u_1 := 20 \cdot \frac{ft}{s}$ $\quad molwt := 44 \cdot \frac{gm}{mol}$

$V_1 := 9.25 \cdot \frac{ft^3}{lb_m}$ $\quad V_2 := 0.28 \cdot \frac{ft^3}{lb_m}$ $\quad D_1 := 4 \cdot in$ $\quad D_2 := 1 \cdot in$

$$mdot := \frac{\frac{\pi}{4} \cdot D_1^2 \cdot u_1}{V_1} \qquad mdot = 679.263 \frac{lb}{hr}$$

$$u_2 := mdot \cdot \frac{V_2}{\frac{\pi}{4} \cdot D_2^2} \qquad u_2 = 9.686 \frac{ft}{sec} \qquad W_s := 5360 \cdot \frac{BTU}{lbmol}$$

Eq. (2.32a): $Q := H_2 - H_1 + \frac{u_2^2 - u_1^2}{2} - \frac{W_s}{molwt}$ $\quad Q = -98.82 \frac{BTU}{lb_m}$

$Qdot := mdot \cdot Q$ $\quad$ $Qdot = -67128 \frac{BTU}{hr}$ **Ans.**

2.36 $T_1 := 300 \cdot K$ $\quad$ $P := 1 \cdot bar$ $\quad$ $n := \frac{1 \cdot kg}{28.9 \cdot \frac{gm}{mol}}$ $\quad$ $n = 34.602\,mol$

$V_1 := 83.14 \cdot \frac{bar \cdot cm^3}{mol \cdot K} \cdot \frac{T_1}{P}$ $\quad$ $V_1 = 24942 \frac{cm^3}{mol}$

$$W = -n \cdot \int_{V_1}^{V_2} P\,dV = n \cdot P \cdot (V_1 - V_2) = n \cdot P \cdot (V_1 - 3 \cdot V_1)$$

Whence $\quad W := -n \cdot P \cdot 2 \cdot V_1$ $\quad$ $W = -172.61\,kJ$ **Ans.**

Given: $\quad T_2 = T_1 \cdot \frac{V_2}{V_1} = T_1 \cdot 3$ $\quad$ **Whence** $\quad T_2 := 3 \cdot T_1$

$C_P := 29 \cdot \frac{joule}{mol \cdot K}$ $\quad$ $\Delta H := C_P \cdot (T_2 - T_1)$ $\quad$ $\Delta H = 17.4 \frac{kJ}{mol}$ **Ans.**

$Q := n \cdot \Delta H$ $\quad$ $Q = 602.08\,kJ$ **Ans.**

$\Delta U := \frac{Q + W}{n}$ $\quad$ $\Delta U = 12.41 \frac{kJ}{mol}$ **Ans.**

2.37 Work exactly like Ex. 2.10: 2 steps, (a) & (b). A value is required for PV/T, namely R.

$R = 8.314 \frac{J}{mol \cdot K}$ $\quad$ $T_1 := 293.15 \cdot K$ $\quad$ $T_2 := 333.15 \cdot K$

$P_1 := 1000 \cdot kPa$ $\quad$ $P_2 := 100 \cdot kPa$

(a) Cool at const V1 to P2
(b) Heat at const P2 to T2

$C_P := \frac{7}{2} \cdot R$ $\quad$ $C_V := \frac{5}{2} \cdot R$

$T_{a2} := T_1 \cdot \frac{P_2}{P_1}$ $\quad$ $T_{a2} = 29.315\,K$

$\Delta T_b := T_2 - T_{a2}$ $\quad \Delta T_b = 303.835\,K$ $\quad \Delta T_a := T_{a2} - T_1$ $\quad \Delta T_a = -263.835\,K$

$\Delta H_b := C_P \cdot \Delta T_b$ $\quad \Delta H_b = 8.841 \times 10^3 \dfrac{J}{mol}$

$\Delta U_a := C_V \cdot \Delta T_a$ $\quad \Delta U_a = -5.484 \times 10^3 \dfrac{J}{mol}$

$V_1 := \dfrac{R \cdot T_1}{P_1}$ $\quad V_1 = 2.437 \times 10^{-3} \dfrac{m^3}{mol}$ $\quad V_2 := \dfrac{R \cdot T_2}{P_2}$ $\quad V_2 = 0.028 \dfrac{m^3}{mol}$

$\Delta H_a := \Delta U_a + V_1 \cdot (P_2 - P_1)$ $\quad \Delta H_a = -7.677 \times 10^3 \dfrac{J}{mol}$

$\Delta U_b := \Delta H_b - P_2 \cdot (V_2 - V_1)$ $\quad \Delta U_b = 6.315 \times 10^3 \dfrac{J}{mol}$

$\Delta U := \Delta U_a + \Delta U_b$ $\quad \Delta U = 0.831 \dfrac{kJ}{mol}$ **Ans.**

$\Delta H := \Delta H_a + \Delta H_b$ $\quad \Delta H = 1.164 \dfrac{kJ}{mol}$ **Ans.**

2.39 $\rho := 996 \dfrac{kg}{m^3}$ $\quad \mu := 9.0 \cdot 10^{-4} \dfrac{kg}{m \cdot s}$ $\quad \varepsilon D := 0.0001$ **Note: εD = ε/D in this solution**

$D := \begin{pmatrix} 2 \\ 5 \\ 2 \\ 5 \end{pmatrix} cm$ $\quad u := \begin{pmatrix} 1 \\ 1 \\ 5 \\ 5 \end{pmatrix} \dfrac{m}{s}$

$Re := \overrightarrow{\dfrac{D \cdot \rho \cdot u}{\mu}}$ $\quad Re = \begin{pmatrix} 22133 \\ 55333 \\ 110667 \\ 276667 \end{pmatrix}$

$$f_F := \overrightarrow{\left[0.3305\cdot\left[\ln\left[0.27\cdot\varepsilon D + \left(\frac{7}{Re}\right)^{0.9}\right]\right]^{-2}\right]}$$

$$f_F = \begin{pmatrix} 0.00635 \\ 0.00517 \\ 0.00452 \\ 0.0039 \end{pmatrix}$$

$$mdot := \overrightarrow{\left(\rho\cdot u\cdot\frac{\pi}{4}D^2\right)}$$

$$mdot = \begin{pmatrix} 0.313 \\ 1.956 \\ 1.565 \\ 9.778 \end{pmatrix}\frac{kg}{s}$$ **Ans.**

$$\Delta P\Delta L := \overrightarrow{\left(\frac{-2}{D}\cdot f_F\cdot\rho\cdot u^2\right)}$$

$$\Delta P\Delta L = \begin{pmatrix} -0.632 \\ -0.206 \\ -11.254 \\ -3.88 \end{pmatrix}\frac{kPa}{m}$$ **Ans.**

2.42 $mdot := 4.5\frac{kg}{s}$ $H_1 := 761.1\frac{kJ}{kg}$ $H_2 := 536.9\cdot\frac{kJ}{kg}$

Assume that the compressor is adiabatic (Qdot = 0). Neglect changes in KE and PE.

$$Wdot := mdot\cdot\left(H_2 - H_1\right)$$

$$Wdot = -1.009\times 10^3\,kW$$

$$Cost := 15200\cdot\left(\frac{|Wdot|}{kW}\right)^{0.573}$$

$$Cost = 799924\,dollars$$ **Ans.**

Chapter 2 - Section B - Non-Numerical Solutions

2.3 Equation (2.2) is here written: $\partial\, U^t + \partial\, E_P + \partial\, E_K = Q + W$

(*a*) In this equation W does not include work done by the force of gravity on the system. This is accounted for by the $\partial\, E_K$ term. Thus, $W = 0$.

(*b*) Since the elevation of the egg decreases, sign($\partial\, E_P$) is $(-)$.

(*c*) The egg is at rest both in its initial and final states; whence $\partial\, E_K = 0$.

(*d*) Assuming the egg does not get scrambled, its internal energy does not change; thus $\partial\, U^t = 0$.

(*e*) The given equation, with $\partial\, U^t = \partial\, E_K = W = 0$, shows that sign(Q) is $(-)$. A detailed examination of the process indicates that the kinetic energy of the egg just before it strikes the surface appears instantly as internal energy of the egg, thus raising its temperature. Heat transfer **to** the surroundings then returns the internal energy of the egg to its initial value.

2.6 If the refrigerator is entirely contained within the kitchen, then the electrical energy entering the refrigerator must inevitably appear in the kitchen. The only mechanism is by heat transfer (from the condenser of the refrigerator, usually located behind the unit or in its walls). This raises, rather than lowers, the temperature of the kitchen. The only way to make the refrigerator double as an air conditioner is to place the condenser of the refrigerator outside the kitchen (outdoors).

2.7 According to the phase rule [Eq. (2.7)], $F = 2 - \kappa + N$. According to the laboratory report a pure material ($N = 1$) is in 4-phase ($\kappa = 4$) equilibrium. If this is true, then $F = 2 - 4 + 1 = -1$. This is not possible; the claim is invalid.

2.8 The phase rule [Eq. (2.7)] yields: $F = 2 - \kappa + N = 2 - 2 + 2 = 2$. Specification of T and P fixes the intensive state, and thus the phase compositions, of the system. Since the liquid phase is pure species 1, addition of species 2 to the system increases its amount in the vapor phase. If the composition of the vapor phase is to be unchanged, some of species 1 must evaporate from the liquid phase, thus *decreasing* the moles of liquid present.

2.9 The phase rule [Eq. (2.7)] yields: $F = 2 - \kappa + N = 2 - 2 + 3 = 3$. With only T and P fixed, one degree of freedom remains. Thus changes in the phase compositions are possible for the given T and P. If ethanol is added in a quantity that allows T and P to be restored to their initial values, the ethanol distributes itself between the phases so as to form new equilibrium phase compostions and altered amounts of the vapor and liquid phases. Nothing remains the same except T and P.

2.10 (*a*) Since $F = 3$, fixing T and P leaves a single additional phase-rule variable to be chosen.

(*b*) Adding or removing liquid having the composition of the liquid phase or adding or removing vapor having the composition of the vapor phase does not change the phase compositions, and does not alter the intensive state of the system. However, such additions or removals do alter the *overall* composition of the system, except for the unusual case where the two phase compositions are the same. The overall composition, depending on the relative amounts of the two phases, can range from the composition of the liquid phase to that of the vapor phase.

2.14 If the fluid density is constant, then the compression becomes a constant-V process for which the work is zero. Since the cylinder is insulated, we presume that no heat is transferred. Equation (2.10) then shows that $\partial\, U = 0$ for the compression process.

2.16 Electrical and mechanical irreversibilities cause an increase in the internal energy of the motor, manifested by an elevated temperature of the motor. The temperature of the motor rises until a dynamic equilibrium is established such that heat transfer from the motor to the srroundings exactly compensates for the irreversibilities. Insulating the motor does nothing to decrease the irreversibilities in the motor and merely causes the temperature of the motor to rise until heat-transfer equilibrium is reestablished with the surroundings. The motor temperature could rise to a level high enough to cause damage.

2.19 Let symbols without subscripts refer to the solid and symbols with subscript w refer to the water. Heat transfer from the solid to the water is manifested by changes in internal energy. Since energy is conserved, $\Delta U^t = -\Delta U^t_w$. If total heat capacity of the solid is C^t $(= mC)$ and total heat capacity of the water is C^t_w $(= m_w C_w)$, then:

$$C^t(T - T_0) = -C^t_w(T_w - T_{w_0})$$

or
$$T_w = T_{w_0} - \frac{C^t}{C^t_w}(T - T_0) \qquad (A)$$

This equation relates instantaneous values of T_w and T. It can be written in the alternative form:

$$TC^t - T_0 C^t = T_{w_0} C^t_w - T_w C^t_w$$

or
$$T_{w_0} C^t_w + T_0 C^t = T_w C^t_w + TC^t \qquad (B)$$

The heat-transfer rate from the solid to the water is given as $\dot{Q} = K(T_w - T)$. [This equation implies that the solid is the system.] It may also be written:

$$C^t \frac{dT}{d\tau} = K(T_w - T) \qquad (C)$$

In combination with Eq. (A) this becomes:

$$C^t \frac{dT}{d\tau} = K\left[T_{w_0} - \frac{C^t}{C^t_w}(T - T_0) - T\right]$$

or
$$\frac{dT}{d\tau} = K\left(\frac{T_{w_0} - T}{C^t} - \frac{T - T_0}{C^t_w}\right) = -TK\left(\frac{1}{C^t} + \frac{1}{C^t_w}\right) + K\left(\frac{T_{w_0}}{C^t} + \frac{T_0}{C^t_w}\right)$$

Define:
$$\beta \equiv K\left(\frac{1}{C^t} + \frac{1}{C^t_w}\right) \qquad \alpha \equiv K\left(\frac{T_{w_0}}{C^t} + \frac{T_0}{C^t_w}\right)$$

where both α and β are constants. The preceding equation may now be written:

$$\frac{dT}{d\tau} = \alpha - \beta T$$

Rearrangement yields:
$$\frac{dT}{\alpha - \beta T} = -\frac{1}{\beta}\frac{d(\alpha - \beta T)}{\alpha - \beta T} = d\tau$$

Integration from T_0 to T and from 0 to τ gives:

$$-\frac{1}{\beta}\ln\left(\frac{\alpha - \beta T}{\alpha - \beta T_0}\right) = \tau$$

which may be written: $$\frac{\alpha - \beta T}{\alpha - \beta T_0} = \exp(-\beta\tau)$$

When solved for T and rearranged, this becomes:

$$\boxed{T = \frac{\alpha}{\beta} + \left(T_0 - \frac{\alpha}{\beta}\right)\exp(-\beta\tau)}$$

where by the definitions of α and β, $$\frac{\alpha}{\beta} = \frac{T_{w_0}C_w^t + T_0 C^t}{C_w^t + C^t}$$

When $\tau = 0$, the preceding equation reduces to $T = T_0$, as it should. When $\tau = \infty$, it reduces to $T = \alpha/\beta$. Another form of the equation for α/β is found when the numerator on the right is replaced by Eq. (B):

$$\frac{\alpha}{\beta} = \frac{T_w C_w^t + T C^t}{C_w^t + C^t}$$

By inspection, $T = \alpha/\beta$ when $T_w = T$, the expected result.

2.20 The general equation applicable here is Eq. (2.30):

$$\boxed{\Delta\left[\left(H + \tfrac{1}{2}u^2 + zg\right)\dot{m}\right]_{\text{fs}} = \dot{Q} + \dot{W}_s}$$

(a) Write this equation for the single stream flowing within the pipe, neglect potential- and kinetic-energy changes, and set the work term equal to zero. This yields:

$$(\Delta H)\dot{m} = \dot{Q}$$

(b) The equation is here written for the two streams (I and II) flowing in the two pipes, again neglecting any potential- and kinetic-energy changes. There is no work, and the the heat transfer is internal, between the two streams, making $\dot{Q} = 0$. Thus,

$$(\Delta H)_{\text{I}}\dot{m}_{\text{I}} + (\Delta H)_{\text{II}}\dot{m}_{\text{II}} = 0$$

(c) For a pump operating on a single liquid stream, the assumption of negligible potential- and kinetic-energy changes is reasonable, as is the assumption of negligible heat transfer to the surroundings. Whence,

$$(\Delta H)\dot{m} = \dot{W}$$

(d) For a properly designed gas compressor the result is the same as in Part (c).

(e) For a properly designed turbine the result is the same as in Part (c).

(f) The purpose of a throttle is to reduce the pressure on a flowing stream. One usually assumes adiabatic operation with negligible potential- and kinetic-energy changes. Since there is no work, the equation is:

$$\Delta H = 0$$

(g) The sole purpose of the nozzle is to produce a stream of high velocity. The kinetic-energy change must therefore be taken into account. However, one usually assumes negligible potential-energy change. Then, for a single stream, adiabatic operation, and no work:

$$\Delta\left[\left(H + \tfrac{1}{2}u^2\right)\dot{m}\right] = 0$$

The usual case is for a negligible inlet velocity. The equation then reduces to:

$$\Delta H + \tfrac{1}{2}u_2^2 = 0$$

2.21 We reformulate the definition of Reynolds number, with mass flowrate $\dot{m}$ replacing velocity u:

$$\dot{m} = uA\rho = u\,\frac{\pi}{4}D^2\,\rho$$

Solution for u gives: $$u = \frac{4}{\pi}\frac{\dot{m}}{D^2\rho}$$

Whence, $$\mathrm{Re} \equiv \frac{u\rho D}{\mu} = \frac{4}{\pi}\frac{\dot{m}}{D^2\rho}\frac{\rho D}{\mu} = \frac{4}{\pi}\frac{\dot{m}}{D\mu}$$

(a) Clearly, an increase in $\dot{m}$ results in an increase in Re.

(b) Clearly, an increase in D results in a decrease in Re.

2.24 With the tank as control volume, Eqs. (2.25) and (2.29) become:

$$\frac{dm}{dt} + \dot{m}' = 0 \qquad \text{and} \qquad \frac{d(mU)}{dt} + H'\dot{m}' = 0$$

Expanding the derivative in the second equation, and eliminating $\dot{m}'$ by the first equation yields:

$$m\frac{dU}{dt} + U\frac{dm}{dt} - H'\frac{dm}{dt} = 0$$

Multiply by dt and rearrange: $$\boxed{\frac{dU}{H' - U} = \frac{dm}{m}}$$

Substitution of H' for H requires the assumption of uniform (though not constant) conditions throughout the tank. This requires the absence of any pressure or temperature gradients in the gas in the tank.

2.32 From the given equation: $$P = \frac{RT}{V - b}$$

By Eq. (1.3), $$W = -\int_{V_1}^{V_2} P\,dV = -\int_{V_1}^{V_2} \frac{RT}{V - b}d(V - b)$$

Whence, $$\boxed{W = RT\ln\left(\frac{V_1 - b}{V_2 - b}\right)}$$

2.35 Recall: $$d(PV) = P\,dV + V\,dP \qquad \text{and} \qquad dW = -P\,dV$$

Whence, $$dW = V\,dP - d(PV) \qquad \text{and} \qquad \boxed{W = \textstyle\int V\,dP - \Delta(PV)}$$

By Eq. (2.4), $dQ = dU - dW$

By Eq. (2.11), $U = H - PV$ and $dU = dH - P\,dV - V\,dP$

With $dW = -P\,dV$ the preceding equation becomes $dQ = dH - V\,dP$

Whence, $$\boxed{Q = \Delta H - \textstyle\int V\,dP}$$

2.38 (*a*) By Eq. (2.24a), $\dot{m} = uA\rho$ With $\dot{m}$, A, and ρ all constant, u must also be constant. With $q = uA$, q is also constant.

(*b*) Because mass is conserved, $\dot{m}$ must be constant. But $\dot{n} = \mathcal{M}/\dot{m}$ may change, because $\mathcal{M}$ may change. At the very least, ρ depends on T and P. Hence u and q can both change.

2.40 In accord with the phase rule, the system has 2 degrees of freedom. Once T and P are specified, the intensive state of the system is fixed. Provided the two phases are still present, their compositions cannot change.

2.41 In accord with the phase rule, the system has 6 degrees of freedom. Once T and P are specified, 4 remain. One can add liquid with the liquid-phase composition or vapor with the vapor-phase composition or both. In other words, simply change the quantities of the phases.

2.43 Let $\dot{n}'$ represent the moles of air leaving the home. By an energy balance,

$$\dot{Q} = \dot{n}'H + \frac{d(nU)}{dt} = \dot{n}'H + n\frac{dU}{dt} + U\frac{dn}{dt}$$

But a material balance yields $\dot{n}' = -\dfrac{dn}{dt}$

Then $$\dot{Q} = -(H - U)\frac{dn}{dt} + n\frac{dU}{dt}$$

or $$\boxed{\dot{Q} = -PV\frac{dn}{dt} + n\frac{dU}{dt}}$$

2.44 (*a*) By Eq. (2.32a): $$H_2 - H_1 + \tfrac{1}{2}(u_2^2 - u_1^2) = 0$$

By Eq. (2.24a): $$u = \frac{\dot{m}}{A\rho} = \frac{4}{\pi}\frac{\dot{m}}{\rho D^2}$$

Then $u_2^2 - u_1^2 = \left(\dfrac{4}{\pi}\right)^2 \dfrac{\dot{m}^2}{\rho^2}\left(\dfrac{1}{D_2^4} - \dfrac{1}{D_1^4}\right)$ and given $H_2 - H_1 = \dfrac{1}{\rho}(P_2 - P_1)$

$$\frac{1}{\rho}(P_2 - P_1) + \frac{1}{2}\left(\frac{4}{\pi}\right)^2 \frac{\dot{m}^2}{\rho^2}\left(\frac{D_1^4 - D_2^4}{D_1^4 D_2^4}\right) = 0$$

Solve for $\dot{m}$: $$\boxed{\dot{m} = \left[2\rho(P_1 - P_2)\left(\frac{\pi}{4}\right)^2\left(\frac{D_1^4 D_2^4}{D_1^4 - D_2^4}\right)\right]^{1/2}}$$

(*b*) Proceed as in part (*a*) with an extra term, Here solution for $\dot{m}$ yields:

$$\dot{m} = \left[2\left[\rho(P_1 - P_2) - \rho^2 C(T_2 - T_1)\right]\left(\frac{\pi}{4}\right)^2\left(\frac{D_1^4 D_2^4}{D_1^4 - D_2^4}\right)\right]^{1/2}$$

Because the quantity in the smaller square brackets is smaller than the leading term of the preceding result, the effect is to decrease the mass flowrate.