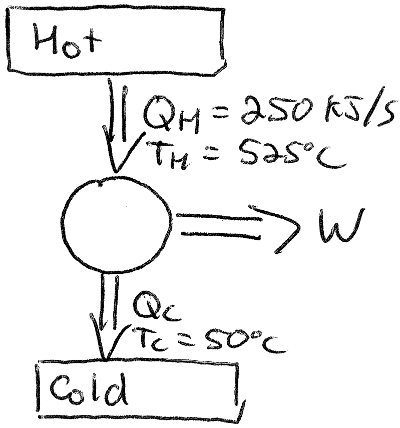
5.2



Definition of efficiency

$$\eta = 1 - \frac{T_C}{T_H} = 1 - \frac{50+273}{525+273} = 0.59$$

$$\eta = \frac{W}{Q_H} \Rightarrow \boxed{W = \eta Q_H = 0.59 \times 250 = 148.8 \text{ kJ/s}}$$

From 1st law energy balance

$$\boxed{Q_C = Q_H - W = 250 - 148.8 = 101.2 \text{ kJ/s}}$$

5.3

$W = 95000$ kW

a) $\eta = 1 - \frac{300}{750} = 0.6$

$$\boxed{\begin{gathered} Q_H = \frac{W}{\eta} = \frac{95000}{0.6} = 1.58 \times 10^5 \text{ kW} \\ Q_C = Q_H - W = 6.3 \times 10^4 \text{ kW} \end{gathered}}$$

b) $$\boxed{\begin{gathered} Q_H = \frac{W}{\eta} = \frac{95000}{0.35} = 2.7 \times 10^5 \text{ kW} \\ Q_C = 1.76 \times 10^5 \text{ kW} \end{gathered}}$$

5.4

$$\eta_{carnot} = 1 - \frac{30+273}{350+273} = 0.51$$

a) $\eta_{actual} = 0.55 \times 0.51 = 0.28$

b) $\eta_{actual} = 0.55 \times \left(1 - \frac{30+273}{T}\right) = 0.35$

$T = 833K = 560°C$

5.6

$$\eta = 1 - \frac{T_C}{T_H}$$

$$\left(\frac{\partial \eta}{\partial T_C}\right)_{T_H} = \frac{-1}{T_H} \quad \text{and} \quad \left(\frac{\partial \eta}{\partial T_H}\right)_{T_C} = \frac{T_C}{T_H^2} = \frac{T_C}{T_H} \times \frac{1}{T_H}$$

Since $\frac{T_C}{T_H}$ is less than 1, η changes faster with T_C than with T_H $\therefore$ in theory more effective to change T_C and T_H

In practice, T_C is fixed by the environment and it is more practical to change T_H

5.9

$$n = \frac{P_1 V}{R T_1} = 1.443 \text{ mol}$$

$$Q = 15000 \text{ J}$$

$$C_v = \frac{5}{2} \times R$$

a) constant volume heating

$$\Delta U = Q + \cancel{W}^{0} = Q = n C_v (T_2 - T_1)$$

$$T_2 = T_1 + \frac{Q}{n C_v} = 500 + \frac{15000}{1.443 \times \left(\frac{5}{2} \times 8.314\right)} = 1 \times 10^3 \text{ K}$$

$$\Delta S = n\left(C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}\right)$$

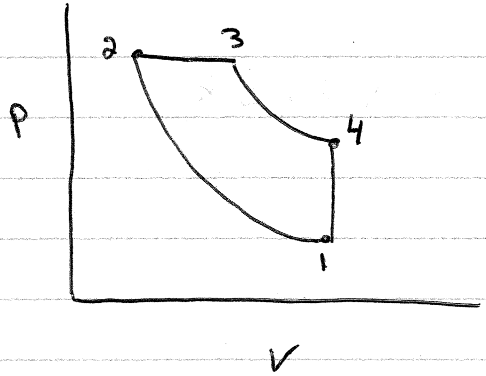
But $\frac{P_2}{P_1} = \frac{T_2}{T_1}$

$$\Delta S = n\left[(C_p - R) \ln\left(\frac{T_2}{T_1}\right)\right] = n C_v \ln \frac{T_2}{T_1} = 1.443 \times \frac{5}{2} \times 8.314 \times \ln\left(\frac{1000}{500}\right)$$

$$\boxed{\Delta S = 20.794 \text{ J/K}}$$

b) Entropy change of the gas is the same since T_2 is the same

5.19



For adiabatic steps $1 \to 2$ and $3 \to 4$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \qquad T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$$

where $\gamma = C_P / C_V$

For isochoric step $4 \to 1$

$$V_4 = V_1$$

For isobaric step $2 \to 3$

$$\frac{T_2}{V_2} = \frac{T_3}{V_3}$$

Thermal efficiency $= \eta = \dfrac{Q_H + Q_C}{Q_H} = 1 + \dfrac{Q_C}{Q_H}$

For step $2 \to 3$

$$Q_{23} = C_P (T_3 - T_2) = Q_H$$

For step $4 \to 1$

$$Q_{41} = C_V (T_1 - T_4) = Q_C$$

~~T_4 & T_3 V_3~~

$$\eta = 1 + \frac{C_v (T_1 - T_4)}{C_p (T_3 - T_2)} = 1 + \frac{1}{\gamma} \frac{(T_1 - T_4)}{(T_3 - T_2)}$$

$T_1 = 200°C$ $\quad T_2 = 1000°C$ $\quad T_3 = 1700°C$ $\quad T_4 = ?$

$\therefore$ we need T_4

$$T_4 = T_3 \frac{V_3^{\gamma-1}}{V_4^{\gamma-1}} \qquad \frac{T_1}{T_2} = \frac{V_2^{\gamma-1}}{V_1^{\gamma-1}} = \frac{V_2^{\gamma-1}}{V_4^{\gamma-1}}$$

$$V_2 = \frac{T_2 V_3}{T_3} \qquad \frac{T_1}{T_2} = \left(\frac{T_2}{T_3}\right)^{\gamma-1} \frac{V_3^{\gamma-1}}{V_4^{\gamma-1}}$$

$$\frac{T_1 T_3^{\gamma-1}}{T_2 T_2^{\gamma-1}} = \frac{V_3^{\gamma-1}}{V_4^{\gamma-1}}$$

$$T_4 = \frac{T_3 T_1}{T_2} \frac{T_3^{\gamma-1}}{T_2^{\gamma-1}} = \frac{1973 \times 473}{1273} \times \frac{1973^{0.4}}{1273^{0.4}} = 873.5 K$$

$$\therefore \eta = 1 + \frac{1}{1.4} \frac{(473 - 873)}{(1973 - 1273)} = 0.59$$

FYI: This cycle is the same cycle a standard Diesel engine uses.

5.26

$T = 403.15\,K$ $\quad P_1 = 2\,bar$ $\quad P_2 = 6.5\,bar$ $\quad T_{res} = 298.15\,K$

$$\boxed{\Delta S_{gas} = -R \ln\left(\frac{P_2}{P_1}\right) = -7.944 \frac{J}{mol\,K}}$$

isothermal compression

Irreversible Work: $W_{irr} = 1.3 \times W_{rev} = 1.3 \times RT \ln\left(\frac{P_2}{P_1}\right)$

$$W_{irr} = 4.163 \times 10^3\ J/mol$$

$\cancel{\Delta U}^{0} = W + Q$ $\quad Q = -W$ $\quad$ (note: Q here is with respect to system)

$$\boxed{\Delta S_{res} = \frac{-Q}{T_{res}} = \frac{4.163 \times 10^3}{298.15} = 13.96 \frac{J}{mol\,K}}$$

$$\boxed{\Delta S_{total} = \Delta S_{gas} + \Delta S_{res} = 6.02 \frac{J}{mol\,K}}$$

5.27: Data from NIST chemistry web book (all values in J/K)

```
> restart;
```

For SO2:

```
> A_so2:=21.43049;B_so2:=74.35094;C_so2:=-57.75217;D_so2:=16.35534;E_so2:=0.086731;
```

$$A\_so2 := 21.43049$$

$$B\_so2 := 74.35094$$

$$C\_so2 := -57.75217$$

$$D\_so2 := 16.35534$$

$$E\_so2 := 0.086731$$

```
> dS_so2:=10*int((A_so2 + B_so2*(T/1000) + C_so2*(T/1000)^2 + D_so2*(T/1000)^3 + E_so2/((T/1000)^2))/T,T=473..1373);
```

$$dS\_so2 := 554.8333486$$

For propane: (Shomate equation not available but Cp vs T data is available so using excel to fit polynomial to this data and integrating):

```
> Cp_propane:=-7e-5*T^2+0.2372*T+10.535;
```

$$Cp\_propane := -0.00007\, T^2 + 0.2372\, T + 10.535$$

```
> dS_propane:=12*int(Cp_propane/T,T=250+273..1200+273);
```

$$dS\_propane := 2038.580743$$

```
>
```

5.28: Data from NIST chemistry web book (all values in J/K)

Step 1: Find final temperature: H(200C)-H(T) = Q

```
> restart;
```

a) To find T2, must iterate until dH = 800kJ

```
> A_ethylene:=-6.387880;B_ethylene:=184.4019;C_ethylene:=-112.9718;D_ethylen
  e:=28.49593;E_ethylene:=0.315540;
```

$$A\_ethylene := -6.387880$$

$$B\_ethylene := 184.4019$$

$$C\_ethylene := -112.9718$$

$$D\_ethylene := 28.49593$$

$$E\_ethylene := 0.315540$$

```
> dH_ethylene:=10*int(A_ethylene + B_ethylene*(T/1000) +
  C_ethylene*(T/1000)^2 + D_ethylene*(T/1000)^3
  +E_ethylene/((T/1000)^2),T=473..1379);
```

$$dH\_ethylene := 7.999539313\ 10^{5}$$

So, T2=1379K. dS is in J/K

```
> dS_ethylene:=10*int((A_ethylene + B_ethylene*(T/1000) +
  C_ethylene*(T/1000)^2 + D_ethylene*(T/1000)^3
  +E_ethylene/((T/1000)^2))/T,T=473..1379);
```

$$dS\_ethylene := 899.8052812$$

b) To find T2, follow the same instructions as in part a) except dH=2500

```
> Cp_1butene:=2e-8*T^3-0.0001*T^2+0.2823*T+12.979;
```

$$Cp\_1butene := 2\ 10^{-8}\ T^{3} - 0.0001\ T^{2} + 0.2823\ T + 12.979$$

```
> dH_1butene:=15*int(Cp_1butene,T=260+273..1350);
```

$$dH\_1butene := 2.504840530\ 10^{6}$$

So T2=1350K. dS is in J/K

```
> dS_1butene:=15*int(Cp_1butene/T,T=260+273..1350);
```

$$dS\_1butene := 2717.602062$$

c) To find T2, follow same instructions as in part a) and b) but this time dH=1E6 KJ. T1=260C, n=18143.68mol

```
> dH_ethylene_c:=18143*int(A_ethylene + B_ethylene*(T/1000) +
  C_ethylene*(T/1000)^2 + D_ethylene*(T/1000)^3
  +E_ethylene/((T/1000)^2),T=260+273..1180);
```

$$dH\_ethylene\_c := 1.005952861\ 10^{9}$$

So T2=1180K. dS is in J/K

```
> dS_ethylene:=18143*int((A_ethylene + B_ethylene*(T/1000) +
  C_ethylene*(T/1000)^2 + D_ethylene*(T/1000)^3
  +E_ethylene/((T/1000)^2))/T,T=260+273..1180);
```

$$dS\_ethylene := 1.201750050\ 10^{6}$$

>