Solutions to Assignment 12   J. Murthy   December 11, 2000.

11.49 A Brayton cycle inlet is at 300 K, 100 kPa and the combustion adds 670 kJ/kg. The maximum temperature is 1200 K due to material considerations. What is the maximum allowed compression ratio? For this calculate the net work and cycle efficiency assuming variable specific heat for the air, table A.7.

Combustion: $h_3 = h_2 + q_H$; $_2w_3 = 0$ and $T_{max} = T_3 = 1200$ K

$h_2 = h_3 - q_H = 1277.8 - 670 = 607.8$

$T_2 \approx 600$ K; $P_{r2} = 13.0923$; $T_1 = 300$ K; $P_{r1} = 1.1146$

Ideal Compression: $P_2 / P_1 = P_{r2} / P_{r1} = 11.75$

Ideal Expansion: $P_{r4} = P_{r3} / (P_3 / P_4) = 191.174 / 11.75 = 16.27$

$T_4 \approx 636$ K, $h_4 = 645.7$ linear interpolation

$w_T = h_3 - h_4 = 1277.8 - 645.7 = 632.1$

$-w_C = h_2 - h_1 = 607.8 - 300.47 = 307.3$

$w_{net} = w_T + w_C = 632.1 - 307.3 = \textbf{324.8}$

$\eta = w_{net} / q_H = 324.8 / 670 = \textbf{0.485}$

11.80 At the beginning of compression in a diesel cycle $T = 300$ K, $P = 200$ kPa and after combustion (heat addition) is complete $T = 1500$ K and $P = 7.0$ MPa. Find the compression ratio, the thermal efficiency and the mean effective pressure.

$P_2 = P_3 = 7000$ kPa => $v_1 / v_2 = (P_2/P_1)^{1/k} = (7000 / 200)^{0.7143} = \textbf{12.67}$

$T_2 = T_1(P_2 / P_1)^{(k-1)/k} = 300(7000 / 200)^{0.2857} = 828.4$

$v_3 / v_2 = T_3 / T_2 = 1500 / 828.4 = 1.81$

$v_4 / v_3 = v_1 / v_3 = (v_1 / v_2)(v_2 / v_3) = 12.67 / 1.81 = 7$

$T_4 = T_3(v_3 / v_4)^{k-1} = (1500 / 7)^{0.4} = 688.7$

$q_L = C_{vo}(T_4 - T_1) = 0.717(688.7 - 300) = 278.5$

$q_H = h_3 - h_2 \approx C_{po}(T_3 - T_2) = 1.004(1500 - 828.4) = 674$

$\eta = 1 - q_L / q_H = 1 - 278.5 / 674 = \textbf{0.587}$

$w_{net} = q_{net} = 674 - 278.5 = 395.5$

$v_{max} = v_1 = R\,T_1 / P_1 = 0.287 \times 300 / 200 = 0.4305$ m^3 / kg

$v_{min} = v_{max} / (v_1 / v_2) = 0.4305 / 12.67 = 0.034$ m^3 / kg

mep $= w_{net} / (v_{max} - v_{min}) = 395.5 / (0.4305 - 0.034) = \textbf{997 kPa}$

11.71 To approximate an actual spark-ignition engine consider an air-standard Otto cycle that has a heat addition of 1800 kJ/kg of air, a compression ratio of 7, and a pressure and temperature at the beginning of the compression process of 90 kPa, 10°C. Assuming constant specific heat, with the value from Table A.5, determine the maximum pressure and temperature of the cycle, the thermal efficiency of the cycle and the mean effective pressure.

$q_H = 1800$ kJ
$v_1/v_2 = 7$
$P_1 = 90$ kPa
$T_1 = 10\ ^{\circ}C$
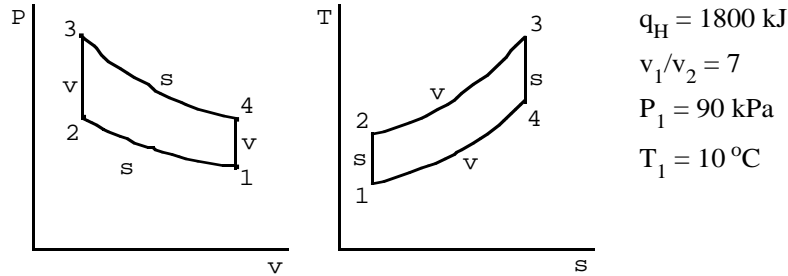
a) $P_2 = P_1(v_1/v_2)^k = 90(7)^{1.4} = 1372$ kPa

$T_2 = T_1(P_2/P_1)(v_2/v_1) = 283.15 \times 15.245 \times \dfrac{1}{7} = 616.6$ K

$T_3 = T_2 + q_H/C_{V0} = 616.6 + 1800/0.717 = \mathbf{3127\ K}$

$P_3 = P_2T_3/T_2 = 1372 \times 3127 / 616.6 = \mathbf{6958\ kPa}$

b) $\quad \eta_{TH} = 1 - T_1/T_2 = 1 - 283.15/616.5 = \mathbf{0.541}$

c) $\quad w_{NET} = \eta_{TH} \times q_H = 0.544 \times 1800 = 979.2$ kJ/kg

$v_1 = RT_1/P_1 = (0.287 \times 283.2)/90 = 0.9029$

$v_2 = (1/7)\,v_1 = 0.1290$ m^3/kg

$\text{mep} = \dfrac{w_{NET}}{v_1 - v_2} = \dfrac{979.2}{0.9029 - 0.129} = \mathbf{1265\ kPa}$

11.85 The air-standard Carnot cycle was not shown in the text; show the *T–s* diagram for this cycle. In an air-standard Carnot cycle the low temperature is 280 K and the efficiency is 60%. If the pressure before compression and after heat rejection is 100 kPa, find the high temperature and the pressure just before heat addition.
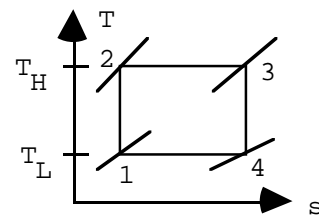
$\eta = 0.6 = 1 - T_H/T_L$

$\Rightarrow\ T_H = T_L/0.4 = 700$ K

$P_1 = 100$ kPa

$P_2 = P_1(T_H/T_L)^{\frac{1}{k-1}} = \mathbf{2.47\ MPa}$

[or $P_2 = P_1(P_{r2}/P_{r1}) = \mathbf{2.645\ MPa}$]

11.92 A refrigerator with R-12 as the working fluid has a minimum temperature of $-10°C$ and a maximum pressure of 1 MPa. The actual adiabatic compressor exit temperature is 60°C. Assume no pressure loss in the heat exchangers. Find the specific heat transfer from the cold space and that to the hot space, the coefficient of performance and the isentropic efficiency of the compressor.

State 1: Inlet to compressor, sat. vap. -10°C,

$h_1 = 183.058$, $s_1 = 0.7014$

State 2: Actual compressor exit, $h_{2AC} = 217.81$

State 3: Exit condenser, sat. liq. 1MPa, $h_3 = 76.155$

State 4: Exit valve, $h_4 = h_3$

C.V. Evaporator: $q_L = h_1 - h_4 = h_1 - h_3 = $ **106.9 kJ/kg**

C.V. Ideal Compressor: $w_{C,S} = h_{2,S} - h_1$, $s_{2,S} = s_1$

State 2s: $T_{2,S} = 49.66$, $h_{2,S} = 209.9$, $w_{C,S} = 26.842$

C.V. Actual Compressor: $w_C = h_{2,AC} - h_1 = 34.752$ kJ/kg

$\beta = q_L/w_C = $ **3.076,** $\eta_C = w_{C,S}/w_C = $ **0.7724**

C.V. Condenser: $q_H = h_{2,AC} - h_3 = $ **141.66 kJ/kg**

11.98 In an actual refrigeration cycle using R-12 as the working fluid, the refrigerant flow rate is 0.05 kg/s. Vapor enters the compressor at 150 kPa, $-10°C$, and leaves at 1.2 MPa, 75°C. The power input to the compressor is measured and found be 2.4 kW. The refrigerant enters the expansion valve at 1.15 MPa, 40°C, and leaves the evaporator at 175 kPa, $-15°C$. Determine the entropy generation in the compression process, the refrigeration capacity and the coefficient of performance for this cycle.
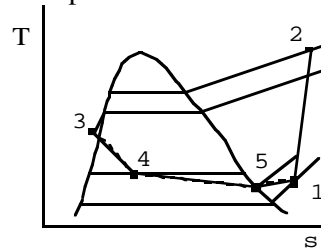
Actual ref. cycle

$P_1 = 0.15$ MPa, $P_2 = 1.2$ MPa

1: comp. inlet $T_1 = -10\ °C$, $T_2 = 75\ °C$

$P_3 = 1.15$ MPa, $P_5 = 0.175$ MPa

$T_3 = 40\ °C$, $T_5 = -15\ °C$ 5: evap. exit

$\dot{W}_{COMP} = 2.4$ kW in, $\dot{m} = 0.05$ kg/s

Table B.3 $h_1 = 184.619$, $s_1 = 0.7318$, $h_2 = 226.543$, $s_2 = 0.7404$

CV Compressor: $h_1 + q_{COMP} = h_2 + w_{COMP}$; $s_1 + \int dq/T + s_{gen} = s_2$

$w_{COMP} = -2.4/0.05 = -48.0$ kJ/kg

$q_{COMP} = h_2 + w_{COMP} - h_1 = 226.5 - 48.0 - 184.6 = -6.1$ kJ/kg

$s_{gen} = s_2 - s_1 - q/T_o = 0.7404 - 0.7318 + 6.1/298.15 = $ **0.029 kJ / kg K**

b) $q_L = h_5 - h_4 = 181.024 - 74.527 = 106.5$ kJ/kg

$\Rightarrow \dot{Q}_L = \dot{m}q_L = 0.05 \times 106.5 = $ **5.325 kW**

c) $\beta = q_L/-w_{COMP} = 106.5/48.0 = $ **2.219**

11.95 A refrigerator using R-134a is located in a 20°C room. Consider the cycle to be ideal, except that the compressor is neither adiabatic nor reversible. Saturated vapor at -20°C enters the compressor, and the R-134a exits the compressor at 50°C. The condenser temperature is 40°C. The mass flow rate of refrigerant around the cycle is 0.2 kg/s, and the coefficient of performance is measured and found to be 2.3. Find the power input to the compressor and the rate of entropy generation in the compressor process.

$$\text{Table B.5:} \quad P_2 = P_3 = P_{sat\ 40C} = 1017 \text{ kPa}, \qquad h_4 = h_3 = 256.54 \text{ kJ/kg}$$

$$s_2 \approx 1.7472, \quad h_2 \approx 430.87 ; \quad s_1 = 1.7395, \quad h_1 = 386.08$$

$$\beta = q_L / w_C \ \text{->}\ w_C = q_L / \beta = (h_1 - h_4) / \beta = (386.08 - 256.54) / 2.3 = 56.32$$

$$\dot{W}_C = \dot{m}\, w_C = \textbf{11.26 kW}$$

C.V. Compressor $h_1 + w_C + q = h_2$ ->

$$q_{in} = h_2 - h_1 - w_C = 430.87 - 386.08 - 56.32 = -11.53 \qquad \text{i.e. a heat loss}$$

$$s_1 + \int dQ/T + s_{gen} = s_2$$

$$s_{gen} = s_2 - s_1 - q / T_o = 1.7472 - 1.7395 + (11.53 / 293.15) = 0.047$$

$$\dot{S}_{gen} = \dot{m}\, s_{gen} = 0.2 \times 0.047 = \textbf{0.0094 kW / K}$$

11.101 A heat exchanger is incorporated into an ideal air-standard refrigeration cycle, as shown in Fig. P11.101. It may be assumed that both the compression and the expansion are reversible adiabatic processes in this ideal case. Determine the coefficient of performance for the cycle.
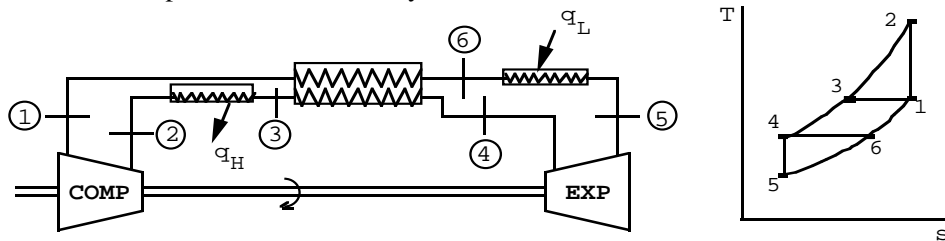
$$T_1 = T_3 = 15\,^\circ C = 288.2 \text{ K}, \quad P_1 = 100 \text{ kPa}, \quad P_2 = 1.4 \text{ MPa}$$

$$T_4 = T_6 = -50\,^\circ C = 223.2 \text{ K}, \quad s_2 = s_1$$

$$\Rightarrow\ T_2 = T_1 (P_2/P_1)^{\frac{k-1}{k}} = 288.2(1400/100)^{0.286} = 613 \text{ K}$$

$$w_C = -w_{12} = C_{P0}(T_2 - T_1) = 1.0035(613 - 288.2) = 326 \text{ kJ/kg}$$

$$s_5 = s_4 \Rightarrow T_5 = T_4(P_5/P_4)^{\frac{k-1}{k}} = 223.2(100/1400)^{0.286} = 104.9 \text{ K}$$

$$w_E = C_{P0}(T_4 - T_5) = 1.0035(223.2 - 104.9) = 118.7 \text{ kJ/kg}$$

$$w_{NET} = 118.7 - 326.0 = -207.3 \text{ kJ/kg}$$

$$q_L = C_{P0}(T_6 - T_5) = 1.0035(223.2 - 104.9) = 118.7 \text{ kJ/kg}$$

$$\beta = q_L / w_{NET} = 118.7/207.3 = \textbf{0.573}$$