ME 24-221
THERMODYNAMICS I

Solutions to Assignment 9
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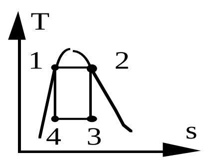
J. Murthy

8.4 In a Carnot engine with water as the working fluid, the high temperature is 250°C and as Q_H is received, the water changes from saturated liquid to saturated vapor. The water pressure at the low temperature is 100 kPa. Find T_L, the cycle thermal efficiency, the heat added per kilogram, and the entropy, *s*, at the beginning of the heat rejection process.



Constant T $\Rightarrow$ constant P from 1 to 2, Table B.1.1

$q_H = h_2 - h_1 = h_{fg} =$ **1716.2 kJ/kg**

States 3 & 4 are two-phase, Table B.1.2

$\Rightarrow$ $T_L = T_3 = T_4 = Tsat(P) =$ **99.63°C**

$$\eta_{cycle} = 1 - T_L/T_H = 1 - \frac{373}{273.15 + 250} = \mathbf{0.287}$$

Table B.1.1: $s_3 = s_2 = s_g(250°C) =$ **6.073 kJ/kg K**

8.17 A heavily insulated cylinder/piston contains ammonia at 1200 kPa, 60°C. The piston is moved, expanding the ammonia in a reversible process until the temperature is –20°C. During the process 600 kJ of work is given out by the ammonia. What was the initial volume of the cylinder?

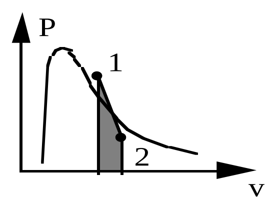
C.V. ammonia. Control mass with no heat transfer.

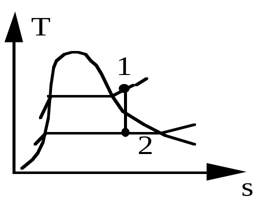
State 1: Table B.2.2 $v_1 = 0.1238$, $s_1 = 5.2357$ kJ/kg K

$$u_1 = h - Pv = 1553.3 - 1200\times0.1238 = 1404.9 \text{ kJ/kg}$$

Entropy Eq.: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,gen}$

Process: reversible (${}_1S_{2\,gen} = 0$) and adiabatic ($dQ = 0$) => $s_2 = s_1$





State 2: $T_2, s_2 \Rightarrow x_2 = (5.2357 - 0.3657)/5.2498 = 0.928$

$$u_2 = 88.76 + 0.928\times1210.7 = 1211.95$$

$${}_1Q_2 = 0 = m(u_2 - u_1) + {}_1W_2 = m(1211.95 - 1404.9) + 600$$

$$\Rightarrow m = 3.110 \text{ kg}$$

$$V_1 = mv_1 = 3.11 \times 0.1238 = \mathbf{0.385\ m^3}$$

8.24 A piston/cylinder contains 2 kg water at 200°C, 10 MPa. The piston is slowly moved to expand the water in an isothermal process to a pressure of 200 kPa. Any heat transfer takes place with an ambient at 200°C and the whole process may be assumed reversible. Sketch the process in a P-V diagram and calculate both the heat transfer and the total work.

Solution:

C.V. Water.

Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

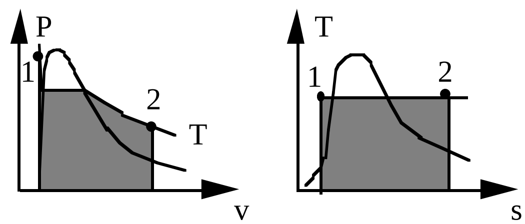
Entropy $m(s_2 - s_1) = {}_1Q_2 / T$

State 1: Table B.1.4 : $v_1 = 0.001148$, $u_1 = 844.49$, $s_1 = 2.3178$,

$V_1 = mv_1 = 0.0023\ m^3$

State 2: Table B.1.3 : $v_2 = 1.08034$, $s_2 = 7.5066$, $u_2 = 2654.4$

$V_2 = mv_2 = 2.1607\ m^3$,



${}_1Q_2 = mT(s_2 - s_1) = 2 \times 473.15\ (7.5066 - 2.3178) =$ **4910 kJ**

${}_1W_2 = {}_1Q_2 - m(u_2 - u_1) =$ **1290.3 kJ**

8.36 A cylinder/piston contains water at 200 kPa, 200°C with a volume of 20 L. The piston is moved slowly, compressing the water to a pressure of 800 kPa. The loading on the piston is such that the product *PV* is a constant. Assuming that the room temperature is 20°C, show that this process does not violate the second law.

C.V.: Water + cylinder out to room at 20°C

Process: PV = constant = Pmv $\Rightarrow$ $v_2 = P_1v_1/P_2$

${}_1w_2 = \int Pdv = P_1v_1 \ln(v_2/v_1)$

State 1: Table B.1.3, $v_1 = 1.0803$, $u_1 = 2654.4$, $s_1 = 7.5066$

State 2: P_2 , $v_2 = P_1v_1/P_2 = 200 \times 1.0803/800 = 0.2701$

Table B.1.3: $u_2 = 2655.0$ kJ/kg , $s_2 = 6.8822$ kJ/kg K

${}_1w_2 = 200 \times 1.0803 \ln(0.2701/1.0803) = -299.5$ kJ/kg

${}_1q_2 = u_2 - u_1 + {}_1w_2 = 2655.0 - 2654.4 - 299.5 = -298.9$

${}_1s_{s,gen} = s_2 - s_1 - {}_1q_2/T_{room} = 6.8822 - 7.5066 + 298.9/293.15$

$= 0.395$ kJ/kg K > 0 **satisfy 2nd law.**

8.40 A foundry form box with 25 kg of 200°C hot sand is dumped into a bucket with 50 L water at 15°C. Assuming no heat transfer with the surroundings and no boiling away of liquid water, calculate the net entropy change for the process.

C.V. Sand and water, constant pressure process

$$m_{sand}(u_2 - u_1)_{sand} + m_{H_2O}(u_2 - u_1)_{H_2O} = -P(V_2 - V_1)$$

$$\Rightarrow \; m_{sand}\Delta h_{sand} + m_{H_2O}\Delta h_{H_2O} = 0$$

For this problem we could also have said that the work is nearly zero as the solid sand and the liquid water will not change volume to any measurable extent. Now we get changes in u's instead of h's. For these phases $C_V = C_P = C$

$$25 \times 0.8 \times (T_2 - 200) + (50\times10^{-3}/0.001001) \times 4.184 \times (T_2 - 15) = 0$$

$$T_2 = 31.2°C$$

$$\Delta S = 25 \times 0.8 \ln\left(\frac{304.3}{473.15}\right) + 49.95 \times 4.184 \ln\left(\frac{304.3}{288.15}\right) = \mathbf{2.57\ kJ/K}$$

8.50 An insulated cylinder/piston contains carbon dioxide gas at 120 kPa, 400 K. The gas is compressed to 2.5 MPa in a reversible adiabatic process. Calculate the final temperature and the work per unit mass, assuming

a. Variable specific heat, Table A.8

b. Constant specific heat, value from Table A.5

c. Constant specific heat, value at an intermediate temperature from Table A.6

a) Table A.8 for CO_2

$$\bar{s}_2 - \bar{s}_1 = \bar{s}^o_{T2} - \bar{s}^o_{T1} - \bar{R}\ln(P_2/P_1)$$

$$\bar{s}^o_{T2} = 225.314 + 8.3145 \ln(2.5/0.12) = 250.561$$

$$T_2 = \mathbf{697.3\ K}$$

$$_1w_2 = -(u_2 - u_1) = -\left((\bar{h}_2 - \bar{h}_1) - \bar{R}(T_2 - T_1)\right)/M$$

$$= -[(17620 - 4003) - 8.3144(697.3 - 400)]/44.01 = \mathbf{-253.2\ kJ/kg}$$

b) $$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 400\left(\frac{2.5}{0.12}\right)^{0.224} = \mathbf{789.7\ K}$$

$$_1w_2 = -C_{Vo}(T_2 - T_1) = -0.6529(789.7 - 400) = \mathbf{-254.4\ kJ/kg}$$

c) For $T_2 \sim 700$ K, $T_{AVE} \sim 550$ K

From Eq. in Table A.6, $\bar{C}_{P_{AVE}} = 46.0244$

$$\bar{C}_{V0_{AVE}} = \bar{C}_{P0_{AVE}} - \bar{R} = 37.71, \quad k = \bar{C}_{P0}/\bar{C}_{V0} = 1.2205$$

$$T_2 = 400\left(\frac{2.5}{0.12}\right)^{0.1807} = \mathbf{692.4\ K}$$

$$_1w_2 = -\frac{37.71}{44.01}(692.4 - 400) = \mathbf{-250.5\ kJ/kg}$$

8.59 A rigid container with volume 200 L is divided into two equal volumes by a partition. Both sides contain nitrogen, one side is at 2 MPa, 200°C, and the other at 200 kPa, 100°C. The partition ruptures, and the nitrogen comes to a uniform state at 70°C. Assume the temperature of the surroundings is 20°C, determine the work done and the net entropy change for the process.

C.V. : A + B no change in volume. $\mathbf{{}_1W_2 = 0}$

$m_{A1} = P_{A1}V_{A1}/RT_{A1} = (2000 \times 0.1)/(0.2968 \times 473.2) = 1.424 \text{ kg}$

$m_{B1} = P_{B1}V_{B1}/RT_{B1} = (200 \times 0.1)/(0.2968 \times 373.2) = 0.1806 \text{ kg}$

$P_2 = m_{TOT}RT_2/V_{TOT} = (1.6046 \times 0.2968 \times 343.2)/0.2 = 817 \text{ kPa}$

$$\Delta S_{SYST} = 1.424\left[1.0416 \ln\frac{343.2}{473.2} - 0.2968 \ln\frac{817}{2000}\right]$$

$$+ 0.1806\left[1.0416 \ln\frac{343.2}{373.2} - 0.2968 \ln\frac{817}{200}\right] = -0.1893 \text{ kJ/K}$$

${}_1Q_2 = \Delta\, {}_1U_2 = 1.424 \times 0.7448(70 - 200) + 0.1806 \times 0.7448(70 - 100)$

$= -141.9 \text{ kJ}$

$\Delta S_{SURR} = -\,{}_1Q_2/T_0 = 141.9/293.2 = +0.4840 \text{ kJ/K}$

$\Delta S_{NET} = -0.1893 + 0.4840 = \mathbf{+0.2947 \text{ kJ/K}}$