UNIVERSITY OF WATERLOO

DEPARTMENT OF ELECTRICAL ENGINEERING
ECE 309 Thermodynamics Electrical Engineering

Final Examination Solutions Spring 1996
M.M. Yovanovich August 8, 1996 2:00 - 5:00 P.M.

Problem 1

Incompressible liquid.
• (1a) (a) $u = u_f(T = 30\, deg\, C) = 125.8\ [kJ/kg]$
• (1a) (b) $h = h_f(T = 30\, deg\, C) = 135.836\ [kJ/kg]$
• (1a) (b) $s = s_f(T = 30\, deg\, C) = 0.4367\ [kJ/kg \cdot K]$

Ideal gas.
• (1b) (a) $u_2 - u_1 = 215.4\ [kJ/kg]$
• (1b) (b) $h_2 - h_1 = 301.2\ [kJ/kg]$
• (1b) (a) $s_2 - s_1 = -0.82096\ [kJ/kg \cdot K]$

• (1c) (a) $T_f = (T_1 + T_2)/2$
• (1c) (b) $S_2 - S_1 = mc_v \ln\left(T_f^2/(T_1 T_2)\right) = 2mc_v \ln\left(T_f/\sqrt{T_1 T_2}\right)$

Problem 2

• CE/CV: $M_2 - M_1 = -M_e$
• FLOT/CV: $M_2 u_2 - M_1 u_1 = -M_e h_e$
• Combining CE/CV and FLOT/CV: $M_2(h_e - u_2) = M_1(h_e - u_1)$
• Determine h_e. Since $h_{g1} > h_e > h_{g2}$ take mean value:
$h_e = (1472.2 + 1453.3)/2 = 1462.8\, [kJ/kg]$
• $M_1 = 1/0.001726 + 1/0.0833 = 579.4 + 12.0 = 591.4\, [kg]$
• $M_2(h_e - u_2) = M_1 h_e - M_1 u_1 = 635190\, [kJ]$
The unknowns are: M_2 and u_2
• Find $x_2 = 0.01104\, [-]$
• $v_2 = v_{f2} + x_2 v_{fg2} = 0.003853\, [m^3/kg]$
$M_2 = V/v_2 = 2/0.003853 = 519.1\, [kg]$

$M_e = M_1 - M_2 = 591.4 - 519.1 = 72.3\,[kg]$

Problem 3

Total values are based om mass flow rate: $\dot{m} = 20\,[kg/s]$
- (a) $\dot{W}_P = 201.398\,[kW]$
- (b) $\dot{Q}_b = 68956.4\,[kW]$
- (c) $\dot{W}_T = 20814\,[kW]$
- (d) $\dot{Q}_c = 48341.80\,[kW]$
- (e) $\dot{m} = \rho\pi D^2/4V_3$ gives $V = 4\dot{m}v_3/(\pi D^2) = 10.857\,[m/s]$
- (f) $\eta = (\dot{W}_T - \dot{W}_P)/\dot{Q}_b = 0.2989$

Problem 4

- (a) Simple sketch of 2-temperature heat pump
- (b)FLOT/CV gives: $Q_H = Q_L + W$
- (c) SLOT/CV gives: $Q_H/Q_L = T_H/T_L$
- (d) $W = Q_H - Q_L = (Q_H/Q_L - 1)\,Q_L = Q_L/cop$

$cop_1 = (T_H/T_{L_1} - 1) = (293.15/268.15 - 1)^{-1} = 10.726$
$cop_2 = (T_H/T_{L_2} - 1) = (293.15/248.15 - 1)^{-1} = 5.5144$
$W_2/W_1 = cop_1 Q_L/(cop_2 Q_L) = 1.945$
94.5% more work required.

Problem 5

- (a) Simple sketches of the temperature distributions in window before and after defroster is activated. Circuit 1 shows linear temperature distribution. Circuit 2 shows a maximum temperature inside the window near the interior surface.
- (b) Simple thermal circuits before and after the defroster is activated. The thermal resistors are the same before and after. Resistors in circuit 1 are in series. Resistors in circuit 2 are in parallel. There is heat input into the central node and the heat input is split into two streams: one into the interior and one into the exterior.
- (c) Thermal resistances per unit area of the window are:

$R_{f,interior} = 1/h_i = 0.166666\,[Km^2/W]$
$R_{f,exterior} = 1/h_o = 0.0181818\,[Km^2/W]$
$R_{glass} = L/k_{glass} = 0.0021428\,[Km^2/W]$

$R_{total} = 1/h_i + 1/h_o + L/k_{glass} = 0.18699\,[Km^2/W]$
$\dot{Q}/A = (T_{f,i} - T_{f,o})/(R_{total}) = (18 - (-10))/0.18699 = 149.74\,[W/m^2]$
• (d) Assume glass temperature is uniform: $T_i = T_o = T_g$
¿From thermal circuit we find:

$$\frac{T_g - T_{f,o}}{1/h_o} = \frac{T_g - T_{f,i}}{1/h_i} = \frac{\dot{Q}_{gen}}{A}$$

$\dot{Q}_{gen}/A = \dot{Q}_{gen}L = 1500\,[W/m^2]$
Solve for $T_g = 17.344\,[^\circ C]$