UNIVERSITY OF WATERLOO
Department of Electrical and Computer Engineering
Introduction to Thermodynamics and Heat Transfer
E&CE 309

Mid-Term Examination — Spring 2002
R. Karimi — June 10, 02, 9:30-11:15 A.M.

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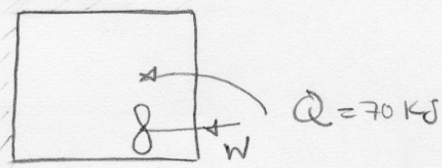
1. **(8)** A closed, rigid tank contains 0.5 kg of dry, saturated steam at 4 bars. Heat is added in the amount of 70 kJ, and some work is done by means of a paddle-wheel until the steam is at 8 bars. Calculate the work required, in kilojoules.

$m = 0.5\,kg$

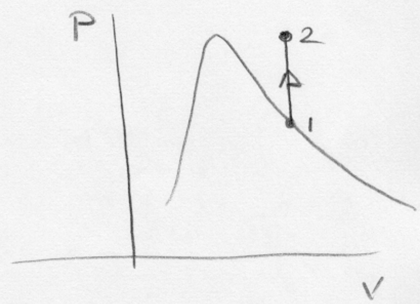


State 1

Sat. steam @ 4 bars

Table A-5
P 850

$T_{sat} = 143.63$ °C
$v_g = .4625$ m^3/kg
$u_g = 2553$ kJ/kg



State 2

$P_2 = 7$ bars

$v_2 = v_1 = .4625\ m^3/kg > v_{g@8bar} = .2404$ (superheated vapor)

Table A-6
P 852

$u_2 = 3182.4$ kJ/kg
$T_2 = 532.8$°C

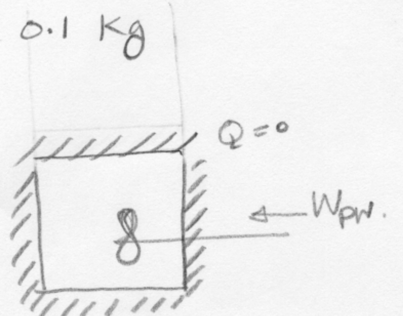
$Q - W = \Delta U$

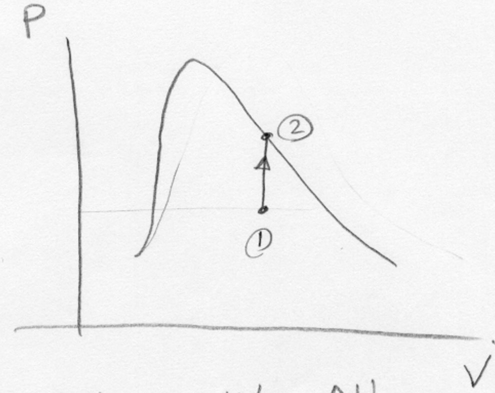
$70 - W = 0.5(3182.4 - 2553)$

$\boxed{W = -244.7\ kJ}$

2. **(10)** One-tenth of a kilogram of water at 3 bars and 76.3% quality is contained in a rigid tank which is thermally insulated. A paddle-wheel inside the tank is turned by an external motor until the substance is a saturated vapor. Determine the work necessary to complete the process and the final pressure and temperature of water.

$m = 0.1$ Kg





$\cancel{Q}^{0} - W = \Delta U \Rightarrow W_{PW} = \Delta U$

State 1 $P_1 = 3$ bars

$x_1 = 0.763$

Table A-5 @ 3bar = 0.3MPa

p850

$$\begin{cases} T_{sat} = 133.55\,^\circ C \\ v_f = .001073 \\ v_g = .6058 \\ u_f = 561.15 \\ u_{fg} = 1982.4 \end{cases}$$

$v_1 = v_f + x v_{fg} = .001073 + .763(.6058 - .001073)$

$v_1 = .4625\ m^3/kg$

$u_1 = u_f + x u_{fg} = 561.15 + .763 \times 1982.4 =$

$u_1 = 2073.72$ KJ/kg.

State 2

$v_2 = v_1 = .4625\,m^3/kg \Rightarrow \begin{cases} P_{sat} = .4\,MPa = 400\ kPa \\ T_{sat} = 143.63\,^\circ C \\ u_g = 2553.6\ KJ/kg \end{cases}$

Saturated vapor

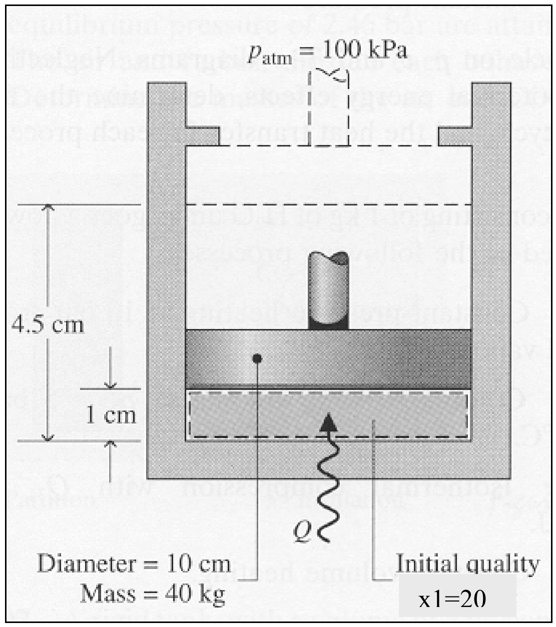
table A-5

p 850

$\Rightarrow W = -\Delta U = -m(u_2 - u_1)$

$W = -0.1(2553.6 - 2073.72) = -48\ KJ$

3. **(12)** A two-phase liquid-vapor mixture of H_2O with an initial quality of 25% is contained in a piston-cylinder assembly as shown in the Figure. The mass of the piston is 40 kg, and its diameter 10 cm. The atmospheric pressure of the surrounding is 1 bar. The initial and final positions of the piston are shown on the diagram. As the water is heated, the pressure inside the cylinder remains constant until the piston hits the stops. Heat transfer to the water continues until its pressure is 3 bar. Friction between the piston and the cylinder wall is negligible. Determine the total amount of heat transfer.



State 1

① $P_1 = P_{pstn} + P_{amb} = \frac{40\times 9.8}{\pi(.1)^2/4} + 100,000 = 149910\ Pa \approx 150K\ Pa$

$x_1 = 0.20$

$V_1 = \frac{\pi D^2}{4} L_1 = \frac{\pi(.1)^2 \times .01}{4} = 7.854\times 10^{-5}\ m^3$

Table A-5, P850 @ P=150kPa = 0.15 MPa

$T_{sat} = 111.37\ °C$
$v_f = .001053\ m^3/kg$
$v_g = 1.1593$
$u_f = 466.94\ kJ/kg$
$u_{fg} = 2052.7$

$\Rightarrow v_{ave,1} = 0.001053 + 0.2(1.1593 - .001053) = .2327\ m^3/kg$

$u_1 = 466.94 + .2(2052.7) = 877.48\ kJ/kg$

$m = \frac{V_1}{v_1} = 3.375\times 10^{-4}\ kg$

State 2

$V_2 = 4.5 \times V_1 = 3.534\times 10^{-4}\ m^3$

$P_2 = P_1 = 150\ kPa$

$v_2 = \frac{V_2}{m} = 1.0474\ m^3/kg < v_g = 1.1593 \Rightarrow$ @ state 2 we still have liq + gas.

$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{1.0474 - .001053}{1.1593 - .001053} \approx 0.90$

$\Rightarrow u_2 = u_f + x u_{fg} = 466.94 + .9(2052.4)$

$u_2 = 2314.37$ KJ/kg

State 3

$P_3 = 3$ bar

$v_3 = v_2 = 1.0474 \; m^3/kg$

from Table A-5 P850 @ 3 bar = 0.3 MPa

Since $v_3 = 1.0474 > v_g = .6058$ we have superheated vapor @ this state.

Table A-6 P852 $\Rightarrow$
$P_3 = 0.3$ MPa, $v_3 = 1.0474$

$$\left\{ \begin{array}{ll} v = 1.0315 & u = 2965.6 \\ v = 1.1867 & 3130.0 \end{array} \right.$$

$v = 1.0474$?

$u_3 = 2982.4$ KJ/kg by interpolation

$$W_{1-3} = \int_1^3 p\,dv = \int_1^2 p\,dv + \int_2^3 p\,dv = P\Delta V =$$

$$= (150 \text{ KPa})(3.534 \times 10^{-4} - 7.854 \times 10^{-5}) = .041 \text{ KJ}.$$

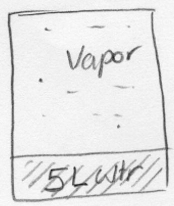
$$Q_{1-3} - W_{13} = \Delta U_{1-3}$$

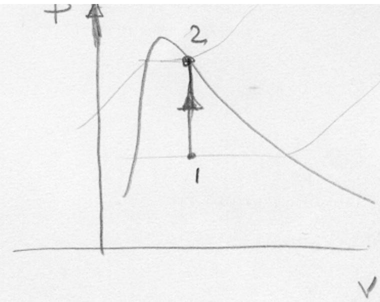
$$Q_{1-3} = \Delta U_{13} + W_{1-3} = [(2982.4 - 877.48) \times 3.375 \times 10^{-4}] + (.041)$$

$$= .71 + .041 = .751 \text{ KJ} \leftarrow$$

4. **(10)** A rigid 1.5 m^3 tank at 200 kPa contains 5 liters of liquid and the remainder steam. Calculate the heat transfer necessary to completely vaporize the water.

$V = 1.5 m^3$





State 1,

$P_1 = 200$ kPa, Liq + Vap.

Table A-5 P 850

@ 0.2 MPa

$T_{sat} = 120.23°C$

$v_f = .001061$ m^3/kg

$v_g = .8857$ "

$u_f = 504.49$ kJ/kg.

$u_{fg} = 2025.0$ "

$$m_{liq} = \frac{V_{liq}}{v_f} = \frac{0.005}{.001061} = 4.71 \text{ kg}.$$

$$m_{vap} = \frac{V_{vap}}{v_g} = \frac{(1.5 - .005)}{.8857} = 1.69 \text{ kg}$$

$$m_t = m_{liq} + m_{vap} = 6.40 \text{ kg}.$$

$$x = \frac{m_{vap}}{m_t} = \frac{1.69}{6.40} = 0.264 \leftarrow$$

$$v_1 = v_f + x v_{fg} = .001061 + .264(.8857 - .001061) = .235 \ m^3/kg$$

$$u_1 = u_f + x u_{fg} = 504.49 + .264(2025.0) = 1039.1 \text{ kJ/kg}.$$

State II

with $v_2 = v_g = v_1 = .235$ in Table A-5, P-850

by interpolation: $u_g = 2577.6$ kJ/kg $\leftarrow$

$$\Rightarrow Q - \cancel{W}^{0} = \Delta U = m_t(u_2 - u_1) = 6.40(2577.6 - 1039.1) = \underline{9846.4 \text{ KJ}}$$