

**Thermodynamics**  
**Professor Anand T N C**  
**Department of Mechanical Engineering**  
**Indian Institute of Technology, Madras**  
**Lecture 48**  
**Tutorial Problems – Part 1**

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1 kg of water at 0.2 MPa is initially enclosed within a volume of 0.10 m<sup>3</sup> in a vertical piston-cylinder arrangement. The piston initially rests on stops and will move when the pressure is 1.0 MPa. During a certain process, an amount heat equal to 2500 kJ is transferred to the water. Determine the work done and the final state of the water.

$m = 1 \text{ kg}$   
 $p_1 = 0.2 \text{ MPa}$   
 $V_1 = 0.1 \text{ m}^3$   
 $Q = 2500 \text{ kJ}$   
 $p_p = 1 \text{ MPa}$   
 $v_1 = \frac{V_1}{m} = \frac{0.1}{1} = 0.1 \text{ m}^3/\text{kg}$

$v_f = 0.001061 \text{ m}^3/\text{kg}$  at saturation  
 $v_g = 0.8857 \text{ m}^3/\text{kg}$  at  $120^\circ\text{C}$

Since  $v_f < v_1 < v_g$ , it is at saturated state  
 $x_1 = ?$   $v_1 = v_f + x(v_g - v_f)$   
 $x = \frac{v_1 - v_f}{v_g - v_f} = \frac{0.1 - 0.001061}{0.8857 - 0.001061} = 0.112$   
 $u_1 = u_f + x(u_g - u_f) = 504.5 + 0.112(2529.1 - 504.5)$   
 $u_1 = 731.25 \text{ kJ/kg}$

C.V. process  
 $V_1 = V_2$   
 $v_1 = v_2$   
 $du = \delta q - \delta w$   
 $\int du = \int \delta q - \int \delta w$   
 $u_2 - u_1 = q - w$   
 $w = q - (u_2 - u_1)$   
 $w = 2500 - (u_2 - 731.25)$   
 $w = 2500 - (u_2 - 731.25)$   
 $w = 2500 - (u_2 - 731.25)$



Figure 1.

Pressure	Temp	sat. liq. v <sub>f</sub>	sat. liq. u <sub>f</sub>	sat. liq. h <sub>f</sub>	sat. liq. s <sub>f</sub>	sat. vapor v <sub>g</sub>	sat. vapor u <sub>g</sub>	sat. vapor h <sub>g</sub>	sat. vapor s <sub>g</sub>
0.01	0.01	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.05	3.28	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.10	6.97	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.20	12.05	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.30	16.78	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.40	21.03	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.50	25.03	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.60	28.86	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.70	32.47	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.80	35.91	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
0.90	39.20	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
1.00	42.50	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
1.20	50.06	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
1.40	57.61	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
1.60	65.05	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
1.80	72.38	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
2.00	79.73	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
2.20	86.99	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
2.40	94.10	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
2.60	101.06	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
2.80	107.93	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
3.00	114.66	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
3.20	121.25	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
3.40	127.70	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
3.60	134.02	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
3.80	140.21	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
4.00	146.28	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
4.20	152.23	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
4.40	158.06	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
4.60	163.78	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
4.80	169.39	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
5.00	174.89	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
5.20	180.28	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
5.40	185.57	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
5.60	190.76	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
5.80	195.85	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
6.00	200.84	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
6.20	205.73	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
6.40	210.52	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
6.60	215.21	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
6.80	219.80	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
7.00	224.29	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
7.20	228.68	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
7.40	232.97	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
7.60	237.16	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
7.80	241.25	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
8.00	245.24	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
8.20	249.13	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
8.40	252.92	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
8.60	256.61	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
8.80	260.20	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
9.00	263.79	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
9.20	267.38	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
9.40	270.87	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
9.60	274.26	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
9.80	277.55	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01
10.00	280.74	0.001000	0.01	0.01	0.01	0.001000	0.01	0.01	0.01



**Solution of the problem in Fig. 1:**

$$m = 1 \text{ kg}, V_1 = 0.1 \text{ m}^3, p_1 = 0.2 \text{ MPa}, v_1 = \frac{V_1}{m} = 0.1 \frac{\text{m}^3}{\text{kg}}, Q = 2500 \text{ kJ}$$

The piston moves when the pressure becomes 1 MPa. Hence, the pressure outside plus the pressure due to the weight of the piston equal 1 MPa.

The initial state is  $p_1 = 0.2 \text{ MPa}$ ,  $v_1 = 0.1 \frac{\text{m}^3}{\text{kg}}$

At 0.2 MPa,  $v_f = 0.001061 \frac{\text{m}^3}{\text{kg}}$ ,  $v_g = 0.8857 \frac{\text{m}^3}{\text{kg}}$  (from steam tables). Hence,  $v_f < v_1 < v_g$ .

Thus, at state 1, we have a mixture of water and vapour (saturated mixture).

Hence, the quality  $x = \frac{v_1 - v_f}{v_g - v_f} = 0.112$

Until the pressure becomes 1 MPa, the process is a constant volume process. Let's calculate the heat required for this constant volume process between  $p_1 = 0.2 \text{ MPa}$ ,  $v_1 = 0.1 \frac{\text{m}^3}{\text{kg}}$  and  $p_2 = 1 \text{ MPa}$ ,  $v_2 = 0.1 \frac{\text{m}^3}{\text{kg}}$ .

The first law for this constant volume process in the integrated form,  $\Delta U = Q$  ( $W = 0$  and there are no changes in kinetic and potential energy)

Now,  $Q = \Delta U = m\Delta u = m(u_2 - u_1)$  .....(1)

Now,  $u_1 = [u_f + x(u_g - u_f)]_{0.2 \text{ MPa}} = 504.5 + 0.112(2529.1 - 504.5) = 731.25 \frac{\text{kJ}}{\text{kg}}$

At  $p_2 = 1 \text{ MPa}$ ,  $v_f = 0.001127 \frac{\text{m}^3}{\text{kg}}$ ,  $v_g = 0.1944 \frac{\text{m}^3}{\text{kg}}$ . Hence,  $v_f < v_2 < v_g$ . Thus, state 2 ( $p_2 = 1 \text{ MPa}$ ,  $v_2 = 0.1 \frac{\text{m}^3}{\text{kg}}$ ) lies inside the liquid-vapour dome.

Now,  $x_2 = \frac{v_2 - v_f}{v_g - v_f} = 0.512$  (The quality has increased in this process. It means there is more vapour now compared to that at the initial state.)

So,  $u_2 = [u_f + x_2(u_g - u_f)]_{1 \text{ MPa}} = 1693.9 \frac{\text{kJ}}{\text{kg}}$ .

Now, (1) implies  $Q = 1(1693.9 - 731.25) = 962.65 \text{ kJ}$ .

Out of the total heat supplied, i.e., 2500 kJ, 962.65 kJ is used up in a constant volume process raising its pressure from 0.2 MPa to 1 MPa (temperature also rises). The remaining heat, which is  $2500 - 962.65 = 1537.35 \text{ kJ}$ , is going to be used in a constant pressure process.

Writing the first law,  $dU = \delta Q - \delta W = \delta Q - pdV$ .

For a constant pressure process,  $dU + pdV + Vdp = \delta Q \rightarrow dH = \delta Q$

Integrating,  $Q_{2-3} = \Delta H = m\Delta h = m(h_3 - h_2)$ .

Now,  $h_2$  is the enthalpy at the state where  $p=1$  MPa and  $v=0.1$  m<sup>3</sup> ( $x_2=0.512$ ).

Hence,

$$h_3 = \frac{Q_{2-3}}{m} + h_2 = \frac{1537.35}{1} + h_f + x_2(h_g - h_f) = 1537.35 + 762.5 + 0.512(2014.6) = 3331.32 \frac{kJ}{kg}.$$

The state 3 is at 1 MPa and  $h_3 = 3331.32$  kJ/kg. At 1 MPa,  $h_g = 2777$  kJ/kg. Since,  $h_3 > h_g$  (at 1 MPa), the state 3 is in the superheated region.

We are also asked to calculate the work done. The work is done only in the second phase of the entire process where pressure was constant.

Writing again the first law for the constant pressure process in the integrated form,

$$\Delta U = Q_{2-3} - W_{2-3} \rightarrow W_{2-3} = Q_{2-3} - m(u_3 - u_2) \dots (2)$$

We need to calculate  $u_3$ .  $h = 3331.32$  kJ/kg lies between the enthalpy values at 400 °C and 450 °C in the table for superheated steam at 1 MPa. Hence, interpolation gives,

$$\frac{T_3 - 400}{450 - 400} = \frac{h_3 - h \text{ at } 400^\circ\text{C}}{h \text{ at } 450^\circ\text{C} - h \text{ at } 400^\circ\text{C}} = \frac{u_3 - u \text{ at } 400^\circ\text{C}}{u \text{ at } 450^\circ\text{C} - u \text{ at } 400^\circ\text{C}}$$

We know  $h_3$ . Solving the above equation,  $T_3 = 431.3$  °C and  $u_3 = 3009.85$  kJ/kg.

Hence, (2) implies  $W_{2-3} = 1537.35 - 1(3009.85 - 1693.9) = 221.4$  kJ.

The entire process on a p-v diagram is shown in Fig. 3. State 3 is the intersection of the isotherm  $T_3 = 431.3$  °C and the isobar  $p=1$  MPa in the superheated zone.

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$\text{Sat. at } 1 \text{ MPa}$   
 $v_f = 0.00127 \text{ m}^3/\text{kg}$   
 $v_g = 0.1944 \text{ m}^3/\text{kg}$   
 $v_2 > v_f \text{ and } v_2 < v_g$   
 $\therefore$  must be in liq-vapour dome  
 $x_2 = ?$   
 $v_2 = v_f + x_2(v_g - v_f)$   
 $\Rightarrow x_2 = \frac{v_2 - v_f}{v_g - v_f} \text{ at } 1 \text{ MPa} \Rightarrow x_2 = \frac{0.1 - 0.00127}{0.1944 - 0.00127} = 0.512$   
 $u_2 = u_f + x_2(u_g - u_f) = 761.4 + 0.512(2582.7 - 761.4)$   
 $u_2 = 1693.9 \text{ kJ/kg}$   
 $u_2 - u_1 = m(u_2 - u_1) = 1 \times (1693.9 - 781.25) = 912.65 \text{ kJ}$   
 $p = c$   
 $du = \delta Q - \delta W$   
 $du = \delta Q - p dv$   
 $du + p dv = \delta Q$   
 $dh = \delta Q \Rightarrow \Delta h = 2500$   
 $\Delta h = 2500$   
 $1 \text{ MPa, } h = 3331.32 \text{ kJ/kg}$   
 $h_2 = h_f + x_2 h_{fg} \text{ at } 1 \text{ MPa}$   
 $= 762.5 + 0.512 \times 2044.6$   
 $= 1793.97 \text{ kJ/kg}$



Pressure	Temp	Volume (m <sup>3</sup> /kg)	Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (kJ/kg.K)
0.01	7.0	0.001000	0.01	0.04	0.035
0.05	16.1	0.001000	0.05	0.18	0.069
0.10	26.1	0.001000	0.10	0.34	0.105
0.20	39.0	0.001000	0.20	0.58	0.161
0.30	49.4	0.001000	0.30	0.78	0.199
0.40	57.8	0.001000	0.40	0.94	0.224
0.50	64.0	0.001000	0.50	1.08	0.241
0.60	68.9	0.001000	0.60	1.20	0.252
0.70	72.9	0.001000	0.70	1.30	0.260
0.80	76.3	0.001000	0.80	1.39	0.266
0.90	79.3	0.001000	0.90	1.47	0.271
1.00	81.1	0.001000	1.00	1.54	0.275
1.20	85.9	0.001000	1.20	1.67	0.283
1.40	90.0	0.001000	1.40	1.78	0.289
1.60	93.5	0.001000	1.60	1.88	0.294
1.80	96.7	0.001000	1.80	1.97	0.298
2.00	99.6	0.001000	2.00	2.05	0.302
2.20	102.3	0.001000	2.20	2.12	0.305
2.40	104.8	0.001000	2.40	2.19	0.308
2.60	107.1	0.001000	2.60	2.25	0.311
2.80	109.3	0.001000	2.80	2.31	0.313
3.00	111.4	0.001000	3.00	2.36	0.315
3.20	113.4	0.001000	3.20	2.41	0.317
3.40	115.3	0.001000	3.40	2.45	0.319
3.60	117.1	0.001000	3.60	2.49	0.321
3.80	118.9	0.001000	3.80	2.53	0.323
4.00	120.6	0.001000	4.00	2.56	0.325
4.20	122.2	0.001000	4.20	2.59	0.327
4.40	123.7	0.001000	4.40	2.62	0.329
4.60	125.1	0.001000	4.60	2.65	0.331
4.80	126.5	0.001000	4.80	2.68	0.333
5.00	127.8	0.001000	5.00	2.70	0.335
5.20	129.1	0.001000	5.20	2.73	0.337
5.40	130.3	0.001000	5.40	2.75	0.339
5.60	131.5	0.001000	5.60	2.78	0.341
5.80	132.6	0.001000	5.80	2.80	0.343
6.00	133.7	0.001000	6.00	2.82	0.345
6.20	134.8	0.001000	6.20	2.84	0.347
6.40	135.8	0.001000	6.40	2.86	0.349
6.60	136.8	0.001000	6.60	2.88	0.351
6.80	137.8	0.001000	6.80	2.90	0.353
7.00	138.8	0.001000	7.00	2.92	0.355
7.20	139.7	0.001000	7.20	2.94	0.357
7.40	140.7	0.001000	7.40	2.96	0.359
7.60	141.6	0.001000	7.60	2.98	0.361
7.80	142.5	0.001000	7.80	3.00	0.363
8.00	143.4	0.001000	8.00	3.02	0.365
8.20	144.3	0.001000	8.20	3.04	0.367
8.40	145.2	0.001000	8.40	3.06	0.369
8.60	146.1	0.001000	8.60	3.08	0.371
8.80	147.0	0.001000	8.80	3.10	0.373
9.00	147.9	0.001000	9.00	3.12	0.375
9.20	148.8	0.001000	9.20	3.14	0.377
9.40	149.7	0.001000	9.40	3.16	0.379
9.60	150.6	0.001000	9.60	3.18	0.381
9.80	151.5	0.001000	9.80	3.20	0.383
10.00	152.4	0.001000	10.00	3.22	0.385



1 kg of water at 0.2 MPa is initially enclosed within a volume of 0.10 m<sup>3</sup> in a vertical piston-cylinder arrangement. The piston initially rests on stops and will move when the pressure is 1.0 MPa. During a certain process, an amount heat equal to 2500 kJ is transferred to the water. Determine the work done and the final state of the water.

$m = 1 \text{ kg}$   
 $p_1 = 0.2 \text{ MPa}$   
 $V_1 = 0.1 \text{ m}^3$   
 $Q = 2500 \text{ kJ}$   
 $v_f = 0.001061 \text{ m}^3/\text{kg}$  at saturation  
 $v_g = 0.8857 \text{ m}^3/\text{kg}$  at  $120.2^\circ\text{C}$   
 Since  $v_1 < v_f$ , 1 is at saturated state  
 $x_1 = ?$   
 $v_1 = v_f + x_1(v_g - v_f)$   
 $x_1 = \frac{v_1 - v_f}{v_g - v_f} = \frac{0.1 - 0.001061}{0.8857 - 0.001061} = 0.112$   
 $u_1 = u_f + x_1(u_g - u_f) = 504.5 + 0.112(2529.1 - 504.5)$   
 $u_1 = 731.25 \text{ kJ/kg}$   
 $p_2 = 1 \text{ MPa}$   
 $v_2 = \frac{V_2}{m} = \frac{0.1}{1} = 0.1 \text{ m}^3/\text{kg}$   
 $v_2 > v_g$  at  $1 \text{ MPa}$   
 $\therefore$  must be in superheated region  
 $u_2 = 2582.7 \text{ kJ/kg}$   
 $Q = 2500 \text{ kJ}$   
 $Q = \Delta u + W$   
 $2500 = (u_2 - u_1) + W$   
 $2500 = (2582.7 - 731.25) + W$   
 $W = 648.25 \text{ kJ}$



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[illegible]

$$T_h = 400^\circ\text{C} \quad 3264.5$$

$$T_c = 450^\circ\text{C} \quad 3374.3$$

$$h = 3331.32$$

$$T_j = 431.3^\circ\text{C}$$

$$x_{H_2O} = m \cdot p \cdot dV = m \cdot \Delta u$$

$$u_{H_2O} = 1693.9$$

$$u_g = 3009.85$$

$$2H_2O = 1 \times (u_3 - u_2)$$

$$2H_2O = 1315.9 \text{ kJ} \checkmark$$

Final state :  $b = 1 \text{ MR}$  superheated steam  
 $T_3 = 431.3^\circ\text{C}$



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Sol: at 1 MPa  $v_2 = 0.1 \text{ m}^3/\text{kg}$   
 $v_f = 0.00127 \text{ m}^3/\text{kg}$   
 $v_g = 0.1944 \text{ m}^3/\text{kg}$   
 $v_2 > v_f \text{ and } v_2 < v_g$   
 $\therefore$  2 meet in dry-vapour dome  
 $x_2 = ?$   $v_2 = v_f + x(v_g - v_f)$   
 $\Rightarrow x_2 = \frac{v_2 - v_f}{v_g - v_f} \} @ 1 \text{ MPa} \Rightarrow x_2 = \frac{0.1 - 0.00127}{0.1944 - 0.00127} = 0.512$   
 $u_2 = u_{f2} + x_2(u_{g2} - u_{f2}) = 761.4 + 0.512 \times (2582.7 - 761.4)$   
 $u_2 = 1693.9 \text{ kJ/kg}$   
 $u_2 - u_1 = m(u_2 - u_1) = 1 \times (1693.9 - 331.25) = 1362.65 \text{ kJ}$   
 $p = c$   
 $du = 6R - 6W$   
 $du = 6R - p dV$   
 $du + p dV = 6R$   
 $dH = 6R \Rightarrow \Delta H = 24.3$   
 $\Delta h = 24.3$   
 $1537.35 = h_3 - h_2$   
 $h_3 = 1537.35 + h_2$   
 $h_3 = 3331.32 \text{ kJ/kg}$   
 $1 \text{ MPa}, h = 3331.32 \text{ kJ/kg}$   
 $h_2 = h_f + x h_{fg} @ 1 \text{ MPa}$   
 $= 762.5 + 204.6$   
 $= 967.1 \text{ kJ/kg}$



Figure 2.