

Thermodynamics

Professor Anand TNC

Department of Mechanical Engineering

Indian Institute of Technology, Madras

Lecture 49

Tutorial Problem Part-2

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A pressure cooker (closed tank) contains water at 100°C with the liquid volume being 1/20th of the vapor volume. It is heated until the pressure reaches 2.0 MPa. Find the final temperature. Does the final state have more or less vapor than the initial state?

$$T_1 = 100^\circ\text{C}$$

$$V_f = \frac{1}{20} V_g$$

$$V_f = v_f \times m_f$$

$$V_g = v_g \times m_g$$

$$v_f = 0.001044 \text{ m}^3/\text{kg}$$

$$v_g = 1.672 \text{ m}^3/\text{kg}$$

$$v_f m_f = \frac{v_f m_g}{20} \quad m_f = \frac{v_f \times m_g}{20}$$

$$x = \frac{m_f}{m_f + m_g} = \frac{m_g}{m_g + 20m_g} = \frac{1}{21} = 0.0476$$



Figure 1.

Properties of Saturated Water									
P (kPa)					P (MPa)				
T (°C)	v _f (m ³ /kg)	v _g (m ³ /kg)	u _f (kJ/kg)	u _g (kJ/kg)	T (°C)	v _f (m ³ /kg)	v _g (m ³ /kg)	u _f (kJ/kg)	u _g (kJ/kg)
0	0.001	206.1	0.000	0.000	0	0.001	206.1	0.000	0.000
5	0.001	206.0	0.000	0.000	5	0.001	206.0	0.000	0.000
10	0.001	205.9	0.000	0.000	10	0.001	205.9	0.000	0.000
15	0.001	205.8	0.000	0.000	15	0.001	205.8	0.000	0.000
20	0.001	205.7	0.000	0.000	20	0.001	205.7	0.000	0.000
25	0.001	205.6	0.000	0.000	25	0.001	205.6	0.000	0.000
30	0.001	205.5	0.000	0.000	30	0.001	205.5	0.000	0.000
35	0.001	205.4	0.000	0.000	35	0.001	205.4	0.000	0.000
40	0.001	205.3	0.000	0.000	40	0.001	205.3	0.000	0.000
45	0.001	205.2	0.000	0.000	45	0.001	205.2	0.000	0.000
50	0.001	205.1	0.000	0.000	50	0.001	205.1	0.000	0.000
55	0.001	205.0	0.000	0.000	55	0.001	205.0	0.000	0.000
60	0.001	204.9	0.000	0.000	60	0.001	204.9	0.000	0.000
65	0.001	204.8	0.000	0.000	65	0.001	204.8	0.000	0.000
70	0.001	204.7	0.000	0.000	70	0.001	204.7	0.000	0.000
75	0.001	204.6	0.000	0.000	75	0.001	204.6	0.000	0.000
80	0.001	204.5	0.000	0.000	80	0.001	204.5	0.000	0.000
85	0.001	204.4	0.000	0.000	85	0.001	204.4	0.000	0.000
90	0.001	204.3	0.000	0.000	90	0.001	204.3	0.000	0.000
95	0.001	204.2	0.000	0.000	95	0.001	204.2	0.000	0.000
100	0.001	204.1	0.000	0.000	100	0.001	204.1	0.000	0.000
105	0.001	204.0	0.000	0.000	105	0.001	204.0	0.000	0.000
110	0.001	203.9	0.000	0.000	110	0.001	203.9	0.000	0.000
115	0.001	203.8	0.000	0.000	115	0.001	203.8	0.000	0.000
120	0.001	203.7	0.000	0.000	120	0.001	203.7	0.000	0.000
125	0.001	203.6	0.000	0.000	125	0.001	203.6	0.000	0.000
130	0.001	203.5	0.000	0.000	130	0.001	203.5	0.000	0.000
135	0.001	203.4	0.000	0.000	135	0.001	203.4	0.000	0.000
140	0.001	203.3	0.000	0.000	140	0.001	203.3	0.000	0.000
145	0.001	203.2	0.000	0.000	145	0.001	203.2	0.000	0.000
150	0.001	203.1	0.000	0.000	150	0.001	203.1	0.000	0.000
155	0.001	203.0	0.000	0.000	155	0.001	203.0	0.000	0.000
160	0.001	202.9	0.000	0.000	160	0.001	202.9	0.000	0.000
165	0.001	202.8	0.000	0.000	165	0.001	202.8	0.000	0.000
170	0.001	202.7	0.000	0.000	170	0.001	202.7	0.000	0.000
175	0.001	202.6	0.000	0.000	175	0.001	202.6	0.000	0.000
180	0.001	202.5	0.000	0.000	180	0.001	202.5	0.000	0.000
185	0.001	202.4	0.000	0.000	185	0.001	202.4	0.000	0.000
190	0.001	202.3	0.000	0.000	190	0.001	202.3	0.000	0.000
195	0.001	202.2	0.000	0.000	195	0.001	202.2	0.000	0.000
200	0.001	202.1	0.000	0.000	200	0.001	202.1	0.000	0.000
205	0.001	202.0	0.000	0.000	205	0.001	202.0	0.000	0.000
210	0.001	201.9	0.000	0.000	210	0.001	201.9	0.000	0.000
215	0.001	201.8	0.000	0.000	215	0.001	201.8	0.000	0.000
220	0.001	201.7	0.000	0.000	220	0.001	201.7	0.000	0.000
225	0.001	201.6	0.000	0.000	225	0.001	201.6	0.000	0.000
230	0.001	201.5	0.000	0.000	230	0.001	201.5	0.000	0.000
235	0.001	201.4	0.000	0.000	235	0.001	201.4	0.000	0.000
240	0.001	201.3	0.000	0.000	240	0.001	201.3	0.000	0.000
245	0.001	201.2	0.000	0.000	245	0.001	201.2	0.000	0.000
250	0.001	201.1	0.000	0.000	250	0.001	201.1	0.000	0.000
255	0.001	201.0	0.000	0.000	255	0.001	201.0	0.000	0.000
260	0.001	200.9	0.000	0.000	260	0.001	200.9	0.000	0.000
265	0.001	200.8	0.000	0.000	265	0.001	200.8	0.000	0.000
270	0.001	200.7	0.000	0.000	270	0.001	200.7	0.000	0.000
275	0.001	200.6	0.000	0.000	275	0.001	200.6	0.000	0.000
280	0.001	200.5	0.000	0.000	280	0.001	200.5	0.000	0.000
285	0.001	200.4	0.000	0.000	285	0.001	200.4	0.000	0.000
290	0.001	200.3	0.000	0.000	290	0.001	200.3	0.000	0.000
295	0.001	200.2	0.000	0.000	295	0.001	200.2	0.000	0.000
300	0.001	200.1	0.000	0.000	300	0.001	200.1	0.000	0.000
305	0.001	200.0	0.000	0.000	305	0.001	200.0	0.000	0.000
310	0.001	199.9	0.000	0.000	310	0.001	199.9	0.000	0.000
315	0.001	199.8	0.000	0.000	315	0.001	199.8	0.000	0.000
320	0.001	199.7	0.000	0.000	320	0.001	199.7	0.000	0.000
325	0.001	199.6	0.000	0.000	325	0.001	199.6	0.000	0.000
330	0.001	199.5	0.000	0.000	330	0.001	199.5	0.000	0.000
335	0.001	199.4	0.000	0.000	335	0.001	199.4	0.000	0.000
340	0.001	199.3	0.000	0.000	340	0.001	199.3	0.000	0.000
345	0.001	199.2	0.000	0.000	345	0.001	199.2	0.000	0.000
350	0.001	199.1	0.000	0.000	350	0.001	199.1	0.000	0.000
355	0.001	199.0	0.000	0.000	355	0.001	199.0	0.000	0.000
360	0.001	198.9	0.000	0.000	360	0.001	198.9	0.000	0.000
365	0.001	198.8	0.000	0.000	365	0.001	198.8	0.000	0.000
370	0.001	198.7	0.000	0.000	370	0.001	198.7	0.000	0.000
375	0.001	198.6	0.000	0.000	375	0.001	198.6	0.000	0.000
380	0.001	198.5	0.000	0.000	380	0.001	198.5	0.000	0.000
385	0.001	198.4	0.000	0.000	385	0.001	198.4	0.000	0.000
390	0.001	198.3	0.000	0.000	390	0.001	198.3	0.000	0.000
395	0.001	198.2	0.000	0.000	395	0.001	198.2	0.000	0.000
400	0.001	198.1	0.000	0.000	400	0.001	198.1	0.000	0.000
405	0.001	198.0	0.000	0.000	405	0.001	198.0	0.000	0.000
410	0.001	197.9	0.000	0.000	410	0.001	197.9	0.000	0.000
415	0.001	197.8	0.000	0.000	415	0.001	197.8	0.000	0.000
420	0.001	197.7	0.000	0.000	420	0.001	197.7	0.000	0.000
425	0.001	197.6	0.000	0.000	425	0.001	197.6	0.000	0.000
430	0.001	197.5	0.000	0.000	430	0.001	197.5	0.000	0.000
435	0.001	197.4	0.000	0.000	435	0.001	197.4	0.000	0.000
440	0.001	197.3	0.000	0.000	440	0.001	197.3	0.000	0.000
445	0.001	197.2	0.000	0.000	445	0.001	197.2	0.000	0.000
450	0.001	197.1	0.000	0.000	450	0.001	197.1	0.000	0.000
455	0.001	197.0	0.000	0.000	455	0.001	197.0	0.000	0.000
460	0.001	196.9	0.000	0.000	460	0.001	196.9	0.000	0.000
465	0.001	196.8	0.000	0.000	465	0.001	196.8	0.000	0.000
470	0.001	196.7	0.000	0.000	470	0.001	196.7	0.000	0.000
475	0.001	196.6	0.000	0.000	475	0.001	196.6	0.000	0.000
480	0.001	196.5	0.000	0.000	480	0.001	196.5	0.000	0.000
485	0.001	196.4	0.000	0.000	485	0.001	196.4	0.000	0.000
490	0.001	196.3	0.000	0.000	490	0.001	196.3	0.000	0.000
495	0.001	196.2	0.000	0.000	495	0.001	196.2	0.000	0.000
500	0.001	196.1	0.000	0.000	500	0.001	196.1	0.000	0.000





$$\begin{aligned}
 x_1 &= v_f + x(v_g - v_f) \\
 &= 0.001044 + 0.012(1.172 - 0.001044) \\
 x_1 &= 0.021 \text{ m}^3/\text{kg} \\
 v_2 &= v_1 = 0.021 \text{ m}^3/\text{kg} \\
 p_2 &= 2 \text{ MPa} \quad v_g = 0.001177 \quad v_f = 0.09959 \\
 v_2 < v_g \text{ and } v_2 > v_f &\Rightarrow 2 \text{ is in saturated state} \\
 x_2 &=? \quad v_2 = v_f + x_2(v_g - v_f) @ 2 \text{ MPa} \\
 x_2 &= \frac{v_2 - v_f}{v_g - v_f} = \frac{0.021 - 0.001177}{0.09959 - 0.001177} = 0.2
 \end{aligned}$$

$$T_2 = T_{\text{sat}} @ 2 \text{ MPa} = 212.4^\circ\text{C}$$

$$m_{\text{vap}1} = x_1 \times m$$

$$m_{\text{vap}2} = x_2 \times m$$

$$\begin{aligned}
 & \text{Vapour} \\
 m_{\text{vap}1} &< m_{\text{vap}2} \\
 0.01 & \quad 0.2
 \end{aligned}$$



Phase	Temp	volume (m ³ /kg)	energy (kJ/kg)	entropy (kJ/kg.K)
0.01	25	0.001000	102.91	0.36723
0.012	9.1	0.001000	108.46	0.36723
0.014	12.1	0.001000	115.07	0.36723
0.015	14.5	0.001000	122.48	0.36723
0.017	15.8	0.001000	130.46	0.36723
0.02	17.5	0.001000	139.10	0.36723
0.025	24.1	0.001000	154.80	0.36723
0.03	29.0	0.001000	170.43	0.36723
0.04	36.0	0.001000	186.00	0.36723
0.05	41.5	0.001000	199.35	0.36723
0.07	49.8	0.001000	214.53	0.36723
0.10	59.8	0.001000	230.86	0.36723
0.15	72.0	0.001000	247.00	0.36723
0.20	81.5	0.001000	253.17	0.36723
0.25	89.0	0.001000	258.27	0.36723
0.30	94.5	0.001000	262.51	0.36723
0.35	98.5	0.001000	265.99	0.36723
0.40	101.5	0.001000	268.81	0.36723
0.45	103.5	0.001000	271.00	0.36723
0.50	104.5	0.001000	272.70	0.36723
0.55	105.0	0.001000	274.00	0.36723
0.60	105.0	0.001000	275.00	0.36723
0.65	105.0	0.001000	275.80	0.36723
0.70	105.0	0.001000	276.40	0.36723
0.75	105.0	0.001000	276.80	0.36723
0.80	105.0	0.001000	277.00	0.36723
0.85	105.0	0.001000	277.10	0.36723
0.90	105.0	0.001000	277.10	0.36723
0.95	105.0	0.001000	277.10	0.36723
1.00	105.0	0.001000	277.10	0.36723



Solution of the problem in Fig .1:

$$T_1 = 100^\circ\text{C}, V_f = \frac{1}{20} V_g, p_2 = 2 \text{ MPa}$$

The insides of the pressure cooker form our system.

Initial state is in the two-phase zone since there is a mixture of water and steam in equilibrium.

Now, $V_f = \frac{1}{20}V_g \rightarrow v_f m_f = \frac{1}{20}v_g m_g$ where v_f and v_g can be found from steam tables at 100 °C. At 100 °C, $v_f = 0.001044 \text{ m}^3/\text{kg}$ and $v_g = 1.672 \text{ m}^3/\text{kg}$. Hence, $m_f = 80.07 m_g$.

$$\text{Now, } x_1 = \frac{m_g}{m_f + m_g} = 0.0123$$

The mixture is heated until the pressure reaches $p_2 = 2 \text{ MPa}$ at constant volume. Hence, $v_1 = v_2$.

$$\text{Now, } v_1 = [v_f + x_1(v_g - v_f)]_{100 \text{ }^\circ\text{C}} = 0.021 \frac{\text{m}^3}{\text{kg}} = v_2 \text{ (at 2 MPa)}$$

At state 2 (final state), $p_2 = 2 \text{ MPa}$, $v_f = 0.001177 \frac{\text{m}^3}{\text{kg}}$, $v_g = 0.09959 \frac{\text{m}^3}{\text{kg}}$. Now, $v_f < v_2 < v_g$.

Hence, the state 2 is inside the liquid-vapor dome.

$$\text{Now, } x_2 = \frac{v_2 - v_f}{v_g - v_f} = 0.2$$

The final temperature $T_2 =$ the saturation temperature at 2 MPa = 212.4 °C.

Now, mass of the vapor at state 1, $m_{vap,1} = x_1 m$. Similarly, $m_{vap,2} = x_2 m$. Since the mass is fixed and $x_2 > x_1$, the mass of the vapor at state 2 is larger than that at state 1.