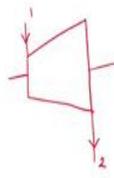


Thermodynamics
Professor Anand T N C
Department of Mechanical Engineering
Indian Institute of Technology Madras
Lecture 56
Tutorial Problems - Part 1

(Refer Slide Time: 00:13)

A steam turbine is having the following specifications:

- Height of the inlet valve from factory floor = 05 m
- Height of the outlet valve from factory floor = 02 m
- Velocity of steam at inlet = 50 m/s
- Velocity of steam at outlet = 100 m/s
- Pressure of steam at the inlet = 02 MPa
- Pressure of steam at the outlet = 15 kPa
- Temperature of steam at the inlet = 400 °C
- Quality of the steam at the outlet = 0.9
- Power output = 10 MW





(a) Compare the relative contribution of change in potential energy, change in kinetic energy and change in enthalpy towards the work output.

(b) Find the mass flow rate of the steam.

$$\frac{dE_{cv}}{dt} = Q - W + \dot{m} \left[h_i + \frac{V_i^2}{2} + g z_i \right] - \dot{m} \left[h_e + \frac{V_e^2}{2} + g z_e \right]$$

$$\frac{dE_{cv}}{dt} = \dot{m}_i - \dot{m}_e ; \dot{m}_i = \dot{m}_e = \dot{m}$$



Figure 1.

$$W = \dot{m} \left[h_i + \frac{V_i^2}{2} + g z_i \right] - \dot{m} \left[h_e + \frac{V_e^2}{2} + g z_e \right]$$

$$10 \times 10^6 \text{ W} = \dot{m} \left[\left[\frac{2248.3}{10^3} + \frac{50^2}{2} + 9.81 \times 5 \right] - \left[\frac{2360.9}{10^3} + \frac{100^2}{2} + 9.81 \times 2 \right] \right]$$

$$10 \times 10^6 = 883679.4 \dot{m}$$

$$\Rightarrow \dot{m} = 11.3 \text{ kg/s}$$

$$w = \frac{W}{\dot{m}} = 883679.4 \text{ J/kg}$$

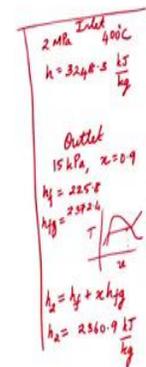
$$\Delta h = 887.4 \times 10^3 \text{ J/kg}$$

$$\frac{\Delta h}{w} = 1$$

$$\Delta ke = -3750 \text{ J/kg}$$

$$\frac{\Delta ke}{w} = -4 \times 10^{-3}$$

$$\Delta pe = 2943 \text{ J/kg} \Rightarrow \frac{\Delta pe}{w} = 3.3 \times 10^{-3}$$





Inlet	400°C
2 MPa	$h = 3248.3 \frac{\text{kJ}}{\text{kg}}$
Outlet	15 kPa, x=0.9
$h_f = 225.8$	$h_{fg} = 2392.4$
$h_2 = h_f + x h_{fg}$	$h_2 = 2360.9 \frac{\text{kJ}}{\text{kg}}$



Properties of saturated Water - Pressure Table													
Pressure	Temp.	sat. liquid (f)			sat. vapor (g)			sat. liquid-vapor mixture			sat. vapor (g)		
MPa	°C	v_f	v_g	v_{fg}	u_f	u_g	u_{fg}	h_f	h_g	h_{fg}	s_f	s_g	
0.01	6.98	0.001000	206.136	206.135	0.02344	2404.7	2404.7	0.00021	2511.8	2511.8	0.00000	8.0333	
0.05	32.82	0.001000	100.643	100.642	0.03240	2403.7	2403.7	0.00021	2511.8	2511.8	0.00000	8.0333	
0.10	50.06	0.001000	69.401	69.400	0.03848	2402.8	2402.8	0.00021	2511.8	2511.8	0.00000	8.0333	
0.20	70.07	0.001000	47.325	47.324	0.04462	2401.9	2401.9	0.00021	2511.8	2511.8	0.00000	8.0333	
0.30	81.33	0.001000	38.133	38.132	0.04978	2401.1	2401.1	0.00021	2511.8	2511.8	0.00000	8.0333	
0.40	89.06	0.001000	32.077	32.076	0.05444	2400.4	2400.4	0.00021	2511.8	2511.8	0.00000	8.0333	
0.50	93.99	0.001000	28.158	28.157	0.05864	2399.8	2399.8	0.00021	2511.8	2511.8	0.00000	8.0333	
0.60	97.76	0.001000	25.674	25.673	0.06244	2399.3	2399.3	0.00021	2511.8	2511.8	0.00000	8.0333	
0.70	100.68	0.001000	23.923	23.922	0.06589	2398.9	2398.9	0.00021	2511.8	2511.8	0.00000	8.0333	
0.80	103.06	0.001000	22.580	22.579	0.06904	2398.6	2398.6	0.00021	2511.8	2511.8	0.00000	8.0333	
0.90	105.06	0.001000	21.527	21.526	0.07184	2398.4	2398.4	0.00021	2511.8	2511.8	0.00000	8.0333	
1.00	106.76	0.001000	20.731	20.730	0.07435	2398.3	2398.3	0.00021	2511.8	2511.8	0.00000	8.0333	
1.20	108.35	0.001000	19.512	19.511	0.07763	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
1.40	109.73	0.001000	18.520	18.519	0.08054	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
1.60	110.93	0.001000	17.699	17.698	0.08313	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
1.80	111.96	0.001000	16.996	16.995	0.08545	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.00	112.84	0.001000	16.373	16.372	0.08754	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.20	113.59	0.001000	15.814	15.813	0.08945	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.40	114.24	0.001000	15.300	15.299	0.09113	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.60	114.80	0.001000	14.821	14.820	0.09263	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.80	115.28	0.001000	14.376	14.375	0.09398	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
3.00	115.69	0.001000	13.956	13.955	0.09519	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
3.20	116.04	0.001000	13.551	13.550	0.09628	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
3.40	116.34	0.001000	13.161	13.160	0.09727	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
3.60	116.60	0.001000	12.785	12.784	0.09817	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
3.80	116.82	0.001000	12.423	12.422	0.09900	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
4.00	117.01	0.001000	12.074	12.073	0.09976	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
4.20	117.17	0.001000	11.738	11.737	0.10056	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
4.40	117.31	0.001000	11.414	11.413	0.10130	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
4.60	117.43	0.001000	11.101	11.100	0.10200	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
4.80	117.53	0.001000	10.798	10.797	0.10266	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
5.00	117.62	0.001000	10.505	10.504	0.10329	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
5.20	117.69	0.001000	10.221	10.220	0.10389	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
5.40	117.75	0.001000	9.946	9.945	0.10446	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
5.60	117.79	0.001000	9.679	9.678	0.10501	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
5.80	117.82	0.001000	9.420	9.419	0.10554	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
6.00	117.84	0.001000	9.169	9.168	0.10606	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
6.20	117.85	0.001000	8.926	8.925	0.10657	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
6.40	117.85	0.001000	8.690	8.689	0.10707	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
6.60	117.84	0.001000	8.461	8.460	0.10756	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
6.80	117.82	0.001000	8.239	8.238	0.10804	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
7.00	117.79	0.001000	8.024	8.023	0.10851	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
7.20	117.75	0.001000	7.815	7.814	0.10897	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
7.40	117.70	0.001000	7.613	7.612	0.10942	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
7.60	117.64	0.001000	7.417	7.416	0.10986	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
7.80	117.57	0.001000	7.227	7.226	0.11029	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
8.00	117.49	0.001000	7.043	7.042	0.11071	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
8.20	117.40	0.001000	6.865	6.864	0.11112	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
8.40	117.30	0.001000	6.693	6.692	0.11152	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
8.60	117.19	0.001000	6.527	6.526	0.11191	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
8.80	117.07	0.001000	6.367	6.366	0.11229	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
9.00	116.94	0.001000	6.213	6.212	0.11266	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
9.20	116.80	0.001000	6.064	6.063	0.11302	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
9.40	116.65	0.001000	5.921	5.920	0.11337	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
9.60	116.49	0.001000	5.783	5.782	0.11371	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
9.80	116.32	0.001000	5.650	5.649	0.11404	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
10.00	116.14	0.001000	5.522	5.521	0.11436	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	



Properties of Saturated Water - Pressure Table													
Pressure	Temp.	sat. liquid (f)			sat. vapor (g)			sat. liquid-vapor mixture			sat. vapor (g)		
MPa	°C	v_f	v_g	v_{fg}	u_f	u_g	u_{fg}	h_f	h_g	h_{fg}	s_f	s_g	
0.01	6.98	0.001000	206.136	206.135	0.02344	2404.7	2404.7	0.00021	2511.8	2511.8	0.00000	8.0333	
0.05	32.82	0.001000	100.643	100.642	0.03240	2403.7	2403.7	0.00021	2511.8	2511.8	0.00000	8.0333	
0.10	50.06	0.001000	69.401	69.400	0.03848	2402.8	2402.8	0.00021	2511.8	2511.8	0.00000	8.0333	
0.20	70.07	0.001000	47.325	47.324	0.04462	2401.9	2401.9	0.00021	2511.8	2511.8	0.00000	8.0333	
0.30	81.33	0.001000	38.133	38.132	0.04978	2401.1	2401.1	0.00021	2511.8	2511.8	0.00000	8.0333	
0.40	89.06	0.001000	32.077	32.076	0.05444	2400.4	2400.4	0.00021	2511.8	2511.8	0.00000	8.0333	
0.50	93.99	0.001000	28.158	28.157	0.05864	2399.8	2399.8	0.00021	2511.8	2511.8	0.00000	8.0333	
0.60	97.76	0.001000	25.674	25.673	0.06244	2399.3	2399.3	0.00021	2511.8	2511.8	0.00000	8.0333	
0.70	100.68	0.001000	23.923	23.922	0.06589	2398.9	2398.9	0.00021	2511.8	2511.8	0.00000	8.0333	
0.80	103.06	0.001000	22.580	22.579	0.06904	2398.6	2398.6	0.00021	2511.8	2511.8	0.00000	8.0333	
0.90	105.06	0.001000	21.527	21.526	0.07184	2398.4	2398.4	0.00021	2511.8	2511.8	0.00000	8.0333	
1.00	106.76	0.001000	20.731	20.730	0.07435	2398.3	2398.3	0.00021	2511.8	2511.8	0.00000	8.0333	
1.20	108.35	0.001000	19.512	19.511	0.07763	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
1.40	109.73	0.001000	18.520	18.519	0.08054	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
1.60	110.93	0.001000	17.699	17.698	0.08313	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
1.80	111.96	0.001000	16.996	16.995	0.08545	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.00	112.84	0.001000	16.373	16.372	0.08754	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.20	113.59	0.001000	15.814	15.813	0.08945	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.40	114.24	0.001000	15.300	15.299	0.09113	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.60	114.80	0.001000	14.821	14.820	0.09263	2398.2	2398.2	0.00021	2511.8	2511.8	0.00000	8.0333	
2.80	115.28	0.001000	14.376	14.375	0.09398	2398.2	2398.2	0.00021	2511.8				

$$\dot{m}_i = \dot{m}_e = \dot{m}.$$

$$\text{Hence, mass flow rate of the steam} = \dot{m} = \frac{\dot{W}_{cv}}{\left(h_i + \frac{1}{2}\bar{v}_i^2 + gZ_i\right) - \left(h_e + \frac{1}{2}\bar{v}_e^2 + gZ_e\right)} \dots (2)$$

At the inlet, at 0.2 MPa, $T_{sat} = 212^\circ\text{C}$. Since, $400^\circ\text{C} > T_{sat}$, the steam is in superheated zone.

From the tables for superheated steam, $h_i = 3248.3 \frac{\text{kJ}}{\text{kg}}$.

At the outlet, $h_e = [h_f + x(h_{fg})]_{15 \text{ kPa}} = 2360.9 \frac{\text{kJ}}{\text{kg}}$

$$(2) \text{ implies } \dot{m} = \frac{10 \times 10^6}{\left(3248.3 \times 10^3 + \frac{50^2}{2} + 9.81 \times 5\right) - \left(2360.9 \times 10^3 + \frac{100^2}{2} + 9.81 \times 2\right)} = 11.316 \frac{\text{kg}}{\text{s}}$$

$$\text{Now, } w = \frac{\dot{W}}{\dot{m}} = 883679.4 \frac{\text{J}}{\text{kg}}$$

$$|\Delta h| = h_i - h_e = 887.4 \times 10^3 \frac{\text{J}}{\text{kg}}$$

$$\frac{|\Delta h|}{w} = 1$$

$$|\Delta ke| = \left| \frac{\bar{v}_i^2}{2} - \frac{\bar{v}_e^2}{2} \right| = 3750. \text{ Hence, } \frac{|\Delta ke|}{w} = 0.004$$

$$\text{Similarly, } \frac{|\Delta pe|}{w} = 3.3 \times 10^{-5}$$

Hence, the major contribution to power is from enthalpy difference. The changes in kinetic and potential energy are negligibly small.