

Thermodynamics
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Lecture 55
Tutorial Problem (3 Numbers).

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Steam enters an adiabatic turbine at a rate of 10 kg/s at 3.5 MPa, 350 °C. At a point where the steam is at 1 MPa, 250 °C, 15% of the total mass is extracted and used to preheat water entering a boiler. The remainder of the steam is expanded further and exhausted from the turbine at 30 kPa with a quality of 90%. Determine the power output of the turbine.

$m_1 = 10 \text{ kg/s}$ $m_2 = 15\% m_1$ $m_3 = 0.85 m_1$
 $P_1 = 3.5 \text{ MPa}$ $P_2 = 1 \text{ MPa}$ $P_3 = 30 \text{ kPa}$
 $T_1 = 350^\circ\text{C}$ $T_2 = 250^\circ\text{C}$ $x_3 = 0.9$

$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum m_i (h_i + \frac{V_i^2}{2} + gZ_i) - \sum m_e (h_e + \frac{V_e^2}{2} + gZ_e)$
 assuming changes in pe and ke are negligible
 $\dot{W} = m_1 h_1 - m_2 h_2 - m_3 h_3$
 $\dot{W} = 10 h_1 - 1.5 h_2 - 8.5 h_3$
 $\dot{W} = 10 \times 3104.8 - 1.5 \times 2943.1 - 8.5 \times 2351.9$
 $\dot{W} = 6310 \text{ kW}$
 $\dot{W} = 6.3 \text{ MW}$

$\frac{dm}{dt} = \sum m_i - \sum m_e$
 $0 = m_2 + m_3 - m_1$
 $10 = 0.15 \times 10 + m_3$
 $m_3 = 0.85 \times 10$
 $30 \times 10^3 \text{ Pa}$
 $x_3 = 0.9$
 $h_3 = h_f + x h_{fg}$
 $h_3 = 289.3 + 0.9 \times 2352$
 3611.3 kJ/kg



Figure 1.

Properties of Saturated Water - Temperature Table										
Temp	Pressure	Specific Volume	Internal Energy	Enthalpy	Entropy	Quality	Specific Volume	Internal Energy	Enthalpy	Entropy
t	P	v_f	u_f	h_f	s_f	x	v_g	u_g	h_g	s_g
0	0.00611	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
5	0.00871	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
10	0.01227	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
15	0.01678	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
20	0.02226	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
25	0.02875	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
30	0.03628	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
35	0.04487	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
40	0.05464	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
45	0.06570	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
50	0.07818	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
55	0.09219	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
60	0.10784	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
65	0.12524	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
70	0.14450	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
75	0.16574	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
80	0.18908	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
85	0.21464	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
90	0.24254	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
95	0.27290	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
100	0.30610	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
105	0.34238	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
110	0.38188	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
115	0.42474	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
120	0.47010	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
125	0.51810	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
130	0.56888	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
135	0.62248	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
140	0.67894	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
145	0.73830	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
150	0.79962	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
155	0.86296	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
160	0.92838	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
165	0.99594	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
170	1.06570	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
175	1.13772	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
180	1.21206	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
185	1.28880	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
190	1.36799	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
195	1.44968	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
200	1.53391	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
205	1.62072	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
210	1.71015	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
215	1.80224	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
220	1.89703	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
225	1.99456	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
230	2.09487	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
235	2.19799	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
240	2.30395	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
245	2.41279	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
250	2.52454	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
255	2.63924	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
260	2.75692	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
265	2.87761	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
270	2.99934	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
275	3.12214	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
280	3.24604	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
285	3.37107	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
290	3.49726	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
295	3.62464	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
300	3.75324	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
305	3.88308	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
310	4.01418	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
315	4.14656	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
320	4.28024	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
325	4.41524	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
330	4.55158	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
335	4.68928	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
340	4.82836	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
345	4.96884	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
350	5.11074	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
355	5.25408	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
360	5.39888	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
365	5.54516	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
370	5.69294	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
375	5.84224	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
380	5.99308	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
385	6.14548	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
390	6.29946	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
395	6.45504	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
400	6.61224	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
405	6.77108	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
410	6.93158	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
415	7.09376	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
420	7.25764	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
425	7.42324	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	0.00000
430	7.59058	0.001000	0.00000	0.00000	0.00000		206.136	0.00000	0.00000	

P.1.1 (MPa) (273.15 K)				P.1.2 (MPa) (273.15 K)				P.1.3 (MPa) (273.15 K)				P.1.4 (MPa) (273.15 K)			
Temp	Volume	Pressure	Internal Energy	Temp	Volume	Pressure	Internal Energy	Temp	Volume	Pressure	Internal Energy	Temp	Volume	Pressure	Internal Energy
100	0.0001	10.0000	100.0000	100	0.0001	10.0000	100.0000	100	0.0001	10.0000	100.0000	100	0.0001	10.0000	100.0000
200	0.0001	10.0000	200.0000	200	0.0001	10.0000	200.0000	200	0.0001	10.0000	200.0000	200	0.0001	10.0000	200.0000
300	0.0001	10.0000	300.0000	300	0.0001	10.0000	300.0000	300	0.0001	10.0000	300.0000	300	0.0001	10.0000	300.0000
400	0.0001	10.0000	400.0000	400	0.0001	10.0000	400.0000	400	0.0001	10.0000	400.0000	400	0.0001	10.0000	400.0000
500	0.0001	10.0000	500.0000	500	0.0001	10.0000	500.0000	500	0.0001	10.0000	500.0000	500	0.0001	10.0000	500.0000
600	0.0001	10.0000	600.0000	600	0.0001	10.0000	600.0000	600	0.0001	10.0000	600.0000	600	0.0001	10.0000	600.0000
700	0.0001	10.0000	700.0000	700	0.0001	10.0000	700.0000	700	0.0001	10.0000	700.0000	700	0.0001	10.0000	700.0000
800	0.0001	10.0000	800.0000	800	0.0001	10.0000	800.0000	800	0.0001	10.0000	800.0000	800	0.0001	10.0000	800.0000
900	0.0001	10.0000	900.0000	900	0.0001	10.0000	900.0000	900	0.0001	10.0000	900.0000	900	0.0001	10.0000	900.0000
1000	0.0001	10.0000	1000.0000	1000	0.0001	10.0000	1000.0000	1000	0.0001	10.0000	1000.0000	1000	0.0001	10.0000	1000.0000



Properties of saturated water - Pressure table									
Pressure	Temp	Volume	Internal Energy	Enthalpy	Entropy	Volume	Internal Energy	Enthalpy	Entropy
0.01	6.97	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
0.05	16.06	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
0.10	21.06	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
0.20	29.71	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
0.30	35.50	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
0.50	46.83	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
1.00	69.10	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
2.00	104.01	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
3.00	133.06	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
5.00	183.06	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
10.00	263.99	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
20.00	372.93	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
30.00	417.35	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
40.00	451.51	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
50.00	477.06	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
60.00	494.53	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
70.00	504.23	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
80.00	506.28	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
90.00	500.14	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
100.00	485.00	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000



Solution of the problem in Fig. 1:

$$\dot{m}_1 = 10 \frac{kg}{s}, p_1 = 3.5 MPa, T_1 = 350 \text{ }^\circ\text{C},$$

$$\dot{m}_2 = 0.15\dot{m}_1 = 1.5 \frac{kg}{s}, p_2 = 1 MPa, T_2 = 250 \text{ }^\circ\text{C},$$

$$p_3 = 30 kPa, x_3 = 0.9$$

A schematic of the turbine is shown in Fig. 1.

The turbine is our control volume. The first law for a control volume,

$$\frac{dE}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_i \left(h_i + \frac{1}{2} \bar{v}_i^2 + gZ_i \right) - \sum \dot{m}_e \left(h_e + \frac{1}{2} \bar{v}_e^2 + gZ_e \right) \dots (1)$$

The process is adiabatic ($\dot{Q} = 0$). We assume that the process is steady ($\frac{dE}{dt} = 0$). Since we are not given any information regarding the velocities and heights at inlet and outlets, we will assume that the changes in kinetic and potential energy are negligible. Hence, equation (1) implies,

$$\dot{W} = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3 \dots (2)$$

$$\text{Now, } \dot{m}_1 = \dot{m}_2 + \dot{m}_3 \rightarrow \dot{m}_3 = 0.85 \dot{m}_1 = 8.5 \frac{kg}{s}$$

We will obtain values of h_1, h_2, h_3 from steam tables.

At the inlet, at 350 °C, the saturation pressure $p_{sat} = 16 \text{ MPa}$. Since $p_{sat} > 3.5 \text{ MPa}$, the steam is in superheated zone. From the tables for superheated steam, $h_1 = 3104.8 \frac{kJ}{kg}$.

At the outlet 2, at 250 °C, $p_{sat} = 4 \text{ MPa}$. Since $p_{sat} > 1 \text{ MPa}$, the steam is in superheated zone. From the tables for superheated steam, $h_2 = 2943.1 \frac{kJ}{kg}$.

$$\text{At the outlet 3, } h_3 = [h_f + x_3(h_{fg})]_{30 \text{ kPa}} = 2391 \frac{kJ}{kg}$$

$$(2) \text{ implies } \dot{W} = 10 \times 3104.8 + 1.5 \times 2943.1 + 8.5 \times 2391 = 6.3 \text{ MW}.$$

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A steam turbine is used to drive an air compressor as well as a generator, as shown in the figure. Heat losses from the turbine and the compressor as well as KE and PE changes can be neglected. Determine the power available to drive the generator.

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_i \left(h_i + \frac{1}{2} \bar{V}_i^2 + gZ_i \right) - \sum \dot{m}_e \left(h_e + \frac{1}{2} \bar{V}_e^2 + gZ_e \right)$$

$$\dot{W} = \sum \dot{m}_i h_i - \sum \dot{m}_e h_e$$

$$\dot{W} = \dot{m}_{air} (h_{2,air} - h_{1,air}) + \dot{m}_{steam} (h_{1,steam} - h_{2,steam})$$

$$\dot{W} = 10 (G_{p295} - G_{p550}) + 25 [3375.1 - 2416.5]$$

$$= 10 \times 1008 \times (295 - 550) + 23966$$

$$= -2570 + 23966$$

$$= 21395 \text{ kW}$$

$$\dot{W} = 21.4 \text{ MW}$$

$G = \frac{P}{\rho} = \frac{1008 \text{ J}}{\text{kg}}$
 $R = 287 \frac{\text{J}}{\text{kgK}}$

$\pi = 0.92$
 $p = 10 \text{ kPa}$
 $p = 10 \times 10^3 \text{ Pa}$
 $h = h_f + x h_{fg}$
 $= 191.8 + 0.93 \times 2392.1$
 $h_e = 2416.5$



Figure 2.

Pressure	Temp	Volume	Energy	Enthalpy	Entropy	Quality
MPa	°C	m³/kg	kJ/kg	kJ/kg	kJ/kgK	
0.01	0.01	1000	0.01	0.01	0.01	
0.01	10	1000	0.01	0.01	0.01	
0.01	20	1000	0.01	0.01	0.01	
0.01	30	1000	0.01	0.01	0.01	
0.01	40	1000	0.01	0.01	0.01	
0.01	50	1000	0.01	0.01	0.01	
0.01	60	1000	0.01	0.01	0.01	
0.01	70	1000	0.01	0.01	0.01	
0.01	80	1000	0.01	0.01	0.01	
0.01	90	1000	0.01	0.01	0.01	
0.01	100	1000	0.01	0.01	0.01	
0.01	110	1000	0.01	0.01	0.01	
0.01	120	1000	0.01	0.01	0.01	
0.01	130	1000	0.01	0.01	0.01	
0.01	140	1000	0.01	0.01	0.01	
0.01	150	1000	0.01	0.01	0.01	
0.01	160	1000	0.01	0.01	0.01	
0.01	170	1000	0.01	0.01	0.01	
0.01	180	1000	0.01	0.01	0.01	
0.01	190	1000	0.01	0.01	0.01	
0.01	200	1000	0.01	0.01	0.01	
0.01	210	1000	0.01	0.01	0.01	
0.01	220	1000	0.01	0.01	0.01	
0.01	230	1000	0.01	0.01	0.01	
0.01	240	1000	0.01	0.01	0.01	
0.01	250	1000	0.01	0.01	0.01	
0.01	260	1000	0.01	0.01	0.01	
0.01	270	1000	0.01	0.01	0.01	
0.01	280	1000	0.01	0.01	0.01	
0.01	290	1000	0.01	0.01	0.01	
0.01	300	1000	0.01	0.01	0.01	
0.01	310	1000	0.01	0.01	0.01	
0.01	320	1000	0.01	0.01	0.01	
0.01	330	1000	0.01	0.01	0.01	
0.01	340	1000	0.01	0.01	0.01	
0.01	350	1000	0.01	0.01	0.01	
0.01	360	1000	0.01	0.01	0.01	
0.01	370	1000	0.01	0.01	0.01	
0.01	380	1000	0.01	0.01	0.01	
0.01	390	1000	0.01	0.01	0.01	
0.01	400	1000	0.01	0.01	0.01	
0.01	410	1000	0.01	0.01	0.01	
0.01	420	1000	0.01	0.01	0.01	
0.01	430	1000	0.01	0.01	0.01	
0.01	440	1000	0.01	0.01	0.01	
0.01	450	1000	0.01	0.01	0.01	
0.01	460	1000	0.01	0.01	0.01	
0.01	470	1000	0.01	0.01	0.01	
0.01	480	1000	0.01	0.01	0.01	
0.01	490	1000	0.01	0.01	0.01	
0.01	500	1000	0.01	0.01	0.01	
0.01	510	1000	0.01	0.01	0.01	
0.01	520	1000	0.01	0.01	0.01	
0.01	530	1000	0.01	0.01	0.01	
0.01	540	1000	0.01	0.01	0.01	
0.01	550	1000	0.01	0.01	0.01	
0.01	560	1000	0.01	0.01	0.01	
0.01	570	1000	0.01	0.01	0.01	
0.01	580	1000	0.01	0.01	0.01	
0.01	590	1000	0.01	0.01	0.01	
0.01	600	1000	0.01	0.01	0.01	
0.01	610	1000	0.01	0.01	0.01	
0.01	620	1000	0.01	0.01	0.01	
0.01	630	1000	0.01	0.01	0.01	
0.01	640	1000	0.01	0.01	0.01	
0.01	650	1000	0.01	0.01	0.01	
0.01	660	1000	0.01	0.01	0.01	
0.01	670	1000	0.01	0.01	0.01	
0.01	680	1000	0.01	0.01	0.01	
0.01	690	1000	0.01	0.01	0.01	
0.01	700	1000	0.01	0.01	0.01	
0.01	710	1000	0.01	0.01	0.01	
0.01	720	1000	0.01	0.01	0.01	
0.01	730	1000	0.01	0.01	0.01	
0.01	740	1000	0.01	0.01	0.01	
0.01	750	1000	0.01	0.01	0.01	
0.01	760	1000	0.01	0.01	0.01	
0.01	770	1000	0.01	0.01	0.01	
0.01	780	1000	0.01	0.01	0.01	
0.01	790	1000	0.01	0.01	0.01	
0.01	800	1000	0.01	0.01	0.01	
0.01	810	1000	0.01	0.01	0.01	
0.01	820	1000	0.01	0.01	0.01	
0.01	830	1000	0.01	0.01	0.01	
0.01	840	1000	0.01	0.01	0.01	
0.01	850	1000	0.01	0.01	0.01	
0.01	860	1000	0.01	0.01	0.01	
0.01	870	1000	0.01	0.01	0.01	
0.01	880	1000	0.01	0.01	0.01	
0.01	890	1000	0.01	0.01	0.01	
0.01	900	1000	0.01	0.01	0.01	
0.01	910	1000	0.01	0.01	0.01	
0.01	920	1000	0.01	0.01	0.01	
0.01	930	1000	0.01	0.01	0.01	
0.01	940	1000	0.01	0.01	0.01	
0.01	950	1000	0.01	0.01	0.01	
0.01	960	1000	0.01	0.01	0.01	
0.01	970	1000	0.01	0.01	0.01	
0.01	980	1000	0.01	0.01	0.01	
0.01	990	1000	0.01	0.01	0.01	
0.01	1000	1000	0.01	0.01	0.01	



Solution of the problem in Fig. 2:

Conditions at the inlet and the outlet of the air compressor and the turbine are shown in Fig. 1. The control volume includes both, the air compressor and the turbine.

The first law for a control volume

$$\frac{dE}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_i \left(h_i + \frac{1}{2} \bar{V}_i^2 + gZ_i \right) - \sum \dot{m}_e \left(h_e + \frac{1}{2} \bar{V}_e^2 + gZ_e \right) \dots (1)$$

Heat losses from the control volume and the changes in kinetic and potential energy can be neglected. Assume steady state conditions. Hence, equation (1) reduces to

$$\dot{W} = \sum \dot{m}_i h_i - \sum \dot{m}_e h_e$$

For the compressor and the turbine, $\frac{dm}{dt} = 0$. The air and steam do not mix. Hence, $\dot{m}_{i\text{air}} = \dot{m}_{e\text{air}} = \dot{m}_{\text{air}}$ and $\dot{m}_{i\text{steam}} = \dot{m}_{e\text{steam}} = \dot{m}_{\text{steam}}$

Hence,

$$\dot{W} = \dot{m}_{\text{air}}(h_{i\text{air}} - h_{e\text{air}}) + \dot{m}_{\text{steam}}(h_{i\text{steam}} - h_{e\text{steam}}) \dots (2)$$

Now, at the inlet of turbine, at 10 MPa, $T_{\text{sat}} = 300 \text{ }^\circ\text{C}$. Since $500 \text{ }^\circ\text{C} > T_{\text{sat}}$, the state is in superheated zone. From the tables for superheated steam, $h_{i\text{steam}} = 3375.1 \frac{\text{kJ}}{\text{kg}}$.

At the exit of turbine, $x_2 = 0.92$. $h_{e\text{steam}} = [h_f + x_2(h_{fg})]_{10 \text{ kPa}} = 2416.5 \frac{\text{kJ}}{\text{kg}}$

Assuming air an ideal gas and C_p is constant, $h_{i\text{air}} = C_p T_i$ and $h_{e\text{air}} = C_p T_e$. $C_p = \frac{\gamma R}{\gamma - 1} = \frac{1.4 \times 288}{0.4} = 1008 \frac{\text{J}}{\text{kg} \cdot \text{K}}$ ($\gamma = 1.4$ assuming air to be a diatomic gas)

(2) implies $\dot{W} = 10 \times 1008 \times (295 - 550) + 25(3375.1 - 2416.5) = -2570 + 23966 = 21395 \text{ kW} = 21.4 \text{ MW}$.

The turbine produces 23966 kW of power. The compressor consumes 2570 kW. 21395 kW is available for the generator.

Table 1: Properties of saturated water and steam at various pressures			
Pressure (kPa)	Temperature (°C)	Specific Volume (m³/kg)	Enthalpy (kJ/kg)
0.01	0.01	206.1	0.01
0.05	32.87	23.74	0.05
0.1	45.81	16.73	0.1
0.2	60.06	10.80	0.2
0.3	69.10	8.35	0.3
0.5	81.33	5.84	0.5
1.0	99.06	3.10	1.0
2.0	120.04	1.72	2.0
3.0	133.06	1.27	3.0
5.0	151.86	0.81	5.0
10.0	179.91	0.47	10.0
20.0	207.34	0.26	20.0
30.0	217.37	0.20	30.0
50.0	233.90	0.12	50.0
100.0	264.57	0.06	100.0
200.0	303.53	0.03	200.0
300.0	316.07	0.02	300.0
500.0	342.24	0.01	500.0
1000.0	373.95	0.00	1000.0



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Steam enters the condenser of a steam power plant at 20 kPa, 95% with a mass flow rate of 20,000 kg/hour. It is to be cooled by water from a nearby river by circulating the water through the tubes of the condenser. To prevent thermal pollution, the river water is not allowed to experience a temperature rise above 10 °C. If the steam is to leave the condenser as a saturated liquid at 20 kPa, determine the mass flow rate of the cooling water required. Assume the specific heat of the river water to be 4.17 kJ/kg.K.

$T_4 - T_3 = 10^\circ\text{C}$

$\dot{m}_w = \dot{m}_s = \dot{m}_4 = ?$

$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_i (h_i + \frac{V_i^2}{2} + g z_i) - \sum \dot{m}_e (h_e + \frac{V_e^2}{2} + g z_e)$

$\sum \dot{m}_1 h_1 = \sum \dot{m}_2 h_2$

$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_1 h_2 + \dot{m}_3 h_4$

$\dot{m}_3 (h_3 - h_4) = \dot{m}_1 (h_2 - h_1)$

$\dot{m}_3 = \frac{\dot{m}_1 (h_2 - h_1)}{h_3 - h_4} = \frac{20000 \times (2514 - 2491)}{417 \times 10} = 1000 \text{ kg/s}$

$\dot{m} = 298.3 \text{ kg/s} = 1074 \text{ t/h}$

$\dot{m} = 20000 \text{ kg/h}$

20 kPa

$x = 0.95$

$T_3 = \text{river water inlet temp}$

$T_4 = \text{sat. liq. @ } 20 \text{ kPa}$

$\frac{dE}{dt} = \sum \dot{m}_1 - \sum \dot{m}_2$

$\dot{m}_1 + \dot{m}_3 = \dot{m}_2 + \dot{m}_4$

$\dot{m}_3 = \dot{m}_4$

$\dot{m}_1 = \dot{m}_2$

$h_1 = h_2 + x h_{fg} \text{ @ } 20 \text{ kPa}$

$h_1 = 2514 + 0.95 \times 2357.5$

$h_1 = 2491 \text{ kJ/kg}$



Figure 3.

$$\text{Now, } h_1 = [h_f + x_1(h_{fg})]_{20 \text{ kPa}} = 2491 \frac{\text{kJ}}{\text{kg}}$$

$$h_2 = h_{f_{20 \text{ kPa}}} = 251.4 \frac{\text{kJ}}{\text{kg}}$$

$$h_3 - h_4 = C_p(T_3 - T_4) = 4.17 \times (-10) = -41.7 \frac{\text{kJ}}{\text{kg}}$$

Hence, $\dot{m}_3 = 298.3 \frac{\text{kg}}{\text{s}}$ = mass flow rate of the cooling water.