6.76

A steam turbine receives steam from two boilers. One flow is 5 kg/s at 3 MPa, 700°C and the other flow is 15 kg/s at 800 kPa, 500°C. The exit state is 10 kPa, with a quality of 96%. Find the total power out of the adiabatic turbine.

Solution:

C.V. whole turbine steady, 2 inlets, 1 exit, no heat transfer $\dot{Q} = 0$

Continuity Eq.6.9: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3 = 5 + 15 = 20$ kg/s

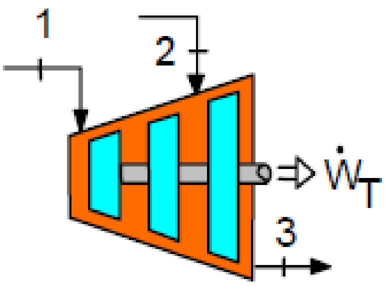
Energy Eq.6.10: $\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{W}_T$

Table B.1.3: $h_1 = 3911.7$ kJ/kg,

$h_2 = 3480.6$ kJ/kg

Table B.1.2: $h_3 = 191.8 + 0.96 \times 2392.8$

$= 2488.9$ kJ/kg



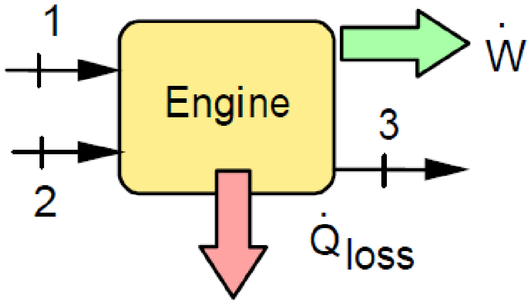
$$\dot{W}_T = 5 \times 3911.7 + 15 \times 3480.6 - 20 \times 2488.9 = 21\,990 \text{ kW} = 22 \text{ MW}$$

6.78

Two steady flows of air enters a control volume, shown in Fig. P6.78. One is 0.025 kg/s flow at 350 kPa, 150°C, state 1, and the other enters at 450 kPa, 15°C, state 2. A single flow of air exits at 100 kPa, –40°C, state 3. The control volume rejects 1 kW heat to the surroundings and produces 4 kW of power. Neglect kinetic energies and determine the mass flow rate at state 2.

Solution:

C.V. Steady device with two inlet and one exit flows, we neglect kinetic energies. Notice here the Q is rejected so it goes out.



Continuity Eq.6.9: $\dot m_1 + \dot m_2 = \dot m_3 = 0.025 + \dot m_2$

Energy Eq.6.10: $\dot m_1 h_1 + \dot m_2 h_2 = \dot m_3 h_3 + \dot W_{CV} + \dot Q_{loss}$

Substitute the work and heat transfer into the energy equation and use constant heat capacity

$$0.025 \times 1.004 \times 423.2 + \dot m_2 \times 1.004 \times 288.2$$

$$= (0.025 + \dot m_2)\ 1.004 \times 233.2 + 4.0 + 1.0$$

Now solve for $\dot m_2$.

$$\dot m_2 = \frac{4.0 + 1.0 + 0.025 \times 1.004 \times (233.2 - 423.2)}{1.004\ (288.2 - 233.2)} = 0.0042 \text{ kg/s}$$

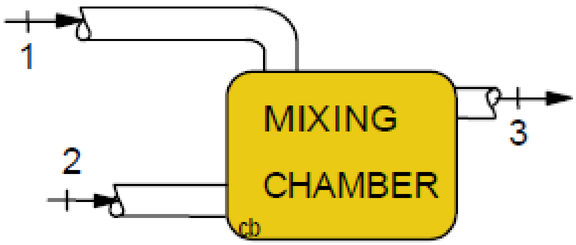
6.95

An open feedwater heater in a powerplant heats 4 kg/s water at 45°C, 100 kPa by mixing it with steam from the turbine at 100 kPa, 250°C. Assume the exit flow is saturated liquid at the given pressure and find the mass flow rate from the turbine.

Solution:

C.V. Feedwater heater.

No external $\dot{Q}$ or $\dot{W}$

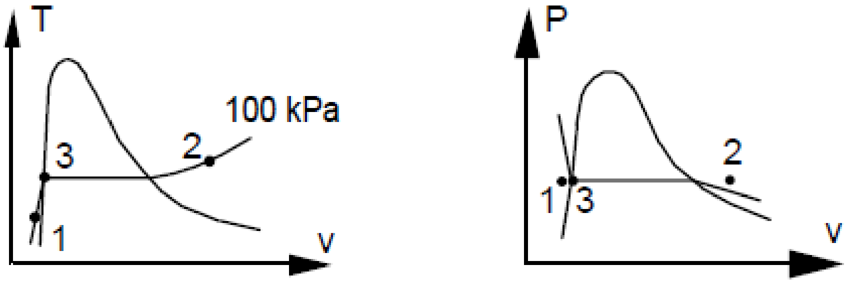


Continuity Eq.6.9: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

Energy Eq.6.10: $\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 = (\dot{m}_1 + \dot{m}_2) h_3$

State 1:	Table B.1.1	$h = h_f = 188.42$ kJ/kg at 45°C
State 2:	Table B.1.3	$h_2 = 2974.33$ kJ/kg
State 3:	Table B.1.2	$h_3 = h_f = 417.44$ kJ/kg at 100 kPa

$$\dot{m}_2 = \dot{m}_1 \times \frac{h_1 - h_3}{h_3 - h_2} = 4 \times \frac{188.42 - 417.44}{417.44 - 2974.33} = 0.358 \text{ kg/s}$$



6.103

The following data are for a simple steam power plant as shown in Fig. P6.103.

State	1	2	3	4	5	6	7
P MPa	6.2	6.1	5.9	5.7	5.5	0.01	0.009
T °C		45	175	500	490		40
h kJ/kg	-	194	744	3426	3404	-	168

State 6 has $x_6 = 0.92$, and velocity of 200 m/s. The rate of steam flow is 25 kg/s, with 300 kW power input to the pump. Piping diameters are 200 mm from steam generator to the turbine and 75 mm from the condenser to the steam generator. Determine the velocity at state 5 and the power output of the turbine.

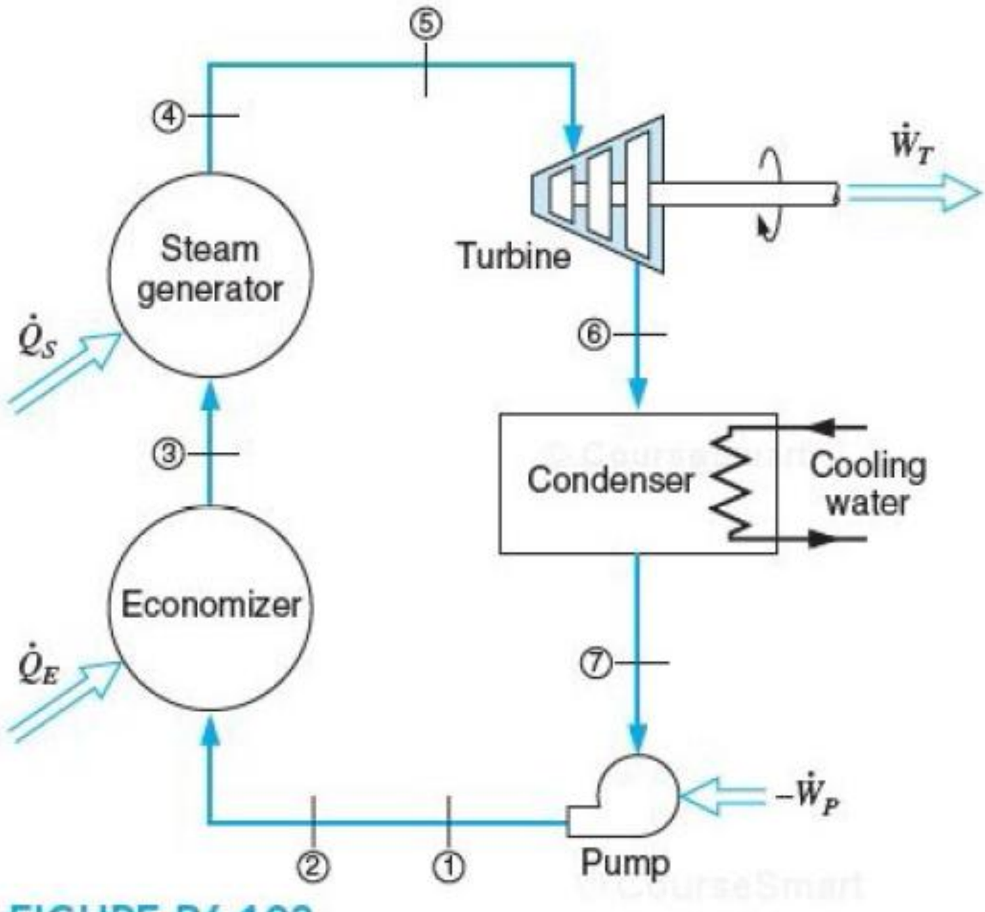


FIGURE P6.103

Solution:

Turbine $A_5 = (\pi/4)(0.2)^2 = 0.031\,42\ m^2$, $v_5 = 0.06163\ m^3/kg$

$$V_5 = \dot{m}v_5/A_5 = 25\ kg/s \times 0.061\,63\ m^3/kg\ /\ 0.031\,42\ m^2 = 49\ m/s$$

$$h_6 = 191.83 + 0.92 \times 2392.8 = 2393.2\ kJ/kg$$

$$w_T = h_5 - h_6 + \frac{1}{2}(V_5^2 - V_6^2)$$

$$= 3404 - 2393.2 + (49^2 - 200^2)/(2 \times 1000) = 992\ kJ/kg$$

$$\dot{W}_T = \dot{m}w_T = 25 \times 992 = 24\,800\ kW$$

Remark: Notice the kinetic energy change is small relative to enthalpy change.

6.106

A somewhat simplified flow diagram for a nuclear power plant shown in Fig. 1.4 is given in Fig. P6.106. Mass flow rates and the various states in the cycle are shown in the accompanying table. The cycle includes a number of heaters in which heat is transferred from steam, taken out of the turbine at some intermediate pressure, to liquid water pumped from the condenser on its way to the steam drum. The heat exchanger in the reactor supplies 157 MW, and it may be assumed that there is no heat transfer in the turbines.

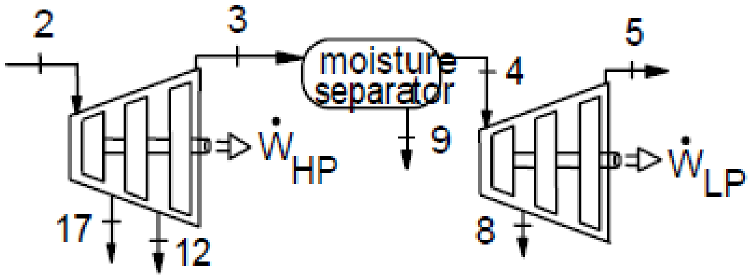
a. Assume the moisture separator has no heat transfer between the two turbinesections, determine the enthalpy and quality (h_4, x_4).

b. Determine the power output of the low-pressure turbine.

c. Determine the power output of the high-pressure turbine.

d. Find the ratio of the total power output of the two turbines to the total power delivered by the reactor.

Solution:



a) Moisture Separator, steady state, no heat transfer, no work

Mass: $\dot{m}_3 = \dot{m}_4 + \dot{m}_9$, Energy: $\dot{m}_3 h_3 = \dot{m}_4 h_4 + \dot{m}_9 h_9$;

$62.874 \times 2517 = 58.212 \times h_4 + 4.662 \times 558 \quad \Rightarrow \quad h_4 = 2673.9$ kJ/kg

$h_4 = 2673.9 = 566.18 + x_4 \times 2160.6 \quad => \quad x_4 = 0.9755$

b) Low Pressure Turbine, steady state no heat transfer

Energy Eq.: $\dot{m}_4 h_4 = \dot{m}_5 h_5 + \dot{m}_8 h_8 + \dot{W}_{CV(LP)}$

$\dot{W}_{CV(LP)} = \dot{m}_4 h_4 - \dot{m}_5 h_5 - \dot{m}_8 h_8$

$= 58.212 \times 2673.9 - 55.44 \times 2279 - 2.772 \times 2459$

$= 22\,489$ kW $= 22.489$ MW

c) High Pressure Turbine, steady state no heat transfer

Energy Eq.: $\dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_{12} h_{12} + \dot{m}_{17} h_{17} + \dot{W}_{CV(HP)}$

$\dot{W}_{CV(HP)} = \dot{m}_2 h_2 - \dot{m}_3 h_3 - \dot{m}_{12} h_{12} - \dot{m}_{17} h_{17}$

$= 75.6 \times 2765 - 62.874 \times 2517 - 8.064 \times 2517 - 4.662 \times 2593$

$= 18\,394$ kW $= 18.394$ MW

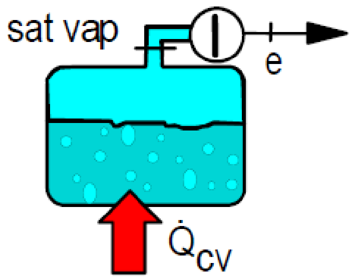
d) $\eta = (\dot{W}_{HP} + \dot{W}_{LP})/\dot{Q}_{REACT} = 40.883/157 = 0.26$

6.120

A 200 liter tank initially contains water at 100 kPa and a quality of 1%. Heat is transferred to the water thereby raising its pressure and temperature. At a pressure of 2 MPa a safety valve opens and saturated vapor at 2 MPa flows out. The process continues, maintaining 2 MPa inside until the quality in the tank is 90%, then stops. Determine the total mass of water that flowed out and the total heat transfer.

Solution:

C.V. Tank, no work but heat transfer in and flow out. Denoting State 1: initial state, State 2: valve opens, State 3: final state.



Continuity Eq.: $m_3 - m_1 = -m_e$

Energy Eq.: $m_3u_3 - m_1u_1 = -m_eh_e + {}_1Q_3$

State 1 Table B.1.2: $v_1 = v_f + x_1v_{fg} = 0.001043 + 0.01\times1.69296$

$= 0.01797\ m^3/kg$

$u_1 = u_f + x_1u_{fg} = 417.33 + 0.01\times2088.72 = 438.22\ kJ/kg$

$m_1 = V/v_1 = 0.2\ m^3/(0.01797\ m^3/kg) = 11.13\ kg$

State 3 (2MPa): $v_3 = v_f + x_3v_{fg} = 0.001177 + 0.9\times0.09845 = 0.8978\ m^3/kg$

$u_3 = u_f + x_3u_{fg} = 906.42 + 0.9\times1693.84 = 2430.88\ kJ/kg$

$m_3 = V/v_3 = 0.2\ m^3/(0.08978\ m^3/kg) = 2.23\ kg$

Exit state (2MPa): $h_e = h_g = 2799.51\ kJ/kg$

Hence: $m_e = m_1 - m_3 = 11.13\ kg - 2.23\ kg = 8.90\ kg$

Applying the 1st law between state 1 and state 3

$${}_1Q_3 = m_3u_3 - m_1u_1 + m_eh_e$$
$$= 2.23 \times 2430.88 - 11.13 \times 438.22 + 8.90 \times 2799.51$$
$$= 25\,459\ kJ = 25.46\ MJ$$

6.123

A nitrogen line, 300 K and 0.5 MPa, shown in Fig. P6.123, is connected to a turbine that exhausts to a closed initially empty tank of 50 m^3. The turbine operates to a tank pressure of 0.5 MPa, at which point the temperature is 250 K Assuming the entire process is adiabatic, determine the turbine work.

Solution:

C.V. turbine & tank $\Rightarrow$ Transient process

Conservation of mass Eq.6.15: $m_i = m_2 \Rightarrow m$

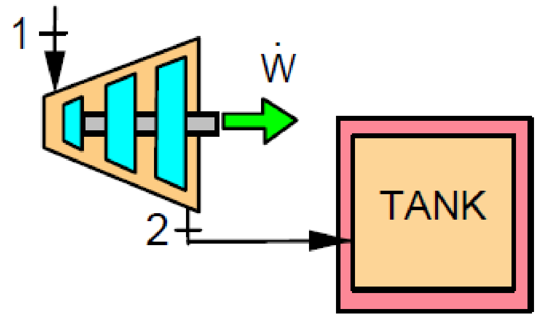
Energy Eq.6.16: $m_i h_i = m_2 u_2 + W_{CV}$; $W_{CV} = m(h_i - u_2)$

Table B.6.2: $P_i = 0.5$ MPa, $T_i = 300$ K, Nitrogen; $h_i = 310.28$ kJ/kg

2: $P_2 = 0.5$ MPa, $T_2 = 250$ K, $u_2 = 183.89$ kJ/kg, $v_2 = 0.154\ m^3/kg$

$m_2 = V/v_2 = 50/0.154 = 324.7$ kg

$W_{CV} = 324.7\ (310.28 - 183.89) = 41\ 039$ kJ $= 41.04$ MJ



We could with good accuracy have solved using ideal gas and Table A.5

6.127

A 2 m tall cylinder has a small hole in the bottom. It is filled with liquid water 1 m high, on top of which is 1 m high air column at atmospheric pressure of 100 kPa. As the liquid water near the hole has a higher P than 100 kPa it runs out. Assume a slow process with constant T. Will the flow ever stop? When?

Solution:

$$P_{bot} = P_{air} + \rho g L_f$$

For the air PV = mRT and the total height is H = 2 m

$$P_{air} = mRT/V_{air} \quad ; V_{air} = A\, L_{air} = A\,(H - L_f)$$

$$P_{bot} = \frac{m_a R_a T_a}{A(H-L_f)} + \rho_f g\, L_f = \frac{P_{a1} V_{a1}}{A(H-L_f)} + \rho_f\, g L_f = \frac{P_{a1} L_{a1}}{H-L_f} + \rho_f\, g L_f \geq P_o$$

Solve for L_f ; $\rho_f = 1/(v_f) = 1/0.0021002 = 998\ kg/m^3$

$$P_{a1}\, L_{a1} + \rho_f\, g\, L_f\,(H - L_f) \geq P_o\,(H - L_f)$$

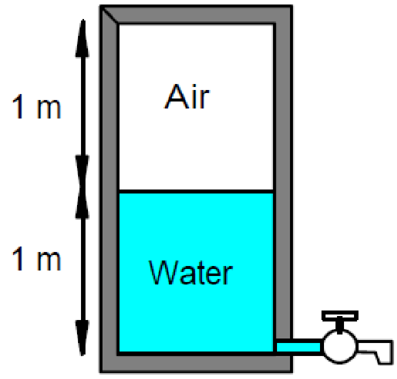
$$(\rho_f g H + P_o)\, L_f - \rho_f g L^2_f = P_o\, H - P_{a1}\, L_{a1} \geq 0$$

Put in numbers and solve quadratic eq.

$$L^2_f - [\, H + (P_o/\rho g)\,]\, L_f + \frac{P_o H - P_{a1} L_{a1}}{\rho g} = 0$$

$$(P_o/\rho g) = \frac{100\ kPa\ m^3\ s^3}{998 \times 9.807\ kg\ m} = 10.217\ m$$

$$\frac{P_o H - P_{a1} L_{a1}}{\rho g} = \frac{100\ (2-1)}{998 \times 9.807} = 10.217\ m$$



$$L^2_f - 12.217\, L_f + 10.217 = 0$$

$$L_f = \frac{12.217}{2} \pm \sqrt{\frac{12.217^2}{4} - \frac{12.217}{4}} = 6.1085 \pm 5.2055$$

=> 11.314 or 0.903 m so the second root is the solution

Verify

$$P_{a2} = P_{a1} \cdot \frac{L_{a1}}{H-L_f} = 100 \frac{1}{2 - 0.903} = 91.158\ kPa$$

$$\rho g L_f = 998 \times 9.807 \times 0.903 = 8838\ Pa = 8.838\ kPa$$

$$P_{bot} = P_{a2} + \rho g L_f = 91.158 + 8.838 = 99.996\ kPa \quad OK$$

6.130

In a glass factory a 2 m wide sheet of glass at 1500 K comes out of the final rollers that fix the thickness at 5 mm with a speed of 0.5 m/s. Cooling air in the amount of 20 kg/s comes in at 17°C from a slot 2 m wide and flows parallel with the glass. Suppose this setup is very long so the glass and air comes to nearly the same temperature (a co-flowing heat exchanger) what is the exit temperature?

Solution:

Energy Eq.: $\dot{m}_{glass}h_{glass\ 1} + \dot{m}_{air}h_{air\ 2} = \dot{m}_{glass}h_{glass\ 3} + \dot{m}_{air}h_{air\ 4}$

$\dot{m}_{glass} = \rho\dot{V} = \rho AV = 2500\times 2 \times 0.005\times 0.5 = 12.5$ kg/s

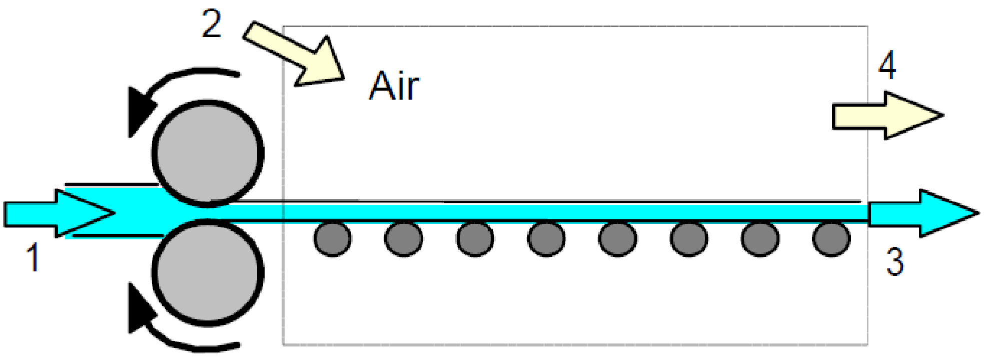
$\dot{m}_{glass}C_{glass}\ (T_3 - T_1) + \dot{m}_{air}\ C_{Pa}\ (T_4 - T_2) = \varnothing$

$T_4 = T_3$, $C_{glass} = 0.80$ kJ/kg K, $C_{Pa} = 1.004$ kJ/kg K

$$T_3 = \frac{\dot{m}_{glass}C_{glass}\ T_1 + \dot{m}_{air}C_{Pa}\ T_2}{\dot{m}_{glass}C_{glass} + \dot{m}_{air}C_{Pa}} = \frac{12.5\times0.80\times1500 + 20\times1.004\times290}{12.5\times0.80 + 20\times1.004}$$

$= 692.3$ K

We could use table A.7.1 for air, but then it will be trial and error



6.142

Liquid water at 80°C flows with 0.2 kg/s inside a square duct, side 2 cm insulat with a 1 cm thick layer of foam k = 0.1 W/m K. If the outside foam surface is a 25°C how much has the water temperature dropped for 10 m length of duct? Neglect the duct material and any corner effects (A = 4sL).

Solution:

Conduction heat transfer

$$\dot{Q}_{out} = kA\frac{dT}{dx} = k\ 4\ sL\ \frac{\Delta T}{\Delta x} = 0.1\times 4\times 0.02\times 10\times(80\text{-}25)/0.01 = 440\ W$$

Energy equation: $\dot{m}_1 h_1 = \dot{m} h_e + \dot{Q}_{out}$

$h_e - h_i = -\dot{Q}/\dot{m} = -\ (440/0.2) = -2200\ J/kg = -\ 2.2\ kJ/kg$

$h_e = h_i\ -2.2\ kJ/kg = 334.88 - 2.2 = 332.68\ kJ/kg$

$$T_e = 80 - \frac{2.2}{334.88\text{-}313.91}\ 5 = 79.48^{o}C$$

$$\Delta T = 0.52^{o}C$$

We could also have used $h_e - h_i = C_p \Delta T$