6.23
In a jet engine a flow of air at 1000 K, 200 kPa and 30 m/s enters a nozzle, as shown in Fig. P6.23, where the air exits at 850 K, 90 kPa. What is the exit velocity assuming no heat loss?
Solution:
C.V. nozzle. No work, no heat transfer
Continuity \( \dot{m}_i = \dot{m}_e = \dot{m} \)
Energy : \( \dot{m} (h_i + \frac{1}{2}V_i^2) = \dot{m}(h_e + \frac{1}{2}V_e^2) \)
Due to high T take h from table A.7.1
\[
\frac{1}{2}V_e^2 = \frac{1}{2}V_i^2 + h_i - h_e
\]
\[
= \frac{1}{2000} (30)^2 + 1046.22 - 877.4
= 0.45 + 168.82 = 169.27 \text{ kJ/kg}
\]
\[
V_e = (2000 \times 169.27)^{1/2} = 581.8 \text{ m/s}
\]
6.37

Liquid water at 180°C, 2000 kPa is throttled into a flash evaporator chamber having a pressure of 500 kPa. Neglect any change in the kinetic energy. What is the fraction of liquid and vapor in the chamber?

Solution:

Energy Eq.6.13: \[ h_1 + \frac{1}{2} V_1^2 + gZ_1 = h_2 + \frac{1}{2} V_2^2 + gZ_2 \]

Process: \[ Z_1 = Z_2 \quad \text{and} \quad V_2 = V_1 \]

\[ \Rightarrow \quad h_2 = h_1 = 763.71 \text{ kJ/kg} \quad \text{from Table B.1.4} \]

State 2: \[ P_2 \& h_2 \quad \Rightarrow \quad 2 - \text{phase} \]

\[ h_2 = h_f + x_2 h_{fg} \]

\[ x_2 = \frac{(h_2 - h_f)}{h_{fg}} = \frac{763.71 - 640.21}{2108.47} = 0.0586 \]

Fraction of Vapor: \[ x_2 = 0.0586 \quad (5.86 \%) \]

Liquid: \[ 1 - x_2 = 0.941 \quad (94.1 \%) \]

Two-phase out of the valve. The liquid drops to the bottom.
6.47

A small, high-speed turbine operating on compressed air produces a power output of 100 W. The inlet state is 400 kPa, 50°C, and the exit state is 150 kPa, −30°C. Assuming the velocities to be low and the process to be adiabatic, find the required mass flow rate of air through the turbine.

Solution:

C.V. Turbine, no heat transfer, no ΔKE, no ΔPE

Energy Eq.6.13: \[ h_{in} = h_{ex} + w_T \]

Ideal gas so use constant specific heat from Table A.5

\[ w_T = h_{in} - h_{ex} \equiv C_p(T_{in} - T_{ex}) \]

\[ = 1.004 \text{ (kJ/kg K)} \left[ 50 - (-30) \right] \text{ K} = 80.3 \text{ kJ/kg} \]

\[ \dot{W} = \dot{m}w_T \quad \Rightarrow \quad \dot{m} = \frac{\dot{W}}{w_T} = 0.1/80.3 = 0.00125 \text{ kg/s} \]

The dentist's drill has a small air flow and is not really adiabatic.
6.61

The air conditioner in a house or a car has a cooler that brings atmospheric air from 30°C to 10°C both states at 101 kPa. If the flow rate is 0.5 kg/s find the rate of heat transfer.

Solution:
CV. Cooler. Steady state single flow with heat transfer.
Neglect changes in kinetic and potential energy and no work term.

Energy Eq. 6.13: \( q_{out} = h_i - h_e \)
Use constant heat capacity from Table A.5 \( (T \text{ is around } 300 \text{ K}) \)
\[
q_{out} = h_i - h_e = C_p \,(T_i - T_e) \\
= 1.004 \frac{\text{kJ}}{\text{kg K}} \times (30 - 10) \text{ K} = 20.1 \text{ kJ/kg}
\]

\[ \dot{Q}_{out} = \dot{m} \, q_{out} = 0.5 \times 20.1 = 10 \text{ kW} \]
A steam turbine receives water at 15 MPa, 600°C at a rate of 100 kg/s, shown in Fig. P6.79. In the middle section 20 kg/s is withdrawn at 2 MPa, 350°C, and the rest exits the turbine at 75 kPa, and 95% quality. Assuming no heat transfer and no changes in kinetic energy, find the total turbine power output.

Solution:

C.V. Turbine

Steady state, 1 inlet and 2 exit flows.

Continuity Eq.6.9: \( \dot{m}_1 = \dot{m}_2 + \dot{m}_3 \); \( \Rightarrow \dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 80 \text{ kg/s} \)

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

Table B.1.3 \( h_1 = 3582.3 \text{ kJ/kg}, \)
\( h_2 = 3137 \text{ kJ/kg} \)

Table B.1.2 \( h_3 = h_f + x_3 h_{fg} = 384.3 + 0.95 \times 2278.6 \)
\( = 2549.1 \text{ kJ/kg} \)

From the energy equation, Eq.6.10

\( \Rightarrow \dot{W}_T = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3 \)
\( = (100 \times 3582.3 - 20 \times 3137 - 80 \times 2549.1) \text{ (kg/s) \times (kJ/kg)} \)
\( = 91565 \text{ kW} = 91.565 \text{ MW} \)
A condenser (heat exchanger) brings 1 kg/s water flow at 10 kPa from 300°C to saturated liquid at 10 kPa, as shown in Fig. P6.83. The cooling is done by lake water at 20°C that returns to the lake at 30°C. For an insulated condenser, find the flow rate of cooling water.

Solution:
C.V. Heat exchanger

Table B.1.1: \( h_{20} = 83.96 \text{ kJ/kg} \), \( h_{30} = 125.79 \text{ kJ/kg} \)

Table B.1.3: \( h_{300, \text{10kPa}} = 3076.5 \text{ kJ/kg} \), B.1.2: \( h_f, 10 \text{ kPa} = 191.83 \text{ kJ/kg} \)

Energy Eq.6.10: \[
\dot{m}_{\text{cool}} h_{20} + \dot{m}_{\text{H}_2\text{O}} h_{300} = \dot{m}_{\text{cool}} h_{30} + \dot{m}_{\text{H}_2\text{O}} h_f, 10 \text{ kPa}
\]

\[
\dot{m}_{\text{cool}} = \dot{m}_{\text{H}_2\text{O}} \frac{h_{300} - h_f, 10 \text{ kPa}}{h_{30} - h_{20}} = 1 \text{ kg/s} \times \frac{3076.5 - 191.83}{125.79 - 83.96} = 69 \text{ kg/s}
\]
6.96

A flow of water at 2000 kPa, 20°C is mixed with a flow of 2 kg/s water at 2000 kPa, 180°C. What should the flowrate of the first flow be to produce an exit state of 200 kPa and 100°C?

Solution:

C.V. Mixing chamber and valves. Steady state no heat transfer or work terms.

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

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

Properties Table B.1.1: \[ h_1 = 85.8 \text{ kJ/kg}; \quad h_3 = 419.0 \text{ kJ/kg} \]

Table B.1.4: \[ h_2 = 763.7 \text{ kJ/kg} \]

\[ \dot{m}_1 = \dot{m}_2 \times \frac{h_2 - h_3}{h_3 - h_1} = 2 \times \frac{763.7 - 419.0}{419.0 - 85.8} = 2.069 \text{ kg/s} \]