5–49 Steam flows steadily through an adiabatic turbine. The inlet conditions of the steam are 10 MPa, 450°C, and 80 m/s, and the exit conditions are 10 kPa, 92 percent quality, and 50 m/s. The mass flow rate of the steam is 12 kg/s. Determine (a) the change in kinetic energy, (b) the power output, and (c) the turbine inlet area. Answers: (a) 1.95 kJ/kg, (b) 10.2 MW, (c) 0.00447 m²

5–49 Steam expands in a turbine. The change in kinetic energy, the power output, and the turbine inlet area are to be determined.

**Assumptions** 1 This is a steady-flow process since there is no change with time. 2 Potential energy changes are negligible. 3 The device is adiabatic and thus heat transfer is negligible.

**Properties** From the steam tables (Tables A-4 through 6)

\[
\begin{align*}
P_1 &= 10 \text{ MPa} \\
T_1 &= 450^\circ \text{C} \\
h_1 &= 3242.4 \text{ kJ/kg}
\end{align*}
\]

and

\[
\begin{align*}
P_2 &= 10 \text{ kPa} \\
v_2 &= 0.92 \\
h_2 &= h_f + x_2 h_g = 191.81 + 0.92 \times 2392.1 = 2392.5 \text{ kJ/kg}
\end{align*}
\]

**Analysis** (a) The change in kinetic energy is determined from

\[
\Delta E_k = \frac{V_2^2 - V_1^2}{2} = \frac{(50 \text{ m/s})^2 - (80 \text{ m/s})^2}{2} \left( \frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) = -1.95 \text{ kJ/kg}
\]

(b) There is only one inlet and one exit, and thus \( \dot{n}_k = \dot{n}_v = \dot{m} \). We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

\[
\dot{E}_\text{in} - \dot{E}_\text{out} = \Delta E_\text{system} \overset{\text{(steady)}}{=} 0
\]

\[
\dot{E}_\text{in} = \dot{E}_\text{out} = \dot{m}(h_1 + \frac{V_1^2}{2})
\]

\[
\dot{W}_\text{out} = \dot{m}(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}) = \dot{m} (h_2 + x_2 h_g) = \dot{m} V_1 \frac{1}{v_1} (x_2 h_g) = \dot{m} \frac{n}{v_1} A_1
\]

Then the power output of the turbine is determined by substitution to be

\[
\dot{W}_\text{out} = -12 \text{ kg/s}(2392.5 - 3242.4 - 1.95) \text{ kJ/kg} = 10.2 \text{ MW}
\]

(c) The inlet area of the turbine is determined from the mass flow rate relation,

\[
\dot{m} = \frac{1}{v_1} A_1 V_1 \rightarrow A_1 = \frac{\dot{m} v_1}{V_1} = \frac{(12 \text{ kg/s})(0.029782 \text{ m}^3/\text{kg})}{80 \text{ m/s}} = 0.00447 \text{ m}^2
Steam is to be condensed in the condenser of a steam power plant at a temperature of 50°C with cooling water from a nearby lake, which enters the tubes of the condenser at 18°C at a rate of 101 kg/s and leaves at 27°C. Determine the rate of condensation of the steam in the condenser. \textbf{Answer: 1.60 kg/s}

\textbf{Assumptions} 1 Steady operating conditions exist. 2 The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. 3 Changes in the kinetic and potential energies of fluid streams are negligible. 4 Fluid properties are constant.

\textbf{Properties} The heat of vaporization of water at 50°C is \( h_{fg} = 2382.0 \text{ kJ/kg} \) and specific heat of cold water is \( c_p = 4.18 \text{ kJ/kg°C} \) (Tables A-3 and A-4).

\textbf{Analysis} We take the cold water tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

\[
\dot{E}_{in} - \dot{E}_{out} = \Delta E_{system}^{70} \text{ (steady)} = 0
\]

\[
\dot{E}_{in} = \dot{E}_{out}
\]

\[
\dot{Q}_{in} + mh_{h} = mh_{l} \quad \text{(since } \Delta ke \equiv \Delta pe \equiv 0\text{)}
\]

\[
\dot{Q}_{in} = m c_p (T_2 - T_1)
\]

Then, the heat transfer rate to the cooling water in the condenser becomes

\[
\dot{Q} = [m c_p (T_{out} - T_{in})]_{\text{cooling water}}
\]

\[
= (101 \text{ kg/s})(4.18 \text{ kJ/kg°C})(27°C - 18°C)
\]

\[
= 3800 \text{ kJ/s}
\]

The rate of condensation of steam is determined to be

\[
\dot{Q} = (m h_{fg})_{\text{steam}} \rightarrow m_{\text{steam}} = \frac{\dot{Q}}{h_{fg}} = \frac{3800 \text{ kJ/s}}{2382.0 \text{ kJ/kg}} = 1.60 \text{ kg/s}
\]