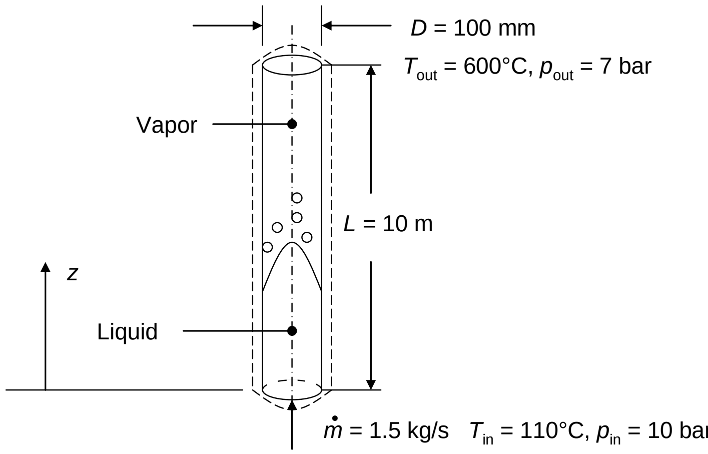
PROBLEM 1.36

KNOWN: Inlet and outlet conditions for flow of water in a vertical tube.

FIND: (a) Change in combined thermal and flow work, (b) change in mechanical energy, and (c) change in total energy of the water from the inlet to the outlet of the tube, (d) heat transfer rate, *q*.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Uniform velocity distributions at the tube inlet and outlet.

PROPERTIES: Table A.6 water (T = 110°C): ρ = 950 kg/m^3, (T = (179.9°C + 110 °C)/2 = 145°C): c_p = 4300 J/kg·K, ρ = 919 kg/m^3. Other properties are taken from Moran, M.J. and Shapiro, H.N., *Fundamentals of Engineering Thermodynamics*, 6th Edition, John Wiley & Sons, Hoboken, 2008 including (p_{sat} = 10 bar): T_{sat} = 179.9°C, i_f = 762.81 kJ/kg; (p = 7 bar, T = 600°C): i = 3700.2 kJ/kg, υ = 0.5738 m^3/kg.

ANALYSIS: The steady-flow energy equation, in the absence of work (other than flow work), is

$$\begin{aligned} &\dot{m}\left(u + pv + \tfrac{1}{2}V^2 + gz\right)_{\text{in}} - \dot{m}\left(u + pv + \tfrac{1}{2}V^2 + gz\right)_{\text{out}} + q = 0 \\ &\dot{m}\left(i + \tfrac{1}{2}V^2 + gz\right)_{\text{in}} - \dot{m}\left(i + \tfrac{1}{2}V^2 + gz\right)_{\text{out}} + q = 0 \end{aligned} \tag{1}$$

while the conservation of mass principle yields

$$V_{\text{in}} = \frac{4\dot{m}}{\rho\pi D^2} = \frac{4 \times 1.5\ \text{kg/s}}{950\ \text{kg/m}^3 \times \pi \times (0.100\ \text{m})^2} = 0.201\ \text{m/s}\ ;\ V_{\text{out}} = \frac{\upsilon 4\dot{m}}{\pi D^2} = \frac{0.5738\ \text{m}^3/\text{kg} \times 4 \times 1.5\ \text{kg/s}}{\pi \times (0.100\ \text{m})^2} = 110\ \text{m/s}$$

(a) The change in the combined thermal and flow work energy from inlet to outlet:

$$\begin{aligned} E_{i,\text{out}} - E_{i,\text{in}} &= \dot{m}(i)_{\text{out}} - \dot{m}(i)_{\text{in}} = \dot{m}(i)_{\text{out}} - \dot{m}[i_{f,\text{sat}} + c_p(T_{\text{in}} - T_{\text{sat}})] \\ &= 1.5\ \text{kg/s} \times \left(3700.2\ \text{kJ/kg} - [762.81\ \text{kJ/kg} + 4.3\ \text{kJ/kg}\cdot\text{K} \times (110 - 179.9)°\text{C}]\right) \\ &= 4.86\ \text{MW} \end{aligned}$$

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where $i_{f,sat}$ is the enthalpy of saturated liquid at the phase change temperature and pressure.

(b) The change in mechanical energy from inlet to outlet is:

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PROBLEM 1.36 (cont.)

$$E_{m,\text{out}} - E_{m,\text{in}} = \dot{m}\left(\tfrac{1}{2}V^2 + gz\right)_{\text{out}} - \dot{m}\left(\tfrac{1}{2}V^2 + gz\right)_{\text{in}}$$

$$= 1.5\ \text{kg/s} \times \left(\tfrac{1}{2}\left[(110\ \text{m/s})^2 - (0.201\ \text{m/s})^2\right] + 9.8\ \text{m/s}^2 \times 10\ \text{m}\right) = 9.22\ \text{kW} \qquad <$$

(c) The change in the total energy is the summation of the thermal, flow work, and mechanical energy change or

$$E_{\text{in}} - E_{\text{out}} = 4.86\ \text{MW} + 9.22\ \text{kW} = 4.87\ \text{MW} \qquad <$$

(d) The total heat transfer rate is the same as the total energy change, $q = E_{\text{in}} - E_{\text{out}} = 4.87$ MW $<$

COMMENTS: (1) The change in mechanical energy, consisting of kinetic and potential energy components, is negligible compared to the change in thermal and flow work energy. (2) The average heat flux at the tube surface is $q'' = q/(\pi DL) = 4.87\text{MW}/(\pi \times 0.100\ \text{m} \times 10\ \text{m}) = 1.55\ \text{MW/m}^2$, which is very large. (3) The change in the velocity of the water is inversely proportional to the change in the density. As such, the outlet velocity is very large, and large pressure drops will occur in the vapor region of the tube relative to the liquid region of the tube.