31.12 A steam condensate drain is designed to accomodate $50,000\frac{lb}{hr}$ of $5psig$ water containing 5% vapor by mass. The maximum allowable velocity for liquid and vapor are $15\frac{ft}{s}$ and $100\frac{ft}{s}$,respectively. What is the minimum diameter of a schedule 40 steel pipe suitible for this application?

A. $3in$

B. $4in$

C. $5in$

D. $6in$

The pipe needs to be sized to accomodate both the liquid water and the vapor. Start by determining the mass flow rates of liquid and vapor which are 95% and 5%, respectively. For convenience, change the units to $\frac{lb}{s}$ for use in the next step.

$$\dot{m}_{liquid} = (0.95)\left(50,000\frac{lb}{hr}\right)\left(\frac{1hr}{3600s}\right) = 13.19\frac{lb}{s}$$

$$\dot{m}_{vapor} = (0.05)\left(50,000\frac{lb}{hr}\right)\left(\frac{1hr}{3600s}\right) = 0.69\frac{lb}{s}$$

Mass flow rate is the product of density and volume flow rate: $\dot{m} = \rho Q$.

Volume flow rate is the product of velocity and area: $Q = VA$.

Combine the above and solve for area. Substite specific volume in the numerator for density in the denominator, since they are inverses.

$$\dot{m} = \rho V A$$

$$A = \frac{\dot{m}}{\rho V} = \frac{\dot{m}v}{V}$$

The mass flow rates have been establisted. The *maximum* velocities for liquid and vapor are given, which ensures the *minimum* areas will be determined.

Use the steam table by looking up Properties of Saturated Water and Steam by pressure and locating $p = 5psig \approx 20psia$. Note the specific volume of liquid and vapor.

$$v_f = 0.0168\frac{ft^3}{lb}$$

$$v_g = 20.09\frac{ft^3}{lb}$$

Substitute into the area expression to determine the minimum area for liquid and vapor.

$$A_{min,liquid} = \frac{\dot{m}_{liquid}v_f}{V_{max,liquid}} = \frac{\left(13.19\frac{lb}{s}\right)\left(0.0168\frac{ft^3}{lb}\right)}{15\frac{ft}{s}} = 0.0148ft^2$$

$$A_{min,vapor} = \frac{\dot{m}_{vapor} v_g}{V_{max,vapor}} = \frac{\left(0.69 \frac{lb}{s}\right)\left(20.1 \frac{ft^3}{lb}\right)}{100 \frac{ft}{s}} = 0.139 ft^2$$

Take the sum to find the minimum required area in square feet. Solve for the diameter and convert to inches.

$$A_{min} = A_{min,liquid} + A_{min,vapor} = 0.0148 ft^2 + 0.139 ft^2 = 0.187 ft^2$$

$$A = \frac{\pi}{4} D^2 \rightarrow D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4\left(0.187 ft^2\right)}{\pi}} = 0.487 ft \left(\frac{12 in}{1 ft}\right) = 5.85 in$$

Check the table Schedule 40 Steel Pipe to confirm the minimum nominal size based on inside diameter. 6 inch nominal pipe size has an inside diameter of $6.065 in$ and will suffice for this application.

Answer D