8.27

8.27 Asphalt at 120 °F, considered to be a Newtonian fluid with a viscosity 80,000 times that of water and a specific gravity of 1.09, flows through a pipe of diameter 2.0 in. If the pressure gradient is 1.6 psi/ft determine the flowrate assuming the pipe is **(a)** horizontal; **(b)** vertical with flow up.

If the flow is laminar, then $Q = \dfrac{\pi(\Delta p - \gamma \ell \sin\theta)D^4}{128 \mu \ell}$ (1)

where $\gamma = SG\, \gamma_{H_2O} = 1.09\left(62.4 \frac{lb}{ft^3}\right) = 68.0 \frac{lb}{ft^3}$

and

$$\mu = 80{,}000 \mu_{H_2O} = 8 \times 10^4 \left(1.164 \times 10^{-5} \frac{lb \cdot s}{ft^2}\right) = 0.931 \frac{lb \cdot s}{ft^2}$$

a) For horizontal flow, $\theta = 0$

Thus, from Eq.(1)

$$Q = \frac{\pi\left(1.6 \times 144 \frac{lb}{ft^2}\right)\left(\frac{2}{12} ft\right)^4}{128\left(0.931 \frac{lb \cdot s}{ft^2}\right)(1 ft)} = \underline{\underline{4.69 \times 10^{-3} \frac{ft^3}{s}}}$$

b) For vertical flow up, $\theta = 90$

Thus, from Eq.(1)

$$Q = \frac{\pi\left(1.6 \times 144 \frac{lb}{ft^2} - 68 \frac{lb}{ft^3}(1 ft)\right)\left(\frac{2}{12} ft\right)^4}{128\left(0.931 \frac{lb \cdot s}{ft^2}\right)(1 ft)} = \underline{\underline{3.30 \times 10^{-3} \frac{ft^3}{s}}}$$

Note: We must check to see if our assumption of laminar flow is correct.

Since $V = \frac{Q}{A} = \dfrac{4.69 \times 10^{-3} \frac{ft^3}{s}}{\frac{\pi}{4}\left(\frac{2}{12}\right)^2} = 0.215 \frac{ft}{s}$ it follows that

$$Re = \frac{\rho V D}{\mu} = \frac{1.09\left(1.94 \frac{slug}{ft^3}\right)(0.215)\left(\frac{2}{12} ft\right)}{0.931 \frac{lb \cdot s}{ft^2}} = 0.0814 < 2100$$

The flow is laminar.