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 $Q = \frac{\pi(\Delta p - \gamma \ell \sin\theta)D^4}{128\mu\ell}$ (1)

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

and

$$\mu = 80{,}000\,\mu_{H_2O} = 8\times10^4(1.164\times10^{-5}\frac{lb\cdot s}{ft^2}) = 0.931\frac{lb\cdot s}{ft^2}$$

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

Thus, from Eq.(1)

$$Q = \frac{\pi(1.6\times144\frac{lb}{ft^2})(\frac{2}{12}ft)^4}{128(0.931\frac{lb\cdot s}{ft^2})(1ft)} = \underline{\underline{4.69\times10^{-3}\frac{ft^3}{s}}}$$

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

Thus, from Eq.(1)

$$Q = \frac{\pi(1.6\times144\frac{lb}{ft^2} - 68\frac{lb}{ft^3}(1ft))(\frac{2}{12}ft)^4}{128(0.931\frac{lb\cdot s}{ft^2})(1ft)} = \underline{\underline{3.30\times10^{-3}\frac{ft^3}{s}}}$$

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

Since $V = \frac{Q}{A} = \frac{4.69\times10^{-3}\frac{ft^3}{s}}{\frac{\pi}{4}(\frac{2}{12})^2} = 0.215\frac{ft}{s}$ it follows that

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

The flow is laminar.