Problem 1A.1

Estimation of dense-gas viscosity. Estimate the viscosity of nitrogen at 68°F and 1000 psig by means of Fig. 1.3-1, using the critical viscosity from Table E.1. Give the result in units of $\text{lb}_m/\text{ft}\cdot\text{s}$. For the meaning of "psig," see Table F.3-2.

Answer: $1.4 \times 10^{-5}\ \text{lb}_m/\text{ft}\cdot\text{s}$

Solution

From Table E.1 on page 864 we look up some facts about nitrogen gas N_2, namely the critical temperature T_c, the critical pressure p_c, and the critical viscosity μ_c:

$$T_c = 126.2\ \text{K} \qquad p_c = 33.5\ \text{atm} \qquad \mu_c = 180 \times 10^{-6}\ \frac{\text{g}}{\text{cm}\cdot\text{s}}.$$

In order to calculate the reduced temperature T_r and the reduced pressure p_r, we use the formulas,

$$T_r = \frac{T}{T_c} \quad \text{and} \quad p_r = \frac{p}{p_c}.$$

To use them, though, we have to make the units consistent, so convert 68°F into K and 1000 psig (pounds per square inch gage pressure) into atm. Use the formula,

$$K = \frac{5}{9}(F + 459.67),$$

to calculate the temperature in Kelvin: $T = 293.15$ K. From Table F.3-2 on page 869, we find that 1 psig $= 6.8046 \times 10^{-2}$ atm, so

$$p = 1000\ \cancel{\text{psig}} \times \frac{6.8046 \times 10^{-2}\ \text{atm}}{1\ \cancel{\text{psig}}} = 68.046\ \text{atm}.$$

Thus,

$$T_r = \frac{293.15\ \cancel{\text{K}}}{126.2\ \cancel{\text{K}}} \approx 2.32 \quad \text{and} \quad p_r = \frac{68.046\ \cancel{\text{atm}}}{33.5\ \cancel{\text{atm}}} \approx 2.03.$$

Now that we know T_r and p_r, we can use the graph on page 22 to determine μ_r, the reduced viscosity.

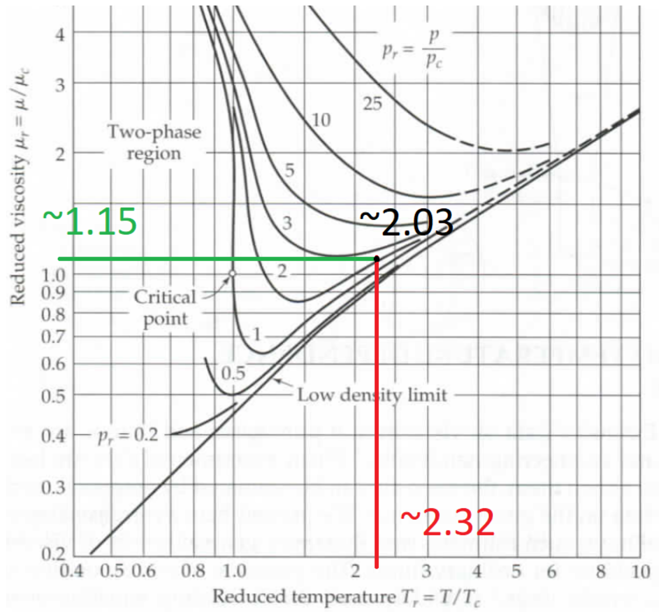

Figure 1: Use Fig. 1.3-1 in the text to determine μ_r.

We see that $\mu_r \approx 1.15$. The relationship between the viscosity μ and μ_r is

$$\mu_r = \frac{\mu}{\mu_c},$$

so

$$\mu = \mu_r \mu_c \approx 1.15 \left(180 \times 10^{-6} \, \frac{\text{g}}{\text{cm} \cdot \text{s}}\right) = 2.07 \times 10^{-4} \, \frac{\text{g}}{\text{cm} \cdot \text{s}}.$$

To convert this to the desired units, use the conversion factor in Table F.3-4 on page 870, $1 \text{ g/cm} \cdot \text{s} = 6.7197 \times 10^{-2} \text{ lb}_m/\text{ft} \cdot \text{s}$.

$$\mu \approx 2.07 \times 10^{-4} \, \frac{\cancel{\text{g}}}{\cancel{\text{cm}} \cdot \text{s}} \times \frac{6.7197 \times 10^{-2} \, \frac{\text{lb}_m}{\text{ft} \cdot \text{s}}}{1 \, \frac{\cancel{\text{g}}}{\cancel{\text{cm}} \cdot \text{s}}} \approx 1.39098 \times 10^{-5} \, \frac{\text{lb}_m}{\text{ft} \cdot \text{s}}$$

Because of 68°F in the problem statement, we round to two significant figures. Therefore, the viscosity of nitrogen gas is

$$\mu \approx 1.4 \, \frac{\text{lb}_m}{\text{ft} \cdot \text{s}}.$$