

Oil Pipeline Case Study

Input data

$$\begin{aligned}
 \text{bbl} &:= 42 \text{ gal} & \rho_{\text{water}} &:= 1000 \frac{\text{kg}}{\text{m}^3} & \mu &:= 0.01 \text{ Pa}\cdot\text{s} & P_2 &:= 1 \text{ atm} & \text{MP} &:= 10^6 \text{ Pa} \\
 Q &:= 170000 \frac{\text{bbl}}{\text{day}} & Q &= 0.313 \frac{\text{m}^3}{\text{s}} & L &:= 55 \text{ km} & g &= 9.807 \frac{\text{m}}{\text{s}^2} & Q &= 11.047 \frac{\text{ft}^3}{\text{s}} \\
 \text{API} &:= 43 & \text{SG} &:= \frac{141.5}{\text{API} + 131.5} & \text{SG} &= 0.811 & \mu &= 0.1 \cdot \text{poise} & D &:= 395 \text{ mm}
 \end{aligned}$$

Solution

$$\begin{aligned}
 A &:= \frac{\pi \cdot D^2}{4} & A &= 0.123 \text{ m}^2 & A &= 1.319 \cdot \text{ft}^2 & D &= 15.551 \cdot \text{in}
 \end{aligned}$$

$$\begin{aligned}
 V &:= \frac{Q}{A} & V &= 2.553 \frac{\text{m}}{\text{s}} & V &= 8.375 \frac{\text{ft}}{\text{s}}
 \end{aligned}$$

Calculate the Reynolds Number

$$\begin{aligned}
 \text{Re} &:= \frac{(\text{SG}) \cdot (\rho_{\text{water}}) \cdot (V) \cdot (D)}{\mu} & \text{Re} &= 8.177 \times 10^4
 \end{aligned}$$

$$\boxed{\varepsilon/D := 0.001} \quad \text{Roughness factor or relative roughness}$$

Calculate the friction factor using Colburn formula

$$f := 0.02 \quad \text{Use this value as initial guess}$$

Given Find friction factor by find option of MathCad

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\text{Re} \cdot \sqrt{f}} \right) \quad f := \text{Find}(f) \quad f = 0.0226 \quad \text{This is calculated value}$$

$$\Delta P_{\text{friction}} := f \cdot \frac{L}{D} \cdot \frac{V^2}{2} \cdot (\text{SG}) \cdot (\rho_{\text{water}})$$

$$\boxed{\Delta P_{\text{friction}} = 8.325 \cdot \text{MPa}} \quad \Delta P_{\text{friction}} = 1.207 \times 10^3 \cdot \text{psi}$$

Gas Pipeline Case Study

Input data

$$\begin{aligned} \text{lbmole} &:= 454 \text{mole} & \text{kmole} &:= 1000 \text{mole} & \mu &:= \frac{0.011}{1000} \text{Pa}\cdot\text{s} & C &:= 5.7 \cdot 10^{-4} \frac{\text{MPa}}{\text{K}} \\ P_S &:= 101.325 \cdot 10^3 \text{Pa} & T_S &:= (15 + 273) \text{K} & R_g &:= 8.314 \cdot \frac{\text{Pa}\cdot\text{m}^3}{\text{mole}\cdot\text{K}} & L &:= 43 \text{km} \\ MW &:= 19.5 \frac{\text{gm}}{\text{mole}} & \gamma &:= \frac{MW}{28.9 \frac{\text{kg}}{\text{kmole}}} & Q_{\text{Std}} &:= 70 \cdot 10^6 \frac{\text{ft}^3}{\text{day}} \end{aligned}$$

Solution

$$\begin{aligned} \text{mass} &:= Q_{\text{Std}} \cdot \left(\frac{\text{lbmole}}{379.5 \text{ft}^3} \right) & \text{mass} &= 7.686 \times 10^3 \cdot \frac{\text{lbmole}}{\text{hr}} & \text{mass} &= 3.489 \times 10^3 \cdot \frac{\text{kmole}}{\text{hr}} \\ Q_{\text{Std}} &:= \text{mass} \cdot \left(23.64 \frac{\text{m}^3}{\text{kmole}} \right) & Q_{\text{Std}} &= 22.913 \frac{\text{m}^3}{\text{s}} \\ P_{\text{in}} &:= 130 \text{bar} & P_{\text{in}} &= 13 \cdot \text{MPa} & P_{\text{out}} &:= 102.7 \text{bar} \quad (\text{Assumed Value}) \\ P_{\text{Avg}} &:= \frac{P_{\text{in}} + P_{\text{out}}}{2} & P_{\text{Avg}} &= 116.35 \cdot \text{bar} \\ T &:= (5 + 273) \text{K} & T &= 278 \text{K} \end{aligned}$$

@ P_{avg} & $T=5 \text{ C}$

Calculate gas compressibility calculations. First estimate T_c and P_c from gas specific gravity

$$\begin{aligned} T_C &:= (-18.02332 + 1107.182 \cdot \gamma - 1036.64 \cdot \gamma^2 + 392.815 \cdot \gamma^3) \text{R} & T_C &= 209.9 \cdot \text{K} \\ P_C &:= (748.19 - 280.17 \cdot \gamma + 373.6546 \cdot \gamma^2 - 203.2991 \cdot \gamma^3) \text{psi} & P_C &= 4.6 \cdot \text{MPa} \\ Tr &:= \frac{T}{T_C} & Tr &= 1.325 \\ Pr &:= \frac{P_{\text{Avg}}}{P_C} & Pr &= 2.531 \\ A_1 &:= 0.3265 - \frac{1.07}{Tr} - \frac{0.5339}{Tr^3} + \frac{0.01569}{Tr^4} - \frac{0.05165}{Tr^5} & A_1 &= -0.718 \\ A_2 &:= 0.5475 - \frac{0.7361}{Tr} + \frac{0.1844}{Tr^2} & A_2 &= 0.097 \\ A_3 &:= 0.1056 \cdot \left(-\frac{0.7361}{Tr} + \frac{0.1844}{Tr^2} \right) & A_3 &= -0.048 \end{aligned}$$

$$x := \frac{0.27Pr}{Tr}$$

$$A_4 := 0.6134$$

$$A_5 := 0.7210$$

Assume: $Z := 1$ Find Z=compressibility factor by "Find" option of MathCad

Given

$$Z = 1 + A_1 \cdot \frac{x}{Z} + A_2 \cdot \left(\frac{x}{Z}\right)^2 - A_3 \cdot \left(\frac{x}{Z}\right)^5 + A_4 \cdot \left[1 + A_5 \cdot \left(\frac{x}{Z}\right)^2\right] \cdot \left[\frac{\left(\frac{x}{Z}\right)^2}{Tr^3}\right] \cdot e^{-A_5 \cdot \left(\frac{x}{Z}\right)^2}$$

$$Z := \text{Find}(Z)$$

$$Z = 0.66$$

$$Q_{Ac} := Z \cdot \left(\frac{T}{T_S}\right) \left(\frac{P_S}{P_{Avg}}\right) \cdot Q_{Std}$$

$$Q_{Ac} = 0.127 \frac{m^3}{s}$$

$$D := 190mm \quad A := \frac{\pi}{4} \cdot D^2$$

$$A = 0.028 m^2$$

$$V := \frac{Q_{Ac}}{A}$$

$$V = 4.492 \frac{m}{s}$$

$$\rho := \frac{P_{Avg} \cdot MW}{Z \cdot R_g \cdot T}$$

$$\rho = 148.459 \frac{kg}{m^3}$$

$$Re := \frac{(\rho) \cdot (V) \cdot (D)}{\mu}$$

$$Re = 1.152 \times 10^7 \quad \text{Reynolds Number}$$

Roughness factor or relative roughness

$$\epsilon/D := 0.000001$$

$$f := 0.01 \quad \text{Given}$$

Find friction factor by Colburn formula and "Find" option of MathCad

$$\frac{1}{\sqrt{f}} = -2 \log\left(\frac{\epsilon/D}{3.7} + \frac{2.51}{Re \cdot \sqrt{f}}\right) \quad f := \text{Find}(f)$$

$$f = 0.0081 \quad \text{Calculated friction factor}$$

$$\rho_S := \frac{P_S \cdot MW}{R_g \cdot T_S}$$

$$\rho_S = 0.825 \frac{kg}{m^3}$$

$$P_{out} := \sqrt{P_{in}^2 - C \cdot f \cdot L \cdot Z \cdot T \cdot \rho_S \cdot \frac{Q_{Std}^2}{D^5}}$$

$$P_{out} = 10.27 \cdot MPa$$

$$P_{out} = 1489.5 \cdot psi$$

$$\Delta P_{friction} := P_{in} - P_{out}$$

$$\Delta P_{friction} = 2.731 \cdot MPa$$

$$\Delta P_{friction} = 396 \cdot psi$$