ME 423: FLUIDS ENGINEERING

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Pressure Drop

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Panhandle A Equation

The **Panhandle A Equation** was developed for use in natural gas pipelines, incorporating an **efficiency factor, *E*** for Reynolds numbers in the range of 5 to 11 million ($5x10^6$ - $11x10^6$).

In this equation, the pipe roughness is not used. The general form of the Panhandle A equation is expressed in USCS units as follows:

$$Q = 435.87E\left(\frac{T_b}{P_b}\right)^{1.0788}\left(\frac{P_1^2 - e^s P_2^2}{G^{0.8539} T_f L_e Z}\right)^{0.5394} D^{2.6182} \quad \text{(USCS units)} \qquad (2.55)$$

where

Q = volume flow rate, standard ft³/day (SCFD)
E = pipeline efficiency, a decimal value less than 1.0
P_b = base pressure, psia
T_b = base temperature, °R (460 + °F)
P_1 = upstream pressure, psia
P_2 = downstream pressure, psia
G = gas gravity (air = 1.00)
T_f = average gas flow temperature, °R (460 + °F)
L_e = equivalent length of pipe segment, mi → $L_e = \frac{L(e^s - 1)}{s}$ (2.9)
Z = gas compressibility factor, dimensionless
D = pipe inside diameter, in.

$$s = \text{elevation adjustment parameter} = 0.0375G\left(\frac{H_2 - H_1}{T_f Z}\right) \qquad (2.10)$$

Panhandle A Equation

Since the gas gravity is several orders of magnitude lower that the liquid, the influence of elevation is generally insignificant in a pipeline that transports gas. And hence, in calculation of flow rate/pressure drop, elevation difference in not being considered (in general).

Accordingly, the **Panhandle A** equation takes the following form:

$$Q = 435.87E\left(\frac{T_b}{P_b}\right)^{1.0788}\left(\frac{P_1^2 - P_2^2}{G^{0.8539}T_f LZ}\right)^{0.5394} D^{2.6182} \qquad \text{(USCS units)}$$

where

- Q = volume flow rate, standard ft³/day (SCFD)
- E = pipeline efficiency, a decimal value less than 1.0
- P_b = base pressure, psia
- T_b = base temperature, °R (460 + °F)
- P_1 = upstream pressure, psia
- P_2 = downstream pressure, psia
- G = gas gravity (air = 1.00)
- T_f = average gas flow temperature, °R (460 + °F)
- L = length of pipe segment, mi
- Z = gas compressibility factor, dimensionless
- D = pipe inside diameter, in.

$$L_e = \frac{L(e^s - 1)}{s} \Rightarrow \frac{L_e}{L} = \lim_{s\to 0}\frac{e^s - 1}{s}$$

$$\Rightarrow \frac{L_e}{L} = \lim_{s\to 0}\frac{e^s}{1} = 1 \qquad \text{(L'Hospital rule)}$$

$$\therefore L_e = L$$

Panhandle A Equation

By comparing the **Panhandle A equation** with **General Flow equation**, an equivalent transmission factor in USCS units can be calculated as follows:

$$F = 7.2111E\left(\frac{QG}{D}\right)^{0.07305} \quad \text{(USCS)} \qquad (2.57)$$

$$Q = 435.87E\left(\frac{T_b}{P_b}\right)^{1.0788}\left(\frac{P_1^2 - P_2^2}{G^{0.8539}T_f LZ}\right)^{0.5394} D^{2.6182} \quad \text{(USCS units)}$$

Panhandle A Eq.

$$Q = 38.77F\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - P_2^2}{GT_f LZ}\right)^{0.5} D^{2.5} \quad \text{(USCS units)} \qquad (2.4)$$

General Flow Eq.

Panhandle B Equation

The **Panhandle B equation**, also known as the revised Panhandle equation, is used in large diameter, high pressure transmission lines. In fully turbulent flow, it is found to be accurate for values of **Reynolds number in the range of 4 to 40 million** ($4\text{x}10^6$ - $40\text{x}10^6$).

This equation in USCS units is as follows:

$$Q = 737E\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{P_1^2 - e^s P_2^2}{G^{0.961} T_f L_e Z}\right)^{0.51} D^{2.53} \qquad \text{(USCS units)} \qquad (2.59)$$

Neglecting the elevation difference, **Panhandle B equation** takes the following form:

$$Q = 737E\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{P_1^2 - P_2^2}{G^{0.961} T_f L Z}\right)^{0.51} D^{2.53} \qquad \text{(USCS units)}$$

Panhandle B Equation

In SI units, Panhandle equation takes the following form:

$$Q = 4.5965 \times 10^{-3} E \left(\frac{T_b}{P_b} \right)^{1.0788} \left(\frac{P_1^2 - e^s P_2^2}{G^{0.8539} T_f L_e Z} \right)^{0.5394} D^{2.6182} \quad \text{(SI units)} \qquad (2.56)$$

Panhandle A Eq.

$$Q = 1.002 \times 10^{-2} E \left(\frac{T_b}{P_b} \right)^{1.02} \left(\frac{P_1^2 - e^s P_2^2}{G^{0.961} T_f L_e Z} \right)^{0.51} D^{2.53} \quad \text{(SI units)} \qquad (2.60)$$

Panhandle B Eq.

where

- Q = gas flow rate, standard m³/day
- E = pipeline efficiency, a decimal value less than 1.0
- T_b = base temperature, K (273 + °C)
- P_b = base pressure, kPa
- T_f = average gas flow temperature, K (273 + °C)
- P_1 = upstream pressure, kPa (absolute)
- P_2 = downstream pressure, kPa (absolute)
- L_e = equivalent length of pipe segment, km
- Z = gas compressibility factor at the flowing temperature, dimensionless

Other symbols are as defined previously.

Problem

Example 15

Using the Panhandle A equation, calculate the outlet pressure in a natural gas pipeline, NPS 16 with 0.250 in. wall thickness, 15 miles long. The gas flow rate is 100 MMSCFD at an inlet pressure of 1000 psia. The gas gravity = 0.6 and viscosity = 0.000008 lb/ft-sec. The average gas temperature is 80°F. Assume base pressure = 14.73 psia and base temperature = 60°F. For compressibility factor Z, use the CNGA method. Assume pipeline efficiency of 0.92.

Solution:

The average pressure, P_{avg}, needs to be calculated before the compressibility factor Z can be determined. Since the inlet pressure P_1 = 1,000 psia, and the outlet pressure P_2 is unknown, we will have to assume a value of P_2 (such as 800 psia) and calculate P_{avg} and then calculate the value of Z. Once Z is known, from the Panhandle A equation we can calculate the outlet pressure P_2. Using this value of P_2, a better approximation for Z is calculated from a new P_{avg}. This process is repeated until successive values of P_2 are within allowable limits, such as 0.5 psia.

Assume P_2 = 800 psia. The average pressure comes as:

$$P_{avg} = \frac{2}{3}\left(1000 + 800 - \frac{1000 \times 800}{1000 + 800}\right) = 903.7\,\text{psia}$$

Problem

Now, calculate the compressibility factor, Z using the CNGA method;

$$Z = \frac{1}{\left[1 + \left(\frac{P_{avg} \times 344400(10)^{1.785G}}{T_f^{\,3.825}}\right)\right]} \; ; \; P_{avg} \text{ in Psig} \qquad (1.34)$$

$$\Rightarrow \; Z = \frac{1}{\left[1 + \frac{(903.7 - 14.73) \times 344400(10)^{1.785 \times 0.6}}{(80+460)^{3.825}}\right]} = 0.8869$$

Use Panhandle A equation & neglecting elevation difference

$$Q = 435.87E\left(\frac{T_b}{P_b}\right)^{1.0788}\left(\frac{P_1^2 - P_2^2}{G^{0.8539} T_f L Z}\right)^{0.5394} D^{2.6182} \qquad \text{(USCS units)}$$

$$\Rightarrow 100 \times 10^6 = 435.87 \times 0.92\left(\frac{60+460}{14.73}\right)^{1.0788}\left(\frac{1000^2 - P_2^2}{(0.6)^{0.8539}(80+460)(15)(0.8869)}\right)^{0.5394}(16 - 0.25 \times 2)^{2.6182} \qquad \text{(USCS units)}$$

$P_2 = 968.02$ psia → $P_2\big|_{\text{assumed}} = 800$ psia → $\Delta P_2 = 168.02$ psia, too big!!

Problem

Use this new P_2 for next iteration;

$$P_{avg} = \frac{2}{3}\left(1000 + 968.02 - \frac{1000 \times 968.02}{1000 + 968.02}\right) = 984.10\,\text{psia}$$

$$\therefore\; Z = \frac{1}{\left[1 + \frac{(984.10 - 14.73) \times 344400(10)^{1.785 \times 0.6}}{(80+460)^{3.825}}\right]} = 0.8780$$

Use Panhandle A equation & neglecting elevation difference

$$Q = 435.87E\left(\frac{T_b}{P_b}\right)^{1.0788}\left(\frac{P_1^2 - P_2^2}{G^{0.8539} T_f L Z}\right)^{0.5394} D^{2.6182} \qquad \text{(USCS units)}$$

$$\Rightarrow 100 \times 10^6 = 435.87 \times 0.92\left(\frac{60+460}{14.73}\right)^{1.0788}\left(\frac{1000^2 - P_2^2}{(0.6)^{0.8539}(80+460)(15)(0.8780)}\right)^{0.5394}(16 - 0.25 \times 2)^{2.6182} \qquad \text{(USCS units)}$$

$$P_2 = 968.35\ \text{psia}$$

$$P_2\big|_{\text{last iter}} = 968.02\ \text{psia}$$

$$\Delta P_2 = 0.33\ \text{psia} < 0.5\,\text{psia (no further iteration)}$$

$$\therefore P_2 = 968.35\ \text{psia} \quad \text{Ans.}$$

Problem

Using the **Panhandle B equation**, calculate the outlet pressure in a natural gas pipeline, NPS 16 with 0.250 in. wall thickness, 15 miles long. The gas flow rate is 100 MMSCFD at an inlet pressure of 1000 psia. The gas gravity = 0.6 and viscosity = 0.000008 lb/ft-sec. The average gas temperature is 80°F. Assume base pressure = 14.73 psia and base temperature = 60°F. For compressibility factor *Z*, use the CNGA method. Assume pipeline efficiency of 0.92.

Compare the result with that obtained from **Panhandle A equation**.

(Homework)

Summary table

DESCRIPTION	PANHANDLE A EQUATION	PANHANDLE B EQUATION
Published	Early 1940s	1956
Reynolds number range	5 – 11 Million	4 – 40 Million
Efficiency factor (E)	less than 1 and normally assumed as 0.92	less than 1 and generally varies between 0.88 – 0.94
Pipeline diameters	generally 12 – 60 inch (305 – 1524 mm)	generally used for larger pipelines > 36 inch (> 914 mm)
Pressure	around 800 – 1500 psia (5516 – 10342 kPa)	> 1000 psia (> 6895 kPa)

Other Flow Equations for Gas Transport in Pipeline

$$Q = 433.5E\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{GT_f L_e Z}\right)^{0.5} D^{2.667} \qquad (2.52)$$

Weymouth eq.

$$Q = 136.9E\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{G^{0.8} T_f L_e \mu^{0.2}}\right)^{0.555} D^{2.667} \quad \text{(USCS units)} \qquad (2.63)$$

Institute of Gas Technology (IGT) eq.

μ = gas viscosity, lb/ft-s

$$Q = 85.7368E\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{G^{0.7391} T_f L_e \mu^{0.2609}}\right)^{0.575} D^{2.725} \quad \text{(USCS units)} \qquad (2.69)$$

Mueller eq.

$$Q = 410.1688E\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - P_2^2}{G^{0.8587} T_f L_e}\right)^{0.538} D^{2.69} \quad \text{(USCS units)} \qquad (2.71)$$

Fritzsche eq.

Comparison of Flow Equations

In Figure 2.5, we consider a pipeline 100 mi long, NPS 16 with 0.250 in. wall thickness, operating at a flow rate of 100 MMSCFD. The gas flowing temperature is 80°F. With the upstream pressure fixed at 1400 psig, the downstream pressure was calculated using the different flow equations. By examining Figure 2.5, it is clear that the highest pressure drop is predicted by the Weymouth equation and the lowest pressure drop is predicted by the Panhandle B equation.

It must be noted that we used a pipe roughness of 700 μin. for both the AGA and Colebrook equations, whereas a pipeline efficiency of 0.95 was used in the Panhandle and Weymouth equations.

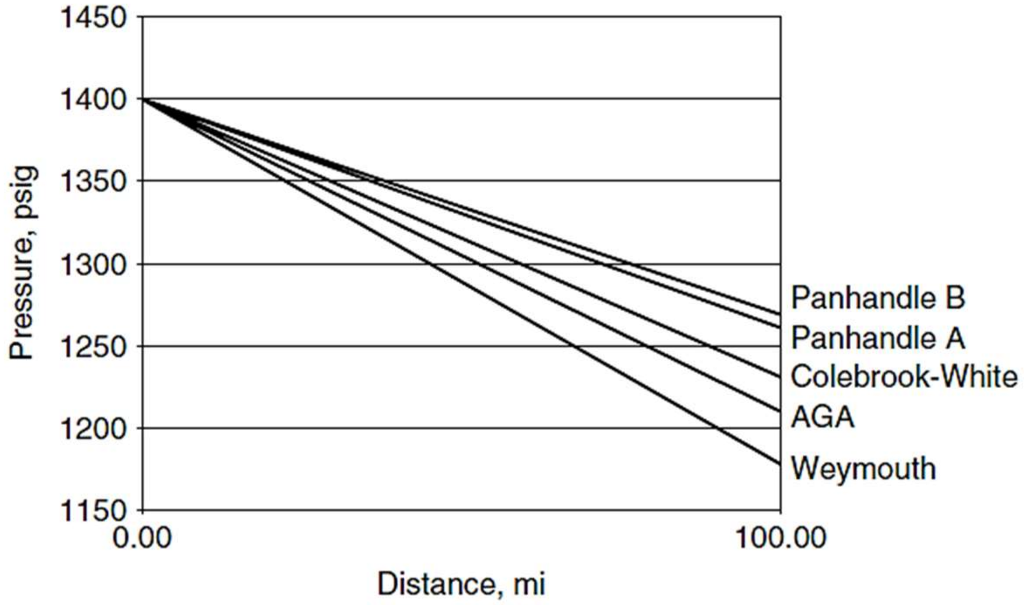

Figure 2.5 Comparison of flow equations.

Comparison of Flow Equations

Figure 2.6 shows a comparison of the flow equations from a different perspective. In this case, we calculated the upstream pressure required for an NPS 30 pipeline, 100 miles long, holding the delivery pressure constant at 800 psig. The upstream pressure required for various flow rates, ranging from 200 to 600 MMSCFD, was calculated using the five flow equations. Again it can be seen that the Weymouth equation predicts the highest upstream pressure at any flow rate, whereas the Panhandle A equation calculates the least pressure.

We therefore conclude that the most conservative flow equation that predicts the highest pressure drop is the Weymouth equation and the least conservative flow equation is Panhandle A.

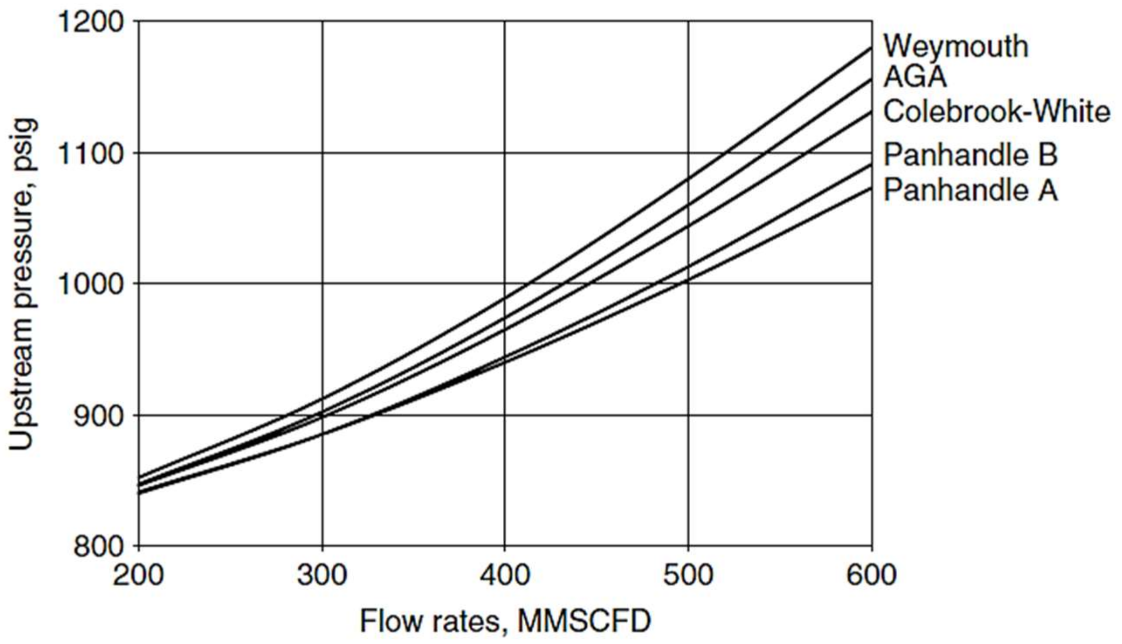

Figure 2.6 Upstream pressures for various flow equations.