

ME 423: FLUIDS ENGINEERING

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Pressure Drop

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Several equations are available that relate the gas flow rate with gas properties, pipe diameter and length, and upstream and downstream pressures. These equations are listed as follows:

1. General Flow equation
2. Colebrook-White equation
3. Modified Colebrook-White equation
4. AGA equation
5. Weymouth equation
6. Panhandle A equation
7. Panhandle B equation
8. IGT equation
9. Spitzglass equation
10. Mueller equation
11. Fritzsche equation

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 ($5 \times 10^6 - 11 \times 10^6$).

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

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

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)

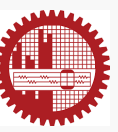
T_f = average gas flow temperature, °R (460 + °F)

L_e = equivalent length of pipe segment, mi $\rightarrow L_e = \frac{L(e^s - 1)}{s}$ (2.9)

Z = gas compressibility factor, dimensionless

D = pipe inside diameter, in.

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



Panhandle A Equation

Since the gas gravity is several orders of magnitude lower than 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 is not being considered (in general).

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

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

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.

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

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

$$\therefore L_e = L$$

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:

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

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

Panhandle A Eq.

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

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** ($4 \times 10^6 - 40 \times 10^6$).

This equation in USCS units is as follows:

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

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

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

Panhandle B Equation



In SI units, **Panhandle equation** takes the following form:

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

Panhandle A Eq.

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

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.



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.

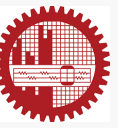
Solution:

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;

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

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

Use Panhandle A equation & neglecting elevation difference

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

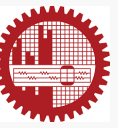
$$\Rightarrow 100 \times 10^6 = 435.87 \times 0.92 \left(\frac{60 + 460}{14.73} \right)^{1.0788} \left(\frac{1000^2 - P_2^2}{(0.6)^{0.8539} (80 + 460)(15)(0.8869)} \right)^{0.5394} (16 - 0.25 \times 2)^{2.6182} \quad (\text{USCS units})$$

$$\rightarrow P_2 = 968.02 \text{ psia}$$

$$P_2|_{\text{assumed}} = 800 \text{ psia}$$

$$\Delta P_2 = 168.02 \text{ psia, too big!!}$$

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

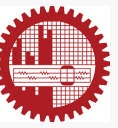
$$Q = 435.87 E \left(\frac{T_b}{P_b} \right)^{1.0788} \left(\frac{P_1^2 - P_2^2}{G^{0.8539} T_f LZ} \right)^{0.5394} D^{2.6182} \quad (\text{USCS units})$$

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

→ $P_2 = 968.35 \text{ psia}$ $P_2|_{\text{last iter}} = 968.02 \text{ psia}$ $\Delta P_2 = 0.33 \text{ psia} < 0.5 \text{ psia}$ (no further iteration)

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

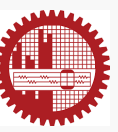
Problem



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



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

Weymouth eq.

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

Institute of Gas Technology (IGT) eq.

μ = gas viscosity, lb/ft-s

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

Mueller eq.

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

Fritzsche eq.