Gas Pipeline Flow - SI Units

American Gas Association (AGA) equation for fully turbulent isothermal gas flo

(Reference: Eq-17-18, Section 17, GPSA Engineering Data Book, Eleventh Edition, 1998

$$Q = 0.018 \times \frac{T_s}{P_s} \times E \times \left[4\log_{10}\left(\frac{3.7d}{\varepsilon}\right)\right] \times \left[\frac{P_1^{2} - P_2^{2}}{\gamma L_m T_{avg} Z_{avg}}\right]^{0.5} \times d^{2.5}$$

where:

Q = flow rate of gas, m^3/day at standard conditions

T_s = Standard Temperature = 288.9 K

P_s = Standard Pressure = 101.56 kPa (abs)

E = pipeline efficiency factor (fraction)

= 1 in the absence of field data (also for new straight pipe with no diameter change

= 0.95 for very good operating conditions, typically through first 12–18 months

= 0.92 for average operating conditions

= 0.85 for unfavourable operating conditions

d = internal diameter of pipe, mm

ε = pipe material absolute roughness, mm (commonly used value for bare steel pipe = 0.046

P_1 = Inlet or Start Pressure, kPa (abs)

P_2 = Outlet or End Pressure, kPa (abs)

γ = relative density of flowing gas (air = 1.0), dimensionless

Can be calculated as follows:

$$\gamma = \frac{MW}{28.96}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, m

T_{avg} = average temperature, K

$$T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\dfrac{T_{in} - T_{soil}}{T_{out} - T_{soil}}\right)}\right] + T_{soil}$$

T_{in} = Gas temperature at inlet, K

T_{out} = Gas temperature at outlet, K

T_{soil} = Soil temperature, K

Z_{avg} = average compressibility factor, dimensionless

$$Z_{avg} = \frac{1}{\left[1 + \left(\dfrac{P_{avg} \times 5270 \times 10^{1.785\gamma}}{T_{avg}^{3.825}}\right)\right]^{2}}$$

$$P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]$$

Inputs

T_s =	288.9	K	
P_s =	101.56	kPa (abs)	
E =	0.92	dimensionless	
d =	489	mm	
ε =	0.046	mm	(standard value for bare CS pipe)
P_1 =	7,000	kPa (abs)	
P_2 =	5,600	kPa (abs)	
L_m =	16,000	m	
MW =	17.38	kg/kg-mol	
T_{in} =	30	°C	
T_{out} =	27	°C	
T_{soil} =	18	°C	

Calculations

γ =	0.6	dimensionless	
T_{in} =	303.15	K	
T_{out} =	300.15	K	
T_{soil} =	291.15	K	
T_{avg} =	301.58	K	
P_{avg} =	6,325.9	kPa (abs)	
Z_{avg} =	0.78	dimensionless	
Q =	12,756,926	m^3/day	@std. conditions of 101.56 kPa(abs) & 15.75°C
	531,538.6	m^3/h	@std. conditions of 101.56 kPa(abs) & 15.75°C

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Gas Pipeline Flow - U.S. Customary Units

American Gas Association (AGA) equation for fully turbulent isothermal gas flo

(Reference: Eq-17-18, Section 17, GPSA Engineering Data Book, Twelfth Edition-FPS, 2

$$Q = 38.77 \times \frac{T_b}{P_b} \times E \times \left[4\log_{10}\left(\frac{3.7D}{\varepsilon}\right)\right] \times \left[\frac{P_1^2 - P_2^2}{S L_m T_{avg} Z_{avg}}\right]^{0.5} \times d^{2.5}$$

where:

Q = flow rate of gas, ft^3/day at base conditions

T_b = Base Temperature = 520 R

P_b = Base Pressure = 14.73 psia

E = pipeline efficiency factor (fraction)

= 1 in the absence of field data (also for new straight pipe with no diameter change

= 0.95 for very good operating conditions, typically through first 12–18 months

= 0.92 for average operating conditions

= 0.85 for unfavourable operating conditions

d = internal diameter of pipe, inch

D = internal diameter of pipe, ft

ε = pipe material absolute roughness, ft (commonly used value for bare steel pipe = 0.0001

P_1 = Inlet or Start Pressure, psia

P_2 = Outlet or End Pressure, psia

S = specific gravity of flowing gas (air = 1.0), dimensionless

Can be calculated as follows:

$$S = \frac{MW}{28.96}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, miles

T_{avg} = average temperature, R

$$T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\frac{T_{in} - T_{soil}}{T_{out} - T_{soil}}\right)}\right] + T_{soil}$$

T_{in} = Gas temperature at inlet, R

T_{out} = Gas temperature at outlet,R

T_{soil} = Soil temperature, R

Z_{avg} = average compressibility factor, dimensionless

$$Z_{avg} = \frac{1}{\left[1 + \left(\frac{(P_{avg} + 14.7) \times 344400 \times 10^{1.785S}}{T_{avg}^{3.825}}\right)\right]}$$

$$P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]$$

$$\boxed{P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]}$$

Inputs

T_b =	520	R	
P_b =	14.73	psia	
E =	0.92	dimensionless	
d =	19.25	inch	
ε =	0.00015	ft	(standard value for bare CS pipe)
P_1 =	1,015	psia	
P_2 =	812	psia	
L_m =	10	miles	
MW =	17.38	lb/lb-mol	
T_{in} =	86	°F	
T_{out} =	81	°F	
T_{soil} =	64	°F	

Calculations

S =	0.6	dimensionless	
T_{in} =	546	R	
T_{out} =	541	R	
T_{soil} =	524	R	
T_{avg} =	543.39	R	
P_{avg} =	917.3	psia	
D =	1.6	ft	
Z_{avg} =	0.88	dimensionless	
Q =	426,925,291	ft^3/day	@base conditions of 14.73 psia & 60°F
	296,475.9	ft^3/min	@base conditions of 14.73 psia & 60°F

Gas Pipeline Flow - SI Units

Weymouth equation for fully turbulent isothermal gas flow

(Reference: Equation 2.32, Gas Pipeline Hydraulics by E. Shashi Menon)

$$Q = 0.0037435 \times \frac{T_s}{P_s} \times E \times \left[\frac{P_1^{\,2} - P_2^{\,2}}{\gamma L_m T_{avg} Z_{avg}} \right]^{0.5} \times d^{\,2.667}$$

where:

Q = flow rate of gas, m^3/day at standard conditions

T_s = Standard Temperature = 288.9 K

P_s = Standard Pressure = 101.56 kPa (abs)

d = internal diameter of pipe, mm

P_1 = Inlet or Start Pressure, kPa (abs)

P_2 = Outlet or End Pressure, kPa (abs)

γ = relative density of flowing gas (air = 1.0), dimensionless

Can be calculated as follows:

$$\gamma = \frac{MW}{28.96}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, km

T_{avg} = average temperature, K

$$T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\frac{T_{in} - T_{soil}}{T_{out} - T_{soil}} \right)} \right] + T_{soil}$$

T_{in} = Gas temperature at inlet, K

T_{out} = Gas temperature at outlet, K

T_{soil} = Soil temperature, K

Z_{avg} = average compressibility factor, dimensionless

$$Z_{avg} = \frac{1}{\left[1 + \left(\frac{P_{avg} \times 5270 \times 10^{1.785\gamma}}{T_{avg}^{\;3.825}} \right) \right]^2}$$

$$P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2} \right]$$

Notes:

1. Weymouth equation is recommended to be used for short pipelines & gathering stations.

Inputs

T_s = 288.9 K

P_s = 101.56 kPa (abs)

E = 0.92 dimensionless

d = 489 mm

P_1 = 7,000 kPa (abs)

P_2 = 5,600 kPa (abs)

L_m = 16 km

MW = 17.38 kg/kg-mol

T_{in} = 30 °C

T_{out} = 27 °C

T_{soil} = 18 °C

Calculations

γ = 0.6 dimensionless

T_{in} = 303.15 K

T_{out} = 300.15 K

T_{soil} = 291.15 K

T_{avg} = 301.58 K

P_{avg} = 6,325.9 kPa (abs)

Z_{avg} = 0.78 dimensionless

Q = 12,839,373 m^3/day @std. conditions of 101.56 kPa(abs) & 15.75°C

534,973.9 m^3/h @std. conditions of 101.56 kPa(abs) & 15.75°C

Observation:

For the same conditions inlet & outlet pressure, line size, line length, efficiency factor E & avg. gas flowing temperature, Weymouth equation gives **closer approximation** of flow to the AGA equation compared to the Panhandle A & B equation.

Gas Pipeline Flow - U.S. Customary Units

Weymouth equation for fully turbulent isothermal gas flow

(Reference: Equation 2.30, Gas Pipeline Hydraulics by E. Shashi Menon)

$$Q = 433.5 \times \frac{T_b}{P_b} \times E \times \left[\frac{P_1^2 - P_2^2}{S L_m T_{avg} Z_{avg}} \right]^{0.5} \times d^{2.667}$$

where:

Q = flow rate of gas, ft^3/day at base conditions

T_b = Base Temperature = 520 R

P_b = Base Pressure = 14.73 psia

d = internal diameter of pipe, inch

P_1 = Inlet or Start Pressure, psia

P_2 = Outlet or End Pressure, psia

S = specific gravity of flowing gas (air = 1.0), dimensionless
Can be calculated as follows:

$$S = \frac{MW}{28.96}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, miles

T_{avg} = average temperature, R

$$T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\frac{T_{in} - T_{soil}}{T_{out} - T_{soil}} \right)} \right] + T_{soil}$$

T_{in} = Gas temperature at inlet, R

T_{out} = Gas temperature at outlet, R

T_{soil} = Soil temperature, R

Z_{avg} = average compressibility factor, dimensionless

$$Z_{avg} = \frac{1}{\left[1 + \left(\frac{(P_{avg} + 14.7) \times 344400 \times 10^{1.785S}}{T_{avg}^{3.825}} \right) \right]}$$

$$P_{avg} = \frac{2}{3} \left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2} \right]$$

Notes:

1. Weymouth equation is recommended to be used for short pipelines & gathering stations.

Inputs

T_b =	520	R
P_b =	14.73	psia
E =	0.92	dimensionless
d =	19.25	inch
P_1 =	1,015	psia
P_2 =	812	psia
L_m =	10	miles
MW =	17.38	lb/lb-mol
T_{in} =	86	°F
T_{out} =	81	°F
T_{soil} =	64	°F

Calculations

S =	0.6	dimensionless	
T_{in} =	546	R	
T_{out} =	541	R	
T_{soil} =	524	R	
T_{avg} =	543.39	R	
P_{avg} =	917.3	psia	
Z_{avg} =	0.88	dimensionless	
Q =	425,379,559	ft^3/day	@base conditions of 14.73 psia & 60°F
	295,402.5	ft^3/min	@base conditions of 14.73 psia & 60°F

Observation:

For the same conditions inlet & outlet pressure, line size, line length, efficiency factor E & avg. gas flowing temperature, Weymouth equation gives **closer approximation** of flow to the AGA equation compared to the Panhandle A & B equation.

Gas Pipeline Flow - SI Units

Panhandle A equation for partially turbulent isothermal gas flow

(Reference: Equation 2.35, Gas Pipeline Hydraulics by E. Shashi Menon)

$$0.0045965 \times \left(\frac{T_s}{P_s}\right)^{1.0788} \times E \times \left[\frac{P_1^{\,2} - P_2^{\,2}}{\gamma^{0.8539} L_m T_{avg} Z_{avg}}\right]^{0.5394} \times d^{\,2.6182}$$

where:

Q = flow rate of gas, m^3/day at standard conditions

T_s = Standard Temperature = 288.9 K

P_s = Standard Pressure = 101.56 kPa (abs)

E = pipeline efficiency factor (fraction)
= 1 in the absence of field data (also for new straight pipe with no diameter changes)
= 0.95 for very good operating conditions, typically through first 12–18 months
= 0.92 for average operating conditions
= 0.85 for unfavourable operating conditions

d = internal diameter of pipe, mm

P_1 = Inlet or Start Pressure, kPa (abs)

P_2 = Outlet or End Pressure, kPa (abs)

γ = relative density of flowing gas (air = 1.0), dimensionless
Can be calculated as follows:

$$\gamma = \frac{MW}{28.96}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, km

T_{avg} = average temperature, K

$$T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\dfrac{T_{in} - T_{soil}}{T_{out} - T_{soil}}\right)}\right] + T_{soil}$$

T_{in} = Gas temperature at inlet, K

T_{out} = Gas temperature at outlet, K

T_{soil} = Soil temperature, K

Z_{avg} = average compressibility factor, dimensionless

$$Z_{avg} = \frac{1}{\left[1 + \left(\dfrac{P_{avg} \times 5270 \times 10^{1.785\gamma}}{T_{avg}^{\;3.825}}\right)\right]^2}$$

$$P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]$$

$$\mathrm{Re} = 0.5134 \times \frac{P_s}{T_s} \times \left(\frac{\gamma \times Q}{\mu_{avg} \times d}\right)$$

where:

Re = Reynolds no.

μ_{avg} = avg. viscosity of gas, Poise (From "Gas Viscosity Panhandle A" sheet)

Notes:

1. Panhandle A equation should be used for large diameter (≥250 mm) pipelines & for long distance pipelines.
2. Efficiency factor of E = 0.92 is recommended for use with the Panhandle A equation.
3. Panhandle A eqn gives reasonable flow rates (low errors) if Reynolds no. is between 5 & 11 million

Inputs

T_s =	288.9	K
P_s =	101.56	kPa (abs)
E =	0.92	dimensionless
d =	489	mm
P_1 =	7,000	kPa (abs)
P_2 =	5,600	kPa (abs)
L_m =	16	km
MW =	17.38	kg/kg-mol
T_{in} =	30	°C
T_{out} =	27	°C
T_{soil} =	18	°C
μ_{avg} =	0.000127	P

Calculations

γ =	0.6	dimensionless	
T_{in} =	303.15	K	
T_{out} =	300.15	K	
T_{soil} =	291.15	K	
T_{avg} =	301.58	K	
P_{avg} =	6,325.9	kPa (abs)	
Z_{avg} =	0.78	dimensionless	
Q =	17,298,972	m^3/day	@std. conditions of 101.56 kPa(abs) & 15.75°C
	720,790.5	m^3/h	@std. conditions of 101.56 kPa(abs) & 15.75°C
Re =	30,211,495	dimensionless	
	FLOW ERROR HIGH		

Observation:

For the same conditions inlet & outlet pressure, line size, line length, efficiency factor E & avg. gas flowing temperature, Panhandle A equation gives **much higher** flow than AGA & Weymouth equation.

Gas Pipeline Flow - U.S. Customary Units

Panhandle A equation for partially turbulent isothermal gas flow

(Reference: Equation 2.35, Gas Pipeline Hydraulics by E. Shashi Menon)

$$\boxed{435.87 \times \left(\frac{T_b}{P_b}\right)^{1.0788} \times E \times \left[\frac{P_1^{\,2} - P_2^{\,2}}{S^{0.8539} L_m T_{avg} Z_{avg}}\right]^{0.5394} \times d^{\,2.6182}}$$

where:

Q = flow rate of gas, ft^3/day at base conditions

T_b = Base Temperature = 520 R

P_b = Base Pressure = 14.73 psia

E = pipeline efficiency factor (fraction)

= 1 in the absence of field data (also for new straight pipe with no diameter changes)

= 0.95 for very good operating conditions, typically through first 12–18 months

= 0.92 for average operating conditions

= 0.85 for unfavourable operating conditions

d = internal diameter of pipe, inch

P_1 = Inlet or Start Pressure, psia

P_2 = Outlet or End Pressure,psia

S = specific gravity of flowing gas (air = 1.0), dimensionless

Can be calculated as follows:

$$\boxed{S = \frac{MW}{28.96}}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, miles

T_{avg} = average temperature, R

$$\boxed{T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\dfrac{T_{in} - T_{soil}}{T_{out} - T_{soil}}\right)}\right] + T_{soil}}$$

T_{in} = Gas temperature at inlet, R

T_{out} = Gas temperature at outlet, R

T_{soil} = Soil temperature, R

Z_{avg} = average compressibility factor, dimensionless

$$\boxed{Z_{avg} = \frac{1}{\left[1 + \left(\dfrac{(P_{avg} + 14.7) \times 344400 \times 10^{1.785S}}{T_{avg}^{\;3.825}}\right)\right]}}$$

$$\boxed{P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]}$$

$$\boxed{\mathrm{Re} = 0.0004778 \times \frac{P_b}{T_b} \times \left(\frac{S \times Q}{\mu_{avg} \times d}\right)}$$

where:

Re = Reynolds no.

μ_{avg} = avg. viscosity of gas, lb/ft.s (From "Gas Viscosity Panhandle A" sheet)

Notes:

1. Panhandle A equation should be used for large diameter (≥250 mm) pipelines & for long distance pipelines.
2. Efficiency factor of E = 0.92 is recommended for use with the Panhandle A equation.
3. Panhandle A eqn gives reasonable flow rates (low errors) if Reynolds no. is between 5 & 11 million

Inputs

T_b = 520 R
P_b = 14.73 psia
E = 0.92 dimensionless
d = 19.25 inch
P_1 = 1,015 psia
P_2 = 812 psia
L_m = 10 miles
MW = 17.38 lb/lb-mol
T_{in} = 86 °F
T_{out} = 81 °F
T_{soil} = 64 °F
μ_{avg} = 0.000008 lb/ft.s

Calculations

S = 0.6 dimensionless
T_{in} = 546 R
T_{out} = 541 R
T_{soil} = 524 R
T_{avg} = 543.39 R
P_{avg} = 917.3 psia
Z_{avg} = 0.88 dimensionless
Q = 570,232,691 ft^3/day @base conditions of 14.73 psia & 60°F
395,994.9 ft^3/min @base conditions of 14.73 psia & 60°F
Re = 28,740,594 dimensionless
FLOW ERROR HIGH

Observation:

For the same conditions inlet & outlet pressure, line size, line length, efficiency factor E & avg. gas flowing temperature, Panhandle A equation gives **much higher** flow than AGA & Weymouth equation.

Gas Pipeline Flow - SI Units

Panhandle B equation for fully turbulent isothermal gas flow

(Reference: Equation 2.37, Gas Pipeline Hydraulics by E. Shashi Menon)

$$\boxed{0.01002 \times \left(\frac{T_s}{P_s}\right)^{1.02} \times E \times \left[\frac{P_1^{\,2} - P_2^{\,2}}{\gamma^{0.961} L_m T_{avg} Z_{avg}}\right]^{0.51} \times d^{\,2.53}}$$

where:

Q = flow rate of gas, m^3/day at standard conditions

T_s = Standard Temperature = 288.9 K

P_s = Standard Pressure = 101.56 kPa (abs)

E = pipeline efficiency factor (fraction)
= 1 in the absence of field data (also for new straight pipe with no diameter changes)
= 0.95 for very good operating conditions, typically through first 12–18 months
= 0.92 for average operating conditions
= 0.85 for unfavourable operating conditions

d = internal diameter of pipe, mm

P_1 = Inlet or Start Pressure, kPa (abs)

P_2 = Outlet or End Pressure, kPa (abs)

γ = relative density of flowing gas (air = 1.0), dimensionless
Can be calculated as follows:

$$\boxed{\gamma = \frac{MW}{28.96}}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, km

T_{avg} = average temperature, K

$$\boxed{T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\dfrac{T_{in} - T_{soil}}{T_{out} - T_{soil}}\right)}\right] + T_{soil}}$$

T_{in} = Gas temperature at inlet, K

T_{out} = Gas temperature at outlet, K

T_{soil} = Soil temperature, K

Z_{avg} = average compressibility factor, dimensionless

$$\boxed{Z_{avg} = \frac{1}{\left[1 + \left(\dfrac{P_{avg} \times 5270 \times 10^{1.785\gamma}}{T_{avg}^{\;3.825}}\right)\right]^2}}$$

$$\boxed{P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]}$$

$$\boxed{\mathrm{Re} = 0.5134 \times \frac{P_s}{T_s} \times \left(\frac{\gamma \times Q}{\mu_{avg} \times d}\right)}$$

where:

Re = Reynolds no.

μ_{avg} = avg. viscosity of gas, Poise (From "Gas Viscosity Panhandle B" sheet)

Notes:

1. Panhandle B equation should be used for large diameter (≥250 mm) pipelines & for long distance pipelines.
2. Efficiency factor varies between about 0.88 & 0.94 for use with the Panhandle B equation.
3. Panhandle B equation is found to be fairly accurate in turbulent flow for Reynolds numbers between 4 to 40 million.

Inputs

T_s = 288.9 K
P_s = 101.56 kPa (abs)
E = 0.92 dimensionless
d = 489 mm
P_1 = 7,000 kPa (abs)
P_2 = 5,600 kPa (abs)
L_m = 16 km
MW = 17.38 kg/kg-mol
T_{in} = 30 °C
T_{out} = 27 °C
T_{soil} = 18 °C
μ_{avg} = 0.000127 P

Calculations

γ = 0.6 dimensionless
T_{in} = 303.15 K
T_{out} = 300.15 K
T_{soil} = 291.15 K
T_{avg} = 301.58 K
P_{avg} = 6,325.9 kPa (abs)
Z_{avg} = 0.78 dimensionless
Q = 16,265,509 m^3/day @std. conditions of 101.56 kPa(abs) & 15.75°C
677,729.5 m^3/h @std. conditions of 101.56 kPa(abs) & 15.75°C
Re = 28,406,621 dimensionless
FLOW ERROR LOW

Observation:

For the same conditions inlet & outlet pressure, line size, line length, efficiency factor E & avg. gas flowing temperature, Panhandle B equation gives **lower** flow than Panhandle A equation.

Gas Pipeline Flow - U.S. Customary Units

Panhandle B equation for fully turbulent isothermal gas flow

(Reference: Equation 2.36, Gas Pipeline Hydraulics by E. Shashi Menon)

$$\boxed{737 \times \left(\frac{T_b}{P_b}\right)^{1.02} \times E \times \left[\frac{P_1^{\,2} - P_2^{\,2}}{S^{0.961} L_m T_{avg} Z_{avg}}\right]^{0.51} \times d^{\,2.53}}$$

where:

Q = flow rate of gas, ft^3/day at base conditions

T_b = Base Temperature = 520 R

P_b = Base Pressure = 14.73 psia

E = pipeline efficiency factor (fraction)

= 1 in the absence of field data (also for new straight pipe with no diameter changes)

= 0.95 for very good operating conditions, typically through first 12–18 months

= 0.92 for average operating conditions

= 0.85 for unfavourable operating conditions

d = internal diameter of pipe, inch

P_1 = Inlet or Start Pressure, psia

P_2 = Outlet or End Pressure, psia

S = specific gravity of flowing gas (air = 1.0), dimensionless

Can be calculated as follows:

$$\boxed{S = \frac{MW}{28.96}}$$

where MW = molecular weight of the gas under consideration

L_m = length of pipeline, miles

T_{avg} = average temperature, R

$$\boxed{T_{avg} = \left[\frac{T_{in} - T_{out}}{\ln\left(\frac{T_{in} - T_{soil}}{T_{out} - T_{soil}}\right)}\right] + T_{soil}}$$

T_{in} = Gas temperature at inlet, R

T_{out} = Gas temperature at outlet, R

T_{soil} = Soil temperature, R

Z_{avg} = average compressibility factor, dimensionless

$$\boxed{Z_{avg} = \frac{1}{\left[1 + \left(\frac{(P_{avg} + 14.7) \times 344400 \times 10^{1.785S}}{T_{avg}^{\;3.825}}\right)\right]}}$$

$$\boxed{P_{avg} = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right]}$$

$$\boxed{\mathrm{Re} = 0.0004778 \times \frac{P_b}{T_b} \times \left(\frac{S \times Q}{\mu_{avg} \times d}\right)}$$

where:

Re = Reynolds no.

μ_{avg} = avg. viscosity of gas, lb/ft.s (From "Gas Viscosity Panhandle B" sheet)

Notes:

1. Panhandle B equation should be used for large diameter (≥10 inch) pipelines & for long distance pipelines.
2. Efficiency factor varies between about 0.88 & 0.94 for use with the Panhandle B equation.
3. Panhandle B equation is found to be fairly accurate in turbulent flow for Reynolds numbers between 4 to 40 million.

Inputs

T_b =	520	R
P_b =	14.73	psia
E =	0.92	dimensionless
d =	19.25	inch
P_1 =	1,015	psia
P_2 =	812	psia
L_m =	10	miles
MW =	17.38	lb/lb-mol
T_{in} =	86	°F
T_{out} =	81	°F
T_{soil} =	64	°F
μ_{avg} =	0.000008	lb/ft.s

Calculations

S =	0.6	dimensionless	
T_{in} =	546	R	
T_{out} =	541	R	
T_{soil} =	524	R	
T_{avg} =	543.39	R	
P_{avg} =	917.3	psia	
Z_{avg} =	0.88	dimensionless	
Q =	538,175,445	ft^3/day	@base conditions of 14.73 psia & 60°F
	373,732.9	ft^3/min	@base conditions of 14.73 psia & 60°F
Re =	27,124,860	dimensionless	
	FLOW ERROR LOW		

Observation:

For the same conditions inlet & outlet pressure, line size, line length, efficiency factor E & avg. gas flowing temperature, Panhandle B equation gives **lower** flow than Panhandle A equation.

Gas Viscosity Correlation (Lee, Gonzalez & Eakin) (For "Panhandle A Eqn US" worksh

$$\boxed{\mu_{avg} = K \times \exp(X \times \rho_{avg}{}^{Y})}$$

where:

μ_{avg} = average gas viscosity, cP

ρ_{avg} = average gas density, g/ml

$$\boxed{K = \frac{0.0001 \times (7.77 + 0.0063\,MW) \times T_{avgR}^{\;1.5}}{122.4 + 12.9\,MW + T_{avgR}}}$$

where:

MW = molecular weight of the gas

T_{avgR} = Avg. temperature of the gas in R

$$\boxed{X = 2.57 + \frac{19145}{T_{avgR}} + 0.0095\,MW}$$

$$\boxed{Y = 1.11 + 0.04X}$$

$$\boxed{\rho_{avg} = \frac{P_{avg} \times MW}{R \times T_{avg} \times Z_{avg} \times 1000}}$$

where:

R = 8.314 kPaa*m^3/kmol-K

P_{avg} = Avg. Pressure of gas, kPa(abs) (from "Panhandle A Eqn US"sheet)

T_{avg} = Avg. temperature of the gas, K (from "Panhandle A Eqn US"sheet)

Z_{avg} = average compressibility factor, dimensionless (from "Panhandle A Eqn US"sheet)

Inputs

P_{avg} =	6324.3	kPa (abs)
T_{avg} =	301.89	K
Z_{avg} =	0.88	
MW =	17.38	kg/k-mol
R =	8.314	kPaa*m^3/kmol-K

Calculations

T_{avgR} =	543.40	R
ρ_{avg} =	0.049	g/ml
K =	0.0112	
X =	6.2583	
Y =	1.3603	
μ_{avg} =	0.0125	cP
	0.000125	P