National Exams May 2019

17-Pet-B2, Natural Gas Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK exam.

3. Any non-communicating calculator is permitted.

4. Seven (7) questions constitute a complete exam paper.

5. The first five questions as they appear in the answer book will be marked.

6. Each question is of equal value.

7. Pay close attention to units, some questions involve oilfield units, and these should be answered in the field units. Questions that are set in other units should be answered in the corresponding units.

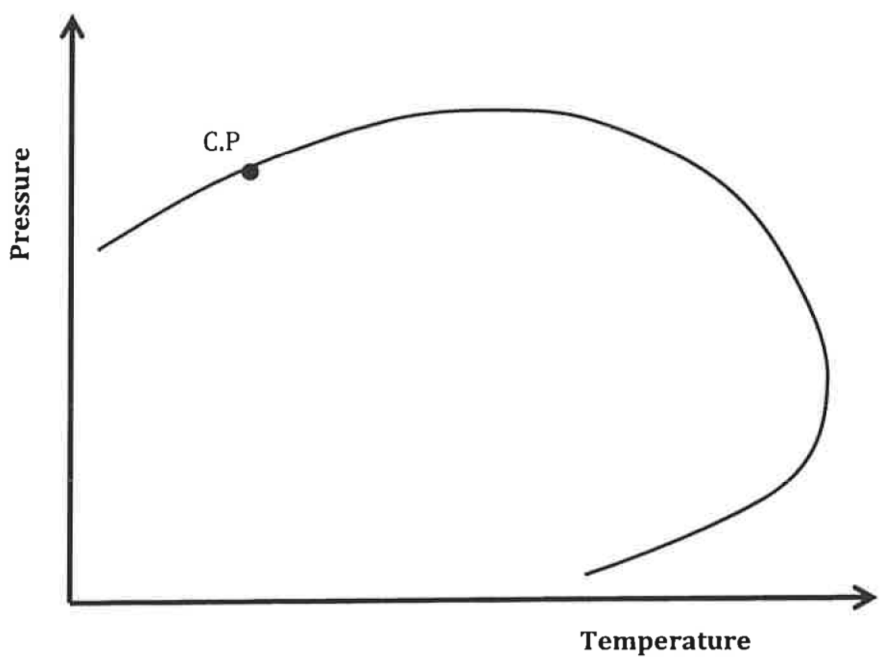
Question Number I *(10 Marks)*

a) Define briefly and concisely the following terms that are commonly used in natural gas recovery and processing:
   i. Gas reserve
   ii. Effective permeability
   iii. Relative permeability
   iv. Interfacial tension
   v. Resistivity index
   vi. Capillary pressure
   vii. Gas volume formation factor
   viii. Wettability

Question Number II (10 Marks)

The following graph presents the phase envelope of a typical natural gas reservoir. Redraw the graph on your exam book and show the followings on the graph:

a. Liquid phase region
b. Gas phase region
c. Two phase region (liquid and vapour)
d. Bubble point line
e. Dew point line
f. Cricondenbar point
g. Cricondentherm point



Question Number III *(10 Marks)*
A gas mixture with compositions listed in the table below is held at a pressure of 10.19 MPa and a temperature of 271 K. Calculate:

a) The molar volume (m^3/kmol) and the density (kg/m^3) of the mixture using the Kay's rule and the Katz correlation?
b) The molar volume (m^3/kmol) and the density (kg/m^3) of the mixture using the approach of Wichert and Aziz to adjust for CO_2 and H_2S?
c) If the gas flows to a processing facility at a rate of 2800 x $10^3 Sm^3$/d, what is the mass flow of the gas in kg/s?

Component	Mole fraction (y)
N_2	0.0050
CO_2	0.2250
H_2S	0.1000
C_1	0.6610
C_2	0.0070
C_3	0.0015
i-C_4	0.0003
n-C_4	0.0002
	1.0000

Question Number IV *(10 Marks)*

a) Using the results from Part b in Question III above, and the flow rate from Part c, what is the actual volumetric flow rate of the gas at the plant in m^3/s?
b) Determine the standard gas flow rate in MMSCFD if the standard conditions are 60 °F and 14.69 psia?

Question Number V *(10 Marks)*
Use the following information in the table below to calculate the gas flowrate in a horizontal pipeline. You are free to use any flow equation (like Basic, Weymouth, Panhandle A, Panhandle A and AGA equations).

Variable	Value	Units
P_1 = inlet absolute pressure	7000	kPa
P_2 = outlet absolute pressure	5600	kPa
PSC = standard pressure	101.325	kPa
TSC = standard temperature	15	°C
d = inside pipe diameter	0.3049	m
γ = gas relative density	0.7	
L = pipe length	50,000	m
T_m = mean temperature of the line	27	°C
z_m = mean compressibility factor	0.79	
μ = gas viscosity	0.0114	cP
E = pipeline efficiency	0.92	
ε = roughness	40	µm

Question Number VI *(10 Marks)*

A hydrocarbon gas-liquid mixture is flowing horizontally in a pipe having an inside diameter of 200 mm and length of 10 km. The liquid density is 840 kg/m^3 and the gas density is 35 kg/m^3. The liquid volumetric flow rate is 50 m^3/h and the gas flow rate is 500 m^3/h measured at standard conditions. The temperature and pressure at the inlet of the pipeline are 40 °C and 5000 kPa, respectively. The gas average compressibility and molecular weight is 0.85 and 22 kg/kmol, respectively. **Estimate** the expected flow regime using the method developed by Gregory-Aziz-Mandhane?

Question Number VII *(10 Marks)*

You have obtained the following dray-gas reservoir data estimated from subsurface maps, core analysis, well tests and fluid samples obtained at several wells. Using the volumetric method, **estimate** the original gas in place?

p_i	2000 psia
T	160 °F
A	8000 acres
ϕ	20%
S_{wi}	22%
h	8 ft
z_i	0.88

Formula Sheet

Gas properties:

$M_a = \sum y_i M_i$, where y is mole fraction and M is molecular weight in lb_{mass}/lb_{mole},

$\gamma_g = \frac{M_a}{M_{air}}$, γ_g is gas specific gravity (Air=1),

$T_{pc} = 169.2 + 349.5\gamma_g - 74.0\gamma_g^2$, T_{pc} is the pseudo critical temperature in degree R,

$p_{pc} = 756.8 - 131.0\gamma_g - 3.6\gamma_g^2$, p_{pc} is the pseudo critical pressure in psia,

Correction for N_2, H_2S, and CO_2: $T'_{pc} = T_{pc} - 80y_{CO_2} + 130y_{H_2S} - 250y_{N_2}$

Correction for N_2, H_2S, and CO_2: $p'_{pc} = p_{pc} + 440y_{CO_2} + 600y_{H_2S} - 170y_{N_2}$

$T_r = \frac{T}{T'_{pc}}$, $p_r = \frac{p}{p'_{pc}}$

T_r and p_r are reduced pseudo critical temperature and pressure, respectively.

$\rho = \frac{pM}{ZRT}$ where ρ is gas density in lb_{mass}/ft^3, p in psia, *T* in *R*, *M* is in lb_{mass}/lb_{mole}, *R*=10.732 psi-ft³/(lb_{mol}-°R)

Gas formation volume factor, $B_g = 0.02827\frac{ZT}{p}$ in $\frac{ft^3}{SCF}$, where p in psia, *T* in °*R*.

Standard condition: T_{sc}=60 °F, p_{sc}=14.7 psia.

Pipeline flow capacity equations:

$q_{sc} = 5.634\left(\frac{T_{sc}}{p_{sc}}\right)\sqrt{\frac{(p_1^2 - p_2^2)d^5}{f\gamma_g Z_{av} TL}}$ where T in °R, d in inch, L in ft, q in MSCFD.

$N_{Re} = 710.39\frac{p_{sc}}{T_{sc}}\frac{\gamma_g q_{sc}}{\mu d}$ q in MSCFD, viscosity in cP, d in inches.

Decline curve analysis

Exponential decline: $q = q_i e^{-Dt}$,

Harmonic decline: $q = q_i/(1 + Dt)$

Hyperbolic decline $q = q_i(1 + bDt)^{-1/b}$

Cumulative production $G_p = \int q dt$

where q is rate in SCFD, G_p is the cumulative production in SCF, t is time in day , *D* is the decline rate in 1/day and subscript *i* stands for the initial condition.

Transient flow equations in field units:

$\psi(r,t) = \psi_i - \frac{1.422 q_{sc} T}{kh} p_D$, $\eta = \frac{6.33k}{\phi\mu_i c_i}$, $t_D = \frac{\eta t}{r_w^2}$

$p_D = \frac{1}{2}(\ln t_D + 0.809)$ only if t_D>100,

$$\psi(r,t) = \psi_i - \frac{1.422 q_{sc} T}{kh} p_D$$

where qsc is gas rate in MSCFD, ψ is the real gas pseudo pressure in psi^2/cp, ϕ is porosity, t is time in day, t_D is the dimensionless time, k is permeability in Darcy, h is formation thickness in ft, r is radius in ft, p is pressure in psia, c is the isothermal compressibility in psi^{-1}, μ is the gas viscosity in cP, T is temperature in R, S is skin factor, and p_D is the dimensionless pressure. The subscript *i* denotes the initial condition.

Gas wells drawdown test

Slope of the semilog-plot: $m = \dfrac{1637 q_g T}{kh}$, q_g is in MSCFD, T is °R, k in mD, h in ft.

Test skin factor: $S' = 1.151\left(\dfrac{\psi_i - \psi(\Delta t = 1hr)}{|m|} - \log\left(\dfrac{k}{\phi \mu_i c_{ti} r_w^2}\right) + 3.23\right)$, where S' is the test skin factor, c is the gas isothermal compressibility in psi^{-1}, μ is the gas viscosity in cP, and ϕ is porosity

True skin factor: S'=S+Dq, where D is the non-Darcy or turbulent factor in 1/MSCFD

Gas wells build up test

Slope of the semilog-plot: $m = \dfrac{1637 q_g T}{kh}$, q_g is in MSCFD, T is °R, k in mD, h in ft.

Test skin factor: $S' = 1.151\left(\left(\dfrac{\psi_{1hr} - \psi_{wf}(\Delta t = 0)}{m}\right)_{1hr} - \log\left(\dfrac{k}{\phi \bar{\mu} c_t r_w^2}\right) + 3.23\right)$ where S' is the test skin factor, c is the gas isothermal compressibility in psi^{-1}, μ is the gas viscosity in cP, and ϕ is porosity

Gas wells deliverability equation:

$q = C(\bar{p}^2 - p_{wf}^2)^n$ where $\bar{p}$ is the average reservoir pressure, and p_{wf} is the stabilized flowing wellbore pressure, q is the gas production rate, *C* is the coefficient of the equation in any consistent systems of unit and n is an exponent.

<u>**Conversion Factors**</u>

1 m^3 = 6.28981 bbl =35.3147 ft^3
1acre = 43560 ft^2
1ac-ft = 7758 bbl
1Darcy = 9.869233×10^{-13} m^2
1 atm =14.6959488 psi =101.32500 kPa=1.01325 bar
1 cP = 0.001 Pa-sec
1 m = 3.28084 ft = 39.3701 inch = 0.000621371 mile

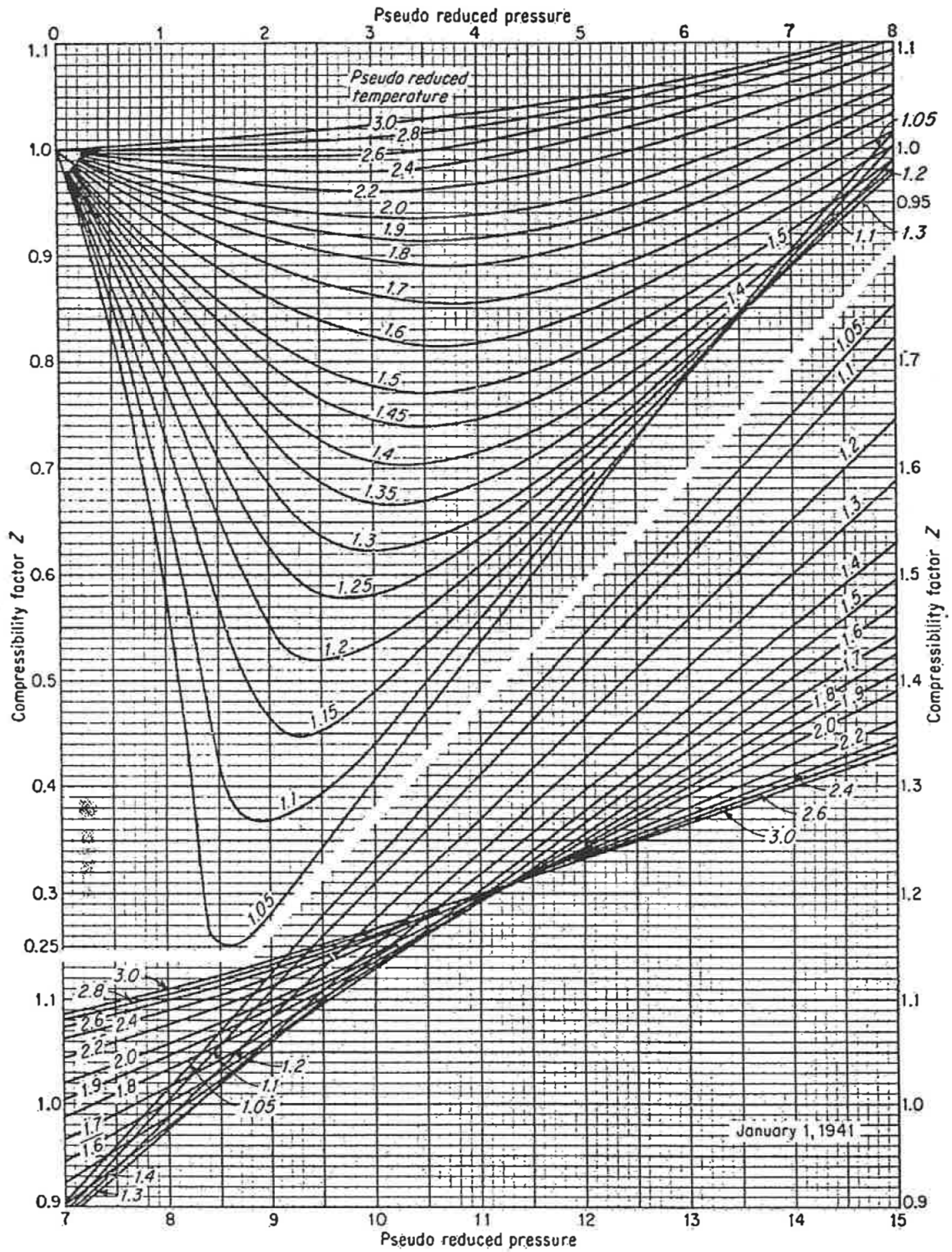
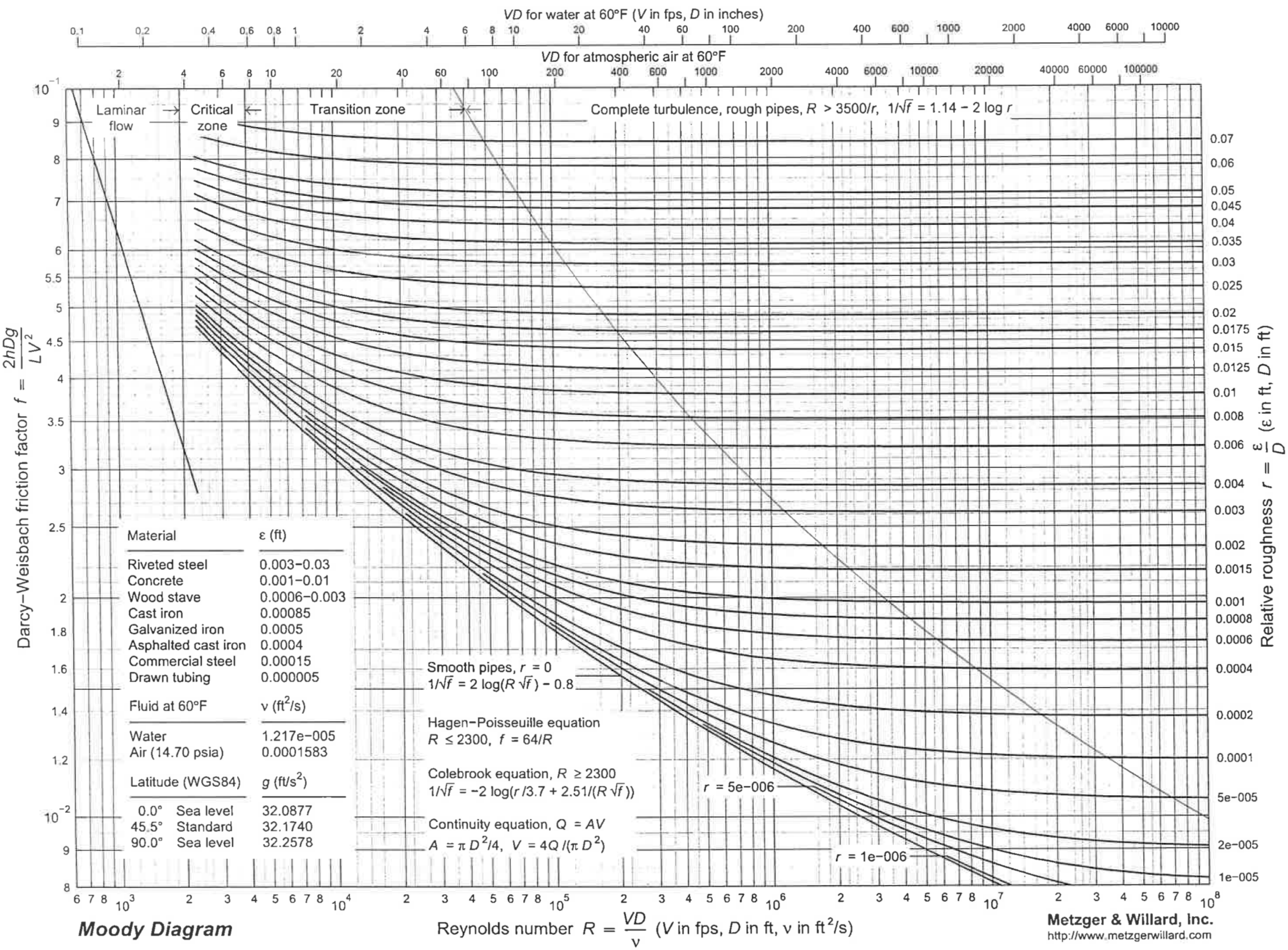


Fig. 4-16. Compressibility factor for natural gases. *(Standing and Katz, 4-87. Courtesy AIME.)*


VD for water at 60°F (V in fps, D in inches)
VD for atmospheric air at 60°F
Laminar flow
Critical zone
Transition zone
Complete turbulence, rough pipes, R > 3500/r, 1/√f = 1.14 − 2 log r
Darcy−Weisbach friction factor f = 2hDg / LV²
Relative roughness r = ε/D (ε in ft, D in ft)
Material
ε (ft)
Riveted steel 0.003−0.03
Concrete 0.001−0.01
Wood stave 0.0006−0.003
Cast iron 0.00085
Galvanized iron 0.0005
Asphalted cast iron 0.0004
Commercial steel 0.00015
Drawn tubing 0.000005
Fluid at 60°F
ν (ft²/s)
Water 1.217e−005
Air (14.70 psia) 0.0001583
Latitude (WGS84)
g (ft/s²)
0.0° Sea level 32.0877
45.5° Standard 32.1740
90.0° Sea level 32.2578
Smooth pipes, r = 0
1/√f = 2 log(R √f) − 0.8
Hagen−Poisseuille equation
R ≤ 2300, f = 64/R
Colebrook equation, R ≥ 2300
1/√f = −2 log(r/3.7 + 2.51/(R √f))
Continuity equation, Q = AV
A = π D²/4, V = 4Q/(π D²)
r = 5e−006
r = 1e−006
Reynolds number R = VD/ν (V in fps, D in ft, ν in ft²/s)
Moody Diagram
Metzger & Willard, Inc.
http://www.metzgerwillard.com