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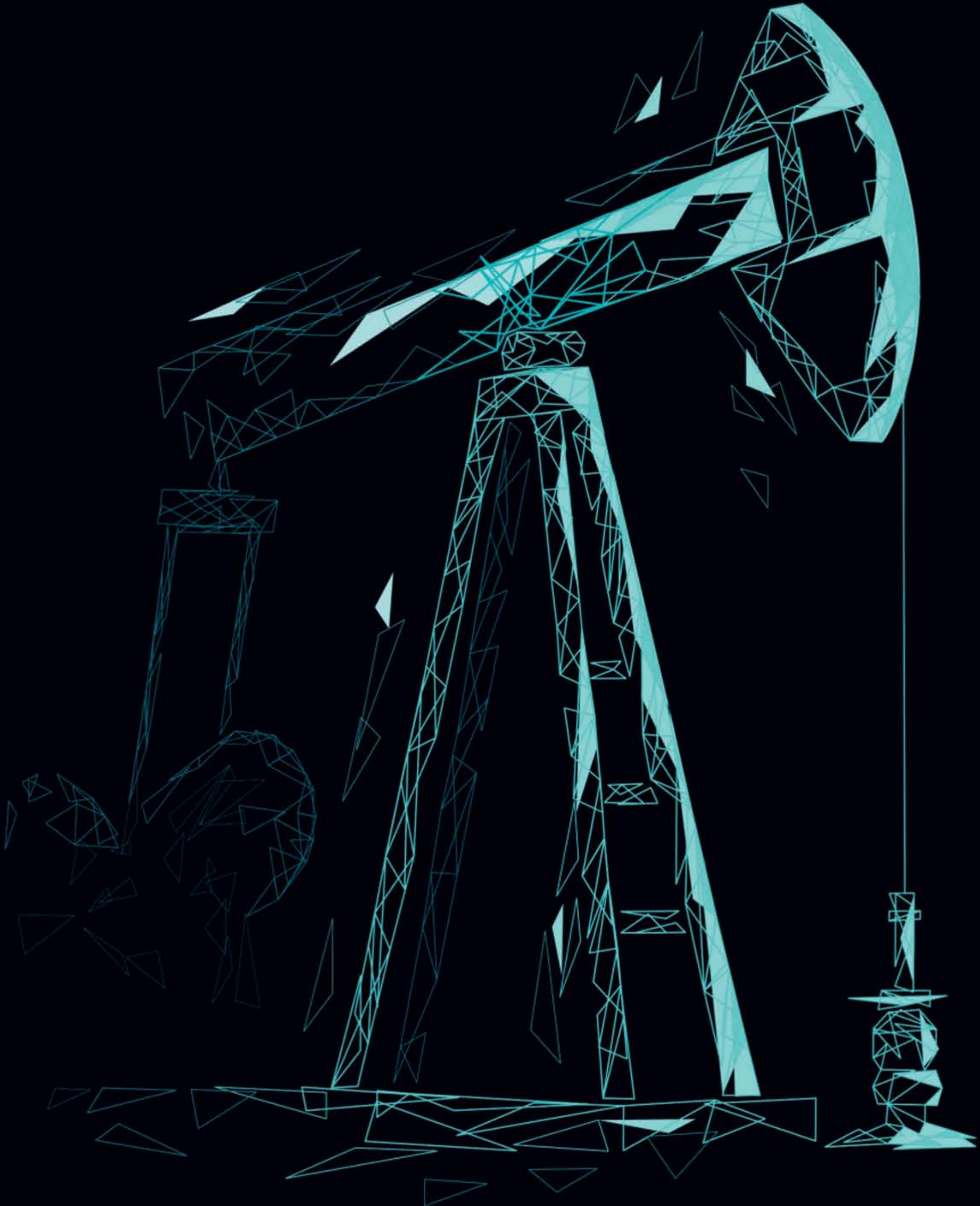
Mehmet Melih Oskay, Luigi A. Saputelli

Formulas and Calculations for Petroleum Engineering



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Biographies of authors

Cenk Temizel is a reservoir engineer with 15 years of international experience in the industry with expertise in reservoir simulation, smart fields, heavy oil, optimization, unconventionals and enhanced oil recovery. He was a teaching/research assistant at the University of Southern California and Stanford University before joining the industry. He won the 2nd place at SPE Global R&D Competition at SPE ATCE 2014 in Amsterdam and the 2nd place in Technical Excellence Awards at 22nd World Petroleum Congress in 2017 in Istanbul. He received the Halliburton Award in Innovation in 2012. He serves as a technical reviewer for petroleum engineering journals. His interests include reaction kinetics/dynamics of fluid flow in porous media and enhanced oil recovery processes. He served as a session chair and member of organizing committees for several SPE conferences. He has published around 100 publications in the area of reservoir management, production optimization, enhanced oil recovery processes and smart fields along with US patents. He holds a BS degree (Honors) from Middle East Technical University—Ankara (2003) and an MS degree (2005) from University of Southern California (USC), Los Angeles, CA both in petroleum engineering.

Tayfun Tuna is a data scientist and software developer who holds a MS and a PhD degree in computer science from the University of Houston. His graduate research focus was on text mining; applying machine learning techniques to lecture videos in order to segment video content for a better learning experience. He is a cofounder of Videopoints LLC, previously known as ICS Video Project, an interactive educational video platform which have been used more than 50K users across multiple university campuses. While he was the chief operating officer and principal investigator, his project is rewarded by National Science Foundation Small Business Innovation Research (NSF SBIR) Phase I Grant.

In his professional career, he has worked with Halliburton to develop a patented machine learning-based web-based interface that predicts chance of getting of stuck while drilling for oil. He has two patents and 20 research paper publications on educational technology, social networks, and oil&gas field.

Mehmet Melih Oskay earned his PhD from UT Austin, and he has been in academia and industry as advisors and managerial positions for more than 30 years at several major operators.

He has represented operators at Joint Operations Committee and Joint Operations Tender Committees.

He has taught at University of Texas—Austin, TX; Louisiana Tech University-Ruston, Louisiana; Middle East Technical University—Ankara, Turkey; and King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

He has participated in several Organizing Committees and Session Chairmanship positions at many SPE Oil Show and Technical Conferences.

Luigi A. Saputelli is a reservoir engineering senior advisor with over 28 years of experience. He worked in various operators and services companies around the world. He is a founding member of the Society of Petroleum Engineers' Real-time Optimization Technical Interest Group and the Petroleum Data-driven Analytics technical section. He is the recipient of the 2015 SPE International Production and Operations Award.

He has published more than 90 industry papers on applied technologies related to reservoir management, real-time optimization, and production operations. He holds a BSc. in electronic engineer from Universidad Simon Bolivar (1990), with a master in petroleum engineering from Imperial College (1996), and a PhD in chemical engineering from University of Houston (2003). He also serves as managing partner for, a petroleum engineering services firm based in Houston.

Foreword

Formulas and Calculations for Petroleum Engineering unlocks the capability for any petroleum engineering individual, experienced or not, to solve problems and locate quick answers, eliminating nonproductive time spent searching for that right calculation. Enhanced with lab data experiments, practice examples, and a complimentary online software toolbox, the book presents the most convenient and practical reference for all oil and gas phases of a given project. Covering the full spectrum, this reference gives single-point reference to all critical modules, including drilling, production, reservoir engineering, well testing, well logging, enhanced oil recovery, well completion, fracturing, fluid flow, and even petroleum economics.

ptlbx.com *provides access to calculations of these formulas.*

Acknowledgement

Authors

This book is dedicated to my wife, my love, Saule who has supported me unconditionally in my endeavors and has been an inspiration for me in life with her love, care, and understanding and to my daughter Ada Ayca who has brought joy and happiness to our life and to my parents Yuksel and Rasim Temizel and my brother Efe for their continuous support and love.

Cenk Temizel

I am indebted to my wife Suhendan and to my daughter Ceyda for their unflagging support to finish this book.

Mehmet Melih Oskay

I dedicate this book to my parents Julia and Emilio, who are eternal symbols of unconditional love and true parenthood, from whom I learned what exemplary human values.

Luigi A. Saputelli

Reviewers

My effort that went into the completion of this book is dedicated to my wife Ezgi who assisted me with her love and patience, to Serkan who made me feel lucky to have an honest brother like him, and also to my beloved parents Fusun and Kaya Canbaz who gave their true love without any expectations and supported me with patience in any circumstances.

Celal Hakan Canbaz

I would like to express my deepest love and respect to especially my beloved parents and wife Elif who always has supported and inspired me to contribute to this book and my self-improvement in terms of both professional and personal ways during all my life.

Yildiray Palabiyik

Chapter 1

Reservoir engineering formulas and calculations

Chapter Outline

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1.1 API gravity

Input(s)

SG_o: Specific Gravity of Oil Phase (fraction)

Output(s)

API: API Gravity (dimensionless)

Formula(s)

$$API = \frac{141.5}{SG_o} - 131.5$$

Notes: $SG_o = \frac{\rho_{oil}}{\rho_{water}}$ at 60 F.

Reference: *Wikipedia.org*.

1.2 Average permeability for linear flow—Layered beds

Input(s)

k_1: Permeability for Layer 1 (mD)
k_2: Permeability for Layer 2 (mD)
k_3: Permeability for Layer 3 (mD)
A_1: Area of Layer 1 (ft^2)
A_2: Area of Layer 2 (ft^2)
A_3: Area of Layer 3 (ft^2)

Output(s)

k_{avg}: Average Permeability in Linear Systems when there is no crossflow between layers (mD)

Formula(s)

$$k_{avg} = \frac{k_1 * A_1 + k_2 * A_2 + k_3 * A_3}{A_1 + A_2 + A_3}$$

Reference: *Ahmed, T. (2006). Reservoir Engineering Handbook. Elsevier, Page: 238.*

1.3 Average permeability for linear flow—Series beds

Input(s)

k_1: Permeability for layer 1 (mD)
k_2: Permeability for layer 2 (mD)
k_3: Permeability for layer 3 (mD)
L_1: Length of layer 1 (ft)
L_2: Length of layer 2 (ft)
L_3: Length of layer 3 (ft)

Output(s)

k_{avg}: Average Permeability in Linear Systems Series (mD)

Formula(s)

$$k_{avg} = \frac{L_1 + L_2 + L_3}{\frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3}}$$

Reference: *Ahmed, T. (2006). Reservoir Engineering Handbook. Elsevier, Page: 240.*

1.4 Average permeability for parallel-layered systems

Input(s)

k_1: Permeability for Layer 1 (mD)
k_2: Permeability for Layer 2 (mD)
k_3: Permeability for Layer 3 (mD)
h_1: Height of Layer 1 (ft)
h_2: Height of Layer 2 (ft)
h_3: Height of Layer 3 (ft)

Output(s)

k_{avg}: Average Permeability for Parallel-layered Systems (mD)

Formula(s)

$$k_{avg} = \frac{k_1 * h_1 + k_2 * h_2 + k_3 * h_3}{h_1 + h_2 + h_3}$$

Reference: *Ahmed, T. (2006). Reservoir Engineering Handbook. Elsevier, Page: 237.*

1.5 Average permeability in radial systems

Input(s)

k_a: Permeability between r_w and r_a (mD)
k_e: Permeability between r_e and r_a (mD)
r_e: Drainage radius (ft)
r_w: Well bore radius (ft)
r_a: Radius lesser than r_e (ft)

Output(s)

k_{avg}: Average Permeability in Radial Systems Series (mD)

Formula(s)

$$k_{avg} = \frac{k_a * k_e * \ln\left(\frac{r_e}{r_w}\right)}{k_a * \ln\left(\frac{r_e}{r_a}\right) + k_e * \ln\left(\frac{r_a}{r_w}\right)}$$

Reference: *Applied Reservoir Engineering Vol. 1, Smith, Tracy & Farrar, Equation 7–7.*

1.6 Average temperature of a gas column

Input(s)

T_t: Tubing Head Temperature (°R)
T_b: Wellbore Temperature (°R)

Output(s)

T: Arithmetic Average Temperature (°R)

Formula(s)

$$T = \frac{T_t + T_b}{2}$$

Reference: *Ahmed, T., McKinney, P.D.2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 199.*

1.7 Calculation of fractional flow curve

Input(s)

μ_w: Water Viscosity (cP)
k_{rw}: Relative Permeability to Water (dimensionless)
k_{ro}: Relative Permeability to Oil (dimensionless)
μ_o: Oil Viscosity (cP)

Output(s)

f_w: Fraction of Total Flowing Stream Composed of Water (dimensionless)

Formula(s)

$$f_w = \frac{1}{1 + \frac{\mu_w * k_{ro}}{k_{rw} * \mu_o}}$$

Reference: *Craig Jr. F. F., 2004, the Reservoir Engineering Aspects of Waterflooding, Vol. 3. Richardson, Texas: Monograph Series, SPE, Page: 112.*

1.8 Capillary number

Input(s)

μ_w: Viscosity of Displacing Fluid (cP)
V: Characteristic Velocity (ft/D)
σ_{ow}: Surface or Interfacial Tension of Oil and Water Phases (dyn/cm)

Output(s)

N_c: Capillary Number (dimensionless)

Formula(s)

$$Nc = \frac{\mu_w * V}{\sigma_{ow}}$$

Reference: *Wikipedia.org*.

1.9 Capillary pressure

Input(s)

σ: Fluid interfacial Tension (dyn/cm)
θ: Angle of Wettability (degree)
r: Radius of Capillary (cm)

Output(s)

P_C: Capillary Pressure (dyn/cm)

Formula(s)

$$P_C = \frac{2 * \sigma * \cos(\theta)}{r}$$

Reference: *Wikipedia.org*.

1.10 Characteristic time for linear diffusion in reservoirs

Input(s)

Φ: Porosity (fraction)
β_f: Fluid Compressibility (1/psi)
β_r: Rock Compressibility (1/psi)
μ: Viscosity (cP)
l: Characteristic Length Scale of Diffusion (ft)
k: Permeability (mD)

Output(s)

τ: Time (s)

Formula(s)

$$\tau = \frac{\left(\Phi * \beta_f + \beta_r\right) * \mu * I^2}{k}$$

Reference: *Zoback, M. D. Reservoir Geomechanics, Cambridge University Express, UK, Page: 41.*

1.11 Cole plot

Input(s)

G: GIP (MSCF)
E_g: Gas Expansion Term (bbl/MSCF)
W_e: Water influx (bbl)

Output(s)

F: Underground Water Withdrawal (bbl)

Formula(s)

$$F = G * E_g + W_e$$

Reference: *Ahmed, T., McKinney, P. D. Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.12 Communication between compartments in tight gas reservoirs

Input(s)

G: Gas in Place (MSCF)
E_g: Gas Expansion Term (bbl/MSCF)
W_e: Cumulative Water Influx (bbl)

Output(s)

F: Underground Fluid Withdrawal (bbl)

Formula(s)

$$F = G * E_g + W_e$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 209.*

1.13 Communication factor in a compartment in tight gas reservoirs

Input(s)

K: Permeability (mD)
A: Area (ft^2)
T: Temperature (R)
L: Length of Compartment (ft)

Output(s)

C: Communication Factor ($SCF/d/psi^2/cP$)

Formula(s)

$$C = \frac{0.111924 * k * A}{T * L}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 235.*

1.14 Compressibility drive in gas reservoirs

Input(s)

G: Gas in place (MSCF)
G_P: Gas Produced (MSCF)
B_g: Gas Formation Volume Factor (MSCF/ft^3)
E_f: Gas Compressibility Drive (ft^3/MSCF)

Output(s)

CI: Compressibility Index (dimensionless)

Formula(s)

$$CI = \frac{G * E_f}{B_g * G_P}$$

Reference: *Ahmed, T. & McKinney, P. D. Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.15 Correction factor—Hammerlindl

Input(s)

G: Gas in Place (MSCF)
G_p: Gas Produced (MSCF)
B_g: Gas Formation Volume Factor (bbl/MSCF)
$E_{f,\,w}$: Rock and Water Expansion Term (bbl/MSCF)

Output(s)

CDI: Compressibility Drive Index (dimensionless)

Formula(s)

$$CDI = \frac{G * E_{f,w}}{G_p * B_g}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 211.*

1.16 Critical rate for horizontal Wells in edge-water drive reservoirs

Input(s)

$e1$: Constant for C1 Equals +0.023 or − 0.023 (dimensionless)
$e2$: Constant for C2 equals +0.0013 or − 0.0013 (dimensionless)
$e3$: Constant for C3 equals +0.022 or − 0.022 (dimensionless)
$e4$: Constant for C4 equals +0.0013 or − 0.0013 (dimensionless)
Δ_ρ: Density Difference between water and oil or, oil and gas (gm/cc)

h: Pay Zone Thickness (ft)
L: Length of Well (ft)
x_e: Distance between Horizontal Well and Constant Pressure Boundary (ft)
μ_o: Oil Viscosity (cP)
k_h: Vertical Permeability (mD)
k_v: Horizontal Permeability (mD)

Output(s)

c_1: Dimensionless Constant for calculation (dimensionless)
c_2: Dimensionless Constant for calculation (dimensionless)
c_3: Dimensionless Constant for calculation (dimensionless)
c_4: Dimensionless Constant for calculation (dimensionless)
q_c: Dimensionless Critical Rate per Unit length (STB/day/ft)
q_o: Critical Rate (STB/day)
z_c: Critical Height Representing the Difference between the Apex of the Gas/Water Crest from the Well Elevation (ft)

Formula(s)

$$c_1 = 1.4426 + e1$$

$$c_2 = -0.9439 + e2$$

$$c_3 = 0.4812 + e3$$

$$c_4 = -0.9534 + e4$$

$$q_c = c_1 * \left(\frac{x_e}{h * \left(\frac{k_h}{k_v} \right)^{0.5}} \right)^{c_2}$$

$$q_o = \left(4.888 * 10^{-4}\right) * \Delta_\rho * h * (k_h * k_v)^{0.5} * L * \frac{q_c}{\mu_o}$$

$$z_c = c_3 * h * \left(\frac{x_e}{h * \left(\frac{k_h}{k_v} \right)^{0.5}} \right)^{c_4}$$

Reference: *Joshi, S.D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 309, 310.*

1.17 Crossflow index

Input(s)

N_{pcf}: Oil Recovery from Layered System with Crossflow (STB)
N_{pncf}: Oil Recovery from Stratified System with No Crossflow (STB)
N_{pu}: Oil Recovery from Uniform System with Average Permeability (STB)

Output(s)

CI: Crossflow Index (dimensionless)

Formula(s)

$$CI = \frac{N_{pcf} - N_{pncf}}{N_{pu} - N_{pncf}}$$

Reference: *Willhite, G.P. 1986. Waterflooding, Vol. 3. Richardson, Texas: Textbook Series, SPE, Chapter: 2, Page: 166.*

1.18 Cumulative effective compressibility—Fetkovich

Input(s)

S_{wi}: Initial Water Saturation (fraction)
$\overline{c}_w$: Cumulative Total Water Compressibility (1/psi)
M: Dimensionless Volume Ratio (dimensionless)
$\overline{c}_f$: Total PV (Formation) Compressibility (psi^{-1})

Output(s)

$\overline{c}_e$: Effective Compressibility (1/psi)

Formula(s)

$$\overline{c}_e = \frac{S_{wi} * \overline{c}_w + M * \left(\overline{c}_f + \overline{c}_w\right) + \overline{c}_f}{1 - S_{wi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 215,216.*

1.19 Cumulative gas production—Tarner's method

Input(s)

N: Initial Oil-in Place (STB)
R_s: Gas Solubility (SCF/STB)
R_{si}: Initial Gas Solubility (SCF/STB)
B_o: Oil Formation Volume Factor at the Assumed Reservoir Pressure (bbl/STB)
B_{oi}: Oil Formation Volume Factor at Initial Reservoir Pressure (bbl/STB)
B_g: Gas Formation Volume Factor at the Assumed Reservoir Pressure (bbl/SCF)
N_p: Cumulative Oil Production (STB)

Output(s)

G_p: Cumulative Gas Production (SCF)

Formula(s)

$$G_p = N * \left[\left(R_{si} - R_s\right) - \left(\frac{B_{oi} - B_o}{B_g}\right)\right] - N_p * \left[\frac{B_o}{B_g} - R_s\right]$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 340.*

1.20 Cumulative oil production—Undersaturated oil reservoirs

Input(s)

N: Initial Oil-in Place (STB)
c_e: Effective Compressibility (1/psi)
B_o: Oil Formation Volume Factor at the Assumed Reservoir Pressure (bbl/STB)
B_{oi}: Oil Formation Volume Factor at Initial Reservoir Pressure (bbl/STB)
ΔP: Pressure Differential (psi)

Output(s)

N_p: Cumulative Oil Production (STB)

Formula(s)

$$N_p = N * c_e * \left(\frac{B_o}{B_{oi}}\right) * \Delta P$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 333.*

1.21 Deliverability equation for shallow gas reservoirs

Input(s)

k: Permeability (mD)
h: Thickness (ft)
T: Temperature (°R)
μ: Viscosity (cP)
z: Compressibility Factor (dimensionless)
r_e: Radius of Drainage Area (ft)
r_w: Wellbore Radius (ft)

Output(s)

C: Performance Coefficient (dimensionless)

Formula(s)

$$C = \frac{k * h}{1422 * T * \mu_g * Z * \left(\ln\left(\frac{r_e}{r_w}\right) - 0.5 \right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 287.*

1.22 Dimensionless pressure—Kamal and Brigham

Input(s)

Q: Flow Rate (STB/day)
$\bar{k}$: Average Permeability (mD)
h: Thickness (ft)

B: Formation Volume Factor (bbl/STB)
μ: Viscosity (cP)
ΔP: Pressure Difference (psi)

Output(s)

ΔP_d: Dimensionless Pressure (dimensionless)

Formula(s)

$$\Delta P_d = \frac{\bar{k} * h * \Delta P}{141.2 * Q * \mu * B}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 125.*

1.23 Dimensionless radius of radial flow—Constant-rate production

Input(s)

r: Effective Radius/Reservoir Radius (ft)
r_w: Wellbore Radius (ft)

Output(s)

r_d: Dimensionless Radius (dimensionless)

Formula(s)

$$r_d = \frac{r}{r_w}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 8.*

1.24 Dimensionless time—Myhill and Stegemeier's method

Input(s)

M_s: Volumetric Heat Capacity of Steam (btu/ft^3 K)
M_R: Volumetric Heat Capacity of the Reservoir (btu/ft^3 K)
α_s: Overburden Heat Transfer Coefficient (ft^2/d)
h_t: Thickness of Column (ft)
t: Time (day)

Output(s)

t_D: Dimensionless Time (dimensionless)

Formula(s)

$$t_D = 4 * \left(\frac{M_s}{M_R}\right)^2 * \left(\frac{\alpha_s}{h_t^2}\right) * t$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 5, Page: 44.*

1.25 Dimensionless time for interference testing in homogeneous reservoirs—Earlougher

Input(s)

k: Permeability (mD)
ø: Porosity (fraction)
t: Time (h)
k: Overall Production (mD)
μ: Viscosity (cP)
c_t: Total Compressibility (1/psi)
r_w: Wellbore Radius (ft)

Output(s)

t_D: Dimensionless Time (dimensionless)

Formula(s)

$$t_D = \frac{0.0002637 * k * t}{ø * c_t * \mu * \left(r_w^2\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 117.*

1.26 Dimensionless vertical well critical rate correlations—Hoyland, Papatzacos, and Skjaeveland

Input(s)

h: Oil Column Thickness (ft)
k_h: Effective Oil Permeability (mD)
ρ_w: Water Density (g/cc)
μ_o: Oil Viscosity (cP)
ρ_o: Oil Density (g/cc)
B_o: Oil Formation Volume Factor (RB/STB)
q_o: Critical Oil Rate (STB/day)

Output(s)

Q_{oD}: Dimensionless Critical Rate (dimensionless)

Formula(s)

$$QoD = 651.4 * \mu_o * B_o * \frac{q_o}{h^2 * (\rho_w - \rho_o) * k_h}$$

Reference: *Reservoir Engineering Handbook, Fourth Edition, Ahmed, Page: 607.*

1.27 Dimensionless wellbore storage coefficient of radial flow—Constant-rate production

Input(s)

h: Reservoir Thickness (ft)
C: Wellbore Storage Coefficient (STB/psi)

Ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
r_w: Wellbore Radius (ft)

Output(s)

C_d: Dimensionless Wellbore-Storage Coefficient (dimensionless)

Formula(s)

$$C_d = \frac{0.8936 * C}{Ø * c_t * h * r_w^2}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineer, Page: 8.*

1.28 Effective compressibility in undersaturated oil reservoirs—Hawkins

Input(s)

S_{oi}: Initial Oil Saturation (fraction)
S_{wi}: Initial Water Saturation (fraction)
c_o: Oil Compressibility (1/psi)
c_w: Water Compressibility (1/psi)
c_f: Formation Compressibility (1/psi)

Output(s)

c_e: Effective Compressibility (1/psi)

Formula(s)

$$c_e = \frac{S_{oi} * c_o + S_{wi} * c_w + c_f}{1 - S_{wi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 334.*

1.29 Effective wellbore radius of a horizontal well—Method 1—Anisotropic reservoirs

Input(s)

L: Horizontal Well Length (ft)
h: Pay Zone Thickness (ft)
r_w: Wellbore Radius (ft)
k_h: Horizontal Permeability (mD)
k_v: Vertical Permeability (mD)
A: Drainage Area (acre)

Output(s)

r_{eh}: Effective Drainage Radius (ft)
a: Horizontal wellbore variable from Joshi (dimensionless)
β: Permeability Ratio constant (dimensionless)
r_{wd}: Effective Wellbore Radius (ft)

Formula(s)

$$reh = sqrt\left(A * \frac{43560}{3.14}\right)$$

$$a = \left(\frac{L}{2}\right) * sqrt\left(.5 + sqrt\left(0.25 + 2 * \left(\frac{reh}{L}\right)^4\right)\right)$$

$$\beta = sqrt\left(\frac{kh}{kv}\right)$$

$$rwd = reh * \frac{\frac{L}{2}}{a * \left(\left(1 + sqrt\left(1 - \left(\frac{L}{2 * a}\right)^2\right)\right) * \left(h * \frac{\beta}{2 * rw}\right)^{\beta * \frac{h}{L}}\right)}$$

Reference: *Horizontal Well Technology, Joshi, Page: 90.*

1.30 Effective wellbore radius of a horizontal well—Method 1—Isotropic reservoirs

Input(s)

L: Horizontal Well Length (ft)
h: Pay Zone Thickness (ft)
r_w: Wellbore Radius (ft)
k_h: Horizontal Permeability (mD)
k_v: Vertical Permeability (mD)
A: Drainage Area (acre)

Output(s)

r_{eh}: Effective Drainage Radius (ft)
a: Horizontal wellbore variable from Joshi (dimensionless)
r_{wd}: Effective Wellbore Radius (ft)

Formula(s)

$$reh = sqrt\left(A * \frac{43560}{3.14}\right)$$

$$a = \left(\frac{L}{2}\right) * sqrt\left(.5 + sqrt\left(0.25 + 2 * \left(\frac{reh}{L}\right)^4\right)\right)$$

$$rwd = reh * \frac{\frac{L}{2}}{a * \left(\left(1 + sqrt\left(1 - \left(\frac{L}{2 * a}\right)^2\right)\right) * \left(\frac{h}{2 * rw}\right)^{\frac{h}{L}}\right)}$$

Reference: *Horizontal Well Technology, Joshi, Page: 90.*

1.31 Effective wellbore radius of a horizontal well—van der Vlis et al. method

Input(s)

h: Pay Zone Thickness (ft)
r_w: Wellbore Radius (ft)
α: Slant Angle (degrees)

Output(s)

L: Length of Slant Wellbore (ft)
r_w: Effective Wellbore Radius (ft)

Formula(s)

$$L = \frac{h}{\cos(\alpha)}$$

$$r_w = \frac{L}{4} * \left[0.454 * \sin\left(360 * \left(\frac{r_w}{h}\right)\right)\right]^{\frac{h}{L}}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 3, Page: 96.*

1.32 Effective wellbore radius of a well in presence of uniform-flux fractures

Input(s)

x_f: Fracture Half Length (ft)
e: Logarithmic Constant = 2.718 (dimensionless)

Output(s)

r_w: Effective Wellbore Radius (ft)

Formula(s)

$$r_w = \frac{x_f}{e}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 5, Page: 135.*

1.33 Effective wellbore radius to calculate slant well productivity—van der Vlis et al.

Input(s)

h: Pay Zone Thickness (ft)
r_w: Wellbore Radius (ft)
α: Slant Angle (degrees)

Output(s)

L: Length of Slant Wellbore (ft)
r_w: Effective Wellbore Radius (ft)

Formula(s)

$$L = \frac{h}{\cos(\alpha)}$$

$$r_w = \frac{L}{4} * \left[0.454 * \sin\left(360 * \left(\frac{r_w}{h}\right)\right)\right]^{\frac{h}{L}}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 3, Page: 96.*

1.34 Estimation of average reservoir pressure—MDH method

Input(s)

p_{ws}: Shut-In Pressure (psi)
p_{DMDH}: MDH Pressure (dimensionless)
m: Semi-log Straight Line of the MDH Plot (psi/cycle)

Output(s)

P_r: Average Reservoir Pressure (psi)

Formula(s)

$$P_r = p_{ws} + m * \frac{p_{DMDH}}{1.1513}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 59.*

1.35 Formation temperature for a given gradient

Input(s)

T_s: Temperature Near Surface (degree °F)
D: Total Depth (ft)
g_G: Geothermal Gradient (degree °F/100 ft)

Output(s)

T_f: Formation Temperature (degree °F)

Formula(s)

$$T_f = T_s + g_G * \left(\frac{D}{100}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 4, Page: 75.*

1.36 Fraction of the total solution gas retained in the reservoir as free gas

Input(s)

N: Oil in Place (STB)
R_p: Produced Gas-Oil Ratio (SCF/STB)
N_p: Cumulative Oil Production (STB)
R_{si}: Initial Gas Solubility (SCF/STB)
R_s: Gas Solubility (SCF/STB)

Output(s)

α_g: Retained Gas Volume of the Total Gas (fraction)

Formula(s)

$$\alpha_g = 1 - \left(\frac{N_p * R_p}{N * R_{si} - \left(N - N_p\right) * R_s} \right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 314.*

1.37 Fractional gas recovery below the critical desorption pressure in coal bed methane reservoirs

Input(s)

V_m: Langmuir (constant)
G_c: Gas Content at Critical Desorption Pressure (SCF/ton)
b: Langmuir (constant)
P: Pressure of Reservoir (psi)
a: Recovery Exponent (dimensionless)

Output(s)

RF: Recovery Factor (fraction)

Formula(s)

$$RF = 1 - \left(\left(\frac{V_m}{G_c} \right) * \left(\frac{b * P}{1 + b * P} \right) \right)^a$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 223.*

1.38 Free gas in place

Input(s)

A: Drainage Area (acres)
h: Thickness (ft)
Ø: Porosity (fraction)
S_{wi}: Initial Water Saturation (fraction)
E_{gi}: Gas Expansion Factor at Initial Reservoir Pressure (SCF/bbl)

Output(s)

G_f: Original Free Gas-in-Place (SCF)

Formula(s)

$$G_f = 7758 * A * h * Ø * (1 - S_{wi}) * E_{gi}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 227.*

1.39 Gas adsorbed in coal bed methane reservoirs

Input(s)

A: Area (acres)
h: Height (ft)
ρ_b: Density (g/cc)
V: Adsorption Gas (SCF/ton)

Output(s)

G_a: Gas Adsorbed (SCF)

Formula(s)

$$G_a = 1359.7 * A * h * \rho_b * V$$

Reference: *Ahmed, T. & McKinney, P.D. Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.40 Gas bubble radius

Input(s)

A: Drainage Area (acres)
h: Thickness (ft)
σ_B: Bulk (g/cc)
G_c: Gas Content (SCF/ton)

Output(s)

G: Gas-in-Place (SCF)

Formula(s)

$$G = 1359.7 * A * h * \sigma_B * G_c$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 227.*

1.41 Gas cap ratio

Input(s)

G: Initial Gas Cap Volume (SCF)
B_{gi}: Initial Gas Formation Volume Factor (bbl/SCF)
N: Initial Oil in Place (STB)
B_{oi}: Initial Oil Formation Volume Factor (bbl/STB)

Output(s)

m: Gas Cap Ratio (dimensionless)

Formula(s)

$$m = \frac{G * B_{gi}}{N * B_{oi}}$$

Reference: *Ahmed,T., McKinney,P. Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015, Chapter: 4, Page: 317.*

1.42 Gas cap shrinkage

Input(s)

G_{pc}: Cumulative Gas Production from Gas Cap (SCF)
B_g: Gas Formation Volume Factor (bbl/SCF)
m: Gas Cap Ratio (fraction)
N: Oil in Place (STB)
B_{oi}: Initial Oil Formation Volume Factor (bbl/STB)
B_{gi}: Initial Gas Formation Volume Factor (bbl/SCF)

Output(s)

G_s: Gas Cap Shrinkage (bbl)

Formula(s)

$$G_s = G_{pc} * B_g - m * N * B_{oi} * \left(\left(\frac{B_g}{B_{gi}} \right) - 1 \right)$$

Reference: *Ahmed, T., McKinney, P.D.2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 333.*

1.43 Gas drive index in gas reservoirs

Input(s)

G: Gas Initially in Place (SCF)
G_p: Cumulative Gas Production (SCF)
B_{gi}: Initial Gas Formation Volume Factor (ft^3/SCF)
B_g: Gas Formation Volume Factor (ft^3/SCF)

Output(s)

GDI: Gas (dimensionless)

Formula(s)

$$GDI = \left(\frac{G}{G_p} \right) * \left(1 - \frac{B_{gi}}{B_g} \right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 211.*

1.44 Gas expansion factor

Input(s)

E_{gi}: Initial Gas Expansion Factor (SCF/bbl)
A: Drainage Area (acres)
h: Thickness (ft)
Ø: Porosity (fraction)
S_{wi}: Initial Water Saturation (fraction)
G_p: Gas Produced (SCF)

Output(s)

E_g: Gas Expansion Factor (SCF/bbl)

Formula(s)

$$E_g = E_{gi} - \left(\frac{1}{43560 * A * h * Ø * (1 - S_{wi})}\right) * G_p$$

Reference: *Ahmed, T., McKinney, P.D.2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 202.*

1.45 Gas expansion term in gas reservoirs

Input(s)

B_g: Gas Formation Volume Factor (ft^3/SCF)
B_{gi}: Initial Gas Formation Volume Factor (ft^3/SCF)

Output(s)

E_g: Gas Expansion Term (ft^3/SCF)

Formula(s)

$$E_g = B_g - B_{gi}$$

Reference: *Ahmed, T., McKinney, P.D.2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 209.*

1.46 Gas flow rate into the wellbore

Input(s)

k: Permeability (mD)
∂P: Pressure Differential (psi)
L: Length of Section Open to Wellbore (ft)
u: Viscosity of intruding Gas (cP)
R_e: Radius of Drainage (ft)
R_w: Radius of Wellbore (ft)

Output(s)

Q: Flow Rate (bbl/min)

Formula(s)

$$Q = \frac{0.007 * k * (\partial P) * L}{u * \ln\left(\frac{R_e}{R_w}\right) * 1440}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 136.*

1.47 Gas flow under laminar viscous conditions

Input(s)

k: Permeability (mD)
h: Thickness (ft)
φ_r: Average Reservoir Real-Gas Pseudo-Pressure (psi)
φ_{wf}: Real-Gas Pseudo-flowing Pressure (psi)
T: Temperature (R)
A: Drainage Area (ft^2)
C_A: Shape Factor (dimensionless)
r_w: Wellbore Radius (ft)
S: Skin (dimensionless)

Output(s)

Q_g: Gas Flow Rate (MSCF/d)

Formula(s)

$$Q_g = \frac{k * h * \left(\varphi_r - \varphi_{wf}\right)}{1422 * T * \left(0.5 * \ln\left(\frac{4 * A}{1.781 * C_A * r_w^2}\right) + S\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 188.*

1.48 Gas formation volume factor

Input(s)

z: Gas Deviation Factor (dimensionless)
T: Temperature (R)
P: Pressure (psi)

Output(s)

B_g: Gas Formation Volume Factor (bbl/SCF)

Formula(s)

$$B_g = \frac{0.005035 * z * T}{P}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 15.*

1.49 Gas hydrate dissociation pressure

Input(s)

γ_h: Specific Gravity of Hydrate-forming Components (dimensionless)
F_m: Molar Ratio between the Non-hydrate-forming and Hydrate-forming Components (dimensionless)
T: Temperature (°R)

Output(s)

p_h: Disassociation Pressure (psi)

Formula(s)

$$p_h = 0.1450377 * \exp\left\{\left[\frac{2.50744 * 10^{-3}}{(\gamma_h + 0.46852)^3} + F_m * \left(1.214644 * 10^{-2}\right) + \left(-4.676111 * 10^{-4}\right) * F_m^2 + 0.0720122\right]\right.$$
$$\left. * T + \frac{3.6625 * 10^{-4}}{(\gamma_h + (-0.485054))^3} + F_m * (-5.44376) + F_m{}^2 * \left(3.89 * 10^{-3}\right) + (-29.9351)\right\}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 274.*

1.50 Gas material balance equation

Input(s)

$\frac{P_i}{z_i}$: Ratio of Pressure to Compressibility Factor at Initial Conditions (psi)
P_{SC}: Pressure at Standard Conditions (psi)
T_{SC}: Temperature at Standard Conditions (°R)
T: Current Temperature (°R)
V: Original Gas Volume (ft^3)
G_p: Cumulative Gas Production (SCF)

Output(s)

$\frac{P}{z}$: Ratio of Pressure to Compressibility Factor at Current Conditions for P/z vs G_p plot (psi)

Formula(s)

$$\frac{P}{z} = \left(\frac{P_i}{z_i}\right) - \left(\frac{P_{SC} * T}{T_{SC} * V}\right) * G_p$$

Reference: *Ahmed, T., McKinney, P.D.2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 203.*

1.51 Gas produced by gas expansion

Input(s)

A: Drainage Area (acres)
h: Thickness (ft)
Ø: Porosity (fraction)
S_{wi}: Initial Water Saturation (fraction)
B_g: Gas Formation Volume Factor (ft^3/SCF)
B_{gi}: Initial Gas Formation Volume Factor (ft^3/SCF)

Output(s)

G_p: Gas Produced (SCF)

Formula(s)

$$G_p = 43560 * A * h * Ø * (1 - S_{wi}) * \left(\frac{1}{B_{gi}} - \frac{1}{B_g}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 202.*

1.52 Gas saturation—Water-drive gas reservoirs

Input(s)

G: Gas Initially in Place (SCF)
G_p: Cumulative Gas Production (SCF)
B_g: Volume Factor (bbl/SCF)
B_{gi}: Initial Gas Formation Factor (bbl/SCF)
W_e: Cumulative Water Influx (bbl)
W_p: Cumulative Water Production (STB)
B_w: Water Formation Volume Factor (rb/STB)
S_{wi}: Initial Water Saturation (fraction)
S_{grw}: Residual Gas Saturation to Water Displacement (fraction)

Output(s)

S_g: Gas Saturation (fraction)

Formula(s)

$$S_g = \frac{\left(G - G_p\right) * B_g - \frac{W_e - W_p * B_w}{1 - S_{wi} - S_{grw}} * S_{grw}}{\left(\frac{G * B_{gi}}{1 - S_{wi}}\right) - \left(\frac{W_e - W_p * B_w}{1 - S_{wi} - S_{grw}}\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 208.*

1.53 Gas solubility in coalbed methane reservoirs

Input(s)

ρ_B: Bulk Coal Steam Density (g/cc)
$Ø_m$: Actual Coalbed Cleat Porosity (fraction)
S_{om}: Initial Oil Saturation (fraction)
V: Gas Content (SCF/STB)

Output(s)

R_s: Equivalent Gas Solubility (dimensionless)

Formula(s)

$$R_s = \left(\frac{0.17525 * \rho_B}{\O_m * S_{om}}\right) * V$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 222.*

1.54 Geertsma's model for porosity/transit-time relationship

Input(s)

K_b: Bulk Modulus Constant for Formation (dimensionless)
σ_b: Bulk Density (kg/m^3)
μ_b: Poisson Ratio for Formation (dimensionless)
K_{ma}: Bulk Modulus Constant for Matrix (dimensionless)
σ_{ma}: Matrix Density (kg/m^3)
μ_{ma}: Poisson (dimensionless)

Output(s)

V_b: Acoustic Velocity in Bulk Formation (m/s)
V_{ma}: Acoustic Velocity in Matrix (m/s)

Formula(s)

$$V_b = \left(\left(3 * \frac{K_b}{\sigma_b}\right) * \left(\frac{1-\mu_b}{1+\mu_b}\right)\right)^{0.5}$$

$$V_{ma} = \left(\left(3 * \frac{K_{ma}}{\sigma_{ma}}\right) * \left(\frac{1-\mu_{ma}}{1+\mu_{ma}}\right)\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 55.*

1.55 Geothermal gradient

Input(s)

T_{bh}: Maximum Recorded Temperature (degree °F)
T_s: Temperature Near Surface (degree °F)
D_{bh}: Total Depth of Logged Borehole (ft)

Output(s)

g_G: Geothermal Gradient (degree °F/100 ft)

Formula(s)

$$g_G = \left(\frac{T_{bh} - T_s}{D_{bh}}\right) * 100$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 4, Page: 75.*

1.56 Hagen Poiseuille equation

Input(s)

P_o: Input Pressure (psi)
P_L: Output Pressure (psi)
R: Radius (ft)
w: Mass rate of Flow (lb/s)
ρ: Density (ppg)
L: Length (ft)

Output(s)

μ: Viscosity (cP)

Formula(s)

$$\mu = \frac{(P_o - P_L) * \pi * (R^4) * \rho}{8 * w * L}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 51.*

1.57 Hagoort and Hoogstra gas flow in tight reservoirs

Input(s)

Γ: Transmissibility between Compartments (dimensionless)
P_1: Pressure of Compartment 1 (psi)
P_2: Pressure of Compartment 2 (psi)
μ_{gavg}: Average Viscosity (cP)
B_{gavg}: Average Gas Formation Factor (MSCF/STB)

Output(s)

Q: Gas Flow (MSCF/d)

Formula(s)

$$Q = \frac{\Gamma * \left(P_1^2 - P_2^2\right)}{2 * P_1 * \mu_{gavg} * B_{gavg}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 236.*

1.58 Hammerlindl method for gas in place

Input(s)

G_{app}: Apparent Gas in Place (SCF)
R: Ratio of the effective Total System Compressibility to gas Compressibility (dimensionless)

Output(s)

G: Gas in Place (SCF)

Formula(s)

$$G = \frac{G_{app}}{R}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 216.*

1.59 High-pressure region gas flow rate

Input(s)

k: Permeability (mD)
h: Thickness (ft)
P_r: Average Reservoir Pressure (psi)
P_{wf}: Bottom-hole Flowing Pressure (psi)
μ_{gavg}: Average Gas Viscosity (cP)
B_{gavg}: Average Gas Formation Volume Factor (bbl/SCF)
r_e: Drainage Radius (ft)
r_w: Wellbore Radius (ft)
S: Skin (dimensionless)

Output(s)

Q_g: Gas Flow Rate (MSCF/d)

Formula(s)

$$Q_g = \frac{7.08 * (10^{-6}) * k * h * \left(P_r - P_{wf}\right)}{\mu_{gavg} * B_{gavg} * \left(\ln\left(\frac{r_e}{r_w}\right) - 0.75 + S\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 189.*

1.60 Horizontal well breakthrough time—With gas cap or bottom water

Input(s)

ρ_o: Oil Density (g/cc)
ρ_q: Gas Density (g/cc)
t_{bt}: Breakthrough Time (days)
ϕ: Porosity (fraction)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
q_o: Flow Rate (cP)
B_o: Oil Formation Volume Factor (rb/STB)
k_h: Vertical Permeability (mD)
k_v: Horizontal Permeability (mD)

Output(s)

t_{dbt}: Breakthrough Time if breakthrough time is given (days)
q_d: Dimensionless Flow Rate (dimensionless)

Formula(s)

$$t_{dbt} = k_v * \left(\rho_o - \rho_g\right) * \frac{t_{bt}}{364.72 * h * ø * \mu_o}$$

$$q_d = 325.86 * \mu_o * q_o * \frac{B_o}{(k_v * k_h)^{0.5} * h * \left(\rho_o - \rho_g\right)}$$

Reference: *Horizontal Well Technology, Joshi, Page: 301.*

1.61 Horizontal well critical rate correlation—Chaperon

Input(s)

ρ_o: Oil Density (g/cc)
ρ_w: Water Density (g/cc)
x_A: Location of a Constant Pressure Boundary (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
F: F = 5.48 for $k_v/k_h = 1$, F = 4.8 for $k_v/k_h = 0.01$ and F = 4.16 for $k_v/k_h = 0.01$ (mD)
k_h: Horizontal Permeability (mD)
L: Horizontal Well Length (m)

Output(s)

Q_c: Critical Oil Rate (m^3/h)

Formula(s)

$$Q_c = \left(3.486 * 10^{-5}\right) * \frac{L}{x_A} * h^2 * (\rho_w - \rho_o) * \frac{F}{k_h * \mu_o}$$

Reference: *Chaperon, I. 1986. Theoretical Study of Coning Toward Horizontal and Vertical in Anisotropic Formations: Subcritical and Critical Rates. SPE ATCE, New Orleans, Louisiana.*

1.62 Horizontal well critical rate correlations—Efros

Input(s)

ρ_o: Oil Density (g/cc)
ρ_w: Water Density (g/cc)
y_e: Half of Horizontal Well Spacing (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (RB/STB)
k_h: Horizontal Permeability (mD)
L: Length of Reservoir (ft)

Output(s)

q_o: Critical Oil Rate (STB/day)

Formula(s)

$$q_o = \left(4.888 * 10^{-4}\right) * k_h * h^2 * (\rho_w - \rho_o) * \frac{L}{B_o * \mu_o * \left(\left(2^* y_e + \left(2^* y_e\right)^2 + \frac{h^2}{3}\right)^{0.5}\right)}$$

Reference: *Horizontal Well Technology, Joshi, Page: 286–295.*

1.63 Horizontal well critical rate correlations—Giger and Karcher

Input(s)

$\Delta\rho$: Specific Gravity Difference (g/cc)
h: Thickness (m)
μ: Oil Viscosity (mPa s)
B: Oil Formation Volume Factor (RB/STB)
k_h: Horizontal Permeability (mD)
L: Distance Between Lines of Horizontal Wells (m)
g: Acceleration of Gravity (m/s^2)

Output(s)

q_c: Critical Oil Rate (m^3/day)

Formula(s)

$$q_c = \left(\frac{k_h * h^2 * g * \Delta\rho}{B * \mu * L}\right) * \left(1 - \left(\left(\frac{1}{6}\right) * \left(\frac{h}{L}\right)^2\right)\right)$$

Reference: *B.J. Karcher, E.F. Aquitaine, F.M. Giger, Some Practical Formulas to Predict Horizontal Well Behavior.1986. SPE ATCE, New Orleans, Louisiana.*

1.64 Horizontal well critical rate correlations—Joshi method for gas coning

Input(s)

ρ_o: Oil Density (g/cc)
ρ_g: Gas Density (g/cc)
r_e: Effective Radius of drainage (ft)
r_w: Radius of Wellbore (ft)
l_v: Distance between Gas/Oil interphase and perforated top of Vertical Well (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (RB/STB)
k_h: Horizontal Permeability (mD)

Output(s)

q_o: Critical Oil Rate (STB/day)

Formula(s)

$$q_o = 1.535 * 10^{-3} * \left(\rho_o - \rho_g\right) * k_h * \frac{h^2 - (h - l_v)^2}{B_o * \mu_o * \ln\left(\frac{r_e}{r_w}\right)}$$

Reference: *Horizontal Well Technology, Joshi, Page: 286–295.*

1.65 Hydrocarbon pore volume occupied by evolved solution gas

Input(s)

N: Initial Oil in Place (STB)
N_p: Cumulative Oil Production (STB)
R_{si}: Gas Solubility at Initial Reservoir Pressure (SCF/STB)
R_s: Current Gas Solubility (SCF/STB)
B_g: Current Gas Formation Volume Factor (bbl/SCF)
R_p: Net Cumulative Produced Gas-Oil Ratio (SCF/STB)

Output(s)

V: Volume of the Evolved Gas that Remains in the PV (PV)

Formula(s)

$$V = \left(N * R_{si} - N_p * R_p - \left(N - N_p\right) * R_s\right) * B_g$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 301.*

1.66 Hydrocarbon pore volume occupied by gas cap

Input(s)

m: Ratio of Initial Gas Cap Gas Reservoir Volume to Initial Reservoir Volume (bbl/bbl)
N: Initial Oil in Place (STB)
B_{oi}: Initial Oil Formation Volume Factor (bbl/STB)
B_{gi}: Initial Gas Formation Volume Factor (bbl/SCF)
B_g: Current Gas Formation Volume Factor (bbl/SCF)

Output(s)

V: Volume of the Gas Cap at Current Pressure (bbl)

Formula(s)

$$V = \frac{m * N * B_{oi} * B_g}{B_{gi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 301.*

1.67 Hydrocarbon pore volume occupied by remaining oil

Input(s)

N: Oil in Place (STB)
N_p: Cumulative Oil Production (STB)
B_o: Oil Formation Volume Factor (bbl/STB)

Output(s)

V_{ro}: Volume of the Remaining Oil (bbl)

Formula(s)

$$V_{ro} = \left(N - N_p\right) * B_o$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 301.*

1.68 Hydrostatic pressure

Input(s)

mw: Mud weight (ppg)
TVD: True Vertical Depth (ft)

Output(s)

HP: Hydrostatic Pressure (psi)

Formula(s)

$$HP = mw * 0.052 * TVD$$

Reference: *Wikipedia.org*.

1.69 Incremental cumulative oil production in undersaturated reservoirs

Input(s)

N_p: Cumulative Oil Production (STB)
ϕ_o: Oil PVT Function (rb/STB)
G_p: Cumulative Gas Production (MSCF)
ϕ_g: Gas PVT Function (rb/MSCF)
GOR: Average Gas Oil Ratio (SCF/STB)

Output(s)

ΔN_p: Incremental Oil Produced (STB)

Formula(s)

$$\Delta N_p = \frac{1 - N_p * \phi_o - G_p * \phi_g}{(\phi_o) + \left(GOR * \phi_g\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 335.*

1.70 Ineffective porosity

Input(s)

V_{dis}: Volume of Completely Disconnected Pores (cm^3)
V_b: Bulk Volume (cm^3)

Output(s)

$Ø_{in}$: Ineffective Porosity (fraction)

Formula(s)

$$Ø_{in} = \frac{V_{dis}}{V_b}$$

Reference: *Dandekar, A. Y. 2006. Petroleum Reservoir Rock and Fluid Properties. Boca Raton, FL: CRC Press Taylor & Francis Group, Chapter: 3, Page: 15.*

1.71 Initial gas cap

Input(s)

m: Ratio of Initial Gas Cap Gas Reservoir Volume to Initial Reservoir Oil Volume (bbl/bbl)
N: Original Oil in Place (STB)
B_{oi}: Oil Formation Volume Factor (bbl/STB)
B_{gi}: Initial Gas Formation Volume Factor (bbl/SCF)

Output(s)

G: Initial Gas Cap Gas (SCF)

Formula(s)

$$G = \frac{m * N * B_{oi}}{B_{gi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 300.*

1.72 Initial gas in place for water-drive gas reservoirs

Input(s)

G_p: Cumulative Gas Production at Depletion Pressure (SCF)
B_g: Gas Formation Volume Factor at Depletion Pressure (bbl/SCF)
W_e: Cumulative Water Influx (bbl)
W_p: Cumulative Water Production at Depletion Pressure (STB)
B_w: Water Formation Volume Factor (bbl/STB)
B_{gi}: Initial Gas Formation Volume Factor (bbl/SCF)

Output(s)

G: Gas Initially in Place (MSCF)

Formula(s)

$$G = \frac{G_p * B_g - \left(W_e - W_p * B_w\right)}{B_g - B_{gi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 207.*

1.73 Injectivity index

Input(s)

q: Flow Rate of injection Well (STB/day)
p: Reservoir Pressure (psi)
p_{wf}: Well Flow Pressure (psi)

Output(s)

I: Injectivity Index (STB/day/psi)

Formula(s)

$$I = \frac{q}{pwf - p}$$

Reference: *Horizontal Well Technology, Joshi, Page: 10.*

1.74 Instantaneous gas-oil ratio

Input(s)

R_s: Gas Solubility (SCF/STB)
k_{rg}: Relative Gas Permeability (dimensionless)
k_{ro}: Relative Oil Permeability (dimensionless)
μ_o: Viscosity of Oil (cP)
μ_g: Viscosity of Gas (cP)
B_o: Oil Formation Volume Factor (bbl/STB)
B_g: Gas Formation Volume Factor (bbl/SCF)

Output(s)

GOR: Gas Oil Ratio (SCF/bbl)

Formula(s)

$$GOR = R_s + \frac{k_{rg} * \mu_o * B_o}{k_{ro} * \mu_g * B_g}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 16.*

1.75 Interporosity flow coefficient

Input(s)

A: Surface Area of the Matrix Block (ft^2)
V: Volume of the Matrix Block (ft^3)
x: Characteristic Length of the Matrix Block (ft)
k_m: Permeability of Matrix (mD)
k_f: Permeability of Fracture (mD)
r_w: Wellbore Radius (ft)

Output(s)

α: Block-Shape Parameter ($1/ft^2$)
λ: Interporosity Flow Coefficient (dimensionless)

Formula(s)

$$\alpha = \frac{A}{V * x}$$

$$\lambda = \frac{\alpha * k_m * \left(r_w^2\right)}{k_f}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 82.*

1.76 Interstitial velocity

Input(s)

q: Flow Rate (cm^3/s)
Ø: Porosity (fraction)
A: Area (cm^2)

Output(s)

V: Interstitial Velocity (cm/s)

Formula(s)

$$V = \frac{q}{Ø * A}$$

Reference: *Civan, F. Reservoir Formation Damage: Fundamentals, Modeling, Assessment, and Mitigation. Gulf Publishing Company, Houston, Texas, Page: 493.*

1.77 Isothermal compressibility of oil—Vasquez-Beggs correlation—P > Pb

Input(s)

p: Pressure (psi)
T: Temp (F)
γ_g: Specific Gravity of Gas (fraction)
R_{sob}: Solution oil gas ratio at bubble point (fraction)
ρ: Density of oil (API)

Output(s)

c_o: Isothermal Compressibility of Oil (/psi)

Formula(s)

$$c_o = \frac{5 * Rsob + 17.2 * T - 1180 * \gamma_g + 12.61 * \rho - 1433}{p * 10^5}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 39.*

1.78 Isothermal compressibility of oil—Villena-Lanzi correlation—P < Pb

Input(s)

p: Pressure (psi)
p_b: Bubble point pressure (psi)
T: Temp (F)
Rsob: Solution oil gas ratio at bubble point (fraction)
ρ: Density of oil (API)

Output(s)

lc_o: Isothermal Compressibility of Oil (/psi)

Formula(s)

$$lc_o = -0.664 - 1.430 * \ln(p) - 0.395 * \ln(p_b) + 0.39 * \ln(T) + 0.455 * \ln(Rsob) + 0.262 * \ln(\rho)$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 39.*

1.79 Isothermal compressibility of water—Osif correlation

Input(s)

C_{NaCl}: Salinity (g NaCl/L)
T: Temperature (F)
p: Pressure (psi)

Output(s)

c_w: Isothermal Compressibility of Water (Osif Correlation) (SCF/STB)

Formula(s)

$$c_w = \frac{1}{7.033 * p + 541.5 * CNaCl - 537.0 * T + 403300}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 46.*

1.80 Kerns method for gas flow in a fracture

Input(s)

k: Permeability (mD)
μ: Viscosity (cP)
P: Pressure (psi)

Output(s)

V_g: Gas Velocity (cc)

Formula(s)

$$V_g = \frac{k * P^2}{2 * \mu}$$

Reference: *Ahmed, T. & McKinney, P.D. Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.81 Klinkenberg gas effect

Input(s)

k_l: Permeability of liquid (mD)
p: Mean flowing pressure of the gas (atm)
b: Klinkenberg factor, fixed for a gas (constant)

Output(s)

k_g: Apparent permeability of gas (mD)

Formula(s)

$$k_g = k_l * \left(1 + \frac{b}{p}\right)$$

Reference: *Wikipedia.org*.

1.82 Kozeny equation

Input(s)

Ø: Porosity (fraction)
k_z: Kozeny Constant (dimensionless)
S_p: Specific Surface Area (cm^{-1})

Output(s)

k: Permeability (cm^2)

Formula(s)

$$k = \frac{Ø}{k_z * S_p^2}$$

Reference: *Dandekar, A. Y. 2006. Petroleum Reservoir Rock and Fluid Properties. Boca Raton, FL: CRC Press Taylor & Francis Group, Page: 52.*

1.83 Kozeny-Carman relationship

Input(s)

B: Geometric factor (dimensionless)
Ø: Porosity (fraction)
d: Diameter of Particle (cm)
τ: Tortuosity (dimensionless)

Output(s)

k: Permeability (mD)

Formula(s)

$$k = \frac{B * Ø^3 * d^2}{\tau}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Express, UK, Page: 41.*

1.84 Leverett J-function

Input(s)

σ: Fluid interfacial tension (dyn/cm^2)
θ: Angle of wettability (fraction)
Pc: Capillary Pressure (dyn/cm)
k: Permeability (mD)
ø: Porosity (fraction)

Output(s)

J: Leverett J-function (dimensionless)

Formula(s)

$$J = \frac{Pc}{\sigma * \cos(\theta)} * \left(\frac{k}{ø}\right)^{0.5}$$

Reference: *Reservoir Engineering Handbook, Fourth Edition, Ahmed, Page: 224.*

1.85 Line-source solution for damaged or stimulated wells

Input(s)

P_i: Initial Pressure (psi)
t: Time of production (h)
k: Permeability (mD)
B: Volume factor (RB/STB)
Ø: Porosity (fraction)
c_t: Compressibility (1/psi)
h: Thickness of reservoir (ft)
μ: Viscosity of Oil (cP)
r: Radius of wellbore (ft)
q: Flow Rate (STB/day)
s: Skin Factor (dimensionless)

Output(s)

P_{wf}: Line-Source Solution for Damaged or Stimulated Wells (psi)

Formula(s)

$$P_{wf} = P_i + 70.6 * q * B * \mu * \frac{\left(\ln\left(\frac{1688 * Ø * \mu * c_t * r^2}{k * t}\right)\right) - 2 * s}{k * h}$$

Reference: *Pressure Transient Testing, Lee, Rollins & Spivey, Page: 11.*

1.86 Low-pressure region gas flow rate for non-circular drainage area

Input(s)

k: Permeability (mD)
h: Thickness (ft)
P_r: Average Reservoir Pressure (psi)
P_{wr}: Well Flowing Pressure (psi)
μ_{gavg}: Average Gas Viscosity (cP)
Z_{avg}: Average Gas Compressibility Factor (Dimensionless) A: Drainage Area (ft^2)
C_A: Shape Factor (dimensionless)
r_w: Wellbore Radius (ft)
S: Skin (dimensionless)
T: Temperature (R)

Output(s)

Q_g: Gas Flow Rate (MSCF/day)

Formula(s)

$$Q_g = \frac{k * h * \left(\left(P_r^2\right) - \left(\left(P_{wf}\right)^2 \right) \right)}{1422 * \mu_{gavg} * T * Z_{avg} * \left(0.5 * \ln\left(\frac{4 * A}{1.781 * C_A * \left(r_w^2\right)} \right) + S \right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 189.*

1.87 Material balance for cumulative water influx—Havlena and Odeh

Input(s)

G: Gas in Place (SCF)
E_G: Gas Expansion Term (bbl/SCF)
W_e: Cumulative Water Influx (bbl)

Output(s)

F: Fluid Withdrawal (bbl)

Formula(s)

$$F = G * E_G + W_e$$

Reference: *Ahmed, T., McKinney P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 209.*

1.88 Maximum height of oil column in cap rock

Input(s)

P_a: Total Potential energy of accumulation (psi)
P_w: Water Potential in Reservoir (psi)
G_o: Initial oil pressure gradient in Reservoir rock (cm^2)
α: Height Constant (dimensionless)
h: Depth (ft)
P_c: Capillary Pressure (psi)
ρ: Density differential between fluids (ppg)

Output(s)

H: Maximum Height of Oil Column (ft)

Formula(s)

$$H = \frac{P_a - P_w + G_o * h * \alpha + P_c}{\rho - G_o}$$

Reference: *Tarek Ahmed, Paul McKinney, Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.89 Modified Cole plot

Input(s)

G: Gas in Place (SCF)
W_e: Cumulative Water Influx (bbl)
E_t: Total Expansion Term (bbl/SCF)

Output(s)

$\frac{F}{E_t}$: Fluid Withdrawal (bbl)

Formula(s)

$$\frac{F}{E_t} = G + \left(\frac{W_e}{E_t}\right)$$

Reference: *Ahmed, T., McKinney P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 212.*

1.90 Modified Kozeny-Carman relationship

Input(s)

Ø: Porosity (fraction)
Ø*c*: Percolation Porosity (fraction)
B: Geometric Factor (fraction)
d: Average Grain Diameter (m)

Output(s)

k: Permeability (m^2)

Formula(s)

$$k = B * \frac{(\text{Ø} - \text{Ø}c)^3}{(1 + \text{Ø}c - \text{Ø})^2} * d^2$$

Reference: *Wikipedia.org*.

1.91 Normalized saturation

Input(s)

S_w: Saturation of Water (fraction)
S_{or}: Residual Water Saturation (fraction)
S_{wi}: Initial Water Saturation (fraction)

Output(s)

Son: Normalized Saturation (fraction)

Formula(s)

$$Son = \frac{1 - S_w - S_{or}}{1 - S_{wi} - S_{or}}$$

Reference: *Wikipedia.org*.

1.92 Oil bubble radius of the drainage area of each well represented by a circle

Input(s)

N_p: Well Current Cumulative Oil Production (bbl)
Ø: Porosity (fraction)
h: Thickness (ft)
S_{wi}: Initial Water Saturation at bubble point pressure (fraction)
B_o: Oil Formation Volume factor (bbl/STB)
B_{oi}: Initial Oil Formation Volume Factor (bbl/STB)
S_o: Current Oil Saturation (fraction)

Output(s)

r_{ob}: Oil Bubble Radius (ft)

Formula(s)

$$r_{ob} = \left(\frac{5.615 * N_p}{\pi * \text{Ø} * h * \left(\frac{1 - S_{wi}}{B_{oi}} - \frac{S_o}{B_o} \right)} \right)^{0.5}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 313.*

1.93 Oil density—Standing's correlation

Input(s)

γ_o: Oil Specific Gravity (fraction)
R_s: Solution Gas Oil Ratio (SCF/STB)
γ_g: Gas Specific Gravity (fraction)
t: Temperature (F)

Output(s)

ρ_o: Oil density (lbm/ft^3)

Formula(s)

$$\rho_o = \frac{62.4 * \gamma_o + 0.0136 * R_s * \gamma_g}{0.972 + 0.000147 * \left(R_s * \left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25 * t\right)^{1.175}}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 2/20.*

1.94 Oil formation volume factor—Standing's correlation

Input(s)

R_s: Gas Oil Ratio (SCF/STB)
γ_o: Specific Gravity of Oil Phase (fraction)
γ_g: Specific Gravity of Gas Phase (fraction)
t: Temperature (F)

Output(s)

B_o: Oil FVF (RB/STB)

Formula(s)

$$B_o = 0.9759 + 0.00012 * \left(R_s * \left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25 * t\right)^{1.2}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 2/20.*

1.95 Oil formation volume factor—Beggs-standing correlation—$P < P_b$

Input(s)

R_s: Solution Gas oil ratio (fraction)
γ_g: Specific Gravity of Gas (fraction)
γ_o: Specific Gravity of Oil (fraction)
T: Temperature (F)

Output(s)

F: Dimensionless Factor (fraction)
B_o: Oil formation factor (fraction)

Formula(s)

$$F = R_s * \left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25 * T$$

$$B_o = 0.972 + 0.000147 * F^{1.175}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 37.*

1.96 Oil formation volume factor—Beggs-standing correlation—P > P_b

Input(s)

B_b: Oil formation vol factor at bubble pt pressure (fraction)
c_o: Oil compressibility (/psi)
p_b: Bubble point pressure (psi)
p: Pressure (psi)

Output(s)

B_o: Oil formation factor (fraction)

Formula(s)

$$B_o = B_b * \exp(c_o * (p_b - p))$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 37.*

1.97 Oil in place for undersaturated oil reservoirs without fluid injection

Input(s)

N_p: Produced Oil (STB)
B_o: Oil Formation Volume Factor (rb/STB)
B_{oi}: Initial Oil Formation Volume Factor (rb/STB)
S_{wi}: Initial Water Saturation (fraction)
c_w: Water Compressibility (1/psi)
c_f: Formation Compressibility (1/psi)
ΔP: Pressure Differential (psi)

Output(s)

N: Oil in Place (STB)

Formula(s)

$$N = \frac{N_p * B_o}{B_o - B_{oi} + B_{oi} * \left(\frac{S_{wi} * c_w + c_f}{1 - S_{wi}}\right) * \Delta P}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 333.*

1.98 Oil in place in saturated oil reservoirs

Input(s)

N_p: Cumulative Oil Production (STB)
B_o: Oil Formation Volume Factor (bbl/STB)
G_p: Cumulative Gas Production (MSCF)
R_s: Gas Solubility (SCF/STB)
B_g: Gas Formation Volume Factor (bbl/SCF)
B_{oi}: Initial Oil Formation Volume Factor (bbl/STB)
R_{si}: Initial Gas Solubility (SCF/STB)

Output(s)

N: Oil in Place (bbl)

Formula(s)

$$N = \frac{N_p * B_o + \left(G_p - N_p * R_s\right) * B_g}{B_o - B_{oi} + (R_{si} - R_s) * B_g}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 334.*

1.99 Oil lost in migration

Input(s)

h: Average Change in Depth of the Gas-Oil Contact (ft)
Ø: Porosity (fraction)
A: Average Cross-Sectional Area of the Gas-Oil Contact (acres)
S_{org}: Residual Oil Saturation in The Gas Cap Shrinking Zone (fraction)
B_{oa}: Oil Formation Volume Factor at Abandonment (bbl/STB)

Output(s)

O: Volume of Oil Lost (bbl)

Formula(s)

$$O = 7758 * A * h * Ø * \left(\frac{S_{org}}{B_{oa}}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 5, Page: 333.*

1.100 Oil saturation at any depletion state below the bubble point pressure

Input(s)

S_{wi}: Initial Water Saturation (fraction)
N_p: Cumulative Oil Production (STB)
N: Oil in Place (STB)
B_{oi}: Initial Oil Formation Volume Factor (bbl/STB)
B_o: Oil Formation Volume Factor (bbl/STB)

Output(s)

S_o: Oil Saturation (fraction)

Formula(s)

$$S_o = (1 - S_{wi}) * \left(1 - \frac{N_p}{N}\right) * \left(\frac{B_o}{B_{oi}}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 312.*

1.101 Original gas in place

Input(s)

A: Area of Reservoir (acres)
h: Average Reservoir Thickness (ft)
Ø: Porosity (fraction)
S_{wi}: Initial Water Saturation (fraction)
B_{gi}: Gas Formation Volume Factor at Initial Pressure (ft3/SCF)

Output(s)

G: Gas-in-Place (SCF)

Formula(s)

$$G = \frac{43560 * A * h * Ø * (1 - S_{wi})}{B_{gi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 202.*

1.102 Payne method for intercompartmental flow in tight gas reservoirs

Input(s)

k: Permeability (mD)
T: Temperature (°R)
A: Cross-Sectional Area (ft^2)
L: Distance between the Center of the Two Compartments (ft)
$m(P_1)$: Gas Pseudo pressure in Compartment (Tank) 1 (psi^2/cP)
$m(P_2)$: Gas Pseudo pressure in Compartment (Tank) (psi^2/cP)

Output(s)

Q_{12}: Flow Rate between the Two Compartments (SCF/day)

Formula(s)

$$Q_{12} = \left(\frac{0.111924 * k * A}{T * L}\right) * (m(P_1) - m(P_2))$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 234, 235.*

1.103 Performance coefficient for shallow gas reservoirs

Input(s)

k: Permeability (mD)
h: Thickness (ft)
T: Temperature (°R)
μ: Viscosity (cP)
z: Compressibility Factor (dimensionless)
r_e: Radius of Drainage Area (ft)
r_w: Wellbore Radius (ft)

Output(s)

C: Performance Coefficient (dimensionless)

Formula(s)

$$C = \frac{k * h}{1422 * T * \mu_g * Z * \left(\ln\left(\frac{r_e}{r_w}\right) - 0.5\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 287.*

1.104 Poisson's ratio

Input(s)

ξ_t: Transverse Strain (dimensionless)
ξ_l: Longitudinal Strain (dimensionless)

Output(s)

μ: Poisson (dimensionless)

Formula(s)

$$\mu = \frac{\xi_t}{\xi_l}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 55.*

1.105 Pore throat sorting

Input(s)

Q_3: Capillary pressure at 75% saturation (psi)
Q_1: Capillary pressure at 25% saturation (psi)

Output(s)

PTS: Pore Throat Sorting (fraction)

Formula(s)

$$PTS = \left(\frac{Q_3}{Q_1}\right)^{0.5}$$

Reference: *Dandekar, A. Y. 2006. Petroleum Reservoir Rock and Fluid Properties. Boca Raton, FL: CRC Press Taylor & Francis Group, Chapter: 8, Page: 176.*

1.106 Pore volume occupied by injection of gas and water

Input(s)

W_{INJ}: Cumulative Water Injected (STB)
B_w: Water Formation Volume Factor (bbl/STB)
G_{INJ}: Cumulative Gas Injected (SCF)
B_{GINJ}: Injected Gas Formation Volume Factor (bbl/SCF)

Output(s)

V_t: Total Volume (bbl)

Formula(s)

$$V_t = W_{INJ} * B_w + G_{INJ} * B_{GINJ}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 302.*

1.107 Pore volume through squared method in tight gas reservoirs

Input(s)

$\mu_{g,\,avg}$: Average Gas Viscosity (cP)
z_{avg}: Compressibility Factor (dimensionless)
q_i: Initial Gas Rate (MSCF/day)
μ_{gi}: Initial Gas Viscosity (cP)
c_{ti}: Initial Total Compressibility (1/psi)
P_i: Initial Pressure (psi)
P_{wf}: Bottom-hole Flowing Pressure (psi)
D_i: Decline Rate (day^{-1})
T: Temperature (°R)

Output(s)

PV: Pore Volume (dimensionless)

Formula(s)

$$PV = \frac{28.27 * T * \mu_{g,avg} * z_{avg}}{\mu_{gi} * c_{ti} * \left(P_i^2 - P_{wf}^2\right)} * \left(\frac{q_i}{D_i}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 252.*

1.108 Porosity determination—IES and FDC logs

Input(s)

ρ_b: Bulk Density (g/cm^3)
ρ_{ma}: Matrix Density (g/cm^3)
ρ_f: Average Fluid Density in Pore Spaces (g/cm^3)

Output(s)

Ø: Porosity (fraction)

Formula(s)

$$Ø = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 11, Page: 210.*

1.109 Produced gas-oil ratio

Input(s)

N_p: Cumulative Oil Production (STB)
G_p: Cumulative Gas Production (SCF)

Output(s)

R_p: Net Cumulative Produced Gas-Oil Ratio (SCF/STB)

Formula(s)

$$R_p = \frac{G_p}{N_p}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 302.*

1.110 Productivity index for a gas well

Input(s)

k: Permeability (mD)
h: Thickness (ft)
T: Temperature (°R)
A: Drainage Area (ft^2))
C_A: Shape Factor (dimensionless)
r_w: Wellbore Radius (ft)
S: Skin (dimensionless)

Output(s)

J: Productivity Index (MSCF/day/psi^2/cP)

Formula(s)

$$J = \frac{k * h}{1422 * T * \left(0.5 * \ln\left(\frac{4 * A}{1.781 * C_A * r_w^2}\right) + S\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 188.*

1.111 Pseudo-steady state productivity of horizontal Wells—Method 1

Input(s)

A: Drainage Area (ft^2)
s: Skin Factor (dimensionless)
D: Turbulence Coefficient (1/BOPD for oil and 1/MSCFD for gas)
C: Shape Factor Conversion Constant = 1.386 (dimensionless)
s_{CAh}: Shape-Related Skin Factor (dimensionless)
h: Thickness of Reservoir (ft)
k_v: Vertical Permeability (mD)
k_h: Horizontal Permeability (mD)
k: Permeability (mD)
q: Flow Rate (BOPD for oil and MSCFD for gas)
L: Fracture Length (ft)
r_w: Radius of Wellbore (ft)
μ_o: Viscosity of Oil (cP)
B_o: Oil Formation Volume Factor (RB/STB)

Output(s)

r_e: Effective Radius of Drainage Area (ft)
s_m: Mechanical Skin Factor (dimensionless)
s_f: Skin Factor of an Infinite-conductivity, Fully Penetrating Fracture of Length L (dimensionless)
J_h: Pseudo-steady State Productivity of a Horizontal Well (bbl/day/psi)

Formula(s)

$$r_e = \left(\frac{A}{\pi}\right)^{0.5}$$

$$s_m = s * \frac{h}{L} * \left(\frac{k_h}{k_v}\right)^{0.5}$$

$$s_f = -\ln\left(\frac{L}{4 * r_w}\right)$$

$$J_h = \frac{0.007078 * k * \frac{h}{\mu_o * B_o}}{\ln\left(\frac{r_e}{r_w}\right) - A + s_f + s_m + s_{CAh} - C + D * q}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 221.*

1.112 Pseudo-steady state productivity of horizontal Wells—Method 2

Input(s)

μ_o: Viscosity of Oil (cP)
B_o: Oil Formation Volume (RB/STB)
A_t: Horizontal Well Drainage Area in the Vertical Plane = 2 y_eh (ft^2)
s_R: Skin Factor Due to Partial Penetration of Horizontal Well (dimensionless)
x_e: Half Length of the Short Side of the Rectangular Drainage Area (ft)
y_e: Half Length of the Long Side of the Rectangular Drainage Area (ft)
y_w: Distance from the Horizontal Well to the Closest Boundary in Y Direction (ft)
h: Thickness of Reservoir (ft)
k_v: Vertical Permeability (mD)
k_y: Horizontal Permeability (mD)
r_w: Radius of Wellbore (ft)
z_w: Vertical Distance between Horizontal Well and Bottom Boundary of Reservoir (ft)

Output(s)

InC_h: A Constant Related to the Natural Logarithm of Shape Factor (dimensionless)
J_h: Pseudo-steady State Productivity of Horizontal Wells (bbl/day/psi)

Formula(s)

$$InC_h = 6.28 * \left(2 * \frac{y_e}{h}\right) * \left(\frac{k_v}{k_y}\right)^{0.5} * \left(\frac{1}{3} - \frac{y_w}{2 * y_e} + \left(\frac{y_w}{2 * y_e}\right)^2\right) - \ln\left(\sin\left(180 * \frac{z_w}{h}\right)\right) - 0.5 * \ln\left(\left(2 * \frac{y_e}{h}\right) * \left(\frac{k_v}{k_y}\right)^{0.5}\right) - 1.088$$

$$J_h = 0.007078 * 2 * x_e * \frac{\frac{\left(k_y * k_v\right)^{0.5}}{\mu_o * B_o}}{\ln\left(\frac{(A_t)^{0.5}}{r_w}\right) + InC_h - 0.75 + s_R}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 22.*

1.113 Pseudo-steady state productivity of horizontal wells—Method 3

Input(s)

μ_o: Viscosity of Oil (cP)
s_x: Skin Factor (dimensionless)
h: Thickness of Reservoir (ft)
k_v: Vertical Permeability (mD)
k_h: Horizontal Permeability (mD)
F: Dimensionless Function (ft)
L: Length of Fracture (ft)

Output(s)

J_h: Pseudo-steady State Productivity of Horizontal Wells (bbl/day psi)

Formula(s)

$$J_h = k_h * \frac{\frac{h}{70.6 * \mu_o}}{F + \left(\frac{h}{0.5 * L}\right) * \left(\frac{k_h}{k_v}\right)^{0.5} * s_x}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 224.*

1.114 Pseudo-steady state radial flow equation

Input(s)

k: Permeability (mD)
h: Thickness of Reservoir (ft)
P_i: Average Reservoir Pressure (psi)
P_{wf}: Well Flowing Pressure (psi)
B: Formation Volume Factor (bbl/STB)
μ: Viscosity (cP)
r_e: Drainage Radius (ft)
r_w: Wellbore Radius (ft)

Output(s)

Q: Flow Rate (STB/day)

Formula(s)

$$Q = \frac{0.00708 * k * h * \left(P_i - P_{wf}\right)}{B * \mu * \left(\ln\left(\frac{r_e}{r_w}\right) - 0.75\right)}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 33.*

1.115 Relative permeability—Corey exponents

Input(s)

k_{roe}: Permeability at end point (mD)
S_w: Saturation of Water (fraction)
S_{or}: Residual Water Saturation (fraction)
S_{wi}: Initial Water Saturation (fraction)
N_o: Corey Coefficient (fraction)

Output(s)

k_{ro}: Relative Permeability at given Saturation (mD)

Formula(s)

$$k_{ro} = k_{roe} * \left(\frac{1 - S_w - S_{or}}{1 - S_{wi} - S_{or}}\right)^{N_o}$$

Reference: *Dandekar, A. Y. 2006. Petroleum Reservoir Rock and Fluid Properties. Boca Raton, FL: CRC Press Taylor & Francis Group, Chapter: 9, Page: 233.*

1.116 Remaining gas in place in coalbed methane reservoirs

Input(s)

A: Drainage Area (acres)
Ø: Porosity (fraction)
h: Thickness (ft)
B_w: Water Formation Volume Factor (bbl/STB)
W_p: Cumulative Water Produced (bbl)
S_{wi}: Water Saturation (fraction)
P_i: Initial Pressure (psi)
P: Current Reservoir Pressure (psi)
c_f: Formation Compressibility (1/psi)
c_w: Water Compressibility (1/psi)
E_g: Gas Expansion Factor (SCF/bbl)

Output(s)

G_R: Remaining Gas at Reservoir Pressure (SCF)

Formula(s)

$$G_R = 7758 * A * h * Ø * E_g * \left(\frac{\left(\frac{B_w * W_p}{7758 * A * h * Ø}\right) + (1 - S_{wi}) - (P_i - P) * (c_f + c_w * S_{wi})}{1 - (P_i - P) * c_f}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 227.*

1.117 Roach plot for abnormally pressured gas reservoirs

Input(s)

p_i/Z_i: Initial P/z Ratio (psi)
c_t: Rock Compressibility (1/psi)
G_p: Gas Produced (SCF)
G: Gas in Place (SCF)

Output(s)

$\frac{p}{Z}$: Current P/z Ratio (psi)

Formula(s)

$$\frac{p}{Z} = \left(\frac{p_i}{Z_i * c_t}\right) * \left(1 - \left(\frac{G_p}{G}\right)\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 213.*

1.118 Rock expansion term in abnormally pressured gas reservoirs

Input(s)

c_f: Formation Compressibility (1/psi)
c_w: Water Compressibility (1/psi)
S_{wi}: Initial Water Saturation (fraction)

Output(s)

E_R: Rock Expansion Term (1/psi)

Formula(s)

$$E_R = \frac{c_f + c_w * S_{wi}}{1 - S_{wi}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 213.*

1.119 Shape factor—Earlougher

Input(s)

m: Slope of Transient Semi-log Straight Line (psi/log cycle)
m': Slope of Semi-steady State Cartesian Straight Line (psi/h)
P_{1hr}: Pressure at $t = 1$ h from Transient Semi-log Straight Line (psi)
$P_\int$: Pressure at $t = 0$ from Pseudo-steady State Cartesian Straight Line (psi)

Output(s)

C_A: Shape Factor (dimensionless)

Formula(s)

$$C_A = 5.456 * \left(\frac{m}{m'}\right) * \exp\left(2.303 * \frac{P_{1hr} - P\int}{m'}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 47.*

1.120 Solution gas oil ratio—Beggs-standing correlation—P < Pb

Input(s)

T: Temperature (F)
γ_g: Specific gravity of produced gas (fraction)
p: Pressure1 (psi)
p_o: Pressure at given API (psi)

Output(s)

Y_g: Constant (fraction)
R_{so}: Solution Gas Oil Ratio (fraction)

Formula(s)

$$Y_g = 0.00091 * T - 0.0125 * p_o$$

$$R_{so} = \gamma_g * \left(\frac{p}{18 * 10^{Y_g}}\right)^{1.204}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 33.*

1.121 Solution gas oil ratio—Standing's correlation

Input(s)

γ_g: Gas Specific Gravity (fraction)
p: Pressure (psi)
API: API Gravity of Oil (API)
t: Temperature (F)

Output(s)

R_s: Solution Gas Oil Ratio (SCF/STB)

Formula(s)

$$R_s = \left(\gamma_g\right) * \left(\left(\frac{p}{18}\right) * \left(\frac{10^{0.0125*API}}{10^{0.00091*t}}\right)\right)^{1.2048}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach Page: 2/20.*

1.122 Solution gas water ratio

Input(s)

T: Temperature (F)
S: Salinity (% by weight solids)
R_{swp}: Solution gas to pure water ratio (SCF/STB)

Output(s)

R_{sw}: Solution Gas Water Ratio (SCF/STB)

Formula(s)

$$Rsw = Rswp * 10^{-0.0840655*S*T^{-0.285854}}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 46.*

1.123 Somerton method for formation permeability in coalbed methane reservoirs

Input(s)

k_o: Original Permeability at Zero Net Stress (mD)
$\Delta\sigma$: Net Stress (psi)

Output(s)

k: Permeability (mD)

Formula(s)

$$k = k_o * \left(\exp\left(\frac{(-0.003) * \Delta\sigma}{k_o^{0.1}} \right) + 0.0002 * \left((\Delta\sigma)^{\frac{1}{3}} \right) * \left((k_o)^{\frac{1}{3}} \right) \right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005, Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 226.*

1.124 Specific gravity of gas hydrate forming components

Input(s)

m_h: Molar Mass (g)

Output(s)

Γ_h: Specific Gravity of Hydrate-forming Components (dimensionless)

Formula(s)

$$\Gamma_h = \frac{m_h}{28.96}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 274.*

1.125 Time to reach the semi-steady state for a gas well in a circular or square drainage area

Input(s)

μ_{gi}: Initial Gas Viscosity (cP)
Ø: Porosity (fraction)
c_{ti}: Initial Total Compressibility (1/psi)
A: Drainage Area (ft^2)
k: Effective Gas Permeability (mD)

Output(s)

t_{pss}: Time (h)

Formula(s)

$$t_{pss} = \frac{15.8 * Ø * \mu_{gi} * c_{ti} * A}{k}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 194.*

1.126 Time to the end of infinite-acting period for a well in a circular reservoir

Input(s)

Ø: Porosity (fraction)
μ: Viscosity (cP)
c_t: Total Compressibility (1/psi)
A: Well Drainage Area (ft^2)
k: Permeability (mD)

Output(s)

t_{eia}: Time to the End of Infinite-acting Period (h)

Formula(s)

$$t_{eia} = \frac{380 * Ø * \mu * c_t * A}{k}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 50.*

1.127 Torcaso and Wyllie's correlation for relative permeability ratio prediction

Input(s)

S_o: Oil Saturation (fraction)
S_{wi}: Initial Water Saturation (fraction)
krg: Gas Relative Permeability (dimensionless)

Output(s)

S: Saturation (fraction)
kog: Oil Relative Permeability Ratio (fraction)

Formula(s)

$$S = \frac{S_o}{1 - S_{wi}}$$

$$kog = krg * \frac{(1-S)^2 * \left(1 - S^2\right)}{S^4}$$

Reference: *Ahmed, T. & McKinney, P.D. Advanced reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.128 Total compressibility

Input(s)

c_g: Compressibility of gas (/psi)
c_o: Compressibility of oil (/psi)
c_w: Compressibility of water (/psi)
c_f: Compressibility of formation (/psi)
S_g: Saturation of gas (fraction)
S_o: Saturation of oil (fraction)
S_w: Saturation of water (fraction)

Output(s)

c_t: Total Compressibility (/psi)

Formula(s)

$$c_t = c_g * S_g + c_o * S_o + c_w * S_w + c_f$$

Reference: *Petrowiki.org*.

1.129 Total pore volume compressibility

Input(s)

P_i: Initial Pressure (psi)
P: Pressure (psi)
$(PV)_i$: Pore Volume at Initial Reservoir Pressure (bbl)
$(PV)_p$: Pore Volume at Pressure P (bbl)

Output(s)

c_f: Cumulative Pore Volume (Formation or Rock) Compressibility (1/psi)

Formula(s)

$$c_f = \left(\frac{1}{(PV)_i}\right) * \left(\frac{(PV)_i - (PV)_p}{P_i - P}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 213.*

1.130 Transmissibility between compartments

Input(s)

γ_a: Transmissibility of Compartment 1 (mD ft^2/cP)
γ_b: Transmissibility of Compartment 2 (mD ft^2/cP)
L_1: Length of Compartment 1 (ft)
L_2: Length of Compartment 2 (ft)

Output(s)

γ: Transmissibility Between Compartments (mD ft^2/cP)

Formula(s)

$$\gamma = \frac{\gamma_a * \gamma_b * (L_1 + L_2)}{\gamma_a * L_2 + L_1 * \gamma_b}$$

Reference: *Ahmed, T., McKinney, P.D. 2015. Advanced Reservoir Engineering, Gulf Publishing Elsevier, Chapter: 3, Page: 236.*

1.131 Transmissibility of a compartment

Input(s)

k: Permeability (mD)
A: Cross-sectional Area (ft^2)
z: Compressibility Factor (dimensionless)
μ_g: Gas Viscosity (cP)

Output(s)

γ: Transmissibility (mD ft^2/cP)

Formula(s)

$$\gamma = \frac{k * A}{z * \mu_g}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 236.*

1.132 Transmissivity

Input(s)

C: Hazen (dimensionless)
D: Diameter of 10 percentile grain size (mm)

Output(s)

K: Transmissivity (mm^2)

Formula(s)

$$K = C * (D)^2$$

Reference: *Wikipedia.org*.

1.133 Trapped gas volume in water-invaded zones

Input(s)

W_e: Cumulative Water Influx (bbl)
W_p: Cumulative Water Produced (bbl)
B_w: Water Formation Volume Factor (bbl/STB)
s_{wi}: Initial Water Saturation (fraction)
s_{grw}: Relative Gas Saturation (fraction)

Output(s)

TG: Trapped Gas Volume (MSCF)

Formula(s)

$$TG = \left(\frac{W_e - W_p * B_w}{1 - s_{wi} - s_{grw}}\right) * s_{grw}$$

Reference: *Ahmed, T., McKinney, P.D.2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 208.*

1.134 Two-phase formation volume factor

Input(s)

Bo: Oil formation vol factor (fraction)
Bg: Gas formation vol factor (fraction)
R_{soi}: Initial Solution oil gas ratio (fraction)
R_{so}: Solution oil gas ratio (fraction)

Output(s)

B_t: Oil formation factor (fraction)

Formula(s)

$$B_t = Bo + (Bg * (Rsoi - Rso))$$

Reference: *Petrowiki.org*.

1.135 Underground fluid withdrawal—Havlena and Odeh

Input(s)

G_p: Cumulative Gas Production (SCF)
B_g: Gas Formation Volume Factor (bbl/SCF)
W_p: Cumulative Water Production (STB)
B_w: Water Formation Volume Factor (bbl/STB)

Output(s)

F: Fluid Withdrawal (bbl)

Formula(s)

$$F = G_p * B_g + W_p * B_w$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 259.*

1.136 Vertical well critical rate correlations—Craft and Hawkins method

Input(s)

b: Penetration Ratio, (h_p/h) (dimensionless)
r_e: Radius of Drainage (ft)
r_w: Radius of Wellbore (ft)
h_p: Thickness of Perforated interval (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (RB/STB)
k_o: Effective Oil Permeability (mD)
p_{ws}: Static Well Pressure Corrected to the Middle of the Producing Interval (psi)
p_{wf}: Flowing Well Pressure at the Middle of the Producing Interval (psi)

Output(s)

PR: Productivity Ratio (dimensionless)
q_o: Critical Rate (Maximum Oil Rate without Coning) (STB/day)

Formula(s)

$$PR = b * \left(1 + 7 * \left(\frac{r_w}{2 * b * h}\right)^{0.5} * \cos(b * 90°)\right)$$

$$q_o = \frac{0.007078 * k_o * h * \left(p_{ws} - p_{wf}\right)}{\mu_o * B_o * \ln\left(\frac{r_e}{r_w}\right)} * PR$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 8, Page: 254.*

1.137 Vertical well critical rate correlations—Hoyland, Papatzacos, and Skjaeveland—Isotropic reservoirs

Input(s)

h: Oil Column Thickness (m)
h_p: Perforated Interval (m)
re: Drainage Radius (m)
k_o: Effective Oil Permeability (mD)
ρ_w: Water Density (kg/m^3)
μo: Oil Viscosity (cP)
ρ_o: Oil Density (kg/m^3)
Bo: Oil Formation volume Factor (RB/STB)

Output(s)

Q_{oc}: Critical Rate (m^3/day)

Formula(s)

$$Qoc = \frac{(\rho_w - \rho_o) * ko}{Bo * \mu o * 10822} * \left(1 - \left(\frac{hp}{h}\right)^2\right)^{1.325} * h^{2.238} * (\ln(re))^{-1.99}$$

Reference: *Horizontal Well Technology, Joshi, Page: 257.*

1.138 Vertical well critical rate correlations—Meyer, Gardner, and Pirson—Simultaneous gas and water coning

Input(s)

ρ_o: Oil Density (g/cc)
ρ_w: Water Density (g/cc)
r_e: Drainage Radius (ft)
r_w: Radius of Wellbore (ft)
h_p: Thickness of Perforated Interval (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (RB/STB)
k_o: Effective Oil Permeability (mD)

Output(s)

q_o: Critical Rate (Maximum Oil Rate without Water Coning) (STB/day)

Formula(s)

$$q_o = 0.001535 * \frac{\rho_w - \rho_o}{\ln\left(\frac{r_e}{r_w}\right)} * \left(\frac{k_o}{\mu_o * B_o}\right) * \left(h^2 - \left(h_p\right)^2\right)$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 8, Page: 255.*

1.139 Vertical well critical rate correlations—Meyer, Gardner, and Pirson—Water coning

Input(s)

ρ_o: Oil Density (g/cc)
ρ_g: Gas Density (g/cc)
r_e: Radius of Drainage (ft)
r_w: Radius of Wellbore (ft)
h_p: Thickness of Perforated interval (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (RB/STB)
k_o: Effective Oil Permeability (mD)

Output(s)

q_o: Critical Rate (Maximum Oil Rate without Gas Coning) (STB/day)

Formula(s)

$$q_o = 0.001535 * \left(\frac{\rho_o - \rho_g}{\ln\left(\frac{r_e}{r_w}\right)} \right) * \left(\frac{k_o}{\mu_o * B_o} \right) * \left(h^2 - \left(h - h_p \right)^2 \right)$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 8, Page: 255.*

1.140 Vertical well critical rate correlations—Meyer, Gardner, and Pirson—Gas coning

Input(s)

ρ_o: Oil Density (g/cc)
ρ_g: Gas Density (g/cc)
r_e: Radius of Drainage (ft)
r_w: Radius of Wellbore (ft)
h_p: Thickness of Perforated interval (ft)
h: Oil Column Thickness (ft)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (RB/STB)
k_o: Effective Oil Permeability (mD)

Output(s)

q_o: Critical Rate (Maximum Oil Rate without Gas Coning) (STB/day)

Formula(s)

$$q_o = 0.001535 * \left(\frac{\rho_o - \rho_g}{\ln\left(\frac{r_e}{r_w}\right)} \right) * \left(\frac{k_o}{\mu_o * B_o} \right) * \left(h^2 - \left(h - h_p \right)^2 \right)$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 8, Page: 255.*

1.141 Viscosibility

Input(s)

μ: Viscosity of displacing fluid (cP)
$d\mu$: Change in viscosity (cP)
dP: Change in pressure (psi)

Output(s)

cv: Viscosibility (1/psi)

Formula(s)

$$cv = \left(\frac{1}{\mu}\right) * \left(\frac{d\mu}{dP}\right)$$

Reference: *Petrowiki.org*.

1.142 Viscosity of crude oil through API

Input(s)

a: Coefficient (dimensionless)
A: API Gravity (dimensionless)

Output(s)

μ: Logarithmic Viscosity (cP)

Formula(s)

$$\mu = a - 0.035 * A$$

Reference: *Campbell, J. M., (1992, Houston, TX (United States)), Gas Conditioning and Processing, Vol. 1, Campbell Petroleum Series, Page: 74.*

1.143 Viscosity of dead oil—Standing's correlation

Input(s)

API: API Gravity of Oil (API)
t: Temperature (F)

Output(s)

μ_{od}: Viscosity of Dead Oil (cP)

Formula(s)

$$\mu_{od} = \left(0.32 + \left(1.8 * \frac{10^7}{API^{4.53}}\right)\right)\left(\frac{360}{t+200}\right)^{10^{0.43+\frac{8.33}{API}}}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 2/20.*

1.144 Viscosity of dead-oil—Egbogah correlation—P < Pb

Input(s)

ρ: Density of oil (API)
T: Temp (F)

Output(s)

μod: Viscosity of Dead-Oil (cP)

Formula(s)

$$\mu od = 10^{10^{1.8653-0.025086*\rho-0.5644*\log(T)}}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 41.*

1.145 Viscosity of live oil—Beggs/Robinson correlation

Input(s)

μod: Viscosity of dead oil (cP)
R_{so}: Solution oil gas ratio (fraction)

Output(s)

A: Constant A for Beggs Robinson Correlation (fraction)
B: Constant B for Beggs Robinson Correlation (fraction)
μo: Viscosity of Live-Oil (cP)

Formula(s)

$$A = 10.715 * (Rso + 100)^{-0.515}$$

$$B = 5.44 * (Rso + 150)^{-0.338}$$

$$\mu o = A * \mu od^{B}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 41.*

1.146 Viscosity of oil—Vasquez/Beggs correlation—P > Pb

Input(s)

μod: Oil viscosity at bubble point (cP)
Rso: Solution oil gas ratio (fraction)
p: Pressure (psi)
p_b: Bubble Point Pressure (psi)

Output(s)

m: Exponential Constant for Beggs Correlation (dimensionless)
μo: Viscosity of Live-Oil (cP)

Formula(s)

$$m = 2.6 * \left(p^{1.187}\right) * \exp\left(-11.513 - 8.98 * \left(10^{-5}\right) * p\right)$$
$$\mu o = \mu od * \left(\frac{p}{p_b}\right)^m$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 41.*

1.147 Viscosity of water at atmospheric pressure—McCain correlation

Input(s)

S: Salinity (% weight by solids)
T: Temperature (F)

Output(s)

μ_{w1}: Viscosity of water (cP)

Formula(s)

$$\mu w1 = (109.574 - 8.40564 * S + 0.313314 * S^\wedge 2 + 8.72213 * 10^\wedge - 3 * S^\wedge 3) \\ * T^\wedge\left(-1.12166 + 2.63951 * 10^{-2} * S - 6.79461 * 10^{-4} * S^2 - 5.47119 \right. \\ \left. * 10^{-5} * S^3 + 1.55586 * 10^{-6} * S^4\right.$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft and Hawkins, Page: 48.*

1.148 Viscosity of water at reservoir pressure—McCain correlation

Input(s)

p: Pressure (psi)
$\mu w1$: Viscosity of Water at Atmospheric Pressure (cP)

Output(s)

μ_w: Viscosity of water at Reservoir Pressure (cP)

Formula(s)

$$\mu w = \mu w1 * \left(0.9994 + 4.0295 * 10^{-5} * p + 3.1062 * 10^{-9} * p^2\right)$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 48.*

1.149 Volume of gas adsorbed in coalbed methane reservoirs

Input(s)

V_m: Langmuir's Isotherm Constant (SCF/ton)
b: Langmuir's Pressure Constant (1/psi)
p: Pressure (psi)

Output(s)

V: Volume of Gas Currently Adsorbed (SCF/ton)

Formula(s)

$$V = \frac{V_m * b * p}{1 + b * p}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 320.*

1.150 Volumetric heat capacity of a reservoir

Input(s)

M_s: Volumetric Heat Capacity of Solids (btu/ft^3 F)
Ø: Porosity (fraction)
S_o: Oil Saturation (fraction)
M_o: Volumetric Heat Capacity of Oil (btu/ft^3 F)
S_w: Water Saturation (fraction)
M_w: Volumetric Heat Capacity of Water (btu/ft^3 F)
S_g: Saturation of Gas (fraction)
f: Fraction of non-condensable Gases (fraction)
M_g: Volumetric Heat Capacity of Gases (btu/ft^3 F)
ρ_s: Density of Solids (g/cc)
C_w: Isobaric Specific Heat of Water (btu/lb F)
ΔT: Temperature Differential (K)
L_v: Latent Heat of Vaporization (btu/lb)

Output(s)

M_r: Volumetric Heat Capacity of Reservoir (btu/ft^3 F)

Formula(s)

$$M_r = (1 - Ø) * M_s + Ø * M_o * S_o + Ø * S_w * M_w + Ø * S_g * \left(f * M_g + (1 - f) * \left(\frac{L_v * \rho_s}{\Delta T} + \rho_s * C_w \right) \right)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 12, Page: 164.*

1.151 Water breakthrough correlation in vertical wells—Bournazel and Jeanson

Input(s)

h: Oil Column Thickness (ft)
g: Gravitational Acceleration (ft/s^2)
k_v: Vertical Permeability (mD)
ρ_w: Water Density (g/cc)
μ_o: Oil Viscosity (cP)
ρ_o: Oil Density (g/cc)
t_{BT}: Water Breakthrough Time (s)
ϕ_e: Porosity (fraction)
f_m: Mobility Function Ratio (dimensionless)

Output(s)

t_d: Dimensionless Breakthrough Time (days)

Formula(s)

$$t_d = \frac{(\rho_w - \rho_o) * g * k_v * t_{BT} * f_m}{\mu_o * \text{ø}_e * h}$$

Reference: *Bournazel, C., Jeanson, B. 1971. Fast Water-coning Evaluation Method. SPE AIME, New Orleans, Louisiana.*

1.152 Water breakthrough correlations in vertical wells—Sobocinski and Cornelius

Input(s)

h: Oil Column Thickness (ft)
h_t: Height of the Apex of the Water Cone above the Average Water-Oil Contact (ft)
k_v: Vertical Permeability (mD)
k_h: Horizontal Permeability (mD)
ρ_w: Water Density (g/cc)
μ_o: Oil Viscosity (cP)
ρ_o: Oil Density (g/cc)
q_o: Oil Production Rate (STB/D)
B_o: Oil Formation Volume Factor (RB/STB)
α: Constant Value of 0.5 for $M < 1$ and 0.6 for M between 1 and 10 (RB/STB)
M: Water Oil Mobility Ratio (fraction)
t: Breakthrough Time (days)
ø: Porosity (fraction)

Output(s)

Z: Dimensionless Cone Height (feet)
t_D: Dimensionless Breakthrough Time (days)

Formula(s)

$$Z = \frac{0.00307 * (\rho_w - \rho_o) * k_h * h * h_t}{\mu_o * q_o * B_o}$$

$$t_D = \frac{0.00137 * (\rho_w - \rho_o) * k_h * (1 + M^{\alpha}) * t}{\mu_o * \text{ø} * h * \left(\frac{k_h}{k_v}\right)}$$

Reference: *Sobocinski, D.P., Cornelius, A.J. 1965. A Correlation for Predicting Water Coning Time. SPE ATCE, Houston, Texas.*

1.153 Water content of sour gas

Input(s)

y: Mole Content of Hydrocarbon (fraction)
Whc: Water Content of hydrocarbon Part (fraction)
yco: Mole Content of Carbon Dioxide (fraction)
Wco: Water Content of Carbon Dioxide (fraction)
yhs: Mole Content of Hydrogen Sulfide (fraction)
Whs: Water Content of Hydrogen Sulfide (fraction)

Output(s)

W: Water Content (fraction)

Formula(s)

$$W = y * Whc + yco * Wco + yhs * Whs$$

Reference: *Campbell, J. M., (1992, Houston, TX (United States)), Gas Conditioning and Processing, Vol. 1, Campbell Petroleum Series, Page: 149.*

1.154 Water cut—Stiles

Input(s)

k: Permeability (mD)
h: Cumulative Thickness for Breakthrough Layer & Above (ft)
M_{wo}: Mobility Ratio (fraction)
k_t: Cumulative Flow Capacity for Breakthrough Layer & Above (mD ft)
h_t: Cumulative Flow Capacity for the Whole Model (mD ft)

Output(s)

f_w: Water Cut (fraction)

Formula(s)

$$f_w = \frac{k * h * M_{wo}}{k * h * M_{wo} + k_t * h_t - k * h}$$

Reference: *Ehrlich, R. 2016. Enhanced Oil Recovery, Lecture Notes.*

1.155 Water-drive index for gas reservoirs

Input(s)

W_e: Cumulative Water Influx (bbl)
W_p: Cumulative Water Production (bbl)
B_w: Water Formation Volume Factor (rb/STB)
G_p: Cumulative Gas Production at Depletion Pressure (MSCF)
B_g: Gas Formation Volume Factor at Depletion Pressure (bbl/SCF)

Output(s)

WDI: Water Drive Index (dimensionless)

Formula(s)

$$WDI = \frac{W_e - W_p * B_w}{G_p * B_g}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 211.*

1.156 Water-drive recovery

Input(s)

Ø: Porosity (fraction)
S_w: Water Saturation (fraction)
B_{oi}: FVF at Initial Conditions of Reservoir (RB/STB)
k: Permeability (D)
μ_{wi}: Water Viscosity (cP)
μ_{oi}: Oil Viscocity (cP)
P_i: Initial Pressure (psi)
P_a: Pressure at Depletion (psi)

Output(s)

E_R: Fractional Recovery Efficiency (fraction)

Formula(s)

$$E_R = 54.898 * \left(\frac{Ø * (1 - S_w)}{B_{oi}}\right)^{0.0422} * \left(\frac{k * \mu_{wi}}{\mu_{oi}}\right)^{0.0770} * (S_w)^{-0.1903} * \left(\frac{P_i}{P_a}\right)^{-0.2159}$$

Reference: *Craig Jr. F. F., 2004, The Reservoir Engineering Aspects of Waterflooding, Vol. 3. Richardson, Texas: Monograph Series, SPE, Page: 83.*

1.157 Water expansion term in gas reservoirs

Input(s)

B_g: Initial Gas Formation Factor (MSCF/ft^3)
c_w: Water Compressibility (1/psi)
s_w: Initial Water Saturation (fraction)
c_f: Formation Compressibility (1/psi)
P: Pressure Differential (psi)

Output(s)

E_f: Expansion Term (fraction)

Formula(s)

$$E_f = \frac{B_g * \left(c_w * s_w - c_f\right) * P}{1 - s_w}$$

Reference: *Ahmed, T. & McKinney, P. Advanced Reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.158 Water formation volume factor—McCain correlation

Input(s)

T: Temperature (F)
p: Pressure (psi)

Output(s)

B_w: Water Formation Volume Factor (McCain Correlation) (bbl/STB)

Formula(s)

$$B_w = \left(1 - 1.00010 * 10^{-2} + 1.33391 * \left(10^{-4}\right) * T + 5.50654 * \left(10^{-7}\right) * T^2\right) \\ * \left(1 - 1.95301 * 10^{-9} * p * T - 1.72834 * 10^{-13} * p^2 * T - 3.58922 * 10^{-7} * p - 2.25341 * 10^{-10} * p^2\right)$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 45.*

1.159 Water influx—Pot aquifer model

Input(s)

c_t: Aquifer Total Compressibility (1/psi)
W_i: Initial Volume of Water in Aquifer (bbl)
P_i: Initial Reservoir Pressure (psi)
P: Current Reservoir Pressure (Pressure at Oil-Water Contact) (psi)

Output(s)

W_e: Cumulative Water Influx (bbl)

Formula(s)

$$W_e = c_t * W_i * (P_i - P)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 2, Page: 152.*

1.160 Water influx constant for the van Everdingen and Hurst unsteady-state model

Input(s)

c_t: Total Aquifer Compressibility (1/psi)
Ø: Porosity of the Aquifer (fraction)
r_e: Radius of Reservoir (ft)
h: Thickness of the Aquifer (ft)
f: Encroachment Angle (Divided by 360)

Output(s)

B: Water Influx (bbl)

Formula(s)

$$B = 1.119 * Ø * c_t * \left(r_e^2\right) * h * f$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 4, Page: 310.*

1.161 Water two-phase formation volume factor

Input(s)

B_w: Water Formation Volume Factor (one phase) (rb/STB)
B_g: Gas Formation Volume Factor (MSCF/STB)
R_s: Gas Oil ratio (rb/MSCF)
R_i: Initial Gas Oil Ratio (rb/MSCF)

Output(s)

B_t: Water Formation Factor (rb/STB)

Formula(s)

$$B_t = B_w + B_g * \left(R_s - R_i\right)$$

Reference: *Ahmed, T. & McKinney, P. Advanced reservoir Engineering, Gulf Publishing House, Burlington, MA, 2015.*

1.162 Waxman and Smits model—Clean sands

Input(s)

F: Shaly-Sand Formation Resistivity Factor (dimensionless)
Øe: Effective Porosity (fraction)
C_{cl}: Clay Exchange Cation Conductivity (1/Ω m)
C_w: Formation Water Conductivity (1/Ω m)

Output(s)

C_o: Brine Saturated Rock Conductivity (1/Ω m)

Formula(s)

$$C_o = \left(\frac{1}{F}\right) * (C_{cl} + C_w)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 17.*

1.163 Welge extension—Fractional flow

Input(s)

f_o: Fractional Flow of Oil Obtained (fraction)
μ_w: Viscosity of Water (cP)
μ_o: Viscosity of Oil (cP)

Output(s)

relpr: Relative Permeability Ratio of Water to Oil (fraction)

Formula(s)

$$\text{relpr} = \frac{\mu_w}{\mu_o} * \left(\frac{1 - f_o}{f_o}\right)$$

Reference: *Dandekar, A. Y. 2006. Petroleum Reservoir Rock and Fluid Properties. Boca Raton, FL: CRC Press Taylor & Francis Group, Chapter: 9, Page: 215.*

Chapter 2

Drilling engineering formulas and calculations

Chapter Outline

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2.1 Accumulator capacity

Input(s)

BC: Bottle Volume per capacity (gallons)
P_P: Pre-charge Pressure (psi)
P_S: System Pressure (psi)
P_f: Final Pressure (psi)

Output(s)

V: Accumulator Capacity (gallon)

Formula(s)

$$V = BC * \left(\frac{P_P}{P_f} - \frac{P_P}{P_S}\right)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 39.*

2.2 Accumulator precharge pressure

Input(s)

V_a: Total Accumulator Volume (bbl)
P_S: Starting Accumulator Pressure (psi)
V_r: Volume of Fluid Removed (bbl)
P_f: Final Accumulator Pressure (psi)

Output(s)

P: Accumulator Pressure (psi)

Formula(s)

$$P = \frac{V_r}{V_a} * \left(\frac{P_f * P_s}{P_s - P_f}\right)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 41.*

2.3 Amount of additive required to achieve a required cement slurry density

Input(s)

ρ: Required Slurry Density (lb/gal)
S_{Gc}: Specific Gravity of Cement (unitless)
C: Water Requirement of Cement (gal/stroke)
A: Water Requirement of Additive (gal/stroke)
S_{Ga}: Specific Gravity of Additive (unitless)

Output(s)

x: Amount of Additive Required (lb/stroke)

Formula(s)

$$x = \frac{\left(\frac{\rho * 11.207983}{S_{Gc}}\right) + (\rho * C) - 94 - (8.33 * C)}{\left(1 + \left(\frac{A}{100}\right)\right) - \left(\frac{\rho}{8.33 * S_{Ga}}\right) - \left(\rho + \frac{A}{100}\right)}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 53.*

2.4 Amount of cement to be left in casing

Input(s)

L_c: Casing Length (ft)
D: Setting Depth of Cementing Tool (ft)
C_c: Casing Capacity (ft^3/ft)

Output(s)

AC: Amount of Cement (ft^3)

Formula(s)

$$AC = (L_c - D) * C_c$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 58.*

2.5 Amount of mud required to displace cement in drillpipe

Input(s)

L_d: Length of Drillpipe (ft)
C_p: Drill Pipe Capacity (bbl/ft)

Output(s)

A_m: Amount of Mud Required (bbl)

Formula(s)

$$A_m = L_d * C_p$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 58.*

2.6 Angle of twist—Rod subjected to torque

Input(s)

E: Modulus of Elasticity (psi)
υ: Poisson (dimensionless)

D_o: Outer Diameter (ft)
D_i: Inner Diameter (ft)
T: Torque (ft lbf)
L: Length of Section (ft)

Output(s)

G: Modulus of Rigidity (psi)
J: Polar Moment of Inertia (ft^4)
θ: Angle of Twist (rad)

Formula(s)

$$G = \frac{E}{2*(1+\upsilon)}$$

$$J = \frac{3.142*\left((D_o)^4 - (D_i)^4\right)}{32}$$

$$\theta = \frac{T*L}{G*J}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 369.*

2.7 Annular capacity between casing and multiple strings of tubing

Input(s)

D_i: Inner Diameter of Casing (in.)
T_1: Diameter of Tubing 1 (in.)
T_2: Diameter of Tubing 2 (in.)

Output(s)

C_a: Annular Capacity (gal/ft)

Formula(s)

$$C_a = \frac{D_i^2 - \left(T_1^2 + T_2^2\right)}{1029.4}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 15.*

2.8 Annular capacity between casing and multiple tubing strings

Input(s)

D_h: Hole Size (in.)
T_a: Outer Diameter of Tubing No.1 (in.)
T_b: Outer Diameter of Tubing No.2 (in.)

Output(s)

AC: Annular Capacity (gal/ft)

Formula(s)

$$AC = \frac{D_h^2 - \left(T_a^2 + T_b^2\right)}{1029.4}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 14.*

2.9 Annular velocity—Using circulation rate in Gpm

Input(s)

Q: Circulation Rate (Pump Output) (gpm)
D_h: Inside Diameter of Casing (in.)
D_p: Outside Diameter of Pipe, Tubing or Collars (in.)

Output(s)

AV: Annular Velocity (ft/min)

Formula(s)

$$AV = \frac{24.5 * Q}{\left(D_h^2\right) - \left(D_p^2\right)}$$

Notes: The Formula Calculates Annular Velocity (ft/min) using Circulation Rate (Pump Output) (gal/min)

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 10.*

2.10 Annular velocity—Using pump output in bbl/min

Input(s)

Q: Circulation Rate (gpm)
D_h: Inside Diameter of Casing or Hole Size (in.)
D_p: Outside Diameter of Pipe, Tubing or Collars (in.)

Output(s)

AV: Annular Velocity (ft/min)

Formula(s)

$$AV = \frac{[24.5 * Q]}{\left[(D_h)^2 - \left(D_p\right)^2\right]}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 10.*

2.11 Annular velocity for a given circulation rate

Input(s)

Q: Circulation Rate (gpm)
d_h: Inner Diameter of Casing (in.)
d_p: Outer Diameter of Casing (in.)

Output(s)

AV: Annular Velocity (ft/min)

Formula(s)

$$AV = \frac{24.5 * Q}{\left(d_h^2 - d_p^2\right)}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 21.*

2.12 Annular velocity for a given pump output

Input(s)

O_p: Pump Output (bbl/min)
d_h: Inner Diameter of Casing (in.)
d_p: Outer Diameter of Casing (in.)

Output(s)

AV: Annular Velocity (bbl/min)

Formula(s)

$$AV = \frac{O_p * 1029.4}{d_h^2 - d_p^2}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 21.*

2.13 Annular volume capacity of pipe

Input(s)

D_h: Inner Diameter of Casing against Pipe (in.)
D_o: Outside Diameter of Pipe (in.)
L: Length of Pipe (ft)

Output(s)

V_a: Annular Volume Capacity (bbl)

Formula(s)

$$V_a = \frac{0.7854 * \left(D_h^2 - D_o^2\right) * L}{808.5}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 44.*

2.14 API water loss calculations

Input(s)

V_a: Water Loss in 7.5 min (cm^3)
V_{sp}: Spurt Loss (cm^3)

Output(s)

V_{30}: Water Loss (cm^3)

Formula(s)

$$V_{30} = (2 * V_a) - \left(V_{sp}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 199.*

2.15 Area below the casing shoe

Input(s)

D_c: Casing Diameter (in.)

Output(s)

A: Area Below Shoe (in.^{2})

Formula(s)

$$A = D_c^2 * 0.7854$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 67.*

2.16 Axial loads in slips

Input(s)

A: Cross Sectional Area of the Pipe body (in.^{2})
σ: Yield Strength of the Casing (psi)
r: Outside Casing Radius (in.)
L: Slip Gripping Length (in.)
K: Transverse Load Factor (dimensionless)

Output(s)

F_c: Critical Axial Load (lbm)
C: Crushing Factor (dimensionless)

Formula(s)

$$F_c = C \cdot A \cdot \sigma$$

$$C = \frac{1}{\left[1 + \frac{rK}{L} + \left(\frac{rK}{L}\right)^2\right]^{1/2}}$$

Reference: *Suman Jr, G. O., & Ellis, R. C. (1977). Cementing Handbook. World Oil, Page: 18.*

2.17 Beam force

Input(s)

H: Significant Wave Height (ft)
B: Vessel Beam Length (ft)
L: Vessel Length (ft)
A: Wave Period (s)
D: Vessel Draft (ft)

Output(s)

F_{ba}: Beam Force When a Is Greater Than 0.642*(b+2*d)0.5 (ft^5/s)
F_{bb}: Beam Force When a Is Lower Than 0.642*(b+2*d)0.5 (ft^5/s)

Formula(s)

$$F_{ba} = \frac{2.1 * (H^2) * (B^2) * L}{A^4}$$

$$F_{bb} = \frac{2.1 * (H^2) * (B^2) * L}{\left(1.28 * \left((B + 2 * D)^{0.5}\right) - A\right)^4}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 457.*

2.18 Bit nozzle pressure loss

Input(s)

N_a: Nozzle Area (in.^{2})
Q: Flow Rate (gpm)
MW: Mud Weight (ppg)

Output(s)

P_b: Bit Nozzle Pressure Loss (psi)

Formula(s)

$$P_b = (Q^2) * \frac{MW}{10858 * (N_a)^2}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 165.*

2.19 Bit nozzle selection—Optimized hydraulics for two and three jets

Input(s)

N_a: Jet Size for nozzle 1 (in.)
N_b: Jet Size for nozzle 2 (in.)
N_c: Jet Size for nozzle 3 (in.)
Ca: Circulation Rate (gpm)
Cb: Circulation Rate (gpm)
Wm: Mud Weight (ppg)
Cpa: Circulating Pressure 1 (psi)
Cpb: Circulating Pressure 2 (psi)
P_{max}: Max surface pressure (psi)
d: Dia of the nozzle chosen (in.)
n: No. of nozzles (unit)

Output(s)

A: Nozzle Area (in.^{2})
Pba: Bit Nozzle Pressure Loss 1 (psi)
Pbb: Bit Nozzle Pressure Loss 2 (psi)
P_{ca}: Total Pressure Loss for pump pressure 1 except bit nozzle (psi)
P_{cb}: Total Pressure Loss for pump pressure 2 except bit nozzle (psi)
M: Slope of Line (unitless)
P_{iopt}: Optimum Pressure for Impact Force (psi)
P_{hopt}: Optimum Pressure for hydraulic Horsepower (psi)
Pilb: Pressure loss at the bit due to impact force (psi)
Phlb: Pressure loss at the bit due to hydraulic horsepower (psi)
Q_{iopt}: Optimum flowrate for impact force (gpm)
Q_{hopt}: Optimum flowrate for hydraulic horsepower (gpm)
A_{in}: Area of nozzle for Impact force (in.^{2})
A_{hn}: Area of nozzle used for hydraulic horsepower (in.^{2})
A_n: Area of nozzle used (in.^{2})

Formula(s)

$$A = \frac{N_a^2 + N_b^2 + N_c^2}{1303.8}$$

$$Pba = (Ca)^2 * \frac{Wm}{10858 * A}$$

$$Pbb = (Cb)^2 * \frac{Wm}{10858 * A}$$

$$P_{ca} = Cpa - Pba$$

$$P_{cb} = Cpb - Pbb$$

$$M = \frac{\log\left(\frac{P_{ca}}{P_{cb}}\right)}{\log\left(\frac{Ca}{Cb}\right)}$$

$$P_{iopt} = 2 * \frac{P_{max}}{M + 1}$$

$$P_{hopt} = 2 * \frac{P_{max}}{P_{max} + 1}$$

$$Pilb = \left(\frac{P_{iopt}}{P_{max}}\right)^{1+M} * Ca$$

$$Phlb = \left(\frac{P_{hopt}}{P_{max}}\right)^{1+M} * Ca$$

$$Q_{iopt} = P_{max} - P_{iopt}$$

$$Q_{hopt} = P_{max} - P_{hopt}$$

$$A_{in} = \left(Q_{iopt}^2 * \frac{Wm}{10858 * P_{max}}\right)^{0.5}$$

$$A_{hn} = \left(Q_{hopt}^2 * \frac{Wm}{10858 * P_{max}}\right)^{0.5}$$

$$A_n = d * \left(\frac{A}{n * 0.7854}\right)^{0.5}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 166.*

2.20 Borehole torsion—Cylindrical helical method

Input(s)

k_h: Horizontal Curvature (degree/100ft)
k_v: Vertical Curvature (degree/100ft)
k: Curvature of Wellbore Trajectory (degree/100ft)
a: Inclination Angle (degree)

Output(s)

t: Borehole Torsion—Cylindrical Helical Method (degree/100ft)

Formula(s)

$$t = k_h * \left(1 + \left(2 * \frac{(k_v)^2}{k^2}\right)\right) * \sin(a) * \cos(a)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 84.*

2.21 Bottomhole annulus pressure

Input(s)

ρ_a: Annulus Fluid Density (ppg)
D_{av}: Vertical Height in the Annulus (ft)

Output(s)

P_{bh}: Annulus Pressure (psi)

Formula(s)

$$P_{bh} = 0.052 * (\rho_a) * (D_{av})$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 134.*

2.22 Bottomhole assembly length required for a desired weight on bit

Input(s)

W_b: Desired Weight to be used while Drilling (lb)
f: Safety Factor (fraction)
W_d: Drill Collar Weight (lb/ft)
BF: Buoyancy Factor (unitless)

Output(s)

L: Length of Bottomhole Assembly (ft)

Formula(s)

$$L = \frac{W_b * f}{W_d * BF}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 42.*

2.23 Bulk density of cuttings—Using the mud balance

Input(s)

W_r: Resulting Mud Weight with Cuttings and Water (ppg)

Output(s)

SG_c: Specific Gravity (Average Bulk Density) of Cuttings (gm/cm^3)

Formula(s)

$$SG_c = \frac{1}{2 - (0.12 * W_r)}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 21.*

2.24 Bulk modulus using Poisson's ratio and Young's modulus

Input(s)

E: Young's Modulus (N/m^2)
μ: Poisson's Ratio (dimensionless)

Output(s)

K: Bulk Modulus (N/m^2)

Formula(s)

$$K = \frac{E}{3 * (1 - 2 * \mu)}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs.* SPE *Textbook Series Vol. 4. Chapter 3, Page: 46.*

2.25 Buoyancy weight

Input(s)

ρ_m: Density of Mud (ppg)
ρ_s: Density of Pipe Material (ppg)
d: Depth (ft)
m: Weight (ppf)

Output(s)

B: Buoyancy Factor (fraction)
W: Buoyancy Weight (lbf)

Formula(s)

$$B = \left(1 - \left(\frac{\rho_m}{\rho_s}\right)\right)$$

$$W = B * m * d$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 20.*

2.26 Buoyancy factor

Input(s)

MW: Mud Weight (ppg)

Output(s)

BF: Buoyancy Factor (ppg)

Formula(s)

$$BF = \frac{65.5 - MW}{65.5}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 20.*

2.27 Buoyancy factor using mud weight

Input(s)

MW: Mud Weight (ppg)
65.5: Weight of Steel (Plain Carbon Steel 1020 (AISI and SAE) = 7.86 gm/cm3 (ppg)

Output(s)

BF: Buoyancy Factor (fraction)

Formula(s)

$$BF = \frac{65.5 - MW}{65.5}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 24.*

2.28 Calculations for the number of feet to be cemented

Input(s)

H: Hole Size (in.)
OD: Outer Diameter (in.)
ID: Inner Diameter (in.)
N_s: Number of Sacks of Cement to be Used (sacks)
Y_s: Slurry Yield (ft^3/stroke)
h_c: Feet of Casing (ft)
h_{sd}: Setting Depth of Cementing Tool or Feet of Drill Pipe (ft)
DC: Drill Pipe Capacity (bbl/stroke)
E: Original+extra Volume Req in Percentage (fraction)
PO: Pump Output (bbl/stroke)

Output(s)

AC: Annular Capacity (ft^3/ft)
CC * *: Casing Capacity (ft^3/ft)
C_c: Casing Capacity (ft^3)
V_s: Volume of Slurry (ft^3)
h_a: Height of Cement in Annulus (ft)
h_{tc}: Depth of Top of Cement in Annulus (ft^3/stroke)
N_m: Number of Barrels of Mud Required to Displace the Cement (bbl)
S: Number of Strokes Required to Displace the Cement (Strokes)

Formula(s)

$$AC = \frac{H^2 - OD^2}{183.35}$$

$$CC = \frac{(ID)^2}{183.35}$$

$$C_c = N_s * Y_s$$

$$V_s = (h_c - h_{sd}) * CC$$

$$h_a = \frac{(V_s - C_c)}{\frac{AC}{E}}$$

$$h_{tc} = h_c - h_a$$

$$N_m = h_{sd} * DC$$

$$S = \frac{N_m}{PO}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 57.*

2.29 Calculations required for spotting pills

Input(s)

hd: Diameter of Hole (in.)
pd: Diameter of Drill Pipe (in.)
cd: Diameter of Drill Collar (in.)
L_s: Length of Section (ft)
L_e: Length Above the Collar (ft)
WF: Washout Factor (fraction)
V_{ds}: Volume Left in Drill String (bbl)
C_{dc}: Drill Collar Capacity (bbl/ft)
C_{dp}: Drill Pipe Capacity (bbl/ft)
L: Length (ft)
PO: Pump Output (bbl/stroke)
S_{ds}: Strokes of Drill Pipe (fraction)

Output(s)

AC_{dc}: Annular Capacity of Drill Collar (bbl/ft)

AC_{dp}: Annular Capacity of Drill Pipe (bbl/ft)
V_{dc}: Volume in Drill Collar (bbl)
V_{dp}: Volume in Drill Pipe (bbl)
V_a: Volume of Pill Required in Annulus (bbl)
V_{ts}: Total Volume of Pill Required (bbl)
C_t: Total Capacity of Drill String (bbl)
S_{pp}: Strokes for Pump Pill (no.)
V_{cp}: Volume Req for Chase Pill (bbl)
S_{cp}: Strokes for Chase Pill (no.)
S_t: Total Strokes to Spot the Pill (no.)

Formula(s)

$$AC_{dc} = \frac{(hd)^2 - (cd)^2}{1029.4}$$

$$AC_{dp} = \frac{(hd)^2 - (pd)^2}{1029.4}$$

$$V_{dc} = AC_{dc} * L_s * WF$$

$$V_{dp} = AC_{dp} * L_e * WF$$

$$V_a = V_{dc} + V_{dp}$$

$$V_{ts} = V_a + V_{ds}$$

$$C_t = (C_{dc}) * L_s + \left(C_{dp}\right) * L$$

$$S_{pp} = \frac{V_{ts}}{PO}$$

$$V_{cp} = C_t - V_{ds}$$

$$S_{cp} = \left(\frac{V_{cp}}{PO}\right) + S_{ds}$$

$$S_t = \left(S_{pp}\right) + \left(S_{cp}\right)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishin, Page: 75.*

2.30 Capacity formulas—bbl/ft

Input(s)

d_h: Inside Diameter of Casing (in.)
d_p: Outside Diameter of Casing (in.)

Output(s)

AC: Annular Capacity (bbl/ft)

Formula(s)

$$AC = \frac{d_h^2 - d_p^2}{1029.4}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Work-over, Second Edition, Gulf Professional Publishing, Page: 12.*

2.31 Capacity formulas—gal/ft

Input(s)

d_h: Inside Diameter of Casing (in.)
d_p: Outside Diameter of Casing (in.)

Output(s)

AC: Annular Capacity (gal/ft)

Formula(s)

$$AC = \frac{d_h^2 - d_p^2}{24.51}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 12.*

2.32 Capacity of tubulars and open-hole

Input(s)

D_i: Inner Diameter (in.)

Output(s)

C: Capacity of any Cylindrical Object (drillpipe, drill collars, tubing, casing, openhole) (bbl/ft)

Formula(s)

$$C = \frac{D_i^2}{1029.4}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition Gulf Professional, Publishing, Page: 16.*

2.33 CO_2 solubility in oil and oil-mud emulsifiers

Input(s)

p: Pressure (psi)
a: Solubility Equation Constant (dimensionless)
b: Solubility Equation Constant (dimensionless)
c: Solubility Equation Constant (dimensionless)

Output(s)

$dr_{s(CO_2)}$: CO2 Solubility in Oil and Oil-Mud Emulsifiers (SCF/bbl)

Formula(s)

$$dr_{s(CO_2)} = \left(\frac{p}{aT^b}\right)^c$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 16.*

2.34 Combined solubility—Hydrocarbon gas, CO_2, and H_2S—in each of the mud components

Input(s)

f_h: Mole Fraction of Hydrocarbon Gas (dimensionless)
f_{CO_2}: Mole Fraction of Carbon Dioxide (dimensionless)
f_{H_2S}: Mole Fraction of Hydrogen Sulphure (dimensionless)
r_{sh}: Solubility of Hydrocarbon Gas (SCF/bbl)
r_{sCO_2}: Solubility of Carbon Dioxide (SCF/bbl)
r_{sH_2S}: Solubility of Hydrogen Sulphure (SCF/bbl)

Output(s)

$dr_{s(o,w,e)}$: Combined Solubility of Hydrocarbon Gas, CO_2 and H_2S (SCF/bbl)

Formula(s)

$$r_{s(o,\,e)} = f_h r_{sh} + f_{CO_2} r_{sCO_2} + f_{H_2S} r_{sH_2S}$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 16.*

2.35 Control drilling—Maximum drilling rate

Input(s)

q: Circulation Rate (gpm)
D_h: Hole Diameter (in.)
MW_o: Mud Wt. out (ppg)
MW_i: Mud Wt. in (ppg)

Output(s)

MDR: Maximum Drilling Rate (ft/h)

Formula(s)

$$MDR = 67 * (MW_o - MW_i) * \frac{q}{(D_h)^2}$$

Notes: The formula is valid when drilling in large diameter holes (14 3/4 in. and Larger).

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 24.*

2.36 Conversion of pressure into the mud weight

Input(s)

TVD: True Vertical Depth (ft)
P: Hydrostatic Pressure (psi)

Output(s)

M_w: Mud Weight (ppg)

Formula(s)

$$M_w = \frac{P}{0.052 * TVD}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 4.*

2.37 Cost per foot during drilling

Input(s)

C_b: Bit Cost ($)
C_{to}: Tool Cost ($)
C_m: Mud Cost ($)
T_d: Drilling Time (h)
T_t: Trip Time (h)
T_c: Connection Time and Extras (h)
C_r: Rig Rate ($/h)
C_s: Support Rate ($/h)
C_t: Tool Rental Rate ($/h)
F: Footage (ft/h)
T_d: Drilling Time (h)

Output(s)

C_d: Cost of Drilling Per Foot ($/h)

Formula(s)

$$C_d = \frac{C_b + C_{to} + C_m + (T_d + T_t + T_c) * (C_r + C_s + C_t)}{F * T_d}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 468.*

2.38 Cost per foot of coring

Input(s)

C_b: Core Bit Cost ($)
C: Rig Cost ($)
T_d: Total Coring Time (h)
T_t: Trip Time (h)
T_r: Core Recovery Time (h)
F: Footage Cored (ft)
R_c: Core Recovery Percentage (fraction)

Output(s)

C: Cost per Foot of Coring ($/ft)

Formula(s)

$$C = \frac{C_b + C_r * (T_d + T_t + T_r)}{F * R_c}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 469.*

2.39 Critical annular velocity and critical flow rate

Input(s)

$\theta600$: 600 Viscometer Dial Reading (dimensionless)
$\theta300$: 300 Viscometer Dial Reading (dimensionless)
Dh: Diameter of Hole (in.)
Dp: Diameter of Drill Pipe (in.)
MW: Mud Weight in Use (ppg)

Output(s)

n: Power Constant (dimensionless)
K: Constant (dimensionless)
x: Constant (dimensionless)
AVc: Critical Annular Velocity (ppg)
GPMc: Critical Flow Rate (ppg)

Formula(s)

$$n = 3.32 * \log\left(\frac{\theta 600}{\theta 300}\right)$$

$$K = \frac{\theta 600}{1022^{n}}$$

$$x = 81600 * K * \frac{(n)^{0.387}}{((Dh - Dp)^{n}) * MW}$$

$$AVc = x^{\frac{1}{2-(n)}}$$

$$GPMc = AVc * \frac{Dh^2 - Dp^2}{24.5}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 212.*

2.40 Critical flow rate for flow regime change

Input(s)

V_c: Critical Velocity (ft/s)
D_i: Integral Diameter of Pipe (in.)

Output(s)

Q_c: Critical Flow Rate (gpm)

Formula(s)

$$Q_c = 2.448 * V_c * \left(D_i^2\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 220.*

2.41 Critical velocity for change in flow regime

Input(s)

PV: Plastic Viscosity (cP)
YP: Yield Stress or Yield Point (lb/100 ft^2)
ρ_m: Mud Density (ppg)
D_i: inside Diameter of Pipe (in.)

Output(s)

V_c: Critical Velocity (ft/s)

Formula(s)

$$V_c = \frac{(1.08 * PV) + \left(1.08 * \left(PV^2 + 12.34 * \rho_m * \left(D_i^2\right) * YP\right)^{0.5}\right)}{\rho_m * D_i}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 220.*

2.42 Crown block capacity

Input(s)

H_l: Net Static Hook Load Capacity (lb)
S: Effective Weight of Suspended Equipment (lb)
n: No. of Lines Strung to the Traveling Block (unitless)

Output(s)

R_c: Crown Block Capacity (lb)

Formula(s)

$$R_c = \frac{(H_l + S) * (n + 2)}{n}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 26.*

2.43 Current drag force—Offshore

Input(s)

g: Acceleration due to Gravity (ft/s^2)
V_c: Current Velocity (ft/s)
C_s: Drag Coefficient (dimensionless)
A: Area (ft^2)

Output(s)

F: Current Force (lbf)

Formula(s)

$$F = g * \left(V_c^2\right) * C_s * A$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 37.*

2.44 Curvature radius for a borehole

Input(s)

C: Constant Related to the Unit of Borehole Curvature (unitless)
k: Curbature of Wellbore Trajectory (degree/100ft)

Output(s)

R: Curvature Radius of Borehole (ft)

Formula(s)

$$R = \frac{180 * (C)}{3.1415 * k}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 77.*

2.45 Cutting slip velocity

Input(s)

PV: Plastic Viscosity (cP)
MW: Mud Weight (ppg)
Dp: Diameter of Particle (in.)
DenP: Density of Particle (ppg)

Output(s)

V_s: Slip Velocity (ft/min)

Formula(s)

$$V_s = 0.45 * \left(\frac{PV}{MW * Dp}\right) * \left(\left(\left(\left(\frac{36800}{\left(\frac{PV}{MW * Dp}\right)^2}\right) * Dp * \left(\frac{DenP}{MW} - 1\right)\right) + 1^{-1}\right)^{0.5}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition Gulf Professional, Publishing, Page: 176.*

2.46 Cuttings produced per foot of hole drilled—bbls

Input(s)

D_h: Diameter of Bit or Hole Size (Plus Washout) (in.)
Ø: Porosity (fraction)

Output(s)

V_c: Amount of Cuttings Produced per each Foot of Hole Drilled (bbls)

Formula(s)

$$V_c = \frac{D_h^2}{1029.4} * (1 - Ø)$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 18.*

2.47 Cuttings produced per foot of hole drilled—lbs

Input(s)

C_a: Capacity of Hole (bbl/ft)
L_d: Footage Drilled (ft)
SG: Specific Gravity of Cuttings (fraction)
Ø: Porosity (fraction)

Output(s)

W_{cg}: Amount of Cuttings Produced per each Foot of Hole Drilled (lb)

Formula(s)

$$W_{cg} = 350 * (C_a) * (L_d) * (1 - Ø) * SG$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 19.*

2.48 D—Exponent

Input(s)

d: Penetration Rate (ft/h)
N: Rotary Speed (rpm)
W: Weight on Bit in 1000lb (lb)
D: Bit Size (in.)

Output(s)

d: D Exponent (dimensionless)

Formula(s)

$$d = \frac{\log\left(\frac{R}{60 * N}\right)}{\log\left(\frac{12 * W}{1000 * D}\right)}$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover Third Edition Gulf Professional Publishing, Page: 214.*

2.49 Depth of a washout—Method 1

Input(s)

N_s: Number of Strokes Required (unitless)
P_o: Pump Output per Stroke (bbl/stroke)
C_p: Drillpipe Capacity (bbl/ft)

Output(s)

D_w: Depth of Washout (ft)

Formula(s)

$$D_w = N_s * \frac{P_o}{C_p}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition Gulf Professional, Publishing, Page: 70.*

2.50 Depth of a washout—Method 2

Input(s)

N_s: Number of Strokes Required (unitless)
P_o: Pump Output per Stroke (bbl/stroke)
C_p: Drillpipe Capacity (bbl/ft)
C_a: Annular Capacity (bbl/ft)

Output(s)

D_w: Depth of Washout (ft)

Formula(s)

$$D_w = N_s * \frac{P_o}{C_p + C_a}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition Gulf Professional, Publishing, Page: 70.*

2.51 Derrick efficiency factor

Input(s)

E: Power Efficiency (per cent)
n: Number of Lines strung between crown block and travelling block (dimensionless)

Output(s)

E_d: Derrick Efficiency Factor (per cent)

Formula(s)

$$E_d = \frac{\left(\frac{1+E+En}{En}\right)W}{\left(\frac{n+4}{n}\right)W}$$

Reference: *Bourgoyne, A. T., Millheim, K. K., Chenevert, M. E., & Young, F. S. (1986). Applied Drilling Engineering, Page: 10.*

2.52 Difference in pressure gradient between the cement and mud

Input(s)

W_c: Cement Weight (ppg)
W_m: Mud Weight (ppg)

Output(s)

PG: Pressure Gradient between Cement and Mud (psi/ft)

Formula(s)

$$PG = (W_c - W_m) * 0.052$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition Gulf Professional, Publishing, Page: 66.*

2.53 Differential hydrostatic pressure between cement in the annulus and mud inside the casing

Input(s)

h_w: Well Depth (ft)
h_f: Float Collar (Feet Number Above the Shoe) (ft)
h_l: Lead Slurry Depth (ft)
h_t: Tail Slurry Depth (ft)
w_m: Mud Weight (lb/gal)
w_l: Lead Slurry Weight (lb/gal)
w_t: Tail Slurry Weight (lb/gal)

Output(s)

P_a: Total Pressure in Annulus (psi)
P_c: Total Pressure in Casing (psi)
P_d: Total Pressure Differential (psi)

Formula(s)

$$P_a = 0.052 * (w_l * h_l + w_t * h_t + w_m * (h_w - h_l - h_t))$$
$$P_c = 0.052 * (w_m * (h_w - h_f) + w_t * h_f)$$
$$P_d = P_a - P_c$$

Reference: *Lyons, W. C., Carter, T., and Lapeyrouse, N. J., 2012, Formulas and Calculations for Drilling, Production and Workover, Third Edition, Gulf Professional Publishing, Page: 84.*

2.54 Dilution of a mud system

Input(s)

V_m: Mud in Circulation System (bbl)
F_{ct}: Per cent of Low Gravity Solids in System (per cent)
F_{cop}: Per cent of Total Optimumlow Gravity Solids (per cent)
F_{ca}: Per cent of Low Gravity Solids (Bentonite and or Chemicals Added) (per cent)

Output(s)

V_{wm}: Dilution Water or Mud Required (bbl)

Formula(s)

$$V_{wm} = \frac{V_m * \left(F_{ct} - F_{cop}\right)}{F_{cop} - F_{ca}}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 96.*

2.55 Direction of dip

Input(s)

h: Height of Fracture (ft)
d:D iameter of Well (ft)

Output(s)

D: Dip Direction (radian)

Formula(s)

$$D = \operatorname{atan}\left(\frac{h}{d}\right)$$

Reference: *Wikipedia.org*.

2.56 Directional curvature for a deviated well

Input(s)

$\partial\,Ø$: Directional Change (degree)
∂L: Course Length (ft)

Output(s)

DC: Directional Curvature (degree/ft)

Formula(s)

$$DC = (\partial Ø) * \frac{100}{\partial L}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 84.*

2.57 Downward force or weight of casing

Input(s)

W: Casing Weight (lb/ft)
L: Length of Casing (ft)
BF: Buoyancy Factor (unitless)

Output(s)

W_d: Downward Force of Casing (lb)

Formula(s)

$$W_d = W * L * BF$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition Gulf Professional, Publishing, Page: 67.*

2.58 Drill pipe or drill collar capacity

Input(s)

ID: Inner Diameter (in.)

Output(s)

C: Drill Collar Capacity (bbl/ft)

Formula(s)

$$C = \frac{ID^2}{1029.4}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, second edition, Gulf Professional Publishing, Page: 25.*

2.59 Drill pipe or drill collar displacement and weight

Input(s)

ID: Inner Diameter (in.)
OD: Outer Diameter (in.)

Output(s)

Disp: Drill Pipe/drill Collar Displacement (bbl/ft)
W: Drill Pipe/drill Collar Weight (lb/bbl)

Formula(s)

$$Disp = \frac{OD^2 - ID^2}{1029.4}$$

$$W = Disp * 2747$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, second edition, Gulf Professional Publishing, Page: 25.*

2.60 Drill string design—Drill pipe length for bottomhole assembly

Input(s)

BF: Buoyancy Factor (dimensionless)
T: Tensile Strength for New Pipe (lb)
f: Safety Factor to Correct New Pipe to No. 2 Pipe Equal to 1-safety Factor of Pipe (fraction)
MOP: Margin of Overpull (lb)
W_{bha}: Bha Weight in Air (lb)
W_{dp}: Drill Pipe Wt in Air including Tool Joint (lb)
BHA_l: Length of Bore Hole Assembly (dimensionless)

Output(s)

L_{max}: Drill Pipe Length for a Specific Bore Hole Assembly (fraction)
$Depth_t$: Total Depth That Can be Reached with a Specific Bottomhole Assembly (ft)

Formula(s)

$$L_{max} = \frac{65.5 - MW}{65.5}$$

$$Depth_t = [(T * f) - MOP - W_{bha}] * \left(\frac{BF}{W_{dp}}\right)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, second edition, Gulf Professional Publishing, Page: 43.*

2.61 Drilled gas entry rate

Input(s)

d_b: Bit Diameter (in.)
R: Penetration Rate (ft/h)
S_g: Gas Saturation (fraction)
Ø: Formation Porosity (per cent)
p: Pressure (psi)
z: Gas Compressibility Factor (dimensionless)
t: time (h)

Output(s)

q_{gsc}: Drilled Gas Entry Rate (SCF/min)

Formula(s)

$$q_{gsc} = \frac{d_b^2 R Ø S_g p}{310\, zT}$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers., Page: 19.*

2.62 Drilling cost per foot

Input(s)

B: Bit Cost ($)
C_R: Rig Cost ($)
T: Rotating Time (spm)
t: Round Trip Time (spm)
F:F ootage per Bit (ft)

Output(s)

C_T:Drilling Cost ($)

Formula(s)

$$C_T = \frac{B + C_R * (t + T)}{F}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 28.*

2.63 Drilling ton miles—Coring operation ton miles

Input(s)

T_4: Ton Miles for One Round Trip-depth Where Coring Stopped Before Coming out of Hole (ton miles)
T_3: Ton-miles for One Round Trip-depth Where Coring Started After Going in Hole (ton miles)

Output(s)

T_c: Coring Operation Ton Miles (ton miles)

Formula(s)

$$T_c = 2 * (T_4 - T_3)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 46.*

2.64 Drilling ton miles—Drilling/connection ton miles

Input(s)

T_2: Ton Miles for One Round Trip-Depth Where Drilling Stopped Before Coming out of Hole (ton miles)
T_1: Ton-miles for One Round Trip-Depth Where Drilling Started (ton miles)

Output(s)

T_D: Drilling/connection Ton Miles (ton miles)

Formula(s)

$$T_D = 3 * (T_2 - T_1)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, second edition, Gulf Professional Publishing, Page: 46.*

2.65 Drilling ton miles—Round trip ton miles

Input(s)

W_p: Buoyed Weight of Drill Pipe (lb/ft)
D: Depth of Hole (ft)
L_p: Length of One Stand of Drill Pipe (ft)
W_b: Weight of Travelling Block (lb)
Wdc: Weight of Drill Collar Per Feet (lb/ft)

Wdp: Drill Pipe Weight Per Feet (lb/ft)
L: Drill Collar Length (ft)
BF: Buoyancy Factor (dimensionless)

Output(s)

W_c: Buoyed Weight of Drill Collars-buoyed Weight of Drill Pipe (lb)
RT_{TM}: Round Trip Ton Miles (ton miles)

Formula(s)

$$W_c = L * BF * (Wdc - Wdp)$$

$$RT_{TM} = \frac{W_p * D * \left(L_p + D\right) + (2 * D) * (2 * W_b + W_c)}{5280 * 2000}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 44.*

2.66 Drilling ton miles—While making short trip ton miles

Input(s)

T_6: Ton Miles for One Round Trip-at the Deeper Depth, the Depth of the Bit Before Starting Short Trip (ton miles)
T_5: Ton-miles for One Round Trip-at Shallower Depth,the Depth that the Bit is Pulled up to (ton miles)

Output(s)

T_{ST}: Short Trip Ton Miles (ton miles)

Formula(s)

$$T_{ST} = (T_6 - T_5)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 47.*

2.67 Drilling ton miles—Setting casing ton miles

Input(s)

W_p: Buoyed Weight of Casing (lb/ft)
L_{cs}: Length of One Joint of Casing (ft)
D: Depth of the Setting (ft)
W_b: Weight of Travelling Block Assembly (lb)

Output(s)

T_c: Setting Casing Ton Miles (ton miles)

Formula(s)

$$T_c = \left(W_p * D * (L_{cs} + D) + D * W_b\right) * \frac{0.5}{5280 * 2000}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 47.*

2.68 Duplex pump factor

Input(s)

D_L: Piston Diameter (in.)
D_r: Rod Diameter (in.)
L_S: Stroke Length (in.)

Output(s)

PF_d: Duplex Pump Factor (bbl/stroke)

Formula(s)

$$PF_d = \frac{3.1415 * L_S * \left(\left(2 * D_L^2\right) - D_r^2\right)}{2 * 9702}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 84.*

2.69 Duplex pump output—Using liner diameter

Input(s)

d_I: Liner Diameter (in.)
l_s: Stroke Length (in.)

Output(s)

q_o: Pump Output (bbl/stroke)

Formula(s)

$$q_o = 0.000324 * \left(d_l^2\right) * (l_s)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 8.*

2.70 Duplex pump output—Using rod diameter

Input(s)

d_r: Rod Diameter (in.)
l_s: Stroke Length (in.)

Output(s)

q_o: Pump Output (bbl/stroke)

Formula(s)

$$q_o = 0.000162 * (d_r^2) * l_s$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 8.*

2.71 Duplex pump output by using liner and rod diameters

Input(s)

d_l: Liner Diameter (in.)
d_r: Rod Diameter (in.)
l_s: Stroke Length (in.)

Output(s)

q_o:Pump Output (bbl/stroke)

Formula(s)

$$q_o = 0.000162 * l_s * \left(\left(2 * \left(d_l^2\right)\right) - \left(d_r^2\right)\right)$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 9.*

2.72 Dynamically coupled linear flow—Formation invasion

Input(s)

x_f: Transient Invasion Front (in.)
$x_{f,\ o}$: Initial Displacement, i.e., Spurt (in.)
L: Lineal Core Length (in.)
p_m: Constant Mud Pressure (psi)
p_r: Constant Reservoir Pressure (psi)
$Ø_{eff}$: Effective Rock Porosity (fraction)
$Ø_c$: Mudcake Porosity (fraction)
k_1: Mudcake Permeability to Filtrate (mD)
k_2: Rock Permeability to Filtrate (mD)
k_3: Rock Permeability to "Oil" (mD)
μ_f: Mud Filtrate Viscosity (cP)
μ_o: Viscosity of "Oil" or Formation Fluid (cP)
f_s: Mud Solid Fraction (fraction)

Output(s)

$x_f(t)$: Minimum Number of Jobs to Survive in a Minimum Chance Scenario (dimensionless)

Formula(s)

$$x_f(t) = -H + \sqrt{\left\{H^2 + 2\left(Hx_{f,o} + ½\, x_{f,o}{}^2 + Gt\right)\right\}}$$

$$G = -\left\{k_1(p_m - p_r)/\mu_f Ø_{eff}\right\} \Big/ \left\{\frac{\mu_o k_1}{\mu_f k_3} - \frac{k_1}{k_2} - \frac{Ø_{eff} f_s}{\{(1-Ø_c)(1-f_s)\}}\right\}$$

$$H = \left[\frac{x_{f,o} Ø_{eff} f_s}{\{(1-Ø_c)(1-f_s)\}} - \frac{\mu_o k_1 L}{\mu_f k_3}\right] \Big/ \left\{\frac{\mu_o k_1}{\mu_f k_3} - \frac{k_1}{k_2} - \frac{Ø_{eff} f_s}{\{(1-Ø_c)(1-f_s)\}}\right\}$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 16.*

2.73 Effective weight during drilling

Input(s)

w_s: Weight of Drillstring Material (lbs)
ρ_o: Density of Mud (ppg)
ρ_s: Density of Drillstring Material (ppg)

Output(s)

w_o: Effective Weight (lbs)

Formula(s)

$$w_o = w_s * \left(1 - \left(\frac{\rho_o}{\rho_s}\right)\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 26.*

2.74 Effective wellbore radius for finite-conductivity fractures

Input(s)

k_f: Fracture Conductivity (mD)
b_f: Fracture Width (ft)
k: Formation Conductivity (mD)
x_f: Fracture Half Length (ft)

Output(s)

F_{CD}: Dimensionless Fracture Conductivity (dimensionless)
r_w: Effective Wellbore Radius (ft)

Formula(s)

$$F_{CD} = \frac{k_f * b_f}{k * x_f}$$

$$r_w = 0.2807 * \frac{k_f * b_f}{k}$$

Notes: r_w is valid if $F_{CD} < 0.1$.

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma:PennWell Publishing Company. Chapter: 5, Page: 135.*

2.75 Effective wellbore radius in infinite-conductivity fractures

Input(s)

x_f: Fracture Half Length (ft)
L: Total Fracture Length (ft)

Output(s)

r_w: Effective Wellbore Radius (ft)
r_w: Effective Wellbore Radius (ft)

Formula(s)

$$r_w = \frac{L}{4}$$

$$r_w = \frac{x_f}{2}$$

Notes: Check Validity, for $\frac{x_f}{x_e} <= 0.30$ where x_e is Half Length of a Side of a Drainage Area Square.

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter:5, Page: 134.*

2.76 Efficiency of block and tackle system

Input(s)

F_h: Load Hoisted (lb)
v_t: Traveling Block Velocity (fpm)
F_f: Load in Fast Line (lb)
v_f: Fast Line Speed (fpm)

Output(s)

E: Efficiency (fraction)

Formula(s)

$$E = \frac{F_h * v_t}{F_f * v_f}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 10.*

2.77 Equivalent area of pipe subject to uniform axial force

Input(s)

A_b: Area of Body (in.^{2})
A_j: Area of Joint (in.^{2})
α: Length Factor for Pipe Body (fraction)

Output(s)

A_p:Area of Pipe (in.^{2})

Formula(s)

$$A_p = \frac{A_b * A_j}{\alpha * A_b * (1 - \alpha) * A_j}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 44.*

2.78 Equivalent circulating density

Input(s)

ρ_m: Mud Weight (ppg)
δP_a: Annulus Pressure Loss (psi)
L_t: True Vertical Depth (ft)

Output(s)

ECD: Equivalent Circulating Density (ppg) (ppg)

Formula(s)

$$ECD = \rho_m + \left(\frac{\delta P_a}{0.052 * L_t}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 258.*

2.79 Equivalent density of a wellbore fluid

Input(s)

M_w: Mud Weight (ppg)
TVD: True Vertical Depth (ft)
APL: Annular Pressure Loss (psi)

Output(s)

ECD: Equivalent Circulating Density (ppg)

Formula(s)

$$ECD = \frac{APL}{0.052 * TVD} + M_w$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 6.*

2.80 Equivalent formation water resistivity from SP log

Input(s)

R_{mfeq}: Equivalent Resistivity of Mud Filtrate (ohm m)
SSP: Static Spontaneous Potential (mV)
T: Temperature (F)

Output(s)

R_{weq}: Equivalent Formation Water Resistivity (ohm m)

Formula(s)

$$R_{weq} = (-61 + 0.133 * T) * \frac{R_{mfeq}}{10^{-\frac{SSP}{61 + 0.133*T}}}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 74.*

2.81 Equivalent mud weight—Deviated well

Input(s)

P_h: Pressure (psi)
D_h: Measured Depth (ft)
α: Deviation Angle (degree)

Output(s)

EMW: Equivalent Mud Weight (ppg)

Formula(s)

$$EMW = \frac{P_h}{0.052 * D_h * \cos(\alpha)}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 139.*

2.82 Equivalent mud weight—Vertical well

Input(s)

P_h: Pressure (psi)
L_{tvd}: True Vertical Depth (ft)

Output(s)

EMW: Equivalent Mud Weight (ppg)

Formula(s)

$$EMW = \frac{P_h}{0.052 * (L_{tvd})}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 139.*

2.83 Evaluation of centrifuge

Input(s)

MW: Mud Density into centrifuge (ppg)
QM: Mud Volume into centrifuge (gal/min)
PW: Dilution water density (ppg)
QW: Dilution Water volume (gal/min)
PU: Underflow Mud density (ppg)
PO: Overflow Mud Density (ppg)
CC: Clay content in mud (lb/bbl)
CD: Additive content in mud (lb/bbl)

Output(s)

QU: Underflow Mud Vol (gal/min)
FU: Fraction of old mud in underflow (fraction)
QC: Mass rate of Clay (lb/min)
QD: Mass rate of Additive (lb/min)
QP: Water flow rate into mixing pit (gal/min)
QB: Mass rate of API Barite (lb/min)

Formula(s)

$$QU = \frac{QM * (MW - PO) - QW * (PO - PW)}{PU - PO}$$

$$FU = \frac{35 - PU}{35 - MW + \frac{QW}{QM} * (35 - PW)}$$

$$QC = CC * \frac{QM - (QU * FU)}{42}$$

$$QD = CD * \frac{QM - (QU * FU)}{42}$$

$$QP = \frac{(QM * (35 - MW)) - (QU * (35 - PU)) - 0.6129 * QC - 0.6129 * QD}{35 - PW}$$

$$QB = \left(QM - QU - QP - \frac{QC}{21.7} - \frac{QD}{21.7} \right) * 35$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 99.*

2.84 Evaluation of hydrocyclone

Input(s)

MW: Average Density of discarded mud (ppg)
V: Volume of Slurry sample collected (quarts)
T: Time to collect slurry sample (s)

Output(s)

SF: Fraction percentage of solids (fraction)
MS: Mass rate of solids removed by one come of a hydroclone (lb/h)
WR: Volume of wate ejected by one cone of a hydroclone (gal/h)

Formula(s)

$$SF = \frac{MW - 8.33}{13.37}$$

$$\mathrm{MS} = 19530 * \mathrm{SF} * \frac{\mathrm{V}}{\mathrm{T}}$$

$$WR = 900 * (1 - SF) * \frac{V}{T}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 97.*

2.85 Fluid volume required to spot a plug

Input(s)

L_t: Length of Tubing or Pipe (ft)
L_p: Length of Plug (ft)
C_t: Tubing or Pipe Capacity (bbl/ft)
V_s: Spacer Volume behind Slurry (bbl)

Output(s)

V: Fluid Volume Required (bbl)

Formula(s)

$$V = \left(\left(L_t - L_p\right) * C_t\right) - V_s$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 62.*

2.86 Force applied to stretch material

Input(s)

A: Area (m^2)
E: Young (N/m^2)
L_a: New Length (m)
L_b: Old Length (m)

Output(s)

F: Force (N)

Formula(s)

$$F = A * E * \left(\frac{L_a - L_b}{L_b}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 350.*

2.87 Force exerted by the fluid on the solid surface of flow through an annulus

Input(s)

R: Radius (m)
K: Boltzmann Constant ($m^2\ kg\ s^{-2}\ K^{-1}$)
po: Pressure at initial point (Pa)
pL: Pressure at point L (Pa)

Output(s)

Fz: Force (Newton)

Formula(s)

$$Fz = \pi * R^2 * \left(1 - K^2\right) * (po - pL)$$

Reference: *Wikipedia.org*.

2.88 Friction factor in drill pipe

Input(s)

μ_s: Static Viscosity (cP)
σ: Normal Stess at Contact (psi)
k: Exponential Constant (dimensionless)
t: Average Contact Time (s)
V_t: Trip Speed (ft/s)
ω: Angular Speed (ft/s)

Output(s)

μ: Constant (dimensionless)

Formula(s)

$$\mu = \frac{\mu_s}{1 + \left(\frac{\mu_s * \sigma * \left(\left(V_t^2 + \omega^2 \right)^{0.5} \right)}{k * t} \right)}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 375.*

2.89 Front displacement of a particle in the reservoir—Formation invasion

Input(s)

x_o: Initial Marked Position (ft)
k: Permeability (mD)
μ: Viscosity (cP)
Ø: Porosity (fraction)
P_r: Constant "Reservoir" Pressure at x = L (psi)
P_l: Pressure at x = 0 location (psi)
t: time (days)
L: Length (ft)

Output(s)

$x(t)$: Front Displacement of an Initially Marked Particle in the Reservoir (ft)

Formula(s)

$$x(t) = x_o - \left(\frac{k}{\mu Ø} \right) \left(\frac{(P_r - P_l)t}{L} \right)$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 30.*

2.90 Gas migration velocity

Input(s)

Δp_{cs}: Pressure (psi)
g_m: Depth (ft)
Δt: Time over which the Rise in Casing Pressure Occurs (h)

Output(s)

v_{sl}: Gas Migration Velocity (ft/h)

Formula(s)

$$v_{sl} = \Delta p_{cs}/g_m \Delta t$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 12.*

2.91 Gas solubility in a mud system

Input(s)

f_o: Volume Fraction of Base Oil (fraction)
f_w: Volume Fraction of Water (fraction)
f_e: Volume Fraction of Emulsifier (fraction)
r_{so}: Solution Gas/Component Ratio of Base Oil (fraction)
r_{sw}: Solution Gas/Component Ratio of Water (fraction)
r_{se}: Solution Gas/Component Ratio of Emulsifier (fraction)

Output(s)

r_{sm}: Solution Gas/Component of the Mud (fraction)

Formula(s)

$$r_{sm} = f_o r_{so} + f_w r_{sw} + f_e r_{se}$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 16.*

2.92 Gas/mud ratio

Input(s)

d_b: Bit Diameter (in.)
R: Penetration Rate (ft/h)
S_g: Gas Saturation (fraction)
Ø: Formation Porosity (per cent)
p: Pressure (psi)
z: Gas Compressibility Factor (dimensionless)
t: time (h)
q_m: Mud Circulation Rate (bbl/min)

Output(s)

r_m: Gas/Mud Ratio (SCF/bbl)

Formula(s)

$$r_m = \frac{d_b^2 R Ø S_g p}{310\, zTq_m}$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 19.*

2.93 Gel strength—Optimal solid removal efficiency

Input(s)

V_s: Expected Drilled Solids in Drilling Fluid (fraction)
V_c: Drilled Solids in Discard (fraction)

Output(s)

η_{sr}: Optimal Solid Removal Efficiency (fraction)

Formula(s)

$$\eta_{rs} = 1 - \left(\frac{1 - V_s}{1 - V_s + \left(\frac{V_c}{V_s} \right)} \right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 192.*

2.94 Gel strength—Solid control efficiency

Input(s)

V_r: Fraction of the Solids Removed (unitless)
V_h: Hole Volume (BBL)
V_d: Volume of Solids Discarded (BBL)

Output(s)

$(\eta_s)ce$: Solid Control Efficiency (fraction)

Formula(s)

$$(\eta_s)ce = (V_r) * \frac{V_d}{V_h}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 191.*

2.95 Gel strength—Solids build-up in system

Input(s)

V_h: Hole Volume (BBL)
η_s: Solid Control Efficiency (fraction)

Output(s)

V_{sb}: Solids Build Up (BBL)

Formula(s)

$$V_{sb} = V_h * (1 - \eta_s)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 188.*

2.96 Height of cement in the annulus

Input(s)

V_s: Slurry Volume (ft^3)
C_c: Casing Capacity (ft^3/ft)
AC: Cement Remaining in Casing (ft^3)
E: Excess Volume (fraction)

Output(s)

H: Height of Cement in Annulus (ft)

Formula(s)

$$H = \frac{V_s - AC + C_c}{E}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 58.*

2.97 Hydraulic horsepower

Input(s)

q: Flow Rate (gpm)
P: Pressure (psi)

Output(s)

HHP: Hydraulic Horsepower (hp)

Formula(s)

$$HHP = \frac{q * P}{1714}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 46.*

2.98 Hydraulics analysis

Input(s)

N_1: Jet Size for nozzle 1 (in.)
N_2: Jet Size for nozzle 2 (in.)
N_3: Jet Sizefor nozzle 3 (in.)
Q: Circulation Rate (gpm)
Dh: Diameter of Hole (in.)
Dp: Dia of Drill Pipe (in.)
MW: Mud Weight (psi)
B: Bit Size (in.)
P_s: Surface pressure (psi)

Output(s)

AV: Annular Velocity (ft/min)
Pb: Bit Nozzle Pressure Loss (psi)
HHP: Hydraulic Horsepower at bit (hp)
HHPba: Power per unit area in sq inc (hp/in.^{2})
P_{psib}: Percentage pressure loss at bit (percent)
V_n: Jet Velocity (ft/s)
IFa: Impact force per unit area in sq inc (lb/in.^{2})

Formula(s)

$$AV = 24.5 * \frac{Q}{Dh^2 - Dp^2}$$

$$Pb = 156.5 * Q^2 * \frac{MW}{\left(N_1^2 + N_2^2 + N_3^2\right)^2}$$

$$HHP = P_s * \frac{Q}{1714}$$

$$HHPba = Q * Pb * \frac{1.27}{1714 * B^2}$$

$$P_{psib} = Pb * \frac{100}{P_s}$$

$$V_n = 417.2 * \frac{Q}{N_1^2 + N_2^2 + N_3^2}$$

$$IFa = MW * V_n * Q * \frac{1.27}{1930 * B^2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 170.*

2.99 Hydromechanical specific energy

Input(s)

WOB: Weight on Bit (lbf)
A_b: Area of Bit (ft^2)
N: Rotational Speedfor a Bit (ft/s)
η: Factor for Energy Reduction (dimensionless)
P_b: Presure Drop Across Bit (psi)
Q: Flow Rate (ft^3/s)
ROP: Rate of Penetration (s/ft)
T: Torque (lbf ft)

Output(s)

HMSE: Hydro Mechanical Specific Energy (lbf/ft^2)

Formula(s)

$$\mathrm{HMSE} = \left(\frac{\mathrm{WOB}}{\mathrm{A_b}}\right) + \left(\frac{120 * 3.142 * \mathrm{N} * \mathrm{T} + 1154 * \eta * \mathrm{P_b} * \mathrm{Q}}{\mathrm{A_b} * \mathrm{ROP}}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 415.*

2.100 Hydrostatic pulling

Input(s)

NS: Number of Stands Pulled (number)
Lavg: Average length per stand (ft)
PD: Pipe Displacement (bbl/ft)
mw: Mud Weight (ppg)
cc: Casing Capacity (bbl/ft)
pd: Pipe Disp. (bbl/ft)

Output(s)

BD: Barrel Displaced (bbl)
HP: Hydrostatic Pressure Decrease (Pulling Dry Pipe out of the Hole) (psi)

Formula(s)

$$BD = NS * Lavg * PD$$

$$HP = BD * 0.052 * \frac{mw}{cc - pd}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 20.*

2.101 Hydrostatic pulling wet pipe out of the hole

Input(s)

NS: Number of Stands Pulled (number)
Lavg: Average length per stand (ft)
mw: Mud Weight (ppg)
cc: Casing Capacity (bbl/ft)
pd: Pipe disp. (bbl/ft)
pc: Pipe capacity. (bbl/ft)

Output(s)

BD: Barrel Displaced (bbl)
HP: Hydrostatic Pressure Decrease (Pulling Wet Pipe out of the Hole) (psi)

Formula(s)

$$BD = NS * Lavg * (pd + pc)$$

$$HP = BD * 0.052 * \frac{mw}{cc - (pd + pc)}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 21.*

2.102 Hydrostatic pressure in annulus due to slug

Input(s)

V_a: Volume of Annulus (ft/bbl)
V_s: Volume of Slug (bbl)
W_s: Slug Weight (ppg)
W_m: Mud Weight (ppg)

Output(s)

P: Hydrostatic Pressure (psi)

Formula(s)

$$P = V_a * V_s * (W_s - W_m) * 0.052$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 36.*

2.103 Hydrostatic pressure decrease at total depth caused by gas-cut mud

Input(s)

MG: Mud Gradient (psi/ft)
C: Annular Volume (bbl/ft)
V: Pit Gain (bbl)

Output(s)

P: Reduction in Bottomhole Pressure (psi)

Formula(s)

$$P = \left(\frac{MG}{C}\right) * V$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 129.*

2.104 Impact force—Nozzle hydraulic analysis

Input(s)

MW: Mud Weight (ppg)
v_n: Jet Velocity (ft/s)
Q: Flowrate (gpm)

Output(s)

IF: Impact Force (lb)

Formula(s)

$$IF = (MW) * (v_n) * \frac{Q}{1930}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 170.*

2.105 Impringing jet

Input(s)

$\Psi 1$: Mass Rate Of Flow for stream (kg/s)
v1: Velocity of Stream (m/s)
θ: Angle of inclination of plate (rad)

Output(s)

$\Psi 2a$: Mass Rate Of Flow for stream 2a (kg/s)
$\Psi 2b$: Mass Rate Of Flow for stream 2b (kg/s)
v2a: Velocity of Stream 2a (m/s)
v2b: Velocity of Stream 2b (m/s)

Formula(s)

$$\Psi 2a = v1$$

$$\Psi 2b = v1$$

$$v2a = 0.5 * \Psi 1 * (1 + \cos(\theta))$$

$$v2b = \Psi 1 * (1 - \cos(\theta))$$

Reference: *Transport Phenomena, Second Edition, Bird, Page: 201.*

2.106 Increase mud density by barite

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt (ppg)

Output(s)

B: Sacks of barite required per 100 bbl (stroke/100bbl)

Formula(s)

$$B = 1470 * \frac{W_2 - W_1}{35 - W_2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 81.*

2.107 Increase mud density by calcium carbonate

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt (ppg)

Output(s)

B: Sacks of Calcium Carbonate required per 100 bbl (stroke/100bbl)

Formula(s)

$$B = 945 * \frac{W_2 - W_1}{22.5 - W_2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 82.*

2.108 Increase mud density by hematite

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)

Output(s)

B: Sacks of Hematite required per 100 bbl (stroke/100bbl)

Formula(s)

$$B = 1680 * \frac{W_2 - W_1}{40 - W_2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 84.*

2.109 Increase volume by barite

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)

Output(s)

V: Volume increase per 100 bbl (bbl/100bbl)

Formula(s)

$$V = 100 * \frac{W_2 - W_1}{35 - W_2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 82.*

2.110 Increase volume by calcium carbonate

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)

Output(s)

V: Volume increase per 100 bbl (bbl/100bbl)

Formula(s)

$$V = 100 * \frac{W_2 - W_1}{22.5 - W_2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 82.*

2.111 Increase volume by hematite

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)

Output(s)

V: Volume increase per 100 bbl (bbl/100bbl)

Formula(s)

$$V = 100 * \frac{W_2 - W_1}{40 - W_2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 82.*

2.112 Initial volume required to achieve a volume with barite

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)
V_f: Final Volume (ppg)

Output(s)

V_i: Starting Volume (bbl)

Formula(s)

$$V_i = V_f * \frac{35 - W_2}{35 - W_1}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 82.*

2.113 Initial volume required to achieve a volume with calcium carbonate

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)
V_f: Final Volume (ppg)

Output(s)

V_i: Starting Volume (bbl)

Formula(s)

$$V_i = V_f * \frac{22.5 - W_2}{22.5 - W_1}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 83.*

2.114 Initial volume required to achieve a volume with hematite

Input(s)

W_1: Initial Mud wt. (ppg)
W_2: Required mud wt. (ppg)
V_f: Final Volume (ppg)

Output(s)

V_i: Starting Volume (bbl)

Formula(s)

$$V_i = V_f * \frac{40 - W_2}{40 - W_1}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 84.*

2.115 Injection/casing pressure required to open valve

Input(s)

P_{bt}: Bellows or Dome Pressure at Valve Depth (psi)
P_2: Production or Tubing Pressure at Valve Depth (psi)
A_p: Area of Valve Port or Seat (in.^{2})
A_b: Area of Bellows (in.^{2})

Output(s)

P1: Injection/Casing Pressure Existing at the Valve Depth (psi)

Formula(s)

$$P1 = \frac{P_{bt} - \left(P_2 * \left(\frac{A_p}{A_b}\right)\right)}{1 - \left(\frac{A_p}{A_b}\right)}$$

Reference: *Beggs, H. D. 2003. Production Optimization using Nodal Analysis,* OGCI *and Petroskills Publications, Second Edition, Chapter 5, Page: 166.*

2.116 Input power of a pump—Using fuel consumption rate

Input(s)

Q_f: Rate of Fuel Consumption (lbm/h)
H: Fuel Heating Value (BTU/lb)

Output(s)

P_i: Input Power (hp)

Formula(s)

$$P_i = \frac{Q_f * H}{2545}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 6.*

2.117 Jet velocity—Nozzle hydraulic analysis

Input(s)

Q: Flow Rate (GPM)
F: Jet Size (1) (in.)
C: Jet Size (2) (in.)
B: Jet Size (3) (in.)

Output(s)

v_c: Jet Velocity (ft/s)

Formula(s)

$$v_c = \frac{417.2 * Q}{F^2 + C^2 + B^2}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 170.*

2.118 Kick analysis—Influx

Input(s)

SICP: Shut in Casing Pressure (psi)
SIDPP: Shut in Drill Pipe Pressure (psi)
h_i: Height of Influx (ft)
mw: Mud weight (ppg)

Output(s)

I: Influx (ppg)

Formula(s)

$$I = mw - \frac{SICP - SIDPP}{h_i * 0.052}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 127.*

2.119 Kick analysis—Formation pressure with well shut-in on a kick

Input(s)

SIDPP: Maximum allowable shut in casing pressure (psi)
mw: Mud weight (ppg)
h: Height (ft)

Output(s)

P_{fp}: Kick Analysis (Formation Pressure with well shut in on a kick) (psi)

Formula(s)

$$P_{fp} = SIDPP + (mw * 0.052 * h)$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 125.*

2.120 Kick analysis—Maximum pit gain from a gas kick in water-based mud

Input(s)

P: Formation Pressure (psi)
V: Pit Gain (bbl)
KWM: Kill weight mud (ppg)
C: Annular Capacity (bbl/ft)

Output(s)

MPG: Maximum pit gain resulting from a gas kick in a water-based mud (bbl)

Formula(s)

$$MPG = 4 * \left(P * V * \frac{C}{KWM}\right)^{0.5}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 127.*

2.121 Kick analysis—Maximum surface pressure from a gas kick in water-based mud

Input(s)

P: Formation Pressure (psi)
V: Pit Gain (bbl)
KWM: Kill weight mud (ppg)
C: Annular Capacity (bbl/ft)

Output(s)

MSP: Max surface pressure resulting from a gas kick in a water-based mud (psi)

Formula(s)

$$MSP = 0.2 * \left(P * V * \frac{KWM}{C}\right)^{0.5}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 129.*

2.122 Kick analysis—Shut-in drill pipe pressure

Input(s)

P_{fp}: Formation Pressure (psi)
mw: Mud weight (ppg)
h: height (ft)

Output(s)

SIDPP: Shut in Drill Pipe Pressure (psi)

Formula(s)

$$SIDPP = P_{fp} - (mw * 0.052 * h)$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 131.*

2.123 Kick analysis—Height of influx

Input(s)

PG: Pit Gain (bbl)
AC: Annular Capacity (bbl/ft)

Output(s)

h: Height of Influx (ft)

Formula(s)

$$h = \frac{PG}{AC}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 126.*

2.124 Kill weight mud determination—Moore equation

Input(s)

SIDPP: Shut-in Drill Pipe Pressure (psi)
OMW: Original Mud Weight (ppg)
TVD: True Vertical Depth (ft)

Output(s)

KWM: Kill Weight Mud (ppg)

Formula(s)

$$\mathrm{KWM} = \left(\frac{\mathrm{SIDPP}}{0.052 * (\mathrm{TVD})}\right) + (\mathrm{OMW})$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 131.*

2.125 Kinetic friction

Input(s)

μ_s: Static Viscosity (cP)
a: Constant of Friction in X Direction (dimensionless)
g: Acceleration Due to Gravity (ft/s^2)

Output(s)

φ: Angle of Friction (rad)
μ_k: Kinetic Viscosity (cP)

Formula(s)

$$\varphi = \tan(\mu_s)$$

$$\mu_k = \mu_s - \left(\frac{a}{g * \sin(\varphi)}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 375.*

2.126 Laser specific energy

Input(s)

P: Power intensity (w/ft^2)
t: Time (s)
T: Thermal Penetration Depth (ft)

Output(s)

LSE: Laser Specific Energy (W s/ft)

Formula(s)

$$\mathrm{LSE} = \frac{P * t}{T}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 415.*

2.127 Lateral load imposed on a casing centralizer—Cementing

Input(s)

m: Steel in Mud Buoyancy Factor (dimensionless)
W: Weight per foot of Casing (lbm)
L: Distance from Centralizer to next Lower Centralizer (ft)
θ: Borehole Angle (degree)
T: Tension (Pulling Force) due to casing below Centralizer (lbm)
δ: One-half the change in Angle between Centralizer and next Lower Centralizer (degrees)

Output(s)

F_L: Lateral Load, Casing Weight Component ± Tension Component (lbm)

Formula(s)

$$F_L = m \cdot W \cdot L \cdot \sin\theta \pm 2(T)\sin\delta$$

Reference: *Suman Jr, G. O., & Ellis, R. C. (1977). Cementing handbook. World Oil, Page: 44.*

2.128 Lateral load imposed on a casing centralizer with a dogleg—Cementing

Input(s)

m: Steel in Mud Buoyancy Factor (dimensionless)
W: Weight per foot of Casing (lbm)
L: Distance from Centralizer to next Lower Centralizer (ft)
θ: Borehole Angle (degree)
T: Tension (Pulling Force) due to casing below Centralizer (lbm)
δ: One-half the change in Angle between Centralizer and next Lower Centralizer (degrees/100 ft)

Output(s)

F_L: Lateral Load, Casing Weight Component ± Tension Component (lbm)

Formula(s)

$$F_L = m \cdot W \cdot L \cdot \sin\theta \pm 2(T)\sin\delta$$

$$\delta = \frac{Dogleg\left(\frac{degrees}{100ft}\right) \cdot Spacing(ft)}{200}$$

$$T = \sum m \cdot W \cdot L \cdot \cos\theta$$

Reference: *Suman Jr, G. O., & Ellis, R. C. (1977). Cementing handbook. World Oil, Page: 44.*

2.129 Linear annular capacity of pipe

Input(s)

D_h: Inside Diameter of Casing Against the Pipe (in.)
D_o: Outside Diameter of Pipe (in.)

Output(s)

C_o: Annular Linear Capacity of Pipe (bbl/ft)

Formula(s)

$$C_o = \frac{0.7854 * \left(\left((D_h)^2\right) - \left((D_o)^2\right)\right)}{808.5}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 44.*

2.130 Linear capacity of pipe

Input(s)

D_i: Inside Diameter of Pipe (in.)

Output(s)

C_i: Linear Capacity of Pipe (bbl/ft)

Formula(s)

$$C_i = \frac{0.7854 * \left((D_i)^2\right)}{808.5}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 44.*

2.131 Load to break cement bond—Cementing

Input(s)

S_c: Compressive Strength (psi)
d: Outside Diameter of Casing (in.)
H: Height of Cement Column (ft)

Output(s)

F: Force or Load to Break Cement Bond (lbm)

Formula(s)

$$F = 0.969 \cdot S_c \cdot d \cdot H$$

Reference: *Suman Jr, G. O., & Ellis, R. C. (1977). Cementing handbook. World Oil, Page: 6.*

2.132 Mass rate of flow through annulus

Input(s)

po: Pressure at initial point (Pa)
pL: Pressure at point L (Pa)
R: Radius (m)
ρ: Density (kg/m^3)
mu: Viscosity (kg/(ms))
L: Length (m)
K: Boltzmann Constant (m^2 kg s^{-2} K^{-1})

Output(s)

Ψ: Mass Rate of Flow (kg/s)

Formula(s)

$$\Psi = \frac{\pi * (po - pL) * R^4 * \rho}{8 * \mu * L} * \left(\left(1 - K^4\right) - \frac{\left(1 - K^2\right)^2}{\ln\left(\frac{1}{K}\right)} \right)$$

Reference: *Transport Phenomena, Second Edition, Bird, Chapter 2.*

2.133 Matching conditions at the cake-to-rock interface—Formation invasion

Input(s)

P_{i_wall}: Pressure value at Cake to Rock Interface (psi)
$P_{i_{wall-1}}$: Pressure value at previous grid of Cake to Rock Interface (psi)
$P_{i_{wall+1}}$: Pressure value at the following grid of Cake to Rock Interface (psi)
k_c: Permeability of the Mudcake (mD)
k_r: Permeability of the Rock (mD)

Output(s)

$(k_c + k_r)P_{i\_wall}$: Relationship for matching conditions at the Cake-to-Rock interface (mD psi)

Formula(s)

$$(k_c + k_r)P_{i\_wall} = k_c P_{i_{wall-1}} + k_r P_{i_{wall+1}}$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 147.*

2.134 Maximum allowable mud weight

Input(s)

mw: Mud weight (ppg)
tvd: True Vertical Depth of Casing Shoe (ft)
P_l: Leak-off Pressure (psi)

Output(s)

mw_{max}: Max Allowable Mud wt (ppg)

Formula(s)

$$mw_{max} = \frac{P_l}{0.052 * tvd} + mw$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 120.*

2.135 Maximum drilling rate—Larger holes

Input(s)

MW_o: Mud Weight out (ppg)
MW_i: Mud Weight in (ppg)
q_c: Circulation Rate (gpm)
D_h: Hole Size (in.)

Output(s)

MDR: Maximum Drilling Rate (ft/h)

Formula(s)

$$\mathrm{MDR} = \frac{67 * (\mathrm{MW_o} - \mathrm{MW_i}) * \mathrm{q_c}}{\mathrm{D_h^2}}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 19.*

2.136 Maximum equivalent derrick load

Input(s)

F_h: Load Hoisted (lb)
n: No. of Lines Strung Between Crown Block and Traveling Block (unitless)

Output(s)

F_{de}: Maximum Equivalent Derrick Load (lb)

Formula(s)

$$\mathrm{F_{de}} = \left(\frac{\mathrm{n}+4}{\mathrm{n}}\right) * \mathrm{F_h}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 11.*

2.137 Maximum length of a slanted well in a given reservoir thickness

Input(s)

h: Pay Zone Thickness (ft)
α: Angle of inclination of drilling (degrees)

Output(s)

L: Length of Slant Wellbore (ft)

Formula(s)

$$L = \frac{h}{\cos\left(\alpha * \frac{\pi}{180}\right)}$$

Reference: *Horizontal Well Technology, Joshi, Page: 96.*

2.138 Maximum length of drillpipe for a specific bottomhole assembly

Input(s)

T: Tensile Strength of Pipe (lb)
f: Safety Factor (unitless)
MOP: Margin of Overpull (unitless)
W_b: Weight of Bha in Air (lb/ft)
W_d: Weight of Drill Pipe in Air (lb/ft)
BF: Buoyancy Factor (unitless)

Output(s)

L_m: Maximum Length (ft)

Formula(s)

$$L_m = \frac{((T * f) - MOP - W_b) * BF}{W_d}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 43.*

2.139 Maximum recommended low-gravity solids

Input(s)

SF: Maximum Recommended Solids Fractions (% by vol)
MW: Mud Weight (ppg)

Output(s)

LGS: Maximum Recommended Lgs (% by vol)

Formula(s)

$$LGS = \left(\left(\frac{SF}{100}\right) - \left(0.3125 * \left(\left(\frac{MW}{8.33}\right) - 1\right)\right)\right) * 200$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 95.*

2.140 Maximum recommended solids fractions in drilling fluids

Input(s)

MW: Mud Weight (ppg)

Output(s)

SF: Maximum Recommended Solid Fraction (percent by volume)

Formula(s)

$$SF = (2.917 * MW) - 14.17$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 96.*

2.141 Maximum weight on bit

Input(s)

L_d: Length of Drill Collar (ft)
W_d: Unit Wight of Collar (lbf/ft)
SF: Safety Factor (dimensionless)
BF: Buoyancy Factor (dimensionless)
α: Wellbore Inclination (degree)

Output(s)

WOB: Maximum Weight on Bit (lbf)

Formula(s)

$$WOB = \frac{L_d * W_d * BF * \cos(\alpha)}{SF}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 380.*

2.142 Mechanical energy balance for wellbore fluids

Input(s)

p_1, p_2: Pressure at positions 1 and 2 (psi)
ρ_f: Fluid Density (lbm/ft^3)

g_c: Gravitational System Conversion Constant (32.17 (lbm/ft)/(lbf/s^2))
g: Acceleration of Gravity (ft/s^2)
Z_1, Z_2: Fluid elevation at Positions 1 and 2 (ft)
v_1, v_2: Fluid velocity at Positions 1 and 2 (ft/s)
E_l: Irreversible Energy Loss between Positions 1 and 2 (ft lbf/lbm)

Output(s)

W: Work done by the Fluid while in Flow (ft lbf/lbm)

Formula(s)

$$W = -\left[\int_{P_1}^{P_2} \frac{dp}{\rho_f} + \frac{g}{g_c}(Z_2 - Z_1) + \frac{\rho_f\left(v_2^2 - v_1^2\right)}{2g_c} + E_l\right]$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 8.*

2.143 Mechanical specific energy

Input(s)

WOB: Weight on Bit (lbf)
A_b: Area of Bit (in.^{2})
N: Rotational Speed of Bit (in./m)
T: Torque of Bit (lbf in.)
ROP: Rate of Penetration (m/in.)

Output(s)

MSE: Mechanical Specific Energy (lbf/in.^{2})

Formula(s)

$$\mathrm{MSE} = \left(\frac{\mathrm{WOB}}{\mathrm{A_b}}\right) + \left(\frac{120 * \pi * \mathrm{N} * \mathrm{T}}{\mathrm{A_b} * \mathrm{ROP}}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 414.*

2.144 Mud rheology—Herschel and Buckley law

Input(s)

τ_y: Yield Stress (lb/100 ft^2)
K: Consistency Index (lb/100 ft^2)
γ: Shear Rate (1/s)
n: Power Law Index, Slope of Plot Between Log Shear Stress and Log Shear Rate (dimensionless)

Output(s)

τ: Shear Stress (lb/100 ft^2)

Formula(s)

$$\tau = \tau_y + K * (\gamma^n)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 185.*

2.145 Mud rheology—Power-law model—Consistency index

Input(s)

θ_a: Fann Dial Reading at 300 Rpm (cP)
n: Power-Law index (dimensionless)

Output(s)

K: Consistency index (cP)

Formula(s)

$$K = \frac{510 * \theta_a}{511^n}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 194.*

2.146 Mud rheology—Power-law model—Power-law index

Input(s)

θ_a: Fann Dial Reading at 600 Rpm (cP)
θ_b: Fann Dial Reading at 300 Rpm (cP)

Output(s)

n: Power Law index (dimensionless)

Formula(s)

$$n = 3.322 * \log\left(\frac{\theta_b}{\theta_a}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 194.*

2.147 Mud rheology—Power-law

Input(s)

K: Consistency Index (cP)
n: Power-Law Index (fraction)
γ: Shear Rate (1/s)

Output(s)

τ: Shear Stress (lbf/100 ft^2)

Formula(s)

$$\tau = K * (\gamma^n)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 184.*

2.148 Mud rheology calculations—Bingham plastic model

Input(s)

τ_y: Yield Stress (lb/100 ft^2)
μ_p: Bingham Plastic Viscosity (cP)
γ: Shear Rate (1/s)

Output(s)

τ: Shear Stress (lb/100 ft^2)

Formula(s)

$$\tau = \tau_y + \left(\mu_p * \gamma\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 185.*

2.149 Mud weight increase required to balance pressure

Input(s)

F: Differential Force (lb)
A: Area Below Casing Shoe ($in.^2$)
L_c: Casing Length (ft)

Output(s)

W_m: Mud Weight increase Required (ppg)

Formula(s)

$$W_m = \frac{F}{A * 0.052 * L_c}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 67.*

2.150 Mud weight reduction by dilution—Water/diesel/any liquid

Input(s)

W_2: Required mud density (ppg)
W_1: Initial Mud density (ppg)
V_m: Initial Mud Volume (bbl)
D_w: Water/Diesel density (ppg)

Output(s)

V_r: Required Volume of water/diesel/any liq (bbl)

Formula(s)

$$V_r = V_m * \frac{W_1 - W_2}{W_2 - D_w}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 85.*

2.151 Mudcake growth equation—Formation invasion

Input(s)

f_s: Mud Solid Fraction (fraction)
$Ø_c$: Mudcake Porosity (fraction)
v_N: Darcy Velocity of the Filtrate through the cake and past the paper (in./s)

Output(s)

$\frac{dx_c(t)}{dt}$: Mudcake Growth by time (in./s)

Formula(s)

$$\frac{dx_c(t)}{dt} = \left(\frac{f_s}{(1-f_s)(1-Ø_c)}\right)|v_n|$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 39.*

2.152 Mudcake growth equation-2—Formation invasion

Input(s)

$Ø_{eff}$: Effective Porosity (fraction)
f_s: Mud Solid Fraction (fraction)
$Ø_c$: Mudcake Porosity (fraction)
x_f: Transient Invasion Front (in.)
$x_{f,\,o}$: Initial Displacement, i.e., Spurt (in.)

Output(s)

$x_c(t)$: Mudcake Growth by time (in./s)

Formula(s)

$$x_c(t) = \left[Ø_{eff} f_s / \{(1-Ø_c)(1-f_s)\}\right]\left(x_f - x_{f,o}\right)$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 45.*

2.153 Mudcake permeability—Formation invasion

Input(s)

μ: Viscosity (cP)
$h(t)$: Filtrate Height (in.)
$x_c(t)$: Mudcake Growth by time (in./s)
Δp: Pressure Change (psi)
t: Time (s)

Output(s)

k: Viscous Shear Stress at the outer Mudcake boundary (lb/in.^{2})

Formula(s)

$$k = \frac{\mu \cdot h(t) x_c(t)}{(2t\Delta p)}$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 95.*

2.154 New pump circulating pressure

Input(s)

P_p: Present Circulating Pressure (psi)
q_n: New Pump Rate (spm)
q_o: Old Pump Rate (spm)

Output(s)

P_c: New Circulating Pressure (psi)

Formula(s)

$$P_c = P_p * \left(\frac{q_n}{q_o}\right)^2$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 27.*

2.155 Nozzle area calculation

Input(s)

F: 1st Nozzle Size (in.)
C: 2nd Nozzle Size (in.)
B: 3rd Nozzle Size (in.)

Output(s)

N_a: Nozzle Area (in.^{2})

Formula(s)

$$N_a = \frac{F^2 + C^2 + B^2}{1303.8}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 165.*

2.156 Number of sacks of cement required

Input(s)

H: Hole Size (in.)
OD: Outer Dia (in.)
ID: Inner Dia (in.)
h_c: Feet to be Cemented (ft)
E: Original+extra Volume Req in Percentage (fraction)
h_{fc}: Feet Between Float Collar and Shoe (ft)
Y1: Yield of Lead/filler Cement (ft^3/stroke)
Y2: Yield of Tail Cement (ft^3/stroke)
FC: Float Collar (Number of Feet Above Shoe) (ft)
Csd: Casing Setting Depth (ft)
PO: Pump Output (bbl/stroke)

Output(s)

AC: Annular Capacity (ft3/ft) C:Casing Capacity (ft^3/ft)
N_f: Number of Sacks of Cement Required (stroke)
N_a: Sacks Required for Annulus (stroke)
N_c: Sacks Required for Casing (stroke)
N_t: Total Number of Sacks Required (stroke)
Cd: Casing Capacity in Barrels (bbl/ft)
SS: Number of Strokes Required to Bump the Plug (strokes)

Formula(s)

$$AC = \frac{H^2 - OD^2}{183.35}$$

$$C = \frac{(ID)^2}{183.35}$$

$$N_f = \frac{h_c * AC * E}{Y1}$$

$$N_a = h_c * AC * \frac{E}{Y2}$$

$$N_c = h_{fc} * \frac{C}{Y2}$$

$$N_t = N_a + N_c$$

$$Cd = \frac{(ID)^2}{1029.4}$$

$$SS = \frac{Cd}{PO}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 54.*

2.157 Number of sacks of cement required for a given length of plug

Input(s)

L_p: Plug Length (ft)
C_c: Casing Capacity (ft^3/ft)
E: Excess Volume (fraction)
Y: Slurry Yield (ft^3/stroke)

Output(s)

N_s: Sacks of Cement Required (unitless)

Formula(s)

$$N_s = \frac{L_p * C_c * E}{Y}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 61.*

2.158 Number of sacks of lead cement required for annulus

Input(s)

L_c: Feet to be Cemented (ft)
C_a: Annular Capacity (ft^3/ft)
E: Excess Volume (fraction)
Y: Slurry Yield of Lead Cement (ft^3/stroke)

Output(s)

N_s: Sacks Required (unitless)

Formula(s)

$$N_s = \frac{L_c * C_a * E}{Y}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 54.*

2.159 Number of sacks of tail cement required for casing

Input(s)

L_c: Distance between Float Collar and Shoe (ft)
C_c: Casing Capacity (ft^3/ft)
Y: Slurry Yield of Tail Cement (ft^3/stroke)

Output(s)

N_s: Sacks Required by Casing (unitless)

Formula(s)

$$N_s = \frac{L_c * C_c}{Y}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 56.*

2.160 Open-ended displacement volume of pipe

Input(s)

D_o: Outside Diameter of Pipe (in.)
D_i: Inside Diameter of Pipe (in.)
L: Length of Pipe (ft)

Output(s)

V_o: Open-ended Displacement Volume of Pipe (bbl)

Formula(s)

$$V_o = \frac{0.7854 * \left(D_o^2 - D_i^2\right) * L}{808.5}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 45.*

2.161 Overall efficiency—Diesel engines to mud pump

Input(s)

n_e: Engine Efficiency (unitless)
n: Electric Motor Efficiency (unitless)
n_m: Mud Pump Mechanical Efficiency (unitless)
n_v: Mud Pump Volumetric Efficiency (unitless)

Output(s)

n_o: Overall Efficiency (unitless)

Formula(s)

$$n_o = n_e * n_l * n_m * n_v$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 49.*

2.162 Overall power system efficiency

Input(s)

P: Power Output (hp)
Q_i: Total Heat Energy consumed by the Engine (hp)

Output(s)

E_i: Total Heat Energy consumed by the Engine (hp)

Formula(s)

$$E_i = \frac{P}{Q_i}$$

Reference: *Bourgoyne, A. T., Millheim, K. K., Chenevert, M. E., & Young, F. S. (1986). Applied Drilling Engineering, Page: 7.*

2.163 Penetration rate—Drill-rate model—Alternative equation

Input(s)

K': Drill-Rate Model Proportionality Constant (dimensionless)
N: Bit rotating Speed (rev/min)
a_N: Rotating Speed Exponent (dimensionless)

Output(s)

R: Penetration Rate (ft/h)

Formula(s)

$$\log R = \log K' + a_N \log N$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 49.*

2.164 Penetration rate—Drill-rate model—Basic equation

Input(s)

d_b: Bit Diameter (in.)
K: Drill-Rate Model Proportionality Constant (dimensionless)
N: Bit rotating Speed (rev/min)
W: Applied Bit Weight (lbf)
a_W: Bit Weight Exponent (dimensionless)
a_N: Rotating Speed Exponent (dimensionless)

Output(s)

R: Penetration Rate (ft/h)

Formula(s)

$$R = K\left(\frac{W}{d_b}\right)^{a_W} N^{a_N}$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 48.*

2.165 Percentage of bit nozzle pressure loss

Input(s)

P_b: Jet Pressure Nozzle (psi)
P: Surface Pressure (psi)

Output(s)

%ψb: Percent Pressure Loss (fraction)

Formula(s)

$$\%\psi b = \left(\frac{P_b}{P}\right) * 100$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 165.*

2.166 Plastic viscosity—Bingham plastic model

Input(s)

θ_{600}: Fann Dial Reading at 600 Rpm (cP)
θ_{300}: Fann Dial Reading at 300 Rpm (cP)

Output(s)

PV: Plastic Viscosity (cP)

Formula(s)

$$PV = (\theta_{600}) - (\theta_{300})$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 192.*

2.167 Plug length to set a balanced cement plug

Input(s)

N_s: Number of Sacks of Cement to be Used (stroke)
AC: Annular Capacity (ft^3/ft)
P_c: Pipe or Tubing Capacity (ft^3/ft)
E: Original+extra Volume Req in Percentage (fraction) Y_s:Yield of Slurry (ft^3/stroke)

Output(s)

L_p: Length of Plug (stroke)

Formula(s)

$$L_p = \frac{N_s * Y_s}{AC * E + P_c}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 61.*

2.168 Polar moment of inertia

Input(s)

J_b: Polar Moment of Inertia of Pipe Body (ft^4)
J_j: Polar Moment of Inertia of Tool Joint (ft^4)
L: Length of Pipe (ft)
l: Joint Tool Length (ft)

Output(s)

J_p: Polar Moment of Inertia of Pipe (ft^4)

Formula(s)

$$J_p = \frac{J_b * J_j}{\left(\frac{L-l}{L}\right) * J_j * \left(\frac{l}{L}\right) * J_b}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 356.*

2.169 Polished rod horsepower—Sucker-rod pump

Input(s)

C: Calibration Constant of Dynamometer (lb/in.)
A: Upper Area of Card (in.^{2})
L: Length of Card (in.)
S: Maximum Theoretical Polished Rod Position (in.)
N: Strokes Per Minute (spm)

Output(s)

PRHP: Polished Rod Horsepower (hp)

Formula(s)

$$\text{PRHP} = \text{C} * \text{S} * \text{N} * \frac{\text{A}}{33000 * 12 * \text{L}}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering:A Computer-Assisted Approach, Page: 18.*

2.170 Pore-pressure gradient—Rehm and McClendon

Input(s)

d_{cn}: Normal dc (Modified Bit-Weight exponent in Bingham equation) exponent (dimensionless)
d_{co}: Observed dc (Modified Bit-Weight exponent in Bingham equation) exponent (dimensionless)

Output(s)

g_p: Pore Pressure Gradient (psi/ft)

Formula(s)

$$g_p = (0.398 \log (d_{cn} - d_{co})) + 0.86$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 52.*

2.171 Pore-pressure gradient—Zamora

Input(s)

d_{cn}: Normal dc (Modified Bit-Weight exponent in Bingham equation) exponent (dimensionless)
d_{co}: Observed dc (Modified Bit-Weight exponent in Bingham equation) exponent (dimensionless)
g_n: Normal Pore Pressure Gradient (psi/ft)

Output(s)

g_p: Pore Pressure Gradient (psi/ft)

Formula(s)

$$g_p = g_n \left(\frac{d_{cn}}{d_{co}} \right)$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 52.*

2.172 Pressure analysis—Pressure by each barrel of mud in casing

Input(s)

Dh: Hole Dia (in.)
Dp: Pipe Dia (in.)
mw: Mud wt (ppg)

Output(s)

P: Hydrostatic Pressure (psi/bbl)

Formula(s)

$$P = 1029.4 * 0.052 * \frac{mw}{(Dh)^2 - (Dp)^2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 138.*

2.173 Pressure analysis—Surface pressure during drill stem test

Input(s)

h: Total Vertical Depth (ft)
EMW: Equivalent Mud Weight for Formation Pressure (ppg)
SG: Oil Specific Gravity (fraction)

Output(s)

P: Hydrostatic Pressure (psi/bbl)

Formula(s)

$$P = 0.052 * h * (EMW - SG * 8.33)$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 138.*

2.174 Pressure gradient

Input(s)

mw: Mud weight (ppg)

Output(s)

PG: Pressure Gradient (psi/ft)

Formula(s)

$$PG = mw * 0.052$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 1.*

2.175 Pressure required to break circulation—Annulus

Input(s)

y: Gel strength of drilling fluid (lb/100ft^2)
L: Length of Drill String (ft)
Dh: Diameter of hole (in.)
Dp: Diameter of drill pipe (in.)

Output(s)

P_{gs}: Pressure to overcome mud's gel strength inside annulus (psi)

Formula(s)

$$P_{gs} = \frac{y}{300 * (Dh - Dp)} * L$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 79.*

2.176 Pressure required to break circulation—Drill string

Input(s)

y: Gel Strength of drilling fluid (lb/100ft^2)
L: Length of Drill String (ft)
d: Inside diameter of drill pipe (in.)

Output(s)

P_{gs}: Pressure to overcome mud's gel strength inside drill string (psi)

Formula(s)

$$P_{gs} = \left(y * \frac{L}{300 * d}\right)$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 79.*

2.177 Pressure required to overcome gel strength of mud inside the drill string

Input(s)

y: Gel Strength of Drilling Fluid (lb/100 ft^2)
d: Inside Diameter of Drill Pipe (in.)
L: Length of Drill String (ft)

Output(s)

P_m: Pressure Required (psi)

Formula(s)

$$P_m = \frac{y * L}{300 * d}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 79.*

2.178 Pressure required to overcome mud's gel strength in annulus

Input(s)

y: Gel Strength of Drilling Fluid (lb/100 ft^2)
D_h: Hole Diameter (in.)
D_p: Pipe Diameter (in.)
L: Length of Drillstring (ft)

Output(s)

P_m: Pressure Required (psi)

Formula(s)

$$P_m = \frac{y * L}{300 * \left(D_h - D_p\right)}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 79.*

2.179 Pump calculation—Pump pressure

Input(s)

P_d: Frictional Pressure Losses (psi)
ΔP: Bit Pressure Drop (psi)

Output(s)

P_p: Pump Pressure (psi)

Formula(s)

$$P_p = \Delta P + P_d$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 69.*

2.180 Pump calculations—Power required

Input(s)

Q: Flow Rate (gpm)
ΔP: Bit Pressure Drop (psi)

Output(s)

HP_P: Power Required (hp)

Formula(s)

$$HP_P = \frac{Q * \Delta P}{1714}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 70.*

2.181 Pump displacement

Input(s)

D: Rotor Diameter (in.)
E: Rotor/Stator Eccentricity (in.)
P_s: Pitch Length of Stator (ft)

Output(s)

V_o: Pump Displacement (ft^3)

Formula(s)

$$V_o = 0.028 * D * E * P_s$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering:A Computer-Assisted Approach, Page: 14.*

2.182 Pump flow rate

Input(s)

D: Rotor Diameter (in.)
E: Rotor/Stator Eccentricity (in.)
N: Rotary Speed (rpm)
Q_s: Leak Rate (bbl/d)
P_s: Pitch Length of Stator (ft)

Output(s)

Q_e: Pump Flow Rate (bbl/d)

Formula(s)

$$Q_e = 7.12 * D * E * P_s * N - Q_s$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering:A Computer-Assisted Approach, Page: 14.*

2.183 Pump head rating

Input(s)

n_p: Number of Pitches of Stator (unitless)
Δp: Head Rating Developed into an Elementary Cavity (psi)

Output(s)

ΔP: Pump Head Rating (psi)

Formula(s)

$$\Delta P = \left(2 * n_p - 1\right) * \Delta p$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 14.*

2.184 Pump output—gpm

Input(s)

d: Liner Diameter (in.)
S: Stroke Length (in.)
spm: Strokes per minute (dimensionless)

Output(s)

PO: Pump Output gpm (bbl/stroke)

Formula(s)

$$PO = 3 * \left(d^2 * 0.7854\right) * S * 0.00411 * spm$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 8.*

2.185 Pump output triplex pump

Input(s)

ld: Liner Diameter (in.)
sl: Stroke Length (in.)

Output(s)

PO: Pump Output (bbl/stroke)

Formula(s)

$$PO = 0.000243 * ld^2 * sl$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 7.*

2.186 Pump pressure/pump stroke relationship

Input(s)

PCP: Present Circulation Pressure (psi)
NPR: New Pump Rate (spm)
OPR: Old Pump Rate (spm)

Output(s)

PP: Pump Pressure—Pump Stroke Relationship (psi)

Formula(s)

$$PP = PCP * \left(\frac{NPR}{OPR}\right)^2$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, second edition, Gulf Professional Publishing, Page: 27.*

2.187 Radial force related to axial load—Cementing

Input(s)

F: Force or Load to Break Cement Bond (lbm)
α: Slip Bowl Taper Angle (degree)
μ: Constant (Usually 0.2) (dimensionless)

Output(s)

W: Radial Force related to Axial Load (lbm)

Formula(s)

$$W = \frac{1 - (\mu \cdot tan\alpha)}{\mu + tan\alpha} \cdot F$$

Reference: *Suman Jr, G. O., & Ellis, R. C. (1977). Cementing Handbook. World Oil, Page: 18.*

2.188 Range of load—Sucker-Rod pump

Input(s)

PPRL: Peak Polished Rod Load (lb)
MPRL: Minimum Polished Rod Load (lb)

Output(s)

ROL: Range of Load (lb)

Formula(s)

$$ROL = PPRL - MPRL$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering:A Computer-Assisted Approach, Page: 18.*

2.189 Rate of fuel consumption by a pump

Input(s)

N: Pump Rotary Speed (rpm)
T: Output Torque (ft lbs)
n: Pump Efficiency (%)
H: Fuel Heating Value (BTU/lb)

Output(s)

Q_f: Fuel Consumption Rate (lbm/h)

Formula(s)

$$Q_f = 48.46 * \frac{N * T}{n * H}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 6.*

2.190 Rate of gas portion that enters the mud

Input(s)

q_r: Rock Removal Rate (SCF/min)
S_g: Gas Saturation (fraction)
Ø: Formation Porosity (per cent)

Output(s)

q_g: The Rate of Gas Portion that enters the Mud with Bulk Rock (SCF/min)

Formula(s)

$$q_g = q_r ØS_g$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers, Page: 19.*

2.191 Relationship between traveling block speed and fast line speed

Input(s)

v_f: Fast Line Speed (fpm)
n: Number of Lines Strung B/w Crown and Traveling Block (unitless)

Output(s)

v_{tb}: Traveling Block Velocity (fpm)

Formula(s)

$$v_{tb} = \frac{v_f}{n}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 10.*

2.192 Rock removal rate

Input(s)

d_b: Bit Diameter (in.)
R: Penetration Rate (ft/h)

Output(s)

q_r: Rock Removal Rate (SCF/min)

Formula(s)

$$q_r = \frac{\pi}{4}\frac{d_b^2 R(12)}{(1,728)(60)} = \frac{d_b^2 R}{11000}$$

Reference: *Watson, D., Brittenham, T., & Moore, P. L. (2003). Advanced Well Control (Vol. 10). Society of Petroleum Engineers., Page: 19.*

2.193 Rotating horsepower

Input(s)

T: Torque (ft lbf)
N: Speed (rpm)

Output(s)

RHP: Rotating Horsepower (hp)

Formula(s)

$$RHP = \frac{T * N}{5252}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 46.*

2.194 Side force at bit in anisotropic formation

Input(s)

p: Buoyed Weight of Drill Collar (ppf)
E: Modulus of Elasticity (psi)
I: Moment of inertia of Drill Collar (in.^{4})
r: Radial Clearance Between Hole and Collar (ft)
θ: inclination Angle (degree)
W: Weight on Bit (lbf)

Output(s)

F: Side Force on Bit (lbf)

Formula(s)

$$F = p * \left((E*I)^{0.5}\right) * \left(\left(\frac{W}{24}\right) * \left(\left(\frac{24*r}{E*I*p*\sin(\theta)}\right)^{0.75}\right) - \left(\left(\frac{1.5*r}{E*I*p*\sin(\theta)}\right)^{0.25}\right)\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 378.*

2.195 Sinusoidal buckling

Input(s)

E: Modulus of Elasticity (psi)
I: Moment of Inertia (ft^4)
W: Weight on Bit (lbf)
θ: Angle of Wellbore Inclination (degree)
r: Radial Clearence Between Wellbore and Component (ft)

Output(s)

F_s: Buckling Force (lbf)

Formula(s)

$$F_s = 2 * \left(\left(\frac{E*I*W*\sin(\theta)}{r}\right)^{0.5}\right)$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 426.*

2.196 Slurry density for cementing calculations

Input(s)

V_s: Volume of Slurry (gal/stroke)
W_a: Weight of Additive Per Sack (lb/stroke)
Q_w: Total Water Requirement (gal/stroke)

Output(s)

σ_s: Slurry Density (lb/gal)

Formula(s)

$$\sigma_s = \frac{94 + W_a + (8.33 * Q_w)}{V_s}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 48.*

2.197 Solids analysis—High-salt content muds

Input(s)

C_{Cl}: Concentration of Chlorine (ppm)
P_{vw}: Percentage by vol of water (percent)
P_{vo}: Percentage by vol of oil (percent)
S: CEC of shale (lb/bbl)
M: CEC of Mud (lb/bbl)
mw: Mud Weight (ppg)

Output(s)

SW: Percentage by vol of salt water (percent)
SS: Percentage by vol of suspended solids (percent)
ASG_{sw}: Average specific gravity of salt water (fraction)
ASG: Average specific gravity of solids (fraction)
LGS: Percentage by volume of low gravity solids (% by vol)
P_b: Pounds per barrel of barite (% by vol)
P_{be}: Percentage of Bentonite (lb/bbl)
P_{ds}: Percentage of Drilled Solids (lb/bbl)

Formula(s)

$$SW = \left(\left(5.88 * 10^{-8}\right) * \left(\left(C_{Cl}\right)^{1.2}\right) + 1\right) * P_{vw}$$

$$SS = 100 - P_{vo} - SW$$

$$ASG_{sw} = \left(\left(C_{Cl}\right)^{0.95}\right) * 1.94 * 10^{-6} + 1$$

$$ASG = \frac{(12 * mw) - \left(SW * ASG_{sw}\right) - 0.84 * P_{vo}}{SS}$$

$$LGS = SS * \frac{4.2 - ASG}{1.6}$$

$$P_b = (SS - LGS) * 14.71$$

$$P_{be} = \frac{\left((M - 9) * \frac{S}{65}\right) * \frac{LGS}{1 - \frac{S}{65}}}{9.1}$$

$$P_{ds} = \left(LGS - P_{be}\right) * 9.1$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 91.*

2.198 Solids analysis low-salt content muds

Input(s)

C_{Cl}: Concentration of Chlorine (ppm)
P_{vw}: Percentage by vol of water (percent)
P_{vo}: Percentage by vol of oil (percent)
S: CEC of shale (lb/bbl)
M: CEC of Mud (lb/bbl)
mw: Mud Weight (ppg)

Output(s)

SW: Percentage by vol of salt water (percent)
SS: Percentage by vol of suspended solids (percent)
ASG_{sw}: Average specific gravity of salt water (fraction)
ASG: Average specific gravity of solids (fraction)
LGS: Percentage by volume of low gravity solids (% by vol)
P_b: Pounds per barrel of barite (% by vol)
P_{be}: Percentage of Bentonite (lb/bbl)
P_{ds}: Percentage of Drilled Solids (lb/bbl)

Formula(s)

$$SW = \left(\left(5.88 * 10^{-8}\right) * \left(\left(C_{Cl}\right)^{1.2}\right) + 1\right) * P_{vw}$$

$$SS = 100 - P_{vo} - SW$$

$$ASG_{sw} = \left(\left(C_{Cl}\right)^{0.95}\right) * 1.94 * 10^{-6} + 1$$

$$ASG = \frac{(12 * mw) - \left(SW * ASG_{sw}\right) - 0.84 * P_{vo}}{SS}$$

$$LGS = SS * \frac{4.2 - ASG}{1.6}$$

$$P_b = (SS - LGS) * 14.71$$

$$P_{be} = \frac{\left((M - 9) * \frac{S}{65}\right) * \frac{LGS}{1 - \frac{S}{65}}}{9.1}$$

$$P_{ds} = \left(LGS - P_{be}\right) * 9.1$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 92.*

2.199 Spacer volume behind slurry required to balance the plug

Input(s)

C_a: Annular Capacity (ft/bbl)
E: Excess Volume (fraction)
V_a: Spacer Volume Ahead (bbl)
C_p: Capacity of Pipe or Tubing (bbl/ft)

Output(s)

V_s: Spacer Volume (bbl)

Formula(s)

$$V_s = \left(\frac{C_a}{E}\right) * V_a * C_p$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 62.*

2.200 Specific gravity of cuttings by using mud balance

Input(s)

R_w: Resulting Weight with Cuttings Plus Water (ppg)

Output(s)

SG: Specific Gravity of Cuttings (unitless)

Formula(s)

$$SG = \frac{1}{2 - (0.12 * R_w)}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 41.*

2.201 Stripping/snubbing calculations—Breakover point between stripping and snubbing

Input(s)

Dp: Pipe or collar OD (in.)
P: Wellbore Pressure (psi)
W_{dc}: Weight of Drill Collar (lb/ft)
L: Drill Collar Length (ft)
BF: Buoyancy Factor (dimensionless)
W_{dp}: Drill Pipe Weight (lb/ft)

Output(s)

F: Force created by wellbore pressure on Drill collar or pipe (lb)
W: Weight of Drill Collar (lb)
W_{adp}: Additional weight required from Drill Pipe (lb)
L_{bp}: Length of Drill Pipe required to reach over breakover point (ft)
L_{ds}: Length of Drill string req to reach breakover point (ft)

Formula(s)

$$F = Dp^2 * 0.7854 * P$$
$$W = W_{dc} * L * BF$$
$$W_{adp} = F - W$$
$$L_{bp} = \frac{W_{adp}}{BF * W_{dp}}$$
$$L_{ds} = L + L_{bp}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 139.*

2.202 Stripping/snubbing calculations—Height gain and casing pressure from stripping into influx

Input(s)

C_{dp}: Capacity of Drill Pipe or tubing (bbl/ft)
D_{dp}: Displacement of Drill Pipe,Drill Collar or tubing (bbl/ft)
C_a: Annular Capacity (bbl/ft)
L: Length of Drill Pipe Stripped (ft)
G: Gradient of Mud (psi/ft)
G_i: Gradient of Influx (psi/ft)

Output(s)

H: Height gain from stripping into influx (ft)
P: Casing Pressure increase from stripping into influx (psi)

Formula(s)

$$H = L * \frac{C_{dp} + D_{dp}}{C_a}$$
$$P = H * (G - G_i)$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 140.*

2.203 Stripping/snubbing calculations—Maximum Allowable surface pressure governed by casing burst pressure

Input(s)

W_o: Mud Weight behind casing (ppg)
W_u: Mud Weight in use (ppg)
H: Casing Shoe TVD (ft)
P_{bc}: Casing Burst Pressure (psi)
S: Safety Factor (e.g., 80% represent 0.8) (dimensionless)

Output(s)

MASP: Maximum Allowable Surface Pressure governed by Casing Burst Pressure (psi)

Formula(s)

$$MASP = (P_{bc} * S) - (W_u - W_o) * 0.052 * H$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 143*.

2.204 Stripping/snubbing calculations—Maximum allowable surface pressure governed by formation

Input(s)

W_{max}: Max allowable mud Weight (ppg)
W_u: Mud Weight in use (ppg)
H: Casing Shoe TVD (ft)

Output(s)

MASP: Maximum Allowable Surface Pressure governed by Formation (psi)

Formula(s)

$$MASP = (W_{max} - W_u) * 0.052$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 143*.

2.205 Stripping/snubbing calculations—Minimum surface pressure before stripping

Input(s)

W_c: Weight per feet of one stand of Drill Collar (lb/ft)
L: Length of one stand (feet)
D: Drill Collar Dia (in.)

Output(s)

$P_{\min}$: Minimum surface Pressure before stripping is possible (psi)

Formula(s)

$$P_{\min} = W_c * \frac{L}{D^2 * 0.7854}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 141*.

2.206 Stripping/snubbing calculations—Constant BHP with a gas bubble rising

Input(s)

Dp: Incremental pressure steps that the casing pressure will be allowed to increase (psi)
Ca: Annular Capacity (in.^{2})
G: Gradient of Mud (psi/ft)

Output(s)

V: V for constant BHP with a Gas Bubble Rising (bbl)

Formula(s)

$$V = (Dp) * \frac{Ca}{G}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 142.*

2.207 Stroke per minute required for a given annular velocity

Input(s)

AV: Annular Velocity (ft/min)
AC: Annular Capacity (bbl/ft)
q_o: Pump Output (bbl/stroke)

Output(s)

SPM: Strokes Per Minute Required (unitless)

Formula(s)

$$\mathrm{SPM} = \frac{\mathrm{AV} * \mathrm{AC}}{q_o}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 12.*

2.208 Stuck pipe calculations—Method-1

Input(s)

OD: Outer dia of tubing (in.)
ID: Inner dia of tubing (in.)
S: Stretch (in.)
PF: Pull force in thousands of pounds (1000lb)

Output(s)

fpc: Free Point Constant (dimensionless)
h_f: Feet of Free pipe (ft)

Formula(s)

$$fpc = \left(OD^2 - ID^2\right) * 0.7854 * 2500$$

$$h_f = S * \frac{fpc}{PF}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 74.*

2.209 Stuck pipe calculations—Method-2

Input(s)

e: Pipe Stretch (in.)
Wdp: Drill Pipe Wt. (lb/ft)
Pd: Differential Pull (lb)

Output(s)

h_f: Feet of Free pipe (ft)

Formula(s)

$$h_f = 735294 * e * \frac{Wdp}{Pd}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 74.*

2.210 Subsea considerations—Adjusting choke line pressure loss for higher mud weight

Input(s)

W_o: Old mud weight (ppg)
W_n: Higher mud weight (ppg)
CLPLO: Old Choke line Pressure Loss for higher mud weight (psi)

Output(s)

CLPL: Adjusted CLPL for higher mud weight (psi)

Formula(s)

$$CLPL = W_n * \frac{CLPLO}{W_o}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 144.*

2.211 Subsea considerations—Casing burst pressure-subsea stack

Input(s)

YP: Internal Yield Pressure (psi)

SF: Safety Factor (fraction)
W_u: Mud Weight in use (ppg)
H: Depth from Rotary Kelly Bushing to Mudline (ft)
H_s: Depth of Seawater (ft)
W_s: Seawater Weight (ppg)

Output(s)

YP_c: Corrected Internal Yield Pressure (psi)
HP: Hydrostatic Pressure of Mud in Use (psi)
HP_{sw}: Hydrostatic Pressure exerted by sea water (psi)
CBP: Casing Burst Pressure (psi)

Formula(s)

$$YP_c = YP * SF$$

$$HP = W_u * 0.052 * H$$

$$HP_{sw} = H_s * 0.052 * W_s$$

$$\mathrm{CBP} = YP_c - HP + \left(HP_{sw}\right)$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 146.*

2.212 Subsea considerations—Choke line pressure loss

Input(s)

W_m: Mud Weight (ppg)
L: Choke Line Length (ft)
R_c: Circulation Rate (gpm)
D_i: Choke Line ID (in.)

Output(s)

CLPL: Choke Line Pressure Loss (psi)

Formula(s)

$$CLPL = \frac{0.000061 * W_m * L * \left(R_c^{1.86}\right)}{D_i^{4.86}}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 148.*

2.213 Subsea considerations—Maximum allowable mud weight—Subsea stack from leakoff test

Input(s)

P_{lo}: Leak off test pressure (psi)
H: TVD Rotary Bushing to Casing Shoe (ft)
W_u: Mud weight in use (ppg)

Output(s)

W_{max}: Maximum Allowable Mud Weight (ppg)

Formula(s)

$$W_{max} = \frac{P_{lo}}{0.052 * H} + W_u$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 150.*

2.214 Subsea considerations—Casing pressure decrease when bringing well on choke

Input(s)

SICP: Shut in casing Pressure (psi)
CLPL: Choke Line Pressure Loss (psi)

Output(s)

P_r: Casing Pressure Decrease when bringing well on choke (psi)

Formula(s)

$$P_r = SICP - CLPL$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 144.*

2.215 Subsea considerations—Velocity through choke line

Input(s)

Gpm: Mud Circulation rate (gpm)
ID: Choke line ID (in.)

Output(s)

V: Velocity through Choke Line (ft/min)

Formula(s)

$$V = 24.5 * \frac{Gpm}{ID^2}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 148.*

2.216 Surface test pressure required to frac the formation

Input(s)

FG: Fracture Gradient (psi/ft)
D: Depth (ft)
ρ: Mud Density (ppg)

Output(s)

P_{ST}: Surface Test Pressure (psi)

Formula(s)

$$P_{ST} = (FG \cdot D) - (0.052 \cdot \rho \cdot D)$$

Reference: *Suman Jr, G. O., & Ellis, R. C. (1977). Cementing Handbook. World Oil, Page: 69.*

2.217 Total amount of solids generated during drilling

Input(s)

C_h: Capacity of Hole (bbl/ft)
L: Footage Drilled (ft)
SG: Specific Gravity of Cuttings (unitless)
Ø: Porosity (fraction)

Output(s)

W_s: Amount of Solids Generated (pounds)

Formula(s)

$$W_s = 350 * C_h * L * (1 - Ø) * SG$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 19.*

2.218 Total heat energy consumed by the engine

Input(s)

w_f: Mass Rate of Fuel Consumption (lbm/min)
H: Heating value of Fuel (ft lbf/Btu)

Output(s)

Q_i: Total Heat Energy consumed by the Engine (hp)

Formula(s)

$$Q_i = \frac{w_f H}{33{,}000}$$

Reference: *Bourgoyne, A. T., Millheim, K. K., Chenevert, M. E., & Young, F. S. (1986). Applied Drilling Engineering, Page: 6.*

2.219 Total number of sacks of tail cement required

Input(s)

N_a: Sacks Required by Annulus (unitless)
N_c: Sacks Required by Casing (unitless)

Output(s)

N: Total Number of Sacks of Tail Cement Required (unitless)

Formula(s)

$$N = N_a + N_c$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 55.*

2.220 Total water requirement per sack of cement

Input(s)

Q_c: Cement Water Requirement Per Sack of Cement (gal/stroke)
Q_a: Additive Water Requirement Per Sack of Cement (gal/stroke)

Output(s)

Q_w: Total Water Requirement Per Sack of Cement (gal/stroke)

Formula(s)

$$Q_w = Q_c + Q_a$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 48.*

2.221 Triplex pump factor

Input(s)

D_L: Piston diameter (in.)
L_s: Stroke length (in.)

Output(s)

PF_t: Triplex pump factor (bbl/stroke)

Formula(s)

$$PF_t = \frac{3 * 3.1415 * D_L^2 * L_s}{4 * 9702}$$

Reference: *501 Solved Problems and Calculations for Drilling Operations; Page: 48.*

2.222 Upward force acting at the bottom of the casing shoe

Input(s)

A: Area Below Casing Shoe (in.^{2})
∂P: Differential Pressure B/w Cement and Mud (psi)

Output(s)

F_u: Upward Force (lb)

Formula(s)

$$F_u = A * \partial P$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 67.*

2.223 Vertical curvature for deviated wells

Input(s)

I_a: Original Hole Inclination (degree)
I_b: Desired Hole Inclination (degree)
∂L: Course Length (ft)

Output(s)

VC: Vertical Curvature (degree/ft)

Formula(s)

$$VC = (I_b - I_a) * \frac{100}{\partial L}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 84.*

2.224 Viscous shear stress at the outer mudcake boundary

Input(s)

R_c: Radius from the Center of Drillpipe to the beginning of Mudcake (in.)
R_p: Radius from the Center to the Inner Boundary of the Drillpipe (in.)
v_z: Axial Velocity Parallel to the Wellbore Axis (in/s)
x_f: Transient Invasion Front (in.)
$x_{f,o}$: Initial Displacement, i.e., Spurt (in.)
$\frac{dp}{dz}$: Pressure change with Z direction that is parallel to the Wellbore Axis (psi/in.)
μ: Viscosity (cP)

Output(s)

$\tau_{(Rc)}$: Viscous Shear Stress at the outer Mudcake boundary (lb/in.^{2})

Formula(s)

$$\tau_{(Rc)} = \mu\left(dv_z/dr\right)_{(Rc)}$$

$$\tau_{(Rc)} = \frac{1}{4}\left[2R_c + \left\{\left(R_c^2 - R_p^2\right)/\left(R_c \log\left(R_p/R_c\right)\right)\right\}\right]\frac{dp}{dz}$$

Reference: *Chin, W. C. (1995). Formation Invasion, Page: 59.*

2.225 Volume of cuttings generated per foot of hole drilled

Input(s)

D_h: Hole Size (in.)
Ø: Porosity (fraction)

Output(s)

V_c: Volume of Cuttings (bbl/ft)

Formula(s)

$$V_c = \frac{D_h^2 * (1 - Ø)}{1029.4}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover (2nd Edition), Page: 18.*

2.226 Volume of dilution water or mud required to maintain circulating volume

Input(s)

V_m: Volume of Mud in Circulating System (bbl)
F_l: % Low Gravity Solids in System (%)
F_o: % Optimum Low Gravity Solids Desired (%)
F_a: % Low Gravity Solids Added (%)

Output(s)

V_{wm}: Volume of Dilution Water or Mud Required (bbl)

Formula(s)

$$V_{wm} = \frac{V_m * (F_l - F_o)}{F_l - F_a}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 96.*

2.227 Volume of fluid displaced for duplex pumps

Input(s)

D_L: Piston Diameter (in.)

D_r: Rod Diameter (in.)
L_S: Stroke Length (in.)
N_C: Number of Cylinders (unitless)
n_v: Volumetric Efficiency (unitless)

Output(s)

V_t: Volume of Fluid Displaced (bbl/stroke)

Formula(s)

$$V_t = \frac{N_C * L_S * \left(\left(2 * D_L^2\right) - D_r^2\right) * n_v}{42 * 294}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 49.*

2.228 Volume of fluid displaced for single-acting pump

Input(s)

D_L: Piston Diameter (in.)
L_S: Stroke Length (in.)
N_C: Number of Cylinders (unitless)

Output(s)

V_t: Volume of Fluid Displaced (bbl)

Formula(s)

$$V_t = \frac{\pi * D_L^2 * L_S * N_C}{4}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 47.*

2.229 Volume of fluid displaced for triplex pump

Input(s)

D_L: Piston Diameter (in.)
L_s: Stroke Length (in.)
n_v: Volumetric Efficiency (unitless)

Output(s)

V_t: Volume of Fluid Displaced (bbl/stroke)

Formula(s)

$$V_t = \frac{L_s * D_L^2 * n_v}{42 * 98.03}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 49.*

2.230 Volume of liquid (oil plus water) required to prepare a desired volume of mud

Input(s)

W_1: Initial Density of oil water mix (ppg)
W_2: Desired Density of oil water mix (ppg)
DV: Desired Volume (bbl)

Output(s)

SV: Starting Volume Of Liquid (Oil Plus Water) Required To Prepare A Desired Volume Of Mud (ppg)

Formula(s)

$$SV = \frac{35 - W_2}{35 - W_1} * DV$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 88.*

2.231 Volume of slurry per sack of cement

Input(s)

S_c: Specific Gravity of Cement (unitless)
W_a: Weight of Additive per Sack of Cement (lb/stroke)
S_a: Specific Gravity of Additive (unitless)
Q_w: Total Water Requirement per Sack of Cement (gal/stroke)

Output(s)

V_s: Volume of Slurry (gal/stroke)

Formula(s)

$$V_s = \left(\frac{94}{S_c * 8.33}\right) + \left(\frac{W_a}{S_a * 8.33}\right) + Q_w$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 48.*

2.232 Volumes and strokes—Annular volume

Input(s)

Dh: Drill Hole Diameter (in.)
Dp: Drillpipe Outer Diameter (in.)

Output(s)

B: Annular Volume (bbl)

Formula(s)

$$B = \frac{Dh^2 - Dp^2}{1029.4}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 39.*

2.233 Volumes and strokes—Drill string volume

Input(s)

ID: Internal Diameter (in.)
PL: Pipe Length (ft)

Output(s)

B: Drill String Volume (bbl)

Formula(s)

$$B = \left(\frac{(ID)^2}{1029.4}\right) * PL$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, second edition, Gulf Professional Publishing, Page: 31.*

2.234 Volumes and strokes—Total strokes

Input(s)

V_{DS}: drill String Volume (bbl)
V_{AV}: Annular Volume (bbl)
O: Pump Output (bbl/stroke)

Output(s)

S: Total Strokes (Surface to Bit+Bit to Surface) (No)

Formula(s)

$$S = \frac{V_{DS} + V_{AV}}{O}$$

Reference: *Formulas and Calculations for Drilling, Production and Workover, Second Edition, Lapeyrouse, Page: 104.*

2.235 Weight of additive per sack of cement

Input(s)

P_a: Percentage of Additive (fraction)
W_c: Weight of Cement Per Sack (lb/stroke)

Output(s)

W_a: Weight of Additive (lb)

Formula(s)

$$W_a = P_a * W_c$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Workover, Second Edition, Gulf Professional Publishing, Page: 47.*

2.236 Weighted cementing calculations

Input(s)

wt: Req. Slurry Density (lb/gal)
SG_c: Specific Gravity of Cement (fraction)
CW: Water Req of Cement (gal/stroke)
AW: Water Req of Additive (gal/stroke)
SG_a: Specific Gravity of Additive (fraction)

Output(s)

x: Additive Req. Pounds Per Sack of Cement (lb/stroke)

Formula(s)

$$x = \frac{\left(\frac{wt * 11.207983}{SG_c}\right) + ((wt) * (CW)) - 94 - (8.33 * (CW))}{\left(1 + \frac{AW}{100}\right) - \frac{wt}{(SG_a) * 8.33} - \left(wt + \frac{AW}{100}\right)}$$

Reference: *Lapeyrouse, N. J., 2002, Formulas and Calculations for Drilling, Production and Work-over, Second Edition, Gulf Professional Publishing, Page: 47.*

Chapter 3

Well test analysis formulas and calculations

Chapter Outline

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3.1 Analysis of a flow test with smoothly varying rates

Input(s)

t_1: Time at P_{wf1} from Given Values or Trendline (h)
t_2: Time at P_{wf2} from Given Values or Trendline (h)
q_1: Flow Rate at P_{wf1} (STB/day)
q_2: Flow Rate at P_{wf2} (STB/day)
p_i: Initial Pressure (psi)
p_{wf2}: Wellflow Pressure at Point 2 from Given Values or Trendline (psi)
p_{wf1}: Wellflow Pressure at Point 1 from Given Values or Trendline (psi)
p_{wf}: Pressure Value at $t = 1$ h (psi)
q: Flow Rate (STB/day)
B: Volume Factor (RB/STB)
h: Thickness of Reservoir (ft)
μ: Viscosity of Oil (cP)
Ø: Porosity (fraction)
c_t: Compressibility (1/psi)
r_w: Wellbore Radius (ft)

Output(s)

m: Slope of Line (dimensionless)
k: Permeability (mD)
s: Skin Factor (dimensionless)

Formula(s)

$$m = \frac{\left(\frac{p_i - p_{wf2}}{q_2}\right) - \left(\frac{p_i - p_{wf1}}{q_1}\right)}{\log(t_2) - \log(t_1)}$$

$$k = 162.6 * B * \frac{\mu}{m * h}$$

$$s = 1.151 * \left(\frac{1}{m\left(\frac{p_i - p_{wf}}{q}\right)} - \log\left(\frac{k}{Ø * \mu * c_t * r_w^2}\right) + 3.23\right)$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 31.*

3.2 Analysis of a post-fracture—Constant-rate flow test with boundary effects

Input(s)

q_g: Gas Flow Rate (MSCF/day)
B_g: Gas formation Volume Factor (RB/MSCF)

m: Slope from Curve (psi/cycle)
m_L: Slope from linear Region of Curve (psi/cycle)
p_{ai}: Initial Adjusted Well Pressure (psi)
p_{ahr}: Adjusted Well pressure at $t = 1$ h (psi)
p_D: Dimensionless Pressure (dimensionless)
Ø: Porosity (dimensionless)
c_t: Compressibility (1/psi)
r_w: Radius of Wellbore (ft)
μ: Viscosity (cP)
h: Formation Thickness (ft)
t_{LfD}: Time of end of Linear or Pseudo Radial flow from Plot (dimensionless)
Δt_a: Adjusted Delta Time from Derivative Curve (h)

Output(s)

k: Permeability (mD)
L_{fPR}: Length of Fracture for Pseudo Radial Flow (ft)
L_{fL}: Length of Fracture for Linear Flow (ft)
L_{fMP}: Length of Fracture from Match Point Analysis (ft)
s: Skin Factor (dimensionless)
$\Delta P_{a_{MP}}$: Adjusted Pressure Difference at Match Point from Plot (psi)

Formula(s)

$$k = 162.6 * q_g * B_g * \frac{\mu}{m * h}$$

$$L_{fPR} = 1.151 * \left(\left(\frac{p_{ai} - p_{ahr}}{m} \right) - \log \left(\frac{k}{Ø * \mu * c_t * r_w^2} \right) + 3.23 \right)$$

$$L_{fL} = 2 * r_w * 2.71^{-s}$$

$$L_{fMP} = 4.064 * q_g * \frac{B_g}{m_L * h * k^{0.5}} * \left(\left(\frac{\mu}{Ø} * c_t \right)^{\frac{1}{2}} \right)$$

$$s = \left(141.2 * q_g * B_g * \frac{\mu}{k} * h \right) * (p_D)$$

$$\Delta P_{a_{MP}} = \left(\left(\frac{0.0002637 * k}{Ø * \mu * c_t} \right) * \left(\frac{\Delta t_a}{t_{LfD}} \right) \right)^{\frac{1}{2}}$$

Reference: *Lee, J., Rollins J.B., and Spivey J.P. 2003, Pressure Transient Testing, Vol. 9, SPE Textbook Series, Vol. 9, Henry L. Doherty Memorial Fund of AIME, Richardson, Texas, SPE, Chapter: 6, Page: 121.*

3.3 Analysis of a post-fracture pressure buildup test with wellbore-storage distortion

Input(s)

q_g: Gas flow rate (MSCF/day)
B_g: Gas formation Volume Factor (RB/MSCF)
p_D: Dimensionless Pressure (dimensionless)
$Ø$: Porosity (dimensionless)
c_t: Compressibility (1/psi)
μ: Viscosity (cP)
h: Formation Thickness (ft)

$t_{(L_f)_D}$: Time of end of linear or pseudo radial flow from plot (dimensionless)
C_{rD}: Dimensionless fracture conductivity (dimensionless)
C_{fD}: Dimensionless Wellbore storage coefficient (dimensionless)
L_f: Length of fracture (ft)
k: Permeability (mD)
Δt_{AE}: Equivalent Adjusted delta time from derivative curve (h)

Output(s)

C: Well bore storage coefficient (bbl/psi)
w_{fk_f}: Min Fracture conductivity for infinite conductive fracture (mD ft)
L_{fMP}: Length of fracture from match point analysis (ft)
$(\Delta P_a)_{MP}$: Adjusted Pressure difference at match point from plot (psi)

Formula(s)

$$C = \left(141.2 * q_g * B_g * \frac{\mu}{k * h}\right) * (p_D)_{MP}$$

$$w_{fk_f} = \left(\left(\frac{0.0002637 * k}{\text{Ø} * \mu * c_t}\right) * \left(\frac{\Delta t_{AE}}{t_{(L_f)_D}}\right)_{MP}\right)^{\frac{1}{2}}$$

$$L_{fMP} = \left(\text{Ø} * h * c_t * \frac{L_f^2}{0.8936}\right) * C_{fD}$$

$$(\Delta P_a)_{MP} = 3.14 * k * C_{rD} * L_f$$

Reference: *Lee, J., Rollins J.B., and Spivey J.P. 2003, Pressure Transient Testing, Vol. 9, SPE Textbook Series, Vol. 9, Henry L. Doherty Memorial Fund of AIME, Richardson, Texas, SPE, Chapter: 6, Page: 127.*

3.4 Analysis of a well from a PI test

Input(s)

P: Average Reservoir Pressure (psi)
q: Flow Rate (STB/day)
P_{wf}: Well Flowing Pressure (psi)
k: Permeability (mD)
B: Volume Factor (RB/STB)
h: Thickness of Reservoir (ft)
μ: Oil Viscosity (cP)
r_e: Drainage Radius (ft)
r_w: Wellbore Radius (ft)

Output(s)

J: Productivity index (STB/day/psi)
k_j: Average Permeability (mD)
s: Skin Factor (dimensionless)

Formula(s)

$$J = \frac{q}{P - P_{wf}}$$

$$k_j = 141.2 * J * B * \mu * \frac{\ln\left(\frac{r_e}{r_w}\right) - 0.75}{h}$$

$$s = \left(\frac{k}{k_j} - 1\right) * \left(\ln\left(\frac{r_e}{r_w}\right) - 0.75\right)$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 16.*

3.5 Analysis of DST flow data with Ramey type curves

Input(s)

p_i: Initial Pressure (psi)
p_{wf}: Well Flowing Pressure (psi)
p_o: Pressure at Time $T = 0$ (psi)
Ø: Porosity (dimensionless)
c_t: Total Compressibility (1/psi)
h: Formation Thickness (ft)
C: Wellbore Storage Coefficient (bbl/psi)
r_w: Radius of Wellbore (ft)
μ: Viscosity (cP)
t_c: Dimensionless Parameter from Curve Fitting as $\frac{T_d}{c_d}$ (dimensionless)
t: Time (h)
CES: Match Point for Dimensionless Well Bore Coefficient from Curve as (Cd E ̂(2 s))_(mp) (dimensionless)

Output(s)

p_{DR}: Dimensionless Pressure (dimensionless)
q_{DR}: Dimensionless Flow Rate (dimensionless)
C_D: Dimensionless Well Bore Storage Coefficient (dimensionless)
k: Permeability (mD)
s: Skin Factor (dimensionless)

Formula(s)

$$p_{DR} = \frac{p_i - (p_{wf})(t)}{p_i - p_o}$$

$$q_{DR} = 1 - p_{DR}$$

$$C_D = 0.8936 * \frac{C}{Ø * h * c_t * (r_w^2)}$$

$$k = \left(3390 * \mu * \frac{C}{h}\right) * \left(\frac{t_c}{t}\right)$$

$$s = 0.5 * \ln\left(\frac{CES}{C_D}\right)$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 155.*

3.6 Average fracture permeability (pseudo-steady state case for pressure build-up test)

Input(s)

q: Flow Rate (bbl/d)
μ: Viscosity (cP)
B: Formation Volume Factor (BBL/STB)
m: Slope of Horner Plot (psi/cycles)
h: Formation Thickness (ft)

Output(s)

k_f: Average Fracture Permeability (mD)

Formula(s)

$$k_f = 162.6 * q * B * \frac{\mu}{m * h}$$

Notes: Horner Plot Analysis (Semi-Log Plot).

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 107.*

3.7 Bottomhole flowing pressure during infinite-acting pseudoradial flow

Input(s)

p_i: Initial Reservoir Pressure (psi)
Q_o: Well Flow Rate (STB/day)
B_o: Oil Formation Volume Factor (bbl/STB)
μ_o: Oil Viscosity (cP)
k: Permeability (mD)
h: Thickness (ft)
t: Flowing Time (h)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
r_w: Wellbore Radius (ft)
S: Skin (dimensionless)

Output(s)

P_{wf}: Wellbore Flowing Pressure (psi)

Formula(s)

$$P_{wf} = p_i - \left(\frac{162.6 * Q_o * \mu_o * B_o}{k * h}\right) * \left(\log(t) + \log\left(\frac{k}{ø * \mu_o * c_t * r_w^2}\right) - 3.23 + 0.87 * S\right)$$

$$p_i - p_{wf} = \Delta p = a + m\log(t)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 98.*

3.8 Calculation of pressure beyond the wellbore (line-source solution)

Input(s)

P_i: Initial Pressure (psi)
t: Time of Production (h)
k: Permeability (mD)
B: Volume Factor (RB/STB)
ø: Porosity (fraction)
c_t: Compressibility (1/psi)
h: Thickness of Reservoir (ft)
μ: Viscosity of Oil (cP)
r: Radius of Wellbore (ft)
q: Flow Rate (STB/day)

Output(s)

P: Pressure (psi)

Formula(s)

$$P = P_i + 70.6 * q * B * \mu * \frac{\ln\left(1.688 * ø * \mu * c_t * \frac{r^2}{k * t}\right)}{k * h}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: SPE, Page: 11.*

3.9 Conventional DST design without a water cushion (collapse pressure calculation)

Input(s)

g_w: Water Gradient (psi/ft)
W_m: Mud Weight (lbm/gal)
D_c: Depth (ft)
F_d: Design Factor (dimensionless)
W_w: Water Weight (lbm/gal)

Output(s)

$p_{collapse}$: Collapse Pressure (psi)

Formula(s)

$$p_{collapse} = \frac{g_w * W_m * D_c * F_d}{W_w}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 153.*

3.10 Diffusion depth in a geothermal well

Input(s)

w: Mass Flow Rate (lb/h)
c: Thermal Heat Capacity of the Fluid (BTU/lbm °F)
k: Thermal Conductivity of Earth (= 33.6 BTU/(ft·day °F))
$f(t)$: Dimensionless Time Function that Represents the Transient Heat Transfer to the formation (dimensionless)

Output(s)

$A(t)$: Diffusion Depth as a Function of Time (ft)

Formula(s)

$$A(t) = \frac{wcf(t)}{2\pi k}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University. Equation (6–2).*

3.11 Dimensionless buildup pressure for field calculations

Input(s)

P_i: Initial Reservoir Pressure (psi)
P_{ws}: Shut in Pressure (psi)
m: Slope of Semi-Log Graph (kg/cm^2)/ Log cycle for Liquid

Output(s)

P_{Ds}: Dimensionless Pressure (dimensionless)

Formula(s)

$$P_{Ds} = \frac{(P_i - P_{ws})}{0.87m}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.8).*

3.12 Dimensionless buildup pressure for liquid flow

Input(s)

k: Effective Permeability of Flowing Phase (D)
h: Net Formation Thickness (m)
P_i: Initial Reservoir Pressure (psi)
P_{ws}: Shut in Pressure (psi)
v_{sc}: Specific Volume at Standard Conditions (cc/g)
q: Production Rate (tons/h (1000 kg/h))
B: Formation Volume Factor (Reservoir Volume/Standard Volume)
μ: Viscosity of Flowing Fluid (cP)

Output(s)

P_{Ds}: Dimensionless Pressure (dimensionless)

Formula(s)

$$P_{Ds} = \frac{kh(P_i - P_{ws})}{0.4568 v_{sc} q B \mu}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.7).*

3.13 Dimensionless buildup pressure for steam or gas flow

Input(s)

k: Effective Permeability of Flowing Phase (D)
h: Net Formation Thickness (m)
P_i: Initial Reservoir Pressure (psi)
P_{ws}: Shut in Pressure (psi)
M: Molecular Weight (g/g mol)
q: Production Rate (tons/h (1000 kg/h))
Z: Real Gas Law Deviation Factor (Ratio)
μ: Viscosity of Flowing Fluid (cP)
T: Absolute Formation Temperature (°K)

Output(s)

P_{Ds}: Dimensionless Pressure (dimensionless)

Formula(s)

$$P_{Ds} = \frac{Mkh(P_i^2 - P_{ws}^2)}{0.01291 q \mu Z T}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.7).*

3.14 Dimensionless buildup time

Input(s)

k: Effective Permeability of Flowing Phase (D)
t: Time (h)
$\varnothing$: Porosity (Per cent)
μ: Viscosity of Flowing Fluid (cP)
c_t: Total System Effective Isothermal Compressibility $(\text{kg/cm}^2)^{-1}$
r_w: Well Radius (m)

Output(s)

t_D: Dimensionless time (dimensionless)

Formula(s)

$$t_D = \frac{0.3604\, kt}{\varnothing \mu c_t r_w^2}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.7).*

3.15 Dimensionless cumulative production (radial flow constant-pressure production)

Input(s)

p_i: Initial Reservoir Pressure (psi)
Q_p: Flow Rate of Production (STB/day)
B: Volume Factor (RB/STB)
μ: Oil Viscosity (cP)
k: Permeability (mD)
r_w: Radius of Wellbore (ft)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
h: Thickness of Reservoir (ft)
p_{wf}: Well Flowing Pressure (psi)

Output(s)

Q_{pd}: Dimensionless Cumulative Production (dimensionless)

Formula(s)

$$Q_{pd} = \frac{B}{1.119 * \phi * c_t * h * r_w^2 * \left(p_i - p_{wf}\right)} * Q_p$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 9.

3.16 Dimensionless drawdown correlating parameter by Carter

Input(s)

μ_{gi}: Initial Gas Viscosity (cP)
μ_{gavg}: Average Gas of Viscosity (cP)
c_{gi}: Initial Gas Compressibility (1/psi)
c_{gavg}: Average Gas Compressibility (1/psi)

Output(s)

λ: Dimensionless Drawdown Correlating Parameter (dimensionless).

Formula(s)

$$\lambda = \frac{\mu_{gi} * c_{gi}}{\mu_{gavg} * c_{gavg}}$$

Reference: Ahmed, T., *McKinney*, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 256.

3.17 Dimensionless length (linear flow constant rate production/hydraulically fractured wells)

Input(s)

x: Length of Flow (ft)
L_f: Half Length of Fracture (ft)

Output(s)

L_D: Dimensionless Length (dimensionless)

Formula(s)

$$L_D = \frac{x}{L_f}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 10.*

3.18 Dimensionless length (linear flow/constant-rate production/general case)

Input(s)

x: Fracture Length (ft)
A: Cross Sectional Area (ft)

Output(s)

x_D: Dimensionless Length (dimensionless)

Formula(s)

$$x_D = \frac{x}{A^{0.5}}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 9.*

3.19 Dimensionless pressure (linear flow/constant rate production/general case)

Input(s)

p_i: Initial Reservoir Pressure (psi)

B: Volume Factor (RB/STB)
μ: Oil Viscosity (cP)
k: Permeability (mD)
A: Cross Section Area (ft)
q: Flow Rate (STB/day)
p: Pressure (psi)

Output(s)

p_D: Dimensionless Pressure (dimensionless)

Formula(s)

$$p_D = \frac{k * A^{0.5}}{141.2 * q * B * \mu} * (p_i - p)$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 9.*

3.20 Dimensionless pressure (linear flow/constant rate production/hydraulically-fractured wells)

Input(s)

p_i: Initial Reservoir Pressure (psi)
B: Formation Volume Factor (RB/STB)
μ: Oil Viscosity (cP)
k: Permeability (mD)
h: Reservoir Thickness (ft)
q: Flow Rate (STB/day)
p: Pressure (psi)

Output(s)

p_d: Dimensionless Pressure (dimensionless)

Formula(s)

$$p_d = \frac{k * h}{141.2 * q * B * \mu} * (p_i - p)$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 10.*

3.21 Dimensionless pressure (radial-flow/constant pressure production)

Input(s)

P_i: Initial Reservoir Pressure (psi)
P: Final Reservoir Pressure (psi)
P_{wf}: Well Flowing Pressure (psi)

Output(s)

P_d: Dimensionless Pressure (dimensionless)

Formula(s)

$$P_d = \frac{P_i - P}{P_i - P_{wf}}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 9.

3.22 Dimensionless pressure (radial-flow/constant rate production)

Input(s)

p_i: Initial Reservoir Pressure (psi)
p: Reservoir Thickness (psi)
k: Permeability (mD)
h: Reservoir Thickness (ft)
q: Formation Volume Factor (STB/day)
B: Volume Factor (RB/STB)
μ: Oil Viscosity (cP)

Output(s)

P_d: Dimensionless Pressure (dimensionless)

Formula(s)

$$P_d = \frac{k * h}{141.2 * q * B * \mu} * (p_i - p)$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 8.

3.23 Dimensionless pressure drop across a skin at the well face

Input(s)

k: Effective Permeability of Flowing Phase (D)
h: Net Formation Thickness (m)
P_i: Initial Reservoir Pressure (psi)
P_{1hr}: Pressure at 1 hour on semi-log straight line or its extension (psi)
P_{ws}: Shut in Pressure (psi)
P_{wf}: Bottomhole Pressure at a flowing well (psi)
v_{sc}: Specific Volume at Standard Conditions (cc/g)
q: Production Rate (m^3/h)
B: Formation Volume Factor (Reservoir Volume/Standard Volume)
μ: Viscosity of Flowing Fluid (cP)
c_t: Total System Effective Isothermal Compressibility $(kg/cm^2)^{-1}$
r_w: Well Radius (m)
m: Slope of Semi-Log Graph (kg/cm^2)/ Log cycle for Liquid
$\varnothing$: Porosity (Per cent)

Output(s)

P_{Dw}: Dimensionless Pressure at the well face (dimensionless)
s: Skin Effect (dimensionless)

Formula(s)

$$P_{Dw} + s = \frac{kh(P_i - P_{ws})}{0.4568 v_{sc} q B \mu}$$

$$s = 1.151 \left[\frac{\left(P_{1hr}{}^2 - P_{wf}{}^2\right)}{m} - \log_{10} \frac{k}{\varnothing \mu c_t r_w^2} + 0.0919 \right]$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.13).*

3.24 Dimensionless pressure drop during pseudo-steady state flow for a fractured vertical well in a square drainage area

Input(s)

t_{DA}: Dimensionless Time (dimensionless)
C_f: Shape Factor for a Fractured Vertical Well (dimensionless)
x_e: Half the Side of Square Drainage Area (ft)
x_f: Fracture Half Length (ft)

Output(s)

P_D: Wellbore Dimensionless Pressure Drop (dimensionless)

Formula(s)

$$P_D = 2 * \pi * t_{DA} + 0.5 * \ln\left(\frac{x_e}{x_f}\right)^2 + 0.5 * \ln\left(\frac{2.2458}{C_f}\right) + 0.5 * 2.77$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 211.*

3.25 Dimensionless pressure drop during pseudo-steady state flow for a horizontal well in a bounded reservoir

Input(s)

t_{DA}: Dimensionless Time (dimensionless)
C_{Ah}: Shape Factors for Horizontal Wells (dimensionless)
L: Length of Horizontal Well (ft)
A: Drainage Area (ft)

Output(s)

P_D: Wellbore Dimensionless Pressure Drop (dimensionless)

Formula(s)

$$P_D = 2 * \pi * t_{DA} + 0.5 * \ln\left(\frac{A}{4 * \left(\left(\frac{L}{2}\right)^2\right)}\right) + 0.5 * \ln\left(\frac{2.2458}{C_{Ah}}\right) + 0.5 * 2.77$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 216.*

3.26 Dimensionless production time

Input(s)

t_D: Dimensionless time (dimensionless)
A: Drainage Area (m^2)
r_w: Well Radius (m)

Output(s)

t_{DA}: Dimensionless Production time (dimensionless)

Formula(s)

$$t_{DA} = t_D \frac{r_w^2}{A}$$

Reference: *Ramey Jr., H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.7).*

3.27 Dimensionless rate (radial flow/constant pressure production)

Input(s)

p_i: Initial Reservoir Pressure (psi)
q: Flow Rate (STB/day)
B: Formation Volume Factor (RB/STB)
μ: Oil Viscosity (cP)
k: Permeability (mD)
h: Reservoir Thickness (ft)
p_{wf}: Well Flowing Pressure (psi)

Output(s)

q_d: Dimensionless Rate (dimensionless)

Formula(s)

$$q_d = \frac{q * B * \mu}{0.00708 * k * h * \left(p_i - p_{wf}\right)}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 9.

3.28 Dimensionless shut-in time for MDH method

Input(s)

k: Permeability (mD)
Δt: Total Shut-in Time (day)
ø: Porosity (fraction)
μ: Viscosity (cP)
c_t: Total Compressibility (1/psi)
A: Drainage Area (ft^2)

Output(s)

Δt_{DA}: Dimensionless Shut-in Time (dimensionless)

Formula(s)

$$\Delta t_{DA} = \frac{0.0002637 * k * \Delta t}{\phi * \mu * c_t * A}$$

Reference: Ahmed, T., *McKinney*, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 59.

3.29 Dimensionless storage constant for gases

Input(s)

C': Wellbore Storage (tons/$(kg/cm^2)^2$)
Z: Real Gas Law Deviation Factor (ratio)
T: Absolute Formation Temperature (°K)
M: Molecular Weight (g/g mol)
$\varnothing$: Porosity (Per cent)
h: Net Formation Thickness (m)
c_t: Total System Effective Isothermal Compressibility $(kg/cm^2)^{-1}$
r_w: Well Radius (m)

Output(s)

C_D: Dimensionless Storage Constant for Gases (dimensionless)

Formula(s)

$$C_D = \frac{27 C' Z T}{M \varnothing h c_t r_w^2}$$

Reference: *Ramey Jr., H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.18).*

3.30 Dimensionless storage constant for liquids

Input(s)

C: Storage
B: Formation Volume Factor (Reservoir Volume/Standard Volume)

V_{sc}: Specific Volume at Standard Conditions (cc/g)
$\varnothing$: Porosity (fraction)
h: Net Formation Thickness (m)
c_t: Total System Effective Isothermal Compressibility $(kg/cm^2)^{-1}$
r_w: Well Radius (m)

Output(s)

C_D: Dimensionless Storage Constant for Liquids (dimensionless)

Formula(s)

$$C_D = \frac{C\,B\,V_{sc}}{2\pi \varnothing h c_t r_w^2}$$

Reference: *Ramey Jr., H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.18).*

3.31 Dimensionless time (linear flow/constant rate production/general case)

Input(s)

t: Production Time (h)
k: Permeability (mD)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
μ: Oil Viscosity (cP)
A: Cross Sectional Area (ft)

Output(s)

t_{AD}: Dimensionless Time (dimensionless)

Formula(s)

$$t_{AD} = \frac{0.0002637 * k * t}{\phi * \mu * c_t * A}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 9.

3.32 Dimensionless time (linear flow/constant rate production/hydraulically fractured wells)

Input(s)

t: Production Time (h)
k: Permeability (mD)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
μ: Oil Viscosity (cP)
L_f: Half Length of Fracture (ft)

Output(s)

$t_{L_{fD}}$: Dimensionless Time (dimensionless)

Formula(s)

$$t_{L_{fD}} = \frac{0.0002637 * k * t}{\phi * \mu * c_t * L_f^2}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 10./*

3.33 Dimensionless time (radial flow/constant rate production)

Input(s)

t: Production Time (h)
k: Permeability (mD)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
μ: Oil Viscosity (cP)
r_w: Wellbore Radius (ft)

Output(s)

t_d: Dimensionless Time (dimensionless)

Formula(s)

$$t_d = \frac{0.0002637 * k * t}{\phi * \mu * c_t * r_w^2}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 8.

3.34 Dimensionless time function (transient heat transfer to the formation)

Input(s)

α: Thermal Diffusivity of the Formation (ft^2/day)
r: Diffusion Depth (ft)
t: Production Time (day)

Output(s)

f(*t*): Dimensionless Time Function that Represents the Transient Heat Transfer to the formation (dimensionless)

Formula(s)

$$f(t) = -\ln\frac{r}{2\sqrt{\alpha t}} - 0.290$$

Reference: Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. *Department of Petroleum Engineering, Stanford University*, Equation no (6.3).

3.35 Dimensionless wellbore storage coefficient (compressible fluids for pressure build-up test)

Input(s)

C: Well Bore Storage Coefficient (bbl/psi)
ø: Porosity (fraction)
c_f: Formation Compressibility (1/psi)
h: Pay zone Thickness (ft)
r_w: Well Bore Radius (ft)

Output(s)

C_d: Dimensionless Wellbore Storage Coefficient (dimensionless)

Formula(s)

$$C_d = \frac{0.8936 * C}{\phi * c_f * h * r_w^2}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 105.

3.36 Flow period duration (hydraulically fractured wells)

Input(s)

ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
μ: Viscosity (cP)
L_f: Fracture Length (ft)
t_{LfD}: Time of End of Linear or Start Pseudo Radial Flow from Plot (dimensionless)
k: Permeability (mD)

Output(s)

t: Duration of Flow Periods (h)

Formula(s)

$$t = \frac{\phi * \mu * c_t * \left(L_f^2\right) * t_{LfD}}{0.0002637 * k}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 115.

3.37 Fracture conductivity (bilinear-flow regime in gas wells)

Input(s)

q: Flow Rate (bbl/d)
ø: Porosity (fraction)
μ: Viscosity (cP)
B: Formation Volume Factor (BBL/STB)

m_b: Slope of Pressure vs Fourth Root of Time (Bi-linear Flow Analysis) (psi/h$^{0.25}$)
c_t: Total Compressibility (1/psi)
k: Permeability (mD)
h: Reservoir Thickness (ft)

Output(s)

w_f. k_f: Fracture Conductivity (ft mD)

Formula(s)

$$w_f.k_f = \left(\frac{44.1 * q * \mu * B}{h * m_b}\right)^2 * \left(\frac{1}{\phi * \mu * c_t * k}\right)^{0.5}$$

Reference: Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 117.

3.38 Fracture conductivity during bilinear flow

Input(s)

Q: Flow Rate (STB/day)
B: Formation Volume Factor (bbl/STB)
μ: Viscosity (cP)
m_{bf}: Slope of Bilinear Flow during Build-up Test (psi/cycle)
h: Thickness (ft)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
k: Permeability (mD)

Output(s)

F_C: Fracture Conductivity (mD ft)

Formula(s)

$$F_C = \left(\frac{44.1 * Q * \mu * B}{m_{bf} * h * (\phi * \mu * c_t * k)^{0.25}}\right)^2$$

Reference: Ahmed, T., *McKinney*, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 95.

3.39 Inflow performance relationship (IPR) for horizontal wells in solution gas-drive reservoirs (Fetkovich)

Input(s)

q_{omax}: Maximum Flow Rate for Maximum Drawdown (STB/day)
P_{wf}: Flowing Bottomhole Pressure (psi)
P: Shut in Pressure or Average Reservoir Pressure (psi)
n: Exponent (dimensionless)

Output(s)

q_o: Oil Flow Rate (STB/day)

Formula(s)

$$q_o = q_{omax} * \left(1 - \left(\frac{P_{wf}}{P}\right)^2\right)^n$$

Reference: Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: *PennWell* Publishing Company. Chapter: 7, Page: 240.

3.40 Inflow performance relationship (IPR) for horizontal wells in solution gas-drive reservoirs (Vogel)

Input(s)

q_{omax}: Maximum Flow Rate for 100% Drawdown (STB/day)
P_{wf}: Flowing Bottomhole Pressure (psi)
P: Shut in Pressure or Average Reservoir Pressure (psi)

Output(s)

q_o: Oil Flow Rate (STB/day)

Formula(s)

$$q_o = q_{omax} * \left(1 - 0.2 * \left(\frac{P_{wf}}{P}\right) - 0.8 * \left(\frac{P_{wf}}{P}\right)^2\right)$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 240.*

3.41 Interporosity flow coefficient in pressure build-up test

Input(s)

ω: Storativity of the Fractures (dimensionless)
ϕ_m: Matrix Porosity (fraction)
h_m: Matrix Thickness (ft)
c_m: Matrix Compressibility (1/psi)
μ: Viscosity (cP)
r_w: Wellbore Radius (ft)
k_f: Fracture Permeability (mD)
t_p: Production Time (day)
Δt: Shut-in Time (h)

Output(s)

λ: Interporosity Flow Coefficient (dimensionless)

Formula(s)

$$\lambda = \left(\frac{w}{1-\omega}\right) * \left(\frac{\phi_m * h_m * c_m * \mu * r_w^2}{1.781 * k_f * t_p}\right) * \left(\frac{tp + \Delta t}{\Delta t}\right)_1$$

or

$$\lambda = \left(\frac{1}{1-\omega}\right) * \left(\frac{\phi_m * h_m * c_m * \mu * r_w^2}{1.781 * k_f * t_p}\right) * \left(\frac{tp + \Delta t}{\Delta t}\right)_2$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 84.*

3.42 Minimum shut-in time to reach pseudo-steady state for tight gas reservoirs being hydraulically fractured

Input(s)

μ_g: Gas Viscosity (cP)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
x_f: Fracture Half Length (ft)
k: Permeability (mD)

Output(s)

t_{pss}: Time (h)

Formula(s)

$$t_{pss} = \frac{474 * \phi * \mu_g * c_t * \left(x_f^2\right)}{k}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 23.*

3.43 Permeability and reservoir pressure from buildup tests

Input(s)

t_p: Time till which drawdown was done (h)
dt_a: Time of shut in 1 from given values or trendline (h)
dt_b: Time of shut in 2 from given values or trendline (h)
pws_a: Well flowing Pressure at shut in point 2 from given values or trendline (psi)
pws_b: Well flowing Pressure at shut in point 1 from given values or trendline (psi)
h: Thickness of Reservoir (ft)
μ: Viscosity of Oil (cP)
p_{hr}: Pressure at $t = 1$ h (psi)
p_{wf}: Pressure flowing well (psi)
Ø: Porosity (fraction)

c_t: Compressibility (1/psi)
r_w: Wellbore Radius (ft)

Output(s)

s: Skin Factor (dimensionless)

Formula(s)

$$s = 1.151 * \left((phr - pwf) - \log\left(\frac{\frac{pws_a - pws_b}{\log\left(\frac{tp + dt_b}{dt_b}\right) - \log\left(\frac{tp + dt_a}{dt_a}\right)}}{\text{Ø} * \mu * c_t * r_w^2} \right) + 3.23 \right)$$

Reference: *Pressure Buildup and Flow Tests in Wells, Matthews & Russell, Page: 21.*

3.44 Permeability and skin factor from a constant-rate flow test

Input(s)

t_a: Time at Pwf1 from given values or trendline (h)
t_b: Time at Pwf2 from given values or trendline (h)
p_w: Well flowing Pressure at point 2 from given values or trend line (psi)
p_{wf}: Well flowing Pressure at point 1 from given values or trendline (psi)
p_i: Initial Pressure (psi)
p_{hr}: Pressure Value at $t = 1$ h (psi)
q: Flow Rate (STB/day)
B: Volume factor (RB/STB)
h: Thickness of reservoir (ft)
μ: Viscosity of Oil (cP)
Ø: Porosity (fraction)
c_t: Compressibility (1/psi)
r_w: Wellbore Radius (ft)

Output(s)

s: Skin Factor (dimensionless)

Formula(s)

$$s = 1.151 * \left(\frac{p_i - phr}{\frac{p_{wf} - p_w}{\log(t_b) - \log(t_a)}} - \log\left(\frac{162.6 * q * B * \frac{\mu}{\left(\frac{p_{wf} - p_w}{\log(t_b) - \log(t_a)}\right) * h}}{\text{Ø} * \mu * c_t * r_w^2} \right) + 3.23 \right)$$

Reference: *Pressure Buildup and Flow Tests in Wells, Matthews & Russell, Page: 57.*

3.45 Pressure buildup equation (Horner equation)

Input(s)

P_i: Initial Reservoir Pressure (psi)
Q_o: Stabilized Well Flow Rate before Shut-in (bbl/d)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (rb/stb)
k: Permeability (mD)
h: Height (ft)
t_p: Flowing Time before Shut-in (day)
Δt: Shut-in Time (day)

Output(s)

P_{ws}: Pressure (psi)

Formula(s)

$$P_{ws} = P_i - \left(\frac{162.6 * Q_o * B_o * \mu_o}{k * h}\right) * \log\left(\frac{t_p + \Delta t}{\Delta t}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 54.*

3.46 Radius of investigation

Input(s)

k: Permeability (mD)
t: Time (h)
ø: Porosity (fraction)
μ: Viscosity (cP)
c_t: Total Compressibility (1/psi)

Output(s)

r_i: Radius of Investigation at the end of Injection Time (ft)

Formula(s)

$$r_i = 0.0359 * \left(\left(\frac{k * t}{\phi * \mu * c_t}\right)^{0.5}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 134.*

3.47 Radius of investigation (flow time)

Input(s)

t: Flow time (h)
k: Permeability (mD)

μ: Viscosity of Oil (cP)
$Ø$: Porosity (fraction)
c_t: Compressibility (1/psi)

Output(s)

r_i: Radius of investigation (ft)

Formula(s)

$$r_i = \left(k * \frac{t}{948 * Ø * \mu * c_t}\right)^{0.5}$$

Reference: *Pressure Buildup and Flow Tests in Wells, Matthews & Russell, Page: 116.*

3.48 Radius of investigation (shut-in time)

Input(s)

dt: Time of shut in (h)
k: Permeability (mD)
μ: Viscosity of Oil (cP)
$Ø$: Porosity (fraction)
c_t: Compressibility (1/psi)

Output(s)

r_i: Radius of investigation (ft)

Formula(s)

$$r_i = \left(k * \frac{dt}{948 * Ø * \mu * c_t}\right)^{0.5}$$

Reference: *Pressure Buildup and Flow Tests in Wells, Matthews & Russell, Page: 117.*

3.49 Raymer hunt transform (porosity/transit time relationship)

Input(s)

ø: Porosity (fraction)
Δt_{ma}: Travel Time in Matrix (μs/ft)
Δt_f: Travel Time in Liquid/fluid (μs/ft)

Output(s)

Δt: Total Travel Time (μs/ft)

Formula(s)

$$\Delta t = \left(\frac{(1-\phi)^2}{\Delta t_{ma}} + \left(\frac{\phi}{\Delta t_f} \right) \right)^{-1}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 56.*

3.50 Reservoir permeability

Input(s)

q_o: Oil Flow Rate (bbl/d)
B_o: Oil Formation Volume Factor (bbl/STB)
μ_o: Oil Viscosity (cP)
m: Slope of Horner Plot (psi/cycle)
h: Pay zone of Thickness (ft)

Output(s)

k_o: Reservoir Permeability (mD)

Formula(s)

$$k_o = 162.6 * (q_o) * (B_o) * \frac{\mu_o}{m * h}$$

Notes: Permeability Evaluated from Horner Plot (Semi-Log Plot).

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 104.*

3.51 Shut-in time for pressure build-up test (Dietz method)

Input(s)

ø: Porosity (fraction)
A: Drainage Area (ft^2)
C_A: Shape Factor (dimensionless)
μ: Viscosity (cP)
c_t: Total Compressibility (1/psi)
k: Permeability (mD)

Output(s)

t_s: Shut-in Time (h)

Formula(s)

$$t_s = \frac{\phi * \mu * c_t * A}{0.0002637 * C_A * k}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 63.*

3.52 Skin during infinite-acting pseudoradial flow for vertical wells

Input(s)

p_i: Initial Pressure (psi)
p_{1hr}: Pressure After 1 Hour (psi)
m: Slope (psi/h)
k: Permeability (mD)
ø: Porosity (fraction)
μ_{Total}: Viscosity (cP)
c_t: Total Compressibility (1/psi)
r_w: Wellbore Radius (ft)

Output(s)

S: Skin (dimensionless)

Formula(s)

$$S = 1.151 * \left(\left(\frac{p_i - p_{1hr}}{m} \right) - \log\left(\frac{k}{ø * \mu_{Total} * c_t * r_w^2} \right) + 3.23 \right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 99.*

3.53 Skin estimation type-1 (pressure buildup test)

Input(s)

P_{hr}: Pressure After One Hour of Well Shut-in (psi)
P_{wf}: Well Flowing Pressure (psi)
m: Slope of Horner Plot (psi/cycle)
k: Permeability (mD)
ø: Porosity (fraction)
c_t: Total Compressibility (1/psi)
r_w: Wellbore Radius (ft)
μ_o: Oil Viscosity (cP)

Output(s)

s: Skin Factor (dimensionless)

Formula(s)

$$s = 1.151 * \left(\left(\frac{(P_{hr}) - P_{wf}}{m} \right) - \log\left(\frac{k}{ø * \mu_o * c_t * r_w^2} \right) + 3.23 \right)$$

Notes: Skin Estimation from Horner Plot (Semi Log Plot).

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 104.*

3.54 Slope of Horner plot in pressure buildup test

Input(s)

Q_o: Stabilized Well Flow Rate before Shut-in (STB/day)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (bbl/STB)
k: Permeability (mD)
h: Thickness (ft)

Output(s)

m: Slope (psi/cycle)

Formula(s)

$$m = \frac{162.6 * Q_o * \mu_o * B_o}{k * h}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 54.*

3.55 Slope of pseudo-steady state flow in pressure buildup test

Input(s)

Q: Flow Rate (STB/day)
B: Formation Volume Factor (bbl/STB)
c_t: Total Compressibility (1/psi)
A: Drainage Area (ft^2)
ø: Porosity (fraction)
h: Thickness (ft)

Output(s)

m_{pss}: Slope (psi/h)

Formula(s)

$$m_{pss} = \frac{0.23396 * Q * B}{c_t * A * h * \phi}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 33.*

3.56 Time to pseudo-steady state (single well-circular reservoir)

Input(s)

Ø: Porosity (fraction)
μ: Viscosity (cP)
c_t: Compressibility (/psi)
r_e: Radius of reservoir (ft)
k: Permeability (mD)

Output(s)

t_{pss}: Pseudo steady state (h)

Formula(s)

$$tpss = 1200 * Ø * \mu * c_t * \frac{r_e^2}{k}$$

Reference: *Pressure Buildup and Flow Tests in Wells, Matthews & Russell, Page: 13.*

3.57 Time to reach the semi-steady state for a gas well in a circular or square drainage area

Input(s)

μ_{gi}: Initial Gas Viscosity (cP)
ø: Porosity (fraction)
A: Drainage Area (ft^2)
k: Effective Gas Permeability (mD)
c_{ti}: Initial Total Compressibility (1/psi)

Output(s)

t_{pss}: Time (h)

Formula(s)

$$t_{pss} = \frac{15.8\phi * \mu_{gi} * c_{ti} * A}{k}$$

Reference: Ahmed, T., *McKinney*, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 194.

3.58 True wellbore storage coefficient (pressure build-up test)

Input(s)

A_{wb}: Cross Sectional Area of Well Bore (ft^2)
ρ_{wb}: Density of Fluid in Well Bore (lbm/ft^3)

Output(s)

C: Wellbore Storage Coefficient (BBL/PSI)

Formula(s)

$$C = 25.65 * \frac{A_{wb}}{\rho_{wb}}$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 105.*

3.59 Well flow efficiency (geothermal well)

Input(s)

p^*: Horner's False Pressure at (t + Δt =1) (psi)
P_{wf}: Bottomhole Pressure at a flowing well (psi)
Δp_{skin}: Pressure Drop caused by the Skin Effect (psi)

Output(s)

FE: Flow Efficiency (per cent)

Formula(s)

$$FE = \frac{p^* - p_{wf} - \Delta p_{skin}}{p^* - p_{wf}}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University, Page: (5.14).*

3.60 Well shut-in pressure during buildup (Horner plot)

Input(s)

p_i: Initial False Pressure (psi)
Q_o: Stabilized Well Flow Rate before Shut-in (STB/day)
B_o: Oil Formation Volume Factor (bbl/STB)
k: Permeability (mD)
μ_o: Oil Viscosity (cP)
t_p: Flowing Time before Shut-in (h)
Δt: Shut-in Time (h)
h: Thickness (ft)

Output(s)

p_{ws}: Shut-in Pressure (psi)

Formula(s)

$$p_{ws} = p_i - \left(\frac{162.6 * Q_o * \mu_o * B_o}{k * h}\right) * \log\left(\frac{t_p + \Delta t}{\Delta t}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 56.*

Chapter 4

Production engineering formulas and calculations

Chapter Outline

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4.1 Acid penetration distance (acidizing)

Input(s)

$\overline{w}$: Average Fracture Width (ft)
L_{aD}: Dimensionless Acid Penetration Distance (dimensionless)
N_{Re}: Reynolds Number (dimensionless)
N_{Re^*}: Reynolds Number for Fluid Loss (dimensionless)

Output(s)

xL: Acid Penetration Distance (ft)

Formula(s)

$$xL = \frac{\overline{w} L_{aD}}{2} \left(\frac{N_{re}}{N_{Re^*}} \right)$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 62.*

4.2 Additional pressure drop in the skin zone

Input(s)

Q_o: Well Flow Rate (STB/day)
B_o: Oil Formation Volume Factor (bbl/STB)
μ_o: Oil Viscosity (cP)
k: Reservoir Permeability (mD)
h: Thickness (ft)
S: Skin (dimensionless)

Output(s)

ΔP_{skin}: Pressure Drop Due to Skin (psi)

Formula(s)

$$\Delta P_{skin} = \left(\frac{141.2 * Q_o * B_o * \mu_o}{k * h} \right) * S$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 37.*

4.3 Additive crystalline salt amount to increase the density—Method I (single-salt systems)

Input(s)

V_i: Volume of Initial Brine Formulation (bbl)
ρ_i: Density of Fluid (g/cm^3)
C_{sf}: Concentration of Salt in Final Formulation (%)
C_{si}: Concentration of Salt in Initial Formulation (%)
P_s: Purity of Salt to be added (%)

Output(s)

m_s: Additional Salt need to raise the Density (lbm)

Formula(s)

$$m_s = \frac{V_i(42\,gal/bbl)(\rho_i)\left(C_{sf} - C_{si}\right)}{P_s - mC_{sf}}$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 54.*

4.4 Additive crystalline salt amount to increase the density—Method II (single-salt systems)

Input(s)

V_i: Volume of Initial Brine Formulation (bbl)
V_f: Volume of Brine Following the Adjustment (bbl)
C_{sf}: Concentration of Salt in Final Brine Formulation (lbm/bbl)
C_{si}: Concentration of Salt in Initial Brine Formulation (lbm/bbl)

Output(s)

m_s: Additional Salt need to raise the Density (lbm)

Formula(s)

$$m_s = \left(C_{sf}V_f\right) - \left(C_{si}V_i\right)$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 55.*

4.5 Additive crystalline salt and water amount to increase the density—Method I (two-salt systems)

Input(s)

V_i: Volume of Initial Brine (bbl)
V_w: Total Water Volume to add to achieve the Final Brine Density (bbl)
C_{msf}: Concentration of More Soluble Salt in Final Brine Formulation (%) (lbm/bbl)
C_{lsf}: Concentration of Less Soluble Salt in Final Brine Formulation (lbm/bbl)
C_{msi}: Concentration of More Soluble Salt in Initial Brine Formulation (lbm/bbl)
C_{lsi}: Concentration of Less Soluble Salt in Initial Brine Formulation (lbm/bbl)
W_i: Water Fraction in Initial Brine Formulation (fraction)
W_f: Water Fraction in Final Brine Formulation (fraction)
V_f: Final Volume of Brine after Adjustment (bbl)

Output(s)

m_{ms}: Additional More Soluble Salt need to raise the Brine Density (lbm)

Formula(s)

$$m_{ms} = (V_i)\frac{C_{lsi}C_{msf}}{C_{lsf}} - C_{msi}$$

$$V_w = (V_i)\frac{C_{lsi}W_f}{C_{lsf}} - W_i$$

$$V_f = \frac{C_{lsi}V_i}{C_{lsf}}$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 56.*

4.6 Annulus pressure loss due to friction during hydraulic fracturing (laminar flow)

Input(s)

v: Average Velocity (ft/s)
L: Pipe Length (ft)
d_0: Inner Diameter of the Outer Pipe (in.)
d_1: Outer Diameter of the Inner Pipe (in.)
μ_p: Plastic Viscosity (cP)
τ_y: Yield Point of the Liquid (lb/100ft^2)

Output(s)

ΔP_f: Pressure Loss in the wellbore due to Frictions during Hydraulic Fracturing (psi)

Formula(s)

$$\Delta P_f = \frac{\mu_p L v}{1000\,(d_0 - d_i)^2} + \frac{\tau_y \cdot L}{200 \cdot (d_0 - d_i)}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publiching Co., Page: 31.*

4.7 Annulus pressure loss due to friction during hydraulic fracturing (turbulence flow)

Input(s)

ρ: Liquid Density (lb/gal)
v: Average Velocity (ft/s)
f: Fanning Friction Factor (dimensionless)
L: Pipe Length (ft)
d_0: Inner Diameter of the Outer Pipe (in.)
d_1: Outer Diameter of the Inner Pipe (in.)

Output(s)

ΔP_f: Pressure Loss in the wellbore Sourced by Frictions during Hydraulic Fracturing (psi)

Formula(s)

$$\Delta P_f = \frac{f \cdot L \cdot \rho \cdot v^2}{25.80 \cdot (d_0 - d_i)}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 31.*

4.8 Approximate ideal counterbalanced load

Input(s)

PPRL: Peak Polished Rod Load (lb)
MPRL: Minimum Polished Rod Load (lb)

Output(s)

AICB: Ideal Counterbalance (lb)

Formula(s)

$$AICB = \frac{PPRL + MPRL}{2}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 12/169.*

4.9 Average downstroke load (sucker-rod pump)

Input(s)

C: Calibration Constant of Dynamometer Card (lb/in.)
A: Lower Area of Card (in.^{2})
L: Length of Card (in.)

Output(s)

ADL: Average Downstroke Load (lb)

Formula(s)

$$ADL = C * \frac{A}{L}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 18/269.*

4.10 Average fracture width (acidizing)

Input(s)

π: Pi Number (dimensionless)
w_w: Fracture width at the Wellbore (m)

Output(s)

$\overline{w}$: Average Fracture width at the Wellbore (m)

Formula(s)

$$\overline{w} = \frac{\pi w_w}{4}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 41.*

4.11 Average permeability of a hydraulically fractured formation

Input(s)

k_{avgz}: Average Permeability of a Hydraulically Fractured Zone (mD)
k: Permeability of the Formation (mD)
h: Formation Thickness (ft)
W: Fracture Thickness (ft)
r_e: Drainage Radius of the Well (in.)
r_w: Radius of the Well (in.)
r_f: Radius of the Fracture (in.)

Output(s)

k_{avg}: Average Permeability of a Hydraulically Fractured Formation (mD)

Formula(s)

$$k_{avg} = \frac{k \cdot k_{avgz} \cdot ln\left(\frac{r_e}{r_w}\right)}{k_{avgz} \cdot ln\left(\frac{r_e}{r_f}\right) + k \cdot ln\left(\frac{r_f}{r_w}\right)}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 7.*

4.12 Average specific weight of the formation (hydraulic fracturing)

Input(s)

γ_{min}: Specific Weight of Minerals (p/cm^3)
γ_{Liq}: Specific Weight of Liquid Phase (p/cm^3)
Ø: Porosity (fraction)

Output(s)

$\gamma_{formation}$: Average Specific Weight of the Formation (p/cm^3)

Formula(s)

$$\gamma_{formation} = (1 - \text{Ø})\,\gamma_{min} + \text{Ø} \cdot \gamma_{Liq}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 5.*

4.13 Average upstroke load (sucker-rod pump)

Input(s)

C: Caliberation Constant of Dynamometer (lb/in.)
a: Lower Area of Card (in.^{2})
A: Area of Upper Card (in.^{2})
L: Length of Dynamometer Card (in.)

Output(s)

AUL: Average Upstroke Load (lb)

Formula(s)

$$AUL = C * \frac{A + a}{L}$$

Notes: Calculations Based on Dynamometer Card.

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 18/269.*

4.14 Average wellbore fluid density (completion and workover fluids)

Input(s)

ρ_m: Measured Ambient (or Surface) Fluid Density (lbm/bbl)
$\Delta\rho_i$: Incremental Wellbore Fluid Density Change (lbm/bbl)
n: Number of Linear Depth intervals (dimensionless)

Output(s)

$\overline{\rho}$: Average Wellbore Fluid Density (lbm/bbl)

Formula(s)

$$\overline{\rho} = \rho_m - \left[\sum_{i=1}^{n} \frac{(\Delta\rho_i)}{n} - 1\right]$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 46.*

4.15 Capacity ratio of a hydraulically fractured surface

Input(s)

k_f: Fracture Permeability (mD)
k: Average Formation Permeability (mD)
h: Formation Thickness (ft)
W: Fracture Thickness (ft)

Output(s)

c_f: Cumulative Present Value of Production ($)

Formula(s)

$$c_f = \frac{k_f \cdot W}{k \cdot h}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 92.*

4.16 Choke discharge coefficient

Input(s)

d: Upstream Pipe Diameter (in.)
d_c: Choke Diameter (in.)
N_R: Reynold's Number based on d_c (dimensionless)

Output(s)

C_d: Choke Discharge Coefficient (dimensionless)

Formula(s)

$$C_d = \left(\frac{d_c}{d}\right) + \left(\frac{0.3167}{\left(\frac{d_c}{d}\right)^{0.6}}\right) + 0.025 * (\log(N_R) - 4)$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 5/60.*

4.17 Close-ended displacement volume of pipe

Input(s)

D_o: Outside Diameter of Pipe (in.)
L: Length of Pipe (ft)

Output(s)

V_c: Close-ended Diameter of Pipe (bbl)

Formula(s)

$$\mathrm{V\_c} = \left(0.7854 * \mathrm{D_o}^2 * \mathrm{L}\right)/808.5$$

$$V_c = \frac{0.7854 * D_o^2 * L}{808.5}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 45.*

4.18 Convective mass transfer for laminar flow (acidizing)

Input(s)

D_A: Diffusion Coefficient of Component A (cm^2/s)
$\partial c_A/\partial Y$: Concentration Gradient (mol/cm^4)
c_a: Concentration of Flowing Acid (mol/cm^3)
V_N: Fluid Velocity Normal to the Surface (cm/s)

Output(s)

$U_{a,\,y}$: Diffusion Flux of a Component A in Y direction (mol/cm^2 s)

Formula(s)

$$U_{a,y} = -D_A \frac{\partial c_a}{\partial Y} + c_a V_N$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page 22.*

4.19 Convective mass transfer for turbulent flow (acidizing)

Input(s)

D_A: Diffusion Coefficient of Component A (cm^2/s)
D_E: Effective Diffusion Coefficient of Component A (cm^2/s)
dc_a/dY: Concentration Gradient (mol/cm^4)
c_a: Concentration of Flowing Acid (mol/cm^3)
$<c_a>$: Average Concentration of Flowing Acid (mol/cm^3)
$<c_a(w)>$: Average Concentration of Flowing Acid (mol/cm^3)
V_N: Fluid Velocity Normal to the Surface (cm/s)
$<V_N>$: Average Fluid Velocity Normal to the Surface (cm/s)
K_g: Effective Mass Transfer Coefficient (cm/s)

Output(s)

$U_{a,\,y}$: Diffusion Flux of a Component A in Y direction (mol/cm^2 s)
$<U_{a,\,y}>$: Average Diffusion Flux of a Component A in Y direction (mol/cm^2s)

Formula(s)

$$<U_{a,y}> = -D_A \frac{d<c_a>}{\partial Y} + <c_a V_N>$$

$$<U_{a,y}> = -D_E \frac{d<c_a>}{dY} + <c_a><V_N>$$

$$<U_{a,y}> = K_g[<c_a> - <c_a(w)>] + <c_a><V_N>$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page 23.*

4.20 Correct counterbalance (sucker-rod pump)

Input(s)

AUL: Average Upstroke Load (lb)
ADL: Average Downstroke Load (lb)

Output(s)

CCB: Correct Counterbalance (lb)

Formula(s)

$$CCB = \frac{AUL + ADL}{2}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 18/269.*

4.21 Corresponding reciprocal rate (post-fracture production—Constant Bottomhole flowing conditions)

Input(s)

q_D: Dimensionless Reciprocal Rate from Match Point (1/q_d) (dimensionless)
B_g: Gas Formation Volume Factor (RB/MSCF)
p_{ai}: initial Adjusted Pressure (psi)
p_{awf}: Adjusted Well Flowing Pressure (psi)
ϕ: Porosity (dimensionless)
c_t: Total Compressibility (1/psi)
μ: Viscosity (cP)
h: Formation Thickness (ft)
C_{rD}: Dimensionless Fracture Conductivity (dimensionless)
L_f: Fracture Length (ft)
t_{LfD}: Ending of Linear Part or Starting Time of Pseudo Radial Flow from Plot (dimensionless)
k: Permeability (mD)
Δt: Time Difference from Data (h)

Output(s)

$\left(\frac{1}{q}\right)_{MP}$: Reciprocal Rate from Match Point (1/q)_(mp) (Days/MSCF)
L_{fMP}: Length of Fracture from Match Point Analysis (ft)
w_{fk_f}: Fracture Conductivity from Dimensionless Fracture Conductivity (mD ft)

Formula(s)

$$\left(\frac{1}{q}\right)_{MP} = \left(141.2 * B_g * \frac{\mu}{k * h * \left(p_{ai} - p_{awf}\right)}\right) * \left(\frac{1}{q_D}\right)$$

$$L_{fMP} = \left(\left(\frac{0.0002637 * k}{\phi * \mu * c_t}\right) * \left(\frac{\Delta t}{t_{LfD}}\right)\right)^{\frac{1}{2}}$$

$$w_{fk_f} = \pi * k * C_{rD} * L_f$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 126.*

4.22 Damaged/undamaged zone productivity comparison (acidizing)

Input(s)

F_k: Permeability Ratio (dimensionless)
r_e: Drainage Radius (in.)
r_w: Wellbore Radius (in.)
r_s: Damaged Zone Radius (in.)

Output(s)

J_s: Damaged or Stimulated Formation Productivity Index (STB/day/psi)
J_o: Undamaged Formation Productivity Index (STB/day/psi)

Formula(s)

$$\frac{J_s}{J_o} = \frac{F_k log\, r_e/r_w}{log\, r_s/r_w + F_k log\, r_e/r_s}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 6.*

4.23 Density of brine (completion and workover fluids)

Input(s)

ρ_m: Density of Brine at ambient Surface Pressure and Temperature (lbm/gal)
C_{te}: Coefficient of Thermal Expansion or Volume Expansion Factor (dimensionless)
T_m: Ambient Temperature of Brine-Density Measurement (°F)
T_s: Standard Reference Temperature (70 °F)

Output(s)

ρ_s: Density of Brine at Standard Reference Temperature (lbm/gal)

Formula(s)

$$\rho_s = \rho_m \left[1 + C_{te}\left(T_m - T_s\right)\right]$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 45.*

4.24 Dimensionless fracture width for linear vertical fracture (Geertsma & Klerk)

Input(s)

C: Over-all Fluid-Loss Coefficient (m/(s$^{0.5}$))
h: Fracture Height (m)
E: Young's Modulus of the Formation Rock (kg/m-s^2)
i: Fluid Injection Rate (m^3/s)
t: Total time for Fluid Injection (s)
w_w: Fracture width at the Wellbore (m)
V_{spt}: The Spurt Volume (m^3/m^2)

Output(s)

K_L: Dimensionless Fracture Length (dimensionless)
K_u: Reciprocal Dimensionless Fracture Width (dimensionless)
K_s: Dimensionless Fluid-Loss Coefficient (dimensionless)
$K_{\eta L}$: Dimensionless Variable (dimensionless)

Formula(s)

$$K_L = CLh/i\sqrt{t}$$
$$K_u = C\sqrt{t}/w_w$$
$$K_s = C\sqrt{t}/V_{spt}$$
$$K_{\eta L} = 21.8\left(\frac{i}{hC^2}\right)^3\left(\frac{\mu}{Et}\right)$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 40.*

4.25 Downhole operating pressure (hydraulic fracturing)

Input(s)

ΔP_f: Pressure Loss Sourced by Friction (psi)
ΔP_p: Pressure Loss sourced by Perforations(psi)
ΔP_h: Hydrostatic Pressure Change (psi)
P_{inj}: Injection Pressure (psi)
D: Fracture Elevation Depth (ft)
G_f: Fracture Gradient (psi/ft)

Output(s)

P_F: Downhole Operating Pressure (psi)

Formula(s)

$$P_F = G_f \cdot D$$
$$G_f = \frac{P_{inj} + \Delta P_h - \Delta P_f - \Delta P_p}{D}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 25.*

4.26 Entrance hole size (perforation)

Input(s)

σ_y: Yield Strength of Casing of Interest (ksi)
σ_{yr}: Yield Strength of Reference Casing (ksi)
d_r: Entrance Hole Diameter in Reference Casing (in.)

Output(s)

d: Entrance Hole Diameter in Casing of Interest (in.)

Formula(s)

$$d = \left(\frac{\sigma_{yr}}{\sigma_y}\right)^{0.5} d_r$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 50.*

4.27 Equivalent skin factor in fractured wells

Input(s)

x_f: Fracture Half Length (ft)
r_w: Wellbore Radius (ft)

Output(s)

S_f: Equivalent Skin (unitless)

Formula(s)

$$S_f = 0.7 - \ln\left(\frac{x_f}{r_w}\right)$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 17/257.*

4.28 Filter cake on the fracture (acidizing)

Input(s)

C_w: Fluid Loss Coefficient, (m/s$^{1/2}$)
$\sqrt{t}$: Time root (s$^{1/2}$)

Output(s)

v_N: Fluid Loss Velocity (m/s)

Formula(s)

$$v_N = \frac{C_w}{\sqrt{t}}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 41.*

4.29 Flow coefficient during drawdown

Input(s)

p_{wf}: Wellbore Flowing Pressure (psi)
P_i: Average Pressure (psi)
Δp_{skin}: Pressure Drop Due to Skin (psi)

Output(s)

E: Flow Coeffcient (fraction)

Formula(s)

$$E = \frac{P_i - p_{wf} - \Delta p_{skin}}{P_i - p_{wf}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 64.*

4.30 Flow rate through orifice

Input(s)

Cd: Dimensionless Flow Factor (dimensionless)
ρ_1: Initial Density (ppg)
ρ_2: Final Density (ppg)
P_1: Initial Pressure (psi)
P_2: Final Pressure (psi)
γ: Adiabatic Constant (dimensionless)
S_o: Output Cross Section (ft^2)
S_1: Input Cross Section (ft^2)

Output(s)

w: Flow Rate (ft^3/s)

Formula(s)

$$w = Cd * \rho_2 * S_o * \left(\frac{2 * \left(\frac{P_1}{\rho_1}\right) * \left(\frac{\gamma}{\gamma - 1}\right) * \left(1 - \left(\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)\right)}{1 - \left(\left(\frac{S_o}{S_1}\right)^2\right) * \left(\left(\frac{P_2}{P_1}\right)^{\frac{2}{\gamma}}\right)} \right)^{0.5}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 15, Page: 472.*

4.31 Flow through fracture in response to pressure gradient

Input(s)

μ: Fluid Viscosity (cP)
L: Length (ft)

υ: Poisson (dimensionless)
P_f: Fracture Pressure (psi)
S_c: Least Principle Stress (psi)
E: Young Modulus (psi)
ΔP: Pressure Gradient (psi)

Output(s)

Q: Flow Rate (ft^3/s)

Formula(s)

$$Q = \left(\frac{\pi * \Delta P}{8 * \mu}\right) * \left(\left(\frac{L * (1 - \upsilon^2) * \left(P_f - S_c\right)}{E}\right)^3\right)$$

Reference: *Mark D. Zoback., Reservoir Geomechanics, Cambridge University Express, UK, Page: 142.*

4.32 Formation fluid compressibility (acidizing)

Input(s)

K_o, K_w, K_g: Isothermal coefficient of Compressibility of Reservoir Oil. Water and Gas (psi^{-1})
S_o, S_w, S_g: Oil, Water and Gas Saturation Fractions (dimensionless)

Output(s)

K_{fl}: Fracture Conductivity (mD in.)

Formula(s)

$$K_{fl} = S_o(K_o) + S_w(K_w) + S_g\left(K_g\right)$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing Fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 56.*

4.33 Fracture area of a hydraulically fractured formation

Input(s)

q_i: Injection Rate (m^3/min)
W: Fracture Thickness (ft)
t: Injection Time (min)
C: Fracture Liquid Coefficient $\left(m/\sqrt{min}\right)$

Output(s)

$A(t)$: Fracture Area in time “t” (m^2)

Formula(s)

$$A(t) = \left[\frac{q_i \cdot W}{4\pi \cdot C^2}\right] \cdot \left[e^{x^2} erfc(x) + \frac{2x}{\sqrt{\pi}} - 1\right]$$

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2} dt$$

$$x = 2C\frac{\sqrt{\pi t}}{W}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 12.*

4.34 Fracture coefficient of a hydraulically fractured reservoir

Input(s)

m: Slope of the Production Decline Curve (ft^3/min)
A_f: Fractured Surface Area (ft^2)

Output(s)

C_f: Fracture Coefficient of a Hydraulically Fractured Well (ft/min)

Formula(s)

$$C_f = \frac{0.0164 \cdot m}{A_f}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 99.*

4.35 Fracture fluid coefficient for reservoir-controlled liquids

Input(s)

k: Effective Permeability (Darcy)
Ø: Effective Porosity (%)
μ: Viscosity of Reservoir Fluid (cP)
ΔP: Pressure difference in Fracture Face (psi)
c_f: Isothermal Compressibility of Reservoir Fluid (psi^{-1})
c: Conversion Coefficient (dimensionless)

Output(s)

C_r: Fracture Fluid Coefficient for Viscosity-Controlled Liquids (dimensionless)

Formula(s)

$$C_r = c \cdot \Delta P \left(\frac{k \cdot c_f \cdot Ø}{\mu}\right)^{1/2}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 20.*

4.36 Fracture fluid coefficient for viscosity-controlled liquids

Input(s)

k: Effective Permeability (Darcy)
$Ø$: Effective Porosity (%)
μ_f: Viscosity of Fracturing Fluid in Reservoir Conditions (cP)
ΔP: Pressure difference in Fracture Face (psi)
c: Conversion Coefficient (dimensionless)

Output(s)

C_v: Fracture Fluid Coefficient for Viscosity-Controlled Liquids (dimensionless)

Formula(s)

$$C_v = c\left(\frac{k \cdot \Delta P \cdot Ø}{\mu_f}\right)^{1/2}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 17.*

4.37 Fracture geometry (acidizing)

Input(s)

i/h: Injection Rate per unit of Fracture Height (m^2/s)
μ: Fluid Viscosity (kg/m s)
E: Young's Modulus (kg/m s^2)
L: Fracture Length (m)

Output(s)

W_w: Fracture width at the Wellbore (m)

Formula(s)

$$\frac{W_w}{L} \approx \left(\frac{\mu i}{EhL^2}\right)^{0.25}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 29.*

4.38 Fracture gradient (hydraulic fracturing)

Input(s)

ΔP_f: Pressure Loss Sourced by Friction (psi)
ΔP_p: Pressure Loss sourced by Perforations (psi)
ΔP_h: Hydrostatic Pressure Change (psi)
P_{inj}: Injection Pressure (psi)

Output(s)

G_f: Fracture Gradient (psi/ft)

Formula(s)

$$G_f = \frac{P_{inj} + \Delta P_h - \Delta P_f - \Delta P_p}{D}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 25.*

4.39 Fracture-fluid invasion of the formation (acidizing)

Input(s)

ΔP_v: Pressure difference between the fracture wall and the interface between the penetrating fracture fluid-formation fluids (psi)

μ: Viscosity (cP)
Ø: Porosity (per cent)
k: Permeability (Darcy)
t: Time (min)

Output(s)

v_N: Fluid Loss Velocity (ft/min)

Formula(s)

$$v_N = 0.0374\sqrt{\frac{k\text{Ø}(\Delta P_v)}{\mu t}}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 41.*

4.40 Frictional pressure drop (Economides and Nolte)

Input(s)

q: Injection Rate (bbl/min)
μ: Fluid Viscosity (cP)
ρ: Density of Fluid (g/cc)
D: Tubing Diameter (in.)
L: Tubing Length (ft)

Output(s)

ΔP_f: Frictional Pressure Drop (psi)

Formula(s)

$$\Delta P_f = 518 * \rho^{0.79} * q^{1.79} * \mu^{0.207} * \frac{L}{1000 * D^{4.79}}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 16/246.*

4.41 Gas velocity under sonic flow conditions (through choke)

Input(s)

K_s: Empirical Gas Constant (ft/s)
ρ_l: Liquid Density (g/cc)
ρ_g: Gas Density (g/cc)

Output(s)

v: Allowable Gas Velocity (ft/s)

Formula(s)

$$v = K_s * \left(\frac{\rho_l - \rho_g}{\rho_g}\right)^{0.5}$$

Reference: *John M. Campbell, 1992. Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, Vol. 2, Page: 73.*

4.42 Hydraulic fracture efficiency

Input(s)

x: Fracture Length (ft)
t: Injection Time (min)
C: Fracture Liquid Coefficient $\left(\mathrm{m}/\sqrt{\mathrm{min}}\right)$

Output(s)

η: Hydraulic Fracture Efficiency (%)

Formula(s)

$$\eta = \left[\frac{1}{x^2}\right] \cdot \left[e^{x^2} erfc(x) + \frac{2x}{\sqrt{\pi}} - 1\right]$$

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2} dt$$

$$x = 2C \frac{\sqrt{\pi t}}{W}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 23.*

4.43 Hydraulic horse power for a hydraulic fracturing operation

Input(s)

P_{inj}: Injection Pressure (psi)
q_t: Injection Rate (bbl/day)

Output(s)

H_h: Hydraulic Horse Power (hp)

Formula(s)

$$H_h = 0.0245 \cdot P_{inj} \cdot q_t$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 24.*

4.44 Ideal fracture conductivity created by acid reaction (acidizing)

Input(s)

h: Fracture Height (ft)
i: Injection rate (ft^3/min)
t: Time (min)
xL: Acid Penetration Distance (ft)
X: Acid Dissolving Power (ft^3/ft^3)
Ø: Porosity (per cent)

Output(s)

w_a: Opened Channel of (Dissolved) Width (ft)

Formula(s)

$$w_a = \frac{X \cdot i \cdot t}{2\,xL \cdot h(1 - Ø)}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 49.*

4.45 Incremental density in any wellbore interval (completion and workover fluids)

Input(s)

g_p: Pressure Gradient (psi/ft)
ΔD: Depth Interval (ft)
B: Pressure Compressibility Coefficient (lbm/gal/1000 psi)
A: Thermal Expansion Coefficient ($°F^{-1}$)
g_T: Temperature Gradient (°F/ft)

Output(s)

$\Delta\rho_i$: Incremental Wellbore Fluid Density Change (lbm/bbl)

Formula(s)

$$\Delta\rho_i = (B)\cdot\left(g_p\right)\cdot(\Delta D) - (A)\cdot(g_T)\cdot(\Delta D)$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 46.*

4.46 Initial rate following a hydraulic fracturing operation

Input(s)

Q_{pre}: Rate before the Hydraulic Fracturing Operation (bbl/d)
r_e: Drainage Radius of the Well (in.)
r_w: Hole Radius of the Well (in.)
r_f: Radius of the Fracture (in.)
k_f: Fracture Permeability (mD)
k_e: Average Formation Permeability (mD)

Output(s)

Q: Initial Rate Following a Hydraulic Fracturing Operation (bbl/d)

Formula(s)

$$Q = Q_{pre}\left[\frac{\left(k_f/k_e\right)\log\left(r_e/r_w\right)}{\log\frac{r_f}{r_w} + \left(\frac{k_f}{k_e}\cdot\log\frac{r_e}{r_f}\right)}\right]$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 84.*

4.47 Injection pressure for hydraulic fracturing

Input(s)

P_F: Downhole Fracturing Operation Pressure (psi)
ΔP_f: Pressure Loss Sourced by Friction (psi)
ΔP_p: Pressure Loss sourced by Perforations (psi)
ΔP_h: Hydrostatic Pressure Change (psi)

Output(s)

P_{inj}: Injection Pressure (psi)

Formula(s)

$$P_{inj} = P_F + \Delta P_f + \Delta P_p - \Delta P_h$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 24.*

4.48 Lifetime of a hydraulically fractured well

Input(s)

m: Slope of the Production Decline Curve (bbl/day)
Q_a: Production Rate just before the Abandonment of the Well (bbl/d)
Q_0: Initial Production Rate following the Hydraulic Fracturing Operation (bbl/d)

Output(s)

t: Lifetime of a Hydraulically Fractured Well (days)

Formula(s)

$$t = ln\left(\frac{Q_a}{Q_0}\right) \cdot \frac{1}{|m|}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 86.*

4.49 Mass of rock dissolved per unit mass of acid (acidizing)

Input(s)

M_{wm}: Molecular Weight of Mineral (Rock) (g/mol)
M_{wa}: Molecular Weight of Acid (g/mol)
A: Stoichiometric Coefficient of Mineral (Rock) (Number of Molecules)
B: Stoichiometric Coefficient of Acid (Number of Molecules)

Output(s)

β: Acid Dissolving Power (g/g)

Formula(s)

$$\beta = \frac{M_{wm} \times A}{M_{wa} \times B}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing Fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 13.*

4.50 Mass transfer in acid solutions by Fick's law (acidizing)

Input(s)

D_A: Diffusion Coefficient of Component A (cm^2/s)
$\partial c_a / \partial Y$: Concentration Gradient (mol/cm^4)

Output(s)

$U_{a,y}$: Diffusion Flux of a Component A in Y direction (mol/cm^2 s)

Formula(s)

$$U_{a,y} = -D_A \frac{\partial c_a}{\partial Y}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing Fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 21.*

4.51 Maximum treatment pressure (hydraulic fracturing)

Input(s)

P_b: Formation Breakdown Pressure (psi)
ΔP_h: Hydrostatic Pressure Drop (psi)
ΔP_f: Frictional Pressure Drop (psi)

Output(s)

P_{si}: Surface Injection Pressure (psi)

Formula(s)

$$P_{si} = P_b - \Delta P_h + \Delta P_f$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 17/259.*

4.52 Mechanical resistant torque (PCP)

Input(s)

V_o: Pump Displacement (ft^3)
ΔP: Pump Head Rating (psi)
e_p: Efficiency (fraction)

Output(s)

T_m: Surface Injection Pressure (psi)

Formula(s)

$$T_m = 144 * V_o * \frac{\Delta P}{e_p}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 14/214.*

4.53 Minimum polished rod load (sucker rod pump)

Input(s)

C: Dynamometer Calibration Constant (lb/in.)
d: Minimum Deflection (in.)

Output(s)

MPRL: Minimum Polished Rod Load (lb)

Formula(s)

$$MPRL = C * d$$

Notes: Based on Dynamometer Card.

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 18/269.*

4.54 Peclet number for fluid loss (acidizing)

Input(s)

$\overline{w}$: Average Fracture Width (ft)
$\overline{v_N}$: Average Fluid Loss Velocity (ft/min)
D_e^{∞}: Effective Diffusivity (ft^2/min)

Output(s)

N_{Pe^*}: Peclet Number (dimensionless)

Formula(s)

$$N_{Pe^*} = \frac{\overline{w}\,\overline{v_N}}{2D_e^{\infty}}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 62.*

4.55 Perforation friction factor

Input(s)

q_t: Total Flow Rate (bbl/min)
n: Number of Perforations (dimensionless)
d: Casing Entrance-Hole Diameter (in.)
C_d: Discharge Coefficient (dimensionless)
ρ_o: Oil Density (lbf/in.^{2})

Output(s)

p_f: Perforation Friction (Differential Pressure across Perforations) (psi)

Formula(s)

$$p_f = \frac{0.2369 q_t^2 \rho_o}{n^2 d^4 C_d^2}$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 79.*

4.56 Perforation friction pressure

Input(s)

Q: Flow Rate (m^3/min)
ρ: Fluid Density (kg/L)
n: Number of Perforations (unitless)
D_p: Diameter of Perforation (cm)
C: Perforation Coefficient (0.6–1.0) (unitless)

Output(s)

ΔP_{pf}: Perforation Friction Pressure (MPa)

Formula(s)

$$\Delta P_{pf} = 22.335 * \frac{Q^2 * \rho}{n^2 * C^2 * D_p^4}$$

Reference: *Daneshy, A. 2013. Fundamentals of Hydraulic Fracturing, Daneshy Consultants International, Page: 93.*

4.57 Perforation hole size (perforation)

Input(s)

x: Brinell Hardness of Casing of Interest (dimensionless)
d_r: Entrance Hole Diameter in Reference Casing (in.)
x_r: Brinell Hardness of Reference Casing (dimensionless)

Output(s)

d: Entrance Hole Diameter in Casing of Interest (in.)

Formula(s)

$$d = \left(\frac{[2,250 + 4.2x_r]}{[2,250 + 4.2x]}\right)^{0.5} d_r$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers., Page: 50.*

4.58 Perforation length in formation

Input(s)

L_{pr}: Total Target Penetration in Reference Target (in.)
d_{wb}: Wellbore Diameter (in.)
d_{ci}: Casing Inner Diameter (in.)

Output(s)

L_p: Total Target Penetration in Formation of Interest (in.)

Formula(s)

$$L_p = \left(L_{pc}\right) - 0.5(d_{wb} - d_{ci})$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 52.*

4.59 Perforation penetration ratio (formation of interest/reference formation)

Input(s)

c_r: Compressive Strength of reference Formation (ksi)
c: Compressive Strength of Formation of Interest (ksi)

Output(s)

L_p: Total Target Penetration in Formation of Interest (in.)
L_{pr}: Total Target Penetration in Reference Formation (in.)

Formula(s)

$$\frac{L_p}{L_{pr}} = \exp\left[0.086(c_r - c.\right]$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 51.*

4.60 Perforation skin factor

Input(s)

s_H: Horizontal or Plane Flow Skin (dimensionless)
s_v: Vertical or Converging Flow Skin (dimensionless)
s_{wb}: Skin resulted by the Wellbore Effect (dimensionless)
s_{pd}: Skin caused by the Damaged Zone around Perforation (dimensionless)

Output(s)

s_p: Perforation Skin (dimensionless)

Formula(s)

$$s_p = s_H + s_v + s_{wb} + s_{pd}$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 65.*

4.61 Pore growth function (acidizing)

Input(s)

r_{ave}: Average Wall Reaction Rate taken over the entire Reactive Surface Area (mol/cm^2 s)
β: Acid gravimetric dissolving power (mass rock/mass acid)
ρ_{ma}: Formation Matrix Density (g/cm^3)
Γ: Perimeter of the Pore (μm)
A: Cross-sectional Area of Pore (cm^2)
l: Length of Pore (μm)
t: time (s)

Output(s)

ψ: Pore Growth Function (cm^2/s)

Formula(s)

$$\psi = \frac{r_{ave}\beta\Gamma}{\rho_{ma}}$$

or

$$\rho_{ma} l \frac{dA}{dt} = r_{ave}\beta\Gamma l$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 69.*

4.62 Pressure drop across perforations in gas wells

Input(s)

q_g: Gas Flow Rate through Perforation (bbl/d)
n: Number of Perforations (dimensionless)
μ_g: Gas Viscosity (cP)
Z: Gas Supercompressibility Factor (dimensionless)
T: Formation Temperature (R°)
L_p: Perforation Length (ft)
k_{pd}: Perforation Damaged Zone Permeability (mD)
r_p: Perforation Radius (ft)
r_{pd}: Perforation Damaged Zone Radius (ft)
γ_g: Gas Specific Gravity (air = 1.0)

Output(s)

p_{sf}: Pressure at the Sandface (psi)
p_{wb}: Pressure in the Wellbore (psi)
β_{pd}: Velocity Coefficient of Turbulence Factor (1/ft)

Formula(s)

$$p_{sf}^2 - p_{wb}^2 = \left(A \cdot \left(\frac{q_g}{n}\right)\right) + \left(B \cdot \left(\frac{q_g}{n}\right)^2\right)$$

$$A = \frac{1.424 \cdot 10^3 \cdot \mu_g (Z)(T)}{L_p k_{pd}} In\left(\frac{r_{pd}}{r_p}\right)$$

$$B = \frac{(3.16)\left(10^{-12}\right)\beta_{pd}\gamma_g (Z)(T)}{L_p^2}\left(\frac{1}{r_p} - \frac{1}{r_{pd}}\right)$$

$$\beta_{pd} = (2.33)\left(10^{10}\right) k^{-1.201}$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 62.*

4.63 Pressure drop across perforations in oil wells

Input(s)

q_o: Oil Flow Rate through Perforation (bbl/d)
n: Number of Perforations (dimensionless)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (dimensionless)
L_p: Perforation Length (ft)
k_{pd}: Perforation Damaged Zone Permeability (mD)
r_p: Perforation Radius (ft)
r_{pd}: Perforation Damaged Zone Radius (ft)
ρ_o: Oil Density (lbm/ft^3)

Output(s)

Δp_p: Pressure Drop across Perforations (psi)
β_{pd}: Velocity Coefficient of Turbulence Factor (1/ft)

Formula(s)

$$\Delta p_p = \left(A \cdot \left(\frac{q_o}{n}\right)\right) + \left(B \cdot \left(\frac{q_o}{n}\right)^2\right)$$

$$A = \frac{141.2 \cdot \mu_o B_o}{L_p k_{pd}} In\left(\frac{r_{pd}}{r_p}\right)$$

$$B = \frac{2.3\left(10^{-14}\right)\beta_{pd} B_o^2 \rho_o}{L_p^2}\left(\frac{1}{r_p} - \frac{1}{r_{pd}}\right)$$

$$\beta_{pd} = \frac{(2.33)\left(10^{10}\right)}{k_{pd}^{1.201}}$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 61.*

4.64 Pressure loss due to perforations during hydraulic fracturing

Input(s)

ρ: Specific Gravity (lb/ft^3)
q: Real Flowing Rate (ft^3/s)
g_c: Unit Conversion Factor (32.2 (lb·ft)/(lbf s^2))
A_2: Fracture Area in time "t" (ft^2)

Output(s)

ΔP_p: Pressure Loss in Sourced by Perforations during Hydraulic Fracturing (psi)

Formula(s)

$$\Delta P_p = \frac{\rho \cdot q^2}{1.345 \cdot g_c . A_2^2}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 28.*

4.65 Pressure loss due to perforations during hydraulic fracturing—2

Input(s)

ρ: Specific Gravity (lb/gal)
q: Real Flowing Rate (gal/min)
A_2: Fracture Area in time "t" (in^2)

Output(s)

ΔP_p: Pressure Loss in Sourced by Perforations during Hydraulic Fracturing (psi)

Formula(s)

$$\Delta P_p = \frac{\rho \cdot q^2}{8090 \cdot A_2^2}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 30.*

4.66 Principal stress due to petro-static pressure (hydraulic fracturing)

Input(s)

γ: Average Specific Weight of Formation (p/cm^3)
h: Depth (m)

Output(s)

σ_z: Principal Stress in z-axis (kp/cm^2)

Formula(s)

$$\sigma_z = \frac{\gamma \cdot h}{10}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 5.*

4.67 Productivity index (for generating composite IPR curve)

Input(s)

q: Tested Flow Rate (STB/D)
P_b: Bubble Point Pressure (psi)
P_w: Wellbore Pressure (psi)
P: Reservoir Pressure (psi)

Output(s)

J_i: Productivity Index (STB/D/psi)

Formula(s)

$$J_i = \frac{q}{(P - P_b) + \left(\frac{P_b}{1.8}\right)\left(1 - 0.2 * \left(\frac{P_w}{P}\right) - 0.8 * \left(\frac{P_w}{P}\right)^2\right)}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 3/38.*

4.68 Productivity ratio

Input(s)

J: Productivity Index of a well in any condition (fraction)
J_{sw}: Productivity index of a standard well (fraction)

Output(s)

PR: Productivity Ratio (fraction)

Formula(s)

$$PR = \frac{J}{J_{sw}}$$

Reference: *Horizontal Well Technology, Joshi, Page: 46.*

4.69 Productivity ratio calculation of a hydraulically-fractured formation

Input(s)

k_{avgz}: Average Permeability of a Hydraulically Fractured Zone (mD)
k_F: Permeability of the Fracture (mD)
k: Permeability of the Formation (mD)
h: Formation Thickness (ft)
W: Fracture Thickness (ft)
r_e: Drainage Radius of the Well (in.)
r_w: Radius of the Well (in.)
r_f: Radius of the Fracture (in.)
k_{avg}: Average Permeability of a Hydraulically Fractured Formation (mD)

Output(s)

PR: Productivity Ratio of a Hydraulically Fractured Formation (mD)

Formula(s)

$$PR = \frac{k_{avg}}{k}$$

or,

$$PR = \left[\frac{k_f \cdot W}{k \cdot h}\right] \cdot \frac{\left[\frac{k\,h}{k_f \cdot W} + 1\right] \cdot ln\left(\frac{r_e}{r_w}\right)}{\left[\frac{k_f \cdot W}{k\,h} + 1\right] \cdot ln\left(\frac{r_e}{r_f}\right) + ln\left(\frac{r_f}{r_w}\right)}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 7.*

4.70 Pseudo skin factor due to partial penetration (Brons and Marting method)

Input(s)

h_p: Perforation interval (ft)
h: Total pay thickness (ft)
kh: Vertical permeability (mD)
kv: Horizontal permeability (mD)
rw: Wellbore diameter (ft)

Output(s)

h_d: Dimensionless Payzone Thickness (dimensionless)
b: Penetration Ratio (dimensionless)
Gb: Function for penetration ratio (dimensionless)
s_p: Skin due to partial penetration (dimensionless)

Formula(s)

$$h_d = \frac{h_p}{h}$$

$$b = \frac{h}{rw} * \left(\frac{kh}{kv}\right)^{0.5}$$

$$Gb = 2.948 - 7.363 * b + 11.45 * b^2 - 4.675 * b^3$$

$$s_p = \left(\frac{1}{b} - 1\right) * (\ln(h_d) - Gb)$$

Reference: *Horizontal Well Technology, Joshi, Page: 493.*

4.71 Pseudo-skin factor due to partial penetration (Yeh and Reynolds correlation)

Input(s)

h_p: Perforation Interval (ft)
h: Total pay thickness (ft)
C_d: Location of open interval from graphical co-relation by Yeh and Ronald (dimensionless)
k_v: Horizontal Permeability (mD)
k_h: Vertical Permeability (mD)
r_w: Wellbore Dia (ft)

Output(s)

b: Penetration ratio (dimensionless)
C_1: Location of open interval from graphical co-relation by Yeh and Ronald (dimensionless)
h_d: Dimensionless payzone thickness (dimensionless)
$h_{\{wd\}}$: Effective Wellbore depth (ft)
s_p: Skin due to partial penetration (dimensionless)

Formula(s)

$$b = \frac{h_p}{h}$$

$$C_1 = \frac{h}{r_w} * sqrt\left(\frac{k_h}{k_v}\right)$$

$$h_d = 0.481 + 1.01 * b - 0.838 * b^2$$

$$h_{wd} = C_d * b * (1-b) * \frac{h_d}{2.71_1^C}$$

$$s_p = \frac{1-b}{b} * \ln\left(h_{\{wd\}}\right)$$

Reference: *Horizontal Well Technology, Joshi, Page: 496.*

4.72 Pseudo-skin factor due to partial penetration (Odeh correlation)

Input(s)

h_1: Distance from payzone top to top of open interval (ft)
h_p: Perforation interval (ft)
h: Total pay thickness (ft)
r_w: Wellbore Dia (ft)
k_v: Horizontal Permeability (mD)
k_h: Vertical Permeability (mD)

Output(s)

z_m: Well Perforation Distance (ft)
h_d: Dimensionless Payzone Thickness (dimensionless)
b: Penetration Ratio (dimensionless)
r_{wc}: Effective Wellbore dia (ft)
s_p: Skin due to partial penetration (dimensionless)

Formula(s)

$$z_m = \frac{h_p}{h}$$

$$h_d = \frac{h}{r_w} * sqrt\left(\frac{k_h}{k_v}\right)$$

$$b = h_1 + \frac{h_p}{2}$$

$$r_{wc} = r_w * 2.71^{0.2126*\left(2.753+\frac{z_m}{h}\right)}$$

$$s_p = 1.35 * \left(\frac{1}{b} - 1\right)^{0.825} * \left(\ln(r_w * h_d + 7) - 1.95 - \ln\left(r_{\{wc\}}\right) * (0.49 + 0.1 * \ln(r_w * h_d))\right)$$

Reference: *Horizontal Well Technology, Joshi, Page: 495.*

4.73 Pseudo-skin factor due to partial penetration (Papatzacos correlation)

Input(s)

h_p: Perforation interval (ft)
h: Total pay thickness (ft)
h_1: Distance from top of reservoir to top of open interval (ft)

k_v: Horizontal permeability (mD)
k_h: Vertical permeability (mD)
r_w: Wellbore dia (ft)

Output(s)

b: Penetration ratio (dimensionless)
A: Constant for calc (dimensionless)
B: Constant for calc (dimensionless)
h_d: Dimensionless payzone thickness (dimensionless)
s_p: Skin due to partial penetration (dimensionless)

Formula(s)

$$b = \frac{h_p}{h}$$

$$A = \frac{h}{r_w} * sqrt\left(\frac{k_h}{k_v}\right)$$

$$B = \frac{h}{h_1 + 0.25 * h_p}$$

$$h_d = \frac{h}{h_1 + 0.75 * h_p}$$

$$s_p = \frac{1-b}{b} * \ln\left(\pi * \frac{h_d}{2}\right) + \frac{1}{b} * \ln\left(\frac{b}{b+2} * sqrt\left(\frac{A-1}{B-1}\right)\right)$$

Reference: *Horizontal Well Technology, Joshi, Page: 498.*

4.74 Pseudo-skin factor due to perforations

Input(s)

h_p: Perforation interval (ft)
h: Total pay thickness (ft)
h_1: Distance from top of reservoir to top of open interval (ft)
k_v: Horizontal permeability (mD)
k_h: Vertical permeability (mD)
r_w: Wellbore dia (ft)

Output(s)

b: Penetration ratio (dimensionless)
A: Constant for calc (dimensionless)
B: Constant for calc (dimensionless)
h_d: Dimensionless payzone thickness (dimensionless)
s_p: Skin due to partial penetration (dimensionless)

Formula(s)

$$b = \frac{h_p}{h}$$

$$A = \frac{h}{r_w} * sqrt\left(\frac{k_h}{k_v}\right)$$

$$B = \frac{h}{h_1 + 0.25 * h_p}$$

$$h_d = \frac{h}{h_1 + 0.75 * h_p}$$

$$s_p = \frac{1-b}{b} * \ln\left(\pi * \frac{h_d}{2}\right) + \frac{1}{b} * \ln\left(\frac{b}{b+2} * sqrt\left(\frac{A-1}{B-1}\right)\right)$$

Reference: *Horizontal Well Technology, Joshi, Page: 499.*

4.75 Quantifying formation damage and improvement

Input(s)

p_{wf}: Pressure of Wellflow (psi)
p: Pressure of Reservoir (psi)
s: Skin Factor (dimensionless)
r_s: Radius of skin (ft)
r_w: Radius of Wellbore (ft)
q: Flow Rate (STB/day)
k: Permeability of Formation (mD)
μ: Viscosity of Oil (cP)
B: Volume factor (RB/STB)
h: Thickness of reservoir (ft)

Output(s)

k_s: Permeability of altered zone (mD)
r_{wa}: Effective Radius of Wellbore (ft)
E: Flow Efficiency (fraction)

Formula(s)

$$k_s = \frac{k}{1 + \frac{s}{\ln\left(\frac{r_s}{r_w}\right)}}$$

$$r_{wa} = r_w * 2.71828^{-s}$$

$$E = \frac{p - p_{wf} - \left(141.2 * q * B * \mu * \frac{s}{k * h}\right)}{p - p_{wf}}$$

Reference: *Pressure Transient Testing, Lee, Rollins & Spivey, Page: 43.*

4.76 Recommended underbalanced environment for perforation

Input(s)

k: Formation Permeability (mD)

Output(s)

p_u: Underbalance Pressure (psi)

Formula(s)

$$log_{10} p_u = 3.46055 - 0.3812\, log_{10} k$$

Reference: *Bell, W. T., Sukup, R. A., & Tariq, S. M. (1995). Perforating. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers, Page: 74.*

4.77 Reynolds number for acid flow into the fracture (acidizing)

Input(s)

ρ: Acid Density (lb/ft^3)
i: Injection Rate (ft^3/min)
μ: Viscosity of the Reacted Acid (lb/ft min)
h_g: Formation Thickness (ft)

Output(s)

N_{Re}: Reynolds Number (dimensionless)

Formula(s)

$$N_{Re} = \frac{\rho\, i}{\mu h_g}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing Fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 62.*

4.78 Reynolds number for fluid loss (acidizing)

Input(s)

$\overline{w}$: Average Fracture Width (ft)
$\overline{v_N}$: Average Fluid Loss Velocity (ft/min)
ρ: Acid Density (lb/ft^3)
μ: Viscosity of the Reacted Acid (lb/ft min)
r_c: Radius of Wormhole (ft)

Output(s)

N_{Re}: Reynolds Number (dimensionless)

Formula(s)

For Fracture:

$$N_{Re} = \frac{2\overline{w}\,\overline{v_N}\rho}{\mu}\ ForWormhole:$$

$$N_{Re} = \frac{2r_c\overline{v_N}\rho}{\mu}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 111.*

4.79 Sand weight needed to refill a hydraulically fractured reservoir volume

Input(s)

V: Volume of Unit Area of the Fracture (ft^3/ft^2)
$Ø$: Porosity (fraction)
ρ_{sand}: Density of the Sand (lb/ft^3)

Output(s)

S: Sand Weight needed to Refill the Hydraulically Fractured Reservoir Volume (lb/ft^2)

Formula(s)

$$S = V \cdot (1 - Ø) \cdot \rho_{sand}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 98.*

4.80 Shape factor expressed as skin factor for vertical wells

Input(s)

C_A: Shape Factor (dimensionless)

Output(s)

s_{CA}: Shape Related Skin Factor (dimensionless)

Formula(s)

$$s_{CA} = \ln\left(\left(\frac{31.62}{C_A}\right)^{0.5}\right)$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 7, Page: 208.*

4.81 Single-phase gas flow (subsonic)

Input(s)

P_d: Downstream Pressure (psi)
P_u: Upstream Pressure at Choke (psi)

k: Specific Heat Ratio (dimensionless) A: Cross Sectional Area of Choke (in.^{2})
γ_g: Gas Specific Gravity related to Air (dimensionless)
T_u: Upstream Temperature (R)
C_d: Choke Discharge Coefficient (dimensionless)

Output(s)

q_{sc}: Gas Flow Rate (Mscf/D)

Formula(s)

$$q_{sc} = 1248 * C_d * A * P_u * \left(\left(\left(\frac{k}{(k-1) * \gamma_g * T_u} \right) * \left(\left(\frac{P_d}{P_u} \right)^{\frac{2}{k}} - \left(\frac{P_d}{P_u} \right)^{\frac{k+1}{k}} \right) \right)^{0.5} \right)$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 5/61.*

4.82 Single-phase liquid flow through choke

Input(s)

C_d: Upstream Pressure at Choke (psi)
A: Choke Area (ft^2)
g_c: Unit Conversion Factor (Constant = 32.17) (lb ft/ lbf s^2)
ΔP: Pressure Drop (lbf/ft^2)
ρ: Fluid Densty (lbm/ft^3)

Output(s)

q: Flow Rate (ft^3/s)

Formula(s)

$$q = C_d * A * \left(2 * g_c * \frac{\Delta P}{\rho} \right)^{0.5}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 5.*

4.83 Skin factor

Input(s)

k_s: Permeability of damaged zone (mD)
r_s: Radius of damaged zone (ft)
r_w: Radius of wellbore (ft)
k: Permeability (mD)

Output(s)

s: Skin (dimensionless)

Formula(s)

$$s = \left(\frac{k}{k_s} - 1\right) * \ln\left(\frac{r_s}{r_w}\right)$$

Reference: *Fundamental Principles of Reservoir Engineering, Towler, Page: 62.*

4.84 Skin factor by Hawkins method

Input(s)

k: Permeability of Reservoir (mD)
k_s: Permeability of Skin Zone Near Wellbore (mD)
r_w: Radius of Wellbore (ft)
r_s: Radius of Skin Zone (ft)

Output(s)

S: Skin Factor (dimensionless)

Formula(s)

$$S = \left(\left(\frac{k}{k_s}\right) - 1\right) * \ln\left(\frac{r_s}{r_w}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 37.*

4.85 Skin factor due to partial penetration

Input(s)

h_t: Total Formation Thickness (ft)
rw: Radius of Wellbore (ft)
k_v: Vertical Permeability (mD)
k_h: Horizontal Permeability (mD)
h_p: Height of Perforated interval (ft)
h_a: Height (ft)
h_{pd}: Dimensionless Perforated Thickness (fraction)
h: Thickness of reservoir (ft)

Output(s)

r_d: Permeability of altered zone (mD)
A: Dimensionless Constant A (dimensionless)
B: Dimensionless Constant B (dimensionless)
s_p: Skin Factor from partial penetration (dimensionless)

Formula(s)

$$r_d = \left(\frac{rw}{h_t}\right) * \left(\frac{k_v}{k_h}\right)^{0.5}$$

$$A = \frac{h_p}{h_t}$$

$$B = \frac{h_a}{h_t}$$

$$s_p = \left(\frac{1}{h_{pd}} - 1\right) * 2.303 * \log\left(0.5 * \frac{3.142}{\left(\frac{rw}{h_t}\right) * \left(\frac{k_v}{k_h}\right)^{0.5}}\right) + \frac{1}{h_{pd}} * \ln\left(\frac{h_{pd}}{2 + h_{pd}} * \left(\left(\frac{\left(\frac{h_p}{h_t}\right) - 1}{\left(\frac{h_a}{h_t}\right) - 1}\right)^{0.5}\right)\right)$$

Reference: *Pressure Transient Testing, Lee, Rollins & Spivey, Page: 44.*

4.86 Skin factor due to reduced crushed-zone permeability

Input(s)

h_p: Perforation interval (ft)
kd: Damage Zone permeability (mD)
kdp: Crushed Zone Permeability (mD)
k: Permeability of Formation (mD)
r_{dp}: Crushed Zone radius (ft)
r_p: Perforation Radius (ft)
Lp: Depth of Penetration (ft)
N: Total Number of Perforations (number)

Output(s)

sc: Skin Factor due to Reduced Crushed-Zone Permeability (dimensionless)

Formula(s)

$$sc = \left(\frac{k}{kdp} - \frac{k}{kd}\right) * 12 * \frac{h_p}{N * Lp} * \ln\left(\frac{r_{dp}}{r_p}\right)$$

Reference: *Horizontal Well Technology, Joshi, Page: 504.*

4.87 Skin factor for a deviated well

Input(s)

θ: Angle of Inclination (degree)
kv: Vertical Permeability (mD)
kh: Horizontal Permeability (mD)
h: Formation Thickness (ft)
rw: Radius of Wellbore (ft)
s: Total Skin Factor (dimensionless)

Output(s)

tw: Angle of Inclination due to drilling (degree)

h_d: Dimensionless Effective Thickness (dimensionless)
s_{th}: Directional Drilling Skin Factor (dimensionless)
s_t: Skin Factor other than Directional Drilling (dimensionless)

Formula(s)

$$tw = \left(\operatorname{atan}\left(\left(\frac{kv}{kh}\right)^{0.5} * \tan\left(\theta * \frac{\pi}{180}\right)\right)\right) * \frac{180}{pi}$$

$$h_d = \left(\frac{h}{rw}\right) * \left(\frac{kh}{kv}\right)^{0.5}$$

$$s_{th} = -\left(\frac{tw}{41}\right)^{2.06} - \left(\frac{tw}{56}\right)^{1.865} * \log\left(\frac{h_d}{100}\right)$$

$$s_t = s - s_{th}$$

Reference: *Pressure Transient Testing, Lee, Rollins & Spivey, Page: 44.*

4.88 Slope of Semilog plot for bottom-hole flowing pressure vs time for drawdown test

Input(s)

Q_o: Oil Flow Rate (STB/day)
μ_o: Oil Viscosity (cP)
B_o: Oil Formation Volume Factor (bbl/STB)
k: Permeability (mD)
h: Thickness (ft)

Output(s)

m: Slope (psi/cycle)

Formula(s)

$$m = \frac{162.6 * Q_o * \mu_o * B_o}{k * h}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 45.*

4.89 Sucker rod—Peak polished rod load

Input(s)

C: Calibration Constant of Dynamometer (lb/in.)
D: Maximum Deflection (in.)

Output(s)

PPRL: Peak Polished Rod Load (lb)

Formula(s)

$$PPRL = C * D$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 18/269.*

4.90 Suspension property of static fluids (completion and workover fluids)

Input(s)

d: Particle Diameter (μm)
ρ_p: Density of Solid Particle (g/cm^3)
ρ_f: Density of Fluid (g/cm^3)
g: Acceleration Owing to Gravity (ft/s^2)
μ: Fluid Viscosity (cP)

Output(s)

v: Particle Settling Velocity (in/s)

Formula(s)

$$v = \frac{d^2\left(\rho_p - \rho_f\right)g}{(\mu)\left(4.5 \cdot 10^6\right)}$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 49.*

4.91 Tangential annular flow of a power law fluid

Input(s)

m: Power Law Constant (dimensionless)
n: Power Law Constant 2 (dimensionless)
Ω: Colission Integral (dimensionless)
κ: Dilational Viscocity (cP)
R: Radius (ft)
L: Length (ft)

Output(s)

T_z: Torque Exerted (lb ft^2/s^2)

Formula(s)

$$T_z = 2 * \pi * m * \Omega * \left(\left(\kappa * R\right)^2\right) * L * \left(\left(\frac{\frac{2}{n}}{1 - \left(\kappa^{\frac{2}{n}}\right)}\right)^n\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 8, Page: 244.*

4.92 Temperature at choke outlet

Input(s)

T_u: Upstream Temperature (R)
z_u: Z Factor of Upstream Gas Flow (dimensionless)
z_o: Z Factor of Upstream Gas Flow in Outlet (dimensionless)
k: Specific Heat Ratio (dimensionless)
P_o: Outlet Pressure (psi)
P_u: Upstream Pressure at Choke (psi)

Output(s)

T_{dn}: Downstream Temperature (R)

Formula(s)

$$T_{dn} = T_u * \left(\frac{z_u}{z_o}\right) * \left(\frac{P_o}{P_u}\right)^{\frac{k-1}{k}}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 5/62.*

4.93 The z component of the force of the fluid on the wetted surface of the pipe

Input(s)

po: Pressure at initial point (Pa)
pL: Pressure at point L (Pa)
R: Radius (m)
L: Length (m)
ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)

Output(s)

Fz: z-Component of Force (Newton)

Formula(s)

$$Fz = \pi * R^2 * (po - pL) + \pi * R^2 * L * \rho * g$$

Reference: *Transport Phenomena, Second Edition, Bird, Page: 51.*

4.94 Total skin in partially depleted wells for a buildup test

Input(s)

r_{ew}: Dimensionless Parameter in terms of Perforated Length and Wellbore Radius (dimensionless)
ø: Porosity (fraction)
μ: Viscosity (cP)
c_t: Total Compressibility (1/psi)
k: Permeability (mD)

p_s: Shut-in Pressure at any Shut-in Time (psi)
p_w: Well Flowing Pressure at the Instant of Shut-in (psi)
Δt: Shut-in Time (day)
m: Slope of Cartesian Pressure Build-up Plot (psi/cycle)

Output(s)

S: Skin (dimensionless)

Formula(s)

$$S = 34.7 * r_{ew} * \left(\left(\left(\varnothing * \mu * \frac{c_t}{k} \right) \right)^{0.5} \right) * \left(\left(\frac{p_s - p_w}{m} \right) + \left(\frac{1}{(\Delta t)^{0.5}} \right) \right) - 1$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 81.*

4.95 Velocity distribution in the annular slit of a falling-cylinder viscometer

Input(s)

κ: Ratio of inner Radius to Outer Radius (fraction)
v_o: Velocity (cm/s)
ξ: Radial Coordinate (dimensionless)

Output(s)

v_z: Velocity Profile (cm/s)

Formula(s)

$$\frac{v_z}{v_o} = -\frac{(1-\xi^2) - (1+\kappa^2) * \ln\left(\frac{1}{\xi}\right)}{(1-\kappa^2) - (1+\kappa^2) * \ln\left(\frac{1}{\kappa}\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 70.*

4.96 Velocity distribution in the narrow annular region in annular flow with inner cylinder moving axially

Input(s)

ρ: Density (ppg)
g: Acceleration due to Gravity (ft/s^2)
R: Radius (ft)
r: Position from Point (ft)
a: Ratio of Distance of Rod from Centre (fraction)
μ: Viscosity (cP)

Output(s)

v_z: Velocity (ft/s)

Formula(s)

$$v_z = \left(\frac{\rho * g * (R^2)}{4 * \mu}\right) * \left(1 - \left(\left(\frac{r}{R}\right)^2\right) + 2 * \left(a^2\right) * ln\left(\frac{r}{R}\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 65.*

4.97 Velocity distribution of flow through an annulus

Input(s)

po: Pressure at initial point (Pa)
pL: Pressure at point L (Pa)
R: Radius (m)
μ: Viscosity (kg/(ms))
L: Length (m)
r: Cylindrical Shell of Thickness (m)
K: Boltzmann Constant (m^2 kg s^{-2} K^{-1})

Output(s)

vz: Velocity Distribution (m/s)

Formula(s)

$$vz = \frac{(po - pL) * R^2}{4 * \mu * L} * \left(1 - \left(\frac{r}{R}\right)^2 - \frac{1 - K^2}{\ln\left(\frac{1}{K}\right)} * \ln\left(\frac{R}{r}\right)\right)$$

Reference: *Transport Phenomena, Second Edition, Bird, Page: 55.*

4.98 Velocity of fluid in annulus

Input(s)

Q: Flow rate (gpm)
D_o: Open Hole Diameter (in.)
D_p: Outside Diameter of Pipe (in.)

Output(s)

v_a: Velocity of Fluid in Annulus (ft/s)

Formula(s)

$$v_a = \frac{Q}{2.448 * \left(D_o^2 - D_p^2\right)}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 321.*

4.99 Velocity of fluid in pipe

Input(s)

Q: Flowrate (gpm)
D_i: Inside Diameter of Pipe (in.)

Output(s)

v_p: Velocity of Fluid (ft/s)

Formula(s)

$$v_p = \frac{Q}{2.448 * D_i^2}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 219.*

4.100 Viscous force acting on the rod over the narrow annular region

Input(s)

L: Length (ft)
μ: Viscosity (cP)
v_o: Velocity (ft/s)
κ: Ratio of Inner to Outer Ratio (fraction)

Output(s)

F: Force (N)

Formula(s)

$$F = \frac{-2 * \pi * L * \mu * v_o}{\ln\left(\frac{1}{\kappa}\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 65.*

4.101 Volume capacity of pipe

Input(s)

D_i: Inner Diameter of Pipe (in.)
L: Length of Pipe (ft)

Output(s)

V: Volume Capacity of Pipe (bbl)

Formula(s)

$$V = \frac{0.7854 * \left(D_i^2\right) * L}{808.5}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 44.*

4.102 Volume of fluid loss per unit area measured in a dynamic test (acidizing)

Input(s)

t: Time (s)
V_{spt}: The Spurt Volume (m^3/m^2)
v_N: Fluid Loss Velocity (m/s)

Output(s)

V: Volume of Fluid Loss per Unit Ares (m^3/m^2)

Formula(s)

$$V = V_{spt} + v_N t$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 42.*

4.103 Volume of fluid loss per unit area measured in a static test (acidizing)

Input(s)

C_w: Fluid Loss Coefficient, ($m/s^{1/2}$)
$\sqrt{t}$: Time root ($s^{1/2}$)
V_{spt}: The Spurt Volume (m^3/m^2)

Output(s)

V: Volume of Fluid Loss per Unit Ares (m^3/m^2)

Formula(s)

$$V = V_{spt} + 2C_w\sqrt{t}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 42.*

4.104 Volume of rock dissolved per unit volume of acid (acidizing)

Input(s)

$\rho_{15\ percent\ HCl}$: Density of 15 Weight percent HCl Solution, (g/cc)
ρ_{CaCO_3}: Density of Calcium Carbonate (g/cc)
$\beta_{15\ percent\ HCl}$: Mass of Dissolved Rock with 15 percent of HCl (g/g)

Output(s)

X_{15}: Acid Dissolving Power (cc/cc)

Formula(s)

$$X_{15} = \frac{\rho_{15\,percent\,HCl} \times \beta_{15\,percent\,HCl}}{\rho_{CaCO_3}}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 13.*

4.105 Water quantity that dilutes the original brine with assumed density (two-salt systems)

Input(s)

V_d: Volume of Diluted Brine (bbl)
ρ_i: Density of initial, undiluted Brine (lbm/bbl)
ρ_d: Density of Diluted Brine (lbm/bbl)
$\rho_{8.33}$: Density of Water diluting the Original Brine (lbm/bbl)

Output(s)

$V_{8.33}$: Volume of Water Diluting the Original Brine (bbl)

Formula(s)

$$V_{8.33} = (V_d)\,\frac{(\rho_i - \rho_d)}{(\rho_i - \rho_{8.33})}$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 56.*

4.106 Weight of crystalline $CaCl_2$ and $CaBr_2$ salt addition to brine (two-salt systems)

Input(s)

C_{95}: Concentration of 95% $CaBr_2$ in the Initial undiluted Brine (lbm/bbl)
m_{94}: Mass of 94% $CaCl_2$ needed to weight up diluents water (lbm)
C_{94}: Concentration of 94% $CaCl_2$ in the Initial undiluted Brine (lbm/bbl)
W_i: Water Fraction in the initial undiluted Brine (bbl/bbl)

Output(s)

m_{95}: Mass of 95% $CaBr_2$ needed to weight up diluents water (lbm)

Formula(s)

$$m_{95} = (V_{8.33}) \frac{(C_{95})}{(W_i)}$$

$$m_{94} = (V_{8.33}) \frac{(C_{94})}{(W_i)}$$

Reference: *Bridges, K. L. (2000). Completion and Workover Fluids (Vol. 19). Society of Petroleum Engineers, Page: 56.*

4.107 Well flowing pressure (line-source solution by including skin factor)

Input(s)

P_i: Initial Reservoir Pressure (psi)
q: Flow Rate (bbl/d)
μ: Viscosity (cP)
B: Formation Volume Factor (bbl/STB)
k: Permeability (mD)
h: Payzone Thickness (ft)
ϕ: Porosity (fraction)
c_t: Total Compressibility (1/psi)
r: Radius of Reservoir (ft)
t: Time (days)
S: S Variable (psi)

Output(s)

P_{wf}: Well Flowing Pressure (psi)

Formula(s)

$$P_{wf} = P_i + \left(70.6 * q * \mu * \frac{B}{k * h}\right) * \left(\ln\left(1688 * \phi * \mu * c_t * \frac{r^2}{k * t}\right) - 2 * S\right)$$

Reference: *Lee, J., Rollins, J. B., & Spivey, J. P. (2003). Pressure Transient Testing (Vol. 9). Richardson, Texas: Society of Petroleum Engineers, Page: 13.*

4.108 Well flowing pressure under Pseudo-steady state flow for non-circular reservoirs

Input(s)

p_i: Initial Reservoir Pressure (psi)
k: Permeability (mD)
h: Thickness (ft)
B: Formation Volume Factor (bbl/STB)
μ: Viscosity (cP)
C_A: Shape Factor (dimensionless)
r_w: Wellbore Radius (ft)
Q: Flow Rate (STB/day)
c_t: Total Compressibility (1/psi)
ø: Porosity (fraction)
t: Time (hour) A: Area (ft^2)

Output(s)

P_{wf}: Well Flowing Pressure (psi)

Formula(s)

$$P_{wf} = \left(p_i - \left(\frac{162.6 * Q * B * \mu}{k * h}\right) * \log\left(\frac{2.2458 * A}{C_A * r_w^2}\right)\right) - \left(\frac{0.23396 * Q * B * t}{A * h * ø * c_t}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 33.*

4.109 Wellbore pressure loss due to friction during hydraulic fracturing (laminar flow)

Input(s)

v: Average Velocity (ft/s)
L: Pipe Length (ft)
d: Inner Diameter of Pipe (in.)
μ_p: Plastic Viscosity (cP)
τ_y: Yield Point of the Liquid ($lb/100ft^2$)

Output(s)

ΔP_f: Pressure Loss in the wellbore Sourced by Frictions during Hydraulic Fracturing (psi)

Formula(s)

$$\Delta P_f = \frac{\mu_p L v}{1500\, d^2} \cdot \frac{\tau_y \cdot L}{225 \cdot d}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 30.*

4.110 Wellbore pressure loss due to friction during hydraulic fracturing (turbulence flow)

Input(s)

ρ: Liquid Density (lb/gal)
v: Average Velocity (ft/s)
f: Fanning Friction Factor (dimensionless)
L: Pipe Length (ft)
d: Inner Diameter of Pipe (in.)

Output(s)

ΔP_f: Pressure Loss in the wellbore Sourced by Frictions during Hydraulic Fracturing (psi)

Formula(s)

$$\Delta P_f = \frac{f \cdot L \cdot \rho \cdot v^2}{25.80 \cdot d}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 31.*

4.111 Wellbore storage

Input(s)

ΔV_m: Change in the Volume of Fluid in the Wellbore (bbl)
ΔP: Change in Pressure (psi)

Output(s)

C: Wellbore Storage Coefficient (bbl/psi)

Formula(s)

$$C = \frac{\Delta V_m}{\Delta P}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 49.*

4.112 Wellbore storage due to fluid level

Input(s)

A_a: Annulus Cross Sectional Area (ft^2)
ρ: Wellbore Fluid Density (lb/ft^3)

Output(s)

C_{FL}: Wellbore Storage Coefficient (bbl/psi)

Formula(s)

$$C_{FL} = \frac{144 * A_a}{5.615 * \rho}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 1, Page: 49.*

4.113 Wellhead pressure (multiphase flow across the choke)

Input(s)

C: Emprical Constant (dimensionless)
n: Emprical Constant (dimensionless)
m: Emprical Constant (dimensionless)
R: Producing Gas Liquid Ratio (SCF/BBL)
S: Choke Size (1/64 in.)
q: Gross Liquid Rate (bbl/d)

Output(s)

P_{wh}: Upstream Wellhead Pressure (psi)

Formula(s)

$$P_{wh} = C * R^m * \frac{q}{S^n}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 5/64.*

4.114 Workover operations (maximum allowed tubing pressure)

Input(s)

FG: Fracture Gradient (psi/ft)
P_t: Tubing Pressure (psi)
H: Depth of Perforations (ft)

Output(s)

MATP: Maximum Allowable Tubing Pressure (psi)

Formula(s)

$$MATP = FG * H - P_t$$

Reference: *Petrowiki.org*.

4.115 Young Modulus by using sonic travel time (acidizing)

Input(s)

t_s: Sonic Travel Time (μs/ft)
Ø: Porosity (per cent)
v: Poisson's Ratio (dimensionless)
ρ_{ma}: Density of Formation Matrix (lb/ft^3)
ρ_{fl}: Density of Formation fluids (lb/ft^3)

Output(s)

E: Young's Modulus (psi)

Formula(s)

$$E = 2.16 \times 10^8 \frac{\left[\rho_{ma}(1-Ø) + \rho_{fl}Ø\right](1-2v)(1+v)}{(1-v)t_s^2}$$

Reference: *Williams, B. B., Gidley, J. L., & Schechter, R. S. (1979). Acidizing Fundamentals. Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers of AIME, Page: 56.*

Chapter 5

Fluid flow and transport phenomena formulas and calculations

Chapter Outline

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5.1 Archimedes number

Input(s)

g: Local External Field (For Example Gravitational Acceleration) (m/s^2)
ρl: Density of the Fluid (kg/m^3)
ρ: Density of the Body (kg/m^3)
$\boldsymbol{\mu}$: Dynamic Viscosity (kg/(s*m))
L: Characteristic Length of Body (m)

Output(s)

Ar: Archimedes Number (dimensionless)

Formula(s)

$$Ar = \frac{g * L^3 * \rho_l * (\rho - \rho_l)}{\mu^2}$$

Reference: *Wikipedia.org*.

5.2 Average number of collisions to reduce neutron energy

Input(s)

E_o: Initial Energy Level (eV)
E: Final Energy Level (eV)
ξ: Average Energy Decrement per Collision (dimensionless)

Output(s)

n: Average Number of Collisions to Reduce Neutron Energy (dimensionless)

Formula(s)

$$n = \left(\frac{1}{\xi}\right) * \ln\left(\frac{E_o}{E}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 39.*

5.3 Average velocity of a falling film with variable viscosity

Input(s)

ρ: Density (g/cc)
g: Acceleration due to Gravity (cm/s^2)
δ: Film Thickness (cm)
β: Inclination (rad)
μ: Viscosity (cP)
x: Position in Film (cm)

Output(s)

v: Velocity (cm/s)

Formula(s)

$$v = \left(\frac{\rho * g * (\delta^2) * \cos(\beta)}{2 * \mu}\right) * \left(1 - \left(\frac{x}{\delta}\right)^2\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons., Chapter: 2, Page: 48.*

5.4 Average velocity of flow through a circular tube

Input(s)

P_o: Pressure at Initial Point (Pa)
P_L: Pressure at Point L (Pa)
R: Radius (m)
μ: Viscosity (kg/(ms))
L: Length (m)

Output(s)

v_z: Average Velocity (m/s)
$v_{z,max}$: Maximum Velocity (Occurs at R = 0) (m/s)

Formula(s)

$$v_z = \frac{(P_o - P_L) * R^2}{8 * \mu * L}$$

$$v_{z,max} = \frac{(P_o - P_L) * R^2}{4 * \mu * L}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons., Chapter: 2, Page: 51.*

5.5 Average velocity of flow through an annulus

Input(s)

P_o: Pressure at Initial Point (Pa)
P_L: Pressure at Point L (Pa)
R: Radius (m)
μ: Viscosity (kg/(ms))
L: Length (m)
κ: Ratio of Inner Pipe's Radius to Outer Pipe's Radius (fraction)

Output(s)

v_z: Average Velocity (m/s)

Formula(s)

$$v_z = \frac{(P_o - P_L) * R^2}{8 * \mu * L} * \left[\frac{1-\kappa^4}{1-\kappa^2} - \frac{1-\kappa^2}{\ln\left(\frac{1}{\kappa}\right)} \right]$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 2, Page: 55.*

5.6 Average velocity of fluids in flow of two adjacent immiscible fluids

Input(s)

P_o: Pressure at Initial Point (Pa)
P_L: Pressure at Point L (Pa)
b: Distance (m)
μ_I: Viscosity of Phase I, Denser, More Viscous Fluid (kg/(ms))
μ_{II}: Viscosity of phase II, Less Dense, Less Viscous Fluid (kg/(ms))
L: Length (m)

Output(s)

v_{zI}: Average Velocity for Phase I (m/s)
v_{zII}: Average Velocity for Phase II (m/s)

Formula(s)

$$v_{zI} = \frac{(P_o - P_L) * b^2}{12 * \mu_I * L} * \left(\frac{7 * \mu_I + \mu_{II}}{\mu_I + \mu_{II}}\right)$$

$$v_{zII} = \frac{(P_o - P_L) * b^2}{12 * \mu_{II} * L} * \left(\frac{\mu_I + 7 * \mu_{II}}{\mu_I + \mu_{II}}\right)$$

Reference: *Bird, R.B., Stewart, W.E., and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 2, Page: 58.*

5.7 Average velocity over the cross section of a falling film

Input(s)

ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
δ: Film Thickness (m)
μ: Viscosity (kg/(ms))
β: Angle of Inclination w.r.t Direction of Gravity (rad)
$v_{z,max}$: The Maximum Velocity at $x = 0$ (m/s)

Output(s)

v_z: Average Velocity (m/s)

Formula(s)

$$v_z = \frac{\rho * g * \delta^2 * \cos(\beta)}{3 * \mu}$$

Reference: *Bird, R.B., Stewart, W.E., and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 2, Page: 45.*

5.8 Blowdown time in unsteady gas flow

Input(s)

V: Volume (ft^3)
C_d: Valve Discharge Coefficient (dimensionless)
A_v: Valve Area ($in.^2$)
γ: Gas Specific Density (dimensionless)
z: Average Gas Compressibility (dimensionless)
T: Temperature (K)
P_a: Initial Pressure (psi)
P_b: Output Pressure (psi)
B: Constant

Output(s)

t: Interstitial Velocity2 (cm/s)

Formula(s)

$$t = \left(\frac{B * V}{C_d * A_v}\right) * \left(\frac{\gamma}{z * T}\right)^{0.5} * \ln\left(\frac{P_a}{P_b}\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page 29.*

5.9 Boltzmann equation

Input(s)

C_K: Boltzmann Constant, 1.38042*10 − 23 (J/K)
T_a: Absolute Temperature (Kelvin)

Output(s)

E_{mp}: Most Probable Energy (eV)

Formula(s)

$$E_{mp} = C_K * T_a$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 37.*

5.10 Boussinesq approximation—Buoyancy

Input(s)

g: Acceleration due to Earth (m/s^2)
ρ_2: Final Density (kg/m^3)
ρ_1: Initial Density (kg/m^3)
ρ: Single Density (kg/m3)

Output(s)

g_r: Reduced Acceleration due to Gravity (m/s^2)

Formula(s)

$$g_r = g * \frac{\rho_2 - \rho_1}{\rho}$$

Reference: *Wikipedia.org*.

5.11 Brinkman number

Input(s)

μ: Viscosity (Pa s)
v_b: Velocity at Outer Perimeter (cm/s)
k: Thermal Conductivity (W/cm K)
T_b: Temperature at Outer Perimeter (K)
T_o: Temperature at Inner Perimeter (K)

Output(s)

Br: Brinkman Number (dimensionless)

Formula(s)

$$Br = \mu * \frac{v_b^2}{k * (T_b - T_o)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 300.*

5.12 Buckingham Reiner equation

Input(s)

P_o: Input Pressure (psi)
P_L: Output Pressure (psi)
R: Radius (ft)
ρ: Density of Fluid (ppg)
μ: Viscosity of Fluid (cP)
L: Length (ft)
τ_o: Torque (psi)

Output(s)

τ_R: Shear Stress at the Tube Wall (psi)
Q: Mass Flow Rate (lb/s)

Formula(s)

$$\tau_R = \frac{(P_o - P_L) * R}{2 * L}$$

$$Q = \left[\frac{3.142 * (P_o - P_L) * R^4 * \rho}{8 * \mu * L}\right] * \left(1 - \frac{4 * \tau_o}{3 * \tau_R} + 0.333 * \left(\frac{\tau_o}{\tau_R}\right)^4\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 8, Page: 260.*

5.13 Calculation of mass flow rate

Input(s)

ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
δ: Film Thickness (m)
W: Width (m)
ν: Kinematic Viscosity (m^2/s)

Output(s)

w: Mass Flow Rate (kg/s)

Formula(s)

$$w = \frac{\rho * g * \delta^3 * W}{3 * \nu}$$

Reference: *Bird, R.B., Stewart, W.E., and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 2, Page: 47.*

5.14 Calculation of momentum flux

Input(s)

μ: Fluid Viscosity (cP)
dv_x: Change in Velocity in the x-direction (ft/s)
dy: Plate Separation in the y-direction (ft)

Output(s)

τ_{yx}: Momentum Flux (lb f/ft^2)

Formula(s)

$$\tau_{yx} = -\left(2.0886 * 10^{-5}\right) * \mu * \frac{dv_x}{dy}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 1, Page: 15.*

5.15 Combined momentum flux tensor

Input(s)

$\rho\vee$: Convective Momentum Flux (kg/m s^2)
π: Molecular Momentum Flux (kg/m s^2)

Output(s)

ø: Sum of the Momentum Flux Tensors (kg/m s^2)

Formula(s)

$$ø = \pi + \rho\vee$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 36.*

5.16 Combined radiation and convection

Input(s)

A_i: Area (ft^2)
σ: Stephen Boltzmann Constant (lb/h^3R^4)
e_i: Emissivity (fraction)
T_i: Maximum Air Temperature at the Water Surface (R)

Output(s)

Q: Heat Transfer Rate (Btu/s)

Formula(s)

$$Q = \sigma * A_i * e_i * T_i^4$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 505.*

5.17 Compressible flow in a horizontal circular tube

Input(s)

p_0: Pressure at Initial Point (Pa)
p_L: Pressure at Point L (Pa)
R: Radius (m)
μ: Viscosity (kg/(ms))
L: Length (m)
ρ_{avg}: Average Density (kg/m^3)

Output(s)

ω: Mass Rate of Flow (kg/s)

Formula(s)

$$\omega = \frac{\pi * (p_0 - p_L) * R^4 * \rho_{avg}}{8 * \mu * L}$$

Reference: *Bird, R.B., Stewart, W.E., and Lightfoot, E.N., (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 2, Page: 53.*

5.18 Compton scattering

Input(s)

E_0: Energy of the Photon Before Scattering (MeV)
m_e: Mass of the Electron (kg)
C: Velocity of Light Considered as 3*108 (m/s)
θ: Scattering Angle (degree)

Output(s)

E: Energy of the Photon After Scattering (MeV)

Formula(s)

$$E = \frac{E_0}{1 + \left(\frac{E_0}{m_e * C^2}\right) * (1 - \cos(\theta))}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 33.*

5.19 Correction factor for stagnant film according to the penetration model

Input(s)

ø: Rate Factor (rad)

Output(s)

θ: Correction Factor (dimensionless)

Formula(s)

$$\theta = \frac{\exp\left(\frac{-(ø)^2}{3.142}\right)}{1 + \mathrm{erf}\left(\frac{ø}{(3.142)^{0.5}}\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 707.*

5.20 Darcy Weisbach equation (head loss form)

Input(s)

L: Length of the Pipe (m)
g: Acceleration due to Gravity (m/s^2)
V: Average Velocity of the Fluid Flow, Equal to the Volumetric Flow Rate per Unit Cross-sectional Wetted Area (m/s)
D: Hydraulic Diameter of the Pipe (For a Pipe of Circular Section, this Equals the Internal Diameter of the Pipe) (m)
f_D: Dimensionless Coefficient Called the Darcy Friction Factor (dimensionless)

Output(s)

Δh: Head Loss Due to Friction (m)

Formula(s)

$$\Delta h = f_D * \frac{1}{2*g} * \left(\frac{V^2}{D}\right)$$

Reference: *Wikipedia.org*.

5.21 Darcy Weisbach equation (pressure loss form)

Input(s)

L: Length of the Pipe (m)
ρ: Density of Fluid (kg/m^3)
V: Average Velocity of the Fluid Flow, Equal to the Volumetric Flow Rate per Unit Cross-sectional Wetted Area (m/s)
L: Lift Force (Newton)
D: Hydraulic Diameter of the Pipe (for a Pipe of Circular Section, equals the Internal Diameter of the Pipe) (m)
f_D: Dimensionless Coefficient Called the Darcy Friction Factor (dimensionless)

Output(s)

ΔP: Pressure Loss due to Friction (m)

Formula(s)

$$\Delta P = L * f_D * \frac{\rho}{2} * \left(\frac{V^2}{D}\right)$$

Reference: *Wikipedia.org*.

5.22 Dean number

Input(s)

ρ: Density of the Fluid (kg/m^3)
μ: Dynamic Viscosity (kg/ms)
V: Axial Velocity Scale (m/s)
d: Diameter (m)
R_c: Radius of Curvature of the Path of Channel (m)

Output(s)

De: Dean Number (dimensionless)

Formula(s)

$$De = \frac{\rho * V * d}{\mu} * \left(\sqrt[2]{\left(\frac{d}{2 * R_c} \right)} \right)$$

Reference: *Wikipedia.org*.

5.23 Deborah number

Input(s)

t_c: Relaxation Time Scale (h)
t_p: Time Scale of Observation (h)

Output(s)

De: Deborah Number (dimensionless)

Formula(s)

$$De = \frac{t_c}{t_p}$$

Reference: *Wikipedia.org*.

5.24 Decay of thermal neutrons

Input(s)

n_0: Number of Thermal Neutrons at Time t0 (dimensionless)
t: Time (s)
τ: Thermal Decay Time (s)

Output(s)

n: Number of Thermal Neutrons at Time t (fraction)

Formula(s)

$$n = n_0 * \exp\left(-\frac{t}{\tau} \right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 9, Page: 180.*

5.25 Determination of the controlling resistance

Input(s)

S: Solubility (mol/cc)
M: Mass (g)
x_a: Partial Pressure (kPa)
S_o: Solubility at NTP (mol/cc)
c_l: Concentration of Liquid (g mol/cc)
c_g: Concentration of Gas (g mol/cc)
D_{AB}: Diffusivity in the Liquid Phase (cm^2/s)
D_{AC}: Diffusivity in the Gas Phase (cm^2/s)

Output(s)

m: Slope (dimensionless)
R: Resistance (ohm)

Formula(s)

$$m = \frac{S}{M} \Big/ \frac{x_a}{S_o}$$

$$R = m * \left(\frac{c_l}{c_g}\right) * \left(\left(\frac{D_{AB}}{D_{AC}}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 691.*

5.26 Determination of the diameter of a falling sphere

Input(s)

Re: Reynolds Number (dimensionless)
v: Velocity of Fluid (ft/s)
ρ: Density of Fluid (g/cc)
μ: Viscocity of Fluid (cP)

Output(s)

D: Diameter (ft)

Formula(s)

$$\mathrm{D} = \frac{\mathrm{Re} * \mu}{\rho * \mathrm{v}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons. Chapter: 20, Page: 650.*

5.27 Diffusion from an instantaneous point source

Input(s)

m_A: Mass of Species A (g)
D_{AB}: Binary Diffusivity for System A-B (cm^2/s)
t: Time (s)
r: Radial Coordinate, L (m)

Output(s)

ρ_A: Density of Species A (g/cm^3)

Formula(s)

$$\rho_A = \left(\frac{m_A}{(4*\pi*D_{AB}*t)^{\frac{3}{2}}}\right)*\exp\left(-\frac{r^2}{4*D_{AB}*t}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons, Chapter: 20, Page: 650.*

5.28 Diffusion in a moving film

Input(s)

H: Initial Height of Gas Column (cm)
C: Concentration (g/cc)
t: Time (s)

Output(s)

h(t): Height of Gas Interface (cm)

Formula(s)

$$h(t) = H*\left(\left(1+\left(\frac{Ct}{H^2}\right)^{0.5}\right)-1\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 549.*

5.29 Diffusion in polymers

Input(s)

M: Molar Weight (g/mol)

Output(s)

D_{AB}: Diffusivity (cm^2/s)

Formula(s)

$$D_{AB} = \frac{1}{M^{0.5}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 532.*

5.30 Diffusion Into a falling liquid film (gas absorption)

Input(s)

c: Concetration (mol/cm^3)
D_{AB}: Diffusivity (cm^2/s)
v_{max}: Velocity of Dropping Particle (cm/s)
z: Height of Column (cm)

Output(s)

N: Molar Flux (mol/cm^{2}s)

Formula(s)

$$N = c * \left(\frac{D_{AB} * v_{max}}{\pi * z}\right)^{0.5}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 560.*

5.31 Diffusion of low-density gases with equal mass

Input(s)

T: Temperature (K)
M_A: Mass of Component A (g)
M_B: Mass of Component B (g)
σ_{AB}: Collision Diameter (cm)
P: Pressure (atm)
Ω: Collision integral (dimensionless)

Output(s)

D_{AB}: Diffusivity (cm^2/s)

Formula(s)

$$D_{AB} = 0.0018583 * \left(\left((T^3) * \left(\left(\frac{1}{M_A}\right) + \left(\frac{1}{M_B}\right)\right)\right)^{0.5}\right) * \left(\frac{1}{P * (\sigma_{AB}^2) * \Omega}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 526.*

5.32 Diffusion potential

Input(s)

t_{Cl}: Chlorine Anion Transference Number (dimensionless)
R: Gas Constant (8.31) (J/mol K)
T_a: Absolute Temperature (degree K)
F: Faraday Constant (96516) (C)
a_1: Activities of 1st Electrolyte (dimensionless)
a_2: Activities of 2nd Electrolyte (dimensionless)

Output(s)

E_d: Diffusion Potential (V)

Formula(s)

$$E_d = (2 * t_{Cl} - 1) * \left(R * \frac{T_a}{F}\right) * \ln\left(\frac{a_1}{a_2}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 130.*

5.33 Diffusion through a non-isothermal spherical film

Input(s)

P: Pressure (atm)
D_{AB}: Diffusivity (cm^2/s)
R: Gas Constant (J/mol K)
T_1: Temperature (K)
n: Exponent (dimensionless)
r_1: Radius of Gas Film (cm)
r_2: Radius of Film (cm)
x_{A1}: Position of Gas (fraction)
x_{A2}: Position of Film (fraction)

Output(s)

W_A: Mass Rate (mol/s)

Formula(s)

$$W_A = \frac{4 * \pi * \left(\frac{P * D_{AB}}{R * T_1}\right) * \left(1 + \left(\frac{n}{2}\right)\right)}{\left(r_1^{\frac{n}{2}}\right) * \left(\left(\frac{1}{r_1}\right)^{1+\frac{n}{2}} - \left(\frac{1}{r_2}\right)^{1+\frac{n}{2}}\right)} * \ln\left(\frac{1 - x_{A2}}{1 - x_{A1}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 551.*

5.34 Diffusion through a stagnant film

Input(s)

D_{AB}: Diffusivity (cm^2/s)
z_1: Initial Position (ft)
z_2 : Output Position (ft)
x_{A1}: Mole Fraction of A1 (g/ft)
x_{A2}: Mole Fraction of A2 (g/ft)
x_b: Mole Fraction of B in the Logarithmic Mean of Thermal Concentrations (mol/ft^3)
c: Total Molar Concentration (mol/ft^3)

Output(s)

N: Combined Molar Flux (mol/ft^2s)

Formula(s)

$$N = \frac{c * D_{AB} * (x_{A1} - x_{A2})}{(z_2 - z_1) * (x_b)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 548.*

5.35 Diffusion through a stagnant gas film

Input(s)

x_{B1}: Mole Fraction of B1 (fraction)
x_{B2}: Mole Fraction of B2 (fraction)

Output(s)

x_B: Average Value of Mole Fraction of B in the Logarithmic Mean of Thermal Concentrations (fraction)

Formula(s)

$$x_B = (x_{B2} - x_{B1}) / \ln(x_{B2}/x_{B1})$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 547.*

5.36 Diffusion through cleat spacing in coalbed methane reservoirs

Input(s)

s: Coal Cleat Spacing (ft)
t: Desorption Time from the Canister Test (day)

Output(s)

D: Diffusion Coefficient (ft^2/day)

Formula(s)

$$D = \frac{s^2}{8 * \pi * t}$$

Reference: *Ahmed, T., Paul McKinney, P. D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter:3 Page: 233.*

5.37 Diffusion with a heterogeneous chemical reaction

Input(s)

D_{AB}: Diffusivity (ft^2/s)
δ: Position of Catalytic Film (cm)
x_a: Main Stream Concentration (mol/ft^3)
c: Total Molar Concentration (mol/ft^3)

Output(s)

N: Molar Flux ($mol/ft^2 s$)

Formula(s)

$$N = \left(\frac{2 * c * D_{AB}}{\delta}\right) * \ln\left(\frac{1}{1 - 0.5 * x_a}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 553.*

5.38 Diffusion with a homogeneous chemical reaction

Input(s)

k: Rate Constant (mol cm/s)
L: Length (cm)
D_{AB}: Diffusivity (cm cm/s)
c: Total Molar Concentration (mol/ft^3)

Output(s)

ø: Thiele Modulus (dimensionless)
N: Molar Flux ($mol\ L/cm^2$)

Formula(s)

$$ø = \left(\frac{k * (L^2)}{D_{AB}}\right)^{0.5}$$

$$N = \left(\frac{c * D_{AB}}{L}\right) * ø * \tanh(\pi)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 555.*

5.39 Diffusion, convection, and chemical reaction

Input(s)

k_1: Homogeneous Chemical Reaction Rate Coefficient (1/s)
D_{AB}: Diffusivity (cm^2/s)
v_o: Velocity (cm/s)
c_{AO}: Fraction of Initial Concentration (dimensionless)
z: Vertical Distance (cm)

Output(s)

c_A: Fraction of Initial Concentration remaining (dimensionless)

Formula(s)

$$c_A = (c_{AO}) * \exp\left(-\left(\left(1 + \frac{4 * k_1 * D_{AB}}{v_o^2}\right)^{0.5}\right) - 1\right) * \left(\frac{v_o * z}{2 * D_{AB}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 19, Page: 586.*

5.40 Drag coefficient

Input(s)

ρ: Mass Density of the Fluid (kg/m^3)
u: Flow Speed of the Object Relative to the Fluid (m/s)
F_d: Drag Force (N)
A: Cross Sectional Area (m^2)

Output(s)

c_d: Drag Coefficient (dimensionless)

Formula(s)

$$c_d = \frac{2 * F_d}{\rho * u^2 * A}$$

Reference: *Wikipedia.org*.

5.41 Drag force

Input(s)

ρ: Density of the Fluid (kg/m^3)
v: Speed of the Object Relative to the Fluid (m/s)
C_d: Drag Coefficient (dimensionless)
A: Cross Sectional Area (m^2)

Output(s)

F_D: Drag Force (N)

Formula(s)

$$F_D = \left(\frac{1}{2}\right) * \rho * v^2 * C_d * A$$

Reference: *Wikipedia.org*.

5.42 Draining of a cylindrical tank

Input(s)

μ: Fluid Viscosity (kg/(ms))
L: Height of the Pipe (m)
H: Height of the Cylindrical Tank (m)
D: Diameter of the Pipe (m)
R: Radius of the Cylindrical Tank (m)
ρ: Fluid Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)

Output(s)

t_{efflux} : Efflux Time (s)

Formula(s)

$$t_{efflux} = \frac{128 * \mu * L * R^2}{\rho * g * D^4} * \ln\left(1 + \frac{H}{L}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 7, Page: 228.*

5.43 Draining of a spherical tank

Input(s)

R: Radius of the Sphere (m)
L: Length of the Pipe (m)
A: A Constant Related to Length, Radius, and Height (m^2/s)

Output(s)

t_{efflux}: Efflux Time (s)

Formula(s)

$$t_{efflux} = \left(\frac{L^2}{A}\right) * \left(\left(2 * \frac{R}{L} * \left(1 + \frac{R}{L}\right) - \left(1 + 2 * \frac{R}{L}\right) * \ln\left(1 + 2 * \frac{R}{L}\right)\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 7, Page: 200.*

5.44 Eckert number

Input(s)

V: Characteristic Velocity of Flow (m/s)
c_p: Constant-Pressure Specific Heat of Flow (m/s^2 K)
ΔT: Temperature Difference (K)

Output(s)

Ec: Eckert Number = Advective Transport/(Heat Dissipitation Potential) (dimensionless)

Formula(s)

$$Ec = \frac{V^2}{c_p * \Delta T}$$

Reference: *Wikipedia.org*.

5.45 Effective emissivity of a hole

Input(s)

e: Emissivity of the Cavity Walls (dimensionless)
f: Friction Factor (dimensionless)

Output(s)

e_h: Emissivity of Hole (dimensionless)

Formula(s)

$$e_h = \frac{e}{e + f * (1 - e)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 493.*

5.46 Effective thermal conductivity for a solid with spherical inclusions

Input(s)

T: Initial Temperature (K)
k_{eff}: Effective Thermal Conductivity (J/ft s K)

k_o: Thermal Conductivity of Solid (J/ft s K)
R: Effective Radius (ft)
r: Distance from Centre (ft)
A: Temperature Gradient (K/ft)
Θ: Position of Substance from Centre (rad)

Output(s)

T_r: Temperature at R (K)

Formula(s)

$$T_r = T + \left(1 - \left(\frac{k_{eff} - k_o}{k_{eff} + 2 * k_o}\right) * \left(\left(\frac{R}{r}\right)^3\right)\right) * A * r * \cos(\Theta)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 11, Page: 371.*

5.47 Efflux time for draining a conical tank

Input(s)

z_0: Vertical Coordinate at the Top of the Cone (m)
z_2: Vertical Coordinate just Above the Datum Plane for Potential Energy (m)
g: Gravitational Acceleration (m/s^2)

Output(s)

t_{efflux}: Efflux Time (s)

Formula(s)

$$t_{efflux} = \left(\frac{1}{5}\right) * \left(\frac{z_0}{z_2}\right)^2 * \left(2 * \frac{z_0}{g}\right)^{0.5}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 7, Page: 229.*

5.48 Ekman number

Input(s)

D: Characteristic Length Scale (m)
v: Kinematic Eddy Viscosity (m^2/s)
ω: Angular Velocity of Plenatory Motion (1/s)
ϑ: Latitude (degree)

Output(s)

Ek: Ekman Number (dimensionless)

Formula(s)

$$Ek = \frac{v}{2 * D^2 * \omega * \sin\left(\vartheta * \frac{\pi}{180}\right)}$$

Reference: *Wikipedia.org*.

5.49 Elimination of circulation in a rising gas bubble

Input(s)

R: Radius of bubble (cm)
μ: Viscosity (cP)
v_∞: Velocity (cm/s)
θ: Angle of bubble (rad)

Output(s)

τ: Stress (kPa)

Formula(s)

$$\tau = \frac{3 * \mu * v_\infty * \sin(\theta)}{2 * R}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 701.*

5.50 Energy emitted from the surface of a black body

Input(s)

S: Stephan-Boltzmann Constant (lb/(hr^3 R^4))
T: Temperature (R) A: Area (ft^2)

Output(s)

$(q_b)^e$: Emitted Heat Flux (Btu/h ft^2)

Formula(s)

$$(q_b)^e = \rho * \left(T^4\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 494.*

5.51 Estimation of diffusivity of liquids

Input(s)

ϕ_B: Association Number (dimensionless)
T: Temperature (K)

M_B: Molar Weight (g/g mol)
μ: Viscosity (cP)
V_A: Molar Volume (cm^3/g mol)

Output(s)

D_{AB}: Diffusivity (cm^2/s)

Formula(s)

$$D_{AB} = 0.000000074 * \frac{\left((\varnothing_B * M_B)^{0.5}\right) * T}{\mu * \left(V_A^{0.6}\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 530.*

5.52 Estimation of self diffusivity at high density

Input(s)

a: Concentration (g mol/cm^3)
Daa: Prediction of Self-Diffusivity (g mol/cm s)
$cDaa_r$: Reduced Diffusivity (g mol/cm s)

Output(s)

$cDaa_c$: Critical Diffusivity (g mol/cm s)
CDaa: Prediction of Self-Diffusivity (g mol/cm s)

Formula(s)

$$cDaa_c = \frac{c * Daa}{cDaa_r}$$

$$CDaa = (cDaa_c) * (cDaa_r)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 523.*

5.53 Estimation of the viscosity of a pure liquid

Input(s)

N: Avogadro Number (g/mol)
h: Planck Constant (g cm^2/s)
V: Volume of a Mole of Liquid (cm^3/g mol)
T_b: Boiling Point (Centigrade)
T: Ambient Temperature (Celsius)

Output(s)

μ: Viscosity of a Pure Liquid (g/(cm s))

Formula(s)

$$\mu = \frac{N * h}{V} * \exp\left(3.8 * \frac{T_b}{T}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 31.*

5.54 Euler number

Input(s)

ρ: Density of Fluid (kg/m^3)
Pu: Upstream Pressure (kg/ms^2)
Pd: Downstream Pressure (kg/ms^2)
V: Velocity of Flow (m/s)

Output(s)

Eu: Euler Number (dimensionless)

Formula(s)

$$Eu = (Pu - Pd) * \frac{1.0}{\frac{1}{2} * \rho * V^2}$$

Reference: *Wikipedia.org*.

5.55 Fanning friction factor (laminar flow)

Input(s)

D: Diameter (ft)
v: Velocity (ft/s)
ρ: Density (g/cc)
μ: Viscosity of Fluid (cP)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = \frac{16 * \mu}{D * v * \rho}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 181.*

5.56 Fanning's friction factor (turbulent flow)

Input(s)

D: Diameter (ft)
v: Velocity of Fluid (ft/s)
ρ: Density of Fluid (g/cc)
μ: Visocosity of Fluid (cP)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = \frac{0.0791 * \mu^{0.25}}{(D * v * \rho)^{0.25}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 181.*

5.57 Fick's law of binary diffusion

Input(s)

ρ: Density (g/cc)
D_{AB}: Diffusivity (cm^2/s)
dw_a: Mass Fraction of A (fraction)
dy: Difference in Distance (cm)

Output(s)

j_{Ay}: Mass Flux (g/cm^2 s)

Formula(s)

$$j_{Ay} = D_{AB} * (-\rho) * \frac{dw_a}{dy}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 515.*

5.58 Film condensation on vertical pipes

Input(s)

k: Thermal Conductivity (W/mK)
ρ: Density (g/cc)
g: Acceleration due to Gravity (m/s^2)
H_{vap}: Heat of Vaporization (N)
μ: Viscosity (cP)
L: Length (m)
Td: Dew Point Temperature (K)
To: Outlet Temperature (K)

Output(s)

h_{ml}: Laminar Coefficient of Heat Transfer (W/m K)
h_{mt}: Turbulent Coefficient of Heat transfer (W/m K)

Formula(s)

$$h_{ml} = \left(\frac{2*(\sqrt{2})}{3}\right)*\left(\left(\frac{(k^3)*(\rho*2)*g*H_{vap}}{(\mu^3)*(Td-To)*L}\right)^{0.25}\right)$$

$$h_{mt} = 0.003*\left(\left(\frac{(k^3)*(\rho*2)*g*(Td-To)*L}{(\mu^3)*H_{vap}}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 14, Page: 447.*

5.59 Film condensation on vertical tubes

Input(s)

k: Thermal Conductivity (g m/s s s K)
ρ: Density (g/cc)
g: Gravitational Accelaration (m/s s)
μ: Viscosity (cP)
τ: Rate of Condensate Flow per Unit Width to Bottom (m^2/s)
Td: Dew Point Temperature (K)
To: Temperature Outlet (K)
L: Length (m)
H_{vap}: Heat of Vaporization (N)

Output(s)

h_{ml}: Laminar Coefficient of Heat Transfer (W/m K)
h_{mt}: Turbulent Coefficent of Heat Transfer (W/m K)

Formula(s)

$$\mathrm{h_{ml}} = \frac{4}{3}*\left(\left(\frac{(\mathrm{k}^3)*(\rho^2)*\mathrm{g}}{3*\mu*\tau}\right)^{0.334}\right)$$

$$\mathrm{h_{mt}} = 0.003*\left(\left(\frac{(\mathrm{k}^3)*(\rho^2)*\mathrm{g}*(\mathrm{Td}-\mathrm{To})*\mathrm{L}}{(\mu^3)*\mathrm{H_{vap}}}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 14, Page: 447.*

5.60 Film thickness of a falling film on a conical surface

Input(s)

μ: Viscosity (cP)
w: Mass Rate (lbs/s)
L: Length (ft)
ρ: Density (lb)
g: Acceleration of Gravity (ft/s^2)
β: Inclination (rad)
s: Distance from Cone Apex (ft)

Output(s)

δ: Film Thickness (ft)

Formula(s)

$$\delta = \left(\left(\frac{3 * \mu * L * w}{\pi * (\rho^2) * g * L * \sin(2 * \beta) * s}\right)^{\frac{1}{3}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 71.*

5.61 Flow in a liquid-liquid ejector pump

Input(s)

v_2: Outlet Velocity (ft/s)
ρ: Density of Fluid (g/cc)

Output(s)

v_0: Inlet Velocity (ft/s)
E_v: Energy Dissipation (ft^2/s^2)
$p_2 - p_1$: Pressure Drop (psi)

Formula(s)

$$v_o = 1.5 * v_2$$

$$p_2 - p_1 = \left(\frac{1}{18}\right) * \rho * \left(v_o^2\right)$$

$$E_v = \left(\frac{5}{144}\right) * \left(v_o^2\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 7, Page: 211.*

5.62 Flow in a slit with uniform cross flow

Input(s)

B: Thickness (cm)
L: Length (cm)
W_p: Width (cm)
v_0: Cross-flow Velocity (cm/s)
ρ: Fluid Density (g/cc)
μ: Viscosity (Pa s)
P_O: Input Pressure (Pa)
P_L: Output Pressure (Pa)

Output(s)

A: Constant (dimensionless)
w: Mass Flow Rate (g/s)

Formula(s)

$$A = \frac{B * v_o * \rho}{\mu}$$

$$w = \left(\frac{(P_O - P_L) * (B^3) * W_p}{\mu * L * A}\right) * \left(\frac{1}{2} - \frac{1}{A} + \frac{1}{(\exp(A) - 1)}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 3, Page: 110.*

5.63 Flow near a corner

Input(s)

c: Constant (dimensionless)
B: Velocity Gradient at a Surface (1/s)
x: Length (ft)

Output(s)

v_e: External Flow Velocity (ft/s)

Formula(s)

$$v_e = c * x^{\left(\frac{B}{2-B}\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 4, Page: 139.*

5.64 Flow of power law fluid through a narrow slit

Input(s)

W: Width (cm)
B: Breadth (cm)
L: Length (cm)
ρ: Density of Fluid (g/cc)
P_O: Input Pressure (Pa)
P_L: Output Pressure (Pa)
m: Power Law Constant (dimensionless)
n: Power Law Constant 2 (dimensionless)

Output(s)

w: Mass Rate of Flow (g/s)

Formula(s)

$$w = \left(\frac{2 * W * (B^2) * \rho}{\left(\frac{1}{n}\right) + 2}\right) * \left(\left(\frac{(P_O - P_L) * B}{m * L}\right)^{\frac{1}{n}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 8, Page: 243.*

5.65 Fluid kinetic force in conduits

Input(s)

R: Radius (ft)
L: Length (ft)
ρ: Density of Fluid (lb/ft^3)
v: Velocity of Fluid (ft/s)
f: Friction Factor (dimensionless)

Output(s)

F_k: Force of Fluid Flow (N)

Formula(s)

$$F_k = \pi * R * L * \rho * (v^2) * f$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 178.*

5.66 Fluid kinetic force in flow around submerged objects

Input(s)

R: Radius of Sphere (ft)
ρ: Density of Fluid (lb/ft^3)

v: Velocity of Fluid (ft/s)
f: Friction Factor (dimensionless)

Output(s)

$\boldsymbol{F_k}$: Fluid Kinetic Force (N)

Formula(s)

$$F_k = \pi * 0.5 * \left(R^2\right) * \rho * \left(v^2\right) * f$$

Reference: Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons. Chapter: 3, Page: 110.*

5.67 Form drag

Input(s)

R: Radius (ft)
ρ: Density (ppg)
g: Acceleration due to Gravity (ft/s^2)
μ: Viscosity (cP)
v: Velocity (ft/s)

Output(s)

F: Normal Force (N)

Formula(s)

$$F = \left(\frac{4}{3}\right) * \pi * \left(R^3\right) * \rho * g + 2 * \pi * \mu * R * v$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 60.*

5.68 Free air correction—Gravity survey

Input(s)

$\boldsymbol{\Delta h}$: Elevation change (m)

Output(s)

$\boldsymbol{\Delta g_z}$: Free Air Correction (mGal)

Formula(s)

$$\Delta g_z = 0.3086 * \Delta h$$

Reference: *https://sites.ualberta.ca/~unsworth/UA-classes/210/exams210/210-final-2008-formula-sheet.pdf*.

5.69 Free batch expansion of a compressible fluid

Input(s)

S_2: Output Surface Area (ft^2)
P_1: Input Pressure (psi)
ρ_1: Density (ppg)
γ: Adiabatic Constant (dimensionless)

Output(s)

w_{max}: Discharge Rate (lb/s)

Formula(s)

$$w_{max} = S_2 * \left(\left(P_1 * \rho_1 * \gamma * \left(\left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}} \right) \right)^{0.5} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 15, Page: 474.*

5.70 Free convection heat transfer from a vertical plate

Input(s)

C: Constant of Convection (dimensionless)
Gr: Grashof Number (dimensionless)
Pr: Prandtl (dimensionless)
k: Thermal Conductivity (J/m s K)
H: Height (ft)
T_0: Outer Temperature (K)
T_i: Inner Temperature (K)

Output(s)

Q: Average Heat Transfer Flux (J/m^2 s)

Formula(s)

$$Q = \frac{C * k * (T_o - T_i) * \left((Gr * Pr)^{0.25} \right)}{H}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 11, Page: 348.*

5.71 Friction drag

Input(s)

μ: Viscosity (cP)
R: Radius (ft)
v_∞: Velocity as r Goes to Infinity (ft/s)

Output(s)

F: Force (N)

Formula(s)

$$F = 4 * \pi * \mu * R * v_{\infty}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 60.*

5.72 Friction factor for creeping flow around a sphere

Input(s)

D: Diameter (ft)
v: Velocity of Fluid (ft/s)
ρ: Density of Fluid (g/cc)
μ: Viscosity of Fluid (cP)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = \frac{24 * \mu}{D * v * \rho}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 186.*

5.73 Friction factor in flow around submerged objects

Input(s)

g: Gravitational Acceleration (ft/s^2)
v: Fluid Velocity (ft/s)
D: Diameter (ft)
ρ: Fluid Density (g/cc)
ρ_{sph}: Density of Sphere (g/cc)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = \left(\frac{4 * g * D}{3 * v^2}\right) * \left(\frac{\rho_{sph} - \rho}{\rho}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 179.*

5.74 Friction factor in flow through conduits

Input(s)

D: Diameter of Conduit (ft)
L: Length of Conduit (ft)
v: Fluid Velocity (ft/s)
P_o: Inlet Pressure (psi)
P_L: Outlet Pressure (psi)
ρ: Density (g/cc)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = \frac{0.25 * D * (P_o - P_L)}{0.5 * L * \rho * (v^2)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 178.*

5.75 Friction factor in packed column (laminar)

Input(s)

ε: Fractional Void Space (dimensionless)
D_P: Diameter of Particles (ft)
v_0: Velocity of Fluid (ft/s)
ρ: Density of Fluid (g/cc)
μ: Viscosity of Fluid (cP)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = \left(\frac{(1-\varepsilon)^2}{\varepsilon^3}\right) * \left(\frac{75 * \mu}{\rho * D_P * v_o}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 190.*

5.76 Friction factor in packed column (turbulant)

Input(s)

ε: Fractional Void Space (dimensionless)

Output(s)

f: Friction Factor (dimensionless)

Formula(s)

$$f = 0.875 * \left(\frac{1-\varepsilon}{\varepsilon^3}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 6, Page: 191.*

5.77 Galilei number

Input(s)

v: Characteristic Kinematic Viscosity (m^2/s)
L: Characteristic Length (m)
g: Gravitational Acceleration (m/s^2)

Output(s)

Ga: Galilei Number (dimensionless)

Formula(s)

$$Ga = g * L^3 * \frac{1.0}{v^2}$$

Reference: *wikipedia.org*.

5.78 Gas absorption from rising bubbles for creeping flow

Input(s)

D_{AB}:Diffusivity (cm^2/s)
v_t: Terminal Velocity (cm/s)
D: Bubble Diameter (cm) (N_A)
c_{A0}: Solubility (g/cm^3)

Output(s)

N_A: Average Molar Absorption Rate (g mol/cm^2 s)

Formula(s)

$$N_A = \sqrt{\left(\frac{4 * D_{AB} * v_t}{3 * \pi * D}\right)} * c_{A0}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 561.*

5.79 Gas absorption through bubbles

Input(s)

D_{AB}: Diffusivity (cm^2/s)
v_t: Terminal Velocity (cm/s)
D: Diameter of Bubble (cm)
C_{A0}: Concentration (g mol/cm)

Output(s)

N_a: Molar Flux (g mol/s)

Formula(s)

$$N_a = \sqrt{\left(\frac{4 * D_{AB} * v_t}{3 * \pi * D}\right)} * C_{A0}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 20, Page: 637.*

5.80 Gas absorption with chemical reaction in an agitated tank

Input(s)

k_1: Diffusion Rate (g mol/s)
L: Length (cm)
D_{AB}: Diffusivity (cm^2/s)
V: Volume (cc)
S: Surface Area (cm^2)
δ: Location of Catalytic Bed (fraction)

Output(s)

ø: Thiele Modulus (dimensionless)
N: Flux (g mol/s)

Formula(s)

$$ø = \left(\frac{k_1 * (L^2)}{D_{AB}}\right)^{0.5}$$

$$N = \left(\frac{ø}{\sinh(ø)}\right) * \left(\cosh(ø) - \left(\frac{1}{\cosh(ø) + \left(\frac{V}{\delta * S}\right) * ø * \sinh(ø)}\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 557.*

5.81 Gas absorption with rapid reaction

Input(s)

c: Concentration (mol/cm^3)
γ: Adiabatic Constant (dimensionless)
D_{AS}: Diffusivity (cm^2/s)
t: Time (s)

Output(s)

N_{AZO}: Rate of Absorption (cc/s)

Formula(s)

$$N_{AZO} = \left(\frac{c}{\text{erf}\left(\frac{\gamma}{D_{AS}}\right)^{0.5}}\right) * \left(\left(\frac{D_{AS}}{\pi * t}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 20, Page: 618.*

5.82 Gas mass rate flow in compressible tube flow

Input(s)

m: Molecular Mass (g)
κ: Boltzmann (W/cm K^4)
T: Temperature (K)
P_o: Input Pressure (psi)
P_L: Output Pressure (psi)
R: Radius (cm)
L: Length (cm)

Output(s)

w: Mass Rate (g/cm)

Formula(s)

$$w = \left(\left(\frac{2 * m}{\pi * \kappa * T}\right)^{0.5}\right) * \left(\frac{4}{3} * \pi * \left(R^3\right)\right) * \left(\frac{P_o - P_L}{L}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 66.*

5.83 Graetz number

Input(s)

DH: Diameter in Round Tubes or Hydraulic Diameter in Arbitrary Cross-section Ducts (m)

L: Length (m)
Re: Reynold Number (dimensionless)
Pr: Prandtl Number (dimensionless)

Output(s)

Gz: Graetz Number (dimensionless)

Formula(s)

$$Gz = DH * Re * \frac{Pr}{L}$$

Reference: *Wikipedia.org*.

5.84 Graham equation viscosity ratio

Input(s)

ø: Volume Fraction (dimensionless)
Ψ: Stream Function (dimensionless)

Output(s)

μ_r: Graham Equation Viscosity Ratio (dimensionless)

Formula(s)

$$\mu_r = 1 + \frac{5}{2} * ø + \frac{9}{4} * \left(\frac{1}{\Psi * (1 + 0.5 * \Psi) * (1 + \Psi)^2} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second ed.). John Wiley & Sons. Chapter: 1, Page: 33.*

5.85 Grash of number

Input(s)

g: Acceleration Due to Earth (m/s^2)
β: Volumetric Thermal Expansion Coefficient (1/K)
T_1: Surface Temperature (K)
T_o: Bulk Temperature (K)
I_o: Diameter (m)
v: Kinematic Viscosity (m^2/s)

Output(s)

Gr: Grash of Number (dimensionless)

Formula(s)

$$Gr = \frac{g * \beta * (T_1 - T_o) * l_o^3}{v^2}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 11, Page: 355.*

5.86 Hagen number

Input(s)

PG: Pressure Gradient (Pa/m)
ρ: Fluid Density (kg/m^3)
L: Characteristic Length (m)
v: Kinematic Viscosity (m^2/s)

Output(s)

Hg: Hagen Number (dimensionless)

Formula(s)

$$Hg = -\frac{1}{\rho} * PG * \frac{L^3}{v^2}$$

Reference: *Wikipedia.org*.

5.87 Hagen-Poiseuille equation

Input(s)

$\boldsymbol{P_o}$: Input Pressure (psi)
$\boldsymbol{P_L}$: Output Pressure (psi)
R: Radius (ft)
w: Mass rate of Flow (lb/s)
$\boldsymbol{\rho}$: Density (ppg)
L: Length (ft)

Output(s)

$\boldsymbol{\mu}$: Viscosity (cP)

Formula(s)

$$\mu = \frac{(P_o - P_L) * \pi * \left(R^4\right) * \rho}{8 * w * L}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 51.*

5.88 Influence of changing interfacial area on mass transfer

Input(s)

c_{AO}: Concentration (g mol/cm)
D_{AB}: Diffusivity (cm^2/s)
t: Time (s)
a: Constant (dimensionless)

Output(s)

M_A: Molar Rate (mol/s)

Formula(s)

$$M_A = c_{AO} * \left(\frac{4 * D_{AB} * \left(t^{2*0.667+1}\right)}{\pi * (2*0.667+1)} \right)^{0.5}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons. Chapter: 20, Page: 623.*

5.89 Knudsen flow

Input(s)

m: Molecular Mass (g)
K: Boltzmann Constant ($m^2\ kg\ s^{-2}\ K^{-1}$)
T: Temperature (Kelvin)
R: Radius (m)
po: Pressure at Initial point (Pa)
pL: Pressure at point L (Pa)
L: Length (m)

Output(s)

w: Mass Rate Flow (kg/s)

Formula(s)

$$w = sqrt\left(2 * \frac{m}{K*T}\right) * \left(\frac{4}{3} * R^3\right) * \frac{po - pL}{L},$$

Reference: *Wikipedia.org*.

5.90 Krieger Dougherty equation viscosity ratio

Input(s)

ø: Porosity (fraction)
A: Dimensionless Constant (dimensionless)
$ø_{max}$: Volume Fraction for the Spheres (fraction)

Output(s)

μ_r: Krieger Dougherty Equation Viscosity Ratio (fraction)

Formula(s)

$$\mu_r = \left(1 - \frac{\emptyset}{\emptyset_{max}}\right)^{(-A*\emptyset_{max})}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 33.*

5.91 Laminar flow along a flat plate (approximate solution)

Input(s)

$v\infty$: Fluid Velocity (ft/s)
L: Length of Plate (ft)
W: Width of Plate (ft)
ρ: Density of Fluid (g/cc)
μ: Viscosity (cP)

Output(s)

F_x: Momentum Flux (psi)

Formula(s)

$$F_x = 1.293 * \left(\left(\rho * \mu * L * \left(W^2\right) * \left(v_\infty{}^3\right)\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 4, Page: 137.*

5.92 Laminar flow of an incompressible power-law fluid in a circular tube

Input(s)

ρ: Density of Fluid (g/cc)
P_o: Input Pressure (Pa)
P_L: Output Pressure (Pa)
R: Radius of Tube (cm)
L: Length of Tube (cm)
m: Power Law Constant (dimensionless)
n: Power Law Constant 2 (dimensionless)

Output(s)

w: Mass Rate (g/s)

Formula(s)

$$w = \left(\frac{\pi * (R^3) * \rho}{\left(\frac{1}{n}\right) + 3}\right) * \left(\left(\frac{(P_o - P_L) * R}{2 * m * L}\right)^{\frac{1}{n}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 8, Page: 243.*

5.93 Laplace number

Input(s)

ρ: Density (kg/$\boldsymbol{m^3}$)
L: Characteristic Length (m)
σ: Particle Hard Shell Dia (N/m)
μ: Liquid Viscosity (Pa s)

Output(s)

La: Laplace number (dimensionless)

Formula(s)

$$La = \sigma * \rho * \frac{L}{\mu^2}$$

Reference: *Wikipedia.org*.

5.94 Lewis number

Input(s)

α: Thermal Diffusivity (**m**^{2}/s)
D: Mass diffusivity (**m**^{2}/s)

Output(s)

Le: Lewis number (dimensionless)

Formula(s)

$$Le = \frac{\alpha}{D}$$

Reference: *Wikipedia.org*.

5.95 Mach number

Input(s)

v: Velocity of source relative to medium (m/s)
vs: Speed of sound in the medium (m/s)

Output(s)

M: Mach number (dimensionless)

Formula(s)

$$M = \frac{v}{vs}$$

Reference: *Wikipedia.org*.

5.96 Manning formula

Input(s)

k: Conversion factor of (L1/3)/T, 1 for SI ((m1/3)/s)
Rh: Hydraulic radius (m)
S: Slope of the hydraulic grade line or the linear (kg/m^3)
n: Manning coefficient (dimensionless)

Output(s)

V: Cross-sectional average velocity (m/s)

Formula(s)

$$V = k * Rh^{\frac{2}{3}} * \frac{S^{\frac{1}{2}}}{n}$$

Reference: *Wikipedia.org*.

5.97 Marangoni number

Input(s)

SG: Change in Surface Tension per unit Temp (N/m/K)
L: Characteristic length (m)
dT: Speed of sound in the medium (K)
α: Thermal diffusivity (m^2/s)
σ: Dynamic viscosity (kg/(s m))

Output(s)

Mg: Marangoni number (dimensionless)

Formula(s)

$$Mg = SG * L * \frac{dT}{\alpha * \sigma}$$

Reference: *Wikipedia.org*.

5.98 Mass absorption (attenuation) coefficient

Input(s)

N: Number of Atoms per Unit Volume (m^{-3})
σ: Thin Cross Section Expressed in Barns per Atom (1 barn is $10^{-28} m^2$) (m^2/atom)
ρ: Density (kg/m^3)

Output(s)

α_l: Linear Absorption Coefficient (1/m)
α_m: Mass Absorption Coefficient (m^2/kg)

Formula(s)

$$\alpha_l = \sigma * N$$

$$\alpha_m = \frac{\alpha_l}{\rho}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 33–34.*

5.99 Mass flow rate as a function of the modified pressure drop in a network of tubes

Input(s)

P_A: Pressure at A (psi)
P_B: Pressure at B (psi)
μ: Viscosity (cP)
ρ: Density (ppg)
L: Length (ft)
R: Radius (ft)

Output(s)

w: Mass Flow Rate (lb/s)

Formula(s)

$$w = \frac{3 * \pi * (P_A - P_B) * (R^4) * \rho}{20 * \mu * L}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 68.*

5.100 Mass flow rate in a rotating cone pump

Input(s)

P_o: Input Pressure (psi)
P_L: Output Pressure (psi)
L: Length (ft)
B: Distance from Centre (ft)

ρ: Density (ppg)
z: Distance from Input Side (ft)
β: Inclination (rad)
μ: Viscosity (cP)

Output(s)

w: Mass Flow rate (lb/s)

Formula(s)

$$w = \frac{-2 * (P_o - P_L) * (B^3) * \rho * 2 * \pi * z * \sin(\beta)}{3} * L * \mu$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 72.*

5.101 Mass rate of flow

Input(s)

g: Acceleration due to Gravity (cm/s^2)
ρ: Density (g/cc)
δ: Film Thickness (cm)
v: Kinematic (cm^2/s)
W: Width (cm)

Output(s)

w: Mass Rate of Flow (g/s)

Formula(s)

$$w = \frac{\rho * g * (\delta^3) * W}{3 * v}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 47.*

5.102 Mass rate of flow in a squared duct

Input(s)

P_o: Input Pressure (psi)
B: Duct Boundary (ft)
ρ: Fluid Density (g/cc)
μ: Viscosity (cP)
L: Length (ft)
P_L: Output Pressure (psi)

Output(s)

w: Mass Rate in Square Duct (g/s)

Formula(s)

$$w = \frac{0.563 * (P_o - P_L) * B^4 * \rho}{\mu * L}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 3, Page: 106.*

5.103 Mass rate of flow of a falling film

Input(s)

ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
δ: Film Thickness (m)
W: Width (m)
μ: Kinematic Viscosity (kg/(ms))
β: Angle of Inclination w.r.t Direction of Gravity (rad)

Output(s)

ω: Mass Rate of Flow (kg/s)

Formula(s)

$$\omega = \left(\rho^2 * g * \delta^3 * W * \frac{\cos(\beta)}{3 * \mu}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 46.*

5.104 Mass rate of flow through a circular tube

Input(s)

P_o: Input Pressure (psi)
P_L: Output Pressure (psi)
R: Radius (ft)
ρ: Density (ppg)
μ: Viscosity (cP)
L: Length (ft)

Output(s)

w: Mass Rate (lbm/s)

Formula(s)

$$w = \pi * \left((P_o - P_L) * \left(R^4\right) * \rho\right) / (8 * \mu * L)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 55.*

5.105 Mass transfer for creeping flow around a gas bubble

Input(s)

D_{AB}: Diffusivity (cm^2/s)
v_∞: Velocity (cm/s)
D: Diameter of Bubble (cm)
C_{AO}: Concentration (g mol/cm)

Output(s)

N_{AOavg}: Molar Flux Average (mol/cm^2 s)

Formula(s)

$$N_{AOavg} = C_{AO} * \left(\left(\frac{4 * D_{AB} * v_\infty}{3 * \pi * D}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 20, Page: 637.*

5.106 Mass transfer to drops and bubbles

Input(s)

σ: Interfacial Tension (N)
D: Diameter (cm)
ρ_d: Density of Drops (g/cc)
ρ_c: Density of Continuous Medium (g/cc)

Output(s)

ω: Angular Frequency of Oscillation (rad/s)

Formula(s)

$$\omega = \left(\left(\frac{192 * \sigma}{(D^3) * (3 * \rho_d + 2 * \rho_c)}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 687.*

5.107 Maximum flow rate (Vogel's equation)

Input(s)

q: Tested Production Rate (stb/d)
P: Reservoir Pressure (psi)
P_w: Tested Flowing Bottom Hole Pressure (psi)

Output(s)

q_{max}: Maximum Flow Rate (stb/d)

Formula(s)

$$q_{max} = \frac{q}{1 - 0.2 * \left(\frac{P_w}{P}\right) - 0.8 * \left(\frac{P_w}{P}\right)^2}$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach, Page: 3/34.*

5.108 Maximum velocity of a falling film

Input(s)

ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
δ: Film Thickness (m)
β: Angle of Inclination w.r.t. Direction of Gravity (rad)
μ: Viscosity (kg/(ms))

Output(s)

V_{zmax}: Maximum Velocity (m/s)

Formula(s)

$$V_{zmax} = \frac{\rho * g * (\delta^2) * \cos(\beta)}{2 * \mu}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 45.*

5.109 Maximum velocity of flow through a circular tube

Input(s)

p_o: Pressure at Initial Point (Pa)
p_L: Pressure at Point L (Pa)
R: Radius (m)
μ: Viscosity (kg/(ms))
L: Length (m)

Output(s)

v_{zmax}: Maximum Velocity (m/s)

Formula(s)

$$v_{zmax} = \frac{(p_o - p_L) * R^2}{4 * \mu * L}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 51.*

5.110 Maximum-velocity V_z-maximum of a falling film

Input(s)

ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
δ: Film Thickness (m)
mu: Viscosity (kg/(ms))
β: Angle of inclination w.r.t direction of gravity (rad)

Output(s)

vz: Maximum Velocity (m/s)

Formula(s)

$$vz = \frac{\rho * g * \delta^2 * \cos(\beta)}{2 * \mu}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Page: 45.*

5.111 Method for separating helium from natural gas

Input(s)

D_{AB} : Diffusivity of Helium and Natural gas (cm^2/s)
c_{He1} : Concentration of Helium (g/s)
c_{He2} : Concentration of Natural gas (g/s)
R_2: Outer Radius (cm)
R_1: Inner Radius (cm)
L: Length (cm)

Output(s)

W_{He}: Mass Flux (g/cm)

Formula(s)

$$W_{He} = 2 * \pi * L * \frac{D_{AB} * (c_{He1} - c_{He2})}{\ln\left(\frac{R_2}{R_1}\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 573.*

5.112 Modified capillary number

Input(s)

μ_w: Viscosity of water (cP)
μ_o: Viscosity of oil (cP)
σ: Interfacial tension (dyn/cm)
v: Characteristic velocity (ft/D)

Output(s)

Mc: Modified Capillary Number (dimensionless)

Formula(s)

$$Mc = \left(\mu_w * \frac{v}{\sigma}\right) * \left(\frac{\mu_w}{\mu_o}\right)^{0.4}$$

Reference: *Petrowiki.org*.

5.113 Modified Van Driest equation

Input(s)

v: Velocity (ft/s)
V_m: Friction Velocity (ft/s)
y: Length (ft)

Output(s)

L: Mixing Length (ft)

Formula(s)

$$L = 0.4 * y * \left(\frac{1 - \left(-y * \frac{v}{26} * V_m\right)}{\left(1 - \left(-0.26 * y * \frac{v}{V_m}\right)\right)^{0.5}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 5, Page: 164.*

5.114 Momentum flux distribution of flow through a circular tube

Input(s)

p_o: Pressure at Initial Point (Pa)
p_L: Pressure at Point L (Pa)
r: Cylindrical Shell of Thickness (m)
L: Length (m)

Output(s)

τ_{rz}: Momentum Flux Distribution (Pa)

Formula(s)

$$\tau_{rz} = \frac{p_o - p_L}{2 * L} * r$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 50.*

5.115 Momentum flux distribution of flow through an annulus

Input(s)

p_o : Pressure at Initial Point (Pa)
p_L : Pressure at Point L (Pa)
R : Radius (m)
L: Length (m)
r: Cylindrical Shell of Thickness (m)
K: Ratio of Inner Pipe's Radius to Outer Pipe's Radius (fraction) ($m^2\ kg\ s^{-2}\ K^{-1}$)

Output(s)

τ_{rz}: Momentum Flux Distribution (Pa)

Formula(s)

$$\tau_{rz} = (p_o - p_L) * \frac{R}{2 * L} * \left(\frac{r}{R} - \frac{1 - K^2}{2 * \ln\left(\frac{1}{K}\right)} * \left(\frac{R}{r}\right) \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 55.*

5.116 Momentum flux profile of fluids in flow of two adjacent immiscible fluids

Input(s)

p_o: Pressure at Initial Point (Pa)
p_L: Pressure at point L (Pa)
b: Distance (m)
x : Distance in Cartesian Coordinate x (m)
L : Length (m)
μ_I: Viscosity of More Dense and Viscous Fluid (kg/(ms))
μ_{II}: Viscosity of Less Dense and Viscous Fluid (kg/(ms))

Output(s)

τ_{rz}: Momentum Flux (Pa)

Formula(s)

$$\tau_{rz} = \frac{(p_o - p_L) * b}{L} * \left(\left(\frac{x}{b} \right) - \frac{1}{2} * \frac{\mu_I - \mu_{II}}{\mu_I + \mu_{II}} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 57.*

5.117 Momentum fluxes for creeping flow into a slot

Input(s)

P_i: Pressure input (psi)
P_o: Pressure output (psi)
R: Radius of sphere (cm)
κ: Turbulance coefficient (dimensionless)
ρ: Fluid density (g/cc)
μ: viscosity of fluid (cP)
ξ: angle of contact between two entities (rad)

Output(s)

W: Mass Flow Rate (g/s)

Formula(s)

$$W = \frac{\pi * (P_i - P_o) * (R^3) * \left((1-\kappa)^3 \right) * \rho}{12 * \mu * \ln \left(\cot \left(\frac{\xi}{2} \right) \right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.), John Wiley & Sons, Page: 107.*

5.118 Mooney equation viscosity

Input(s)

μ_0: Viscosity of Suspending Medium (cP)
ø: Volume Fraction (fraction)
$ø_o$: Empirical Constant Between 0.74 and 0.52 (fraction)

Output(s)

μ_{eff}: Effective Viscosity (cP)

Formula(s)

$$\mu_{eff} = \mu_0 * \left(\exp\left(\frac{\frac{5}{2} * ø}{1 - \left(\frac{ø}{ø_o}\right)} \right) \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 32.*

5.119 Non-Newtonian flow in annulus

Input(s)

r: Inner Radius (ft)
R: Outer Radius (ft)
n: Power Law Constant 2 (dimensionless)
κ: Dilatational Viscosity (cP)
$\mathbf{v_0}$: Input Velocity (ft/s)
ρ: Fluid Density (lb/ft^3)

Output(s)

v_z: Output Velocity (ft/s)
w: Mass Flow Rate (lb/s)

Formula(s)

$$v_z = v_o * \left(\frac{\left(\left(\frac{r}{R}\right)^{1-\left(\frac{1}{n}\right)} \right) - 1}{\left(\kappa^{1-\left(\frac{1}{n}\right)} \right) - 1} \right)$$

$$w = \left(\frac{2 * \pi * R^2 * \rho * v_o}{\left(\kappa^{1-\left(\frac{1}{n}\right)} \right) - 1} \right) * \left(\frac{1 - \left(\kappa^{3-\left(\frac{1}{n}\right)} \right)}{3 - \left(\frac{1}{n}\right)} - \left(\frac{1 - \kappa^2}{2} \right) \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 8, Page: 258.*

5.120 Nusselt number

Input(s)

h: Convective Heat Transfer Coefficient of the Fluid ($W/(m^2 K)$)
L: Characteristic Length (m)
k: Thermal Conductivity of Fluid (W/m K)

Output(s)

NuL: Nusselt Number (dimensionless)

Formula(s)

$$NuL = h * \frac{L}{k}$$

Reference: *Wikipedia.org*.

5.121 Ohnesorge number

Input(s)

μ: Liquid Viscosity (Pa s or kg/(m s))
L: Characteristic length (m)
ρ: Liquid Density (kg/m^3)
σ: Surface Tension (N/m)

Output(s)

Oh: Ohnesorge Number (dimensionless)

Formula(s)

$$Oh = \frac{\mu}{(\rho * \sigma * L)^{0.5}}$$

Reference: *Wikipedia.org*.

5.122 Potential flow around a cylinder

Input(s)

v_∞: Fluid Velocity (ft/s)
z: Length (ft)
R: Radius of Cylinder (ft)

Output(s)

W(z): Flow Potential (ft^2/s)

Formula(s)

$$W(z) = (-v_\infty * R) * \left(\left(\frac{z}{R}\right) + \left(\frac{R}{z}\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 4, Page: 128.*

5.123 Prandtl number

Input(s)

v: Kinematic Viscosity (m^2/s)
α: Thermal Diffusivity (m^2/s)

Output(s)

Pr: Prandtl Number (dimensionless)

Formula(s)

$$Pr = \frac{v}{\alpha}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 7, Page: 268.*

5.124 Pressure distribution in a creeping flow around a sphere

Input(s)

p_o: Pressure in the Plane z = 0 far away from the Sphere (Pa)
ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
z: Direction (m)
μ: Viscosity (kg/(ms))
v_∞: Velocity as r Goes to Infinity (m/s)
R: Radius (m)
r: Cylindrical Shell of Thickness (m)

Output(s)

p: Pressure Distribution (Pa)

Formula(s)

$$p = p_o - (\rho * g * z) - \left(\left(\frac{3}{2}\right) * \left(\mu * \frac{v_\infty}{R}\right) * \left(\frac{R}{r}\right)^2\right) * \cos(\theta)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 59.*

5.125 Pressure drop per length of the adsorption unit

Input(s)

B: Constant (dimensionless)
C: Constant (dimensionless)
μ: Viscosity (cP)
v_g: Gas Velocity (ft/m)
ρ_g: Gas Density (lb/ft^3)

Output(s)

($\Delta P/L$): Pressure Drop per Length (psi/ft)

Formula(s)

$$\left(\frac{\Delta P}{L}\right) = B * \mu * v_g + C * \rho_g * \left(v_g^2\right)$$

Reference: *John M. Campbell., Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page 393.*

5.126 Pressure loss due to sudden enlargement

Input(s)

ρ: Density of Fluid (g/cc)
v_1: Input Velocity (m/s)
v_2: Output Velocity (m/s)

Output(s)

β: Velocity Ratio (dimensionless)
$p_2 - p_1$: Pressure Drop (Pa)

Formula(s)

$$\beta = \frac{v_o}{v_i}$$

$$p_2 - p_1 = \rho * \left(v_2^2\right) * \left(\left(\frac{1}{\beta}\right) - 1\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 7, Page: 210.*

5.127 Reynolds number

Input(s)

ρ: Fluid Density (ppg)
v: Bulk Flow Velocity (ft/min)
d: Diameter (ft)
μ: Viscosity (cP)

Output(s)

N_r: Reynolds Number (dimensionless)

Formula(s)

$$N_r = 1488 * \frac{\rho * v * d}{\mu}$$

Reference: *Wikipedia.org*.

5.128 Schmidt number

Input(s)

v: Kinematic Viscosity (m^2/s)
D: Mass Diffusivity (m^2/s)

Output(s)

Sc: Schmidt Number (dimensionless)

Formula(s)

$$Sc = \frac{v}{D}$$

Reference: *Wikipedia.org*.

5.129 Sherwood number

Input(s)

L_o: Characteristic Length (m)
k_x: Single-phase Mass Transfer Coefficient (mol/(m^2 s))
D_{AB}: Diffusivity of the Binary System (m^2/s)
c: Total Molar Concentration (mol/m^3)

Output(s)

Sh: Sherwood number (dimensionless)

Formula(s)

$$Sh = \frac{(k_x * L_o)}{(c * D_{AB})}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 675.*

5.130 Slit flow in Bingham fluid

Input(s)

P_o: Input Pressure (psi)
P_L: Output Pressure (psi)
B: Breadth (ft)
L: Length (ft)
μ_o: Viscosity (cP)
τ_o: Torque (lb/ft s^2)
W: Width (ft)
ρ: Density (ppg)

Output(s)

w: Mass Flow Rate (lb/s)

Formula(s)

$$w = \left(\frac{2*(P_o - P_L)*W*B^3*\rho}{3*\mu_o*L}\right)*\left(1-\left(\frac{3*\tau_o*L}{2*(P_o-P_L)*B}\right)+\left(0.5*\left(\frac{\tau_o*L}{(P_o-P_L)*B}\right)^3\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 8, Page: 260.*

5.131 Smoluchowski equation

Input(s)

$\boldsymbol{\mu_o}$: Viscosity of the Suspension (cP)
ø: Volume Fraction of Spheres (dimensionless)
D: Dielectric Constant ($A^2\ s^2/cm^3$)
R: Particle Radius (cm)
ζ: Electro kinetic Potential of the Particles (J)
$\boldsymbol{k_e}$: Specific Electrical Conductivity of the Suspension (ohm/cm)

Output(s)

$\boldsymbol{\mu_{eff}}$: Effective Viscosity (cP)

Formula(s)

$$\mu_{eff} = \mu_o*\left(1+2.5*ø\left(1+\frac{\left(\frac{D*\zeta}{2*\pi*R}\right)^2}{\mu_o*k_e}\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 34.*

5.132 Stanton number

Input(s)

h: Convective heat transfer coefficient of the fluid ($W/(m^2\ K)$)
ρ: Density of the fluid (kg/m^3)
u: Speed of the fluid (m/s)
cp: Specific heat of the fluid (J/kg K)

Output(s)

St: Stanton number (dimensionless)

Formula(s)

$$St = \frac{h}{\rho * u * cp}$$

Reference: *Wikipedia.org*.

5.133 Stefan number

Input(s)

dt: Temperature difference between phases (Kelvin)
L: Latent Heat of Melting (Joules)
cp: Specific heat of the fluid (J/kg K)

Output(s)

Ste.: Stefan number (dimensionless)

Formula(s)

$$Ste = cp * \frac{dt}{L}$$

Reference: *Wikipedia.org*.

5.134 Stokes number

Input(s)

τ: Relaxation Time of the Particle (s)
Uo: Fluid Velocity of the Flow Well away from the Obstacle (m/s)
dc: Characteristic Dimension of the Obstacle (m)

Output(s)

Stk: Stokes Number (dimensionless)

Formula(s)

$$\mathrm{Stk} = \tau * \frac{\mathrm{Uo}}{\mathrm{dc}}$$

Reference: *Wikipedia.org*.

5.135 Strouhal number

Input(s)

f: Frequency of vortex shedding (/s)
L: Characteristic length (m)
v: Velocity of the fluid (m/s)

Output(s)

St: Strouhal number (dimensionless)

Formula(s)

$$St = f * \frac{L}{v}$$

Reference: *Wikipedia.org*.

5.136 Taylor dispersion (axial dispersion coefficient)

Input(s)

R: Radius (cm)
v_z: Average Velocity (cm/s)
D_{AB}: Diffusivity (cm^2/s)

Output(s)

K: Axial Dispersion Coefficient (cm^2/s)

Formula(s)

$$K = \frac{(R^2) * (v_z^2)}{48 * D_{AB}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 20, Page: 645.*

5.137 Taylor equation viscosity

Input(s)

μ_o: Viscosity of Suspending Medium (cP)
ø: Volume Fraction (fraction)
μ_1: Viscosity of Disperse Phase (cP)

Output(s)

μ_{eff}: Effective Viscosity (cP)

Formula(s)

$$\mu_{eff} = \mu_o * \left(1 + \left(\frac{\mu_o + \frac{5}{2} * \mu_1}{\mu_o + \mu_1}\right) * \phi\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 34.*

5.138 Taylor number

Input(s)

ω: Characteristic angular velocity (rad/s)
R: Characteristic linear dimension perpendicular to the rotation axis (m)
v: Kinematic viscosity (Pas s)

Output(s)

Ta: Taylor number (dimensionless)

Formula(s)

$$Ta = 4 * \omega^2 * \frac{R^4}{v^2}$$

Reference: *Wikipedia.org*.

5.139 Theory of diffusion in colloidal suspensions

Input(s)

K: Molar Transfer Coefficient (mol/s cm^2)
T: Temperature (K)
μ_B: Viscosity (cP)
R_A: Radius (cm)

Output(s)

D_{AB}: Diffusivity (cm^2/s)

Formula(s)

$$D_{AB} = \frac{K * T}{6 * \pi * \mu_B * R_A}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 532.*

5.140 Toricelli equation

Input(s)

g: Gravitational Acceleration (ft/(s^2))
h: Height (ft)

Output(s)

V: Efflux Velocity (ft/s)

Formula(s)

$$V = (2 * g * h)^{0.5}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 3, Page: 110.*

5.141 Total force of the fluid on the sphere in a creeping flow around a sphere

Input(s)

R: Radius (m)
ρ: Density (kg/m^3)
μ: Viscosity (kg/(ms))
g: Gravitational Acceleration (m/s^2)
vs: Apparent Velocity (m/s)

Output(s)

F: Total Force of Fluid (N)

Formula(s)

$$F = \frac{4}{3} * \pi * R^3 * \rho * g + 6 * \pi * \mu * R * vs$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Page: 60.*

5.142 Velocity distribution in a creeping flow around a sphere

Input(s)

P_i: Input Pressure (psi)
P_o: Output Pressure (psi)
L: Length (ft)
μ_a: Viscosity of A (cP)
μ_b: Viscosity of B (cP)
b: Radius (ft)
x: Distance from center (ft)

Output(s)

v: Velocity (ft/s)

Formula(s)

$$v = \left(\frac{(P_i - P_o) * (b^2)}{2 * \mu_a * L}\right) * \left(\frac{2 * \mu_a}{\mu_a + mu_b} + \frac{(\mu_a - \mu_b) * x}{(\mu_a + \mu_b) * b} - \left(\frac{x}{b}\right)^2\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Page: 59.*

5.143 Velocity distribution of a falling film with variable viscosity

Input(s)

ρ: Density (kg/m^3)
g: Gravitational Acceleration (m/s^2)
δ: Film Thickness (m)
x: Distance in Cartesian Coordinate (x)
μ: Viscosity (kg/(ms))
β: Angle of Inclination w.r.t Direction of Gravity (rad)

Output(s)

v_z: Velocity Distribution (m/s)

Formula(s)

$$v_z = \frac{\left(\rho * g * \delta^2\right) * \cos(\beta) * \left(1 - \left(\frac{x}{\delta}\right)^2\right)}{2 * \mu}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 45.*

5.144 Velocity distribution of flow through a circular tube

Input(s)

p_o: Pressure at Initial Point (Pa)
p_L: Pressure at Point L (Pa)
R: Radius of the Tube (m)
μ: Viscosity (kg/(ms))
L: Length of the Tube (m)
r: Cylindrical Shell of Thickness (m)

Output(s)

v_z: Velocity Distribution (m/s)

Formula(s)

$$v_z = \frac{(p_o - p_L) * R^2}{4 * \mu * L} * \left(1 - \left(\frac{r}{R}\right)^2\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 51.*

5.145 Velocity profile of fluids in flow of two adjacent immiscible fluids

Input(s)

P_o: Pressure at Initial Point (Pa)
P_L: Pressure at Point L (Pa)

b: Half Plane Thickness (m)
x: Vertical Distance (m)
L: Length (m)
μ_I: Viscosity of More Dense and Viscous Fluid (kg/(ms))
μ_{II}: Viscosity of Less Dense and Viscous Fluid (kg/(ms))

Output(s)

v_{zI}: Average Velocity (m/s)
v_{zII}: Average Velocity (m/s)

Formula(s)

$$v_{zI} = \frac{(P_o - P_L) * b^2}{2 * \mu_I * L} * \left(\frac{2 * \mu_I}{\mu_I + \mu_{II}} + \frac{\mu_I - \mu_{II}}{mu_I + \mu_{II}} * \frac{x}{b} - \left(\frac{x}{b}\right)^2\right)$$

$$v_{zII} = \frac{(P_o - P_L) * b^2}{2 * \mu_{II} * L} * \left(\frac{2 * \mu_{II}}{\mu_I + \mu_{II}} + \frac{\mu_I - \mu_{II}}{\mu_I + \mu_{II}} * \frac{x}{b} - \left(\frac{x}{b}\right)^2\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 57.*

5.146 Viscosity by a falling-cylinder viscometer

Input(s)

ρ: Density of Fluid (ppg)
ρ_o: Density of Slug (ppg)
g: Acceleration due to Gravity (ft/s^2)
κ: Ratio of Inner to Outer Radii (fraction)
R: Outer Radius (ft)
v_o: Slug Velocity (ft/s)

Output(s)

μ: Viscosity (cP)

Formula(s)

$$\mu = \left(\frac{(\rho_o - \rho) * g * \left((\kappa * R)^2\right)}{2 * v_o}\right) * \left(\left(\ln\left(\frac{1}{\kappa}\right)\right) - \frac{1 - \kappa^2}{1 + \kappa^2}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 2, Page: 70.*

5.147 Winsauer equation

Input(s)

a: Pore Geometry Coefficient (range of 0.35 to 4.78) (dimensionless)
m: Pore Geometry Coefficient2 (range of 1.14 to 2.52) (dimensionless)
ø: Porosity (fraction)

Output(s)

F: Formation resistivity factor (dimensionless)

Formula(s)

$$F = a * (\phi)^{-m}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 7.*

Chapter 6

Well log analysis, geophysics, petrophysics formulas, and calculations

Chapter Outline

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6.1 Acoustic transit time

Input(s)

v: Velocity (ft/s)

Output(s)

Δ_t: Acoustic Transit Time (micros/ft)

Formula(s)

$$\Delta_t = \frac{10^6}{v}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 45.*

6.2 Amplitude transmission coefficient in seismic reflection and refraction

Input(s)

Z_1: Acoustic Impedance of Layer 1 (kg/m^2 s)
Z_2: Acoustic Impedance of Layer 2 (kg/m^2 s)

Output(s)

T: Amplitude Transmission Coefficient (dimensionless)

Formula(s)

$$\mathrm{T} = \frac{2 * \mathrm{Z}_1}{\mathrm{Z}_2 + \mathrm{Z}_1}$$

Reference: *https://sites.ualberta.ca/~unsworth/UA-classes/210/exams210/210-final-2008-formula-sheet.pdf.*

6.3 Apparent intensity reflected by recorder (gamma ray)

Input(s)

J_1: First Pulse Rate Response (counts/s)
J_2: Second Pulse Rate Response (counts/s)
t: Time (s)
r_c: Time Constant of Electric Circuit (s)

Output(s)

$J_{a(t)}$: Apparent Intensity Reflected by Recorder (counts/s)

Formula(s)

$$J_{a(t)} = J_1 + (J_2 - J_1) * \left(1 - \exp\left(-\frac{t}{r_c}\right)\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 7, Page: 148.*

6.4 Apparent resistivity

Input(s)

G_t: Geometric Coefficient (m)
I: Current (Ampere)
ΔV_{12}: Potential Difference between two Points (V)

Output(s)

R: Apparent Resitivity (ohm m)

Formula(s)

$$R = G_t * \left(\frac{\Delta V_{12}}{I}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 5, Page: 93.*

6.5 Apparent sorption compressibility

Input(s)

B_g: Gas Formation Factor (bbl/SCF)
V_m: Langmuir's Constant (dimensionless)
ρ_B: Bulk Density of the Coal Deposit (gm/cm^3)
b: Langmuir's Constant (dimensionless)
ø: Porosity (fraction)
p: Pressure (psi)

Output(s)

c_s: Apparent Sorption Compressibility (1/psi)

Formula(s)

$$c_s = \frac{0.17525 * B_g * V_m * \rho_B * b}{ø * (1 + b * p)^2}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 222.*

6.6 Atlas wireline neutron lifetime log

Input(s)

τ: Half-Decay time for Neutron (s)

Output(s)

Σ: Composite Capture Cross Section of the Formation (dimensionless)

Formula(s)

$$\Sigma = \frac{3.15}{\tau}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 9, Page: 181.*

6.7 Barenblatt-Chorin universal velocity distribution

Input(s)

v_*: Velocity of Fluid (ft/s)
Re: Reynolds Number (ft)
v: Molar Velocity (ft/s)
L: Length (ft)

Output(s)

v_x: Velocity in X-direction (dimensionless)

Formula(s)

$$\frac{v_x}{v_*} = \left(\left(\frac{1}{3^{0.5}}\right) * \ln(\mathrm{Re}) + \frac{5}{2}\right) * \left(\left(L * \frac{v_*}{v}\right)^{\frac{3}{2 * \ln(\mathrm{Re})}}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 5, Page: 161.*

6.8 Coefficient of reflection

Input(s)

R_1: Resistivity of 1st Formation Bed (ohm m)
R_2: Resistivity of 2nd Formation Bed (ohm m)

Output(s)

C_R: Coefficient of Reflection (dimensionless)

Formula(s)

$$C_R = \frac{R_1 - R_2}{R_1 + R_2}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 5, Page: 96.*

6.9 Compaction correction factor for sonic logs in shale lithology

Input(s)

Δt_{sh}: Adjacent Shale Bed's Transit Time (mu s/ft)
c: Shale Compaction Coefficient (dimensionless)

Output(s)

C_p: Compaction Correction Factor (dimensionless)

Formula(s)

$$C_p = (\Delta t_{sh}) * \frac{c}{100}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 87.*

6.10 Composite capture cross section of the formation (Schlumberger thermal decay time tool)

Input(s)

τ: Time Required for Neutron to Diminish to 37% (s)

Output(s):

Σ: Composite Capture Cross Section of Formation (dimensionless)

Formula(s)

$$\Sigma = \frac{4.55}{\tau}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 9, Page: 181.*

6.11 Correlation of mud cake resistivity to mud resistivity

Input(s)

R_m: Mud Resistivity (ohm m)
R_{mf}: Mud Filtrate Resistivity (ohm m)

Output(s)

R_{mc}: Mud Cake Resistivity (ohm m)

Formula(s)

$$R_{mc} = 0.69 * R_{mf} * \left(\frac{R_m}{R_{mf}}\right)^{2.65}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 4, Page: 67.*

6.12 Correlation of mud filtrate resistivity to mud resistivity

Input(s)

K_m: Mud Coefficient Varies with Mud Weight (dimensionless)
R_m: Mud Resistivity (ohm m)

Output(s)

R_{mf}: Mud Filtrate Resistivity (ohm m)

Formula(s)

$$R_{mf} = K_m * (R_m)^{1.07}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 4, Page: 67.*

6.13 Diffuse-layer thickness

Input(s)

n: Salt Concentration (moles per liter)

Output(s)

x_d: Diffuse-Layer Thickness (angstroms)

Formula(s)

$$x_d = 3 * n^{\left(-\frac{1}{2}\right)}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 14.*

6.14 Effect of clay on conductivity

Input(s)

C_w: Conductivity of Water (1/ohm m)
F: Formation Factor (unitless)
C_s: Conductivity due to Salinity (1/ohm m)

Output(s)

C_o: Conductivity of Oil (1/ohm m)

Formula(s)

$$C_o = \left(\frac{C_w}{F}\right) + C_s$$

Reference: *Ellis, D.V., Singer, J.M. 2008. Well Logging for Earth Scientists. Second Edition. Springer. Chapter: 4, Page: 74.*

6.15 Effective photoelectric absorption cross section index

Input(s)

Z: Atomic Number (dimensionless)

Output(s)

Pe: Effective Photoelectric Absorption Cross-Section Index for the Formation (Barns per Electron)

Formula(s)

$$Pe = \left(\frac{Z}{10}\right)^{3.6}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 8, Page: 167.*

6.16 Electric resistance to a radial current from a wellbore

Input(s)

h: Height of Reservoir (ft)
r_e: Drainage Radius (ft)
r_w: Wellbore Radius (ft)
σ: Electric Conductivity (ohm/ft)

Output(s)

R_e: Electric Resistivity (ohm)

Formula(s)

$$R_e = \frac{\ln\left(\frac{r_e}{r_w}\right)}{2 * \pi * h * \sigma}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 14, Page: 188.*

6.17 Electrochemical potential (SP log)

Input(s)

t_{Cl}: Chloride Ion Transference Number (dimensionless)
R: Gas Constant (8.31) (J/mol K)
T_a: Absolute Temperature (degree K)
F: Faraday Constant (96485.336) (s A/mol)
a_1: Activities of 1st Electrolyte (dimensionless)
a_2: Activities of 2nd Electrolyte (dimensionless)

Output(s)

E_c: Electrochemical Potential (V)

Formula(s)

$$E_c = 2 * t_{Cl} * \left(\frac{R * T_a}{F}\right) * \ln\left(\frac{a_1}{a_2}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 131.*

6.18 Electrokinetic potential (developed across a mud cake)

Input(s)

p: Differential Pressure (psi)
x: Constants Related to Mud Composition (dimensionless)
y: Constants Related to Resistivity (dimensionless)

Output(s)

Ek: Electrokinetic Potential (V)

Formula(s)

$$Ek = x * p^\wedge y$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 131.*

6.19 Electron density index (GR absorbtion logging)

Input(s)

N_e: Number of Electrons Per Unit Volume (per m^3)
N_A: Avogadro's Number (per mole)

Output(s)

ρ_e: Electron Density Index (mole per m^3)

Formula(s)

$$\rho_e = \left(\frac{2 * N_e}{N_A}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 36.*

6.20 Epithermal neutron diffusion coefficient

Input(s)

L_e: Slowing-Down Length (cm)
ξ: Logarithmic Energy Decrement Per Collision (dimensionless)
Σ_e: Macroscopic Scattering of Cross Section (cm^2/cm^3)

Output(s)

D_e: Epithermal Diffusion Coefficient (dimensionless)

Formula(s)

$$D_e = \xi * L_e^2 * \Sigma_e$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 40.*

6.21 Epithermal neutron distribution (epithermal neutron flux)

Input(s)

N_N: Source Strength (neutrons/s)
r: Distance from Source (cm)
L_e: Slowing Down Length (cm)
D_e: Epithermal Diffusion Coefficient (cm)

Output(s)

$\psi_e(r)$: Epithermal Neutron Flux at a Distance (r) from the Source (neutrons/cm^2/s)

Formula(s)

$$\psi_e(r) = \left(\frac{N_{\mathrm{N}}}{4 * \pi * D_e}\right) * \frac{\exp\left(-\frac{r}{L_e}\right)}{r}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 39.*

6.22 Fertl and Hammack equation

Input(s)

F: Formation Resistivity Factor (dimensionless)
Φ_e: Effective Porosity (fraction)
R_t: Rock Resistivity (ohm m)
R_w: Formation Water Resistivity (ohm m)
V_{sh}: Bulk Volume Fraction of Shale (fraction)
R_{sh}: Shale Resistivity (ohm m)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \left(\frac{F * R_w}{R_t}\right)^{0.5} - \frac{V_{sh} * R_w}{0.4 * \Phi_e * (R_{sh})}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 16.*

6.23 Formation conductivity in dual water model

Input(s)

F_s: Shaly-Sand Formation Resistivity Factor (dimensionless)
C_{wf}: Free Water Conductivity (m ohm meter)
C_{wb}: Bound Water Apparent Conductivity (m ohm meter)
f_{dl}: Expansion Factor (dimensionless)
Q_v: Volume Concentration of Clay Exchange Cations (meq/mL)
v_Q: Volume Equivalent (cm^3/meq)

Output(s)

F_o: Salinity Dependent Formation Resistivity Factor (dimensionless)
C_o: Brine Saturated Rock Conductivity (m ohm meter)

Formula(s)

$$F_o = F_s * \left(1 - v_Q * Q_v\right)$$
$$C_o = \left(\frac{1}{F_o}\right) * \left(C_{wf} + f_{dl} * v_Q * Q_v * \left(C_{wb} - C_{wf}\right)\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 19.*

6.24 Formation factor—Archie's equation

Input(s)

a: Tortuosity Factor (dimensionless)
Φ: Porosity (fraction)
m: Cementation Factor (dimensionless)

Output(s)

F: Formation Factor (dimensionless)

Formula(s)

$$F = \frac{a}{\Phi^m}$$

Notes: a and m are measured from log-log plot of F vs Porosity.

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 38.*

6.25 Formation factor (Archie's equation with resistivity logs)

Input(s)

T: Tortuosity (unitless)
Φ: Porosity (fraction)

Output(s)

F: Archie (unitless)

Formula(s)

$$F = \frac{T}{\Phi}$$

Reference: *Ellis, D.V., Singer, J.M. 2008. Well Logging for Earth Scientists. Second Edition. Springer. Chapter: 4, Page: 76.*

6.26 Formation resistivity and permeability (Carothers) relation for limestones

Input(s)

F: Formation Resistivity Factor (dimensionless)

Output(s)

k: Permeability (mD)

Formula(s)

$$k = \frac{4 * 10^8}{F^{3.65}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 11.*

6.27 Formation resistivity and permeability (Carothers) relation for sandstones

Input(s)

F: Formation Resistivity Factor (dimensionless)

Output(s)

k: Permeability (mD)

Formula(s)

$$k = \frac{7 * 10^8}{F^{4.5}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 11.*

6.28 Formation resistivity and porosity relations for carbonate rocks

Input(s)

a: Constant (Range of 2.2 to 2.5) (dimensionless)
Φ: Porosity (dimensionless)

Output(s)

F_c: Formation Resistivity Factor for Chalky Rocks (dimensionless)
F_co: Formation Resistivity Factor for Compact Rocks (dimensionless)
F_l: Formation Resistivity Factor for Low Porosity and non-fractured Carbonates, Shell Equation (dimensionless)

Formula(s)

$$F_c = \frac{1}{(\Phi)^2}$$

$$F_c o = \frac{1}{(\Phi)^a}$$

$$F_l = \frac{1}{(\Phi)^{1.87 + \left(\frac{0.019}{\Phi}\right)}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 10.*

6.29 Formation resistivity and porosity relations from well log data based on Porter and Carothers data

Input(s)

Φ: Porosity (dimensionless)

Output(s)

F_g: Formation Resistivity Factor for California Pliocene (dimensionless)
F_c: Formation Resistivity Factor for U.S Gulf Coast Miocene (dimensionless)

Formula(s)

$$F_g = \frac{2.45}{(\Phi)^{1.08}}$$

$$F_c = \frac{1.97}{(\Phi)^{1.29}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 9.*

6.30 Fraction of total porosity occupied by clays

Input(s)

Φ_S: Sonic Log Porosity (fraction)
Φ_D: Density Log Porosity (fraction)

Output(s)

q: Fraction of the Total Porosity Occupied by Clays (fraction)

Formula(s)

$$q = \frac{(\Phi_S) - (\Phi_D)}{\Phi_S}$$

Reference: *Core Laboratories. 2005: Formation Evaluation and Petrophysics, Page: 98.*

6.31 Fresh water-filled porosity (fresh-water-bearing limestones)

Input(s)

ρb: Bulk Density (g/cm^3)
ρls: Limestone Density (g/cm^3)
ρw: Water Density (g/cm^3)

Output(s)

Φ: Water Filled Porosity (fraction)

Formula(s)

$$\Phi = \frac{\rho ls - \rho b}{\rho ls - \rho w}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 8, Page: 164.*

6.32 F_{xo}/F_s approach

Input(s)

F_s: Formation Resistivity Factor (dimensionless)
S_{xo}: Apparent Saturation (fraction)

Output(s)

F_{xo}: Apparent Formation Factor (dimensionless)

Formula(s)

$$F_{xo} = \frac{F_s}{S_{xo}^2}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 12, Page: 250.*

6.33 Gamma ray log shale index

Input(s)

GR_{cl}: Log Response in Clean Beds (API)
GR_{sh}: Log Response in Shale Beds (API)
GR: Log Response in Zone of Interest (API)

Output(s)

I_{GR}: Gamma Ray Shale Index (fraction)

Formula(s)

$$I_{GR} = \frac{GR - GR_{cl}}{GR_{sh} - GR_{cl}}$$

Reference: *Core Laboratories. 2015. Formation Evaluation and Petrophysics, Page: 63.*

6.34 General form of the Archie equation—Water saturation from resistivity logs

Input(s)

m: Cementation Factor (dimensionless)
a: Tortuosity Factor (dimensionless)
Φ: Porosity (fraction)
R_w: Resistivity of Water (ohm m)
R_t: True Resistivity (ohm m)
n: Saturation Exponent (dimensionless)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \left(\left(\frac{a}{\Phi^m}\right) * \left(\frac{R_w}{R_t}\right)\right)^{\frac{1}{n}}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 45.*

6.35 Generalized relationship between formation resistivity factor and porosity (Chevron formula)

Input(s)

Φ: Porosity (dimensionless)

Output(s)

F: Formation Resistivity Factor (dimensionless)

Formula(s)

$$F = \frac{1.13}{(\Phi)^{1.73}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 9.*

6.36 Geometric coefficient for the electrode

Input(s)

r_1: Distance to 1st Electrodes (m)
r_2: Distance to 2nd Electrodes (m)

Output(s)

G_t: Geometric Coefficient for the Electrode Array (m)

Formula(s)

$$G_t = 4 * \pi * \left(r_1 * \frac{r_2}{r_2 - r_1} \right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 5, Page: 93.*

6.37 Geometric coefficient for the lateral device

Input(s)

AM: Midpoint Between Electrodes a and M (m)
AN: Midpoint Between Electrodes a and N (m)
MN: Midpoint Between Electrodes M and N (m)

Output(s)

G_L: Geometric Coefficient for the Lateral Device (m)

Formula(s)

$$G_L = 4 * \pi * \left((AM) * \frac{AN}{MN} \right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 5, Page: 95.*

6.38 Geometric coefficient for the normal sonde

Input(s)

AM: Midpoint Between Electrodes a and M (m)

Output(s)

G_N: Geometric Coefficient for the Normal Sonde (m)

Formula(s)

$$G_N = 4 * \pi * AM$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 5, Page: 95.*

6.39 Half thickness value

Input(s)

α_l: Linear Absorption Coefficient (1/m)

Output(s)

$h_{\frac{1}{2}}$: Half Thickness Value (m)

Formula(s)

$$h_{\frac{1}{2}} = \frac{0.693}{\alpha_l} = 0.693 * \overline{h}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 35.*

6.40 Hingle nonlinear-resistivity/linear-porosity crossplot

Input(s)

S_w: Water Saturation (fraction)
R_w: Formation Water Resistivity (ohm m)
Φ: Mud Filtrate Resistivity (fraction)
a: Pore Geometry Coefficient (Range of 0.35 to 4.78) (dimensionless)
n: Saturation Exponent (dimensionless)
m: Pore Geometry Coefficient2 (Range of 1.14 to 2.52) (dimensionless)

Output(s)

R_t: Rock Resistivity (ohm m)

Formula(s)

$$(R_t)^{-\frac{1}{m}} = \Phi * \left(\frac{S_{\mathrm{w}}^n}{a * R_w}\right)^{\frac{1}{m}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 13, Page: 268.*

6.41 Humble equation (formation resistivity factor vs porosity)

Input(s)

Φ: Porosity (dimensionless)

Output(s)

F: Formation Resistivity Factor (dimensionless)

Formula(s)

$$F = \frac{0.62}{(\Phi)^{2.15}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 8.*

6.42 Integrated radial geometric factor

Input(s)

r: Radial Distance from Borehole Wall (in.)
h: Mean Free Path (in.)

Output(s)

G(r): Integrated Radial Geometric Factor (dimensionless)

Formula(s)

$$G(r) = 1 - e^{-\frac{r}{h}}$$

Reference: Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 7, Page: 152.

6.43 Lennard Jones potential

Input(s)

ε: Potential of Well (N m)
σ: Collision Diameter (m)
r: Distance (m)

Output(s)

phir: Intermolecular potential energy (N m)

Formula(s)

$$phir = 4 * \varepsilon * \left(\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Page: 26.*

6.44 Linear absorption (attenuation) coefficient

Input(s)

N: Number of Atoms Per Unit Volume (m^{-3})
σ: Thin Cross Section Expressed in Barns Per Atom (1 Barn Is 10^{-28} m^2) (m^2/atom)

Output(s)

α_l: Linear Absorption Coefficient (1/m)

Formula(s)

$$\alpha_l = \sigma * N$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 33.*

6.45 Maximum potential for self-potential (SP) log

Input(s)

R_{mfe}: Apparent Resistivity of Mud Filtrate (ohm m)
R_{we}: Apparent Formation Water Resistivity (ohm m)
K: Temperature-dependent Coefficient (Temp. Degree)

Output(s)

SSP: Maximum Potential (millivolts)

Formula(s)

$$\mathrm{SSP} = -\mathrm{K}\,\log_{10}\left(\frac{\mathrm{R_{mfe}}}{\mathrm{AR_{we}}}\right)$$

$$\mathrm{K}\left({}^{o}\mathrm{C}\right) = 61 + 0.133\,\mathrm{T}$$

$$\mathrm{K}\left({}^{o}\mathrm{F}\right) = 65 + 0.24\,\mathrm{T}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal, Systems. Department of Petroleum Engineering, Stanford university, Page (4.5).*

6.46 Mean free path (photon absorption)

Input(s)

α_l: Linear Absorption Coefficient (1/m)

Output(s)

h: Mean Free Path (m)

Formula(s)

$$h = \frac{1}{\alpha_l}$$

Reference*: Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 35.*

6.47 Membrane potential

Input(s)

R: Gas Constant (8.31) (J/mol K)
T_a: Absolute Temperature (degree K)
F: Faraday Constant (96485.336) (s A/mol)
a_1: Activities of 1st Electrolyte (dimensionless)
a_2: Activities of 2nd Electrolyte (dimensionless)

Output(s)

E_m: Membrane Potential (V)

Formula(s)

$$E_m = \left(R * \frac{T_a}{F}\right) * \ln\left(\frac{a_1}{a_2}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 131.*

6.48 Neutron lethargy (logarithmic energy decrement)

Input(s)

E_o: Initial Energy Level (eV)
E: Final Energy Level (eV)

Output(s)

u: Neutron Lethargy (dimensionless)

Formula(s)

$$u = \ln\left(\frac{E_o}{E}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 38.*

6.49 Neutron porosity of shale zone

Input(s)

Φ_T: True Formation Porosity (fraction)
V_{Sh}: Shale Volume Factor (dimensionless)
Φ_{NSh}: Neutron Porosity of a Nearby Shale Region (fraction)

Output(s)

Φ_N: Observed Neutron Porosity in a Shaly Formation (fraction)

Formula(s)

$$\Phi_N = (\Phi_T) + (V_{Sh} * \Phi_{NSh})$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 108.*

6.50 Oil saturation determination (IE and CDN logs)

Input(s)

R_o: Hydrocarbon Formation Resistivity (ohm m)
R_t: Rock Resistivity (ohm m)

Output(s)

S_w: Water Saturation (fraction)
S_o: Oil Saturation (fraction)

Formula(s)

$$S_w = \left(\frac{R_o}{R_t}\right)^{0.5}$$

$$S_o = 1 - S_w$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 11, Page: 213.*

6.51 Pair production (gamma ray interactions)

Input(s)

E_c: Energy of Compton Electrons (MeV)

E: Energy Required to Remove Electron from Shell (MeV)

Output(s)

E_e: Energy of Each Photoelectron in Pair Production (MeV)

Formula(s)

$$E_e = E_c - E$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 33.*

6.52 Phillips equation (sandstones)

Input(s)

Φ: Porosity (dimensionless)

Output(s)

F: Formation Resistivity Factor (dimensionless)

Formula(s)

$$F = \frac{1.45}{(\Phi)^{1.54}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 8.*

6.53 Photoelectric absorption cross sectional area

Input(s)

Z: Atomic Number (dimensionless)
E_γ: Energy of Gamma Rays (keV)

Output(s)

α_{pe}: Photoelectric Absorption Cross Sectional Area (barns/electron)

Formula(s)

$$\alpha_{pe} = 12.1 * \frac{Z^{3.6}}{E_\gamma^{3.15}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 36.*

6.54 Pickett crossplot

Input(s)

S_w: Water Saturation (fraction)
R_w: Formation Water Resistivity (ohm m)
Φ : Mud Filtrate Resistivity (fraction)
n: Saturation Exponent (dimensionless)
m: Pore Geometry Coefficient2 (Range of 1.14 to 2.52) (dimensionless)

Output(s)

logR1: Rock Resistivity (ohm m)

Formula(s)

$$logR1 = -m * \log(\Phi) + \log(R_w) - n * \log(S_w)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 13, Page: 276.*

6.55 Poisson's ratio (seismic arrival time method)

Input(s)

V_p: Velocity of Compressional Waves (ft/s)
V_s : Shear Waves (ft/s)

Output(s)

υ: Poisson's Ratio (dimensionless)

Formula(s)

$$\upsilon = \frac{\left(V_p^2\right) - 2 * \left(V_s^2\right)}{2 * \left(\left(V_p^2\right) - \left(V_s^2\right)\right)}$$

Reference: *Mark D. Zoback., Reservoir Geomechanics, Cambridge University Express, UK, Page: 64.*

6.56 Porosity by using density log data

Input(s)

ρ_b: Bulk Density (g/cm^3)
ρ_{ma}: Matrix Density(g/cm^3)
ρ_f: Average Fluid Density in Pore Spaces (g/cm^3)

Output(s)

Φ: Porosity (fraction)

Formula(s)

$$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 8, Page: 165.*

6.57 Porosity corrected for gas effect

Input(s)

Φ_D: Density Porosity (fraction)
Φ_N: Neutron Porosity (fraction)

Output(s)

$\Phi_{c\ or\ r}$: Corrected Porosity for the Gas Effect (fraction)

Formula(s)

$$\Phi_{c\,or\,r} = \left(\frac{(\Phi_D)^2 + (\Phi_N)^2}{2}\right)^{0.5}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 111.*

6.58 Porosity-neutron flux relationship

Input(s)

N: Neutron Tool Response (dimensionless)
α: Constant Related to Formation Properties and Tool Design (dimensionless)
β: Constant Related to Formation Properties and Tool Design (dimensionless)

Output(s)

Φ: Porosity (fraction)

Formula(s)

$$\Phi = \alpha - \beta * \log(N)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 9, Page: 174.*

6.59 Rate of radioactive decay

Input(s)

N_o: Initial Parent Nuclei (dimensionless)
C_d: Decay Constant (1/s)
t: Half-Life Time (s)

Output(s)

N: Parent Nuclei at a Particular Time (dimensionless)

Formula(s)

$$N = N_o * \exp(-C_d * t)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 28.*

6.60 Relation between concentration of K, Th, or U and recorded total gamma ray signal

Input(s)

C_{Th}: Thorium Concentration (ppm)
C_U: Uranium Concentration (ppm)
C_K: Potassium Concentration (wt %)

Output(s)

γ: Total Gamma Ray (API units)

Formula(s)

$$\gamma = 4 * C_{Th} + 8 * C_U + C_K$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 7, Page: 152.*

6.61 Relationship between rock resistivity and water saturation

Input(s)

F: Formation Resistivity Factor (dimensionless)
R_w: Formation Water Resistivity (ohm m)
R_t: Rock Resistivity (ohm m)
n: Saturation Exponent (dimensionless)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \left(\frac{F * R_w}{R_t} \right)^{\frac{1}{n}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 11.*

6.62 Relationship between SSP and R_w (NaCl predominant)

Input(s)

$R_{(mf)_{eq}}$: Equivalent Resistivity of Mud Filtrate (ohm m)
K: Equilibrium Constant (mV)
A: Proportionality Factor (dimensionless)
a_w: Activity of NaCl (dimensionless)

Output(s)

$(R_w)_{eq}$: Equivalent Resistivity of Formation Water (ohm m)
SSP: Static Self Potential (V)

Formula(s)

$$(R_w)_{eq} = \left(\frac{A}{a_w}\right)$$

$$SSP = -K * \log\left(\left(\frac{R_{(mf)_{eq}}}{(R_w)_{eq}}\right)\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 133.*

6.63 Relationship between SSP and R_w (non-ideal shale membrane)

Input(s)

R_{sh}: Shale Resistivity (ohm m)

Output(s)

m_{eff}: Membrane Efficiency (fraction)

Formula(s)

$$m_{eff} = 0.47 + 0.3 * R_{sh}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 137.*

6.64 Relationship between SSP and R_w for water containing salts (non-NaCl predominant)

Input(s)

a_{Na}: Activity of Na Ions in Water (dimensionless)
K: Equilibrium Constant (mV)
a_{Ca}: Activity of Ca Ions in Water (dimensionless)
a_{Mg}: Activity of Mg Ions in Water (dimensionless)
a_{Nam}: Activity of Na Ions in Mud Filtrate (dimensionless)
a_{Cam}: Activity of Ca Ions in Mud Filtrate (dimensionless)
a_{Mgm}: Activity of Mg Ions in Mud Filtrate (dimensionless)

Output(s)

E_{ssp}: Static Self Potential (V)

Formula(s)

$$E_{ssp} = -K * \log\left(\frac{\left(a_{Na} + \left(a_{Ca} + a_{Mg}\right)^{0.5}\right)}{\left(a_{Nam} + \left(a_{Cam} + a_{Mgm}\right)^{0.5}\right)}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 135.*

6.65 Resistivity of a partially saturated shaly sand with hydrocarbons (V_{sh} models)

Input(s)

S_w: Water Saturation (fraction)
R_w: Formation Water Resistivity (ohm m)
V_{sh}: Bulk Volume Fraction of Shale (fraction)
R_{sh}: Shale Resistivity (ohm meter)
F: Formation Resistivity Factor (dimensionless)

Output(s)

α: Clay Distribution Factor (dimensionless)
β: Clay Distribution Factor (dimensionless)
R_t: Rock Resistivity (ohm m)

Formula(s)

$$\alpha = \frac{V_{sh}}{R_{sh}}$$

$$\beta = 1/F$$

$$\frac{1}{R_t} = (\alpha * S_w) + \frac{\beta * (S_w)^2}{R_w}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 16.*

6.66 Resistivity of a water-saturated shaly sand (V_{sh} models)

Input(s)

R_w: Formation Water Resistivity (ohm m)
V_{sh}: Bulk Volume Fraction of Shale (fraction)
R_{sh}: Shale Resistivity (ohm m)
F: Formation Resistivity Factor (dimensionless)

Output(s)

α: Clay Distribution Factor (dimensionless)
β: Clay Distribution Factor (dimensionless)
$\frac{1}{R_o}$: Formation Hydrocarbon Resistivity (per(ohm m))

Formula(s)

$$\alpha = \left(\frac{V_{sh}}{R_{sh}}\right)$$

$$\beta = \frac{1}{F}$$

$$\frac{1}{R_o} = (\alpha) + \left(\frac{\beta}{R_w}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 16.*

6.67 Rock conductivity (relatively clean water bearing rocks)

Input(s)

F: Formation Resistivity Factor (dimensionless)
C_w: Formation Water Conductivity (micromhos per centimeter)

Output(s)

C_o: Rock Conductivity (micromhos per centimeter)

Formula(s)

$$C_o = \frac{C_w}{F}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 13.*

6.68 Shale index from gamma ray spectrometry

Input(s)

$C_{Th_{log}}$: Log Response for Thorium Curve (ppm)
$C_{Th_{min}}$: Log Response in Zone with Min Radioactivity of Thorium (ppm)
$C_{Th_{sh}}$: Log Response of Thorium for Shale (ppm)
$C_{K_{log}}$: Log Response of Potassium Curve (ppm)
$C_{K_{min}}$: Log Response in Zone with Min Radioactivity of Potassium (ppm)
$C_{K_{sh}}$: Log Response of Potassium for Shale (ppm)
$\gamma_{(uf)_{log}}$: Log Response for Uranium Free Curve (API units)
$\gamma_{(uf)_{min}}$: Log Response in Zone with Min Radioactivity of Uranium (API units)
$\gamma_{(uf)_{sh}}$: Log Response of Uranium for Shale (API units)

Output(s)

$I_{(sh)_{Th}}$: Shale Index for Thorium (dimensionless)
$I_{(sh)_K}$: Shale Index for Potassium (dimensionless)
$I_{(sh)_{Uf}}$: Shale Index for Uranium (dimensionless)

Formula(s)

$$I_{(sh)_{Th}} = \frac{\left[C_{Th_{log}} - C_{Th_{min}}\right]}{\left[C_{Th_{sh}} - C_{Th_{min}}\right]}$$

$$I_{(sh)_K} = \frac{C_{K_{log}} - C_{K_{min}}}{C_{K_{sh}} - C_{K_{min}}}$$

$$I_{(sh)_{Uf}} = \frac{\left[\gamma_{(uf)_{log}} - \gamma_{(uf)_{min}}\right]}{\left[\gamma_{(uf)_{sh}} - \gamma_{(uf)_{min}}\right]}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 7, Page: 156.*

6.69 Simandoux (total shale) equation

Input(s)

Φ_e: Effective Porosity (fraction)
R_t: Rock Resistivity (dimensionless)
R_w: Formation Water Resistivity (ohm m)
V_{sh}: Bulk Volume Fraction of Shale (fraction)
R_{sh}: Shale Resistivity (ohm m)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \left(0.4 * \frac{R_w}{\Phi_e^2}\right) * \left(-\frac{V_{sh}}{R_{sh}} + \left(\left(\frac{V_{sh}}{R_{sh}}\right)^2 + \left(\frac{5 * (\Phi_e)^2}{R_w * R_t}\right)\right)^{0.5}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 16.*

6.70 Sonic porosity (Raymer Hunt Gardner method)

Input(s)

Δt: Sonic Log Reading for Transit Time (μmu s/ft)
Δt_{ma}: Sonic Log Reading for Transit Time (μ-s/ft)
C: Empirical Constant (0.624-0.7) (dimensionless)

Output(s)

Φ_{sonic}: Sonic Porosity (fraction)

Formula(s)

$$\Phi_{sonic} = C * \frac{\Delta t - \Delta t_{ma}}{\Delta t}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 87.*

6.71 Spacing between transmitter and receiver

Input(s)

s_{off}: Tool Standoff (in.)
C_{mf}: Mud/Formaton Velocity Contrast (dimensionless)

Output(s)

$(L_s)_c$: Transmitter-to-Receiver Spacing (ft)

Formula(s)

$$(L_s)_c = 2 * s_{off} * \left(\frac{1 + C_{mf}}{1 - C_{mf}}\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 10, Page: 192.*

6.72 Static self potential

Input(s)

t_{Cl}: Chlorine Anion Transference Number (dimensionless)
R: Gas Constant (J/degree C)
T_a: Absolute Temperature (degree K)
F: Faraday Constant (96485.336) (s A/mol)
a_w: Activity of NaCl (dimensionless)
a_{mf}: Activity of Dilute Solution (dimensionless)

Output(s)

K: Equilibrium Constant (mV)
E_{ssp}: Static Self Potential (V)

Formula(s)

$$K = 4.606 * t_{Cl} * \left(R * \frac{T_a}{F}\right)$$

$$E_{ssp} = -K * \log\left(\frac{a_w}{a_{mf}}\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 6, Page: 131–132.*

6.73 Time between the initiation of the pulse and the first arrival acoustic energy at the receiver

Input(s)

d_h: Borehole Diameter (in.)
d_t: Tool Diameter (in.)
L_s: Spacing (ft)
l_c: Displaced Distance (ft)
v: Formation Compressional Velocity (μs/ft)
v_m: Mud Compressional Velocity (μs/ft)

Output(s)

t_{log}: Time Between Initiation of the Pulse and First Arrival Acoustic Energy at the Receiver (μs/ft)

Formula(s)

$$t_{log} = \left(\frac{L_s}{v}\right) + \left(\frac{d_h - (d_t + 2 * l_c)}{v_m}\right) * \mathrm{sqrt}\left(1 - \left(\frac{v_m}{v}\right)^2\right)$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 10, Page: 189.*

6.74 Time-average relation in compacted formations (porosity/transit time relationships)

Input(s)

δ t: Total Travel Time (μs/ft)
$\delta\ t_f$: Travel Time in Liquid/Fluid (μs/ft)
$\delta\ t_{ma}$: Travel Time in Matrix (μs/ft)

Output(s)

Ø: Porosity (fraction)

Formula(s)

$$\text{Ø} = \frac{\delta t - \delta t_{ma}}{\delta t_f - \delta t_{ma}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 54.*

6.75 Time-average relation in uncompacted formations (porosity/transit time relationships)

Input(s)

δ t: Total Travel Time (μs/ft)
$\delta\ t_f$: Travel Time in Liquid/Fluid (μs/ft)
$\delta\ t_{ma}$: Travel Time in Matrix (μs/ft)
$\delta\ t_{sh}$: Transit Time in Adjacent Shales (μs/ft)

Output(s)

B_{cp}: Compaction Correction Factor (μs/ft)
Ø: Porosity (fraction)

Formula(s)

$$B_{cp} = \frac{\delta t_{sh}}{100}$$

$$Ø = \frac{\frac{\delta t - \delta t_{ma}}{\delta t_f - \delta t_{ma}}}{B_{cp}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 54.*

6.76 Tortuosity (resistivity logs)

Input(s)

L_a: Apparent Length (cm)
L: Actual Length (cm)

Output(s)

T: Tortuosity (unitless)

Formula(s)

$$T = \frac{L_a^2}{L^2}$$

Reference: *Ellis, D.V., Singer, J.M. 2008. Well Logging for Earth Scientists. Second Edition. Springer. Chapter: 4, Page: 76.*

6.77 Total rock conductivity

Input(s)

C_w: Conductivity of Water (1/ohm m)
S_w: Saturation of Water (fraction)
Ø: Porosity (fraction)
E: Electrical Efficiency (fraction)

Output(s)

C_t: Total Conductivity of Rock (1/ohm m)

Formula(s)

$$C_t = C_w * S_w * \text{Ø} * E$$

Reference: *Ellis, D.V., Siger, J.M. 2008. Well Logging for Earth Scientists, Elseiver, 2nd Edition, Chapter: 4, Page: 77.*

6.78 True porosity from sonic log (corrected for compaction)

Input(s)

Φ_a: Calculated Sonic Porosity Without Compaction Correction (fraction)
C_p: Compaction Factor (dimensionless)

Output(s)

Φ_t: True Porosity (fraction)

Formula(s)

$$\Phi_t = \frac{\Phi_a}{C_p}$$

Notes: Works best for unconsolidated sands where Wyllie Time Average Equation Overestimates.

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 90.*

6.79 True resistivity—Archie

Input(s)

F: Factor of Formation (dimensionless)
R_w: Resistivity of the Saturating Brine (ohm length)
RI: Resistivity Index of Saturation (dimensionless)

Output(s)

R_t: True Resistivity (ohm length)

Formula(s)

$$R_t = F * R_w * RI$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 38.*

6.80 Volumetric photoelectric absorption cross section

Input(s)

ρ_e: Electron Density Index (gm/cm^3)
P_e: Effective Photoelectric Absorption Cross-Section Index (Barns per Electron)

Output(s)

U: Volumetric Photoelectric Absorption Cross-Section (Barns per Volume)

Formula(s)

$$U = P_e * \rho_e$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 8, Page: 167.*

6.81 Water salinity index ratio

Input(s)

C: Water Salinity (ppm)
C_a: Apparent Water Salinity (ppm)
ø: Porosity (fraction)
$ø_a$: Apparent Porosity (fraction)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$\mathrm{S_w} = \frac{\mathrm{C_a}}{\mathrm{C}} = \frac{ø_a}{ø}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 9, Page: 183.*

6.82 Water saturation determination (IE and CDN logs)

Input(s)

R_o: Hydrocarbon Formation Resistivity (ohm m)
R_t: Rock Resistivity (ohm m)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \left(\frac{R_o}{R_t}\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 11, Page: 213.*

6.83 Water saturation from neutron tools

Input(s)

Σ_{log}: Measured Capture Cross Section of Formation (dimensionless)
Σ_{ma}: Capture Cross Section of Matrix (dimensionless)

Σ_w: Capture Cross Section of Water (dimensionless)
Σ_h: Capture Cross Section of Hydrocarbon (dimensionless)
Φ: Porosity (fraction)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \frac{\left(\Sigma_{log} - \Sigma_{ma}\right) - \Phi * (\Sigma_h - \Sigma_{ma})}{\Phi * (\Sigma_w - \Sigma_h)}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 9, Page: 181.*

6.84 Water saturation—Resistivity logs

Input(s)

n: Saturation Exponent (dimensionless)
RI: Resistivity Index (dimensionless)

Output(s)

S_w: Water Saturation (fraction)

Formula(s)

$$S_w = \left(\frac{1}{RI}\right)^{\frac{1}{n}}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 42.*

6.85 Wavelength equation

Input(s)

C: Speed of Light (m/s)
f: Frequency (Hz)

Output(s)

λ: Wavelength (m)

Formula(s)

$$\lambda = \frac{C}{f}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 28.*

6.86 Wellbore electric voltage generation

Input(s)

$V_{e,\,w}$: Electric Voltage at Wellbore Radius (V)
ΔV_e: Voltage Drop Between Wellbore Radius and Drainage Radius (V)
r: Specific Location (ft)
r_e: Drainage Radius (ft)
r_w: Wellbore Radius (ft)

Output(s)

V: Voltage (V)

Formula(s)

$$V = V_{e,w} - \Delta V_e * \left[\frac{\ln\left(\frac{r}{r_w}\right)}{\ln\left(\frac{r_e}{r_w}\right)}\right]$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 14, Page: 188.*

Chapter 7

Petroleum economics formulas and calculations

Chapter Outline

7.1 Acceptable reliability level

Input(s)

N: Number of Exploration Wells (dimensionless)

$P_{(x)}$: Binomial Probability of Discovering X number of Fields with Total N number of Exploration Wells (fraction)

P_F: Probability of having X number of fields that averagely includes minimum F barrels of Oil (fraction)

Output(s)

L_{Rel}: Acceptable Reliability Level (dimensionless)

Formulas and Calculations for Petroleum Engineering. https://doi.org/10.1016/B978-0-12-816508-9.00007-X
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Formula(s)

$$L_{Rel} = \sum_{X=1}^{X=N} P_{(x)} \cdot P_F$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 89.*

7.2 Additional production estimation with new wells

Input(s)

K_i: Number of Fields Discovered up to date in Selected Field Class (dimensionless)
K_{i_add}: Number of Fields estimated to be discovered with additional number of Exploration Wells (dimensionless)
N_{p_avg}: Average Annual Production of a Field in the Region (dimensionless)

Output(s)

N_{p_add}: Additional Annual Production of Fields estimated to be explored (dimensionless)

Formula(s)

$$N_{p\_add} = \left(K_i - K_{i\_add}\right)\left(N_{p\_avg}\right)$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 80.*

7.3 Annual gross revenue after royalties and wellhead taxes

Input(s)

$V_{u,j}$: Average Unit Crude Price after Royalties and Wellhead Taxes ($/bbl)
$\Delta N_{p,j}$: Annual Oil Production (bbl)

Output(s)

V_j: Annual Gross Revenue After Royalties and Wellhead Taxes ($)

Formula(s)

$$V_j = V_{u,j} * \Delta N_{p,j}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 12, Page: 162.*

7.4 Annuity from future value

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t: Time (year)
F_v: Future Value (currency unit)

Output(s)

A_v: Annuity from Future Value (currency unit)

Formula(s)

$$A_v = F_v * \left(\frac{i_e}{\left((1+i_e)^t\right) - 1}\right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 67.*

7.5 Annuity from present value

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t: Time (year)
P_v: Annuity from Present Value (currency unit)

Output(s)

A_v: Annuity from Present Value (currency unit)

Formula(s)

$$A_v = P_v * \left(\frac{i_e * \left((1+i_e)^t\right)}{\left((1+i_e)^t\right) - 1}\right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 56.*

7.6 Average annual rate of return method

Input(s)

C: Initial Investment/Capital ($)
I: Interest paid by "i" rate for the Capital ($)
i: Rate of Interest (per cent)
B: Total Balance not Amortized ($)
D: Present worth Factor (dimensionless)

Output(s)

P: Profit ($)
E: Total Net Undiscounted Cash Flow during the whole project ($)
r: Annual Average Rate of Return ($)

Formula(s)

$$P = i\sum B$$

$$E = C \cdot I \cdot P$$

$$r = i\frac{D}{1-D}\left(\frac{E}{C} - 1\right)$$

$$C \le \frac{DE}{\frac{r}{i} - D\left(\frac{r}{i} - 1\right)}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 40.*

7.7 Average book rate of return method

Input(s)

C: Initial Investment/Capital ($)
E: Total Net Undiscounted Cash Flow during the whole project ($)
n: Life of the Project (years)
N: Total Recoverable Oil Amount (bbl)
N_k: Total Recoverable Oil Amount in k^{th} year (bbl)
N_p: Total Recoverable Oil Amount in n^{th} year (bbl)
Q_k: Oil Production in k^{th} year (bbl)
D: Present worth Factor (dimensionless)
W_p: Working Profit per barrel of Oil ($/bbl)

Output(s)

P: Profit ($)
$\sum B$: Total End of Year Balance not Amortized ($)
$\sum B_{md}$: Total Mid-Year Balance not Amortized ($)
r: Annual Average Rate of Return ($)
r_{md}: Average Mid Year Rate of Return ($)

Formula(s)

$$\sum B = \frac{C}{N}\sum_{k=1}^{n} k \cdot Q_k$$

$$\sum B_{md} = C\left(n + \frac{1}{2}\right) - \frac{C}{N_p}\sum_{k=1}^{n} N_k$$

$$r = \frac{\left(E \cdot W_p\right) - C}{\sum B}$$

$$r_{md} = \frac{\left(E \cdot W_p\right) - C}{\sum B_{md}}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 45.*

7.8 Calculation of unknown interest rate

Input(s)

F: Amount to be Payed After End of t Years (currency unit)
P: Amount Borrowed (money)
t: Time at Which F Needs to be Payed (years)

Output(s)

i: Interest Rate (fraction)

Formula(s)

$$i = \exp\left(\frac{\ln\left(\frac{F}{P}\right)}{t}\right) - 1$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 65.*

7.9 Compound interest

Input(s)

P: Principal Amount (currency unit)
i_n: Nominal Interest Rate (fraction per year)
m: Compounding or Interest Periods per Year (where 1 for Annually, 2 for Semi-annually, 4 for quarterly, and 12 for monthly) (dimensionless)
t : The Loan Period or Investment Period (years)

Output(s)

I: Compound Interest (currency unit)

Formula(s)

$$I = \left(\left(1 + \frac{i_n}{m}\right)^{t*m} - 1\right) * P$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 27.*

7.10 Cost depletion

Input(s)

AB: Adjusted Basis for The Taxable Year (currency unit)
Q: Number of Units Sold in That Year (number)
R_r: Number of Remaining Reserves at the End of the Taxable Year (number)

Output(s)

CD: Cost Depletion (currency unit)

Formula(s)

$$CD = AB * \left(\frac{Q}{R_r + Q}\right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 4, Page: 204.*

7.11 Cumulative interest on operational expenses during the lifetime of a well

Input(s)

a: Interest Rate (%)
L: Operational Expenses ($/day)
t: Operating Time (days)

Output(s)

R_c: Cumulative Interest on Operation Expenses during the Lifetime of a Well ($)

Formula(s)

$$R_c = \frac{a \cdot L \cdot t^2}{2}$$

Reference: *Saydam, T., (1967). Principles of Hydraulic Fracturing, ARI Publishing Co., Page: 86.*

7.12 Effective interest rate for periodic compounding

Input(s)

m: Number of Compounding Periods Per Year (for example, 12 for Monthly Compounding) (time)
i_n: Nominal Interest Rate (fraction)

Output(s)

i_e: Effective Interest Rate (fraction)

Formula(s)

$$i_e = \left(1 + \frac{i_n}{m}\right)^m - 1$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 43.*

7.13 Exploration efficiency

Input(s)

F_D: Total Meterage Drilled up to the date of Discovery (ft)
a: Ratio Constant (dimensionless)
E_o: Exploration Efficiency at Initial Conditions (bbl/ft)
R_u: Total Expected Additional Discovery of Resources in Selected Field Class (bbl)
r_u: Latest Rate of Growth for Discovered Resources (fraction)

Output(s)

E: Exploration Efficiency per unit Meterage (bbl/ft)

Formula(s)

$$E = E_o \cdot e^{-a \cdot F_D}$$

$$E_o = \frac{dR_u}{r_u}$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 79.*

7.14 Future value of an annuity

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t: Time (year)
A_v: Annuity (currency unit)

Output(s)

F_v: Future Value of an Annuity (currency unit)

Formula(s)

$$F_v = A_v * \frac{\left((1 + i_e)^t\right) - 1}{i_e}$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 51.*

7.15 Future value of present sum

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t: Time (year)
P_v: Present Value of Future Sum (currency unit)

Output(s)

F_v: Future Sum Received at Time t (currency unit)

Formula(s)

$$F_v = P_v * \left((1 + i_e)^t\right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 44.*

7.16 Generalized expected value calculation

Input(s)

P_i: Possible Result of Probability from case “1” to “n” (fraction)
V_i: Contingency Value of Investment from case “1” to “n” ($)

Output(s)

EV: Expected Value (dimensionless)

Formula(s)

$$EV = \sum_{i=1}^{n} (P_i)(V_i)$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 72.*

7.17 Growth rate of return for continuous compounding

Input(s)

t: Time (years)
PI : Profitability Index (dimensionless)
i_d: Reinvestment Rate (fraction)

Output(s)

GRR: Growth Rate of Return (fraction)

Formula(s)

$$GRR = \frac{1}{t} * \ln(PI) + i_d$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 6, Page: 351.*

7.18 Hoskold method for annual rate of return prediction-1

Input(s)

C: Initial Investment/Capital ($)
r_H: Speculative Ratio (fraction)
i: Rate of Interest (per cent)
n: Life of the Project (years)
D: Present worth Factor (dimensionless)

Output(s)

DE: Present worth Factor with Total Net Undiscounted Cash Flow during the whole project ($)
r_H: Speculative Ratio (fraction)

Formula(s)

$$DE = r_H \cdot C \frac{1-\left(\frac{1}{1+i}\right)^n}{i} + \left(\frac{1}{1+i}\right)^n \cdot C$$

$$r_H = i \cdot \frac{\frac{DE}{C} - (1+i)^{-n}}{1-(1+i)^{-n}}$$

Control Form:

$$C \leq \frac{DE}{\frac{r_H}{i} - \left[\left(\frac{r_H}{i} - 1\right) \cdot (1+i)^{-n}\right]}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 47.*

7.19 Hoskold method for annual rate of return prediction-2

Input(s)

C: Initial Investment/Capital ($)
i: Rate of Interest (per cent)
n: Life of the Project (years)
S: Present Value of Total Net Income ($)

Output(s)

PV_i: Present Value of Income ($)
r_H: Speculative Ratio (fraction)

Formula(s)

$$PV_i = S \cdot \frac{1-(1+i)^{-n}}{i}$$

$$r_H = \frac{S}{C} - \frac{i}{(1+i)^n - 1}$$

Control Form:

$$C \leq \frac{S}{r_H + \frac{i}{(1+i)^n - 1}}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 48.*

7.20 Initial capital needed to survive in a minimum chance scenario

Input(s)

Z: Number of Standard Deviation corresponds to a Certain Change (dimensionless)
σ: Standard Deviation of a Risky Job reduced to Present Value (fraction)
X_E: Present Worth Expectation per a Risky Job ($)

Output(s)

M_G: Initial Capital Needed to Survive in a Minimum Chance Scenario (dimensionless)

Formula(s)

$$M_G = \frac{(Z \cdot \sigma)^2}{4X_E}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 99.*

7.21 Meterage model

Input(s)

F_D: Total Meterage Drilled up to the date of Discovery (ft)
a: Ratio Constant (dimensionless)
R_u: Total Expected Additional Discovery of Resources in Selected Field Class (bbl)
r_u: Latest Rate of Growth for Discovered Resources (fraction)

Output(s)

dR_D/F_D: Total Cumulative Discovered Resources per total drilled Meterage (bbl/ft)
R_D: Total Cumulative Resources of Discovery (bbl)

Formula(s)

$$\frac{dR_D}{dF_D} = a\left(\frac{R_u}{r_u} - R_D\right)$$

For Initial Conditions ($F_D = 0$; $R_D = 0$);

$$R_D = \frac{R_u}{r_u}\left(1 - e^{-a \cdot F_D}\right)$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 83.*

7.22 Minimum number of jobs to survive in a minimum chance scenario

Input(s)

Z: Number of Standard Deviation corresponds to a Certain Change (dimensionless)
σ: Standard Deviation of a Risky Job reduced to Present Value (fraction)
X_E: Present Worth Expectation per a Risky Job ($)

Output(s)

n: Minimum Number of Jobs to Survive in a Minimum Chance Scenario (dimensionless)

Formula(s)

$$n = \left(\frac{-Z \cdot \sigma}{2\,X_E}\right)^2$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 99.*

7.23 Minimum profit ratio per a risky job

Input(s)

y: Wealth Position that could be opened in a certain Probability ($)
y_o: Initial Wealth of the Company ($)
n: Total number of Independent Risky Jobs (dimensionless)
C: Dry-well Drilling Cost in Initial Investment ($)

Output(s)

W: Minimum Profit Ratio per a Risky Job - Minimum Profit/Investment Ratio (fraction)

Formula(s)

$$W = \frac{y - y_o}{n \cdot C}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 92.*

7.24 Net cash flow

Input(s)

R: Receipts (currency unit)
D: Disbursements (currency unit)

Output(s)

NCF: Net Cash Flow (currency unit)

Formula(s)

$$NCF = R - D$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 45.*

7.25 Net present value

Input(s)

t: the time of cash flow
i: discount rate
R_t: the net cash flow

Output(s)

NPV : Net Present Value

Formula(s)

$$NPV = \frac{R_t}{(1+i)\hat{}t}$$

Reference: *Wikipedia.org*.

7.26 Operating cash income

Input(s)

V_j: Annual Gross Revenue after Royalties and Wellhead Taxes ($)
O_j: Operating Charges ($)

Output(s)

I_j: Operating Cash Income ($)

Formula(s)

$$I_j = V_j - O_j$$

Reference: *Wikipedia.org*.

7.27 Payback Period

Input(s)

SN: Cumulative Negative Net Cash Flow (NCF) Years (year)
PN: Positive NCF (currency unit)
NN: Negative NCF (Positive Numeric Value) (currency unit)

Output(s)

PP: Payback Period (year)

Formula(s)

$$PP = SN + \frac{1}{PN + NN} * NN$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 6, Page: 306.*

7.28 Present value of an annuity

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t : Time (year)
A_v: Annuity (currency unit)

Output(s)

P_v: Present Value of an Annuity (currency unit)

Formula(s)

$$P_v = A_v * \frac{((1+i_e)^t) - 1}{i_e * (1+i_e)^t}$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 57.*

7.29 Present value of a deferred annuity

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t : Time (year)
A_v: Annuity (currency unit)

Output(s)

P_v: Present Value of Deferred (currency unit)

Formula(s)

$$P_v = A_v * \frac{((1+i_e)^t) - 1}{i_e * (1+i_e)^t} * \left(\frac{1}{(1+i_e)^{t-2}}\right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 62.*

7.30 Present value of future sum

Input(s)

i_e: Effective Interest or Discount Rate Fraction (fraction)
t: Time (year)
F_v: Future Sum Received at Time t (currency unit)

Output(s)

P_v: Present Value of Future Sum (currency unit)

Formula(s)

$$P_v = F_v * \left(\frac{1}{(1+i_e)^t}\right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 49.*

7.31 Present value of profit/investment ratio for an oil well

Input(s)

RF: Recovery Factor (bbl/acre ft)
h: Formation Thickness (ft)
A: Reservoir Area (acre)
D: Present Worth Factor (dimensionless)
W_p: Working Profit per barrel of Oil ($/bbl)
C_T: Total Cost of an Oil Well ($)

Output(s)

R: Recovery (bbl)
PV_i: Present Value of Income ($)
BE: Break-even Price ($)
PV_{PIR}: Present Value of Profit/Investment Ratio (dimensionless)

Formula(s)

$$R = A \cdot h \cdot RF$$

$$PV_i = (D) \cdot (R) \cdot (WP)$$

$$BE = (PV_i) - (C_T)$$

$$PV_{PIR} = \frac{(PV_i) - (C_T)}{C_T}$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 34.*

7.32 Present value of uniform gradient series

Input(s)

i_e: Effective Interest or Discount Rate (fraction)
t: Time (year)
G: Annual Change (Positive or Negative) (currency unit)
A_1: Cash Flow at the End of the First Year (currency unit)

Output(s)

A_v: Present Value of Uniform Gradient Series (currency unit)

Formula(s)

$$A_v = A_1 \pm G * \left(\frac{1}{i_e} - \frac{t}{\left((1+i_e)^t\right) - 1} \right)$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 68.*

7.33 Present worth expectation for a risky job

Input(s)

$\overline{X_A}$: Present Values of Discounted Probable Outcomes that includes all Costs except Initial Speculative Cost ($)
C: Dry Well Drilling Cost in Initial Investment ($)

Output(s)

X_E: Present Worth Expectation per a Risky Job ($)

Formula(s)

$$X_E = \overline{X_A} - C$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 92.*

7.34 Probability of an oilfield discovery

Input(s)

K_i: Number of Fields Discovered up to date in Selected Field Class (dimensionless)
K_{oi}: Estimated Total Number of Fields in Selected Field Class in the Region (dimensionless)
A_i: Total Area of Discovered Fields in Selected Field Class (acres)
W: Number of Exploration Wells Drilled up to date (dimensionless)
B: Total Area of the Region (acres)
J: Relative Efficiency of Scientific Exploration compared with Random Drilling (dimensionless)
K_{i_add}: Number of Fields will be discovered with additional number of Exploration Wells (dimensionless)
W_{add}: Additional Number of Exploration Wells will be Drilled (dimensionless)

Output(s)

P_D: Probability of an Oilfield Discovery (fraction)

Formula(s)

$$K_{oi} = \frac{K_i}{\left(1 - e^{-JA_iW/B}\right)}$$

$$K_{i\_add} = K_{oi}\left(1 - e^{-JA_i(W + W_{add})/B}\right)$$

$$P_D = \frac{K_{i\_add} - K_i}{W_{add}}$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 79.*

7.35 Profitability index

Input(s)

NPV: Net Present Value of investment (currency unit)
PVC: Present Value of Capital investments (currency unit)

Output(s)

PI: Profitability Index (dimensionless)

Formula(s)

$$PI = \frac{PVC + NPV}{PVC}$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 6, Page: 329.*

7.36 Rate of growth per unit of exploration length

Input(s)

F: Total Meterage Drilled up to date and expected to be drilled at the end Discovery (ft)
F_D: Total Meterage Drilled up to the date of Discovery (ft)
r: The Ratio of Reserves Discovered in F Meterage to the F_D Exploration Metrage (fraction)
r_u: Latest Rate of Growth for Discovered Resources (fraction)
b: Ratio Constant (dimensionless)

Output(s)

$\frac{dr}{d(F-f_D)}$: Increase in Rate of Growth per Additional Unit of Length Drilled (bbl/ft)

Formula(s)

$$\frac{dr}{d(F - F_D)} = b(r_u - r)$$

If There is no Extra Exploration ($F - F_D = 0$; $r = 1$);

$$r = r_u - \left[(r_u - 1) \cdot e^{-b(F - F_D)}\right]$$

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 79.*

7.37 Simple interest

Input(s)

P: Principal Amount (currency unit)
t: Time (12 months or 360 days)
r: Interest Rate per Period (fraction)

Output(s)

SI: Simple interest (currency unit)

Formula(s)

$$SI = P * r * t$$

Reference: *Mian, M. A. 2011. Project Economics and Decision Analysis Volume 1: Deterministic Models, Second Edition. Tulsa, Oklahoma: PennWell Corporation. Chapter 2, Page: 39.*

7.38 Total expected additional production discovery

Input(s)

K_{i_add}: Number of Fields estimated to be discovered with additional number of Exploration Wells (dimensionless)
R_{ui}: Total Production of an Average Size Field in Class "i" (bbl)

Output(s)

R_u: Total Expected Additional Production Discovery in Selected Field Class (acres)

Formula(s)

$$R_u = \sum K_{i\_add} \cdot R_{ui}$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 79.*

7.39 Total expected additional production discovery in constant production per unit area

Input(s)

K_{i_add}: Number of Fields estimated to be discovered with additional number of Exploration Wells (dimensionless)
R_{ui}: Total Production of an Average Size Field in Class "i" (bbl)
A_i: Total Area of Discovered Fields in Field Class "i" (acres)
A_{i_add}: Total Area Estimated to be discovered in Selected Field Class (acres)

Output(s)

R_u: Total Expected Additional Production Discovery in Selected Field Class (acres)

Formula(s)

$$R_u = \sum K_{i\_add} \cdot A_{i\_add} \cdot \frac{R_{ui}}{A_i}$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 81.*

7.40 Total new production area estimation expected to be discovered

Input(s)

K_{i_add}: Number of Fields estimated to be discovered with additional number of Exploration Wells (dimensionless)
A_i: otal Area of Discovered Fields in Field Class "i" (acres)

Output(s)

A_{i_add}: Total Area Estimated to be discovered in Selected Field Class (acres)

Formula(s)

$$A_{i\_add} = \sum \left(K_{i\_add}\right) \cdot (A_i)$$

Note: All Formulas need to be applied in each Field Class separately.

Reference: *Serpen, U., Petroleum Economics, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, (2008) Page: 81.*

Chapter 8

Phase behavior and thermodynamics formulas and calculations

Chapter Outline

8.1 Amount of heat required to increase the temperature

Input(s)

V_r: Volume of Reservoir (acre ft)
M_r: Volumetric Heat Capacity of Reservoir (BTU/ft^3 F)
T_i: Initial Temperature (K)
T_f: Final Temperature (K)

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Output(s)

Q: Amount of Heat Required to Increase the Temperature (BTU)

Formula(s)

$$Q=43560*V_r*M_r*(T_f-T_i)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 5, Page: 41.*

8.2 Benedict-Webb-Rubin PVT equation

Input(s)

R: Gas Constant (BTU/mol psi K)
T: Temperature (K)
ρ: Density (g/cc)
A: Correlation Constant (dimensionless)
B: Correlation Constant (dimensionless)
C: Correlation Constant (dimensionless)
a: Correlation Constant (dimensionless)
b: Correlation Constant (dimensionless)
c: Correlation Constant (dimensionless)
α: Correlation Constant (dimensionless)
γ: Correlation Constant (dimensionless)

Output(s)

P: Pressure (psi)

Formula(s)

$$P=R*T*\rho+\left(\left(B*R*T-A-\frac{C}{T^2}\right)*\left(\rho^2\right)\right)+\left(\rho^3\right)*(b*R*T-a)+a*\alpha*\left(\rho^6\right)+\left(c*\frac{\rho^3}{T^2}\right)*\left(1+\gamma*\left(\rho^2\right)\right)*\exp\left((-1)*\gamma*\left(\rho^2\right)\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 48.*

8.3 Critical pressure Cavett relation

Input(s)

T_b: Boiling Point Temperature (°F)
API: API Gravity of oil (API)

Output(s)

P_c: Critical Pressure (Psi)

Formula(s)

$$P_c=10^{(2.829)}+(0.0009112*T_b)-\left(0.0000030175*T_b^2\right)+\left(0.0000000015141*T_b^3\right)-(0.000020876*T_b*API)+\left(0.000000011048*T_b^2*API\right)+(0.0000000001395*T_b)^2*A$$

Reference: *Wikipedia.org*.

8.4 Critical temperature Cavett method

Input(s)

T_b: Boiling Point Temperature (°F)
API: API Gravity (API)

Output(s)

T_c: Critical Temperature (°F)

Formula(s)

$$T_c = 768.071 + 1.7134 * T_b - \left(0.0010834 * T_b^2\right) + \left(0.0000003889 * T_b^3\right) - \left(0.00089213 * T_b * API\right) + \left(0.00000053095 * T_b^2 * API\right) + \left(0.000000032712 * T_b^2 * API^2\right)$$

Reference: *Wikipedia.org*.

8.5 Effective thermal conductivity of composite solids

Input(s)

k_o: Thermal Conductivity of Continuous Phase (W/m K)
k_1: Thermal Conductivity of Embedded Phase (W/m K)
ø: Porosity (fraction)

Output(s)

k_{eff}: Effective Thermal Conductivity (W/m K)

Formula(s)

$$\frac{k_{eff}}{k_o} = 1 + \left(\frac{3 * ø}{\left(\frac{k_1 + 2 * k_o}{k_1 - k_o}\right) - ø}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 281.*

8.6 Einstein equation effective viscosity

Input(s)

ø: Porosity (volume fraction of the spheres)
μ_0: Viscosity of Suspending Medium (g/cm s)

Output(s)

μ_{eff}: Effective Viscosity (g/cm s)

Formula(s)

$$\mu_{eff} = \mu_0 * \left(1 + \frac{5}{2} * \text{ø}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 1, Page: 32.*

8.7 Equilibrium vaporization ratio

Input(s)

y: Mole Fraction of Component in Vapor Phase (fraction)
x: Mole Fraction of Component in Liquid Phase (fraction)

Output(s)

K: Equilibrium Vaporization Ratio (dimensionless)

Formula(s)

$$K = \frac{y}{x}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 3, Page: 3-1.*

8.8 Equilibrium vaporization ratio of heptane

Input(s)

K_a: Heptane (fraction)
K_b: Ethane (fraction)
b: Constant (dimensionless)

Output(s)

K: Equilibrium Vaporization Ratio (fraction)

Formula(s)

$$K = \frac{K_a}{\left(\frac{K_b}{K_a}\right)^b}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 3. Page: 3-1.*

8.9 Evaporation loss from an oxygen tank

Input(s)

r_o: Inner Diameter (m)
r_1: Outer Diameter (m)
T_o: Inner Layer Temperature (K)
T_1: Outer Layer Temperature (K)

k_o: Thermal Conductivity of Inner Layer (W/m K)
k_1: Thermal Conductivity of Outer Layer (W/m K)

Output(s)

Q_o: Flow Rate of Evaporation (g/s)

Formula(s)

$$Q_o = 4 * \pi * r_o * r_1 * \left(\frac{k_o + k_1}{2}\right) * \left(\frac{T_o - T_1}{r_1 - r_o}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 327.*

8.10 Expansion factor for diffuse layer

Input(s)

n_c: Critical Salt Concentration (mol/L)
n: Salt Concentration (mol/L)

Output(s)

f_{dl}: Expansion Factor (dimensionless)

Formula(s)

$$f_{dl} = \left(\frac{n_c}{n}\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 1, Page: 15.*

8.11 Flat-plate boundary layer model

Input(s)

v_{y0}: Horizontal Velocity (cm/s)
v_∞: Velocity (cm/s)
x: Distance (cm)
μ: Viscosity (cP)

Output(s)

K: Net Mass Flux from the Plate (dimensionless)

Formula(s)

$$K = \left(\frac{v_{y0}}{v_\infty}\right) * \left(\left(\frac{2 * v_\infty * x}{\mu}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 708.*

8.12 Freezing of a spherical drop

Input(s)

v_{y0}: Horizontal Velocity (cm/s)
v_∞: Velocity (cm/s)
x: Distance (cm)
μ: Viscosity (cP)

Output(s)

K: Net Mass Flux from the Plate (dimensionless)

Formula(s)

$$K=\left(\frac{v_{y0}}{v_\infty}\right)*\left(\left(\frac{2*v_\infty*x}{\mu}\right)^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 22, Page: 708.*

8.13 General thermal conductivity

Input(s)

Q: Heat Flow Rate (BTU/s)
L: Length (ft)
A: Area (ft^2)
∂T: Temperature Difference (K)

Output(s)

k: Thermal Conductivity (BTU/ft s K)

Formula(s)

$$k=\frac{Q*L}{A*\partial T}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 266.*

8.14 Heat conduction in a cooling fan

Input(s)

z: Distance from Start of Fan (cm)
L: Length of Fan (cm)
B: Breadth of Fan (cm)
h: Heat Transfer Coefficient (J/s m^2 K)
k: Thermal Conductivity (W/cm K)
T_w: Temperature of Wall (K)
T_a: Ambient Temperature of Air (K)

Output(s)

ξ: Dimensionless Distance (dimensionless)
N: Dimensionless Heat Transfer Coefficient (dimensionless)
Θ: Dimensionless Temperature (dimensionless)
T: Temperature at Distance Z from Wall at the Fan (K)

Formula(s)

$$\xi = \frac{z}{L}$$

$$N = \left(\frac{h * (L^2)}{k * B}\right)^{0.5}$$

$$\Theta = \frac{\cosh(N * (1 - \xi))}{\cosh(N)}$$

$$T = T_a + \Theta * (T_w - T_a)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Pages: 308, 309.*

8.15 Heat flux distribution in a wall

Input(s)

k: Thermal Conductivity (J/ft s K)
x: Distance from Center of Wall (ft)
b: Breadth of Wall (ft)
T_o: Initial Temperature of Wall (K)
T_1: Final Temperature of Wall (K)

Output(s)

Q: Heat Flux (J)

Formula(s)

$$Q = \frac{2 * k * \sec\left(\frac{\pi * x}{b}\right) * (T_1 - T_o)}{b}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 12, Page: 387.*

8.16 Heat loss by free convection from a horizontal pipe

Input(s)

h_m: Heat Transfer Coefficient (W/m K)
D: Diameter (m)
L: Length (m)
T_o: Final Temperature (K)
T_b: Initial Temperature (K)

Output(s)

Q: Heat Loss Rate (J/s)

Formula(s)

$$Q = h_m * pi * D * L * (T_o - T_b)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 14, Page: 445.*

8.17 Heat released during in-situ combustion given by Burger & Sahuquet

Input(s)

m: Molar Ratio of H/C (fraction)
x: Ratio of Carbon Monoxide to Carbon Emissions (fraction)

Output(s)

dh_a: Heat Liberated (BTU/scf)

Formula(s)

$$dh_a = \frac{94 - 67.9 * m + 31.2 * x}{1 - 0.5 * m + 0.25 * x}$$

Reference: *Reference: Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 93.*

8.18 Heat transfer coefficient for condensation—Pure vapors on solid surface

Input(s)

k: Thermal Conductivity (J/m s K)
ρ: Density (g/cc)
g: Acceleration Due to Gravity (m/s^2)
μ: Viscosity (cP)
D: Diameter (m)
T_d: Dew Point Temperature (K)
T_o: Original Temperature (K)
ΔH_{vap}: Heat of Vaporization ($J\ ft^2/s^2$)

Output(s)

h_m: Heat Transfer Coefficient (W/m K)

Formula(s)

$$h_m = 0.725 * \left(\frac{(k^3) * (\rho^2) * g * \Delta H_{vap}}{\mu * D * (T_d - T_o)}\right)^{0.25}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 14, Page: 447.*

8.19 Heat transfer in packed bed

Input(s)

a: Number of Particles in Bed (dimensionless)
S_{dz}: Representative Volume for Each Particle (m^3)
T_o: Final Temperature (K)
T_b: Initial Temperature (K)
h_{loc}: Heat Transfer Coefficient (W/m K)

Output(s)

dQ: Heat Loss (J/s)

Formula(s)

$$dQ = h_{loc} * a * (Sdz) * (T_o - T_b)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 14, Page: 441.*

8.20 Heat transfer rate in laminar forced convection along heated flat plate

Input(s)

W: Width (ft)
L: Length (ft)
T_o: Final Temperature (K)
T_∞: Temperature at X from Center of Temperature Profile (K)
k: Thermal Conductivity (BTU/ft h K)
Pr: Prandtl (dimensionless)
Re: Reynolds (dimensionless)

Output(s)

Q: Heat Loss Rate (BTU/h)

Formula(s)

$$Q = \left(\left(\frac{148}{315}\right)^{0.5}\right) * 2 * W * L * (To - T_\infty) * \left(\frac{k}{L}\right) * (Pr\,0.334) * \left(Re^{0.5}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 12, Page: 390.*

8.21 Jacoby aromaticity factor

Input(s)

γ: Specific Gravity (unitless)
M: Molecular Weight (lbm/lbm mol)

Output(s)

J_a: Jacoby Aromaticity Factor (unitless)

Formula(s)

$$J_a = \frac{(\gamma) + \left(\frac{15.8}{M}\right) - 0.8468}{0.2456 - \left(\frac{1.77}{M}\right)}$$

Reference: *Whitson, C.H., Brule, M.R., 2000. Phase Behavior. SPE Monograph Series. Richardson, Texas, Chapter: 5, Page: 78.*

8.22 Joule Thompson expansion

Input(s)

R: Universal Gas Constant (psi ft^3/K lbmol)
C_p: Specific Heat Capacity at Constant Pressure (J/lb K)
$\left(\frac{\partial Z}{\partial T}\right)_p$: Variation of Gas Compressibility Factor w.r.t. Temperature Change at Constant Pressure (1/K)

Output(s)

$\partial T/\partial p$: Joule-Thompson Expansion (K/psi)

Formula(s)

$$\frac{\partial T}{\partial p} = \left(\frac{RT^2}{pC_p}\right) * \left(\frac{\partial Z}{\partial T}\right)_p$$

Reference: *Ahmed, T. McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter:3, Page: 272.*

8.23 Latent heat of hydrocarbon mixture

Input(s)

T: Average Boiling Point (K)
M: Molecular Weight (dimensionless)

Output(s)

Δh_m: Latent Heat (BTU/lb)

Formula(s)

$$\Delta h_m = \left(\frac{T}{M}\right) * (7.58 + 4.57 * \log(T))$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 207.*

8.24 Mixing fluids of different densities

Input(s)

D_1: Density of fluid 1 (ppg)
D_2: Density of fluid 2 (ppg)
V_1: Volume of fluid 1 (bbl)
V_2: Volume of fluid 2 (bbl)

Output(s)

D_f: Density of final fluid (ppg)
V_f: Volume of final fluid (bbl)

Formula(s)

$$D_f = V_1 + V_2$$

$$V_f = \frac{V_1 * D_1 + V_2 * D_2}{V_f}$$

Reference: *Wikipedia.org*.

8.25 Mole fraction of a component in liquid phase

Input(s)

z: Mole of Component in Feed Per Mole Total Feed (mol)
L: Moles of Liquid Leaving a Stream (mol)
V: Moles of Vapor Leaving a Stream (mol)
K: Equilibrium Vapor Factor (ratio)

Output(s)

x: Mole Fraction of a Component in Liquid Phase (ratio)

Formula(s)

$$x = \frac{z}{L + V * K}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 107.*

8.26 Mole fraction of a component in vapor phase

Input(s)

z: Mole Fraction of Component in Feed (mol)
L: Moles of Liquid in Outlet Stream (mol)
V: Moles of Vapor in Outlet Stream (mol)
K: Equilibrium Vaporization Ratio (ratio)

Output(s)

y: Mole Fraction of Component in Vapor Phase (fraction)

Formula(s)

$$y = \frac{z}{L + \left(\frac{V}{K}\right)}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 107.*

8.27 Necessary inhibitor concentration required in liquid phase to reduce hydrate point

Input(s)

d: Desired Depression of Hydrate Point (F)
M: Molecular Weight of Inhibitor (dimensionless)

Output(s)

X: Interstitial Velocity (cm/s)

Formula(s)

$$X = \frac{d * M * 100}{d * M + 2335}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 180.*

8.28 Peng Robinson characterization factor

Input(s)

M: Molecular weight (g)

Output(s)

k_{Ci}: Characterization factor (unitless)

Formula(s)

$$k_{Ci} = 0.0289 + 0.0001633 * M$$

Reference: *Wikipedia.org.*

8.29 Peng Robinson PVT equation

Input(s)

R: Gas Constant (BTU/psi K mol)
T: Temperature (K)
V: Volume (ft^3)
a: Correlation Constant (dimensionless)
b: Correlation Constant (dimensionless)

Output(s)

P: Pressure (psi)

Formula(s)

$$P=\frac{R*T}{V-b}-\frac{a*T}{V*(V+b)+b*(V-b)}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 48.*

8.30 Pseudo-reduced conditions

Input(s)

P: Pressure (psi)
P_{cA}: Critical Pressure at A (psi)
P_{cB}: Critical Pressure at B (psi)
T: Temperature (K)
T_{cA}: Critical Temperature at A (K)
T_{cB}: Critical Temperature at B (K)

Output(s)

P_r: Pseudo Reduced Pressure (dimensionless)
T_r: Pseudo Reduced Temperature (dimensionless)

Formula(s)

$$P_r=\frac{P}{(P_{cA}*P_{cB})^{0.5}}$$

$$T_r=\frac{T}{(T_{cA}*T_{cB})^{0.5}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 17, Page: 524.*

8.31 Radiant heat transfer between disks

Input(s)

A: Area of Body (ft^2)
σ: Stefan-Boltzmann Constant (BTU/h ft^2 °R^4)
F: View Factor of Body (fraction)
T_1: Initial Temperature of Emitting Body (°R)
T_2: Temperature of Absorbing Body (°R)

Output(s)

Q: Heat Transfer Rate by Radiation (BTU/h)

Formula(s)

$$Q = A * F * \sigma * \left(\left(T_1^4\right) - \left(T_2^4\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 501.*

8.32 Radiated energy flux

Input(s)

c: Speed of Light (ft/s)
h: Planck's Constant (lb ft^2/s)
λ: Wavelength (ft)
k: Stefan-Boltzmann Constant (BTU/h ft^2 $°R^4$)
T: Temperature (K)

Output(s)

q: Radiated Energy Flux from a Black Surface in the Wavelength Range (BTU/ft^2 s^3)

Formula(s)

$$q = \frac{2 * \pi * (c^2) * h}{(\lambda^5) * \left(\exp\left(\frac{c * h}{\lambda * k * T}\right) - 1\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 494.*

8.33 Radiation across an annular gap

Input(s)

T_1: Temperature at Cylinder 1 (K)
T_2: Temperature at Cylinder 2 (K)
e_1: Emissivity at Cylinder 1 (fraction)
e_2: Emissivity at Cylinder 2 (fraction)
A_1: Area at Cylinder 1 (ft)
A_2: Area at Cylinder 2 (ft)
k: Stefan-Boltzmann Constant (BTU/h ft^2 $°R^4$)

Output(s)

Q: Heat Transfer Rate (BTU/h)

Formula(s)

$$Q = \frac{k * \left(\left(T_1^4\right) - \left(T_2^4\right)\right)}{\left(\frac{1}{A_1 * e_1}\right) + \left(\frac{1}{A_2}\right) * \left(\left(\frac{1}{e_2}\right) - 1\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 494.*

8.34 Radiation shields

Input(s)

k: Stefan-Boltzmann Constant (BTU/s ft^2 °R^4)
T_i: First Sheet's Temperature (K)
T_{i+1}: Next Sheet's Temperature (K)
$Q_{i,\ i+1}$: Heat Transfer Rate (BTU/s)

Output(s)

$R_{i,\ i+1}$: Resistance to Radiation (ft^2 K/W)

Formula(s)

$$R_{i,i+1} = \frac{\sigma * \left(T_i^4 - T_{i+1}^4\right)}{Q_{i,i+1}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 509.*

8.35 Rayleigh number

Input(s)

g: Acceleration due to Earth's gravity (m/s^2)
β: Volumetric thermal expansion coefficient (K)
Ts: Surface temperature (K)
Ti: Bulk temperature (K)
x: Characteristic Length (m)
v: Kinematic viscosity (m^2/s)
α: Thermal Conductivity of fluid (K)

Output(s)

Ra: Rayleigh number (dimensionless)

Formula(s)

$$Ra = \frac{g * \beta * (Ts - Ti) * x^3}{v * \alpha}$$

Reference: *Wikipedia.org*.

8.36 Redlich-Kwong PVT equation

Input(s)

R: Gas Constant (BTU/mol K psi)
T: Temperature (K)
V: Volume (ft^3)
a: Correlation Constant (dimensionless)
b: Correlation Constant (dimensionless)

Output(s)

P: Pressure (psi)

Formula(s)

$$P=\frac{R*T}{V-b}-\frac{a}{\left(T^{0.5}\right)*V*(V+b)}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 48.*

8.37 Reservoir gas density

Input(s)

γ_g: Specific Gravity of Gas (fraction)
T: Temperature (°F)
p: Pressure (psi)
z: Gas deviation factor (fraction)
R: Gas Constant (fraction)

Output(s)

ρ_g: Reservoir Gas Density (lb/ft^3)

Formula(s)

$$\rho_g=28.97*\gamma_g*\frac{p}{z*R*T}$$

Reference: *Applied Petroleum Reservoir Engineering, Second Edition, Craft & Hawkins, Page: 32.*

8.38 Stefan-Boltzmann law

Input(s)

σ: Stefan Boltzmann Constant (1.713 E-9) (BTU/ft^2 h °R^4)
T: Temperature (°F)
ε: Emissivity (fraction)

Output(s)

u_i: Rate of Radiation Heat Transfer Per Unit Area (BTU/h ft^2)

Formula(s)

$$u_i=\sigma*\varepsilon*(T+460)^4$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 19.*

8.39 Surface temperature of a heating coil

Input(s)

T_o: Initial Surface Temperature (K)
μ: Viscosity (Pa s)
ρ: Density (g/m^3)
g: Gravitational Acceleration (ft/s^2)
β: Velocity Flux (1/s)
D: Diameter (m)
Q: Net Energy Input Rate (J/s)
k: Thermal Conductivity (J/m s K)

Output(s)

$T_1 - T_o$: Final Temperature of Surface (K)

Formula(s)

$$T_1 - T_o = \frac{\mu^2}{(\rho^2) * g * \beta * (D^3)} * \varnothing\left(\frac{Q * (\rho^2) * g * \beta * (D^2)}{k * (\mu^2)}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 11, Page: 361.*

8.40 Temperature due to free convection

Input(s)

T_1: Temperature at Cooled Plate (K)
T_2: Temperature at Heated Plate (K)
y: Distance from Centre (cm)
B: Half Distance between the Plates (cm)

Output(s)

T: Temperature (K)

Formula(s)

$$T = 0.5 * (T_1 + T_2) - 0.5 * (T_2 - T_1) * \left(\frac{y}{B}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 317.*

8.41 Temperature increase due to forced convection

Input(s)

q: Interfacial Heat Flux (J/m^2 s)
D: Diameter (m)
k: Thermal Heat Conductivity (W/m K)

Output(s)

T: Temperature Increase (K)

Formula(s)

$$T = 11 * q * \frac{D}{48 * k}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons. Chapter: 10, Page: 316.*

8.42 Temperature profile after viscous heat transfer

Input(s)

T_b: Temperature of Outer Perimeter (K)
b: Distance of Outer Boundary (ft)
Br: Brinkman (dimensionless)
T_o: Temperature of Inner Perimeter (K)
x: Distance from Centre of Pipe (ft)

Output(s)

T: Temperature at Distance X (K)

Formula(s)

$$\left(\frac{T - T_o}{T_b - T_o}\right) = \frac{1}{2} * Br * \left(\frac{x}{b}\right) * \left(1 - \frac{x}{b}\right) + \frac{x}{b}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 300.*

8.43 Temperature profile with a nuclear heat source

Input(s)

S_{no}: Volume Rate Heat Production at the Center of the Source (cal/cm^3 s)
R^F: Radius of Fissionable Substance (cm)
K^F: Thermal Conductivity of Fissionable Substance (W/cm K)
r: Radius of Core (cm)
b: Constant of Fission (dimensionless)
k^c: Thermal Conductivity of Casing Substance (W/cm K)
R^c: Radius of Casing Substance (cm)
T_o: Initial Temperature (K)

Output(s)

T_f: Temperature of Fissionable Substance (K)

Formula(s)

$$T_f=\left(\frac{S_{no}*\left(R^{(F)2}\right)}{6*K^F}\right)*\left(\left(1-\left(\frac{r}{R^F}\right)^2\right)+\frac{3}{10}*b*\left(1-\left(\frac{r}{R^F}\right)^4\right)\right)+\left(\frac{S_{no}*\left(R^{(F)2}\right)}{3*k^c}\right)*\left(1+\frac{3}{5}*b\right)*\left(1-\frac{R^F}{R^c}\right)+T_o$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 298.*

8.44 Thermal conductivity for pure metals

Input(s)

L: Lorenz Number (V^2/K^2)
k_e: Electrical Conductivity (S/m)
T: Temperature (K)

Output(s)

k: Thermal Conductivity (W/m K)

Formula(s)

$$k=L*k_e*T$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 280.*

8.45 Thermal conductivity of polyatomic gases

Input(s)

R: Gas Constant (g cm^2/s^2 K gmol)
M: Molecular Weight (g/gmol)
μ: Viscosity (g/cm s)
$\hat{C}_p$: Specific Heat (cal/g –mol K)

Output(s)

k: Thermal Conductivity (W/m K)

Formula(s)

$$k=\left(\hat{C}_p+\frac{5}{4}*R\right)*\left(\frac{\mu}{M}\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 278.*

8.46 Thermal conductivity of liquids

Input(s)

$\tilde{N}$: Avogadro's Number (1/gmol)
k: Thermal Conductivity (J/m s K)
K: Boltzmann Constant (g cm^2/s^2 F)
v_s: Sonic Velocity (cm/s)
$\tilde{v}$: Volume (cm^3)

Output(s)

k: Thermal Conductivity (g c/F s^3)

Formula(s)

$$k=\left(2.80*\left(\frac{\tilde{N}}{\tilde{v}}\right)^{\frac{2}{3}}\right)*K*v_s$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 279.*

8.47 Thermal conductivity of solids with gas pockets

Input(s)

k_o: Thermal Conductivity of Solid Phase (W/m K)
k_1: Thermal Conductivity of the Gas (W/m K)
Ø: Porosity (fraction)
T: Temperature (K)
L: Length (m)
σ: Stefan-Boltzmann Constant (kg/s^3 K^4)

Output(s)

k_{eff}: Effective Thermal Conductivity (W/m K)

Formula(s)

$$\frac{k_{eff}}{k_o}=\frac{1}{1-Ø+\left(\left(\frac{k_1}{k_o*Ø}\right)+\left(\frac{4*\sigma*T^3*L}{k_o}\right)\right)^{-1}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 282.*

8.48 Thermal diffusivity

Input(s)

k: Thermal Conductivity (W/(m K))
$\hat{C}_p$: Heat Capacity at Constant Pressure (J/(kg K))
ρ: Density (kg/m^3)

Output(s)

α: Thermal Diffusivity (m^2/s)

Formula(s)

$$\alpha=\frac{k}{\hat{C}_p*\rho}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 9, Page: 268.*

8.49 Thermal energy of a fissionable substance

Input(s)

S_{no}: Rate of Heat Production at Center of Substance (cal/cm^3 s)
b: Constant of Fission (dimensionless)
r: Radius of Centre of Sphere (cm)
R^F: Radius of Fissionable Material (cm)

Output(s)

S_n: Thermal Energy Resulting from Volume Source (cal/cm^3 s)

Formula(s)

$$S_n = S_{no} * \left(1 + b * \left(\left(\frac{r}{R^F}\right)^2\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 296.*

8.50 Thermoelastic effect on stress

Input(s)

λ: Lame (psi)
δ_{ij}: Kronecker Delta (dimensionless)
ε_{00}: Initial Strain (dimensionless)
G: Modulus of Shear (psi)
ε_{ij}: Final Strain (dimensionless)
α_T: Coefficient of Linear Thermal Expansion (1/K)
P_0: Pressure Applied (psi)
K: Bulk Modulus (psi)
ΔT: Temperature Difference (K)

Output(s)

S_{ij}: Stress (psi)

Formula(s)

$$S_{ij} = \lambda * \delta_{ij} * \varepsilon_{00} + 2 * G * \varepsilon_{ij} - \alpha_T * \delta_{ij} * P_0 - K * \alpha_T * \delta_{ij} * \Delta T$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Express, UK, Page: 83.*

8.51 Unsteady evaporation of a liquid

Input(s)

S: Surface Area (cm^2)
Ø: Location of Film (cm)
D_{AB}: Difussivity (cm^2/s)
t: Time (s)

Output(s)

V_a: Rate of Evaporation (cc/s)

Formula(s)

$$V_a = S * \text{Ø} * \left(\left(\frac{4 * D_{AB} * t}{\pi} \right)^{0.5} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 20, Page: 615.*

8.52 Van Der Waals PVT equation

Input(s)

P: Pressure (psi)
T: Temperature (K)
a: Correlation Constant (dimensionless)
b: Correlation Constant (dimensionless)
V: Volume (ft^3)

Output(s)

R: Gas Constant (BTU/psi mol K)

Formula(s)

$$R = \frac{\left(P + \frac{a}{V^2} \right) * (V - b)}{T}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 1, Page: 48, Campbell Petroleum Series, Oklahoma, 1992.*

8.53 Wien displacement law

Input(s)

λ_{max}: Maximum Wavelength (1/cm)

Output(s)

T: Temperature (K)

Formula(s)

$$T = \frac{0.2884}{\lambda_{max}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 16, Page: 495.*

Chapter 9

Petroleum engineering laboratory formulas and calculations

Chapter Outline

9.1 Absolute viscosity for Saybolt viscosimeter measurements

Input(s)

v: Kinematic Viscosity (Centistokes)
ρ: Measured Density of Fluid (g/cm^3)

Output(s)

μ: Absolute Viscosity (cP)

Formula(s)

$$\mu = v \cdot \rho$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 2–7.*

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9.2 Absolute viscosity for Ubbelohde viscosimeter measurements

Input(s)

t: Measured time (s)
C_u: Viscosimeter Constant (mPa)

Output(s)

μ: Absolute Viscosity (cP)

Formula(s)

$$\mu = C_u \cdot t$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 2–7.*

9.3 Adhesion tension

Input(s)

σ_{so}: Interfacial Tension between the solid and oil (dyn/cm)
σ_{sw}: Interfacial Tension between the solid and water (dyn/cm)
σ_{wo}: Interfacial Tension between the water and oil (dyn/cm)
θ: Contact Angle (degree)

Output(s)

τ: Adhesion Tension (dyn/cm)

Formula(s)

$$\tau = \sigma_{so} - \sigma_{sw} = \sigma_{wo} \cos\theta$$

Reference: *Tiab, D., & Donaldson, E. C. (2015). Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties. Gulf Professional Publishing. Page: 363.*

9.4 Amott-Harvey wettability index

Input(s)

I_o: Oil Spontaneous Imbibition Ratio (dyn/cm)
I_w: Water Spontaneous Imbibition Ratio (dyn/cm)

Output(s)

I_{AH}: Amott-Harvey Index (dimensionless)

Formula(s)

$$I_{AH} = I_w - I_o$$

Reference: *Ghedan, S. G., Canbaz, C. H., Boyd, D. A., Mani, G. M., & Haggag, M. K. (2010, January). Wettability Profile of a Thick Carbonate Reservoir by the New Rise in Core Wettability Characterization Method. Abu Dhabi International Petroleum Exhibition and Conference. Society of Petroleum Engineers. Page: 3.*

9.5 Apparent facial tension (De Nouy ring method)

Input(s)

g: Acceleration of Gravity (980 cm/s^2)
m: Measured Weight (g)
l: Perimeter of the Ring (cm)

Output(s)

S: Apparent Facial Tension (dyn/cm)

Formula(s)

$$S = \frac{m \cdot g}{2 \cdot l}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 4–3.*

9.6 Average compressibility of oil

Input(s)

V: Reference Volume (volume fraction relative to bubble point volume or higher pressure)
V_1: Volume Fraction at Higher Pressure (fraction)
V_2: Volume Fraction at Lower Pressure (fraction)
p_1: Pressure (Relative to V_1) (psi)
p_2: Pressure (Relative to V_2) (psi)

Output(s)

C_o: Average Compressibility of Oil (psi ˆ(−1))

Formula(s)

$$C_o = -\frac{1}{V} * \left(\frac{V_1 - V_2}{p_1 - p_2}\right)$$

Reference: *Craft, B. C., Hawkins, M., & Terry, R. E. (1991). Applied Petroleum Reservoir Engineering. 2nd Edition, Page: 38.*

9.7 Average gas solubility

Input(s)

s_1: Solubility at p_1 (SCF/STB)
s_2: Solubility at p_2 (SCF/STB)
p_1: Pressure1 (psi)
p_2: Pressure2 (psi)

Output(s)

S_{avg}: Average Gas Solubility (SCF/STB/psi)

Formula(s)

$$S_{avg} = \frac{s_1 - s_2}{p_1 - p_2}$$

Reference: *Craft, B. C., Hawkins, M., & Terry, R. E. (1991). Applied Petroleum Reservoir Engineering. 2nd Edition, Page: 32.*

9.8 Characterization factor for oil distillation

Input(s)

T_b: Average Boiling Point (°R (or °F + 460))
$\gamma_{60/60^oF}$: Specific Gravity (dimensionless)

Output(s)

K: Characterization Factor (dimensionless)

Formula(s)

$$\frac{K = T_b^{1/3}}{\gamma_{60/60^oF}}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 5–2.*

9.9 Clasius-Clapeyron equation for water vapor

Input(s)

L_v: Heat of Vaporization of one mole of Liquid (J/mol)
T_1: Absolute Temperature of Condition 1 (°F)
T_2: Absolute Temperature of Condition 2 (°F)
R: Gas Constant for Water Vapor (psi/mol °F s^2)

Output(s)

p_{v1}: Vapor Pressure at the Temperature T_1 (psi)
p_{v2}: Vapor Pressure at the Temperature T_2 (psi)

Formula(s)

$$\ln\left(\frac{p_{v1}}{p_{v2}}\right) = \frac{L_v}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Reference: *McCain Jr, W. D. (1990). Properties of Petroleum Fluids. PennWell Corporation. Page: 54.*

9.10 Clay concentration of drilling mud (methylene blue test)

Input(s)

V_{mb}: Volume of Methylene Blue used in Experiment, meq/100 mL (mL)
V_{dm}: Volume of Drilling Mud used in Experiment, meq/100 mL (mL)

V_{sc}: Volume of Solid Content (Cuttings or Bentonite) in Drilling Mud, meq/100 mL (g)
MBT_m: Methylene Blue Result of Drilling Mud (mL/mL)
MBT_{ds}: Methylene Blue Result of Drilling Cuttings (mL/mL)
MBT_m: Methylene Blue Result of Clay (mL/mL)

Output(s)

f_c: Clay Content Ratio in Drilling Mud (fraction)
C_c: Clay Concentration in Drilling Mud (lb/bbl)

Formula(s)

$$MBT_m = \frac{V_{mb}}{V_{dm}}$$

$$MBT_{ds} = \frac{V_{mb}}{V_{sc}}$$

$$MBT_c = \frac{V_{mb}}{V_{sc}}$$

$$f_c = \frac{MrBT_m - 2.6 \cdot f_{lg} \cdot MBT_{ds}}{2.6(MBT_c - MBT_{ds})}$$

$$C_c = f_c \cdot 21.7 \frac{lb}{gal} \cdot 42 \frac{gal}{bbl}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 3, Page: 4.*

9.11 Contact angle

Input(s)

σ_{so}: Interfacial Tension between the solid and oil (dyn/cm)
σ_{sw}: Interfacial Tension between the solid and water (dyn/cm)
σ_{wo}: Interfacial Tension between the water and oil (dyn/cm)

Output(s)

θ: Contact Angle (degree)

Formula(s)

$$\cos\theta = \frac{\sigma_{so} - \sigma_{sw}}{\sigma_{wo}}$$

Reference: *Tiab, D., & Donaldson, E. C. (2015). Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties. Gulf Professional Publishing. Page: 362.*

9.12 Correction factor for facial tension (De Nouy ring method)

Input(s)

R: Radius of the Ring (cm)
r: Radius of the Ring String (cm)
S: Apparent Facial/Interfacial Tension (dyn/cm)
D: Specific Gravity of Lower Phase (g/cm^3)
d: Specific Gravity of Upper Phase (g/cm^3)
l: Perimeter of the Ring (cm)

Output(s)

C: Correction Factor (dimensionless)

Formula(s)

$$C = 0.7250 + \sqrt{\frac{0.01452 \cdot S}{I^2(D-d)} + 0.04534 - \frac{1.679 \cdot r}{R}}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 4–4.*

9.13 Drilling mud density (solid content analysis of drilling muds)

Input(s)

ρ_w: Density of used Water (lb/gal)
f_w: Water Content Ratio of Drilling Mud (fraction)
ρ_{lg}: Density of Clay and Cuttings (lb/gal)
f_{lg}: Content Ratio of Clay and Cuttings in Drilling Mud (fraction)
ρ_B: Density of Barite (lb/gal)
f_B: Content Ratio of Barite (fraction)
ρ_o: Density of Oil that is used in Oil-based Muds (lb/gal)
f_o: Oil Content Ratio in Drilling Mud (fraction)

Output(s)

ρ_m: Drilling Mud Density (lb/gal)
f_s: Total Solid Content Ratio in a Drilling Mud (fraction)

Formula(s)

$$\rho_m = \rho_w f_w + \rho_{lg} f_{lg} + \rho_B f_B + \rho_o f_o$$

For water-based muds

$$f_w + f_{lg} + f_B = 1$$

$$f_s = f_{lg} + f_B$$

$$f_w = 1 - f_s$$

$$f_s = 0.3125\left[\frac{\rho_m}{8.33} - 1\right] + 0.5 f_{lg}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 3, Page: 1.*

9.14 Effective porosity

Input(s)

V_{P_e}: Effective Pore Volume (cm^3)
V_b: Bulk Volume (cm^3)
V_o: Total Oil Volume in Interconnected Pores (cm^3)
V_g: Total Gas Volume in Interconnected Pores (cm^3)
V_w: Total Water Volume in Interconnected Pores (cm^3)

Output(s)

$ø_{eff}$: Effective Porosity (fraction)

Formula(s)

$$V_{P_e} = V_o + V_g + V_w$$

$$ø_{eff} = \frac{V_{P_e}}{V_b}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, II-Properties of Porous Media, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 1–3.*

9.15 Error percentage of porosity measurements

Input(s)

$ø_m$: Measured Porosity (fraction)
$ø_{ps}$: Calculated Porosity or Pseudo-Porosity (fraction)

Output(s)

$E_ø$: Effective Porosity (fraction)

Formula(s)

$$E_ø = \frac{ø_m - ø_{ps}}{ø_m} \cdot 100$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, II-Properties of Porous Media, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 1–7.*

9.16 Facial tension (De Nouy ring method)

Input(s)

C: Correction Factor (dimensionless)
S: Apparent Facial Tension (dyn/cm)

Output(s)

σ: Real Facial Tension (dyn/cm)

Formula(s)

$$\sigma = S \cdot C$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 4–4.*

9.17 Filtration rate for API fluid loss measurement

Input(s)

h_{mc}: Filter Cake Thickness (cm)
A: Filter Cake Area (cm^2)
ΔP: Pressure Difference (Atm)
k: Permeability of the Filter Cake (D)
μ: Viscosity of the Filtration Fluid (cP)

Output(s)

$\frac{dV_f}{dt}$: Filtration Rate (cc/s)

Formula(s)

$$\frac{dV_f}{dt} = \frac{k \cdot A \cdot \Delta P}{\mu \cdot h_{mc}}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 2, Page: 4.*

9.18 Filtration volume without spurt loss

Input(s)

$V_{7.5}$: Filtration Volume Measurement at 7.5 min (cc)

Output(s)

V_{30}: Filtration Volume Measurement at 30 min (cc)

Formula(s)

$$V_{30} = 2 \cdot V_{7.5}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 2, Page: 6.*

9.19 Filtration volume with spurt loss

Input(s)

V_{sp}: Spurt Loss Volume (cc)
V_{f1}: Filtration Volume at time "1" (cc)
V_{f2}: Filtration Volume at time "2" (cc)
t_1: Time value "1" (min)
t_2: Time value "2" (min)
t: Filtration time of the measured Filtration Volume "V_f" (min)

Output(s)

V_f: Filtration Volume (cc)

Formula(s)

$$V_f = V_{sp} + \frac{V_{f2} - V_{f1}}{\sqrt{t_2} - \sqrt{t_1}}\sqrt{t}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 2, Page: 6.*

9.20 Gas permeability measurement (lab measurement using Klinkenberg effect)

Input(s)

μ: Viscosity of Liquid Phase (cP)
μ_{air}: Viscosity of Air (cP)
μ_{CO_2}: Viscosity of CO_2 (cP)
Q_{avg}: Average Rate in Porous Media (cm^3/s)
P_{avg}: Average Pressure in Porous Media (Atm)
L: Plug Length (cm)
A: Open-Flow Area of the Plug (cm^2)
P_1: Inlet Pressure (Atm)
P_2: Outlet Pressure (Atm)
V: Liquid Volume that flows in time t (cm^3)
V_1: Liquid Volume that flows at Inlet Part in Time t (cm^3)
V_2: Liquid Volume that flows at Outlet Part in Time t (cm^3)
Q_1: Liquid Rate that flows at Inlet Part (cm^3)
Q_2: Liquid Rate that flows at Outlet Part (cm^3)

Output(s)

k: Liquid Permeability (D)
k_g: Gas Permeability (D)

Formula(s)

$$k = \frac{2\mu \cdot Q_{avg} \cdot P_{avg} \cdot L}{A \cdot \left(P_1^2 - P_2^2\right)}$$

$$P_1 \cdot V_1 = P_2 \cdot V_2 = P_{avg} \cdot V_{avg}$$

$$P_1 \cdot Q_1 = P_2 \cdot Q_2 = P_{avg} \cdot Q_{avg}$$

$$k_g = k\left(1 + \frac{b}{P_{avg}}\right)$$

$$\mu_{air} = 0.000044848 \cdot T + 0.0165$$

$$\mu_{CO_2} = 0.00005000 \cdot T + 0.0138$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, II-Properties of Porous Media, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 3–4.*

9.21 Kinematic viscosity for Saybolt viscosimeter measurements

Input(s)

t_o: Measured Discharge Time (s)

Output(s)

v: Kinematic Viscosity (Centistokes)

Formula(s)

$$v = 0.220\, t_o - \frac{180}{t_o}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 2–6.*

9.22 Liquid permeability (permeameter lab measurement)

Input(s)

μ: Viscosity of Liquid Phase (cP)
t: Flowing Time (s)
V: Liquid Volume that flows in time t—Burette Volume (cm^3)
P: Pressure value that read from Pressure Gauge (Atm)
L: Plug Length (cm)
A: Open-Flow Area of the Plug (cm^2)

Output(s)

k: Permeability (D)

Formula(s)

$$k = \frac{\mu \cdot V \cdot L}{A \cdot P \cdot t}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, II-Properties of Porous Media, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 2–6.*

9.23 Permeability determination using porosity data (Kozeny-Carman equation)

Input(s)

ø: Effective Porosity (fraction)
d: Average Diameter of Rock Particles (in.)

Output(s)

k: Permeability (mD)

Formula(s)

$$k = 3.631 \cdot 10^9 \cdot \frac{d^2 - ø^3}{(1 - ø)^2}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, II-Properties of Porous Media, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 1–8.*

9.24 Pycnometer volume correction

Input(s)

V_k: Calibration Volume of Specific Gravity bottle (Pycnometer) (mL or cm^3)
T_t: Test Temperature (°C)
T_k: Calibration Temperature (°C)
Ω: Material Constant (for Ordinary Glass = $0.276 \cdot 10^{-4}$/°C)
Ω: Material Constant (for Pyrex Glass = $0.156 \cdot 10^{-4}$/°C)

Output(s)

V_g: Real Volume of Specific Gravity bottle (Pycnometer) (mL or cm^3)

Formula(s)

$$V_g = V_k \left[1 + \Omega \left(T_g - T_k\right)\right]$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page 1–4.*

9.25 Relative centrifugal force

Input(s)

RPM: Revolutions per Minute (rpm)
d: Expansion Diameter between two confronted tubes (in.)

Output(s)

RCF: Relative Centrifugal Force (cP)

Formula(s)

$$\mathrm{RCF} = \left(\frac{\mathrm{RPM}}{265}\right)^2 \cdot \mathrm{d}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 3–2.*

9.26 Relative permeability

Input(s)

q_o: Oil Flow Rate (cm^3/s)
q_w: Water Flow Rate (cm^3/s)
q_T: Total Flow Rate (cm^3/s)
k_o: Effective Permeability to Oil (mD)
k_w: Effective Permeability to Water (mD)
k: Absolute Permeability (mD)
μ_o: Viscosity of Oil Phase (cP)
μ_w: Viscosity of Water Phase (cP)
P: Pressure value that read from Pressure Gauge (Atm)
L: Plug Length (cm)
A: Open-Flow Area of the Plug (cm^2)

Output(s)

k_{ro}: Relative Permeability to Oil (mD)
k_{rw}: Relative Permeability to Water (mD)

Formula(s)

$$\mathrm{k_{ro}} = \frac{\mathrm{k_o}}{\mathrm{k}}$$

$$\mathrm{k_{rw}} = \frac{\mathrm{k_w}}{\mathrm{k}}$$

$$\mathrm{k_{ro}} = -\frac{1}{0.001127} \cdot \frac{\mathrm{q_o \mu_o L}}{\mathrm{k \cdot A} \cdot \Delta P}$$

$$\mathrm{k_{rw}} = -\frac{1}{0.001127} \cdot \frac{\mathrm{q_w \mu_w L}}{\mathrm{k \cdot A} \cdot \Delta P}$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, II-Properties of Porous Media, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 4–2.*

9.27 Reservoir wettability characterization (rise in core method)

Input(s)

μ_1: Viscosity of Oil Phase (cP)
μ_2: Viscosity of Water Phase (cP)
ρ_1: Density of Oil Phase (g/cm^3)
ρ_2: Density of Water Phase (g/cm^3)
m: Mass of Fluid Penetrated into a Porous Rock (g)

t: Time (min)
C: Characteristic Constant of the Porous Rock (dimensionless)
γ_{L2L1}: Surface Tension between oil and water phases (dyn/cm)

Output(s)

θ_{12}: Contact Angle of Liquid/Liquid/Rock System (degree)

Formula(s)

$$\cos\theta_{12} = \frac{\left(\mu_1 \rho_2^2\right) - \left(\mu_2 \rho_1^2\right)}{\rho_1^2 \rho_2^2 \cdot C \cdot \gamma_{L2L1}} \cdot \frac{m^2}{t}$$

Reference: *Ghedan, S., & Canbaz, C. H. (2014). U.S. Patent No. 8,768,628. Washington, DC: U.S. Patent and Trademark Office, Page: 5.*

9.28 Resistance

Input(s)

dv: Potential drop (V)
I: Current (A)

Output(s)

r: Resistance (ohm)

Formula(s)

$$r = \frac{dv}{I}$$

Reference: *Wikipedia.org*.

9.29 Resistivity

Input(s)

r: Resistance in ohm (ohm)
A: Cross Section area (m^2)
L: Length (m)

Output(s)

R: Resistivity (ohm m)

Formula(s)

$$R = r * \frac{A}{L}$$

Reference: *Wikipedia.org*.

9.30 Resistivity index—Archie's law

Input(s)

R_t: True Resistivity (ohm m)
R_o: Resistivity of Rock Filled with Water (ohm m)

Output(s)

RI: Resistivity Index (unitless)

Formula(s)

$$RI = \frac{R_t}{R_o}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 42.*

9.31 Solid content ratio of drilling mud

Input(s)

V_m: Volume of Drilling Mud (cc)
f_{sc}: Solid Content Ratio of Filter Cake (ratio)
h_{mc}: Filter Cake Thickness (cm)
A: Filter Cake Area (cm^2)

Output(s)

f_{sm}: Solid Content Ratio of Drilling Mud (ratio)

Formula(s)

$$f_{sm} = \frac{f_{sc} \cdot h_{mc} \cdot A}{V_m}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 2, Page: 4.*

9.32 Specific gravity of air (upper phase) (De Nouy ring method)

Input(s)

P: Pressure (psi)
T: Temperature (°R)

Output(s)

ρ_{air}: Specific Gravity of Air at P and T (g/cm^3)

Formula(s)

$$\rho_{air} = 4.324 \cdot 10^{-2}\left(\frac{P}{T}\right)$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 4–4.*

9.33 Standard discharge time for Saybolt viscosimeter measurements

Input(s)

t_o: Measured Discharge Time (s)
T_s: Standard Temperature (°F)
T_o: Test Temperature (°F)

Output(s)

t_s: Standard Discharge Time (s)

Formula(s)

$$t_s = t_o[1 + 0.000064(T_o - T_s)]$$

Reference: *Mihcakan, I.M., Alkan, K.H., Ugur, Z., Petroleum and Natural Gas Laboratory, Course Notes, I-Fluid Properties, ITU, Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2001. Page: 2–6.*

9.34 Total porosity

Input(s)

V_i: Volume of Interconnected Pores (cm^3)
V_d: Volume of Dead-end Pores (cm^3)
V_b: Total or Bulk Volume (cm^3)

Output(s)

ø: Total Porosity (fraction)

Formula(s)

$$ø = \frac{V_i + V_d}{V_b}$$

Reference: *Dandekar, A. Y. 2006. Petroleum Reservoir Rock and Fluid Properties. Boca Raton, FL: CRC Press Taylor & Francis Group, chapter: 3, Page: 15.*

9.35 USBM wettability index

Input(s)

A_1: Area Ratio of Oil Displacing Water (dimensionless)
A_2: Area Ratio of Water Displacing Oil (dimensionless)

Output(s)

I_U: Amott-Harvey Index (dimensionless)

Formula(s)

$$I_U = \log\left(\frac{A_1}{A_2}\right)$$

Reference: *Ghedan, S. G., Canbaz, C. H., Boyd, D. A., Mani, G. M., & Haggag, M. K. (2010, January). Wettability profile of a thick carbonate reservoir by the new rise in core wettability characterization method. In Abu Dhabi International Petroleum Exhibition and Conference. Society of Petroleum Engineers. Page: 3.*

9.36 Yield of clays as drilling fluids

Input(s)

M_{clay}: Weight of Clay used per barrel of mud with 15 cP Apparent Viscosity (tonnes/bbl)

Output(s)

E_{clay}: Efficiency of Selected Clay (bbl/tonnes)

Formula(s)

$$E_{clay} = \frac{1}{M_{clay}}$$

Reference: *Altun, G., Drilling Fluids Lab, Course Notes, ITU Petroleum and Natural Gas Engineering, Istanbul, Turkey, 2013–2014. Experiment 1, Page: 9.*

Chapter 10

Enhanced oil recovery and geothermal formulas and calculations

Chapter Outline

Formulas and Calculations for Petroleum Engineering. https://doi.org/10.1016/B978-0-12-816508-9.00010-X
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10.1 Areal extent of heated zone

Input(s)

Q_i: Amount of Heat Injected (BTU)
h: Height (ft)
M_r: Volumetric Heat Capacity of Reservoir (BTU/ft^3 F)
G: Dimensionless Time Function (dimensionless)
ΔT: Temperature Differential (K)
M_s: Volumetric Heat Capacity of Steam (BTU/ft^3 F)
α_s: Thermal Diffusivity (ft^2/d)

Output(s)

A: Area (acres)

Formula(s)

$$A=\frac{Q_i * h * M_r * G}{43560 * 4 * \Delta T * \alpha_s * M_s^2}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 5, Page: 44.*

10.2 Average reservoir temperature in a cyclical steam injection process

Input(s)

T_i: Initial Temperature (K)
T_s: Temperature of Steam (K)
f_{HD}: Time-dependent Conduction Loss in Direction of Heated interval (dimensionless)
f_{VD}: Time-dependent Conduction Loss Normal to the Direction of Heated interval (dimensionless)
f_{pD}: Time-dependent Quantity for Heat Loss by Produced Fluid (dimensionless)

Output(s)

T_a: Average Temperature within the Heated Zone (K)

Formula(s)

$$T_a=T_i+(T_s-T_i) * \left(f_{VD} * f_{HD} * \left(1-f_{pD}\right)-f_{pD}\right)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 9, Page: 115.*

10.3 Bottomhole pressure in a static geothermal well

Input(s)

ρ: Density (lb/ft^3)
D: Vertical Depth (ft)
g: Acceleration of Gravity (m/s^2)
g_c: Units Conversion Factor (m/s^2)

Output(s)

$\frac{dp}{dD}$: Bottomhole Pressure in a Static Well (psi/ft)

Formula(s)

$$\frac{dp}{dD} = \frac{\rho}{144} \cdot \frac{g}{g_c}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal, Systems. Department of Petroleum Engineering, Stanford University. Page: 7.4.*

10.4 Chromatographic lag in polymer flooding

Input(s)

A: Adsorption Rate (g polymer/g rock)
ρ: Rock Density (g/cc)
ø: Porosity (fraction)
C: Polymer Concentration (g/cc)
S_w: Water Saturation (fraction)

Output(s)

CL: Chromatographic Lag (dimensionless)

Formula(s)

$$CL = \frac{1}{1 + \frac{A * \rho * (1 - \o)}{C * \o * S_w}}$$

Reference: *Petrowiki.org*.

10.5 Cumulative heat injected for steam drive—Myhill and Stegemeier

Input(s)

w_i: Mass Rate of Injection of Steam into Reservoir (lb/d)
c_w: Average Specific Heat (BTU/lb K)
ΔT: Temperature Differential (K)
f_{sdh}: Steam Quality (fraction)
L_{vdh}: Latent Heat of Steam (BTU/lb)

Output(s)

Q_i: Heat Injection Rate (BTU/d)

Formula(s)

$$Q_i = w_i * (c_w * \Delta T + f_{sdh} * L_{vdh})$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 7, Page: 76.*

10.6 Depth of carbon dioxide alteration front (Battlet-Gouedard, 2006)

Input(s)

t: Time in days (d)

Output(s)

D: Depth of Alteration Front (mm)

Formula(s)

$$D = 0.26 * \left(t^{0.5}\right)$$

Reference: *Runar Nygaard. Waban Area Carbon-Dioxide Sequestration project. Energy and Environmental Group, University of Calgary, Calgary, Alberta.*

10.7 Depth of carbon dioxide alteration front (Kutchko, 2008)

Input(s)

t: Time in days (d)

Output(s)

D: Depth of Alteration Front (mm)

Formula(s)

$$D = 0.016 * \left(t^{0.5}\right)$$

Reference: *Runar Nygaard. Waban Area Carbon-Dioxide Sequestration project. Energy and Environmental Group, University of Calgary, Calgary, Alberta.*

10.8 Dimensionless heat injection rate (Gringarten and Sauty)

Input(s)

M_f: Volumetric Heat Capacity of the Injected Hot Fluid (BTU/ft^3 F)
M_r: Volumetric Heat Capacity of the Reservoir (BTU/ft^3 F)
h_t: Height (ft)
i: Injection Rate (ft^3/d)
α_s: Thermal Diffusivity to Overburden (ft^2/d)
M_s: Volumetric Heat Capacity of Steam (BTU/ft^3 F)
L: Length (ft)

Output(s)

Q_{iD}: Dimensionless Injection Rate (dimensionless)

Formula(s)

$$Q_{iD} = \frac{M_f * M_r * h_t * i}{4 * \alpha_s * (M_s^2) * (L^2)}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 5, Page: 51.*

10.9 Dimensionless injection rate of air for in-situ combustion

Input(s)

i_a: Injection Rate (ft^3/d)
L: Length Between Injector and Producer in Pattern (ft)
h: Formation Thickness (ft)
u_{min}: Minimum Air Flux (ft/d)

Output(s)

i_D: Dimensionless Air Injection Rate (dimensionless)

Formula(s)

$$i_D = \frac{i_a}{L * h * u_{min}}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 100.*

10.10 Dimensionless ratio of effective volumetric heat capacity of injected steam to that of the steam zone

Input(s)

ρ_w: Density of Water (g/cc)
C_w: Specific Heat of Water (BTU/K mol psi)
dT: Temperature Differential (K)
f_s: Steam Quality (fraction)
L_v: Latent Heat of Vaporization (BTU/lbm)
M_r: Volumetric Heat Capacity of the Reservoir (BTU/ft^3 K)

Output(s)

F_{dh}: Dimensionless Ratio of Effective Volumetric Heat Capacity of injected Steam to that of the Steam Zone (dimensionless)

Formula(s)

$$F_{dh} = \frac{\rho_w * (C_w * dT + f_s * L_v)}{M_r * dT}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 12, Page: 164.*

10.11 Dimensionless time for semi-steady state flow in coal bed methane reservoirs

Input(s)

k_g: Effective Gas Compressibility (1/psi)
t: Time (h)
ø: Porosity (fraction)
μ_{gi}: Gas Viscosity at Initial Pressure (cP)
c_{ti}: Total Compressibility at Initial Pressure (1/psi)
A: Drainage Area (ft^2)

Output(s)

t_{DA}: Dimensionless Time (dimensionless)

Formula(s)

$$t_{DA} = \frac{0.0002637 * k_g * t}{ø * \mu_{gi} * c_{ti} * A}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 221.*

10.12 Dimensionless time in wet combustion by Kuo

Input(s)

M_s: Volumetric Heat Capacity of Steam (BTU/ft^3 K)
M_r: Volumetric Heat Capacity of the Reservoir (BTU/ft^3 K)
α_S: Thermal Diffusivity of Steam to Overburden (ft^2/d)
h_t: Thickness of Reservoir (ft)
t: Time (d)

Output(s)

t_D: Dimensionless Time (dimensionless)

Formula(s)

$$t_D = \frac{4 * (M_s^2) * \alpha_S * t}{(M_r^2) * h_t^2}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 104.*

10.13 Dykstra-Parsons coefficient

Input(s)

k_{50}: Permeability of Core Samples (mD)
$k_{84.1}$: Permeability of Core Samples (mD)

Output(s)

V: Dykstra-Parsons Coefficient (dimensionless)

Formula(s)

$$V = \frac{k_{50} - k_{84.1}}{k_{50}}$$

Reference: *Willhite, G. P., 1986, Waterflooding, Vol. 3, Richardson, Texas: Textbook Series, SPE, Chapter: 5, Page: 172.*

10.14 Effective (apparent) transmissivity

Input(s)

k_{ai}: Effective Permeability to Steam (mD)
h_a: Net Thickness of Steam Zone (ft)
μ_{ai}: Apparent Viscosity of Steam (cP)

Output(s)

T_{ai}: Transmissivity (mD ft/cP)

Formula(s)

$$T_{ai} = \frac{k_{ai} * h_a}{\mu_{ai}}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 12, Page: 167.*

10.15 Effective oil transmissivity for thermal stimulation

Input(s)

F_G: Geometric Factor (dimensionless)
dP, q_{max}: Maximum Flow Resistance (psi/bbl/d)

Output(s)

T_{ao}: Transmissivity (mD ft/cP)

Formula(s)

$$T_{ao} = 141.2 * \frac{F_G}{dP, q_{max}}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 12, Page: 167.*

10.16 Equivalent atomic H/C ratio of fuel for in-situ combustion

Input(s)

m: Mole Ratio of Carbon Monoxide to Carbon Emissions (fraction)
c_{N_2}: Concentration of Nitrogen (mole fraction)
c_{O_2}: Concentration of Oxygen (mole fraction)
c_{CO_2}: Concentration of Carbon Dioxide (mole fraction)

Output(s)

x: Equivalent Atomic H/C Ratio of Fuel for in-situ Combustion (ratio)

Formula(s)

$$x = 4 * (1 - m) * \left(\frac{0.27 * c_{N_2} - c_{O_2}}{c_{CO_2}} \right) + 2 * m - 4$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 91.*

10.17 Equivalent volume of steam injected—Myhill and Stegemeier

Input(s)

C_w: Specific Heat of Water Steam (BTU/lb K)
T_{sb}: Steam Temperature at Boiler Outlet (K)
T_a: Ambient Temperature (K)
f_{sb}: Steam Quality (fraction)
L_{vb}: Latent Heat of Vaporization (BTU/lb)
T_i: Downhole Steam Injection Temperature (K)
T_o: Input Temperature (K)
f_{vdh}: Quality of Steam Downhole (fraction)
L_{vdh}: Latent Heat of Vaporization Downhole (BTU/lb)

Output(s)

$W_{s,\, eq}$: Equivalent Volume of Steam (bbl)

Formula(s)

$$W_{s,eq} = 2.853 * \left(10^{-6}\right) * \left(\frac{C_w * (T_{sb} - T_a) + f_{sb} * L_{vb}}{C_w * (T_i - T_o) + f_{vdh} * L_{vdh}} \right)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 7, Page: 78.*

10.18 Equivalent water saturation in burned zone in-situ combustion by Nelson

Input(s)

x: Equivalent H/C Molar Ratio (ratio)
ø: Volume of Air Required to Burn through a Unit Volume of Reservoir (Mscf/ft^3)
a_r: Volume Required to Burn through Reservoir (ft^3)
m: Ratio of Carbon Monoxide to Carbon Emissions (fraction)

Output(s)

S_{wF}: Water Saturation Resulting from Combustion (fraction)

Formula(s)

$$S_{wF} = \frac{0.319 * x * a_r}{ø * (4 - 2 * m + x)}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 92.*

10.19 Estimates of cumulative oil displacement

Input(s)

V_p: Pore Volume (bbl)
S_w: Average Water Saturation (fraction)
S_{iw}: Interstitial Water Saturation (fraction)

Output(s)

N_p: Cumulative Oil Displaced (bbl)

Formula(s)

$$N_p = V_p * (S_w - S_{iw})$$

Notes: Where the FVF was assumed to be 1.0.
Reference: *Willhite, G. P., 1986, Waterflooding, Vol. 3, Richardson, Texas: Textbook Series, SPE, Chapter: 3, Page: 65.*

10.20 Estimates of oil displacement rate

Input(s)

S_w: Average Water Saturation (fraction)
S_{iw}: Interstitial Water Saturation (fraction)
f_s: Fraction of Total Flowing Stream (fraction)

Output(s)

Q_p: Oil Displacement Rate (dimensionless)

Formula(s)

$$Q_p = \frac{Sw - Siw}{1 - fs}$$

Reference: *Willhite, G. P., 1986, Waterflooding, Vol. 3, Richardson, Texas: Textbook Series, SPE, Chapter: 3, Page: 65.*

10.21 Estimating fraction of heat injected in latent form (steam-drive)

Input(s)

C_w: Specific Heat of Water (BTU/lbm F)
T_i: Injection Temperature (°F)
T_a: Ambient Temperature (°F)
f_{sdh}: Steam Quality (fraction)
L_{hc}: Latent Heat of Condensation (BTU/lbm)

Output(s)

f_{hv}: Fraction of Heat Injected in Latent Form (fraction)

Formula(s)

$$f_{hv} = \left(1 + \left((C_w) * \frac{T_i - T_a}{f_{sdh} * L_{hc}}\right)\right)^{-1}$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 77.*

10.22 Estimating heat injection rate (steam-drive)

Input(s)

w_i: Boiler Feed Water Rate (B/d)
C_w: Specific Heat Capacity of Water (BTU/lbm F)
T_i: Injection Temperature (°F)
T_a: Ambient Temperature (°F)
f_{sdh}: Steam Quality (fraction)
L_{hc}: Latent Heat of Condensation (BTU/lbm)

Output(s)

Q_i: Heat Injection Rate (BTU/d)

Formula(s)

$$Q_i = w_i * 62.4 * 5.615 * (C_w * (T_i - T_a) + f_{sdh} * L_{hc})$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 76.*

10.23 Estimating performance prediction of steam-drive reservoirs (cumulative oil produced)

Input(s)

ø: Porosity (fraction)
h_n: Net Thickness (ft)
h_t: Gross Thickness (ft)
S_{oi}: Initial Oil Saturation (fraction)
S_{or}: Residual Oil Saturation (fraction)
E_c: Capture Efficiency (fraction)
V_s: Volume of Steam in Reservoir (ac ft)

Output(s)

N_p: Cumulative Oil Produced (BBL)

Formula(s)

$$N_p = 7758 * ø * \left(\frac{h_n}{h_t}\right) * (S_{oi} - S_{or}) * E_c * V_s$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 75.*

10.24 Estimating recovery steam drive (volume of steam in reservoir)

Input(s)

Q_i: Heat Injection Rate (BTU/d)
t: Injection Time (d)
E_{hs}: Thermal Efficiency of Steam Zone (dimensionless)
T_i: Injection Temperature (°F)
T_a: Ambient Temperature (°F)

Output(s)

V_s: Gross Volume of Steam in Reservoir (ac ft)

Formula(s)

$$V_s = \frac{Q_i * t * E_{hs}}{38.1 * 43560 * (T_i - T_a)}$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 76.*

10.25 Estimating steady-state five-spot injection rate (steam-drive)

Input(s)

k: Permeability (mD)
h: Pay zone Thickness (ft)
μ: Viscosity (cP)
A: Area Per Pattern (acre)

r_w: Wellbore Radius (ft)
P_i: Injection Pressure (psi)
P_b: Borehole Pressure (psi)

Output(s)

i: Injection Rate (BBL/d)

Formula(s)

$$i = \left(7.082 * \frac{10^{-3}}{2 * \pi}\right) * \left(\frac{pi * k * \frac{h}{\mu}}{\ln\left(\frac{208.71 * A^{0.5}}{r_w}\right) - 0.964}\right) * (P_i - P_b)$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 83.*

10.26 Estimating volume of steam injection (steam-drive)

Input(s)

C_w: Specific Heat Capacity of Water (BTU/LBM F)
T_{sb}: Temperature of Steam at Boiler Outlet (°F)
T_a: Ambient Temperature (°F)
f_{sb}: Fraction of Steam at Boiler Outlet (fraction)
T_{idh}: Injection Temperature Down Hole (°F)
T_i: Injection Temperature (°F)
f_{sdh}: Fraction of Steam Down Hole (fraction)
L_{vdh}: Latent Heat of Vaporization Down Hole (BTU/lbm)
L_{vb}: Latent Heat of Vaporization at Boiler Outlet (BTU/lbm)

Output(s)

Ws, eq: Volume of Steam injected, as Water Equivalent (BBL/d)

Formula(s)

$$Ws, eq = (2.853 * 10^{-6}) * \frac{C_w * (T_{sb} - T_a) + f_{sb} * L_{vb}}{C_w * (T_{idh} - T_i) + f_{sdh} * L_{vdh}}$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 78.*

10.27 Fraction of heat injected in latent form—Myhill and Stegemeier

Input(s)

h: Height (ft)
h_t: Cumulative Height (ft)
k: Permeability (mD)
k_t: Cumulative Permeability (mD)

Output(s)

FMO: FMO (dimensionless)

Formula(s)

$$FMO = \left(\frac{1}{h_t}\right) * \left(h + \frac{k_t * h_t - k * h}{k}\right)$$

Reference: *Ehrlich, R., 2016.PT E 531 Enhanced Oil Recovery. University of Southern California Lecture Notes.*

10.28 Fraction of injected heat remaining in reservoir

Input(s)

Q_i: Total Heat Injected (BTU)
Q: Total Heat Remaining (BTU)

Output(s)

E_h: Fraction of the Injected Heat Remaining in the Reservoir (fraction)

Formula(s)

$$E_h = \frac{Q}{Q_i}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 5, Page: 44.*

10.29 Fractional flow of water in hot floods dependent on temperature and saturation in hot water flood

Input(s)

$M(S,T)$: Mobility Ratio of the Co-flowing Fluids (dimensionless)

Output(s)

$f_{w(S,T)}$: Fractional Flow (dimensionless)

Formula(s)

$$f_{w(S,T)} = \frac{1}{1 + (M(S,T))^{-1}}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 6, Page: 60.*

10.30 Growth of steam-heated area—Marx-Langenheim

Input(s)

Q_i: Injected Heat Content (BTU)
t_d: Dimensionless Time (dimensionless)
e_t : Error Function of square root of dimensionless function (dimensionless)
T: Temperature Differential (K)
M_r: Volumetric Heat Capacity of the Reservoir (BTU/ft^3 F)
h: Height (ft)

Output(s)

A: Growth of Steam Zone (ac/d)

Formula(s)

$$A = \frac{Q_i * \exp(t_d) * e_t}{43560 * T * M_r * h}$$

Reference: *Michael Prats. Thermal recovery. Society of Petroleum Engineers. New York. 1986, Page: 61.*

10.31 Heat loss over an incremental length of a well (two-phase flow)

Input(s)

T_s: Temperature in the Well (Saturation Temperature) (°F)
T_e: Undisturbed Formation Temperature (°F)
y: Distance from the Bottom of the Well (ft)
k: Thermal Conductivity of Earth (=33.6 BTU/(ft d °F))
$f(t)$: Dimensionless Time Function that Represents the Transient Heat Transfer to the formation (dimensionless)

Output(s)

dq: Heat Loss over an Incremental Length of the Wellbore (BTU/h)

Formula(s)

$$dq = \frac{2\pi k(T_s - T_e)}{f(t)} dy$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University. Page: 6.12.*

10.32 Heat ratio of contents in a geothermal reservoir

Input(s)

$\varnothing$: Porosity (dimensionless)
ρ_w: Water Density (kg/m^3)
C_w: Performance Coefficient, a Function of Mean Pressure Level (KJ/kg °C)

Output(s)

H_w: Heat in Water Content (KJ/m^3 °C)
H_T: Total Heat (KJ/m^3 °C)

Formula(s)

$$\frac{H_w}{H_T} = \frac{\rho_w C_w \varnothing}{\rho_w C_w \varnothing + \rho_r C_r (1 - \varnothing)}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University. Page: 9.6.*

10.33 Heat released during in-situ combustion—Burger & Sahuguet

Input(s)

m: Molar Ratio of H/C Emission (fraction)
x: Proportion of Carbon Monoxide to Carbon Emissions (fraction)

Output(s)

$(dh)_a$: Heat Released (BTU/SCF)

Formula(s)

$$(dh)_a = \frac{94 - 67.9 * m + 31.2 * x}{1 - 0.5 * m + 0.25 * x}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 93.*

10.34 Heat remaining in reservoir—Marx and Langenheim

Input(s)

Q_i: Total Heat Injected (BTU)
M_r: Volumetric Heat Capacity of Reservoir (BTU/ft^3 F)
h: Height (ft)
G: Dimensioless Time Constant (dimensionless)
α_s: Steam Diffusivity (ft^2/d)
M_s: Volumetric Heat Capacity of Formations Adjacent to Surrounding Heated Zone (BTU/ft^{3}F)

Output(s)

Q: Heat Remaining in Reservoir (BTU)

Formula(s)

$$Q = \frac{Q_i * (M_r^2) * (h^2) * G}{4 * \alpha_s * M_s^2}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 5, Page: 44.*

10.35 Horizontal well breakthrough time in a bottom-water-drive reservoir

Input(s)

ø: Porosity (fraction)
S_{wc}: Connate Water Saturation (fraction)
S_{oir}: Residual Oil Saturation (fraction)
E_s: Sweep Efficiency (dimensionless)
k_h: Horizontal Permeability (mD)
k_v: Vertical Permeability (mD)
h: Oil Column Thickness (ft)
q_o: Flow Rate (STB/d)
B_o: Oil Formation Volume Factor (RB/STB)

Output(s)

f_d: Saturation Constant (dimensionless)
t_{BT}: Water Breakthrough Time (d)

Formula(s)

$$f_d = ø * (1 - S_{wc} - S_{oir})$$

$$t_{BT} = \left(f_d * h^3 * \frac{E_s}{5.615 * q_o * B_o} \right) * \frac{k_h}{k_v}$$

Reference: *Joshi, S. D. 1991, Horizontal Well Technology. Tulsa, Oklahoma: PennWell Publishing Company. Chapter: 8, Page: 295.*

10.36 Ignition delay time in in-situ combustion

Input(s)

M_r: Volumetric Heat Capacity of Reservoir (BTU/ft^3 K)
T_a: Initial Absolute Temperature (K)
n: exponent
R: Gas Constant (BTU/mol K psi)
E: Activation Energy (BTU/K mol)
$(dh)_a$: Heat Generated by Oxygen (BTU)
ø: Porosity (fraction)
S_o: Saturation of Oil (fraction)
ρ_o: Density (g/cc)
A_c: Pre Exponential Constant (1/psi K)
P_{o2}: Partial Pressure of Oxygen (psi)

Output(s)

t_{ig}: Ignition Delay (s)

Formula(s)

$$t_{ig} = \frac{2.04 * 10^{-7} * M_r * T_a^2 * \left(1 + \left(\frac{2 * R * T_a}{E}\right)\right) * R * \exp\left(\frac{E}{R * T_a}\right)}{E * (dh)_a * \emptyset * S_o * \rho_o * A_c * P^n{}_{o2}}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 95.*

10.37 Injected air required to burn through unit bulk of reservoir for in-situ combustion by Nelson and McNiel

Input(s)

a_r: Air Required to Burn through Reservoir (MSCF/ft^3)
$T_{sc,\,ab}$: Temperature at Standard Condition (K)
T_{ab}: Temperature at Absolute Condition (K)
$P_{sc,\,ab}$: Pressure at Standard Condition (psi)
$P_{inj,\,ab}$: Pressure at Absolute Condition (psi)
ø: Porosity (fraction)
E_{O2}: Utilization Efficiency of Oxygen (fraction)

Output(s)

a_r: Injected Air Required to Burn through Unit Reservoir Bulk (MSCF/ft^3)

Formula(s)

$$a_r = \frac{a_r + \left(10^{-3}\right) * \left(\frac{T_{sc,ab}}{T_{ab}}\right) * \left(\frac{P_{inj,ab}}{P_{sc,ab}}\right) * \emptyset}{E_{O2}}$$

Reference: *Michael Prats. Thermal recovery. Society of Petroleum Engineers. New York.1986, Page: 96.*

10.38 Mass of fuel burned per unit bulk reservoir volume combustion—Nelson and McNiel

Input(s)

$\emptyset_E$: Effective Porosity (fraction)
ø: Porosity (fraction)
m_E: Mass of Fuel Burned per Unit Bulk Volume in the Laboratory Experiment (lbm/ft^3)

Output(s)

m_R: Mass of Fuel Burned per Unit Bulk Reservoir Volume (lbm/ft^3)

Formula(s)

$$m_R = \left(\frac{1-\text{ø}}{1-\text{ø}_E}\right) * m_E$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 89.*

10.39 Minimum air flux required for advance of fire front—Nelson and McNiel

Input(s)

a_r: Air Required to Burn Unit Volume of Reservoir (MSCF/ft^3)
E_{O2}: Oxygen Consumption Efficiency (fraction)

Output(s)

u_{min}: Minimum Air Flux (SCF/ft^2 d)

Formula(s)

$$u_{min} = \frac{0.125 * a_r}{E_{O2}}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 100.*

10.40 Oil breakthrough newly swept zone

Input(s)

PV: Pore Volume (dimensionless)
dE_{as}: Areal Sweep Efficiency from New Swept Zone (fraction)
S_{wbt}: Water Saturation at Breakthrough in Swept Zone (fraction)
S_{wi}: Initial Water Saturation (fraction)

Output(s)

O_{nsz}: Oil Volume at Breakthrough in New Swept Zones (bbl)

Formula(s)

$$O_{nsz} = PV * dE_{as} * (S_{wbt} - S_{wi})$$

Reference: *Ehrlich Enhanced Oil Recovery, PTE 531, University of Southern California Lecture Notes, 2016.*

10.41 Oil recovery as a function of the fraction of oil displaced from heated zone

Input(s)

F: Air Injected per Unit Oil Produced (Mscf/bbl)
ø: Porosity (fraction)
a_r: Air Required to Burn a Unit Volume of Reservoir (Mscf/ft^3)

S_{oi}: Initial Water Saturation (fraction)
S_{of}: Oil Saturation Burned (fraction)
E_{O2}: Oxygen Consumption Efficiency (fraction)

Output(s)

E_{cb}: Oil Recovery (fraction)

Formula(s)

$$E_{cb} = 5.615 \frac{a_r}{F * ø * E_{O2} * (S_{oi} - S_{of})}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 104.*

10.42 Oil solubilization factor

Input(s)

C_o: Concentration of Oil in Solvent (g/cc)
C_s: Concentration of Solvent in Solution (g/cc)

Output(s)

S: Oil Solubilization Factor (dimensionless)

Formula(s)

$$S = \frac{C_o}{C_s}$$

Reference: *Ehrlich Enhanced, R 2016.PTE 531 Oil Recovery. University of Southern California Lecture Notes.*

10.43 Oil volume at breakthrough by Craig, Geffen, and Morse

Input(s)

PV: Pore Volume (bbl)
$(Eas)_{bt}$: Areal Sweep Breakthrough (%)
$Swbt_{av}$: Water Breakthrough (fraction)
S_{wi}: Initial Water Saturation (fraction)

Output(s)

O: Oil Volume at Breakthrough (bbl)

Formula(s)

$$O = PV * (Eas)_{bt} * (Swbt_{av} - S_{wi})$$

Reference: *Ehrlich. Enhanced Recovery, 2016.PTE 531 Oil Recovery. University of Southern California Lecture Notes.*

10.44 Oil-steam ratio—Marx & Langenheim

Input(s)

$W_{s,\ eq}$: Measure of Steam Used (bbl)
N_p: Cumulative Oil Produced (bbl)

Output(s)

F_{so}: Oil-steam Ratio (bbl)

Formula(s)

$$F_{so} = \frac{W_{s,eq}}{N_p}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 7, Page: 77.*

10.45 Proppant settlement in fracture

Input(s)

ρ_p: Proppant Density (lbm/ft^3)
ρ_f: Fluid Density (lbm/ft^3)
g: Gravity Acceleration (ft/s^2)
d_p: Particle Diameter (ft)
v_t: Terminal Particle Settling Velocity (ft/s)

Output(s)

C_D: Coefficient of Drag (unitless)

Formula(s)

$$C_D = 4 * \left(\rho_p - \rho_f\right) * g * \frac{d_p}{\rho_f * v_t^2}$$

Reference: *Daneshy, A. 2013. Fundamentals of Hydraulic Fracturing, Daneshy Consultants International, Page: 74.*

10.46 Rate of advancement of combustion front (in-situ combustion)

Input(s)

E_O: Oxygen Consumption Efficiency (fraction)
u_a: Air Flux (SCF/d ft^2)
a_r: Air Requirement (Mscf/ft^3)

Output(s)

v_b: Rate of Advancement (ft/d)

Formula(s)

$$v_b = (E_O) * \frac{u_a}{a_r}$$

Reference: *Pratts, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 100.*

10.47 Rate of growth of heated zone in hot water heated reservoir

Input(s)

h: Height of Reservoir (ft)
ϕ: Porosity (fraction)
q: Flow Rate of Ambient Reservoir Temperature and Pressure (bbl/d)
T_j: Temperature of Specific Layer (K)
f_w: Fractional flow of water in hot floods dependent on Temperature and Saturation (dimensionless)

Output(s)

A: Rate of Area Growth with time (ft ft/d)

Formula(s)

$$A = 1.289 * \left(10^{-4}\right) * \left(\frac{q * T_j * f_w}{\phi * h}\right)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Page: 45.*

10.48 Rate of oxygen-reacted per unit mass of fuel

Input(s)

P_o: Partial pressure of Oxygen (psi)
A_c: Pre-exponential Constant (1/s psi)
E: Activation Energy (BTU/lbm mol)
R: Gas Constant (BTU/lbm K mol)
Ta: Absolute Temperature (K)

Output(s)

m: Rate of Oxygen Reacted per unit mass of fuel (mol/s lbm)

Formula(s)

$$m = P_o * A_c * \exp\left(\frac{E}{R * T_a}\right)$$

Reference: *Enhanced Oil Recovery, Green & Willhite, Page: 386.*

10.49 Relationship with real and dimensionless time in hot water floods

Input(s)

h: Thickness of Layer (ft)
M_r: Volumetric Heat Capacity of Reservoir (BTU/ft^3 F)
t_D: Dimensionless Time (dimensionless)
α_s: Steam Diffusivity (ft^2/d)
M_s: Specific Volumetric Heat Capacity of Steam (BTU/ft^3 F)

Output(s)

t: Time (d)

Formula(s)

$$t=\frac{(h^2)*(M_r^2)*t_D}{4*\alpha_s*(M_s^2)}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 6, Page: 61.*

10.50 Reservoir flow for gas flow in a formation

Input(s)

n: The Performance Exponent (dimensionless)
$\overline{p}$: The Mean Formation Pressure in the Drainage System of Well (psi)
P_{wf}: Bottomhole Flowing Pressure (psi)
C: Performance Coefficient, a Function of Mean Pressure Level (bbl/d psi)

Output(s)

W: Flow Rate (bbl/d)

Formula(s)

$$W=C\left(\overline{p}^2-p_{wf}^2\right)^n$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University. Page: 8.8.*

10.51 Reservoir flow through the wellbore of a geothermal well

Input(s)

n`: Performance Exponent for Flow in the wellbore (dimensionless)
P_{tf}: Wellhead Flowing Pressure (psi)
P_{wf}: Bottomhole Flowing Pressure (psi)
C_1: Performance Coefficient for Flow upwards in the Wellbore (bbl/d psi)

Output(s)

W: Flow Rate (bbl/d)

Formula(s)

$$W = C_1 \left(P_{wf}^2 - P_{tf}^2\right)^{\grave{n}}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University. Page: 8.8.*

10.52 Saturation of layer under hot water flood

Input(s)

T_j: Temperature of jth Zone (°F)

Output(s)

S: Saturation (fraction)

Formula(s)

$$S = 0.698 - 0.1 * \left(\frac{T_j - 117}{275}\right)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 6, Page: 64.*

10.53 Slug size in polymer floods

Input(s)

A: Adsorption (g polymer/g rock)
ρ: Density (g/cc)
ø: Porosity (fraction)
C: Concentration (g/cc)

Output(s)

S: Slug Size (dimensionless)

Formula(s)

$$S = \left(A * \rho * \frac{1 - ø}{C * ø}\right)$$

Reference: *Ehrlich., Enhanced R 2016.PTE 531 Oil Recovery. University of Southern California Lecture Notes.*

10.54 Temperature increase with time during in-situ combustion process

Input(s)

S_o: Saturation of Oil (fraction)
ø: Porosity (fraction)
n: exponent
ρ: Density of Oil (lb/ft^3)
A_c: Pre-exponential Constant (1/F psi)
P_{O2}: Partial Pressure of Oxygen (psi)
M_r: Volumetric Heat Capacity of Reservoir (BTU/F ft^3)
E: Activation Eergy (BTU/lbm mol)
R: Gas Constant (BTU/lbm mol F)
T_{ab}: Absolute Temperature (K)

Output(s)

$\frac{dT}{dt}$: Temperature Increase with Time (K/s)

Formula(s)

$$\frac{dT}{dt} = 86{,}400\left(\frac{S_o * \rho * ø * A_c * P^n{}_{O2}}{M_r}\right) * \exp\left(-\frac{E}{R * T_{ab}}\right)$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 8, Page: 95.*

10.55 Temperature of a producing geothermal well

Input(s)

T_o: Inflowing Fluid Temperature (°F)
T_{bh}: Downhole Reservoir Temperature (°F)
a: Geothermal Gradient (°F/ft)
A: Diffusion Depth (ft)
y: Distance from the Bottom of the Well (ft)
t: Function of Time (d)

Output(s)

T: Temperature of a Producing Geothermal Well (°F)

Formula(s)

$$T = (T_{bh} - ay) + aA\left(1 - e^{-y/A}\right) + (T_o - T_{bh})e^{-y/A}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University*. Page: 6.2.

10.56 Temperature of a single-phase liquid or gas injected geothermal well

Input(s)

T_{surf}: Surface Temperature of the Earth (°F)
T_{inj}: Temperature of the Injected Fluid (°F)
a: Geothermal Gradient (°F/ft)
A: Diffusion Depth (ft)
z: Distance from the Bottom of the Well (ft)

Output(s)

T: Temperature of a Single-Phase Liquid or Gas Injected Geothermal Well (°F)

Formula(s)

$$T = T_{surf} + az - aA + \left(T_{inj} - T_{surf} + aA\right)e^{-z/A}$$

Reference: *Ramey Jr, H. J. (1981). Reservoir Engineering Assessment of Geothermal Systems. Department of Petroleum Engineering, Stanford University. Page: 6.6.*

10.57 Total heat loss of a geothermal well

Input(s)

T_o: Inflowing Fluid Temperature (°F)
w: Mass Flow Rate (lb/h)
c: Thermal Heat Capacity of the Fluid (BTU/lbm °F)
a: Geothermal Gradient (°F/ft)
A: Diffusion Depth (ft)
H: Total Well Depth (ft)
b: Surface Temperature (°F)

Output(s)

q: Total Heat Loss of a Geothermal Well (BTU/h)

Formula(s)

$$q = -wc\left[aH - (T_o + aA - b)\left(1 - e^{\frac{-H}{A}}\right)\right]$$

Reference: *Horne, R. N., & Shinohara, K. (1979). Wellbore Heat Loss in Production and Injection Wells. Journal of Petroleum Technology, 31(01), Page: 117.*

10.58 Total oil production from in-situ combustion—Nelson & McNeil

Input(s)

V_r: Volume of reservoir Burned (ft^3)
S_i: Initial oil Saturation (fraction)
S_f: Oil Saturation left after Combustion (fraction)
V_p: Pattern Volume (ft^3)
ø: Porosity (fraction)

Output(s)

N_p: Cumulative Oil production (bbl)

Formula(s)

$$N_p = 7758 * ø * \left(V_r * (S_i - S_f) + 0.4 * \left(V_p - V_r\right) * S_i\right)$$

Reference: *Enhanced Oil Recovery, Green & Willhite, Page: 395.*

10.59 Total oil production from wet in-situ combustion—Nelson & McNeil

Input(s)

V_r: Volume of Burnt reservoir (ft^3)
ø: Porosity (fraction)
S_i: Initial Oil Saturation (fraction)
S_f: Oil Saturation post fire flood (fraction)
V_s: Volume of Steam (ft^3)
S_r: Residual oil Saturation (fraction)
h_n: Net thickness of Reservoir (ft)
h_t: Total thickness of reservoir (ft)
E: Efficiency of Fire Flood (fraction)

Output(s)

N_p: Cumulative oil production (bbl)

Formula(s)

$$N_p = \left(\frac{7758 * ø * E * h_n}{h_t}\right) * (V_r * (S_i - S_f) + V_s * (S_i - S_r))$$

Reference: *Enhanced Oil Recovery, Green & Willhite, Page: 395.*

10.60 Total water production from in-situ combustion—Nelson & McNeil

Input(s)

V_r: Volume of Reservoir burnt (ft^3)
ϕ: Porosity (fraction)
S_i: Initial Water Saturation (fraction)
S_f: Water Saturation after burning Reservoir (fraction)

Output(s)

W_p: Cumulative Water production (bbl)

Formula(s)

$$W_p = 7758 * V_r * \phi * (S_i - S_f)$$

Reference: *Enhanced Oil Recovery, Green & Willhite, Page: 395.*

10.61 Volume of burned part of reservoir (in-situ combustion)

Input(s)

G_a: Total Air Requirement (MMSCF)
E_O: Oxygen Consumption Efficiency (fraction)
a_R: Air Requirement (MSCF/ft^3)

Output(s)

V_{rb}: Volume of Reservoir Burned (ac ft)

Formula(s)

$$V_{rb} = 0.0230 * (G_a) * \frac{E_O}{a_R}$$

Reference: *Prats, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 100.*

10.62 Volume of reservoir burnt by wet combustion

Input(s)

G: Total Amount of Gas Injected (MSCF)
a_r: Air required to burn through reservoir (MSCF)
E: Efficiency of fire flood (fraction)

Output(s)

V_r: Volume of Reservoir Burnt (ft^3)

Formula(s)

$$V_r = \frac{0.023 * G * E}{a_r}$$

Reference: *Prats, M. (1986). Thermal Recovery Monograph Vol. 7. Society of Petroleum Engineers, Houston, Page: 106.*

10.63 Volumetric heat capacity

Input(s)

$M_S\alpha^{0.5}$ Volumetric Heat Capacity of Formations Adjacent to Surrounding Heated Zone (BTU/ft^3 F)
C_w: Specific Heat of Water (BTU/lb F)
T: Temperature Differential (F)

L_v: Latent Heat of Vaporization (BTU/lb)
dt: Time Differential (d)
M_{Rse}: Effective Volumetric Heat Capacity of Steam Zone (BTU/ft^3 F)

Output(s)

dz_s: Steam Zone Growth (ft)

Formula(s)

$$dz_s = \left(\frac{4 * M_S \alpha^{0.5} * C_w * T}{L_v * M_{Rse}}\right) * \left(\frac{dt}{\pi}\right)^{0.5}$$

Reference: *Prats, M. 1986. Thermal Recovery. Society of Petroleum Engineers, New York, Chapter: 7, Page: 80.*

10.64 Wet combustion design (in-situ combustion)

Input(s)

V_{rb}: Volume of Reservoir Burned (ac ft)
S_{oi}: Initial Oil Saturation (fraction)
S_{of}: Oil Saturation burned (fraction)
Ø: Porosity (fraction)
V_s: Maximum Steamzone Volume (ac ft)
S_{or}: Residual Oil saturation of steam flood zone (fraction)
E_c: Capture efficiency (fraction)
h_n: Net thickness (ft)
h_t: Gross thickness (ft)

Output(s)

N_p: Cumulative Oil Production (bbl)

Formula(s)

$$N_p = 7758 * \left(\left(\left(V_{rb} * \left(S_{oi} - S_{of}\right) * Ø\right) + \left(V_s * (S_{oi} - S_{or}) * phi\right)\right)\right) * E_c * \left(\frac{h_n}{h_t}\right)$$

Reference: *Thermal Recovery Monograph Vol. 7, Page: 106.*

Chapter 11

Geomechanics and fracturing formulas and calculations

Chapter Outline

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11.1 Axial stress around vertical wellbore

Input(s)

R: Radius of Wellbore (ft)
r: Position in Respect to Centre of Wellbore (ft)
Θ: Azimuth of S_{hmax} (rad)
S_{hmax}: Maximum Horizontal Stress (psi)
S_{hmin}: Minimum Horizontal Stress (psi)

Output(s)

τ: Twisting Stress (psi)

Formula(s)

$$\tau = 0.5 * (S_{hmax} - S_{hmin}) * \left(1 + \left(\frac{2 * R^2}{r^2}\right) - \left(\frac{3 * R^4}{r^4}\right)\right) * \sin(2 * \Theta)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 170.*

11.2 Axis of a deviated borehole from an arbitrary origin

Input(s)

P_o: Pore Pressure (psi)
R: Radius of Wellbore (ft)
r: Position in Respect to Centre of Wellbore (ft)
Θ: Azimuth of Shmax (rad)
$\sigma^{\Delta t}$: Thermal Stress (psi)
S_{hmax}: Maximum Horizontal Stress (psi)
S_{hmin}: Minimum Horizontal Stress (psi)

Output(s)

σ_{aa}: Stress (psi)

Formula(s)

$$\sigma_{aa} = 0.5 * (S_{hmax} + S_{hmin} - 2 * P_o) * \left(1 + \left(\frac{R^2}{r^2}\right)\right) - 0.5 * (S_{hmax} - S_{hmin}) * \left(1 + \left(\frac{3 * R^4}{r^4}\right)\right) * \cos(2 * \Theta) - \left(\frac{P_o * R^2}{r^2}\right) - \sigma^{\Delta t}$$

Reference: *Mark D. Zoback., Reservoir Geomechanics, Cambridge University Press, UK, Page: 170.*

11.3 Bulk modulus (using Lame)

Input(s)

p: Pressure (Pa)
ΔV: Volume (m^3)
v: Volume (m^3)

Output(s)

K: Bulk Modulus (Pa)

Formula(s)

$$K = \frac{p}{\frac{\Delta V}{v}}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 45.*

11.4 Bulk modulus (using Poisson's ratio and Lame's constant)

Input(s)

λ: Lame (dimensionless)
G: Shear Modulus (N/m^2)

Output(s)

K: Bulk Modulus (N/m^2)

Formula(s)

$$K = \lambda + 2 * \frac{G}{3}$$

Reference: *PetroWiki.org.*

11.5 Bulk modulus (using Poisson's ratio and shear modulus)

Input(s)

λ: Lame (dimensionless)
G: Shear Modulus (N/m^2)

Output(s)

K: Bulk Modulus (N/m^2)

Formula(s)

$$K = \lambda + 2 * \frac{G}{3}$$

Reference: *PetroWiki.org*.

11.6 Change in pore volume due to initial water and rock expansion

Input(s)

λ: Lame (dimensionless)
v: Poisson (dimensionless)

Output(s)

K: Bulk Modulus (N/m^2)

Formula(s)

$$K = \frac{\lambda * (1 + \nu)}{3 * \nu}$$

Reference: *PetroWiki.org*.

11.7 Cohesive strength of rocks

Input(s)

G: Shear Modulus (N/m^2)
v: Poisson (dimensionless)

Output(s)

K: Bulk Modulus (N/m^2)

Formula(s)

$$K = \frac{2 * G * (1 + \nu)}{3 * (1 - 2 * \nu)}$$

Reference: *PetroWiki.org*.

11.8 Compressibility of a coalbed methane formation

Input(s)

W_i: Total Volume of Water in the Reservoir (bbl)
W_p: Total Volume of Water Removed (bbl)
P_i: Initial Reservoir Pressure (psi)
P_d: Desorption Pressure (psi)

Output(s)

c_t: Total Compressibility (1/psi)

Formula(s)

$$c_t = \left(\frac{1}{W_i}\right) * \left(\frac{W_p}{P_i - P_d}\right)$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter:3, Page: 219.*

11.9 Effect of pore pressure on stress

Input(s)

λ: Lames First Constant (psi)
δ: Kronecker Delta (dimensionless)
ξ_o: Initial Strain (dimensionless)
ξ: Final Strain (dimensionless)
G: Modulus of Shear (psi)
α: Biot (dimensionless)
P: Pressure Applied (psi)

Output(s)

S: Stress (psi)

Formula(s)

$$S = \lambda * \xi_o * \delta + 2 * G * \xi - \alpha * \delta * P$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK,* Page: *68.*

11.10 Effective stress on individual grains

Input(s)

S: Normal Stress (psi)
P_p: Pore Pressure (psi)

Output(s)

σ_g: Effective Stress (psi)

Formula(s)

$$\sigma_g = S - P_p$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 87.*

11.11 Failure criteria (Mohr-Coulomb)

Input(s)

σ_a: Principle Stress (psi)
σ_b: Second Strongest Stress (psi)
β: Angle Between Fault and Direction of Principle Stress (degrees)

Output(s)

τ: Shear Stress (psi)
σ: Normal Stress (psi)

Formula(s)

$$\tau = 0.5 * (\sigma_a - \sigma_b) * \sin(2 * \beta)$$
$$\sigma = 0.5 * (\sigma_a + \sigma_b) + 0.5 * (\sigma_a - \sigma_b) * \cos(2 * \beta)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 89.*

11.12 Formation compressibility by using hydrofrac data

Input(s)

Vs: Volume Associated to Conduct a Hydrofrac (bbl)
dVs: Change in Volume (bbl)
dP: Change in Pressure (psi)

Output(s)

β: Formation Compressibility (psi)

Formula(s)

$$\beta = \frac{1}{Vs} * \left(\frac{dVs}{dP}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 221.*

11.13 Fracture conductivity

Input(s)

k_f: Fracture Permeability (mD)
w_f: Width of Fracture (ft)

Output(s)

F_C: Fracture Conductivity (mD ft)

Formula(s)

$$F_C = k_f * w_f$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter:1, Page: 93.*

11.14 Fracture gradient (Eaton)

Input(s)

υ: Poisson (dimensionless)
S_v: Vertical Stress (psi)
P_p: Pore Pressure (psi)

Output(s)

S_{hmin}: Minimum Horizontal Stress (psi)

Formula(s)

$$S_{hmin} = \left(\frac{\upsilon}{1-\upsilon}\right) * \left(S_v - P_p\right) + P_p$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 282.*

11.15 Fracture gradient (Holbrook)

Input(s)

υ: Poisson (dimensionless)
S_v: Vertical Stress (psi)
P_p: Pore Pressure (psi)

Output(s)

S_{hmin}: Minimum Horizontal Stress (psi)

Formula(s)

$$S_{hmin} = \left(\frac{\upsilon}{1-\upsilon}\right) * \left(S_v - P_p\right) + P_p$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 282.*

11.16 Fracture gradient (Matthews and Kelly)

Input(s)

σ_{min}: Minimum Principle Horizontal Stress (psi)
σ_v: Vertical Principle Stress (psi)
S_v: Vertical Stress (psi)
P_p: Pore Pressure (psi)

Output(s)

S_{hmin}: Minimum Horizontal Stress (psi)

Formula(s)

$$S_{hmin} = \left(\frac{\sigma_{min}}{\sigma_v}\right) * \left(S_v - P_p\right) + P_p$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 281.*

11.17 Fracture gradient (Zoback and Healy)

Input(s)

μ: Viscosity (cP)
S_v: Vertical Stress (psi)
S_p: Pore Pressure (psi)

Output(s)

S_{hmin}: Minimum Horizontal Stress (psi)

Formula(s)

$$S_{hmin} = \left(\left(\left(\left(1 + \mu^2\right)^{0.5} \right) + \mu \right)^{-2} \right) * \left(S_v - P_p\right) + P_p$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 281.*

11.18 Fracture pressure (Hubert & Willis)

Input(s)

S_v: Vertical Stress (psi)
P_p: Pore Pressure (psi)

Output(s)

S_{hmin}: Fracture Pressure (psi)

Formula(s)

$$S_{hmin} = 0.3 * \left(S_v - P_p\right) + P_p$$

$$\frac{\sigma_{hmin}}{\sigma_v} = 0.3$$

Notes: Fracture Pressure Is assumed to be Equal to Minimum Horizontal Stress.

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 281.*

11.19 Fracture volume (GDK method)

Input(s)

Q: Flow Rate (B/m)
μ: Viscosity (cP)
L: Length (ft)
H: Height (ft)
G: Shear Modulus (psi)

Output(s)

V_f: Fracture Volume (ft^3)

Formula(s)

$$V_f = 0.03561 * \left(\mu * Q * L^6 * \frac{H^3}{G} \right)^{0.25}$$

Reference: *Daneshy, A. 2013. Fundamentals of Hydraulic Fracturing, Daneshy Consultants International, Page: 70.*

11.20 Fracture volume (Perkins and Kern method)

Input(s)

H: Fracture Height (ft)
ν: Poisson (unitless)
μ: Viscosity (cP)
Q: Flowrate (B/m)
E: Young (psi)
L: Fracture Length (ft)

Output(s)

V_f: Fracture Volume (ft^3)

Formula(s)

$$V_f = 0.04 * H * \left(\left(1 - \nu^2\right) * \mu * \frac{Q}{E} \right)^{0.25} * L^{\frac{5}{4}}$$

Reference: *Daneshy, A. 2013. Fundamentals of Hydraulic Fracturing, Daneshy Consultants International, Page: 57.*

11.21 Fracture width (GDK method)

Input(s)

Q: Flow Rate (B/m)
G: Shear Modulus (psi)
μ: Viscosity (cP)
L: Length (ft)
H: Height (ft)

Output(s)

w: Fracture Width (in.)

Formula(s)

$$w = 0.272 * \left(\mu * Q * \frac{L^2}{G * H} \right)^{0.25}$$

Reference: *Daneshy, A. 2013. Fundamentals of Hydraulic Fracturing, Daneshy Consultants International, Page: 70.*

11.22 Fracture width (Perkins and Kern method)

Input(s)

ν: Poisson (unitless)
Q: Flowrate (B/m)
μ: Viscosity (cP)
L: Fracture Length (ft)
E: Young's Modulus (psi)

Output(s)

W_{max}: Fracture Width (in.)

Formula(s)

$$W_{max} = 0.389 * \left(\left(1-\nu^2\right) * Q * \mu * \frac{L}{E} \right)^{0.25}$$

Reference: *Daneshy, A. 2013. Fundamentals of Hydraulic Fracturing, Daneshy Consultants International, Page: 58.*

11.23 Hoek and Brown criteria for principal stress failure

Input(s)

Co: Unconfined Compressive Strength of Rock (psi)
m: Constant Depending on Property of Rock and Extent to Which It Is Broken (dimensionless)
s: Constant Depending on Property of Rock and Extent to Which It Is Broken (dimensionless)
σ_c: Minimum Effective Principal Stress (psi)

Output(s)

σ_a: Maximum Effective Principal Stress (psi)

Formula(s)

$$\sigma_a = \sigma_c + Co * \left(m * \frac{\sigma_c}{Co} + s \right)^{0.5}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 98.*

11.24 Horizontal effective stress (assuming no lateral strain as per Lorenz and Teufel)

Input(s)

v: Poisson Ratio (dimensionless)
Sv: Vertical Overburden Stress (psi)
α: Biot Coefficient (dimensionless)
P: Pore Pressure (psi)

Output(s)

S_{hor}: Horizontal Stress (psi)

Formula(s)

$$S_{hor} = \left(\frac{\nu}{1-\nu} \right) * Sv + \alpha * P * \left(1 - \frac{\nu}{1-\nu} \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 381.*

11.25 Horizontal maximum stress (Bredehoeft)

Input(s)

S_{hmin}: Minimum Horizontal Stress (psi)

P_b: Breakdown Pressure at initial Hydrofrac (psi)
P_p: Pore Pressure (psi)

Output(s)

S_{hmax}: Maximum Horizontal Stress (psi)

Formula(s)

$$S_{hmax} = 3 * S_{hmin} - P_b - P_p$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 220.*

11.26 Induced fracture dip

Input(s)

h: Height of Fracture (ft)
d: Diameter of Well (ft)

Output(s)

Dip: Dip (degrees)

Formula(s)

$$\mathrm{Dip} = \arctan\left(\frac{h}{d}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 146.*

11.27 Initial effective horizontal stress

Input(s)

ν: Poisson (unitless)
ρ: Overburden Density (lb/ft^3)
H: Formation Depth (ft)
α: Biot Constant (unitless)
p_p: Reservoir Pressure (psi)

Output(s)

σ_h: Effective Horizontal Stress (psi)

Formula(s)

$$\sigma_h = \left(\frac{\nu}{1-\nu}\right) * \left(\left(\rho * \frac{H}{144}\right) - \left(\alpha * p_p\right)\right)$$

Reference: *Boyun, G., William, C., & Ali Ghalambor, G. (2007). Petroleum Production Engineering: A Computer-Assisted Approach Page: 259.*

11.28 Isothermal compressibility of limestones (Newman correlation)

Input(s)

ϕ: Porosity (fraction)

Output(s)

C_t: Compressibility (psi^{-1})

Formula(s)

$$Ct = \frac{97.32 * 10^{-6}}{(1 + 55.8721 * \phi)^{1.42869}}$$

Notes: Check for 0.02 < Ø < 0.23.

Reference: *Applied Petroleum Reservoir Engineering, Craft & Hawkins, Page: 11.*

11.29 Least principal stress as function of depth in Gulf of Mexico (Hubbert and Willis)

Input(s)

Sv: Vertical Overburden Stress (psi)
Pp: Pore Pressure in Reservoir (psi)

Output(s)

S_{hmin}: Minimum Principal Stress in Reservoir (psi)

Formula(s)

$$S_{hmin} = 0.3 * (Sv - Pp) + Pp$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 280.*

11.30 Least principal stress as function of depth in Gulf of Mexico (Matthew and Kelly)

Input(s)

Sv: Vertical Overburden Stress (psi)
Ki: Constant as Function of Depth (dimensionless)
Pp: Pore Pressure in Reservoir (psi)

Output(s)

S_{hmin}: Minimum Principal Stress in Reservoir (psi)

Formula(s)

$$S_{hmin} = Ki * (Sv - Pp) + Pp$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 280.*

11.31 Linearized Mohr failure line

Input(s)

S_o: Stress (psi)
σ_n: Normal Stress (psi)
μ_i: Coefficient of internal Friction (cP)

Output(s)

τ: Shear Stress (psi)

Formula(s)

$$\tau = S_o + \sigma_n * \mu_i$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 89.*

11.32 Linearized Mohr coulomb criteria

Input(s)

C_o: Unconfined Compressive Strength of Rock (psi)
μ: Slope of Failure Line (dimensionless)
σ_c: Minimum Effective Principal Stress (psi)

Output(s)

σ_1: Maximum Effective Principal Stress (psi)

Formula(s)

$$\sigma 1 = (C_o) + \left(\left(\mu^2 + 1\right)^{0.5} + \mu\right)^2 * \sigma_c$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 93.*

11.33 M Modulus (using shear modulus and bulk modulus)

Input(s)

G: Shear Modulus (N/m^2)
K: Bulk Modulus (N/m^2)

Output(s)

M: M Modulus (N/m^2)

Formula(s)

$$M = K + 4 * \frac{G}{3}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 64.*

11.34 M Modulus (using Young's modulus and Poisson's ratio)

Input(s)

v: Poisson Ratio (dimensionless)
E: Young Modulus (N/m^2)

Output(s)

M: M Modulus (N/m^2)

Formula(s)

$$M = E * \frac{1 - \nu}{(1 + \nu) * (1 - 2 * \nu)}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 64.*

11.35 Maximum anisotropic failure stress

Input(s)

σ_c: Minimum Principle Stress (psi)
S_w: Intact Rock Strength (psi)
μ: Internal Friction of Weak Bedding (cP)
β: Angle of Weak Plane to Maximum Principle Stress (degrees)

Output(s)

σ: Stress (cm/s)

Formula(s)

$$\sigma = \frac{\sigma_c * 2 * (S_w + \mu * \sigma_c)}{(1 - \mu * \cot(\beta)) * \sin(2 * \beta)}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 107.*

11.36 Maximum compression at vertical wellbore

Input(s)

σ_c: Minimum Principle Stress (psi)
S_w: Intact Rock Strength (psi)
μ: Internal Friction of Weak Bedding (cP)
β: Angle of Weak Plane to Maximum Principle Stress (degrees)

Output(s)

σ: Stress (cm/s)

Formula(s)

$$\sigma = \frac{\sigma_c * 2 * (S_w + \mu * \sigma_c)}{(1 - \mu * \cot(\beta)) * \sin(2 * \beta)}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 107.*

11.37 Maximum normal stress in tangential direction at wellbore wall (hoop stress)

Input(s)

S_{hmax}: Maximum Principal Stress in Reservoir (psi)
S_{hmin}: Minimum Principal Stress in Reservoir (psi)
Po: Pore Pressure (psi)
S_{dt}: Stress induced Due to Temperature (psi)
dP: Difference Between Wellbore Pressure and Mud Weight (psi)

Output(s)

sig_{th}: Maximum Hoop Stress in Tangential Direction at Wellbore Wall (psi)

Formula(s)

$$\mathrm{sig}_{th} = 3 * S_{hmax} - S_{hmin} - 2 * Po - dP - S_{dt}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 174.*

11.38 Maximum plane tangential stress acting on deviated wellbore

Input(s)

σ_{zz}: Stress in Radial Direction (psi)
σ_{aa}: Stress in Axial Direction (psi)
τ: Shear Stress (psi)

Output(s)

σ_{tmax}: Maximum Tangential Stress (psi)

Formula(s)

$$\sigma_{tmax} = \frac{1}{2} * \left(\sigma_{zz} + \sigma_{aa} + \sqrt{(\sigma_{zz} - \sigma_{aa})^2 + 4 * \tau^2}\right)$$

$$\sigma_{tmax} = \frac{1}{2} * \left(\sigma_{zz} + \sigma_{aa} - \sqrt{(\sigma_{zz} - \sigma_{aa})^2 + 4 * \tau^2}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 239.*

11.39 Maximum principal stress failure (Hoek and Brown)

Input(s)

σ_b: Second Largest Stress (psi)
C: Rock Compressive Strength (lbf)
m: Hoek - Brown Constant Dependent on Rock Type (dimensionless)
s: Hoek and Brown Constant Dependent on Shape (dimensionless)

Output(s)

σ_a: Principal Stress (psi)

Formula(s)

$$\sigma_a = \sigma_b + \left(C * \left(m * \left(\frac{\sigma_b}{C}\right) + s\right)^{0.5}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 98.*

11.40 Maximum principal stress in normal faulting

Input(s)

σ_c: Least Principle Stress (psi)
S_v: Vertical Stress (psi)
P_p: Pore Pressure (psi)
S_{hm}: Minimum Horizontal Stress (psi)

Output(s)

σ: Maximum Principle Stress (psi)

Formula(s)

$$\sigma = \frac{\sigma_c * \left(S_v - P_p\right)}{S_{hm} - P_p}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 133.*

11.41 Maximum principal stress in reverse faulting

Input(s)

σ_c: Least Principle Stress (psi)
P_p: Pore Pressure (psi)
S_v: Vertical Stress (psi)
S_{hmax}: Maximum Horizontal Stress (psi)

Output(s)

σ: Maximum Principle Stress (psi)

Formula(s)

$$\sigma = \frac{\sigma_c * \left(S_{hmax} - P_p\right)}{S_v - P_p}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 133.*

11.42 Maximum principal stress in strike-slip faulting

Input(s)

σ_c: Least Principle Stress (psi)
S_{hmax}: Maximum Horizontal Stress (psi)
P_p: Pore Pressure (psi)
S_{hmin}: Minimum Horizontal Stress (psi)

Output(s)

σ: Maximum Principle Stress (psi)

Formula(s)

$$\sigma = \frac{\sigma_c * \left(S_{hmax} - P_p\right)}{S_{hmin} - P_p}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 133.*

11.43 Maximum principal stress calculation using breakout width

Input(s)

S_{hmin}: Minimum Principal Stress in Reservoir (psi)
C_o: Distance from Wellbore (ft)
Pp: Pore Pressure (psi)
S_{dt}: Stress induced Due to Temperature (psi)
dP: Difference Between Wellbore Pressure and Mud Weight (psi)
Θ: Angle from Wellbore Breakout Width (rad)

Output(s)

S_{hmin}: Maximum Principal Stress in Reservoir (psi)

Formula(s)

$$S_{hmax} = \frac{((C_o) + 2 * Pp + dP + Sdt) - S_{hmin} * (1 + 2 * \cos(\Theta))}{1 - 2 * \cos(\Theta)}$$

Reference: *Mark D. Zoback., Reservoir Geomechanics, Cambridge University Press, UK, Page: 223.*

11.44 Minimum compression at vertical wellbore

Input(s)

S_{hmin}: Minimum Horizontal Stress (psi)
S_{hmax}: Maximum Horizontal Stress (psi)
P_o: Pore Pressure (psi)
P: Pressure Drawdown (psi)
σ_t: Thermal Stress (psi)

Output(s)

$\sigma_{minaxial}$: Minimum Axial Stress (psi)

Formula(s)

$$\sigma_{minaxial} = 3 * S_{hmin} - S_{hmax} - 2 * P_o - P - \sigma_t$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 174.*

11.45 Minimum normal stress in tangential direction at wellbore wall (hoop stress)

Input(s)

S_{hmax}: Maximum Principal Stress in Reservoir (psi)
S_{hmin}: Minimum Principal Stress in Reservoir (psi)
Po: Pore Pressure (psi)
S_{dt}: Stress induced due to Temperature (psi)
dP: Difference Between Wellbore Pressure and Mud Weight (psi)

Output(s)

sig_{th}: Minimum Hoop Stress in Tangential Direction at Wellbore Wall (psi)

Formula(s)

$$sig_{th} = 3 * S_{hmin} - S_{hmax} - 2 * Po - dP - S_{dt}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 238.*

11.46 Maximum plane tangential stress acting on deviated wellbore

Input(s)

σ_{zz}: Radial Stress (psi)
σ_{aa}: Axial Stress (psi)
τ: Shear Stress (psi)

Output(s)

σ_{tmax}: MaximumTangential Stress (psi)

Formula(s)

$$\sigma_{tmax} = 0.5 * \left(\sigma_{zz} + \sigma_{aa} - \left(\left((\sigma_{zz} - \sigma_{aa})^2 \right) + 4 * \tau^2 \right)^{0.5} \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 239.*

11.47 Modified lade criterion

Input(s)

S_a: Principle Stress (psi)
S_b: Intermediate Stress (psi)

S_c: Minimum Stress (psi)
P_a: Pressure (psi)
m: Material Strength Constant (dimensionless)

Output(s)

I_a: First Invariant of Stress Tensor (psi)
I_c: Third Invariant of Stress Tensor (psi3)
η: Lades Coefficient (dimensionless)

Formula(s)

$$I_a = S_a + S_b + S_c$$
$$I_c = S_a * S_b * S_c$$
$$\eta = \left(\left(\frac{I_a^3}{I_c^3}\right) - 27\right) * \left(\left(\frac{I_a}{P_a}\right)^m\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 99.*

11.48 Normal stress in radial direction near wellbore

Input(s)

S_{hmax}: Maximum Principal Stress in reservoir (psi)
S_{hmin}: Minimum Principal Stress in reservoir (psi)
r: Distance from wellbore (ft)
Po: Pore Pressure (psi)
R: Radius of wellbore (ft)
θ: Angle from S_{hmax} at which stress is measured (degrees)

Output(s)

sig_{rr} : Normal Stress in Radial Direction Near Wellbore (psi)

Formula(s)

$$sig_{rr} = 0.5 * (Shmax + Shmin - 2 * Po) * \left(1 - \frac{R^2}{r^2}\right) + 0.5 * (Shmax - Shmin) * \left(1 - 4 * \frac{R^2}{r^2} + 3 * \frac{R^4}{r^4}\right) * \cos\left(2 * \theta * \frac{3.142}{180}\right) + Po * \frac{R^2}{r^2}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 100.*

11.49 Normal stress in rock at failure

Input(s)

S_{hmax}: Maximum Principal Stress in reservoir (psi)
S_{hmin}: Minimum Principal Stress in reservoir (psi)
r: Distance from wellbore (ft)
Po: Pore Pressure (psi)
R: Radius of wellbore (ft)
θ: Angle from S_{hmax} at which stress is measured (degrees)

Output(s)

sig_{rr} : Normal Stress in Radial Direction Near Wellbore (psi)

Formula(s)

$$sig_{rr} = 0.5 * (Shmax + Shmin - 2 * Po) * \left(1 - \frac{R^2}{r^2}\right) + 0.5 * (Shmax - Shmin) * \left(1 - 4 * \frac{R^2}{r^2} + 3 * \frac{R^4}{r^4}\right) * \cos\left(2 * \theta * \frac{3.142}{180}\right) + Po * \frac{R^2}{r^2}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 101.*

11.50 Normal stress in tangential direction at wellbore wall (hoop stress)

Input(s)

Shmax: Maximum Principal Stress in reservoir (psi)
Shmin: Minimum Principal Stress in reservoir (psi)
Po: Pore Pressure (psi)
Sdt: Stress induced due to temperature (psi)
dP: Difference between Wellbore Pressure and Mud Weight (psi)
θ: Angle from S_{hmax} at which stress is measured (degrees)

Output(s)

sig_{th} : Hoop Stress in Tangential Direction at Wellbore Wall (psi)

Formula(s)

$$sig_{th} = (Shmax + Shmin) - 2 * (Shmax - Shmin) * \cos\left(2 * \theta * \frac{3.142}{180}\right) - 2 * Po - dP - Sdt$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 102.*

11.51 Normal stress in tangential direction near wellbore (hoop stress)

Input(s)

Shmax: Maximum Principal Stress in reservoir (psi)
Shmin: Minimum Principal Stress in reservoir (psi)
Po: Pore Pressure (psi)
Sdt: Stress induced due to temperature (psi)
dP: Difference between Wellbore Pressure and Mud Weight (psi)
θ: Angle from S_{hmax} at which stress is measured (degrees)
r: Distance from wellbore (ft)
R: Radius of wellbore (ft)

Output(s)

Sg_{th}: Normal Stress in Tangential Direction Near Wellbore (Hoop Stress) (psi)

Formula(s)

$$Sg_{th} = 0.5*(Shmax + Shmin - 2*Po)*\left(1+\frac{R^2}{r^2}\right) - 0.5*(Shmax - Shmin)*\left(1+3*\frac{R^4}{r^4}\right)*\cos\left(2*\theta*\frac{3.142}{180}\right) - Po*\frac{R^2}{r^2} - Sdt$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 104.*

11.52 Pore pressure increase due to fluid activity (Mody & Hale)

Input(s)

E_m: Membrane Efficiency (dimensionless)
R: Gas Constant (psi/mol K)
T: Temperature (K)
V: Volume (ft^3)
A_p: Pore Fluid Activity (dimensionless)
A_m: Mud Activity (dimensionless)

Output(s)

δP: Pore Pressure Increase (psi)

Formula(s)

$$\delta P = E_m*\left(\frac{R*T}{V}\right)*\ln\left(\frac{A_p}{A_m}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 321.*

11.53 Pore pressure increase due to given fluid activity contrast (Mody and Hale)

Input(s)

E_m: Membrane Efficiency (dimensionless)
R: Gas Constant (dimensionless)
T: Temperature (K)
V: Molar Volume of Water (L/mol)
A_p: Pore Fluid Activity (dimensionless)
A_m: Mud Activity (dimensionless)

Output(s)

dP: Pore Pressure Increase (psi)

Formula(s)

$$dP = Em*\left(R*\frac{T}{V}\right)*\log\left(\frac{Ap}{Am}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 105.*

11.54 Pore pressure of shale (Flemings)

Input(s)

S_v: Sonic Velocity (ft/s)
β_c: Compressibility (1/psi)
$ø_o$: Initial Porosity (fraction)
t: Sonic Travel Time (s)
ø: Porosity from Sonic Log (fraction)

Output(s)

P_p: Pore Pressure (psi)

Formula(s)

$$\boldsymbol{P_p = S_v - \left(\left(\frac{1}{\beta_c}\right) * \ln\left(\frac{ø_o}{ø}\right)\right)}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 48.*

11.55 Pore pressure of shale (Traugott)

Input(s)

z: Depth (ft)
S_v: Sonic Velocity (ft/s)
R_o: Resistivity of Shale (ohm ft)
R_n: Expected Resistivity (ohm ft)
$(P_p)^{hydro}$: Hydrostatic Pore Pressure (psi)

Output(s)

P_{psh}: Pore Pressure of Shale (psi)

Formula(s)

$$\mathrm{P_{psh}} = \mathrm{z} * \left(\left(\frac{\mathrm{S_v}}{\mathrm{z}}\right) - \left(\left(\frac{\mathrm{S_v}}{\mathrm{z}}\right) - \left(\frac{\left(\mathrm{P_p}\right)^{\mathrm{hydro}}}{\mathrm{z}}\right)\right) * \left(\left(\frac{\mathrm{R_o}}{\mathrm{R_n}}\right)^{1.2}\right)\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 47.*

11.56 Porosity irreversible plastic deformation occurs

Input(s)

μ: Viscosity (cP)
S_v: Vertical Stress (psi)
S_H: Maximum Horizontal Stress (psi)
S_h: Minimum Horizontal Stress (psi)
P_p: Change in Pore Pressure (psi)

Output(s)

M: Mobility (dimensionless)
p: Porosity (dimensionless)

Formula(s)

$$M = \frac{6 * \mu}{3 * \left(((\mu^2) + 1)^{0.5} \right) - \mu}$$

$$p = \left(\frac{1}{3 * (S_v * S_H + S_h) - 9 * P_p} \right) * \left(9 * P_p^2 + \left(1 + \frac{9}{M^2} \right) * \left(S_v^2 + S_H^2 + S_h^2 \right) + \left(2 - \frac{9}{M^2} \right) * (S_v * S_H + S_v * S_h + S_H * S_h) - 6 * P_p * (S_v + S_H + S_h) \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 400.*

11.57 Pressure required to induce a tensile fracture (breakdown pressure)

Input(s)

S_{hmax}: Maximum Principal Stress in reservoir (psi)
S_{hmin}: Minimum Principal Stress in reservoir (psi)
P_p: Pore Pressure (psi)
T_o: Minimum Hoop Stress for formation at which crack initiates (psi)

Output(s)

P_b: Breakdown Pressure (psi)

Formula(s)

$$P_b = 3 * Shmin - Shmax - P_p + T_o$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 56.*

11.58 Pressure to grow fractures (Abe, Mura, et al.)

Input(s)

S_c: Minimum Principle Stress (psi)
P_p: Pore Pressure (psi)
c_f: Radius of Fracture (in.)
c_i: Radius of Invaded Zone (in.)

Output(s)

P_{grow}: Growth Pressure (psi)

Formula(s)

$$P_{grow} = S_c * \left(\frac{1 - \left(\frac{P_p}{S_c}\right) * \left(1 - \left(\frac{c_f}{c_i}\right)^2\right)^{0.5}}{1 - \left(\left(1 - \left(\frac{c_f}{c_i}\right)^2\right)^{0.5}\right)} \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 326.*

11.59 Radial stress around vertical wellbore

Input(s)

S_{hmax}: Maximum Horizontal Stress (psi)
S_{hmin}: Minimum Horizontal Stress (psi)
P_o : Pore Pressure (psi)
R: Radius of Wellbore (ft)
r: Relative Position to Centre (ft)
θ: Azimuth of S_{hmax} (rad)

Output(s)

σ_{rr}: Stress (psi)

Formula(s)

$$\sigma_{rr} = 0.5 * (S_{hmax} + S_{hmin} - 2 * P_o) * \left(1 - \left(\frac{R^2}{r^2}\right)\right) + 0.5 * (S_{hmax} - S_{hmin}) * \left(1 + \left(\frac{3 * R^4}{r^4}\right) - \left(\frac{4 * R^2}{r^2}\right)\right) * \cos(2 * \theta) + \left(\frac{P_o * R^2}{r^2}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 170.*

11.60 Ratio of pore pressure change to original due to depletion

Input(s)

P: Change in Pore Pressure (psi)
S_{hmax}: Maximum Horizontal Stress (psi)
S_{hmin}: Minimum Horizontal Stress (psi)

Output(s)

q: Pore Pressure Ratio (fraction)

Formula(s)

$$q = \frac{P_p}{S_{hmax} - S_{hmin}}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 393.*

11.61 Rotation of maximum principal stress near wellbore

Input(s)

A: Stress Field Direction (dimensionless)
P_p: Change in Pore Pressure (psi)
θ: Fault Orientation (degrees)
S_{hmax}: Maximum Principle Stress (psi)
S_{hmin}: Minimum Principle Stress (psi)

Output(s)

γ: Rotation (degrees)

Formula(s)

$$\gamma = 0.5 * \text{atan}\left(\frac{A * P_p * \sin(2 * \theta)}{S_{hmax} - S_{hmin} + A * P_p * \cos(2 * \theta)}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 393.*

11.62 Rotation of maximum principal stress near wellbore (Zoback & Day-Lewis)

Input(s)

A: Constant a Value (dimensionless)
Δ: Fault Orientation (degrees)
q: Ratio of Pore Pressure to Differential Stress (dimensionless)

Output(s)

γ: Stress Rotation (radian)

Formula(s)

$$\gamma = 0.5 * \text{atan}\left(A * q * \frac{\sin(2 * \Delta)}{1 + A * q * \cos(2 * \Delta)}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 393.*

11.63 Shale compaction

Input(s)

Ø: Porosity (fraction)
β: Second Empirical Constant from Porosity vs Vertical Stress Graph (1/MPa)
σ_v: Vertical Effective Stress (MPa)

Output(s)

$Ø_e$: Shale Compaction (fraction)

Formula(s)

$$\text{Ø}_e = \text{Ø} * e^{-\beta * \sigma_v}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 46.*

11.64 Shear modulus

Input(s)

F: Force (N)
A: Area (m^2)
θ: Deformation Angle (degrees)

Output(s)

G: Shear Modulus (Pa)

Formula(s)

$$G = \frac{F/A}{\theta}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 45.*

11.65 Shear modulus from Young's modulus

Input(s)

ν: Poisson's Ratio (dimensionless)
E: Young's Modulus (N/m^2)

Output(s)

G: Modulus of Rigidity (psi)

Formula(s)

$$G = \frac{E}{2 * (1 + \nu)}$$

Reference: *Samuel. E Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 356.*

11.66 Shear stress near vertical well

Input(s)

S_{hmax}: Maximum Principal Stress in reservoir (psi)
S_{hmin}: Minimum Principal Stress in reservoir (psi)
r: Distance from wellbore (ft)
R: Radius of wellbore (ft)
θ: Angle from S_{hmax} at which stress is measured (degrees)

Output(s)

sig_{rth}: Shear Stress near Vertical Well (psi)

Formula(s)

$$\mathrm{sig_{rth}} = 0.5 * (\mathrm{S_{hmax}} + \mathrm{S_{hmin}}) * \left(1 + 2 * \frac{\mathrm{R}^2}{\mathrm{r}^2} - 3 * \frac{\mathrm{R}^4}{\mathrm{r}^4}\right) * \sin\left(2 * \theta * \frac{3.142}{180}\right)$$

Reference: *petrowiki.org*.

11.67 Slowness of the formation

Input(s)

d_h: Borehole Diameter (in.)
Δt_m: Interval Travel Time (μs/ft)
d_t: Tool Diameter (in.)
L_s: Spacing of the Tool (ft)
l_c: Eccentricity of the Tool (ft)
t_l: Time Between Initiation of the Pulse and First Arrival Acoustic Energy at the Receiver (μs/ft)

Output(s)

Δt: Slowness of Formation Observed by Sonic Log (μs/ft)
t_m: Mud Path Correction Time (μs/ft)

Formula(s)

$$\Delta t = \frac{t_l - t_m}{L_s}$$

$$t_m = (\Delta t_m) * (d_h - (d_t + 2 * l_c)) * \left(1 - \left(\frac{\Delta t}{\Delta t_m}\right)^2\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 10, Page: 189.*

11.68 Storativity of fractures

Input(s)

$\varnothing_f$: Porosity of Fracture (fraction)
$\varnothing_m$: Porosity of Matrix (fraction)
h_f: Fracture Thickness (ft)
h_m: Matrix Thickness (ft)
c_{tf}: Total Fracture Compressibility (1/psi)
c_{tm}: Total Matrix Compressibility (1/psi)

Output(s)

ω: Storativity of Fracture (dimensionless)

Formula(s)

$$\omega = \frac{\o_f * h_f * c_{tf}}{\o_f * h_f * c_{tf} + \o_m * h_m * c_{tm}}$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter:1, Page: 82.*

11.69 Stress at edge of wellbore breakout

Input(s)

C_o: Wellbore Strength (psi)
P_p: Pore Pressure (psi)
P: Drawdown Differential in Pressure (psi)
σ_t: Thermally Induced Stress (psi)
w_b: Wellbore Breakout (degrees)
S_{hmin}: Minimum Horizontal Stress (psi)

Output(s)

θ_b: Breakout Angle (degrees)
S_{hmax}: Maximum Principle Stress (psi)

Formula(s)

$$2\theta_b = \pi - w_b$$

$$S_{hmax} = \frac{\left((C_o) + 2 * P_p + P + \sigma_t\right) - S_{hmin} * (1 + 2 * \cos(\theta_b))}{1 - 2 * \cos(\theta_b)}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 223.*

11.70 Stress component near normal faulting in reservoir

Input(s)

α: Biot (dimensionless)
ν: Poisson (dimensionless)
Sh_{max}: Maximum Principal Stress (psi)
Sh_{min}: Minimum Principal Stress (psi)
dP: Change in Pore Pressure (psi)
θ: Fault Orientation (degrees)

Output(s)

A: Constant a Value (dimensionless)
S_x: Stress in X Direction (psi)
S_y: Stress in Y Direction (psi)
T_{xy}: Normal Stress in Y Direction (psi)

Formula(s)

$$A = \alpha * \frac{1 - 2 * \nu}{1 - \nu}$$

$$Sx = Sh_{max} - A * dP - A * \frac{dP}{2} * \left(1 - \cos\left(2 * \theta * \frac{\pi}{180}\right)\right)$$

$$Sy = Sh_{min} - A * dP - A * \frac{dP}{2} * \left(1 + \cos\left(2 * \theta * \frac{\pi}{180}\right)\right)$$

$$Txy = A * \frac{dP}{2} * \sin\left(2 * \theta * \frac{\pi}{180}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 381.*

11.71 Stress components in original coordinate system in depletion drive

Input(s)

S_{hmax}: Maximum Stress in Horizontal Direction (psi)
S_{hmin}: Minimum Stress in Horizontal Direction (psi)
δP_p: Change in Pore Pressure due to Depletion (psi)
A: Stress Path (dimensionless)
Δ: Fault Orientation (degrees)

Output(s)

S_x: Stress in X-direction (psi)
S_y: Stress in Y-direction (psi)
τ: Stress Around Wellbore (psi)

Formula(s)

$$S_x = S_{hmax} - A * P_p - \left(\frac{A * \delta P_p}{2}\right) * (1 - \cos(2 * \Delta))$$

$$S_y = S_{hmin} - A * P_p - \left(\frac{A * \delta P_p}{2}\right) * (1 + \cos(2 * \Delta))$$

$$\tau = \left(\frac{A * \delta P_p}{2}\right) * \sin(2 * \Delta)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 393.*

11.72 Stress intensity at tip of mode I fracture

Input(s)

P_f: Fracture Pressure (psi)
S_c: Minimum Principle Stress (psi)
L: Length of Fracture (ft)

Output(s)

K: Stress Intensity (psi ft)

Formula(s)

$$K = (P_f - S_c) * \pi * \left(L^{0.5}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 122.*

11.73 Stress path (induced normal faulting)

Input(s)

μ: Friction Coefficient (dimensionless)

Output(s)

A: Stress Path (dimensionless)

Formula(s)

$$A = 1 - \frac{1}{\left(\left((\mu^2 + 1)^{0.5}\right) + \mu\right)^2}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 385.*

11.74 Stress path of reservoir with changes in production

Input(s)

α: Biots Coefficient (dimensionless)
υ: Poisson (dimensionless)

Output(s)

A: Stress Path (dimensionless)

Formula(s)

$$A = \frac{\alpha * (1 - 2 * \upsilon)}{1 - \upsilon}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 381.*

11.75 Stress perturbation (Segall and Fitzgerald)

Input(s)

υ: Poisson (dimensionless)
H: Height of Reservoir (ft)
R: Half the Lateral Extent (ft)
α: Constant of Stress Propagation (dimensionless)

Output(s)

M: Stress Perturbation (dimensionless)

Formula(s)

$$M = \alpha * \left(\frac{(1 - 2 * \upsilon) * \pi * H}{(1 - \upsilon) * 4 * 2 * R} \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics. Cambridge University Press. Cambridge, UK, Page: 112.*

11.76 Subsidence due to uniform pore pressure reduction in free surfaces

Input(s)

c_m: Formation Compaction per Unit Change in Pore Pressure Reduction (ft^3/psi)
υ: Poisson's (dimensionless)
r: Radius of Area Involved (ft)
D: Depth of Formation in Consideration (ft)
ΔP_p: Pore Pressure Change (psi)
V: Volume of Reservoir (ft^3)

Output(s)

u_z: Subsidence in Z Direction (ft)
u_r: Subsidence Along R (ft)

Formula(s)

$$u_z = (-1) * \left(\frac{c_m * (1 - \upsilon) * D * \Delta P_p * V}{\pi * \left((r^2) + (D^2) \right)^{1.5}} \right)$$

$$u_r = \left(\frac{c_m * (1 - \upsilon) * r * \Delta P_p * V}{\pi * \left((r^2) + (D^2) \right)^{1.5}} \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 412.*

11.77 Unconfined compressive strength of rock

Input(s)

S_o: Cohesive Strength (psi)
μ: Slope of Failure Line (dimensionless)

Output(s)

C_o: Unconfined Compressive Strength of Rock (psi)

Formula(s)

$$C_o = 2 * S_o * \left((\mu^2 + 1)^{0.5} + \mu \right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 89.*

11.78 Velocity of bulk compressional waves

Input(s)

E: Young's Modulus (lbf/ft^2)
ρ: Density (lbm/ft^3)
μ: Poisson's Ratio (dimensionless)

Output(s)

V_b: Velocity of Bulk Compressional Waves (ft/s)

Formula(s)

$$V_b = \left(\frac{E}{\rho} * \frac{1-\mu}{(1+\mu)*(1-2*\mu)}\right)^{0.5}$$

Reference: *Core Laboratories. 2005. Formation Evaluation and Petrophysics, Page: 23.*

11.79 Velocity of compression waves

Input(s)

K: Bulk Modulus (Pa)
G: Shear Modulus (Pa)
ρ: Density (kg/m^3)

Output(s)

V_p: Velocity of Compression Waves (m/s)

Formula(s)

$$V_p = \left(\left(K + \frac{4}{3}\right) * \frac{G}{\rho}\right)^{0.5}$$

Reference: *Bassiouni, Z. 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 46.*

11.80 Velocity of shear waves

Input(s)

G: Shear Modulus (Pa)
ρ: Density (kg/m^3)

Output(s)

V_s: Velocity of Shear Waves (m/s)

Formula(s)

$$V_s = \left(\frac{G}{\rho}\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and Interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 3, Page: 46.*

11.81 V_p and V_s calculation (Eberhart-Phillips)

Input(s)

ø: Porosity (fraction)
C: Clay Content (fraction)
σ: Effective Stress (psi)

Output(s)

V_p: Velocity of Compressional Waves (ft/s)
V_s: Shear Waves (ft/s)

Formula(s)

$$V_p = 5.77 - 6.94 * ø - 1.73 * \left(C^{0.5}\right) + 0.446 * \left(\sigma - (-1) * e^{(-1) * 16.7 * \sigma}\right)$$

$$V_s = 3.7 - 4.94 * ø - 1.57 * \left(C^{0.5}\right) + 0.361 * \left(\sigma - (-1) * e^{(-1) * 16.7 * \sigma}\right)$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 53.*

11.82 V_p and V_s calculation (geomechanical model)

Input(s)

K: Bulk Modulus (psi)
G: Shear Modulus (psi)
ρ: Density (ppg)

Output(s)

V_p: Velocity of Compressional Waves (ft/s)
V_s: Shear Waves (ft/s)

Formula(s)

$$V_p = \left(\frac{K + \frac{4 * G}{3}}{\rho}\right)^{0.5}$$

$$V_s = \left(\frac{G}{\rho}\right)^{0.5}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, Page: 63.*

11.83 Yield strength (Bingham plastic model)

Input(s)

K: Bulk Modulus (psi)
G: Shear Modulus (psi)
ρ: Density (ppg)

Output(s)

V_p: Velocity of Compressional Waves (ft/s)
V_s: Shear Waves (ft/s)

Formula(s)

$$V_p = \left(\frac{K + \frac{4 * G}{3}}{\rho}\right)^{0.5}$$

$$V_s = \left(\frac{G}{\rho}\right)^{0.5}$$

Reference: *Mark D. Zoback, Reservoir Geomechanics, Cambridge University Press, UK, page 63.*

Chapter 12

Facilities and process engineering formulas and calculations

Chapter Outline

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12.1 Allowable gas velocity through gas separator

Input(s)

K_s: Empirical Gas Constant (ft/s)
ρ_l: Liquid Density (g/cc)
ρ_g: Gas Density (g/cc)

Output(s)

v: Allowable Gas Velocity (ft/s)

Formula(s)

$$v = K_s * \left(\frac{\rho_l - \rho_g}{\rho_g}\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 73.*

12.2 Allowable velocity in downcomer for tray type tower

Input(s)

h: Height of Liquid Downcomer (in.)
t: Residence Time (s)

Output(s)

v_d: Allowable Velocity in Downcomer (in./s)

Formula(s)

$$v_d = \frac{h}{t}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 73.*

12.3 Bed diameter of adsorption unit

Input(s)

q: Flow Rate (bbl/m)
γ: Fluid Relative Density (dimensionless)
P: Pressure Drop (psi)

Output(s)

C_v: Capacity Coefficient (dimensionless)

Formula(s)

$$C_v = \left(\frac{q}{A}\right) * \left(\frac{\gamma}{P}\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 265.*

12.4 Bed length of adsorption unit

Input(s)

x: Maximum Desiccant Useful Capacity (kg water/100 kg desiccant)
x_s: Dynamic Capacity at Saturation (kg water/100 kg desiccant)
h_z: MTZ Length (ft)

Output(s)

h_b: Bed Length (ft)

Formula(s)

$$h_b = \frac{0.45 * h_z * x_s}{x_s - x}$$

Reference: *John M. Campbell, Gas Conditioning and Processing Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 388.*

12.5 Block efficiency factor

Input(s)

F: Friction Factor (unitless)
n: No. of Rolling Sheaves (unitless)

Output(s)

E: Block Efficiency Factor (unitless)

Formula(s)

$$E = \frac{F^n - 1}{F^n * n * (F - 1)}$$

Reference: *Samuel E. Robello. 501 Solved Problems and Calculations for Drilling Operations. Sigma Quadrant. 2015. Houston, Texas, Page: 11.*

12.6 Bottom distillation column rate

Input(s)

L: Liquid Mass Velocity (lbm/ft^2 h)
G: Gas Mass Velocity (lbm/dt^2 h)
σ_g: Gas Density (g/cc)
σ_l: Liquid Density (g/cc)

Output(s)

X: Bottom Distillation Column Rate (dimensionless)

Formula(s)

$$X = \frac{L * \sigma_g}{G * \sigma_l}$$

Reference: *Campbell, J. M., (1992, Houston, TX (United States)), Gas Conditioning and Processing, Vol. 2, Campbell Petroleum Series, Page: 74.*

12.7 Breakthrough time in an adsorption unit

Input(s)

x: Height of Unit (ft)
ρ_b: Bulk Density of Desicant (lb/ft^3)
h_b: Bed Length of Unit (ft)
q: Water Loading (lb/ft^2 h)

Output(s)

Θ: Breakthrough Time (h)

Formula(s)

$$\Theta = \frac{0.01 * x * \rho_b * h_b}{q}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 391.*

12.8 Breathing loss of natural gas

Input(s)

P: Pressure (psi)
D: Tank Diameter (ft)
F_p: Paint Factor (dimensionless)
F_o: Outage Factor (dimensionless)

Output(s)

B: Breathing Loss (API bbl)

Formula(s)

$$B = \left(\frac{P * D^{1.8}}{14.5}\right) * F_p * F_o$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 123.*

12.9 Capacity coefficient of valves in gas processing

Input(s)

q: Flow Rate (bbl/m)
γ: Fluid Relative Density (dimensionless)
P: Pressure Drop (psi)

Output(s)

C_v: Capacity Coefficient (dimensionless)

Formula(s)

$$C_v = \left(\frac{q}{A}\right) * \left(\frac{\gamma}{P}\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 265.*

12.10 Column diameter of packed towers

Input(s)

m: Mass Flow Rate (lb/s)
G: Gas Mass Flow Rate (lb/ft^2 h)

Output(s)

d: Column Diameter (ft)

Formula(s)

$$d = \left(\frac{4 * m}{\pi * G}\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 319.*

12.11 Cooling of an ideal gas

Input(s)

H_1: Initial Enthalpy Per Unit Mass (ft^2/s^2)
H_2: Final Enthalpy Per Unit Mass (ft^2/s^2)
v_1: Initial Velocity (ft/s)
v_2: Final Velocity (ft/s)
g: Acceleration Due to Gravity (ft/s^2)
h_1: Initial Height (ft)
h_2: Final Height (ft)

Output(s)

Q: Energy Rate (Btu/s)

Formula(s)

$$Q = (H_2 - H_1) + 0.5 * \left(\left(v_2^2\right) - \left(v_1^2\right)\right) + g * (h_2 - h_1)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 576.*

12.12 Correction factor for foamless separation

Input(s)

L: Length of Tank (ft)
D: Diameter of Tank (ft)

Output(s)

K: Correction Factor (dimensionless)

Formula(s)

$$K = \left(\frac{L/D}{5}\right)^{0.56}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 73.*

12.13 Correlation factor for Benedict-Webb-Rubin equation

Input(s)

A: Mole Fraction of Hydrogen Sulfide and Carbon Dioxide in Gas Phase (fraction)
B: Mole Fraction of Hydrogen Sulfide in Gas Phase (fraction)

Output(s)

ε: Correlation Factor (R)

Formula(s)

$$\varepsilon = 120 * \left(\left(A^{0.9}\right) - \left(A^{1.6}\right)\right) + 15 * \left(\left(B^{0.5}\right) - \left(B^{4}\right)\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 54.*

12.14 Critical pressure values for pressure in Van Der Waals equation

Input(s)

P: Pseudocritical Pressure (psi)
T: Pseudocritical Temperature (K)
T_c: Critical Temperature (K)
B: Mole Fraction of Hydrogen Sulfide (fraction)
ε: Correlation Constant (dimensionless)

Output(s)

P_c: Critical Pressure (psi)

Formula(s)

$$P_c = \frac{P * T_c}{T + B * (1 - B) * \varepsilon}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 54.*

12.15 Downcomer velocity in tray type tower

Input(s)

h: Height of Liquid Downcomer (in.)
t: Residence Time (s)

Output(s)

v_d: Allowable Velocity in Downcomer (in./s)

Formula(s)

$$v_d = \frac{h}{t}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 73.*

12.16 Electrical heating of a pipe

Input(s)

R: Radius (m)
κ: Ratio of Inner Radius to Outer Radius ($m^2\ kg\ s^{-2}\ K^{-1}$)
L: Length (m)
T_κ: Desired Temperature (K)
T_a: Ambient Air Temperature (K)
k: Thermal Conductivity (W/m K)
h: Heat Transfer Coefficient (W/(m^2 K))

Output(s)

P: Electrical Power (Watt)

Formula(s)

$$P = \frac{\pi * R^2 * (1 - \kappa^2) * L * (T_\kappa - T_a)}{(1 - \kappa^2) * \frac{R}{2 * h} - \frac{(\kappa * R)^2}{4 * k} * \left(1 - \frac{1}{\kappa^2} - 2 * \ln(\kappa)\right)}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 325.*

12.17 Energy requirement of single-stage ideal compressor

Input(s)

v_1: Velocity (ft/s)
P_1: Initial Pressure (psi)
P_2: Final Pressure (psi)
R: Ideal Gas Constant (ft^3 lb/mol K)
T: Temperature (K)
M: Mass (lbs)
γ: Adiabatic Constant (dimensionless)

Output(s)

W: Energy (ft lbf/lbm)

Formula(s)

$$W = \left(\frac{v_1^2}{2}\right) * \left(1 - \left(\left(\frac{P_1}{P_2}\right)^2\right)\right) + \left(\frac{R * T * \gamma}{M * (\gamma - 1)}\right) * \left(\left(\left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}\right) - 1\right)$$

Reference: *Bird R. Byron, Stewart E. Warren, Lightfoot N. Edward.*

12.18 Error in thermocouple temperature measurement

Input(s)

T: Temperature indicated by Thermocouple (K)
T_w: Temperature of Wall (K)
h: Heat Conduction Constant (dimensionless)
L: Length (cm)
k: Thermal Conductivity (W/m K)
B: Breadth (cm)

Output(s)

n: Constant (K)
T_a: Actual Thermocouple Temperature (K)

Formula(s)

$$n = \left(\cosh\left(\left(h * \frac{L^2}{k} * B\right)^{0.5}\right)\right)^{-1}$$

$$T_a = \frac{T - n * T_w}{1 - n}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 310.*

12.19 Eykman molecular refraction

Input(s)

P_v: Vapor Pressure of Water (psi)
P: Pressure (psi)
f: Fugacity of Water at Vapor Pressure (dimensionless)
f_w: Fugacity of Water at Pressure P (dimensionless)

Output(s)

k: Eykman Constant (dimensionless)

Formula(s)

$$k = \left(\frac{P_v}{P}\right) * \left(\frac{f/P_v}{f_w/P_v}\right) * \left(\frac{P}{P_v}\right)^{0.049}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 50.*

12.20 Fenske's method for minimum theoretical plates

Input(s)

X_{lkd}: Distillate Mole Fraction of Light Component (fraction)
X_{hkd}: Distillate Mole Fraction of Heavy Component (fraction)
X_{lkb}: Bottom Mole Fraction of Light Component (fraction)
X_{hkb}: Bottom Mole Fraction of Heavy Component (fraction)
α_a: Relative Volatility (fraction)

Output(s)

S_m: Number of Minimum Theoretical Stages (dimensionless)

Formula(s)

$$S_m = \log\left(\left(\frac{X_{lkd}}{X_{hkd}}\right) * \left(\frac{X_{lkb}}{X_{hkb}}\right)\right) / \log(\alpha_a)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 288.*

12.21 Gas capacity of separator

Input(s)

K_s: Separator Coefficient (ft/s)
d: Total Internal Diameter of Separator (ft)
F: Fraction of Total Area Available to Gas (fraction)
z: Compressibility Factor (dimensionless)
P: Separation Pressure (psi)
P_s: Base Pressure (psi)
T: Absolute Separation Temperature (K)

T_s: Base Temperature (K)
ρ_l: Liquid Density (g/cc)
ρ_g: Gas Density (g/cc)

Output(s)

q_s: Gas Rate (ft^3/d)

Formula(s)

$$q_s = 67824 * K_s * \left(d^2\right) * F * \left(\frac{1}{z}\right) * \left(\frac{P}{P_s}\right) * \left(\frac{T_s}{T}\right) * \left(\frac{\rho_l - \rho_g}{\rho_g}\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 74.*

12.22 Gas mass velocity in an adsorption unit

Input(s)

v_g: Gas Velocity (ft/m)
γ_g: Specific Gravity of Gas (dimensionless)
P: Pressure (psi)
T: Inlet Gas Temperature (K)
z: Compressibility Factor (dimensionless)

Output(s)

w: Gas Mass Velocity (lb/h ft^2)

Formula(s)

$$w = \frac{162 * v_g * \gamma_g * P}{T * z}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 391.*

12.23 Gas mass velocity in separator

Input(s)

w: Mass Mass Flow Velocity (lb/h ft^2)
d: Internal Diameter of Separator (ft)
F: Fraction of Area Available for Gas (fraction)

Output(s)

m: Mass Rate (lb/h)

Formula(s)

$$m = 0.785 * w * (d^2) * F$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 75.*

12.24 Gas originally adsorbed

Input(s)

A: Drainage Area (acres)
h: Thickness (ft)
ρ_B: Bulk Density of Coal (g/cc)
G_c: Gas Content (scf/ton)

Output(s)

G: Gas Initially in Place (scf)

Formula(s)

$$G = 1359.7 * A * h * \rho_B * G_c$$

Reference: *Ahmed, T., McKinney, P.D. 2005. Advanced Reservoir Engineering, Gulf Publishing of Elsevier, Chapter: 3, Page: 227.*

12.25 Gas pressure testing time for unsteady gas flow

Input(s)

d: Internal Pipe Diameter (in.)
L: Length of Pipe (miles)
P: Initial Pressure (psi)

Output(s)

t_m: Minimum Time Needed for Testing (h)

Formula(s)

$$t_m = \frac{3 * (d^2) * L}{P}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 30.*

12.26 Gravitational attraction of a layer (Bouguer correction)

Input(s)

G: Gravitational Constant (N m^2/kg^2)
Δz: Thickness (m)
$\Delta\rho$: Density Contrast (kg/m^3)

Output(s)

Δg_z: Bouguer Gravity (m/s^2)

Formula(s)

$$\Delta g_z = 2 * \pi * G * \Delta z * \Delta \rho$$

Reference: *https://sites.ualberta.ca/~unsworth/UA-classes/210/exams210/210-final-2008-formula-sheet.pdf*.

12.27 Heating of a liquid in an agitated tank

Input(s)

T_1: Initial Temperature (K)
T_s: Steam Temperature (K)
U_0: Heat Coefficient (W/ft K)
A_0: Area (ft^2)
w_1: Weight (lbm)
Cp: Specific Heat of Mass (lbf/lbs K)

Output(s)

T_0: Final Temperature (K)

Formula(s)

$$\frac{T_0 - T_1}{T_s - T_1} = 1 - \left(\frac{1 - \left(\exp\left(\frac{-U_0 * A_0}{w_1 * Cp} \right) \right)}{\frac{U_0 * A_0}{w_1 * Cp}} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 15, Page: 468.*

12.28 Height of downcomer filling

Input(s)

h_c: Clear Liquid Height (in.)
h_e: Dry Tray Height (in.)
h_u: Head Loss Under Downcomer (in.)
ρ_l: Liquid Density (g/cc)
ρ_g: Gas Density (g/cc)
h_i: Tray Inlet Head (in.)

Output(s)

h_d: Height of Downcomer Filling (in.)

Formula(s)

$$h_d = (h_c + h_e + h_u) * \left(\frac{\rho_l}{\rho_l - \rho_g}\right) + h_i + 1$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 316.*

12.29 Inhibitor injection rate required

Input(s)

mw: Mass of Water (lb)
Xr: Rich Inhibitor Concentration (wt%)
Xl: Lean Inhibitor Concentration (wt%)

Output(s)

m: Mass of Inhibitor (lb)

Formula(s)

$$m = m_w * (X_r/(X_l - X_r))$$
$$A = \pi r^2$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 181.*

12.30 Instrumentation noise control

Input(s)

P_a: Pressure of Sound Measured (psi)
P_o: Reference Pressure (psi)

Output(s)

dB: Decibel (dB)

Formula(s)

$$dB = 20 * \log\left(\frac{P_a}{P_o}\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 297.*

12.31 Internal diameter of gas separator

Input(s)

m: Mass Flow Rate (lb/h)
K_s: Separator Coefficient (ft/h)

F: Fraction of Separator Available for Gas (fraction)
ρ_l: Liquid Density (g/cc)
ρ_g: Gas Density (g/cc)

Output(s)

d: Internal Diameter (ft)

Formula(s)

$$d = \frac{0.0188 * \left(\frac{m}{F * K_s}\right)^{0.5}}{\left(\frac{\rho_l - \rho_g}{\rho_g}\right)^{0.25}}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 75.*

12.32 Isostacy—Airy hypothesis

Input(s)

h: Mountain Height (m)
ρ_c: Crustal Density (kg/m^3)
ρ_m: Mantle Density (kg/m^3)

Output(s)

r: Root Depth (m)

Formula(s)

$$r = h * \frac{\rho_c}{\rho_m - \rho_c}$$

Reference: *https://sites.ualberta.ca/~unsworth/UA-classes/210/exams210/210-final-2008-formula-sheet.pdf*.

12.33 Lift coefficient

Input(s)

ρ: Density (kg/m^3)
v: True Air Speed (m/s).
L: Lift Force (Newton)
S: Planform Area (m^2)

Output(s)

C_L: Lift Coefficient (dimensionless)

Formula(s)

$$C_L = 2 * \frac{L}{\rho * v^2 * S}$$

Reference: *Wikipedia.org*.

12.34 Mass of steel Shell in adsorption unit

Input(s)

h: Vessel Length (ft)
d: Vessel Internal Diameter (in.)
t: Shell Thickness (in.)

Output(s)

m: Mass of Steel Shell (lb)

Formula(s)

$$m = 15 * h * d * t$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 2, Page: 398, Campbell Petroleum Series, Oklahoma, 1992.*

12.35 Mass transfer zone length of adsorption unit

Input(s)

q: Water Loading (lb/ft^2 h)
v_g: Velocity (ft/min)
RS: Relative Saturation of Inlet Gas (%)

Output(s)

h_z: Mass Transfer Zone Length (ft)

Formula(s)

$$h_z = \frac{375 * \left(q^{0.7895}\right)}{\left(v_g^{0.5506}\right) * \left(RS^{0.2646}\right)}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 390.*

12.36 Modified Clapeyron criteria

Input(s)

C: Component Constant for Hydrocarbon Levels to Pressure (K)

Output(s)

T: Hydrate Forming Temperature (R)

Formula(s)

$$T = 3.89 * \left(C^{0.5}\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 178.*

12.37 Packed column actual height

Input(s)

HTU: Height of a Transfer Unit (ft)
NTU: Number of Transfer Units (dimensionless)

Output(s)

h: Height of Column (ft)

Formula(s)

$$h = HTU * NTU$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 280.*

12.38 Pan-Maddox equation for density

Input(s)

HTU: Height of a Transfer Unit (ft)
NTU: Number of Transfer Units (dimensionless)

Output(s)

h: Height of Column (ft)

Formula(s)

$$h = HTU * NTU$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 280.*

12.39 Pan-Maddox equation for molecular weight

Input(s)

T_b: Boling Temperature (K)
γ: Relative Density at 15.5 Degrees (g/cc)

Output(s)

M: Molecular Weight (g)

Formula(s)

$$M = 1.66 * \left(10^{-4}\right) * \left(T_b^{2.2}\right) * \left(\gamma^{-1.02}\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 1, Page: 76, Campbell Petroleum Series, Oklahoma, 1992.*

12.40 Photoelectric effect

Input(s)

m: Mass of Body at Rest (kg)
E_k: Kinetic Energy (Joule)
C: Velocity of Light ($3*10^8$ m/s)

Output(s)

v: Velocity of Particle (m/s)

Formula(s)

$$v = C * \left(1 - \left(1 + \left(\frac{E_k}{m * C^2}\right)\right)^{-2}\right)^{0.5}$$

Reference: *Bassiouni, Z., 1994, Theory, Measurement, and interpretation of Well Logs. SPE Textbook Series Vol. 4. Chapter 2, Page: 33.*

12.41 Power requirement for pumping a compressible flow fluid through a long pipe

Input(s)

D: Diameter of Pipe (ft)
ρ_1: Pressure (psi)
M: Mass (lbs)
R: Constant (ft^3 psi/lbmol K)
T: Temperature (K)
Wm: Energy Required by Compressor (ft lbf/lbm)
v: Velocity (ft/s)

Output(s)

P: Power (hp)

Formula(s)

$$P = \frac{(v_1) * \pi * \left(D^2\right) * \rho_1 * M * Wm}{4 * R * T}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 15, Page: 465.*

12.42 Pressure criteria for separator by ASME (external radius)

Input(s)

S: Maximum Allowable Stress (psi)
E: Joint Efficiency (fraction)
t: Shell Plate Thickness (ft)
R_o: Outer Radius (ft)

Output(s)

P: Pressure (psi)

Formula(s)

$$P = \frac{S*E*t}{R_o - 0.4*t}$$

Reference: *John M. Campbell., Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 64.*

12.43 Pressure criteria for separator by ASME (internal radius)

Input(s)

S: Maximum Allowable Stress (psi)
E: Joint Efficiency (fraction)
t: Thickness of Shell (ft)
R_i: Internal Radius of Shell (ft)

Output(s)

P: Pressure (psi)

Formula(s)

$$P = \frac{S*E*t}{R_i + 0.6*t}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 64.*

12.44 Pressure storage

Input(s)

P_{max}: Pressure at Maximum Liquid Temperature (psi)
P_v: Pressure at Which Vacuum Vent Opens (psi)
P_{min}: Pressure at Minimum Liquid Temperature (psi)
T_{max}: Maximum Average Temperature of Vapor (K)
T_{min}: Minimum Average Temperature of Vapor (K)
P_a: Atmospheric Pressure (psi)

Output(s)

P_s: Pressure Storage (psi)

Formula(s)

$$P_s = P_{max} + \left((P_v - Pmin) * \left(\frac{T_{max}}{T_{min}}\right)\right) - P_a$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 206.*

12.45 Proportional band in pressure controller

Input(s)

O: Tolerable Overshoot (psi)
Span: Transmitter Range (psi)

Output(s)

PB: Proportional Band (%)

Formula(s)

$$PB = \frac{200 * O}{Span}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 1, Page: 276, Campbell Petroleum Series, Oklahoma, 1992.*

12.46 Raoult's law in glycol dehydration unit

Input(s)

P: System Pressure (psi)
P_v: Water Vapor Pressure at Reboiler Temperature (psi)
y_w: Mol Fraction of Water in Reboiler Vapor (fraction)

Output(s)

x_w: Mole Fraction of Water in Lean Glycol (fraction)

Formula(s)

$$x_w = \left(\frac{P}{P_v}\right) * y_w$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 334.*

12.47 Refrigerator shaft speed

Input(s)

N: Shaft Speed (rpm)
q_a: Exhaust Turbine Volume (ft^3/s)
h: Isentropic Heat Change (btu/lb)

Output(s)

N_s: Speed (rpm)

Formula(s)

$$N_s = \frac{N * \left(q_a^{0.5}\right)}{(A * h)^{0.75}}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 157.*

12.48 Relative humidity

Input(s)

P_p: Partial Pressure of Water Vapor in Air Mixture (psi)
P_v: Saturation Pressure (psi)

Output(s)

ø: Relative Humidity (dimensionless)

Formula(s)

$$ø = \frac{P_p}{P_v}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 2, Page: 157, Campbell Petroleum Series, Oklahoma, 1992.*

12.49 Required oil length in separator

Input(s)

t_o: Residence Oil Time (min)
q_o: Oil Rate (ft^3/m)
A_o: Area of Oil (ft^2)

Output(s)

L_o: Length Required by Oil Flow (ft)

Formula(s)

$$L_o = \frac{t_o * q_o}{A_o}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 80.*

12.50 Required separator liquid section

Input(s)

q_l: Liquid Throughput (bbl/d)
t: Design Residence Time (min)

Output(s)

V_l: Required Liquid Section Capacity of Separator (bbl)

Formula(s)

$$V_l = \frac{q_l * t}{1440}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 2, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 76.*

12.51 Required water length in separator

Input(s)

t_w: Time of Water Residence (min)
q_w: Rate of Water Flow (ft^3/m)
A_w: Area of Water (ft^2)

Output(s)

L_w: Length of Water Column (ft)

Formula(s)

$$L_w = \frac{t_w * q_w}{A_w}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 80.*

12.52 Residence time of water in separator

Input(s)

h_o: Height of Oil Column in Separator (ft)
v_w: Terminal Velocity of Water (ft/h)

Output(s)

t_w: Residence Time of Water (min)

Formula(s)

$$t_w = \left(\frac{h_o}{60 * v_w}\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 2, Page: 80, Campbell Petroleum Series, Oklahoma, 1992.*

12.53 Residence time oil in separator

Input(s)

h_w: Height of Water Column in Separator (ft)
v_o: Terminal Velocity of Water (ft/min)

Output(s)

t_o: Oil Residence Time (min)

Formula(s)

$$t_o = \left(\frac{h_w}{60 * v_o}\right)$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Vol. 2, Page: 80, Campbell Petroleum Series, Oklahoma, 1992.*

12.54 Retention time in a liquid-liquid vessel

Input(s)

μ: Viscosity of Predominant Phase (cP)
A: Separator Constant—varies from 0.05 to 1.0 (dimensionless)
γ_b: Specific Gravity of Bottom Phase (dimensionless)
γ_t: Specific Gravity of Top Phase (dimensionless)

Output(s)

T: Retention Time (h)

Formula(s)

$$T = \frac{A * \mu}{\gamma_b - \gamma_t}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 87.*

12.55 Safety relief valves sizing in vapor services

Input(s)

C: Specific Heat Ratio (dimensionless)
K_o: Valve Discharge Coefficient (dimensionless)
A: Effective Discharge Area (in.^{2})
B: Conversion constant (dimensionless)
P: Upstream Relieving Pressure (psi)
M: Gas Molecular Weight (dimensionless)
Z: Compressibility Factor (dimensionless)
T: Inlet Temperature (R)

Output(s)

w: Weight Flow Through Valve (lb/h)

Formula(s)

$$w = (B) * C * K_o * A * P * \left(\frac{M}{Z * T}\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 296.*

12.56 Steady-state temperature controller

Input(s)

T_o: Outlet Temperature (K)
T_m: Maximum Controller Temperature (K)
b: Constant (dimensionless)
U: Overall Heat Coefficient (W/ft K)
A: Area (ft)

Output(s)

T_i: Initial Temperature (K)

Formula(s)

$$T_i = T_o * \left(1 - \left(\frac{b}{U * A}\right)\right) + \frac{b * T_m}{U * A}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 15, Page: 470.*

12.57 Still column diameter in glycol dehydration unit

Input(s)

m: Glycol circulation rate (gal/m)

Output(s)

d: Diameter (in.)

Formula(s)

$$d = 9.1 * m^{0.5}$$

Reference: *John M. Campbell. Gas Conditioning & Processing Vol. 2. Campbell Petroleum Series. OK. 1992.*

12.58 Stripping factor

Input(s)

K: Stripping Coefficient (dimensionless)
V: Moles of Stripping Medium Entered (moles)
L: Moles of Lean Oil Leaving Stripper (moles)

Output(s)

S: Stripping Factor (dimensionless)

Formula(s)

$$S = \frac{K * V}{L}$$

Reference: *Campbell, J. M., (1992, Oklahoma (United States)) Gas Conditioning and Processing Volume 2, Campbell Petroleum Series, Page: 313.*

12.59 Surface tension from density

Input(s)

P: Pressure (dyn/cm^2)
M: Molecular Wt (gms)
ρ_l: Liquid Density (g/cc)
ρ_v: Vapor Density (g/cc)

Output(s)

ω: Surface Tension (dyn/cm)

Formula(s)

$$\omega^{0.25} = \left(\frac{P}{M}\right) * (\rho_l - \rho_v)$$

Reference: *Campbell, J. M., (1992, Houston, TX (United States)), Gas Conditioning and Processing, Vol. 1, Campbell Petroleum Series, Page: 75.*

12.60 Tarnishing of metal surfaces

Input(s)

$D_{O2_{MOx}}$: Diffusivity (cm^2/s)
t: Time (s)
x: Mole Fraction of Oxygen (dimensionless)
c_o: Solubility of Oxygen (g/cc)
c_f: Molar Density of the Film (g mol/cc)

Output(s)

z_f: Thickness of Film (cm)

Formula(s)

$$z_f = \left(\left(\frac{2 * D_{O2_{MOx}} * t * c_o}{x * c_f} \right)^{0.5} \right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 18, Page: 576.*

12.61 TEG weight percent in glycol dehydration unit

Input(s)

m: Weight of Lean TEG (g)
w: Weight of Water Absorbed (g)
l: Weight of Water in Lean TEG (g)

Output(s)

wt: Weight Percent (%)

Formula(s)

$$wt = \frac{m * 100}{m + w + 1}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 341.*

12.62 Temperature after refrigeration

Input(s)

T_i: Input Temperature (K)
P_i: Input Pressure (psi)
P_o: Output Pressure (psi)
E: Isentopic Efficiency (dimensionless)
m: Cycle Efficiency (dimensionless)

Output(s)

T_o: Output Temperature (K)

Formula(s)

$$T_o = T_i + T_i * \left(\left(\left(\frac{P_o}{P_i} \right)^m \right) - 1 \right) * E$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 254.*

12.63 Temperature dependent source rate for flow reactor

Input(s)

K: Constant (dimensionless)
E: Constant of Time-dependence (dimensionless)
R: Gas Constant (m cm^2/s^2 K)
T: Temperature (K)

Output(s)

S_e: Entropy (g cm^2/s^2 K)

Formula(s)

$$S_e = K * e^{\frac{-E}{R*T}}$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 326.*

12.64 Temperature distribution in a hot-wire anemometer

Input(s)

D: Diameter (ft)
L: Length (ft)
I: Current (Amp)
h: Heat Transfer Coefficient (btu/h ft^2 F)
k_e: Thermal Conductivity of Ambiance (1/Ω ft)
z: Distance (ft)

Output(s)

T: Temperature increase (F)

Formula(s)

$$T = \left(\frac{D * (I^2)}{4 * h * k_e}\right) * \left(1 - \left(\frac{\cosh\left(\left(\frac{4 * h}{k * D * z}\right)^{0.5}\right)}{\cosh\left(\left(\frac{4 * h}{k * D * L}\right)^{0.5}\right)}\right)\right)$$

Reference: *Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (2002). Transport Phenomena (Second Ed.). John Wiley & Sons, Chapter: 10, Page: 328.*

12.65 Terminal velocity in a separator

Input(s)

g: Acceleration Due to Gravity (ft/s^2)
D_p: Particle Diameter (ft)
N: Drag Coefficient (fraction)
ρ_p: Particle Density (g/cc)
ρ_f: Fluid Density (g/cc)
A: Flow Regime Constant (dimensionless) (dimensionless)
μ: Viscosity (cP)

Output(s)

v_t: Terminal Velocity of a Particle falling through a fluid by the pull of Gravity (ft/s)

Formula(s)

$$v_t = \left(\frac{4 * g * \left(D_p^{N+1}\right) * \left(\rho_p - \rho_f\right)}{3 * A * (\mu^N) * \left(\rho_f^{1-N}\right)}\right)^{\frac{1}{2-N}}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 71.*

12.66 Thickness criteria of spherical shells in separator (ASME)

Input(s)

P: Pressure (psi)
R: Radius (ft)
E: Joint Efficiency (fraction)
S: Maximum Allowable Stress (psi)

Output(s)

t: Thickness of the Spherical Shell (ft)

Formula(s)

$$t = \frac{P * R}{2 * S * E - 0.2 * P}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 64.*

12.67 Top distillation column rate

Input(s)

G: Gas Mass Velocity (lb/ft^2 s)
F: Packing Factor (dimensionless)
μ_l: Liquid Viscosity (cP)
ρ_g: Gas Density (lbm/ft^3)
ρ_l: Liquid Density (lbm/ft^3)

Output(s)

Y: Top Distillation Column Rate (dimensionless)

Formula(s)

$$Y = \frac{(G^2) * F * (\mu_l^{0.1})}{\rho_g * \left(\rho_l - \rho_g\right)}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 317.*

12.68 Vapor mass velocity of tray type tower

Input(s)

K_s: Sizing Constant (ft/s)
ρ_l: Liquid Density (lbm/ft^3)
ρ_g: Gas Density (lbm/ft^3)

Output(s)

w: Vapor Mass Velocity (lbm/h ft^2)

Formula(s)

$$w = 3600 * K_s * \left(\left(\rho_l - \rho_g\right) * \rho_g\right)^{0.5}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 315.*

12.69 Wall thickness criteria for separator by ASME (external radius)

Input(s)

P: Pressure (psi)
R_o: External Radius of Separator (ft)
S: Maximum Allowable Stress (psi)
E: Joint Efficiency (fraction)

Output(s)

t: Thickness (ft)

Formula(s)

$$t = \frac{P * R_o}{S * E + 0.4 * P}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 64.*

12.70 Wall thickness criteria for separator by ASME (internal radius)

Input(s)

P: Pressure (psi)
R_i: Internal Radius (ft)
S: Maximum Allowable Stress (psi)
E: Joint Efficiency (fraction)

Output(s)

t: Thickness (ft)

Formula(s)

$$t = \frac{P * R_i}{S * E - 0.6 * P}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 64.*

12.71 Water loading in adsorption unit

Input(s)

q: Flow Rate (mmscf/d)
w: Water Content (lb/mmscf)
d: Bed Diameter (ft)

Output(s)

q_l: Water Loading (lb/ft^2 h)

Formula(s)

$$q_l = \frac{0.053 * q * w}{d^2}$$

Reference: *Campbell, J. M., (1992, Oklahoma (United States)) Gas Conditioning and Processing Volume 2, Campbell Petroleum Series, Page: 391.*

12.72 Weight of rich TEG in glycol dehydration unit

Input(s)

ρ: Liquid Density (g/cc)
TEG: Weight Percent of TEG in Lean TEG Solution (%)
m: Lean TEG Rate (gal/lb)

Output(s)

R: Weight of Rich TEG in TEG Solution (%)

Formula(s)

$$R = \frac{\rho * TEG}{\rho + \left(\frac{1}{m}\right)}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 2, Page: 341.*

12.73 Wobbe index

Input(s)

GHV: Gross Heating Value (btu/ft^3)
γ: Specific Gravity (dimensionless)

Output(s)

W: Wobbe Number (dimensionless)

Formula(s)

$$W = \frac{GHV}{\gamma^{0.5}}$$

Reference: *John M. Campbell, Gas Conditioning and Processing, Campbell Petroleum Series, Oklahoma, 1992, Vol. 1, Page: 291.*

12.74 Work done by expansion tube refrigerator

Input(s)

E: Efficiency (dimensionless)
m: Mass Flow Rate (lb/ft)

h_o: Outlet Enthalpy (btu/lb)
h_i: Inlet Enthalpy (btu/lb)

Output(s)

w: Work Done (btu)

Formula(s)

$$w = E * m * (h_o - h_i)$$

Reference: *John M. Campbell, Gas Conditioning & Processing Vol. 2. Campbell Petroleum Series. OK. 1992, Page: 89.*

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