PETROCALC

Formulae

A listing of the formulae used in the app PetroCalc. The document also includes formulae the student should be familiar with when undertaking a petroleum engineering course.

1. Reservoir Engineering

1.1. Volumetric Methods

OIL IN PLACE FORMULA

$$N = \frac{7758 A h \Phi (1 - S_w)}{B_{oi}}$$

Symbol	Name	Units
N	Reserves	STB
A	Areal Extent of the reserves	Acres
h	Thickness of the oil zone	ft
Φ	Porosity	Decimal fraction
S_w	Water Saturation	Decimal fraction
B_{oi}	Initial Oil Formation Volume Factor	Reservoir bbl/STB

GAS IN PLACE FORMULA

$$G = \frac{43560 A h \Phi (1 - S_w)}{B_{gi}}$$

$$G_p = 43560 A h \emptyset (1 - S_w) \left(\frac{1}{B_{gi}} - \frac{1}{B_g} \right)$$

$$RF = \frac{G_p}{G}$$

Symbol	Name	Units
G	Gas Reserves	SCF
G_p	Gas Produced	SCF
RF	Recovery Factor	
A	Areal Extent of the reserves	Acres
h	Thickness of the oil zone	ft
Φ	Porosity	Decimal fraction
S_w	Water Saturation	Decimal fraction
B_{gi}	Initial Gas Formation Volume Factor	Reservoir ft^3/SCF
B_g	Gas Formation Volume Factor	Reservoir ft^3/SCF

API TO SPECIFIC GRAVITY CONVERTER

$$\gamma_o = \frac{141.5}{°API + 131.5}$$

Symbol	Name	Units
γ_o	Specific Gravity	Unit less
$°API$	API Gravity	$°API$

1.2. Z-Factor

PSEUDO-CRITICAL TEMPERATURE & PRESSURE

General

$$p_{pc} = 709.604 - 58.71\gamma_g$$

$$T_{pc} = 170.491 + 307.344\gamma_g$$

Natural Gas System

$$p_{pc} = 677 + 15.0\gamma_g - 37.5{\gamma_g}^2$$

$$T_{pc} = 168 + 325\gamma_g - 12.5{\gamma_g}^2$$

Gas − Condensate System

$$p_{pc} = 706 - 51.7\gamma_g - 11.1{\gamma_g}^2$$

$$T_{pc} = 187 + 330\gamma_g - 71.5{\gamma_g}^2$$

Symbol	Name	Units
γ_g	Gas Specific Gravity	
p_{pc}	Pseudo-Critical Pressure	psia
T_{pc}	Pseudo-Critical Temperature	$°R$

PSEUDO-CRITICAL TEMPERATURE & PRESSURE ADJUSTMENT FOR IMPURITIES

Carr – Kobayashi – Burrows Correction

$$p'_{pc} = p_{pc} + 440y_{CO_2} + 600y_{H_2S} - 170y_{N_2}$$

$$T'_{pc} = T_{pc} - 80y_{CO_2} + 130y_{H_2S} - 250y_{N_2}$$

Ahmed Correction

$$p_{pc} = 678 - 50(\gamma_g - 0.5) + 440y_{CO_2} + 606.7y_{H_2S} - 206.7y_{N_2}$$

$$T_{pc} = 326 - 315.7(\gamma_g - 0.5) - 83.3y_{CO_2} + 133.3y_{H_2S} - 240y_{N_2}$$

Symbol	Name	Units
γ_g	Gas Specific Gravity	
p_{pc}	Pseudo-Critical Pressure	psia
T_{pc}	Pseudo-Critical Temperature	°R
p'_{pc}	Corrected Pseudo-Critical Pressure	psia
T'_{pc}	Corrected Pseudo-Critical Temperature	°R
y_{CO_2}	CO_2 Mole Fraction	
y_{H_2S}	H_2S Mole Fraction	
y_{N_2}	N_2 Mole Fraction	

PSEUDO-REDUCED TEMPERATURE & PRESSURE

$$T_{pr} = \frac{T}{T_{pc}}$$

$$p_{pr} = \frac{p}{p_{pc}}$$

Symbol	Name	Units
T	Temperature	°R
p	Pressure	psia
T_{pr}	Pseudo-Reduced Temperature	°R
p_{pr}	Pseudo-Reduced Pressure	psia
p_{pc}	Pseudo-Critical Pressure	psia
T_{pc}	Pseudo-Critical Temperature	°R

Z – FACTOR (BASED ON WORK FROM BRILL & BEGGS)

$$A = 1.39\left(T_{pr} - 0.92\right)^{0.5} - 0.36T_{pr} - 0.10$$

$$B = \left(0.62 - 0.25T_{pr}\right)p_{pr} + \left(\frac{0.66}{T_{pr} - 0.86} - 0.037\right){p_{pr}}^2 + \frac{0.32p_{pr}^2}{10^E}$$

$$C = 0.132 - 0.32\,log\left(T_{pr}\right)$$

$$D = 10^F$$

$$E = 9\left(T_{pr} - 1\right)$$

$$F = 0.3106 - 0.49T_{pr} + 0.1824{T_{pr}}^2$$

$$z = A + \frac{1 - A}{e^B} + C{p_{pr}}^D$$

Symbol	*Name*	*Units/Value*
T_{pr}	*Pseudo-Reduced Temperature*	
p_{pr}	*Pseudo-Reduced Pressure*	
z	*Gas Compressibility Factor*	

Z – FACTOR (BASED ON DATA FROM STANDING & KATZ)

$$Z = 1 + \rho R\left(A_1 + \frac{A_2}{T_R} + \frac{A_3}{{T_R}^3}\right) + \rho R^2\left(A_4 + \frac{A_5}{T_R}\right) + \frac{A_6\rho R^2}{{T_R}^2}$$

$$\rho R = 0.27\frac{P_R}{ZT_R}$$

Symbol	*Name*	*Units/Value*
T_R	*Pseudo-Reduced Temperature*	
A_1		*0.31506*
A_2		*-1.0467*
A_3		*-0.5783*
A_4		*0.5353*
A_5		*-0.6123*
A_6		*0.6815*

1.3. Material Balance

Material Balance Equation

Simplified

$$\begin{aligned} &oil\ zone\ expansion + gas\ cap\ expansion + water\ influx \\ &\quad = cumulative\ oil\ production + gas\ cap\ production + cumulative\ water\ production \end{aligned}$$

Note

$$B_t = B_o + (R_{si} - R_s)B_g$$

With proper terms in place

$$N(B_t - B_{ti}) + \frac{NmB_{ti}\left(B_g - B_{gi}\right)}{B_{gi}} + W_e = N_pB_t + N_p\left(R_p - R_{si}\right)B_g + B_wW_p$$

Re-arranging

$$N\left[B_t - B_{ti} + \frac{mB_{ti}\left(B_g - B_{gi}\right)}{B_{gi}}\right] = N_p\left[B_t + \left(R_p - R_{si}\right)B_g\right] - W_e + B_wW_p$$

In terms of Initial Oil In Place

$$N = \frac{N_p\left[B_t + \left(R_p - R_{si}\right)B_g\right] - \left(W_e - B_wW_p\right)}{B_t - B_{ti} + \frac{mB_{ti}\left(B_g - B_{gi}\right)}{B_{gi}}}$$

For No Water Drive: $W_e = 0$

$$N = \frac{N_p\left[B_t + \left(R_p - R_{si}\right)B_g\right] + B_wW_p}{B_t - B_{ti} + \frac{mB_{ti}\left(B_g - B_{gi}\right)}{B_{gi}}}$$

For No Original Free Gas: $m = 0$

$$N = \frac{N_p\left[B_t + \left(R_p - R_{si}\right)B_g\right] - \left(W_e - B_wW_p\right)}{B_t - B_{ti}}$$

For No Gas Cap or Water Drive: $W_e = 0\ \&\ m = 0$

$$N = \frac{N_p\left[B_t + \left(R_p - R_{si}\right)B_g\right]}{B_t - B_{ti}}$$

Symbol	*Name*	*Units*
p_i	*Initial reservoir pressure*	*psi*
p	*Volumetric average pressure*	*psi*
Δp	*Reservoir pressure change*	*psi*
p_b	*Bubble point pressure*	*psi*
N	*Initial Oil in place*	*STB*
N_p	*Cumulative oil produced*	*STB*
G_p	*Cumulative gas produced*	*scf*
W_p	*Cumulative water produced*	*bbl*

R_p	*Cumulative gas-oil ratio produced*	*scf/STB*
GOR	*Instantaneous gas-oil ratio*	*scf/STB*
R_{si}	*Initial gas solubility*	*scf/STB*
R_s	*Gas Solubility*	*scf/STB*
B_{oi}	*Initial Formation Volume Factor*	*Reservoir bbl/STB*
B_o	*Oil Formation Volume Factor*	*Reservoir bbl/STB*
B_{gi}	*Initial Gas Formation Volume Factor*	*Reservoir* ft^3*/SCF*
B_g	*Gas Formation Volume Factor*	*Reservoir* ft^3*/SCF*
W_{inj}	*Cumulative Water Injected*	*STB*
G_{inj}	*Cumulative Gas Injected*	*scf*
W_e	*Cumulative Water Influx*	*bbl*
G	*Initial Gas-Cap gas*	*scf*
C_w	*Water compressibility*	psi^{-1}
C_f	*Formation rock compressibility*	psi^{-1}
P.V.	*Pore Volume*	*bbl*
m	*Initial gas-cap-gas reservoir volume to initial reservoir oil volume*	*bbl/bbl*

2. Natural Gas Engineering

2.1. Reciprocating Compressor

ISENTROPIC EXPONENT

$$k = \frac{C_p}{C_v} = \frac{C_p}{C_p - 1.986}$$

Symbol	Name	Units
k	Isentropic Exponent	
C_p	Final Dis-Charge Pressure	
C_v	Suction Pressure	

COMPRESSION RATIO

$$r = \left(\frac{p_d}{p_s}\right)^{1/N_s}$$

Symbol	Name	Units
r	Cylinder Compression Ratio	
p_d	Final Dis-Charge Pressure	psia
p_s	Suction Pressure	psia
N_s	Number of Stages Required	

DIS-CHARGE TEMPERATURE (FOR REAL GAS)

$$T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{z_1(k-1)/k}$$

Symbol	Name	Units
k	Isentropic Exponent	
p_1	Suction Pressure	psia
p_2	Dis-Charge Pressure	psia
T_1	Suction Temperature	°R
T_2	Dis-Charge Temperature	°R
z_1	Suction Compressibility Factor	

Volumetric Efficiency

$$E_v = 0.97 - \left[\left(\frac{z_s}{z_d}\right) r^{1/k} - 1\right] C_l - e_v$$

Symbol	*Name*	*Units*
E_v	*Volumetric Efficiency*	
r	*Cylinder Compression Ratio*	
C_l	*Clearance*	
z_s	*Suction gas deviation factor*	
z_d	*Intake gas deviation factor*	
e_v	*Correction factor*	

Horsepower (Work Done) per MMcfd

$$Hp_{MM} = \frac{k}{k-1} \frac{3.027 p_b}{T_b} T_1 \left[\left(\frac{p_2}{p_1}\right)^{z_1(k-1)/k} \right]$$

Symbol	*Name*	*Units*
Hp_{MM}	*Theoretical Compression HP*	*HP/MMcfd*
k	*Isentropic Exponent*	*psia*
p_1	*Suction Pressure*	*psia*
p_2	*Dis-Charge Pressure*	°*R*
T_1	*Suction Temperature*	°*R*
z_1	*Suction Compressibility Factor*	

Brake Horsepower

$$Hp_b = \frac{q Hp_{MM}}{E_o}$$

Symbol	*Name*	*Units*
Hp_{MM}	*Theoretical Compression HP*	*HP/MMcfd*
Hp_b	*Brake Horsepower*	*HP*
E_0	*Overall Efficiency*	*Decimal Fraction*

2.2. Centrifugal Compressors

Centrifugal Compression Ratio		

$$r = \frac{p_2}{p_1}$$

Symbol	*Name*	*Units*
r	*Cylinder Compression Ratio*	
p_2	*Final Dis-Charge Pressure*	*psia*
p_1	*Suction Pressure*	*psia*

Poly-Tropic Ratio		

$$R_p = \frac{n-1}{n} = \frac{k-1}{k} \times \frac{1}{E_p}$$

Symbol	*Name*	*Units*
n	*Polytropic Exponent*	
k	*Isentropic Exponent*	
E_p	*Polytropic Efficiency*	

Polytropic Efficiency		

$$E_p = 0.61 + 0.03 log(q_1)$$

Symbol	*Name*	*Units*
q_1	*Suction Gas Capacity*	*cfm*
E_p	*Polytropic Efficiency*	

Centrifugal Dis-Charge Temperature		

$$T_2 = T_1 r^{R_p}$$

Symbol	*Name*	*Units*
T_1	*Suction Temperature*	°R
T_2	*Dis-Charge Temperature*	°R
r	*Compression Ratio*	
R_p	*Polytropic Ratio*	

$$q_1 = \frac{z_1 p_b}{z_2 p_1} \frac{T_1}{T_b} q$$

Symbol	*Name*	*Units*
T_1	*Suction Temperature*	°R
T_b	*Base Temperature (520)*	°R
q_1	*Suction Flow rate*	*cfm*
q	*Gas Flow rate*	*cfm*
z_1	*Suction Compressibility Factor*	
z_2	*Dis-Charge Compressibility Factor*	
p_b	*Base Pressure (14.7)*	*psia*
p_1	*Suction Pressure*	*psia*

Centrifugal HP Equation

$$Hp_g = \frac{q_1 p_1}{229 E_p} \left(\frac{z_1 + z_2}{2 z_1}\right) \left(\frac{r^{R_p}}{R_p} - 1\right)$$

An alternate form:

$$BHP = 0.0857 [Z_{av}] \left[\frac{(Q_g)(T_s)}{E}\right] \left[\frac{kn}{k-1}\right] \left[\left(\frac{P_d}{P_s}\right)^{\frac{k-1}{kn}} - 1\right]$$

Symbol	*Name*	*Units*
Hp_g	*Gas Horsepower*	*HP*
q_1	*Suction Flowrate*	*cfm*
p_1	*Suction Pressure*	*psia*
E_p	*Polytropic Efficiency*	
E	*Efficiency (centrifugal units = 0.72)*	
z_1	*Suction Compressibility Factor*	
z_2	*Dis-Charge Compressibility Factor*	
R_p	*Polytropic Ratio*	
P_s	*Suction pressure*	*psia*
P_d	*Dis-Charge pressure*	*psia*
Z_{av}	*Average Compressibility Factor*	
n	*Polytropic Exponent*	
k	*Isentropic Exponent*	
Q_g	*Volume of Gas*	*MMscfd*
T_s	*Suction Temperature*	°R

Polytropic Head

$$H_g = RT_1\left(\frac{z_1 + z_2}{2}\right)\left(\frac{r^{R_p}}{R_p} - 1\right)$$

Symbol	Name	Units
H_g	Polytropic Head	HP
R	Gas Constant (1544)	psiaft³/lbm-°R
T_1	Suction Temperature	°R
z_1	Suction Compressibility Factor	
z_2	Dis-Charge Compressibility Factor	
R_p	Polytropic Ratio	

Gas Horse Power

$$Hp_g = \frac{\dot{m}H_g}{33000E_p}$$

Symbol	Name	Units
Hp_g	Gas Horsepower	HP
E_p	Polytropic Efficiency	
H_g	Polytropic Head	HP
$\dot{m}$	Mass Flow Rate	lb/min

Gas Molecular Weight

$$M = 28.96\gamma_g$$

Symbol	Name	Units
M	Apparent Gas Molecular Weight	
γ_g	Specific Gas Gravity	

2.3. Gas Measurement

Orifice Flow Rate		

$$q_h = C'\sqrt{(h_w p_f)}$$

Symbol	*Name*	*Units*
q_h	*Quantity flow rate*	*cfm*
C'	*Orifice flow constant*	
h_w	*Differential Pressure*	*in*
p_f	*Absolute Static pressure*	*psi*

$$F_{bp} = \frac{14.73}{Contracted\ pressure\ base}$$

$$F_{tb} = \frac{T_b}{520}$$

Symbol	*Name*	*Units*
T_b	*Base Temperature*	°*F*

$$F_{tf} = \sqrt{\frac{520}{460 + actual\ flow\ temperature}}$$

$$F_g = \frac{1}{\sqrt{\gamma_g}}$$

Symbol	*Name*	*Units*
γ_g	*Specific Gravity of Gas*	°*F*

$$F_{pv} = \frac{1}{\sqrt{z}}$$

Symbol	*Name*	*Units*
z_b	*Gas Deviation factor at base conditions*	°F
z	*Gas Deviation factor at operating conditions*	

3. Improved Oil Recovery

3.1. Basic Formulae

DISPLACEMENT EFFICIENCY

$$E_D = \frac{Oil\ Volume\ at\ start\ of\ flood - Remaining\ Oil}{Oil\ Volume\ at\ start\ of\ flood}$$

$$= \frac{(Pore\ Volume)\left(\frac{S_{oi}}{B_{oi}}\right) - (Pore\ Volume)\left(\frac{\overline{S_o}}{B_{oi}}\right)}{(Pore\ Volume)\left(\frac{S_{oi}}{B_{oi}}\right)}$$

$$= \frac{\frac{S_{oi}}{B_{oi}} - \frac{\overline{S_o}}{B_{oi}}}{\frac{S_{oi}}{B_{oi}}}$$

Symbol	Name	Units
S_{oi}	Initial oil saturation at oil flood start	
B_{oi}	Oil FVF at oil flood start	bbl/STB
$\overline{S_o}$	Average oil saturation	

FRACTIONAL FLOW EQUATION

$$f_w = \frac{q_w}{q_t} = \frac{q_w}{q_w + q_o} = \frac{1}{1 + \left(\frac{k_{ro}}{k_{rw}}\frac{\mu_w}{\mu_o}\right)}$$

Symbol	Name	Units
f_w	Water cut	bbl/bbl
q_t	Total flow rate	bbl/day
q_w	Water flow rate	bbl/day
q_o	Oil flow rate	bbl/day
μ_w	Water viscosity	cp
μ_o	Oil viscosity	cp
k_{ro}	Relative permeability to oil	
k_{rw}	Relative permeability to water	

SURFACE WOR

$$WOR_s = \frac{B_o}{B_w\left(\frac{1}{f_w} - 1\right)} = \frac{B_o f_w}{B_w(1-f_w)} = WOR_r\left(\frac{B_o}{B_w}\right)$$

Symbol	Name	Units
WOR_s	Surface Water-Oil Ratio	
WOR_r	Reservoir Water-Oil Ratio	
B_w	Water FVF	bbl/STB
f_w	Water cut	bbl/bbl

MOBILITY RATIO

$$M = \left(\frac{k_{rD}}{\mu_D}\right)_{SD}\left(\frac{\mu_d}{k_{rd}}\right)_{sd} = \frac{\lambda_D}{\lambda_d}$$

Symbol	Name	Units
k_{rD}	Relative permeability of the displacing phase	
μ_D	Viscosity of the displacing phase	
μ_d	Viscosity of the displaced phase	
k_{rd}	Relative permeability of the displaced phase	
SD	Avg. saturation of the displacing phase, behind front	
sd	Avg. saturation of the displaced phase, ahead of the front	

RELATIVE PERMEABILITY

$$k_{ro} = \frac{k_o}{k}, k_{ro} = \frac{k_w}{k}$$

Symbol	Name	Units
k_{ro}	Relative permeability to oil	
k_o	Permeability of oil	
k_w	Permeability to water	
k_{rw}	Relative permeability to water	
K	Base permeability	

CAPILLARY PRESSURE		

$$P_c = \frac{2\sigma \cos\theta}{r_c}$$

Symbol	Name	Units
P_c	Capillary pressure	Pa
σ	Interfacial Tension	mN/m
θ	Contact Angle	
r_c	Radius of capillary	M

CAPILLARY NUMBER		

$$\frac{F_v}{F_c} = \frac{v\mu_w}{\sigma_{ow} \cos\theta}$$

Symbol	Name	Units
v	Interstitial velocity	
μ_w	Water viscosity	
σ_{ow}	IFT	

3.2. Production Formulae

WATER INJECTION PERFORMANCE		

$$N_p = \frac{V_p(S_{oi} - S_{or})E_s E_i}{B_o}$$

$$N_p = V_p(\overline{S_w} - S_{wirr})$$

Symbol	Name	Units
N_p	Recovered Oil	bbl
V_p	Pore Volume Swept	
S_{oi}	Initial Oil Saturation	
S_{or}	Residual Oil Saturation	
E_s	Areal Sweep Efficiency	
E_i	Vertical Sweep Efficiency	
B_o	Oil Formation Volume Factor	RB/bbl
$\overline{S_w}$	Average Water Saturation	
S_{wirr}	Irreducible Water Saturation	

4. Reservoir Evaluation

4.1. The Basics

Formation Factor		
$F = \frac{a}{\emptyset^m}$		
Symbol	*Name*	*Units*
a	*Tortuosity Factor*	
Φ	*Porosity*	*Decimal fraction*
m	*Cementation Factor*	
Recommended Values		
Formation Type	*a*	*m*
Carbonates	*1.00*	*2.00*
Sandstones $\emptyset < 16\%$	*0.81*	*2.00*
Sandstones $\emptyset > 16\%$	*0.62*	*2.15*

4.2. Water Saturation

ARCHIE'S EQUATION - WATER SATURATION

$$S_w{}^n = \left(\frac{a}{\emptyset^M}\right)\left(\frac{R_w}{R_t}\right)$$

If we re-arrange the equation

$$S_w = \sqrt[n]{\left(\frac{a}{\emptyset^M}\right)\left(\frac{R_w}{R_t}\right)}$$

If we use the convention n=2 we get

$$S_w = \sqrt{\left(\frac{a}{\emptyset^M}\right)\left(\frac{R_w}{R_t}\right)}$$

Symbol	*Name*	*Units*
S_w	*Water saturation*	
n	*Saturation Exponent (Usually n=2)*	
a	*Tortuosity Factor*	
Φ	*Porosity*	*Decimal fraction*
M	*Cementation Factor*	
R_w	*Resistivity of formation water*	Ωm
R_t	*True Resistivity*	Ωm
Recommended Values		
Formation Type	*a*	*m*
Carbonates	*1.00*	*2.00*
Sandstones $\emptyset < 16\%$	*0.81*	*2.00*
Sandstones $\emptyset > 16\%$	*0.62*	*2.15*

WATER SATURATION		

$$\frac{S_w}{S_{xo}} = \left(\frac{R_{xo}/R_t}{R_{mf}/R_w}\right)^{1/2}$$

Empirical evidence has shown $S_{xo} \approx S_w{}^{1/5}$ *.*
Using that relationship we get:

$$S_w = \left(\frac{R_{xo}/R_t}{R_{mf}/R_w}\right)^{5/8}$$

Symbol	*Name*	*Units*
S_w	*Water saturation*	
S_{xo}	*Water saturation in flushed zone*	
R_w	*Resistivity of formation water*	Ωm
R_t	*True Resistivity*	Ωm
R_{xo}	*Resistivity of flushed zone*	Ωm
R_{mf}	*Resistivity of mud filtrate*	Ωm

4.3. Logging Formulae

POROSITY – LOG & SONIC		

$$\emptyset_D = \frac{(\varrho_{ma} - \varrho_{log})}{(\varrho_{ma} - \varrho_f)}$$

Similarly

$$\emptyset_S = \frac{(t_{log} - t_{ma})}{(t_f - t_{ma})} = c\left(\frac{(t_{log} - t_{ma})}{(t_f)}\right)$$

Symbol	*Name*	*Units*
Φ	*Porosity*	*Decimal fraction*
ϱ_{ma}	*Matrix density (obtained from tables)*	
ϱ_{log}	*Bulk Density from log*	
ϱ_f	*Average fluid density (obtained from tables)*	
t_{log}	*Interval time from log*	
t_{ma}	*Interval time for matrix material*	
t_f	*Interval time for saturated fluid*	
c	*Constant* $(c \cong 0.67)$	

Density Crossplot

$$\emptyset = \sqrt{\frac{\emptyset N^2 + \emptyset D^2}{2}}$$

Symbol	*Name*	*Units*
$\emptyset$	*Porosity*	
$\emptyset N$	*Neutron Porosity*	*Limestone Units*
$\emptyset D$	*Density Porosity*	*Limestone Units*

Density – Gamma Ray Index

$$IGR = \frac{(GR_{log} - GR_{min})}{(GR_{max} - GR_{min})}$$

Symbol	*Name*	*Units*
IGR	*Gamma Ray Index*	*Dimensionless*
GR_{log}	*Gamma ray reading of formation*	
GR_{min}	*Minimum gamma ray (clean sand or carbonate)*	
GR_{max}	*Maximum gamma ray (Shale)*	

R_W from SP

$$SP = -K\left(log\,\frac{R_{mf}}{R_w}\right)$$

$$T_f = T_{surf} + (Depth)(Temperature\ Gradient)$$

$$K = 61 + 0.133T_{°F}$$

$$K = 65 + 0.24T_{°C}$$

$$R_2 = R_1[(T_1 + X)/(T_2 + X)]; \quad X = 6.77$$

$$R_{mfe} = 0.85R_{mf}$$

$$R_{we} = \frac{R_{mfe}}{10^{-SP/K}}$$

Symbol	*Name*	*Units*
R_{mf}	*Resistivity of mud filtrate*	Ωm
R_w	*Resistivity of formation water*	Ωm
K	*Constant*	

4.4. Pressure Transient

Diffusivity Equation		
$$\frac{\partial p}{\partial t} = \frac{k}{\emptyset \mu C_t}\left[\frac{\partial}{\partial r}\left(\frac{\partial p}{\partial r}\right) + \frac{1}{r}\left(\frac{\partial p}{\partial r}\right)\right]$$		
Symbol	*Name*	*Units*

Wellbore Storage		

$$C = \frac{\Delta V}{\Delta p}$$

For Two-Phase

$$C = 25.64\left(\frac{A_{wb}}{\rho_{wb}}\right)$$

For Single Phase

$$C = V_{wb} c_{wb}$$

Symbol	*Name*	*Units*
C	*Wellbore Storage Co-Efficient*	
ΔV	*Change in Volume*	*bbls*
Δp	*Change in Pressure*	*psi*
A_{wb}	*Wellbore area*	ft^2
ρ_{wb}	*Density of fluid in wellbore*	
V_{wb}	*Wellbore volume*	*bbl*
c_{wb}	*Compressibility to wellbore fluids*	psi^{-1}

Flow Efficiency

$$E = \frac{J_{actual}}{J_{ideal}}$$

$$E = \frac{q/(\bar{p} - p_{wf})}{q/(\bar{p} - p_{wf} - \Delta p_s)}$$

$$E = \frac{(\bar{p} - p_{wf} - \Delta p_s)}{(\bar{p} - p_{wf})}$$

Symbol	Name	Units
E	Flow Efficiency	
J_{actual}	Actual Drawdown	
J_{ideal}	Ideal Drawdown	
q	Flow Rate	bbl/Day
$\bar{p}$	Average Reservoir Pressure	psi
p_{wf}	Flowing Bottom Hole Pressure	psi
Δp_s	Pressure drop due to Skin/Formation Damage	psi

Skin Factor

$$s = 1.151\left[\frac{\Delta p_{1hr}}{m} - log\left(\frac{k}{\emptyset \mu c_t r_w^2}\right) + 3.23\right]$$

$$k = \frac{162.6qB\mu}{mh}$$

Symbol	Name	Units
s	Skin Effect	
k	Unaffected Permeability	
m	Slope of semi-log straight line graph	$psi/log_{10\ cycle}$
Δp_{1hr}	Pressure change in the 1st hour	psi
$\emptyset$	Porosity	Decimal Fraction
c_t	Compressibility	psi^{-1}
r_w	Wellbore Radius	
q	Flow Rate	gpm
B	Formation Volume Factor	rb/STB
μ	Viscosity	cp
k	Permeability	md
h	Net Thickness of formation	ft

SKIN FACTOR

$$s = \left(\frac{k}{k_s} - 1\right) ln\left(\frac{r_s}{r_w}\right)$$

We can re-arrange the formula

$$k_s = \frac{k}{1 + [s/ln(r_s/r_w)]}$$

Skin Effect modeled as effective wellbore radius

$$r_{wa} = r_w e^{-s}$$

Skin factor modeled as a pressure drop

$$\Delta p_s = (141.2qB\mu/kh)s$$

Symbol	Name	Units
s	Skin Effect	
k	Unaffected Permeability	
k_s	Affected Permeability	
r_s	Radius of Affected Permeability	
r_w	Wellbore Radius	
q	Flow Rate	gpm
B	Formation Volume Factor	rb/STB
μ	Viscosity	cp
k	Permeability	md
h	Net Thickness of formation	ft

5. Drilling and Completions

5.1. Hydraulics

Pressure Losses

Drill Stem

$$P = \frac{0.000061 \times MW \times L \times Q^{1.86}}{D^{4.86}}$$

Annular

$$P = \frac{(1.4327 \times 10^{-7}) \times MW \times L \times V^{2}}{D_h - D_p}$$

$$V = \frac{24.5 \times Q}{D_h^2 - D_p^2}$$

Symbol	*Name*	*Units*
MW	*Mud Weight*	*ppg*
L	*Length of section/Pipe*	*ft*
Q	*Flow rate*	*gpm*
D	*Pipe Inner Diameter*	*ins.*
D_h	*Hole Diameter*	*ins.*
D_p	*Pipe Outer Diameter*	*ins.*
V	*Annular Velocity*	*ft/min*

Flow Rates

$$G = 4B^2 + 5B$$

$$G_{min} = 12.72B^{1.47}$$

OR

$$G_{min} = 30 \times B$$

$$G_{max} = 50 \times B$$

For PDC Bits

$$G_{min} = 12.72 \times B^{1.47}$$

Symbol	*Name*	*Units*
G	*Optimum Flow rate*	*gpm*
G_{min}	*Minimum Flow rate*	*gpm*
G_{max}	*Maximum Flow rate*	*gpm*
B	*Bit Diameter*	*ins.*

5.2. Rig Sizing

Rig Sizing

$$Static\ Load = weight\ \times length$$

$$Pump\ HP = \left(\frac{flow\ rate\ \times pressure}{1714}\right) \times 0.803$$

$$Draw\ Works\ HP = \left(\frac{Hookload\ \times Trip\ Speed}{33000}\right) \times 0.649$$

$$Rotary\ HP = \left(DP\ Load\left(\frac{DP\ Dia}{24}\right)\right) \times DPrpm$$

Symbol	*Name*	*Units*
	Weight	*lbs*
	Length	*ft*
	Flow Rate	*gpm*
	Pressure	*psi*
	Horse Power	*HP*
	Hook Load	*lbs*
	Trip Speed	*fpm*
DP Load	*Drill Pipe Load*	*lbs*
DP Dia	*Drill Pipe Diameter*	*in*
DP rpm	*Drill Pipe Rotation*	*rpm*

5.3. Volumes

Volume

$$Vol = \left(\frac{Dia^2}{1029.4}\right) \times L$$

Annular Volume

$$Vol = \frac{D_h^2 - D_p^2}{1029.4} \times L$$

Symbol	*Name*	*Units*
Vol	*Volume*	*bbl*
Dia	*Diameter*	*in*
L	*Length*	*ft*
D_h	*Hole Diameter*	*ins.*
D_p	*Pipe Outer Diameter*	*ins.*

5.4. Casing & Cementing

CASING DESIGN

$$p_b = 0.875 \frac{2\sigma_{yield} t}{d_n}$$

$$p_c = 2\left(\sigma_{yield}\right)_e \left[\frac{d_n/t - 1}{(d_n/t)^2}\right]$$

Symbol	Name	Units
p_b	Burst pressure	psi
p_c	Collapse Pressure	psi
σ_{yield}	Minimum Yield	psi
d_n	Nominal Diameter	in
t	Thickness	in

CEMENTING DESIGN

$$wt. = \%\ Additive\ \times 94\ lb/sk$$

$$water\ \ gal/sk = Cmt.water\ requirement\ \ gal/sk + Additive\ water\ requirement\ \ gal/sk$$

$$Vol.\ \ gal/sk = \frac{94\ \ lb/sk}{SG\ \ \times 8.33} + \frac{wt.of\ additive\ \ lb/sk}{SG\ \ \times 8.33} + water\ vol.gal$$

$$wt.lb/sk = 94 + (8.33 \times vol\ of\ water\ gal) + (\%\ of\ additive\ \ \times 94)$$

$$Yield\ \ ft^3/sk = \frac{vol.of\ slurry\ \ gal/sk}{7.48\ \ gal/ft^3}$$

$$Density\ \ lb/gal = \frac{94 + wt.of\ additive + (8.33 \times vol.of\ water/sk)}{vol.of\ slurry\ \ gal/sk}$$

Symbol	Name	Units
Vol.	Volume	bbl
wt	Weight	Lbs.

6. Production Engineering

6.1. Separator Sizing

6.1.1. API Spec 12J

API SEPARATOR SIZING

$$V_a = K\sqrt{\frac{d_L - d_G}{d_G}}$$

$$Actual\ Volume\ flow\ rate\ of\ gas = \frac{Q\ x\ 20.3}{379.5\ x\ 86400\ x\ d_G}$$

$$A = \frac{V_a}{Actual\ Volume\ flow\ rate}$$

$$Min.ID\ of\ separator = \sqrt{\frac{A\ x\ 144}{0.7854}}$$

$$Vol = \frac{D^2 L}{1029.4}$$

$$W = \frac{1440(Vol)}{t}$$

Symbol	*Name*	*Units*
V_a	*Maximum Allowable Superficial Velocity*	*ft/s*
K	*Design Constant*	
d_L	*Liquid density at operating conditions*	lb/ft^3
d_G	*Gas density at operating conditions*	lb/ft^3
Q	*Gas Flow Rate*	*SCF/day*
	Actual Volume flow rate of gas	ft^3/s
A	*Min. gas flow area*	ft^2
Vol	*Volume of Separator*	*bbl*
t	*Retention time*	*mins.*
W	*Liquid Capacity*	*bbl/day*
D	*Minimum ID of separator*	*ins.*
L	*Length of Separator*	*ft*

K-Factor Details		
Separator	*Height or Length (L ft)*	*K- Factor*
Vertical	*5*	*0.12 – 0.24*
	10	*0.18 – 0.35*
Horizontal	*10*	*0.40 – 0.50*
	Other lengths	*0.40* – $0.50x(L/10)^{56}$

Retention Time				
	2 - Phase		*3 - Phase*	
	Oil Gravity	*Minutes*	*Oil Gravity*	*Minutes*
	Above 35 °API	*1*	*Above 35°API*	*3 - 5*
	20°– 30°API	*1 – 2*	*Below 35°API*	
	10°– 20°API	*2 - 4*	*100°F*	*5 - 10*
			80°F	*10 – 20*
			60°F	*20 - 30*

6.1.2. Other Methods

HORIZONTAL SEPARATOR SIZING

$$V_l = 0.0204\left[\frac{(\rho_l - \rho_g)d_m}{\rho_g}\right]^{1/2}$$

$$Re = 0.0049\frac{\rho_g d_m V}{\mu}$$

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$$

$$V_t = 0.0119\left[\left(\frac{\rho_g}{\rho_l - \rho_g}\right)\frac{C_D}{d_m}\right]^{1/2}$$

$$dL_{eff} = 420\left[\frac{TZQ_g}{P}\right]\left[\left(\frac{\rho_g}{\rho_l - \rho_g}\right)\frac{C_D}{d_m}\right]^{1/2}$$

$$d^2L_{eff} = \frac{t_r Q_l}{0.7}$$

$$L_{ss} = L_{eff} + \frac{d}{12}$$

$$Slenderness\ ratio = \frac{12L_{ss}}{d}$$

Symbol	Name	Units
d	Vessel ID	in
L_{eff}	Effective vessel length	ft
L_{ss}	Seam to seam length	ft
P	Operating Pressure	psi
T	Operating Temperature	°R
Z	Gas Compressibility	
Q_g	Gas flow rate	MMscfd
Q_l	Liquid flow rate	bopd
t_r	Desired residence time	min
ρ_g	Gas Density	lb/ft³
ρ_l	Liquid Density	lb/ft³
C_D	Drag Co-Efficient	
d_m	Liquid Droplet Size	micron

VERTICAL SEPARATOR SIZING

$$V_l = 0.0204\left[\frac{(\rho_l - \rho_g)d_m}{\rho_g}\right]^{1/2}$$

$$Re = 0.0049\frac{\rho_g d_m V}{\mu}$$

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$$

$$V_t = 0.0119\left[\left(\frac{\rho_g}{\rho_l - \rho_g}\right)\frac{C_D}{d_m}\right]^{1/2}$$

$$d^2 = 5040\left[\frac{TZQ_g}{P}\right]\left[\left(\frac{\rho_g}{\rho_l - \rho_g}\right)\frac{C_D}{d_m}\right]^{1/2}$$

$$d^2h = \frac{t_r Q_l}{0.12}$$

$$L_{ss} = \frac{h + 76}{12} \quad d \le 36in.$$

$$L_{ss} = \frac{h + d + 40}{12} \quad d > 36in.$$

$$Slenderness\ ratio = \frac{12L_{ss}}{d}$$

Symbol	Name	Units
d	Vessel ID	in
L_{eff}	Effective vessel length	ft
L_{ss}	Seam to seam length	ft
P	Operating Pressure	psi
T	Operating Temperature	°R
Z	Gas Compressibility	
Q_g	Gas flow rate	MMscfd
Q_l	Liquid flow rate	bopd
t_r	Desired residence time	min
ρ_g	Gas Density	lb/ft³
ρ_l	Liquid Density	lb/ft³
C_D	Drag Co-Efficient	
d_m	Liquid Droplet Size	micron

6.2. Production Decline

Exponential Decline

Rate

$$q = q_i e^{-Dt}$$

Cumulative Oil Production

$$N_p = \frac{q_i - q}{D}$$

Nominal Decline Rate

$$D_e = \frac{q_i - q}{q_i}, \; D = -ln(1 - D_e)$$

$$D = \frac{1}{t_2 - t_1} ln \frac{q_1}{q_2}$$

Effective Decline Rate

$$D_e = 1 - e^{-D}$$

$$q = q_i (1 - D_e)^t$$

Life

$$t = \frac{ln(q_i/q)}{D}$$

Symbol	Name	Units
q	Well production @ time t	STB/day
q_i	Well production @ time t = 0	STB/day
N_p	Cumulative oil produced	STB
D	Nominal Exponential Decline Rate	/day
D_e	Effective Decline Rate	/day
t_n	Time @ time = n	Day

Vogel's IPR Equation

$$q = q_{max} \left[1 - 0.2 \left(\frac{p_{wf}}{\bar{P}}\right) - 0.8 \left(\frac{p_{wf}}{\bar{P}}\right)^2\right]$$

Symbol	Name	Units
q	Flow rate	bbl/day
q_{max}	Maximum Flow rate	bbl/day
p_{wf}	Bottom Hole Pressure	psia
$\bar{P}$	Reservoir Pressure	psia

Vogel's Future IPR

$$q = \frac{J_f^* \overline{p_f}}{1.8}\left[1 - 0.2\left(\frac{p_{wf}}{\bar{p}_f}\right) - 0.8\left(\frac{p_{wf}}{\overline{p_f}}\right)^2\right]$$

$$J^* = \frac{k_{ro}}{B_o \mu_o}$$

$$J_f^* = J_p^* \frac{\left(\frac{k_{ro}}{B_o \mu_o}\right)}{\left(\frac{k_{ro}}{B_o \mu_o}\right)_{p\,f}}$$

Symbol	*Name*	*Units*
q	*Flow rate*	*bbl/day*
q_{max}	*Maximum Flow rate*	*bbl/day*
p_{wf}	*Bottom Hole Pressure*	*psia*
$\overline{p_f}$	*Reservoir Pressure*	*psia*
J^*	*Productivity Index*	
J_f^*, J_p^*	*Productivity Index Future, Present*	
k_{ro}	*Oil Relative Permeability*	
B_o	*Oil FVF*	
μ_o	*Oil Viscosity*	

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Appendix