# Mathematical Relationship Between Drainage Area and Slope of Pressure-Cum. Plot For a Volumetric Gas Reservoir

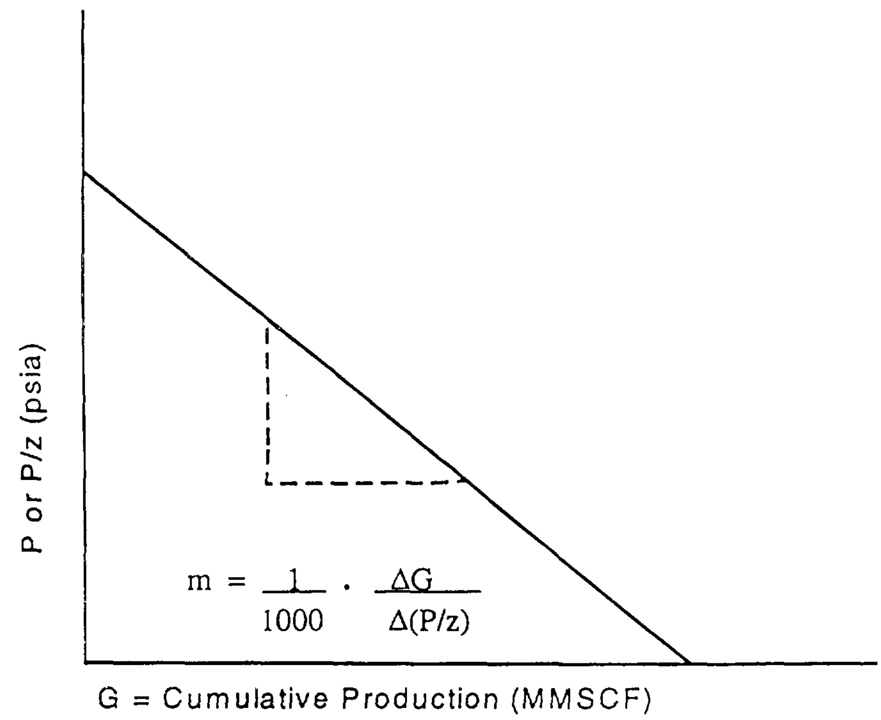
$$G = 43{,}560\ \phi h A\ (1-S_w)\ B_g$$

$$B_g = \frac{T_{sc}}{P_{sc}} \cdot \frac{P}{zT}$$

$$G = 43{,}560\ \phi h A\ (1-S_w) \left(\frac{T_{sc}}{P_{sc}T}\right) \left(\frac{P}{z}\right)$$

$$G = 43{,}560 \cdot \frac{T_{sc}}{P_{sc} \cdot T} \cdot \phi h A \cdot (1-S_w) \cdot \left(\frac{P}{z}\right)$$

m = slope of Pressure-Cum. Plot, MCF/psi




$$1000\ m = \frac{\Delta G_p}{\Delta(P/z)} = -43{,}560 \left(\frac{T_{sc}}{P_{sc} \cdot T}\right) \phi h A (1-S_w)$$

$$A = \frac{-1000\ m}{43{,}560 \cdot \frac{T_{sc}}{P_{sc}T} \cdot \phi h\ (1-S_w)}$$

Where:

| | | |
|---|---|---|
| $A$ | = | drainage area, acres |
| $\Delta G_p$ | = | production or change in gas in place, SCF |
| $\Delta(P/z)$ | = | change in corrected reservoir pressure, psi |
| $B_g$ | = | gas volume factor, SCF/ft.$^3$ |
| $T$ | = | reservoir temperature, °R |
| $T_{sc}$ | = | temperature at standard conditions, °R |
| $P_{sc}$ | = | pressure at standard conditions, psia |
| $\phi$ | = | average pay-section porosity |
| $h$ | = | net pay, ft. |
| $S_w$ | = | average pay-section water saturation |

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OIL CONSERVATION DIVISION
HARTMAN EXHIBIT NO. 25
CASE NOS. 12015 & 12017

## Mathematical Relationship Between Drainage Area and Slope of Pressure-Cum. Plot For Jalmat and Rhodes Gas Pools

$$A = \frac{-1000\,m}{43{,}560 \cdot \frac{T_{sc}}{P_{sc}T} \cdot \phi h\,(1-S_w)}$$

Where:

| | | |
|---|---|---|
| | A | = drainage area, acres |
| | m | = slope of Pressure-Cum. Plot, MCF/psi |
| | T | = reservoir temperature, °R |
| | $T_{sc}$ | = temperature at standard conditions, °R |
| | $P_{sc}$ | = pressure at standard conditions, psia |
| | $\phi$ | = average pay-section porosity |
| | h | = net pay, ft. |
| | $S_w$ | = average pay-section water saturation |

T = 86°F = 546°R (Jalmat and Rhodes Gas Pools)

$T_{sc}$ = 60°F = 520°R

$P_{sc}$ = 15.025 psia

$$A = \frac{-1000\,m}{\frac{(43{,}560)(520)}{(15.025)(546)} \cdot \phi h\,(1-S_w)}$$

$$\mathbf{A = \frac{-m}{2.7611\,\phi h\,(1-S_w)}}$$

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# *Applied* PETROLEUM RESERVOIR ENGINEERING


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**13. Material Balances in Gas Reservoirs.** In the previous sections the initial gas in place was calculated on a unit basis of one acre-foot of bulk productive rock from a knowledge of the porosity and connate water. To calculate the initial gas in place on any particular portion of a reservoir it was necessary to know, in addition, the bulk volume of that portion of the reservoir. In many cases the porosity, connate water, and/or the bulk volumes are not known with any reasonable precision, and the methods described can not be used. In this case the *material-balance* method may be used to calculate the initial gas in place; however, this method is applicable only to the reservoir as a whole, because of the migration of gas from one portion of the reservoir to another in both volumetric and water-drive reservoirs.

The conservation of mass may be applied to gas reservoirs to give the following material balance:

$$\begin{bmatrix}\text{Weight of gas}\\ \text{produced}\end{bmatrix} = \begin{bmatrix}\text{Weight initially}\\ \text{in the reservoir}\end{bmatrix} - \begin{bmatrix}\text{Weight remaining}\\ \text{in the reservoir}\end{bmatrix}$$

The balance may also be made on any definable component, e.g., methane. Where the composition of the production is constant, the standard cubic feet both produced and remaining in the reservoir are directly proportional to the masses, and a material balance may be made in terms of standard cubic feet, as

$$\begin{bmatrix}\text{SCF produced}\\ \text{from the reservoir}\end{bmatrix} = \begin{bmatrix}\text{SCF initially}\\ \text{in the reservoir}\end{bmatrix} - \begin{bmatrix}\text{SCF remaining}\\ \text{in the reservoir}\end{bmatrix}$$

Finally, a material balance may be made in terms of moles of gas, as

$$n_p = n_i - n_f \tag{1.27}$$

The subscripts p, i, and f stand for produced, initial, and final, respectively. The term final means at some later stage of production rather than necessarily at abandonment. If $V_i$ is the initial *gas* pore volume in cubic feet, and if at the final pressure $p_f$, $W_e$ cubic feet of water has encroached into the reservoir and $W_p$ cubic feet of water has been produced from the reservoir, then the final volume $V_f$ after producing $G_p$ standard cubic feet of gas is

$$V_f = V_i - W_e + B_w W_p \tag{1.28}$$

$B_w$ is the volume factor for the water in units of barrels per surface barrel. $V_i$ and $V_f$ are gas pore volumes, i.e., they do not include connate water. The terms in Eq. (1.27) may be replaced by their equivalents using the gas law, Eq. (1.5), and Eq. (1.28), as

$$\frac{p_{sc}G_p}{T_{sc}} = \frac{p_i V_i}{z_i T} - \frac{p_f(V_i - W_e + B_w W_p)}{z_f T} \tag{1.29}$$

$G_p$ is the standard cubic feet of produced gas at standard pressure and temperature, $p_{sc}$ and $T_{sc}$.

For volumetric reservoirs there is no water influx and water production is generally negligible, and Eq. (1.29) reduces to

$$\frac{p_{sc}G_p}{T_{sc}} = \frac{p_iV_i}{z_iT} - \frac{p_fV_i}{z_fT} \tag{1.30}$$

For fixed values of $p_{sc}$ and $T_{sc}$, since $p_i$, $z_i$, and $V_i$ are also fixed for a given volumetric reservoir, Eq. (1.30) may be written as

$$G_p = b - m\left(\frac{p_f}{z_f}\right) \tag{1.31}$$

where $$b = \frac{p_iV_iT_{sc}}{z_ip_{sc}T} \text{ and } m = \frac{V_iT_{sc}}{p_{sc}T}$$

Equation (1.31) indicates that for a *volumetric* gas reservoir the graph of the cumulative gas production $G_p$ in standard cubic feet versus the ratio $p/z$ is a straight line of negative slope $m$. Figure 1.9 shows a plot of cumula-

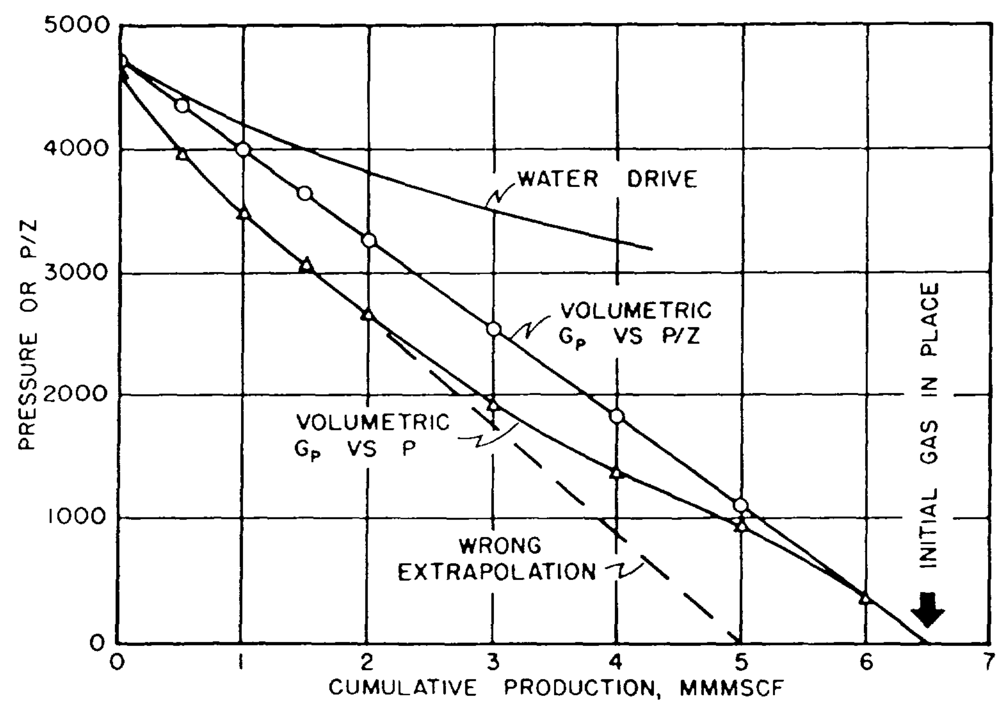


**Fig. 1.9.** Comparison of theoretical values of $p$ and $p/z$ plotted versus cumulative production from a volumetric gas reservoir.

tive gas production in standard cubic feet plotted versus $p/z$. Within the limits of error of the values of average reservoir pressure and cumulative productions, the plot of $G_p$ versus $p/z$ is linear and may be extrapolated to zero pressure to find the initial gas in place, or to any abandonment value of $p/z$ to find the initial reserve. The slope $m$ in Fig. 1.9 is

$$m = \frac{\Delta G_p}{\Delta(p/z)} = \frac{6.5 \times 10^9}{4700} = 1.383 \times 10^6 \text{ SCF/psi}$$

Then for $p_{sc} = 14.7$ psia, $T_{sc} = 520$°R, and $T = 200$°F,

$$V_i = \frac{m p_{sc} T}{T_{sc}} = \frac{1.383 \times 10^6 \times 14.7 \times 660}{520}$$

$$= 25.8\text{MM cu ft}$$

For $B_{gi} = 251.9$ SCF/cu ft, the initial gas in place is

$$G = V_i \times B_{gi} = 25.8 \times 10^6 \times 251.9 = 6.50\text{MMM SCF}$$

Figure 1.9 also contains a plot of cumulative gas production $G_p$ versus pressure. As indicated by Eq. (1.31) this is not linear, and extrapolations from the pressure-production data may be in considerable error. As the minimum value of the gas deviation factor occurs near 2500 psia, the extrapolations will be low for pressures above 2500 psia, and high for pressures below 2500 psia. Equation (1.30) may be used graphically as shown in Fig. 1.9 to find the initial gas in place or the reserves at any pressure for any selected abandonment pressure. For example at 1000 psia (or $p/z = 1220$) abandonment pressure the *initial* reserve is 4.85MMM SCF. At 2500 psia (or $p/z = 3130$) the (remaining) reserve is 4.85 less 2.20, that is 2.65MMM SCF. The equation may be used numerically as illustrated using data from the Bell Gas Field in Example 1.6. Note that the base pressure is 15.025 psia in the calculations of Example 1.6.

**Example 1.6.** Calculating the initial gas in place and the initial reserve of a gas reservoir from pressure-production data for a volumetric reservoir.

*Given:*

Initial pressure = 3250 psia
Reservoir temperature = 213°F
Standard pressure = 15.025 psia
Standard temperature = 60°F
Cumulative production = $1.00 \times 10^9$ SCF
Average reservoir pressure = 2864 psia
Gas deviation factor at 3250 psia = 0.910
Gas deviation factor at 2864 psia = 0.888
Gas deviation factor at 500 psia = 0.951

SOLUTION: Solve Eq. (1.30) for the reservoir gas pore volume $V_i$

$$\frac{15.025 \times 1.00 \times 10^9}{520} = \frac{3250 \times V_i}{0.910 \times 673} - \frac{2864\ V_i}{0.888 \times 673}$$

$V_i = 56.17$MM cu ft