Case 2. Undersaturated Reservoir with Water Influx

Applying same in before assumption, the equation reduces to:

$$F = N[E_o + E_{f,w}] + W_e$$

$$\frac{F}{E_o + E_{f,w}} = N + \frac{W_e}{E_o + E_{f,w}}$$

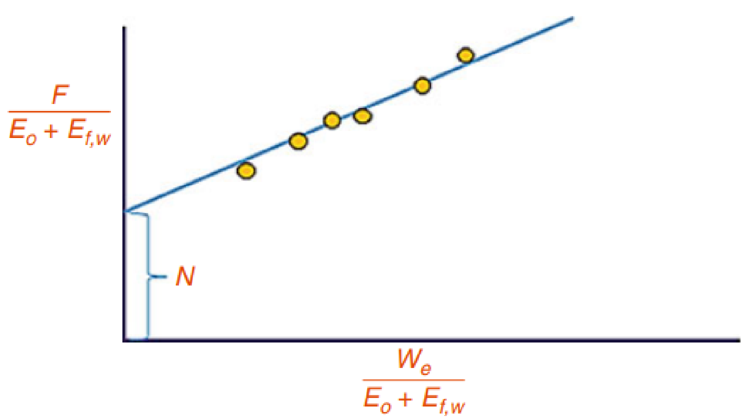
Where

$$F = N_p B_o + W_p B_w$$

$$E_o = B_o - B_{oi}$$

$$E_{f,w} = B_{oi}\left[\frac{c_w S_w + c_f}{1 - S_{wi}}\right]\Delta p$$

A plot of F /[Eo +Ef ,w] versus We/[Eo+Ef ,w] gives N as the intercept and a slop of unit.



Case 3. Volumetric Saturated-Oil Reservoirs (Without Water Influx).

An oil reservoir that originally exists at its bubble point pressure is referred to as a "saturated oil reservoir." The main driving mechanism in this type of reservoir results from the liberation and expansion of the solution gas as the pressure drops below the bubble point pressure. Normally, the water and rock expansion term

Ew,f is negligible in comparison to the expansion of solution gas; however, it is recommended to include the term in the calculations,

$$\boldsymbol{F = N[E_o + mE_g + E_{w,f}] + W_e}$$

can be simplified to give an identical form to that of eq. Below:

$$F = N[E_o + E_{w,f}]$$

However, the parameters F and Eo that constitute the above expression are given in an expanded form to reflect the reservoir condition as **the pressure drops below the bubble point**. The underground withdrawal F and the expansion term ($Eo + Ew,f$) are defined by:

• **F** in terms of Bo $F = Np[Bo + (Rp - Rs)Bg] + BwWp$

or equivalently in $F = Np[Bt + (Rp - Rsi)Bg] + BwWp$ terms of Bt

• **Eo** in terms of Bo $Eo = (Bo - Boi) + (Rsi - Rs)Bg$

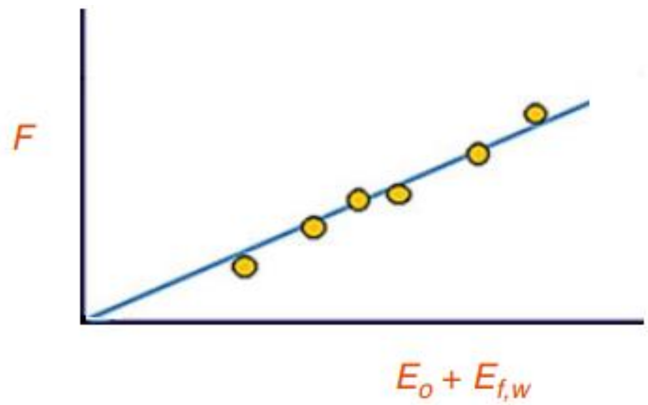
or equivalently in $Eo = Bt - Bti$ terms of Bt

• And $\boldsymbol{Ew,f} = Boi\,[\frac{(CwSwi+Cf)}{(1-Swi)}]\,\Delta\bar{p}$

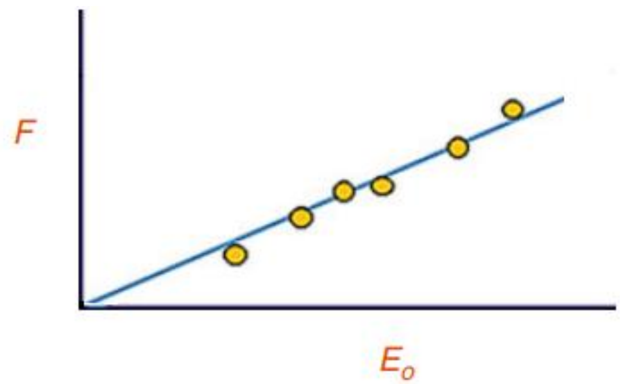
Eq. below:

$$F = N[E_o + E_{w,f}]$$

Indicates that a plot of the underground withdrawal F, evaluated by using the actual reservoir production data, as a function of the fluid expansion term ($Eo + Ew,f$) should result in a **straight line going through the origin with a slope of N**.



Or



The above interpretation technique is useful in that, if a simple linear relationship for equation above is expected for a reservoir and show later the actual plot turns out to be non-linear, then this deviation can itself be diagnostic in determining the actual drive mechanisms in the reservoir. For instance, equation above may turn out to be nonlinear because there is an unsuspected water influx into the reservoir, helping to maintain the pressure.

Case 4: Saturated-Oil Reservoir with Water Influx

Applying the above assumption, the equation reduces to

$$F = NE_o + W_e$$

$$\frac{F}{E_o} = N + \frac{W_e}{E_o}$$

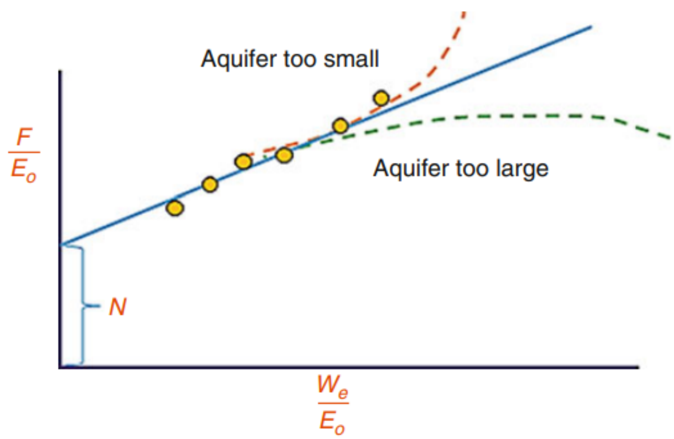
Where

$$F = N_p\left[B_o + (R_p - R_s)B_g\right] + W_pB_w$$

$$E_o = \left[(B_o - B_{oi}) + (R_{si} - R_S)\,B_g\,\right]$$

The above interpretation technique is useful in that, if a simple linear relationship for equation above is expected for a reservoir and show later the actual plot turns out to be non-linear, then this deviation can itself be diagnostic in determining the actual drive mechanisms in the reservoir. For instance, equation above may turn out to be nonlinear because there is an unsuspected water influx into the reservoir, helping to maintain the pressure.

A plot of F/Eo versus We /Eo gives N as the intercept and a slope of unit



Case 5: Gas cap drive reservoirs

For a reservoir in which the expansion of the gas cap, gas is the predominant driving mechanism, the effect of water and pore compressibilities as a contributing driving mechanism can be considered negligible as compared to that of the high compressibility of the gas.

Assuming that there is no natural water influx or it is negligible (i.e., We = 0), the Havlena and Odeh material balance can be expressed as:

$$F = N\left[E_o + mE_g\right]$$

In which the variables F, Eo, and Eg are given by:

• F in terms of Bo $F = Np\ [Bo + (Rp - Rs)Bg] + BwWp$ or equivalently in

$F = Np[\ Bt + (Rp - Rsi)Bg] + BwWp$ terms of Bt

• Eo in terms of Bo $Eo = (Bo - Boi) + (Rsi - Rs\ )Bg$

or equivalently in terms of Bt $Eo = Bt - Bti$

• Eg in terms of Bo $Eg = \frac{Boi}{Bgi}(Bg - Bgi)$

$or\ Eg = Boi\ [(\frac{\mathrm{Bg}}{Bgi}) - 1]$

or equivalently in terms of Bt

$Eg = \frac{\mathrm{Bti}}{Bgi}(Bg - Bgi)$

$or\quad Eg = Bti\ [(\frac{\mathrm{Bg}}{Bgi}) - 1]$

The methodology in which eq.

$$F = N[E_o + mE_g]$$

can be used depends on the number of unknowns in the equation.

There are three possible unknowns in eq. above.

These are:

1. N is unknown, m is known;

2. m is unknown, N is known;

3. N and m are unknown.

The practical use of eq. above in determining the three possible unknowns is presented below.

Unknown N, known m:

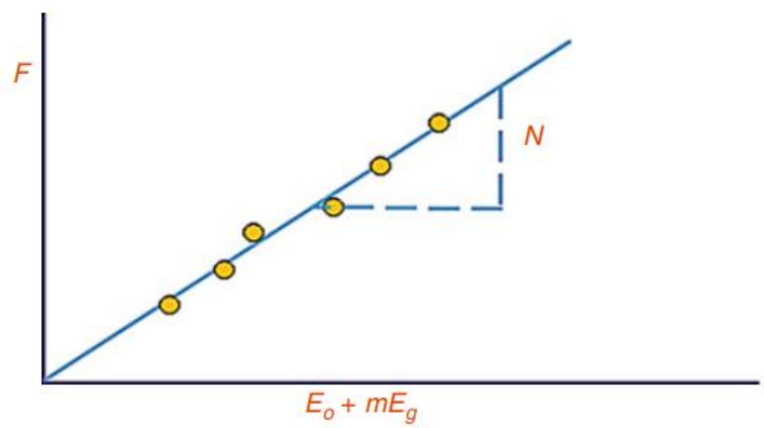
Equation below

$$F = N[E_o + mE_g]$$

Indicates that a plot of F versus ($Eo + mEg$) on a Cartesian scale would produce a straight line through the origin with a slope of N, as shown in figure below.

In making the plot, the underground withdrawal F can be calculated at various times as a function of the production terms Np and Rp.

Conclusion N = slope



Unknown m, known N:

The following equation

$$F = N[E_o + mE_g]$$

Can be rearranged as an equation of straight line, to give:

$$(\frac{F}{N} - Eo) = mEg$$

This relationship shows that a plot of the term ($\frac{F}{N} - Eo$) vs. Eg would produce a straight line with a slope of m. **This particular arrangement is that the straight line must pass through the origin**.

Figure below shows an illustration of such a plot.

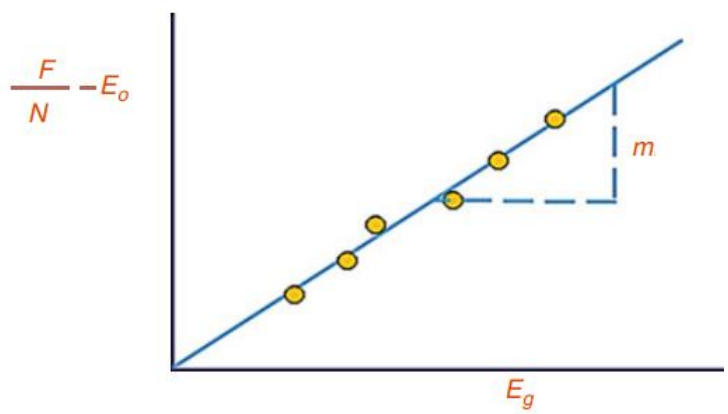
Conclusion m = slope

Also, Equation

$$F = N[E_o + mE_g]$$

can be rearranged to solve form, to give:

$$m = \frac{\text{F}-\text{NEo}}{\text{NEg}}$$



N and m are unknown:

If there is uncertainty in both the values of N and m, *eq*.

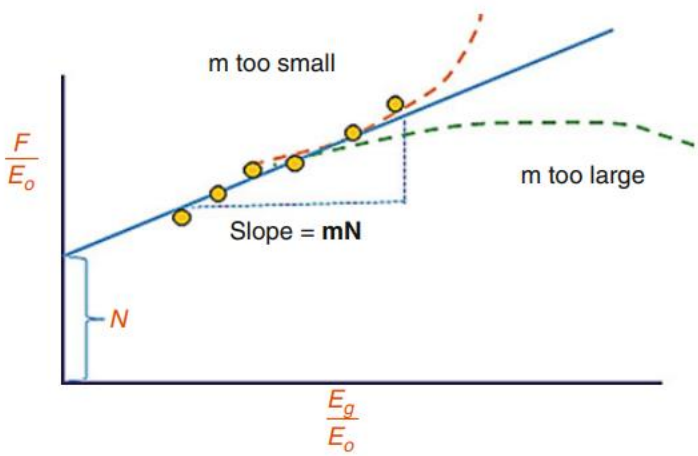
$$F = N[E_o + mE_g]$$

can be re-expressed as:

$\frac{\mathrm{F}}{\mathrm{Eo}} = N + mN\,(\frac{\mathrm{Eg}}{\mathrm{Eo}})$ $\qquad eq.$ (3.59)

A plot of $\frac{\mathrm{F}}{\mathrm{Eo}}$ versus $\frac{\mathrm{Eg}}{\mathrm{Eo}}$ should then be linear with intercept N and slope mN.

This plot is illustrated in figure below.



Conclusions

N = intercept

mN = slope

m = slope/intercept = slope/N

Case 6: Combination Drive Reservoir

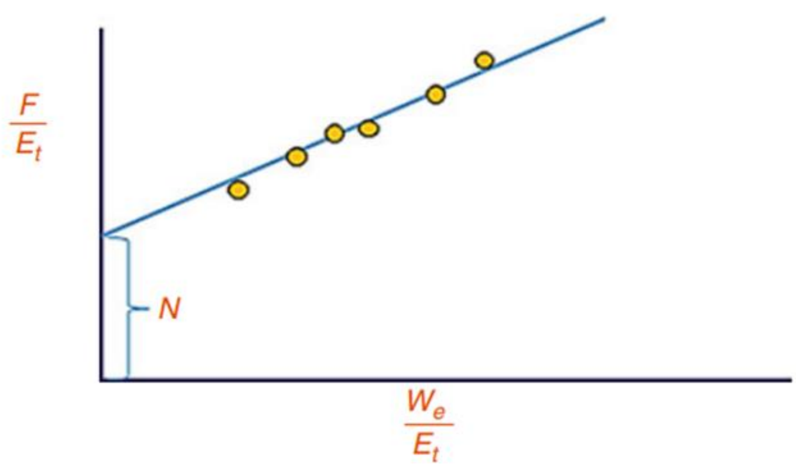
$$F = NE_t + W_e$$
$$\frac{F}{E_t} = N + \frac{W_e}{E_t}$$

Where

$$F = N_p\left[B_o + \left(R_p - R_s\right)B_g\right] + W_pB_w$$

$$E_t = E_o + mE_g + E_{f,w}$$
$$E_o = \left[(B_o - B_{oi}) + (R_{si} - R_S)\; B_g\;\right]$$
$$E_g = B_{oi}\left[\frac{B_g}{B_{gi}} - 1\right]$$
$$E_{f,w} = (1+m)B_{oi}\left(\frac{S_{wi}C_w + C_f}{1 - S_{wi}}\right)\Delta P$$

The plot is shown below



E_t in terms equivalently of Eo, mEg and Ew,f

Linear Form of Gas Material Balance Equation

Havlena and Odeh also expressed the material balance equation in terms of gas production, fluid expansion and water influx as:

Total underground withdrawal = gas expansion + water&pore compaction expansion + water influx

$$G_pB_g + W_pB_w = G(B_g - B_{gi}) + GB_{gi}\left[\frac{c_w s_{wi} + c_f}{1 - s_{wi}}\right]\Delta P + W_eB_w$$

$$F = G(E_g + E_{f,w}) + W_eB_w$$

Where

$$F = G_pB_g + W_pB_w$$

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

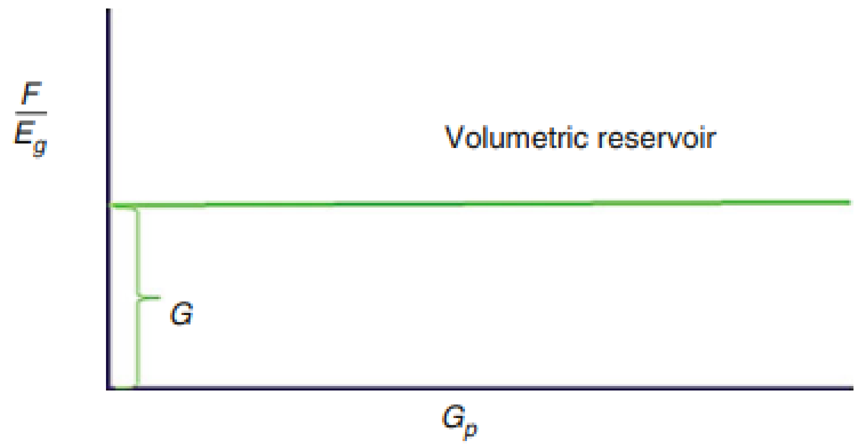
$$E_{f,w} = B_{gi}\left[\frac{c_w s_{wi} + c_f}{1 - s_{wi}}\right]\Delta P$$

Assume that the rock and water expansion term is negligible, the equation reduces to:

$$F = GE_g + W_eB_w$$

$$\frac{F}{E_g} = G + \frac{W_eB_w}{E_g}$$

A plot of F/Eg versus Gp gives a horizontal line with G as the intercept



A plot of F/Eg versus We /Eg gives G as the intercept and a slop, Bw