2) Standing's method

The initial work of Vogel assumed a flow efficiency of 1.00 and did not account for wells that were damaged or improved. Standing (1970) essentially extended the application of Vogel's (Vogel did not consider formation damage) proposed a companion chart to account for conditions where the flow efficiency was not equal to 1.00, as shown in Figure (1-31).

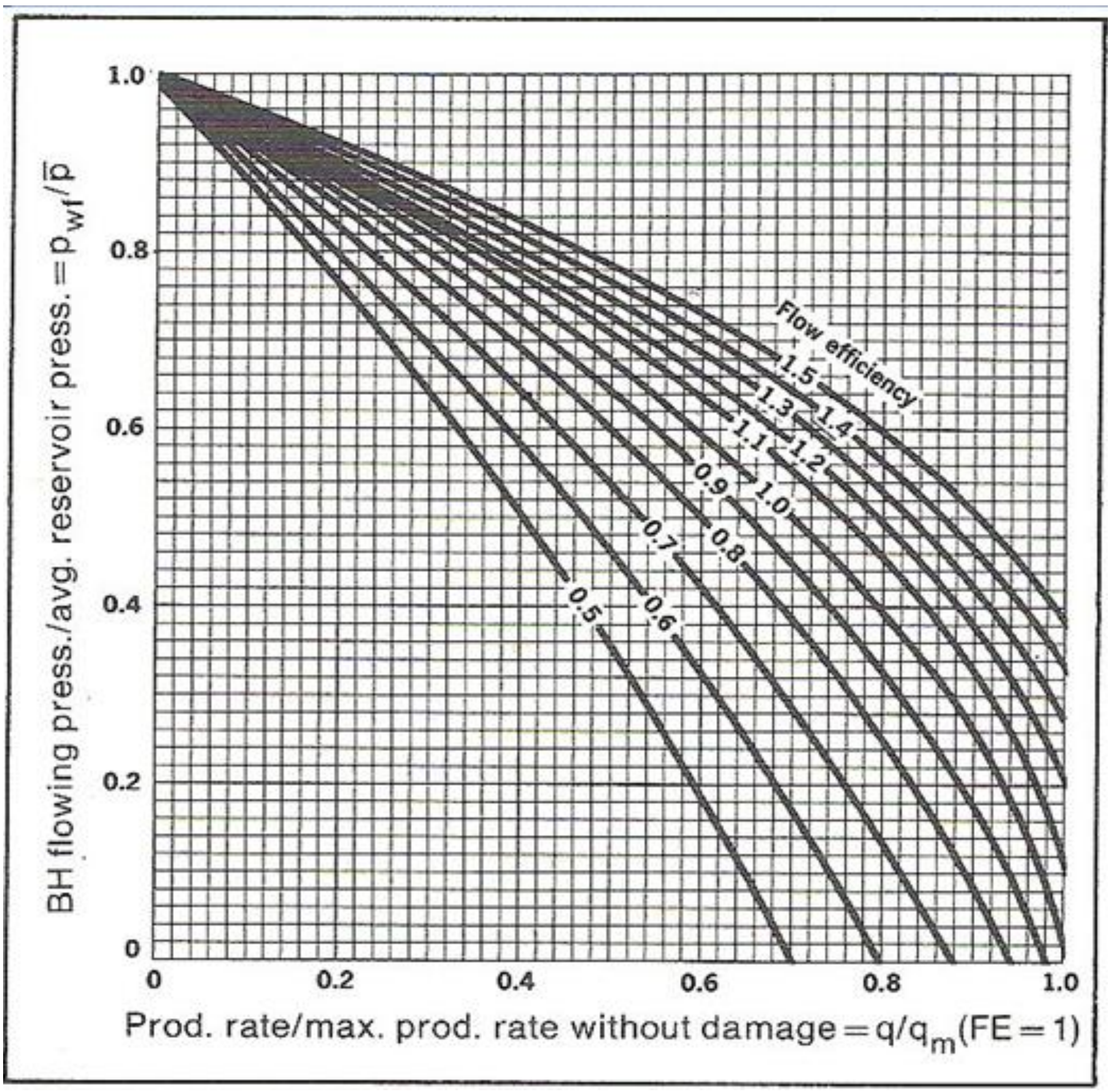

Fig. (1-31): Inflow performance relation, modified by standing.

Flow efficiency is defined as:

$$\mathbf{FE = \frac{Ideal\ drawdown}{Actual\ drawdown} = \frac{P_r - P'_{wf}}{P_r - P_{wf}}} \text{ ------------ } \mathbf{(1.19)}$$

Where:

$$\mathbf{P'_{wf} = P_{wf} + \Delta P_{skin}} \text{ ------------ } \mathbf{(1.20)}$$

Substituting:

$$\mathbf{FE = \frac{P_r - (P_{wf} + \Delta P_{skin})}{P_r - P_{wf}} = \frac{P_r - P_{wf} - \Delta P_{skin}}{P_r - P_{wf}}} \text{ ------------ } \mathbf{(1.21)}$$

Which of the ratio of useful pressure drop a cross the system to total pressure drop. For a well drianing a cylinderical volume:

$$\mathbf{FE = \frac{\ln\frac{0.47\,r_e}{r_w}}{\left[\ln\frac{0.47 r_e}{r_w} + s\right]}} \text{ ------------ } \mathbf{(1.22)}$$

Where:

S is the dimensionless skin factor.

The $\mathbf{\Delta P_{skin}}$ is thus seen to be the difference between $\mathbf{P`_{wf}}$ and $\mathbf{P_{wf}}$. There may be many factors which cause or control this added resistance to flow near the well-bore, **including invasion of the zone by mud or "Kill-fluids", swelling of shale, and others**. This may also represent a region of improvement after a stimulation treatment.

The determination of $\mathbf{\Delta P_{skin}}$ is made by first determining **S**, skin factor from a standard pressure build up test on a well. $\mathbf{\Delta P_{skin}}$ was defined by Van Everding as:

$$\mathbf{\Delta P_{skin} = 141.2\,\frac{Q_o \mu_o B_o}{k_o h}} \text{ ------------ } \mathbf{(1.23)}$$

The standard equation for determining skin is:

$$\mathbf{S = 1.151\left[\frac{P_{1hr} - P_{wf}}{m} - \log\frac{k}{\varphi \mu c r_w^2} + 3.23\right]} \text{ ------------ } \mathbf{(1.24)}$$

We may recall that:

S = 0 indicate no alteration.

S = + indicate damage.

S = - indicate improvement and that values of -3 to -5 are common for fractured reservoir.

The value of ΔP_{skin} is then calculated from:

$$\Delta P_{skin} = 0.87\ S\ m \quad \text{--------------------} \quad (1.25)$$

m = slope from straight line portion of the pressure build up curve, determined from the following equation:

$$m = \frac{162.5 q_o \mu_o B_o}{k_o h} \quad \text{--------------------} \quad (1.26)$$

Standing constructed Figure (1-31), which shows IPR curves for flow efficiencies between 0.5 and 1.5. Several things can be obtained from this plot:

1. The maximum rate possible for a well with damage.
2. The maximum rate possible if the damage is removed and FE = 1.0
3. The rate possible if the well is stimulated and improved.
4. The determination of the flow rate possible for any flowing pressure for different values of FE.
5. The construction of IPR curves to show rate versus flowing pressure for damaged and improved wells.

Figure (1-31) can be slightly confusing if not studied carefully. The abscissa is the ratio of the producing rate divided by the producing rate with no damage that is, each value that is read from the curves is a value to calculate Q_{omax} with FE corrected to 1.

Equation (1.13) may be simplified to the following form:

$$\frac{Q_{o\ FE=j}}{(Q_o)_{max\ FE=1}} = j\,(1-R)[1.8 - 0.8j(1-R)] \quad \text{--------------------} \quad (1.27)$$

Where:

$$R = \frac{P_{wf}}{P_r}$$

Equation (1.27) can replaced Standing`s` chart for IPR of damaged/stimulation wells. plotting equation (1.27) for j = 0.6, 0.8, ..., 1.6 reproduced Standing`s chart as shown in Figure (1-31).

Problem (1-6): Given the following information:

Q_o =**70** bbl/day, P_r = **2400** psi, P_{wf} = **1800** psi, FE= **0.7**.

Our first requirement is to find the maximum flow rate possible assuming the well has no damage (FE=1).

$Q_{o\ (FE=0.7)} / Q_{omax\ (FE=1)} = 0.281$

$Q_{omax\ (FE=1)} = 70/0.281 = 249$ bbl/day.

Our next requirement is to find the maximum flow rate from the damaged well.

The maximum rate occurs when $P_{wf} = 0$, then $P_{wf} / P_r = 0$, and from Figure (1.31) curve we find $Q_o / Q_{omax} = 0.87$, then $Q_o = 0.87 * 249 = 216$ bb/day.

$Q_{o\ (FE=0.7)} \neq (0.7) Q_{omax\ (FE=1)}$ because of the non-linear IPR relationship for solution gas drive reservoir system.

Our next requirement is to find the maximum flow rate if the well is improved

Assume that a stimulation job is performed on the above well and that FE is increased to 1.3. What is the maximum rate possible?

$Q_{omax\ (FE=1)} = 249$ bbl/day (from curve) for $P_{wf} = 0$, then $(P_{wf} / P_r) = 0$, and from Figure (1-31) on the FE = 1.3 curve (by extrapolation) $Q_o / Q_{omax} = 1.1$, then $Q_{omax\ (FE=1.3)} = 1.1 * 249 = 274$ bb/day.

The extrapolation of the curves is not recommended since they appear to give erroneous results for values on the abscissa greater than 1. The solution by equation (1.27) does not appear correct either. Fortunately in practices we normally do not need values of Q_o / Q_{omax} greater than 1 and the curves and equation handle these problems in a satisfactory manner.

➢ Predict Future Inflow Performance Relationship

To predict future inflow performance relationship of a well as a function of reservoir pressure, Standing noted that Vogel's equation (1.13) could be rearranged as:

$$\frac{Q_o}{(Q_o)_{max}} = 1 - 0.2\left(\frac{P_{wf}}{P_r}\right) - 0.8\left(\frac{P_{wf}}{P_r}\right)^2$$

$$\frac{\mathbf{Q_o}}{(\mathbf{Q_o})_{\mathbf{max}}} = \left(\mathbf{1} - \frac{\mathbf{P_{wf}}}{\mathbf{P_r}}\right)\left[\mathbf{1} + \mathbf{0.8}\left(\frac{\mathbf{P_{wf}}}{\mathbf{P_r}}\right)\right] \text{ ------------------------------------ } \mathbf{(1.28)}$$

Standing introduced the productivity index ***J*** as defined by equation (1.1) into equation (1.28) to yield:

$$\mathbf{J} = \frac{(\mathbf{Q_o})_{\mathbf{max}}}{\mathbf{P_r}}\left[\mathbf{1} + \mathbf{0.8}\left(\frac{\mathbf{P_{wf}}}{\mathbf{P_r}}\right)\right] \text{ ------------------------------------ } \mathbf{(1.29)}$$

Standing then defined the present (current) zero drawdown productivity index as:

$$\mathbf{J_p^*} = \mathbf{1.8}\left[\frac{(\mathbf{Q_o})_{\mathbf{max}}}{\mathbf{P_r}}\right] \text{ ------------------------------------ } \mathbf{(1.30)}$$

Where J^*_p is Standing's zero-drawdown productivity index. The J^*_p is related to the productivity index ***J*** by:

$$\frac{\mathbf{J}}{\mathbf{J_p^*}} = \frac{\mathbf{1}}{\mathbf{1.8}}\left[\mathbf{1} + \mathbf{0.8}\left(\frac{\mathbf{P_{wf}}}{\mathbf{P_r}}\right)\right] \text{ ------------------------------------ } \mathbf{(1.31)}$$

Equation (1.1) permits the calculation of **J*p** from a measured value of **J**.

To arrive to the final expression for predicting the desired IPR expression, Standing combines equation (1.31) with equation (1.28) to eliminate $(Q_o)_{max}$ to give:

$$\mathbf{Q_o} = \left[\frac{\mathbf{J_f^*(P_r)_f}}{\mathbf{1.8}}\right]\left\{\mathbf{1} - \mathbf{0.2}\left[\frac{\mathbf{P_{wf}}}{(\mathbf{P_r})_\mathbf{f}}\right] - \mathbf{0.8}\left[\frac{\mathbf{P_{wf}}}{(\mathbf{P_r})_\mathbf{f}}\right]^\mathbf{2}\right\} \text{ ------------------------------------ } \mathbf{(1.32)}$$

Where the subscript **f** refer to future condition.

Standing suggested that J^*_f can be estimated from the present value of J^*_p by the following expression:

$$\mathbf{J_f^*} = \mathbf{J_p^*}\frac{(\mathbf{k_{ro}}/\boldsymbol{\mu}_\mathbf{o}\mathbf{B_o})_\mathbf{f}}{(\mathbf{k_{ro}}/\boldsymbol{\mu}_\mathbf{o}\mathbf{B_o})_\mathbf{p}} \text{ ------------------------------------ } \mathbf{(1.33)}$$

Where the subscript **p** refer to present condition.

If the relative permeability data is not available, J^*_f can be roughly estimated from:

$$\mathbf{J_f^*} = \mathbf{J_p^*}\left[\frac{(\mathbf{P_r})_\mathbf{f}}{(\mathbf{P_r})_\mathbf{p}}\right]^\mathbf{2} \text{ ------------------------------------ } \mathbf{(1.34)}$$

Standing's methodology from predicting a future IPR is summarized in the following steps:

1) Using the current time condition and the available flow test data, calculate $(Q_o)_{max}$ from equation (1.13) or (1.28).
2) Calculate J^* at the present condition, i.e., J^*_p, by using equation (1.30). Notice that other combinations of equations (1.28) through (1.31) can be used to estimate J^*_p.
3) Using fluid property, saturation and relative permeability data, calculate both $[k_{ro}/\mu_o B_o]_f$ and $[k_{ro}/\mu_o B_o]_p$.
4) Calculate J^*_f by using equation (1.33). Use equation (1.34) if the oil relative permeability data is not available.
5) Generate the future IPR by applying equation (1.32).

Problem (1-7): A well is producing from a saturated oil reservoir that exists at its saturation pressure of **4000** psig. The well is flowing at a stabilized rate **600** bbl/day and a P_{wf} = **3200** psig. Material balance calculations provide the following current and future predictions for oil saturation and PVT properties.

Parameter	Present	Future
p_r	4000	3000
μ_o, cp	2.4	2.2
B_o, bbl/STB	1.2	1.13
k_{ro}	1	0.66

Generate the future IPR for the well at **3000** psig by using Standing's method.

Solution:

Calculate the current $(Q_o)_{max}$ from equation (1.28).

$$(Q_o)_{max} = \frac{Q_o}{\left(1-\frac{P_{wf}}{P_r}\right)\left[1+0.8\left(\frac{P_{wf}}{P_r}\right)\right]}$$

$$(Q_o)_{max} = \frac{600}{\left(1-\frac{3200}{4000}\right)\left[1+0.8\left(\frac{3200}{4000}\right)\right]} = \mathbf{1829}\ \text{STB / day}$$

Step 2: Calculate $\mathbf{J^*_p}$ by using equation (1.30).

$$J^*_p = 1.8\left[\frac{(Q_o)_{max}}{P_r}\right]$$

$J_p^* = 1.8 \left[\frac{1829}{4000}\right] = 0.823$

Calculate the following pressure-function:

$[k_{ro}/ \mu_o B_o]_p = [1 / 2.4* 1.2]_p = 0.3472$

$[k_{ro}/ \mu_o B_o]_f = [0.66 / 2.2* 1.15]_f = 0.2609$

Calculate J^*_f by applying equation (1.33)

$J^*_f = 0.832 [0.2609] / [0.3472] = 0.618$

Generate the IPR by using equation (1.32)

P_{wf}	(Q_o) STB / day
3000	0
2000	527
1500	721
1000	870
500	973
0	1030

It should be noted that one of the main disadvantages of Standing's methodology is that it requires reliable permeability information; in addition, it also requires material balance calculations to predict oil saturations at future average reservoir pressures.

3) Couto`s method

He suggested a procedure to solve for flow efficiency (FE) from two flow tests on the well. His procedure makes use of Vogel's equation and dose requires that we known $\mathbf{P_r}$.

From Standing's` work;

$$\mathbf{FE} = \frac{\mathbf{P_r - P'_{wf}}}{\mathbf{P_r - P_{wf}}}$$

$$\mathbf{FE} = \frac{\mathbf{P_r - P_{wf} - P_{skin}}}{\mathbf{P_r - P_{wf}}}$$

Since Standing assumed a constant skin value (s, independent of rate and time). Then it should obtain the same FE value from each flow test. Therefore, in general, this solution