In Flow Performance Relationship - IPR Curves

The Inflow Performance Relationship (IPR) for a well is the relationship between the flow rate of the well \( q \) and the flowing pressure of the well \( p_{wf} \). In single phase flow this is a straight line but when gas is moving in the reservoir, at a pressure below the bubble point, this is not a linear relationship.

Factors influencing the shape of the IPR are the pressure drop and relative \( k \) across the reservoir.

![Figure 3](image)

It can be seen that the majority of the pressure drop caused by production is near the wellbore. This is confirmed by the radial flow equation. In this situation even if the average reservoir pressure is above the bubble point, the area around the wellbore is not, which causes the gas to come out of solution in this area causing the relative permeability (which is based on fluid saturation) of the liquids to
change. As the $p_{wf}$ is lower for a greater flow rate the greater this effect has on the well which causes the IPR Curve to bend down.

2 Stratified Formation or Zones

When zones of varying $kh$ are opened in a well, the one with the highest $kh$ well contribute more to the production of the well, then the lower $kh$ zones will contribute, thus the average reservoir pressure of the high $kh$ zones drops faster than the other zones in the well. This causes the zones to start flowing at different flowing bottom hole pressures. At the lower rates or higher flowing pressures it is the zone with the lowest $kh$ that have the highest average pressure so that it produces first and then as the flowing pressure drops below the average pressure of the other zones that start to contribute to the flow. The PI of the well improves as more of the zones contribute, so the PI improves with the lowering of the flowing pressure.
Vogel’s Method

Vogel developed an empirical equation for the shape of the IPR curve.

$$\frac{q}{q'} = 1 - 0.2 \left( \frac{p_{wf}}{p} \right) - 0.8 \left( \frac{p_{wf}}{p} \right)^2 \quad (1-23)$$

where $q'$ is the potential of the well or maximum production.

Using the productivity index J we get

$$\frac{q}{q'} = J \left( \frac{p_s - p_{wf}}{Jp_s} \right) = 1 - \frac{p_{wf}}{p} \quad (1-24)$$

assuming $p_s$ and average reservoir pressure approximately the same.

Hence the difference between the value of $q$ derived from the Vogel equation and the straight line method is
\[ q_{cm} - q_{sf} = .8q' \left( \frac{p_{wf}}{p} \right) \left( 1 - \frac{p_{wf}}{p} \right) \]  

(1-25)

The value is always positive, and at the end points, \( p_{wf} = p \) and \( p_{wf} = 0 \) it is 0.

Standing rewrote the equation

\[ \frac{q}{q'} = \left( 1 - \frac{p_{wf}}{p} \right) \left( 1 + .8 \frac{p_{wf}}{p} \right) \]  

(1-26)

this gives

\[ J = \frac{q'}{p} \left( 1 + .8 \frac{p_{wf}}{p} \right) \]  

(1-27)

as \( p_{wf} \) goes to \( p \)

\[ J^* = \frac{1.8q'}{p} \]  

(1-28)

combining

\[ J^* = \frac{1.8J}{\left( 1 + .8 \frac{p_{wf}}{p} \right)} \]  

(1-29)

using the pseudo-steady state radial flow equation

\[ J^* = \frac{.007082k_o h}{\beta_o \mu_o \left[ \ln \frac{r_c}{r_w} -.75 \right]} \]  

(1-30)

by canceling out constant terms

\[ \frac{J_{f}}{J_p} = \left( \frac{k_o}{\beta_o \mu_o} \right)_f \left( \frac{k_o}{\beta_o \mu_o} \right)_p \]  

(1-31)
by using \( q' = J^* p/1.8 \) in Vogel’s equation we get

\[
q = \frac{J^* p}{1.8} \left[ 1 - 2 \left( \frac{p_{wf}}{p} \right) - 8 \left( \frac{p_{wf}}{p} \right)^2 \right]
\]  \hspace{1cm} (1-32)

Homework #2

1) Take the data from problem 1, homework on and calculate the \( J \) of a horizontal well with a 1000’ horizontal section and a formation thickness of 25’ and effective radius of 450’ from the well bore. Change the \( L \) to 1500’ and find \( J \). Calculate \( J \) if the well has a vertical \( k \) of 15 md and 30 md.

2) Well #2A is flowing at 1120 bopd through 2 7/8” tubing. There is zero water cut, and the GLR is 820 scf/bbl. A pressure survey on the well shows that the flowing pressure at 6470’ is 675 psig, while the pressure build up shows a static pressure of 2080 psig at a datum level of 6500’.

Using Vogel’s method, draw the IPR curve, and estimate the well’s potential.

Reservoir analysis indicates that the ratio of the value of \( k_{ro}/\beta_0\mu_o \) @ 2080 psi to its value at the static pressure of 1500 psig is 1.57. Estimate what the well’s potential rate will be when the static pressure dropped to 1500 psig.
Fetkovich’s Approximation

Since Vogel’s method is not always in accordance with field data, Fetkovich suggested

\[ q_o = C(p^2 - p_{wf}^2)^n \]  \hspace{1cm} (1-33)

if

\[ J' = \frac{.007082khk_{ro}}{\beta_s \mu_o \ln(\frac{r_e}{r_w})2p_i} \]  \hspace{1cm} (1-34)

the equation becomes

\[ q_o = J'(p^2 - p_{wf}^2)^n \]  \hspace{1cm} (1-35)

\[ q'_o = J'(p^2)^n \]  \hspace{1cm} (1-36)

Fetkovich assumed that the log log plot of \( q_o \) vs \( \Delta p^2 \) is a straight line with a unity slope, \( n=1 \).

Using Fetkovich

1) plot the \( q \) vs \( \Delta p^2 \)
2) Find the slope of line
3) Calculate \( J' \) using one of the flow rates
4) Using \( J' \) calculate the well’s potential and \( p_{wf} \) for any other rate.
5) If only rate and pressure is known assume a slope of 1