Decline Curves

Decline Curves that plot flow rate vs. time are the most common tools for forecasting production and monitoring well performance in the field. These curves quickly show by graphic means which wells or fields are producing as expected or under producing. Mainly used because they are easy to set up and to use in the field. They are not based on any of the physics of the flow of oil and gas through the rock formations, empirical in nature. The most common forms are daily flow rates vs. the month. Water and gas rates are commonly plotted along with the oil rate, or GOR and WOR. Cumulative production vs. the months is also very common, both oil and water can be plotted.

These plots are plotted both on linear plots and semi-log plots with the q on the log scale.

Exponential Decline

It was seen early on, once wells could not produce at the allowable rate that the production rate dropped off at a fairly regular rate. So if a mathematical method could be found to describe this falloff of production, predications could be made about the future of the well.

If the plot is flow rate vs. cumulative production, declining rate becomes a straight line that makes prediction easy. The equation to describe the declining line is

\[ q = mQ + c \]  \hspace{1cm} (1-50)

where \( m \) and \( c \) are constants. Since the line is declining the slope, \( m \), will be a negative value. If the decline starts at \( Q_o \) and the steady flow rate to that point is \( q_o \) equation 1-50 can be rewritten

\[ q_o = -mQ_o + c \]  \hspace{1cm} (1-51)

or

\[ c = q_o + mQ_o \]  \hspace{1cm} (1-52)

Substitute is into equation 1-50

\[ Q - Q_o = \frac{q_o - q}{m} \]  \hspace{1cm} (1-53)

The cumulative production during the decline period is equal to the difference between the initial and the current production rates divided by the continuos decline rate.
Another way to describe the declining line with respect to time is

\[
\frac{dq}{q} = -mdt
\]  

(1-54)

on integration this becomes

\[
\ln q_o = -mt + C
\]  

(1-55)

If the decline starts at time \( t_o \) and the steady rate before this is \( q_o \),

\[
\ln q_o = -mt_o + C
\]  

(1-56)

Substituting into equation 1-55

\[
q = q_o \exp[-m(t - t_o)]
\]  

(1-57)

A plot of the production rate vs. time on semilog paper is a straight line, the slope of the line being equal to minus the continuous decline rate.

The total recoverable oil can be calculated by using the following:

\[
N_{pn} = \frac{q_o - q_n}{D}
\]  

(1-58)

where \( D \) is the decline rate and \( n \) is the time at abandonment.

This is called an exponential decline, constant-rate decline or proportional decline curve. The decline rate is a constant through the life of the well. This is the most common for depletion drive reservoirs under the bubble point.

Hyperbolic and Harmonic Declines

In some fields it is found that the rate of decline is dependent on the production rate. As the production rate declines so does the rate of decline. The rate of decline is less at the end of the life of the well. This will cause the straight-line methods to be conservative in their predictions of the life of the well. This can be described by the equation

\[
q = Kn^{-m}
\]  

(1-59)
where \( q \) is the rate at time \( n \), \( K \) is a constant at the initial time, \( n=1 \). This equation can be rewritten

\[
\log q = \log K - m \log n
\]  

(1-60)

So when plotted on log log paper the line can be shifted left or right by adding a constant \( c \), \( n=n+c \), to get the best straight line. Then \( q \) at any time can be found along with \( K \). Total recovery can be found by the equation

\[
N_{np} = \frac{K}{(m-1)} \left\{ \frac{1}{n_1} - \frac{1}{n_2} \right\}
\]  

(1-61)