HORIZONTAL WELL PERFORMANCE MODELLING USING PSEUDOWELL TECHNIQUE

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ABSTRACT

The potential improvement of horizontal productivity has been recognized since mid 1950s, where horizontal well allows longer flow interval hence higher flow rate with lower pressure drawdown. Such remarkable productivity improvement has fascinated the great interest of petroleum industries around the world to fit the role of effective field development strategy. The objective is to reduce the overall cost of field development. In the case of offshore oil fields, the horizontal well drilling is desired to eliminate required number of vertical wells and utilizing of expensive sub-sea technology.

The continuous development and application of horizontal well drilling technologies have been reported in many publications. Nowadays, the horizontal well drilling and completion with complex trajectory is possible. However, the costs required by horizontal well drilling and completion is still considerably more expensive than the vertical one. The future needs of horizontal well drilling tend to arise depending on the economical aspect by means the horizontal well productivity outweigh the incremental drilling and completion costs. An adequate method is required to estimate it's expected productivity to determine the economic feasibility. This paper proposes a horizontal well performance modeling by the concept of pseudowell technique.

I. INTRODUCTION

Many authors have proposed different approach to model the horizontal well performance. Various assumptions are introduced to simplify the problem. Joshi\(^3\) suggested an analytical equation under assumptions of steady-state flow condition, infinite conductivity wellbore, and elliptical drainage volume. Giger\(^3\) established an analytical equation similar to Joshi on the basis of infinite conductivity wellbore, homogeneous-isotropic reservoir, and horizontal well located in the center of reservoir height. Babu\(^3\) developed an analytical equation under assumptions of uniform flux and pseudo-state flow condition. Goode and Kuchuck\(^3\) generated a model based on assumptions of infinite conductivity wellbore and no-flow or constant pressure outer boundary. Dikken\(^\dagger\) presented a model under assumption of turbulent flow, single phase and finite conductivity (taking into account pressure gradient along horizontal wellbore). The Dikken model facilitates the incorporation of laminar and multiphase flow if a complete mixing of the phases occurs inside the horizontal section assuming a homogeneous fluid phase with average properties. The reservoir properties along the horizontal section are taken as constant (uniform specific productivity index), eventhough the model allows variable specific productivity index.

This paper introduces a new approach to model the horizontal well performance using pseudowell technique. This concept uses several pseudowells to represent a horizontal well. The main goal of this work is to provide an alternative in form of a reliable and practical method for evaluating the horizontal well performance.

II. PSEUDOWELL MODEL

The implementation of pseudowell model to represent a horizontal well is illustrated in Figure 1. The horizontal section is divided into several segments and each segment is represented by a single pseudowell. If L is the total length of horizontal well and N is the number of pseudowell, the

![Figure 1](image-url)
length of each pseudowell is equal to \( L_{sw} = L \cdot \frac{1}{N} \). All pseudowells are assumed identical as fractured vertical wells with a half-fracture length of \( x_f = L / 2 \). By adopting the concept of apparent wellbore radius, the pseudowell can be considered as a vertical well by substituting the well length with an apparent wellbore radius \( (r_{wa}) \). The apparent wellbore radius is calculated depending on the assumption of wellbore hydraulic model. Gintarten\(^5\) suggested the apparent wellbore radius as:

\[
r_{wa} = \frac{x_f}{e} = \frac{x_f}{2.7182} \quad \text{Uniform flux hydraulic model}
\]

\[
r_{wa} = 0.498 \times x_f \quad \text{Infinite conductivity hydraulic model}
\]

General solution of pressure transient for radial flow in vertical well has been presented in many publications. The solution in dimensionless form is expressed as:

\[
P_D(t_D, r_D) = \frac{1}{2} E_i \left( \frac{-r_D}{4t_D^{1/2}} \right)
\]

Where:

\[
P_D = \frac{2\pi kh(P_i - P_w)}{Q_{wh} B}
\]

\[
t_D = \frac{kt}{\phi \mu c_t t_w}
\]

\[
r_D = \frac{r}{r_w}
\]

\[
E_i(x) = \int_{x}^{\infty} e^{-u} du
\]

For the value of \( t_D > 100 \), then the \( E_i \)-function can be approximated as the logarithmic function of:

\[
E_i \left( \frac{-r_D}{4t_D^{1/2}} \right) = -\left[ \ln \left( \frac{t_D^{1/2}}{r_D} \right) + 0.80907 \right]
\]

By substituting equations 3 and 4, then a new equation can be obtained as:

\[
P_D(t_D, r_D) = \frac{1}{2} \left[ \ln \left( \frac{t_D^{1/2}}{r_D} \right) + 0.80907 \right]
\]

If no physical outer boundary, according to Diezlt shape factor the infinite acting period of radial flow geometry in vertical well will end at time \( t_p = 0.1 \). The ultimate radius of investigation of the well is reached at time \( t_p = 0.25 \). Radius of investigation is described as:

\[
r_i = \sqrt{\frac{4kt}{\phi \mu c_t}}
\]

The pressure solution for pseudo steady-state condition can be derived from equations 5 and 6 with \( t_p = 0.25 \).

\[
P_D(r) = \frac{1}{2} \left[ \ln \left( \frac{r^2}{r_w^2} \right) - 0.57722 \right]
\]

By analogy, the pressure solution for pseudowell can be obtained from equation 7 by substituting \( r \) with \( r_{wa} \) as:

\[
P_D(r) = \frac{1}{2} \left[ \ln \left( \frac{r^2}{r_{wa}^2} \right) - 0.57722 \right]
\]

In many oil fields, the reservoir may not isotropic (i.e., vertical permeability is normally less than lateral permeability) and the horizontal well location does not always in the center of reservoir height. The pseudo skin factor should be then taken into account in equation 8 to accommodate the effect of reservoir anisotropy and well eccentricity resulting in:

\[
P_D(r) = \frac{1}{2} \left[ \ln \left( \frac{r^2}{r_{wa}^2} \right) - 0.57722 + 2S_p \right]
\]

The pseudo skin factor \( (S_p) \) is defined by Joshi as:

\[
S_p = \frac{\beta h}{L_{ps}} \ln \left[ 4 \left( \frac{\beta h}{2} \right)^2 \right]
\]

where:

\[
\beta = \sqrt{\frac{k_h}{k_z}}
\]
\[ k_h = \sqrt{k_x k_y} \]

\[ \delta = \text{distance from reservoir midpoint to horizontal wellbore} \]

**III. PSEUDOWELL INTERFERENCE**

The position of each pseudowell along the horizontal well section is expressed as:

\[ X_n = (n - 0.5) \frac{L}{N} \]  

(11)

The interference between pseudowells are connected by superposition principle which is illustrated in Figure 2. The superposition principle to represent a horizontal well by N pseudowells is expressed as:

\[ \begin{bmatrix} P_1 - P_{w1} \\ P_1 - P_{w2} \\ \vdots \\ P_1 - P_{wn} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nn} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_n \end{bmatrix} \]

(14)

If the hydraulic wellbore model assumed infinite conductivity, then \( P_{w1} = P_{w2} = \cdots = P_{wn} \) implying no pressure gradient along the horizontal well section. The flow rate distribution along horizontal section is represented by \( Q_1, Q_2, \ldots, Q_n \) while the total flow rate is provided by the summation of \( Q_1 \) through \( Q_n \).

**IV. EXAMPLE**

A simple horizontal well drilling is conducted in homogeneous and undersaturated oil bearing zone. The objective is to calculate the inflow performance of horizontal well and flow rate distribution along the horizontal section!

**A. Reservoir Data**

Reservoir thickness \( h = 75 \text{ feet} \)
Radius drainage model \( A = 120 \text{ acres} \)
Lateral permeability in x-direction \( kx = 150 \text{ mD} \)
Lateral permeability in y-direction \( ky = 150 \text{ mD} \)
Vertical permeability in z-direction \( kz = 60 \text{ mD} \)
Initial reservoir pressure \( P_i = 1750 \text{ psi} \)
Bubble point pressure \( P_b = 450 \text{ psi} \)
Oil viscosity \( \mu_o = 3.5 \text{ cp} \)
Oil formation volume factor \( B_o = 1.2 \).

\[ \begin{align*}
P_1 - P_{w1} &= \frac{Q_1 \mu B}{4\pi kh} \left[ \ln \frac{r_1^2}{r_{wa}} - 0.57722 + 2S_p \right] + \frac{Q_2 \mu B}{4\pi kh} \left[ \ln \frac{r_2^2}{r_{wa}} - 0.57722 + 2S_p \right] + \cdots + \frac{Q_n \mu B}{4\pi kh} \left[ \ln \frac{r_n^2}{r_{wa}} - 0.57722 + 2S_p \right] \\
P_1 - P_{w2} &= \frac{Q_1 \mu B}{4\pi kh} \left[ \ln \frac{r_1^2}{r_{21}} - 0.57722 + 2S_p \right] + \frac{Q_2 \mu B}{4\pi kh} \left[ \ln \frac{r_2^2}{r_{21}} - 0.57722 + 2S_p \right] + \cdots + \frac{Q_n \mu B}{4\pi kh} \left[ \ln \frac{r_n^2}{r_{2n}} - 0.57722 + 2S_p \right] \\
P_1 - P_{wn} &= \frac{Q_1 \mu B}{4\pi kh} \left[ \ln \frac{r_1^2}{r_{n1}} - 0.57722 + 2S_p \right] + \frac{Q_2 \mu B}{4\pi kh} \left[ \ln \frac{r_2^2}{r_{n1}} - 0.57722 + 2S_p \right] + \cdots + \frac{Q_n \mu B}{4\pi kh} \left[ \ln \frac{r_n^2}{r_{n1}} - 0.57722 + 2S_p \right]
\end{align*} \]

(12)
B. Horizontal Well Data
Well diameter (D= 8.5 inch)  
Total well length (L=750 feet)  
Number of pseudowell (N=10)  
Well position (5 =10 ft)  
Infinite conductivity wellbore.

By implementing equation 12, 13 and 14, the problem can be solved using Gauss elimination method. The flow rate calculation for various \( P_{wf} \) are tabulated in Table 1 through Table 5. The calculation process is performed in SI units in order to minimize errors due to the use improper unit conversion factor. However, input and output data are still presented in field unit aimed at convenience of practical operator. The result of flow rate distribution along the horizontal section for various \( P_{wf} \) is presented in Figure 3, while inflow performance relationship (IPR) is exhibited in Figure 4.

V. DISCUSSION

The assumption of infinite conductivity wellbore model is normally valid for relatively short horizontal section and under laminar fluid flow regime inside the wellbore. Although the above simple example used an infinite conductivity wellbore model, however, the concept described in this paper can be easily modified to accommodate more complex cases. For instance, by taking into account the pressure gradient along the horizontal well that can be made by modifying equation 12. The pressure gradient along the horizontal section becomes significant for multiphase flow condition, viscous fluid, gravitational effect and the effect of radial flow from reservoir through perforations.

VI. CONCLUSIONS

The conclusions of this paper can be summarized as:

1. An alternative approach to evaluate the horizontal well performance has been provided by implementing the concept of pseudowell technique. Hopefully, it will help to obtain the most prospective horizontal well drilling in the field development strategies.

2. The proper evaluation horizontal well performance is important before the decision to drill is taken. It is intended to ensure that the expected well productivity improvement outweighs drilling and completion cost when compared to vertical well drilling.

Nomenclature

- \( B \) : formation volume factor
- \( C_t \) : total compressibility
- \( D \) : wellbore diameter
- \( k_x \) : permeability in x-direction
- \( k_y \) : permeability in y-direction
- \( k_z \) : permeability in z-direction
- \( L_{ps} \) : length of pseudowell
- \( P_D \) : dimensionless pressure
- \( P_i \) : initial pressure
- \( P_{wf} = P_w \) : wellbore pressure
- \( Q \) : flow rate
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>$Q$</td>
<td>total flow rate</td>
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<tr>
<td>$r_D$</td>
<td>dimensionless radius</td>
</tr>
<tr>
<td>$r_i$</td>
<td>radius of investigation or reservoir radius</td>
</tr>
<tr>
<td>$r_w$</td>
<td>wellbore radius</td>
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<td>$r_{wa}$</td>
<td>apparent wellbore radius</td>
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<tr>
<td>$x_f$</td>
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<tr>
<td>$\beta$</td>
<td>Joshi parameter</td>
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<tr>
<td>$\delta$</td>
<td>Distance wellbore to midheight reservoir</td>
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<td>$\phi$</td>
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<td>$\mu$</td>
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**REFERENCES**


