Skin and Reservoir Pressure Profiling Utilizing Production Logging

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Abstract. Production Log is a key log that directly define the facies and layers behavior. The PLT measures the inflow zone thickness and the flow rate of each phase which is directly function of facies properties in terms of deliverability. On the basis of pseudo steady state flow regime (which is the dominant phase of production during PLT log operations) a mathematical relationship developed to determine skin and reservoir pressure per each inflow zone with reasonable error.

1. Introduction
Evaluation of multilayered system in pseudo steady state is required to plan and monitor the well efficiency taking into consideration the commingled system interaction when various flow capacity coexist [1]. Usually with heterogenous carbonates; stratification of difference facies usually occurs, having in between barriers such as non-permeable layers or same facies with non-quantifiable vertical permeability. With these cases, partial depletion is expected and should be closely monitored as it affects the ultimate recovery of the well [2].

Production logging tool can run periodically to determine the pressure and productivity index for all the commingled system inflow zones[3], however, with such technique, multichoke required, and shut-in period required as well[4].

The limitation of this technique is the operation parameter of the well, as may the reservoir pressure low and unable to startup naturally after shut-in and/or multichoke test may not be easy to perform when the flowing bottom hole pressure is close to saturation pressure hence flow after flow will not be representative[3].

Having these limits in mind, a new technique established based on single choke flowing production log

The Model can take two different analysis trends:

a- Customer provides Modular formation dynamics tester pressure profile to calculate skin for each zone

b- Unknown reservoir pressure and the calculation include part of the skin determination.

Two derivation done for both cases for single phase laminar flow pseudo steady state regime for homogenous reservoir (matrix contribution mainly).

2. Skin Profiling
Based on pseudo steady state flow regime during Production testing with Production Log, Darcy equation that defines the system deliverability expressed as [1]:

\[ P_e - Pwf = \frac{141.2QB\mu}{Km}n \left\{ ln \left( \frac{r_e}{r_W} \right) - 0.75 + S \right\} \]

Where \( k_m \) = mean permeability in the pay interval (estimated from well test analysis or from Enhanced...
Processed open hole log; \( h \) = pay thickness; \( Q \) = Total flow rate during production logging; \( B \) = formation volume factor; \( \mu \) = reservoir fluid viscosity; \( P_e \) = reservoir pressure; \( P_{wf} \) = flowing bottom hole pressure; \( r_e \) = reservoir external radius (drainage); \( r_w \) = borehole radius; \( S \) = skin factor.

Considering now a subinterval with thickness \( h_i \) and permeability \( k_i \) with production \( q_i \) and skin of \( s_i \) then equation (1) becomes:

\[
P_e - P_{wf} = \frac{141.2}{k_{hi}} \left( \ln \left( \frac{r_e}{r_w} \right) - 0.75 + S_i \right)
\]  

Combining equation (1) and (2) with respect to skin yields to:

\[
S - S_i = \frac{\Delta P}{141.2 B \mu} \left( \frac{K_h}{Q} - \left( \frac{k_{hi}}{q_i} \right) \right)
\]  

Where:
- \( S \): mathematical expression considers the theoretical total skin factor of the well. This number accounts for other deviation in parameters and will not be the same as the actual total skin of the well
- \( S_i \): layer (i) skin factor corresponds to damage/stimulation of \( i \)th layer.
- \( \Delta P \): Pressure drop between the average reservoir(s) pressure and wellbore flowing pressure (psi)
- \( K_h \): Total well flow capacity mD.ft
- \( k_{hi} \): layer (i) flow capacity mD.ft
- \( Q \): well production rate STB/D
- \( q_i \): Layer (i) production rate STB/D
- \( B \): formation volume factor
- \( \mu \): fluid viscosity cP

Having the corrected matrix permeability log as an input with the pressure drop per inflow zone (In case of vertical compartment or baffles) then simply the term \((S-s_i)\) can be determined per inflow zone.

The second step of interpretation is to compare the measured and calculated productivity index with iterating on \( S \) to determine \( s_i \) per zone where:

From PLT \( PI = \frac{q_i}{\Delta P} \)

* \( \Delta P \) can be either given from customer or determined simply from shut in pass in condition of multi choke test

The productivity index to be calculated with “S” iteration to match the PLT PI using following equation:

\[
\left( \frac{1}{PI} \right) = \frac{141.2 B \mu}{k_{hi}} \left( \ln \left( \frac{r_e}{r_w} \right) - 0.75 + S_i \right)
\]  

Example 1 shows the validity of the derived term.

3-Pressure Drop determination

In case of:
- 1- no previous knowledge of reservoir pressure
- 2- expected compartments and/or pressure baffles
- 3- no shut-in passes performed
- 4- Injection operation ongoing with offset wells that may disturb the pressure map.
Then, a method derived for pss flow to determine the drawdown value based on constant – rate drawdown test given by Ramey and Cobb [5]

\[
P_D(t_{DA}) = 2\pi t_{DA} + 0.5 \left[ \ln \left( \frac{4A}{\varepsilon r C A_A r_{w}^2} \right) \right]
\]

Where dimensionless pressure drop is:

\[
P_D(t_{DA}) = \frac{kh\Delta p}{141.2qB\mu}
\]

Pressure drop:

\[
\Delta p = p_i - P_{wf}(t)
\]

For drawdown and dimensionless time based on drainage are:

\[
t_{DA} = \frac{0.0002637k t \varphi (\mu C_e) A}{(1 - 0.0002637k t \varphi (\mu C_e) A)}
\]

Integrating equation 5 with respect to t_{DA} having

\[
P_{DI} (t_{DA}) = \left( 2\pi t_{DA} + 0.5 \left[ \ln \left( \frac{4A}{\varepsilon r C A_A r_{w}^2} \right) \right] + 0.5 \left[ \ln \left( \frac{4A}{\varepsilon r C A_A r_{w}^2} \right) \right] \right)
\]

Combining equation 5 and 8 yields to

\[
P_{DId} = 0.5 \left[ \ln \left( \frac{4A}{\varepsilon r C A_A r_{w}^2} \right) \right]
\]

Equation 9 suggests that when dimensionless pressure integral function, P_{DId} is plotted against dimensionless time, a horizontal line will be obtained during pss flow regime regardless of the reservoir geometry.

To link the derivation with the main objective of this note, means that, during PLT operation, a constant rate drawdown is to achieve the job objective, hence, without any extrapolation of the pressure versus time plot we can consider that the Pwf reached is basically the start of a zeroline slope which will be the start of the calculations for determining the Drawdown per inflow zone.

Expressing equation 9 in real oilfield variables [5], we have:

\[
(\Delta P)_{Id} = q_o b_{pss}
\]

Where:

\[
b_{pss} = \frac{141.2 B_o}{k_i h_i} \left[ 0.5 \ln \left( \frac{4A}{\varepsilon r C A_A r_{w}^2} \right) \right]
\]

Equation 10 is the basis of the analysis and strictly applicable during pseudo steady state flow regime for a constant rate case.

Two examples will show how to determine skin and reservoir pressure based on above.

Case#1
This is a simulator case of a well having 6 different reservoirs of different properties, vertical scale represent the depth and for convenience the scale subtracted by factor of 2000:

![Figure 1. PLT Profile of well with 6 flow zones](image)

Table 1 summarizes the results of simulated PLT response

**Table 1. PLT simulated analysis of each flow zone**

| h (ft) | qi (stb/d) | ki (mD) | mu (cp) | Bo | Dp (psi) | skin |
|---|---|---|---|---|---|---|
| 16 | 128.5 | 10 | 1.90 | 1.38 | 2922 | -2.03 |
| 17 | 558.4 | 38 | 1.90 | 1.38 | 2922 | -2.98 |
| 28 | 324.3 | 16 | 1.90 | 1.38 | 2922 | -0.99 |
| 16.5 | 80.4 | 11 | 1.90 | 1.38 | 2922 | 6.45 |
| 12.5 | 130.4 | 21 | 1.90 | 1.38 | 2922 | 4.59 |
| 45 | 778 | 33 | 1.90 | 1.38 | 2922 | 3.89 |

Table 1 shows:

- Track 1: layer inflow thickness (ft) from simulated model input
- Track 2: Layer inflow production rate (stb/d) simulated production model output
- Track 3: Layer permeability ki simulated model input, mD
- Track 4&5: PVT data per zone (formation volume factor and viscosity)
- Track 6: The pressure drop per layer (layer reservoir pressure minus borehole flowing pressure) psi
- Track 7: input model skin factor per layer

Applying equation 3 for each inflow zone to determine the expression (S-si), the results are shown in table 2
Table 2 shows:
Track 1: The skin factor per layer calculated using equation 4
Track 2: Productivity index determined from simulated model output
Track 3: Drainage radius in ft per layer part of linear regression output for all layers
Track 4: Productivity index from Darcy equation utilizing solution of equation 2
Track 5: is the error percent in productivity index between the measured in PLT (track 2) and the calculated (track 4)
Track 6: is the error percent between the calculated skin factor per later (track 1) and the actual skin factor (track 7 in table 1)

Case#2
A simulated PLT in a well produced from multilayer system with pressure baffles where cross flow encountered during PLT survey, the result of PLT is illustrated in figure 2

Table 2. Comparison of measured productivity index and skin factor with calculated values

| Si   | Pi from PLT (ft) | Re (ft) | Darcy Pi | E% in Pi | E% in Si |
|------|------------------|---------|----------|----------|----------|
| -2.0 | 0.044            | 56737.5 | 0.047    | 6.0%     | 1.4%     |
| -2.8 | 0.191            | 76488.1 | 0.200    | 4.5%     | 6.5%     |
| -0.9 | 0.111            | 61458.3 | 0.116    | 4.6%     | 9.9%     |
| 6.2  | 0.028            | 56973.4 | 0.028    | 1.8%     | 4.1%     |
| 4.3  | 0.045            | 60976.3 | 0.045    | 1.9%     | 6.8%     |
| 3.4  | 0.266            | 72880.6 | 0.269    | 0.9%     | 14.5%    |

Figure 2. PLT of well producing from 6 layers
The raw data for further calculation are shown in Table 3.

**Table 3.** PLT Analysis of Case #2

| From PLT results | From IPTT | PVT |
|------------------|-----------|-----|
| h (ft) | q(stb/d) | ki (mD) | mu (cp) | Bo |
| 16.0 | -76.5 | 100.0 | 1.90 | 1.38 |
| 17.0 | -105.1 | 380.0 | 1.90 | 1.38 |
| 28.0 | 36.1 | 160.0 | 1.90 | 1.38 |
| 16.5 | 24.4 | 110.0 | 1.90 | 1.38 |
| 12.5 | 94.2 | 210.0 | 1.90 | 1.38 |
| 45.0 | 1026.9 | 330.0 | 1.90 | 1.38 |

With this case, both drawdown per layer and skin is unknown, using equation 3 and 10 to determine both as given in Table 4.

**Table 4.** Summary of calculation and comparison

| dp (psi) | si | q/dp | Re | darcy PI | E% in PI | E% in Si |
|---------|----|------|----|----------|---------|---------|
| -297    | -2 | 0.258 | 56737455 | 0.268 | 3.8% | 0.0% |
| -97     | -3 | 1.084 | 76488135 | 1.129 | 4.2% | 0.0% |
| 53      | -1 | 0.682 | 61458301 | 0.702 | 3.0% | 0.0% |
| 123     | 6  | 0.198 | 56973370 | 0.203 | 2.3% | 0.0% |
| 303     | 4  | 0.311 | 60976268 | 0.319 | 2.6% | 0.0% |
| 563     | 3  | 1.824 | 72880580 | 1.874 | 2.7% | 0.0% |

Track 1: the estimated pressure drop (from equation 10 with optimized linear regression to equation 4)
Track 2: model skin factor calculated using equation 4
Track 3: productivity index using the calculated pressure drop with the determined flow rate per zone from the simulated PLT.
Track 4: Drainage radius in ft per layer part of linear regression output for all layers
Track 5: Productivity index from Darcy equation utilizing solution of equation 2
Track 6: is the error percent in productivity index between the measured in PLT (track 2) and the calculated (track 4)
Track 7: is the error percent between the calculated skin factor per later (track1) and the actual skin factor (track 7 in table 1)
4-Conclusion
This research establishes a new method of determining reservoir pressure and skin profile which will have an impact on well managements in terms of:

1- Work over cost
2- Reservoir depletion
3- Productivity monitoring
4- Unnecessary technology utilization
5- Work over optimization
6- Well troubleshooting
7- Work over cost
8- Reservoir depletion
9- Productivity monitoring
10- Unnecessary technology utilization
11- Work over optimization
12- Well troubleshooting

With this value, the study require development for:
1- multiphase flow,
2- gas wells,
3- Deviated and horizontal wells.
4- Fractured reservoirs

Once the research proves its advantage, to be converted into program linked with two main things:

1- PLT interpretation
2- Work over optimization in terms of acid job, plugs necessity, coning forecast, re-perforation, and tabular management

References
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