Multiple Array Production Suite Acquisition with PLATO Analysis in Unconventional Reservoirs

Quality & Partnership
MAPS- Key Benefits

- Identify oil & gas production and locate water entry points
- Operate in all well inclinations from vertical to horizontal
- MAPS combines the Spinner Array Tool (SAT) and Resistance Array Tool (RAT) to measure phase hold-ups and velocities
- Multiple sensors provide user configurable 3D visualization of multiphase flow with MAPview
- Memory and Real Time logging
• Tools positioned in the center of a well may miss oil, or gas flowing on the high side, or water on the low side of the pipe.
MAPS- Spinner Array Tool

- 6 miniature flowmeters mounted on bowsprings and 6 temperature sensors.
- Capture variable velocities and small entries from temperature (also a 7th centerline temp and spinner in the string)
12 miniature sensors mounted on bowsprings (also a 13th centerline capacitance sensor in the string)

Specially developed to measure the electrical resistance of surrounding fluid
Tool Design

- Bowspring style tools deploy sensors to intercept minority flows at the perimeter of a pipe. The sensors can also be restricted to measure away from pipe wall.
PLATO is a genuine Three Phase Production Logs Analysis system based on a Global Probabilistic Model of the Entire Well. This model is compared to all available data/information and is optimized through successive iterations until it produces the best possible Production Profile.

Therefore

PLATO offers a Dramatic Improvement over traditional production logs analysis, allowing more accurate results in multi-phase flow.
In Traditional analysis a few samples are used in non-producing zones. Flow-rates are calculated for the sample by solving the tool response equations. This method uses as many known's as unknowns. Redundant information and data is ignored. Therefore, here are no constraints to provide quality control and increase accuracy.

5 knowns - 5 unknowns = 0 constraints
PLATO has complete flexibility, allowing the simultaneous use of any number of tools and constraints. In a typical PLATO analysis the temperature log, pressure derivative and stationary spinner measurements are used together with the standard tool set.

700+ knowns - 203 unknowns = 497+ constraints
PLATO

- Powerful quality control
- Most accurate results
- Models can be very complex
- Uses a coherent global three phase flow model.
- Automatic flow regime selection
- Uses all data & surface info.
- Accounts for user information
- Sees thief zones and flow behind the pipe
- Uses flow-meter & temperature
- Uses material balance
- Concurrent use of any tool set, continuous & stationary data
- Open analysis system for easy extension of model & tool set
- Accurate emulation of entire flow profile within the well
- Total user control

TRADITIONAL

- No quality control
- Poor accurate
- Models must be analytically solvable
- Only compound and local flow models can be used
- Manual flow regime selection
- Only data at depth can be used
- User information cannot be included
- Only sees the flow within the pipe
- Only uses flow-meter
- Cannot use material balance
- Restricted tool sets and limited number of concurrent tools
- Closed programs with pre-determined analysis algorithms
- No emulation capabilities
- Limited user control

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Heat exchange between wellbore and reservoir

\[ (Q + \Delta Q) \rho C_p (T + \Delta T) \]

\[ \Delta z U (T_R - T) \]

\[ \Delta Q \rho C_p (T_R - T) \]

\[ Q \rho C_p T \]
Energy conservation equation in the wellbore

\[ \frac{\partial}{\partial z} T \sum_i Q_i \rho_i C_{p_i} = \frac{\partial}{\partial z} P \sum_i Q_i \rho_i C_{p_i} \eta_i - g \cos \theta \sum_i Q_i \rho_i - \sum_i Q_i \]

\[ \rho_i v_i \frac{\partial}{\partial z} v_i \]

\[ - Q_{rG} \rho_G h v_G + U (T_R - T) + \sum_i Q_{p_i} \rho_i C_{p_i} (T_R - T) \]

\[ - \sum_i Q_{p_i} \rho_i C_{p_i} \eta_i (P_R - P) - Q_{prG} \rho_G h v_G - \sum_i Q_{p_i} \rho_i \]

Where:

- \( z \): Measured depth
- \( T \): Well temperature
- \( T_R \): Geothermal temperature
- \( P \): Well pressure
- \( P_R \): Reservoir pressure
- \( g \): Gravity factor
- \( \theta \): Well deviation
- \( U \): Effective heat conductivity btw wellbore and reservoir

\( \sum_i \): Index over phases

- \( Q_i \): Flowrate of phase “i”
- \( Q_{p_i} \): Production rate of phase “i”
- \( Q_{rG} \): Gas coming out of solution
- \( Q_{prG} \): Evaporated gas from reservoir
- \( \rho_i \): Density of phase “i”
- \( C_{p_i} \): Heat capacity of phase “i”
- \( \eta_i \): Joule Thompson of phase “i”
- \( h v_G \): Vaporization heat of gas
- \( v_i \): Velocity of phase “i”
Computation of the Joule Thompson coefficient

\[ \eta_i = (\varepsilon_i - 1) / (\rho_i C_p_i) \]
\[ \varepsilon_i = -T / \rho_i \partial_T \rho_i \mid P = \text{constant} \]

Where:

\[ \varepsilon_{\text{Water}} = [0.1, 0.3] \]
\[ \varepsilon_{\text{Oil}} = [0.1, 0.3] \]
\[ \varepsilon_{\text{Gas}} = [0.8, 2.0] \]
\[ \frac{\partial}{\partial z} T \sum_i Q_i \rho_i C_{p_i} = \frac{\partial}{\partial z} P \sum_i Q_i (\varepsilon_i - 1) - g \cos \theta \sum_i Q_i \rho_i - Q_{r_G} \]
\[ + U (T_R - T) + \sum_i Q_{p_i} \rho_i C_{p_i} (T_R - T) \]
\[ - \sum_i Q_{p_i} (\varepsilon_i - 1) s (P_R - P) - Q_{p_{r_G}} \rho_G \]
\[ \text{Where:} \]
\[ z \quad \text{Measured depth} \]
\[ T \quad \text{Well temperature} \]
\[ T_R \quad \text{Geothermal temperature} \]
\[ P \quad \text{Well pressure} \]
\[ P_R \quad \text{Reservoir pressure} \]
\[ g \quad \text{Gravity factor} \]
\[ \theta \quad \text{Well deviation} \]
\[ U \quad \text{Effective heat conductivity btw wellbore and reservoir} \]
\[ s \quad \text{Skin} \]
\[ i \quad \text{Index over phases} \]
\[ Q_i \quad \text{Flowrate of phase “i”} \]
\[ Q_{p_i} \quad \text{Production rate of phase “i”} \]
\[ Q_{r_G} \quad \text{Gas coming out of solution} \]
\[ Q_{p_{r_G}} \quad \text{Evaporated gas from reservoir} \]
\[ \rho_i \quad \text{Density of phase “i”} \]
\[ C_{p_i} \quad \text{Heat capacity of phase “i”} \]
\[ \varepsilon_i \quad \text{Compressibility of phase “i”} \]
\[ H_{v_G} \quad \text{Vaporization heat of gas} \]
\[
\frac{\partial_z}{T} \sum_i Q_i \rho_i C_{pi} = \frac{\partial_z}{P} \sum_i Q_i (\varepsilon_i - 1) - g \cos \theta \sum_i Q_i \rho_i - Q_{rg}
\]
\[
\rho_G h v_G + U (T_R - T) + \sum_i Q_{pi} \rho_i C_{pi} (T_R - T)
\]
\[
- \sum_i Q_{pi} (\varepsilon_i - 1) s (P_R - P) - Q_{rG} \rho_G h v_G
\]

Where:
- \(z\): Measured depth
- \(T\): Well temperature
- \(T_R\): Geothermal temperature
- \(P\): Well pressure
- \(P_R\): Reservoir pressure
- \(g\): Gravity factor
- \(\theta\): Well deviation
- \(U\): Effective heat conductivity btw wellbore and reservoir
- \(s\): Skin
- \(i\): Index over phases
- \(Q_i\): Flowrate of phase “i”
- \(Q_{pi}\): Production rate of phase “i”
- \(Q_{rG}\): Gas coming out of solution
- \(Q_{rG}\): Evaporated gas from reservoir
- \(\rho_i\): Density of phase “i”
- \(C_{pi}\): Heat capacity of phase “i”
- \(\varepsilon_i\): Compressibility of phase “i”
- \(Hv_G\): Vaporization heat of gas
\[ T = T_B - z \left( G - \Delta G \right) + \left( T_B - T_{RB} - \alpha \left( G - \Delta G \right) - \Delta T \right) \left( e^{-\frac{z}{\alpha} - 1} \right) \]

\[ \alpha = \sum_i Q_i \rho_i C_{pi} / U \]

Where:

- **T**  Well temperature
- **z**  Measured depth
- **T_{RB}**  Geothermal temperature at bottom of flow zone
- **T_B**  Well temperature at bottom of flow zone
- **G**  Geothermal gradient
- **\Delta G**  Correction due to phase changes in wellbore
- **\Delta T**  Correction due to phase changes in wellbore
Temperature changes in flowing zones for small “z”

\[
T = T_B - z (T_B - T_{RB} - \Delta T) / \alpha
\]

\[
\alpha = \sum_i Q_i \rho_i C_{pi} / U
\]

Where:

- **T** Well temperature
- **z** Measured depth
- **T_{RB}** Geothermal temperature at bottom of flow zone
- **T_B** Well temperature at bottom of flow zone
- **G** Geothermal gradient
- **ΔG** Correction due to phase changes in wellbore
- **ΔT** Correction due to phase changes in wellbore
Temperature changes in flowing zones for large “z”

\[ T = T_{RB} + \alpha (G - \Delta G) + \Delta T - z (G - \Delta G) \]

\[ \alpha = \sum_i Q_i \rho_i C_{p_i} / U \]

Where:

- \( T \): Well temperature
- \( z \): Measured depth
- \( T_{RB} \): Geothermal temperature at bottom of flow zone
- \( T_B \): Well temperature at bottom of flow zone
- \( G \): Geothermal gradient
- \( \Delta G \): Correction due to phase changes in wellbore
- \( \Delta T \): Correction due to phase changes in wellbore
Heat exchange due to conduction

\[
U^{-1} = (2\pi)^{-1} \left( K_{\text{Rock}}^{-1} f(t) + K_{\text{Tubus}}^{-1} \ln(DO_{\text{Tubus}}/DI_{\text{Tubus}}) + K_{\text{Annulus}}^{-1} \ln(DO_{\text{Annulus}}/DI_{\text{Annulus}}) + K_{\text{Casing}}^{-1} \ln(DO_{\text{Casing}}/DI_{\text{Casing}}) + K_{\text{Cement}}^{-1} \ln(DO_{\text{Cement}}/DI_{\text{Cement}}) \right)
\]

\[
f(t) = \frac{1}{2} \ln(16 \cdot D_{\text{Rock}} \cdot \text{Time} \cdot DO_{\text{Cement}}^{-2}) - 0.29
\]

Where:

- \(K_x\) Heat conductivity of medium \(X\)
- \(DO_x\) Outer diameter of medium \(X\)
- \(DI_x\) Inner diameter of medium \(X\)
- \(D_{tx}\) Diffusion coefficient of rock
\[ \alpha = \left( 0.348 \, Q_w + 0.191 \, Q_o + 0.059 \, Q_g \right) \cdot \frac{f(t)}{K_{\text{Rock}}} \] (ft)

\[ f(t) = \frac{1}{2} \ln(16 \, D_{t,\text{Rock}} \, \text{Time} \, D_{\text{Pipe}}^{-2}) - 0.29 \]

For 1 year flow in sandstone:

\[ \alpha = 7.71 \, Q_w + 4.25 \, Q_o + 1.31 \, Q_g \] (ft)

Where:

- \( K_{\text{Rock}} \) - Heat conductivity of rock (MJ/m/K/d)
- \( D_{t,\text{Rock}} \) - Diffusion coefficient of rock (inch^2/day)
- \( D_{\text{Pipe}} \) - In inch
- \( \text{Time} \) - In days
- \( Q_w \) - In BPD
- \( Q_o \) - In BPD
- \( Q_g \) - In MCFD
- \( \Delta E = C_p q \rho \Delta T \)

- \( C_p \) is higher for water than oil.
- Higher for oil than gas

We have density from differential pressure and energy is conserved so with pressure and temperature (and determining fluid parameters such as \( B_o, B_g \)), we are able to identify phase flow rates.
Areas of Concern in Horizontal tight gas wells

Well Loading – is water falling back or cycling and hindering production?

Joule Thomson with 7 temperature constraint and array spinner production comparison (stage / perforation mobility and efficiency).

Are the stages stimulated effectively for maximum mobility?

How do some stages compare to others in the same well?

We hoped for more examples of this, but much of that data were not released.

Drilling Trajectory effects on production (Slope, plateaus, etc). Is the way in which the well drilled affecting production now or in the future?

Contribution. Where are the water, oil and gas coming from?

Water Banking. Is the high water holdup due to water production or banking (Energy and Mass balance compared with MapView visualization)

In the following examples, we see all of the above answered.
### 3 Phase producer

#### Horizontal toe

- **QWater**: BFPD 1920
- **QOil**: BFPD 312
- **QGas**: MCFD 12100
Quantifying water holdup with single sensor holdup tools cannot be done, array sensors must be used.
FD1 RAT and FDR Comparison

Note where the single sensor density tool shows complete gas in areas where the sensor cannot detect water due to lower holdup. The sensor never “sees” the water.
FD1 Spinner Array and Fullbore comparison

15,000’ – 15,300’
Water banking seen By SAT, not fullbore
FD1

Full Bore

Fairly consistent spinner data. Only slight evidence of water fallback or loading.
15,000’ – 15,300’
Water banking seen
By SAT, not fullbore
Slow velocity –
High holdup if no energy change

Banking
or water production
or both? PLATO
Analysis answers,
MapView visualizes
FD1

15,000’ – 15,300’
Water banking seen
By SAT, not fullbore
Slow velocity –
High holdup if no energy change.
In this zone, higher
Water holdup is related primarily to uphill trajectory
and not added energy or production

Banking
or water production
or both? PLATO
Analysis answers,
MapView visualizes
Increase in water holdup is primarily banking
Not production
Stage 3  15,790’-16,023’
Slight water production and banking of water with uphill trajectory. Note that the spinner vectors maintain and slightly increase velocity, even with water banking on the uphill trend. Plato calculates added energy to the system, which is seen as additional production. This is confirmed visually by MapView.
Unlike the previous bank, this area (15,790’ – 16,025’) is producing water.
The following surface production rates were reported:

- **QWaterSurf**  BFPD 1920
- **QOilSurf**  BFPD 312
- **QGasSurf**  MCFD12100

<table>
<thead>
<tr>
<th></th>
<th>QWaterSurf</th>
<th>QOilSurf</th>
<th>QGasSurf</th>
<th>% Total Water</th>
<th>% Total Oil</th>
<th>% Total Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>1905.42</td>
<td>326.41</td>
<td>12105.34</td>
<td>6.27</td>
<td>0.00</td>
<td>330.59</td>
</tr>
<tr>
<td>Stage 2</td>
<td>1806.18</td>
<td>310.83</td>
<td>11767.38</td>
<td>8.46</td>
<td>17.93</td>
<td>1266.41</td>
</tr>
<tr>
<td>Stage 3</td>
<td>1813.70</td>
<td>302.02</td>
<td>10410.94</td>
<td>251.01</td>
<td>7.28</td>
<td>848.00</td>
</tr>
<tr>
<td>Stage 4</td>
<td>1642.69</td>
<td>294.75</td>
<td>9502.84</td>
<td>127.56</td>
<td>55.09</td>
<td>1653.42</td>
</tr>
<tr>
<td>Stage 5</td>
<td>1557.94</td>
<td>205.03</td>
<td>5108.18</td>
<td>219.46</td>
<td>31.40</td>
<td>1037.70</td>
</tr>
<tr>
<td>Stage 6</td>
<td>1148.49</td>
<td>171.57</td>
<td>2070.48</td>
<td>85.04</td>
<td>97.50</td>
<td>10.02</td>
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<tr>
<td>Stage 7</td>
<td>1063.45</td>
<td>74.54</td>
<td>2060.46</td>
<td>332.17</td>
<td>31.77</td>
<td>137.96</td>
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<tr>
<td>Stage 8</td>
<td>713.28</td>
<td>43.38</td>
<td>1812.60</td>
<td>347.73</td>
<td>12.30</td>
<td>556.26</td>
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<tr>
<td>Stage 9</td>
<td>383.55</td>
<td>23.08</td>
<td>1364.34</td>
<td>253.94</td>
<td>0.00</td>
<td>754.56</td>
</tr>
<tr>
<td>Stage 10</td>
<td>120.60</td>
<td>23.98</td>
<td>611.68</td>
<td>129.60</td>
<td>29.98</td>
<td>611.63</td>
</tr>
</tbody>
</table>
HL3  2 phase (Loading up Well example)

QWater Surf  BFPD 45.0  
QGas Surf  MCFD 2800

The well went down to 2800 MCFD from an earlier rate of 8000 MCFD due to water being pumped at too high of a rate. Loading occurred.
The fluid density does not quantify the water holdup; whereas the Resistivity Array tool does, such as 15,150’. Note the spike in data at 12,910’ – 13,000’. Water production? Banking?
The full bore does not quantify velocities when mixed phases occur. Therefore no quantification of holdup or velocity from single sensor tools. Array tools must be run. Also, note that some spinners increase in the spike at 12,910', some decrease, indicating higher water holdup with faster moving gas in a smaller area.
Note flat area in trajectory. Gas production between this point and heel as well as slight water production at this step is creating a water bank at this point. Gas production is moving through the bank, but some impedance can eventually occur. This is seen occasionally on “steps” in drilling trajectories.
HL3 SAT and FullBore Comparison
Note flat area in trajectory. Gas production between this point and heel is creating a water bank at this point. Gas production is moving through the bank, but some impedance can eventually occur.
Note flat area in trajectory. Gas production between this point and heel is creating a water bank at this point. Gas production is moving through the bank, but some impedance can eventually occur.
FULL BORE

Loading (water fallback) not Confirmed by Full Bore but Confirmed by SAT.
HL3 Visual Water fallback and loading
Stage 14  12,454’-12,684’

This stage is entering the heel of the well. Water is moving forward, but some is falling back and banking as the well begins an uphill trajectory. Gas is moving rapidly above the banking water. Have a look at MapView.
Near the bottom of the well, slugging is evident when watching the SAT data in MapView. Have a look at Mapview noting the water fallback and slugging.
During logging, gas production at surface dropped from about 8000 MCFD to 2500 MCFD from loading.
During logging, gas production at surface dropped from about 8000 MCFD to 2800 MCFD from loading.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Contribution by Stage</th>
<th>GmWater</th>
<th>GmGas</th>
<th>GmWater</th>
<th>GmGas</th>
<th>% Total Water</th>
<th>% Total Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total BWPD</td>
<td>MCFD</td>
<td>Total MCFD</td>
<td>BWPD</td>
<td>MCFD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11,424</td>
<td>12,014</td>
<td>52.23</td>
<td>2537.23</td>
<td>0.00</td>
<td>6.73</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>11,758</td>
<td>13,018</td>
<td>52.43</td>
<td>2530.53</td>
<td>0.31</td>
<td>7.03</td>
<td>12%</td>
<td>0%</td>
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<tr>
<td>11,062</td>
<td>13,292</td>
<td>46.22</td>
<td>2523.50</td>
<td>4.85</td>
<td>9.35</td>
<td>9%</td>
<td>0%</td>
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<td>11,266</td>
<td>12,506</td>
<td>41.37</td>
<td>2515.15</td>
<td>0.00</td>
<td>7.75</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>11,670</td>
<td>13,900</td>
<td>41.37</td>
<td>2507.39</td>
<td>0.00</td>
<td>10.64</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>11,974</td>
<td>14,204</td>
<td>41.37</td>
<td>2498.75</td>
<td>0.00</td>
<td>93.82</td>
<td>0%</td>
<td>4%</td>
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<tr>
<td>14,278</td>
<td>14,508</td>
<td>41.37</td>
<td>2402.03</td>
<td>0.30</td>
<td>293.80</td>
<td>16%</td>
<td>11%</td>
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<tr>
<td>14,582</td>
<td>14,812</td>
<td>35.07</td>
<td>2398.45</td>
<td>10.49</td>
<td>210.28</td>
<td>20%</td>
<td>3%</td>
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<tr>
<td>14,116</td>
<td>15,116</td>
<td>22.58</td>
<td>1964.15</td>
<td>8.95</td>
<td>438.83</td>
<td>17%</td>
<td>17%</td>
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<tr>
<td>14,190</td>
<td>15,420</td>
<td>13.62</td>
<td>1555.32</td>
<td>4.47</td>
<td>1037.29</td>
<td>9%</td>
<td>39%</td>
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<tr>
<td>15,484</td>
<td>15,724</td>
<td>0.15</td>
<td>518.03</td>
<td>1.60</td>
<td>1539.90</td>
<td>3%</td>
<td>5%</td>
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<tr>
<td>15785</td>
<td>10025</td>
<td>7.33</td>
<td>387.13</td>
<td>7.06</td>
<td>387.13</td>
<td>14%</td>
<td>10%</td>
</tr>
</tbody>
</table>

1 bpm from Stage 3 and contribution from below
Logged behind Protechnics, note spiking GR
Slope effects on production

**QWaterSurf**  BFPD 100

**QGasSurf**  MCFD 9600
HL4 Fluid Density and CWH compared to RAT

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Temperature (°F)</th>
<th>Pressure (psig)</th>
<th>Density (g/cc)</th>
<th>Dielectric</th>
<th>TVD (ft)</th>
<th>Tgtherm (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,650</td>
<td>315</td>
<td>321.1</td>
<td>8000</td>
<td>1.1</td>
<td>34000</td>
<td>320</td>
</tr>
</tbody>
</table>

Fluid Density

Capacitance
HL4 Spinner Array compared to FullBore

Slugging seen by Array spinners. At 13,600’ – 13,950’, significant interference is seen by array spinners, but not picked up very well by fullbore. Also, water being pumped drastically loaded the well while logging.
HL4 Spinner Array compared to FullBore

Pumped water by coiled tubing unit
Drastically loaded the well, and the Production was cut drastically between Passes as shown here.
HL4 Spinner Array compared to FullBore

Slugging seen by Array spinners. At 13,600’ – 13,950’; significant interference is seen by array spinners, but not picked up very well by fullbore.

In looking at data in MapView, a plateau exists and some banking is occurring. No water fallback or loading is occurring here, however some water production is occurring. The banking here is a result of gas production between the heel and the plateau creating a barrier.
HL4 Spinner Array compared to FullBore
HL4 Spinner Array compared to FullBore

Water bank seen by Array spinners and holdup data at 15,850’ – 16,070’

Majority of holdup is due to banking, however slight water production exists. Looking at data in MapView, a plateau exists and some banking is occurring. No water fallback or loading is occurring here. However some gas and water production is occurring.
HL4 Spinner Array compared to FullBore
HL4 Spinner Array compared to FullBore

Water bank seen by Array spinners and holdup data at 15,850’ – 16,070’

Majority of holdup is due to banking, however slight water production exists. Looking at data in MapView, a plateau exists and some banking is occurring. No water fallback or loading is occurring here. However, some water production is occurring.
HL4 Spinner Array compared to FullBore

Water bank seen by Array spinners and holdup data at 15,850’ – 16,070’

Majority of holdup is due to banking, however slight water production exists. Looking at data in MapView, a plateau exists and some banking is occurring. No water fallback or loading is occurring here. However some water production is occurring.
Note that when wellbore trajectory is at a higher slope or gradient, the production across the stage or set of stages increases.
Note that the majority of gas production is occurring in the shallower section of the lateral toward the toe.

QWater BFPD 100.0
QGas MCFD 7800
HL5 Production Fluid Density – Capacitance and Resistivity Array Comparison

Fluid Density and Capacitance miss water bank that is picked up by RAT from 14,530’ – 14,840’.
Full Bore is fairly representative here, however the changing flow regime near the heel is better illustrated by the individual array spinners, as the fullbore is a combination.
Higher water holdup is seen by RAT, but not Picked up by Fluid Density. The increase in water Holdup is subtle, as there is not a regime change, just an increase in water percentage holdup. The spinner behavior illustrates the subtle Change, as there is a surging in the data. PLATO Analysis picks up on the higher water holdup without an evident regime change. Gas production Is occurring here, creating more of a barrier on the Plateau.
HL5 Array and Fullbore Comparison
Higher water holdup is seen by RAT, but not picked up by Fluid Density. The increase in water holdup is subtle, as there is not a regime change, just an increase in water percentage holdup. The spinner behavior illustrates the subtle change, as there is a surging in the data. PLATO Analysis picks up on the higher water holdup without an evident regime change.
Full Bore is fairly representative here, however the changing flow regime near the heel is better illustrated by the individual array spinners, as the fullbore is a combination.

12,220’ – 12,420’
Changing spinner response
In and near the heel.
Full Bore is fairly representative here, however the changing flow regime near the heel is better illustrated by the individual array spinners, as the fullbore is a combination
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HL5 Production Spinner Crossplot

Some water fallback seen on spinner data
The majority of the production is occurring from the shallower lateral near the toe.
The majority of the production is occurring from the shallower lateral near the toe.
SM6 Production

QWater Surf BFPD140
QGas Surf MMCFD6.00

Water banking at peaks or is it producing water?
SM6 Fluid Density compared to Resistivity Array

Resistivity Array quantifies water holdup whereas single sensor tools may only see a part or no holdup.
SM6 Full Bore compared to Spinner Array

Spinner Array quantifies water velocities (i.e. in banks at 13,303’ – 13,800’ and 14,710’ – 15,320’) throughout the well, where fullbore only sees water as it enters the centerline.
SM6 Full Bore compared to Spinner Array

Spinner Array sees the surging banking water that creates noise on the data. The fullbore does not see this to the same extent, therefore water and gas changing velocities cannot be identified as confidently with only fullbore spinner data.
Note banking visualization on MapView at approximately 14,710' – 15,320'.
Analysis shows that water production is occurring from below 15,000' but the water above to 14,710' is primarily banked water. MapView visualizes in a way single sensors cannot and PLATO quantifies.
Note banking visualization on MapView at approximately 13,303’ – 13,800’). Analysis shows that water production is occurring in lower trough, but the water seen toward the peak is primarily banked water. MapView visualizes in a way single sensors cannot and PLATO quantifies.
THANK YOU!

EAGLE Reservoir Services

Production Logging
Array Production Logging
Casing Inspection

Quality & Partnership