Flow Capacity Evaluation in Complex Carbonate Reservoir in Northern Kuwait Fields – Integration of Core Data, Open Hole Logs, Test Data and Production Logs

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Outline

• General Introduction
• Storage & Flow Capacity
• Structure map of study area and well diagram
• Some Premises
• Effect of Dolomitization on reservoir quality
• Comparison of core and log data
• Integration between PLT and well test data
• Wells with Matrix & Fracture Dominated Flow
• Well performance after acid stimulation
• Wells classification from PLT flow profile and K*H
• Well Analysis & summary
Overview of study area

Fields / Structures : 6

Drilled wells : 56
Which petrophysical parameters a completion and production engineer would be interested in?

• How much hydrocarbon is present?

  STORAGE CAPACITY

• Can the hydrocarbon be produced economically? (or later, how can it best be produced to achieve the highest economy benefits)

  FLOW CAPACITY

• What lithology is it? (For stimulation efficiency)
Current Casing Design

Lots of Casing Strings - 7

Very Heavy Wall Casings

(7 5/8” 55.3ppf – 0.75” thick)

Big Casing to Deep Depths

(13.5” to 13,000ft – 1MM lbs)

Non Typical Sizes / Weights

(Drill 9 ¼” Hole)

<table>
<thead>
<tr>
<th>Key Formation</th>
<th>Casing and Hole Details</th>
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<tbody>
<tr>
<td></td>
<td>42” Conductor pre-installed at 60 ft</td>
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<tr>
<td></td>
<td>30” Conductor, 196.1#, B, Vetco-R</td>
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<td>36” hole at 1,300 ft</td>
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<td></td>
<td>3-1/2” Tubing, 12.95#, L-80, NKEL</td>
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<td></td>
<td>24” Casing, top 4,500 ft 171.4#, B, RL-4S</td>
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<tr>
<td></td>
<td>btm 2,000 ft 186.2#, B, RL-4S</td>
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<tr>
<td></td>
<td>28” hole at 6,500 ft</td>
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<tr>
<td></td>
<td>18-5/8” Casing, 136#, C95, BO</td>
</tr>
<tr>
<td></td>
<td>22” Hole at 9,100 ft</td>
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<tr>
<td></td>
<td>10-3/4” Tie-Back, 73.2#, SS110, NKHW</td>
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<tr>
<td></td>
<td>13-1/2” Casing, 81.4#, SS-110, NK3SB</td>
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<tr>
<td></td>
<td>16” Hole at 13,000 ft</td>
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<tr>
<td></td>
<td>7-3/4” Tie-Back, 55.3#, SS110 (top part T95)</td>
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<tr>
<td></td>
<td>10-3/4” Liner, 73.2#, SS-110, NKHW</td>
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<tr>
<td></td>
<td>12-1/4” Hole at 14,100 ft</td>
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<tr>
<td></td>
<td>In selected wells:</td>
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<tr>
<td></td>
<td>5” Liner, 21.4#, Q-125, Hydril 513</td>
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<tr>
<td></td>
<td>6” Hole at 16,500 ft</td>
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Some premises

- Permeability prediction in carbonate is known to be challenging due to matrix heterogeneity.
- Natural fracture characterization from image logs is more challenging in OBM compared to WBM.
- Chemically diverting treating fluid during stimulation is a major challenge in naturally fractured reservoirs since the bulk of the treatment is injected into the zone having higher fracture intensity/density leaving the low porosity/permeability zone untreated.
- Some stimulated wells had flow contribution from top 10'-15' of the perforated interval.
Volume of Dolomite vs Rock Quality in Jurassic fields:

- Dolomitization increases the porosity and permeability of the rock.
- Dolomite crystals make the rock less susceptible of porosity reduction caused by overburden pressure.
Dolomite volume is controlled by magnesium weight % obtained with nuclear spectroscopy. Very good match with grain density.
Integration between PLT and Test data

\[ Q = \frac{k \cdot h \cdot \Delta P}{\mu \cdot C} \quad \Rightarrow \quad k \cdot h = \frac{Q \cdot \mu \cdot C}{\Delta P} \]

\[ k \cdot h \approx Q \]

Normalized cumulative k.h \quad \approx \quad Normalized cumulative flow from PLT
Wells classification from PLT flow profile, matrix $K^*h$ and PBU $K^*h$

- Wells with matrix dominated flow
- Wells with fractures dominated flow
- Wells with flow anomalies
Wells with Matrix Dominated Flow:
Well #1

PLT flow profile matches the prediction
K*H comparison within the uncertainty range

<table>
<thead>
<tr>
<th></th>
<th>KH Test</th>
<th>KH log</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well#1</td>
<td>1020</td>
<td>555</td>
<td>1.85</td>
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</tbody>
</table>
Well #2

- PLT flow profile match the prediction and yes it mostly comes from the top feet
- Completion zones can be optimized
Wells with Fractures Dominated Flow:
• Intensely fractured cores also interpreted on image logs

• Completion zones can be optimized
• Although it seems to follow the matrix flow profile approximatively, the flow capacity from PBU is higher than computed from the logs. Flow support from fractures in the drainage area must exist.
Flow profile anomalies:
No contribution from the bottom
Suspected immovable HC
Look at the mismatch in grain density
Between core and logs over this zone
Fractured interval contributing

Much more obvious and dramatic mismatch

Anomaly in saturation profile (Hydrocarbon computed below water zone)

Residual dead hydrocarbon also observed in nearby wells
PLT logs needed to confirm production behavior in the following wells:
Well #10

- KH test is lower than the PBU
- PLT needed to confirm the perforation interval and flow profile

<table>
<thead>
<tr>
<th>Well #10</th>
<th>KH Test</th>
<th>KH log</th>
<th>Ratio</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>728</td>
<td>3655.4</td>
<td>0.199</td>
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</tbody>
</table>
Well #11

<table>
<thead>
<tr>
<th>KH Test</th>
<th>KH log</th>
<th>Ratio</th>
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</thead>
<tbody>
<tr>
<td>1966</td>
<td>168.85</td>
<td>11.64</td>
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• KH test is higher than the predicted performance

• PLT needed to confirm the perforation interval and flow profile

• Flow is expected to come from behind pipe due to poor cement bound
K*H Log derived vs. PBU Diagnostic plot

Fracture dominated flow

Suspected Cement issue (PLT to confirm)

Suspected damage issue
Summary:

• Estimated matrix dominated flow profile can be derived from cumulative permeability thickness (k.h)

• Comparison with PLT flow profile and flow capacity from PTA can be used for:
  - Stimulation effectiveness diagnosis
  - Fracture/Matrix dominated flow identification
  - Solid bitumen effect confirmation
  - Formation damage zones identification

• The computed flow capacity from open hole log can be used to design perforation and stimulation intervals.
Acknowledgement

- Kuwait Oil Company (KSC)
- Ministry of Oil (MoO)
Thank You
Well Analysis

• Data source
  – PI derived from STT, LTT and Current Performance
  – kh (matrix) from openhole logs

• Interpretation
  – Group A (natural fracture dominated with tight matrix): data points would be plotted closer to the Y-axis (PI), showing a wide range of PI with low kh.
  – Group B (mixed behavior): data points would be in between Group A and C.
  – Group C (matrix dominated with few natural fractures): data points would be plotted closer to the X-axis (kh) and follow a more linear relationship (PI increases as kh increases).
PI vs. Log derived kh – “Diagnostic Plot”