LPS One Day Seminar Dec 2017

Everything Formation Testing

“Milestones in Wireline Formation Testing”

Prof George Stewart
RGS Consulting
WATER GRADIENT = 1.043 g/cc

Field Example Possibly Exhibiting Oil-Wet Behaviour

True Vertical Depth (m)

Formation Pressure (psi)

BRAZIL

Oil Gradient = 0.782 g/cc

WATER GRADIENT = 1.043 g/cc

GOC

WOC

TRANSITION ZONE FROM LOGS

FWL
$P_c = p_o - p_w$

$k = 1 \text{ md}$

$\phi = 0.25$
Phase Pressure Profiles for Mixed Wettability

Phase Pressure (psi)

Radial Distance (cm)

Mixed Wettability

$k = 1 \text{ md}$

$P_c(S_{xo})$

$P_o$

$P_w$
Carnegie asserts that oil production with low water-cut has been observed below the lower inflexion where a water gradient exists.
Fig 2.6.2: Anticline Trap

Section

Map

Hydrostatic Pressure - Depth Diagram

Hydrodynamic Water Flow

A, B, C

GOC

WOC

A, B, C

Pressure

Depth

A

B

C

Pressure - Depth Diagram
RFT Pressure Trends

GOC

HP Gauge

TVD (ft ss)

FWL A-4
FWL A-5
FWL A-3

A-4
A-5
A-3

Kraka Field, Denmark
Sunrise Troubador Formation Pressures

Variation in Free Water Level across the Field

Tilted GWC
Water velocity = 6 m/yr
in a 50 md aquifer

Only points with mobility greater than 5 md/cp plotted
Leaky Trap Hypothesis

Potential Explanation of Observed Near Water Gradient
In the Oil Zone in a Far East Reservoir
Pressure Depth Diagram Well TGT1X

\[ y = 0.7061 \times + 24.184 \]

2650
2700
2750
2800
2850
2900
2950
3750
3800
3850
3900
3950
4000
4050
4100

Pressure (psia)

TVD (m)

1.416 psi/m = 0.432 psi/ft

Datum = 2769 m

\[ p_{\text{Datum}} = 3887 \text{ psia} \]

Close to Water Gradient!

Note: reservoir is very close to being normally pressured

Fitted Regression Gradient

14.6 psi/m

y = 0.7061x + 24.184
WFRO – waterflood residual oil
OFRW – oilflood residual water

Main Forties Field
Bottom Water Reservoir with
natural water drive
(aquifer expansion)

WOC Rises with Production
(BP)

South East Forties
Oil Zone Expands
due to Aquifer Depletion

WOC Falls with Forties Production
(Shell)
South-East Forties Appraisal Wells

WFT Data

Gradients Slightly Less than Oil Hydrostatic Due to Downflow

TVD

Formation Pressure

Observed WOC Falling with Time (Oil Expansion)

Aquifer Depletion due to Forties Production

NTS
Pressure-Depth Diagram for Upflowing Oil Zone

- Oil Hydrostatic Gradient
- Oil Gradient for Upflow
- Straight Line on p-D Diagram implies Homogeneous Reservoir with Low vertical Permeability

TVD

Formation Pressure
Is there any geologic backup for the hypothesis? Has the idea of leaky traps ever been postulated by the geologists?

Yes, in fact the third appraisal well drilled (TGT-4X) to test a separate fault block due north of the TGT-3X encountered what appeared to be residual saturations in the ILBH5.2 formation. The consensus explanation given by the G&G team was the trap had been compromised by a leaking fault, which clearly extends into the shallower measures, something that we do not see with majority of the other bounding faults in the TGT trend. We never tested the 4X well in the ILBH5.2, but did core it and the saturations appeared residual or close to it.
Halford "Heavy" Water Gradient

Very Deep Overpressured Aquifer

Overpressure Increasing Linearly with Depth Giving Straight Line on p-D Plot

TVD

Pressure

Hydrostatic Water Gradient
New Generation Wireline Formation Tester (NGWFT) in the Barbara NW Field

Overview of Oil and Gas Fields in Italy

Cross-Section Showing Separation between the main Barbara Field and the Satellite Field, Barbara NW

After Loi et al. SPE 154426 (2012)
Barbara NW WFT Pressure Data

After Loi et al. SPE 154426

Higher Thickness Levels Hydrostatic Gradient

Pressures Determined from Pump Test

Overpressured Gradient

Gradient = 0.1037 (kg/cm²)/m² (water hydrostatic)
Permeability-Thickness Determination from Mini-DSTs over Thin Beds

Test XX29m  $K_h=0.19$ mdm  $S=8.7$

Test XX34m  $K_h=0.14$ mdm  $S=4.4$

After Loi et al. SPE 145526
Malaysian WFT Pressure Data

TVD (m)

Pressure (psia)

Reference Water Hydrostatic Gradient 1.394 psi/m
Review of SPE 139837


• Demonstrates that mini-DSTs can successfully forecast well deliverability
• Multiple mini-DSTs is now the prevalent form of layered well testing
• Focused on WFT methods to extract productivity parameters of formations
• Model employed is the familiar limited entry analytical solution
Well A

- Vertical exploration well drilled in a clastic reservoir
- Water based mud (WBM)
- 110 probe tests recorded
- 16 PVT samples collected
- Higher permeability at top and bottom from NMR log
History Match for mini-DST1 performed on top sand of well A.

1.7 hr cleanup

Model Match on Log-Log Plot

Well A
mini-DST 1
Buildups
74.5 - 75.3 m

k = 583 md
Permeability Results for Well A

- Geological layer with inter-bedded sand & silt - low Kv
- Geological layer with more massive sand unit - high Kv
Comparison of Permeability-Thickness and Permeability Between Mini-DST and DST Results in Well A

<table>
<thead>
<tr>
<th></th>
<th>Upscaled Mini-DST</th>
<th>DST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness, m</td>
<td>15.2</td>
<td>16.5</td>
</tr>
<tr>
<td>Permeability Thickness, md.m</td>
<td>6149</td>
<td>6948</td>
</tr>
<tr>
<td>Average Permeability, md</td>
<td>405</td>
<td>421</td>
</tr>
</tbody>
</table>

• Unfortunately the authors give no results regarding the skin factor
“Pin-Point” Fracturing Using Coiled Tubing
WFT Straddle Packer

Straddle Packers

Positive Displacement Pump

Formation Permeability $k$

$S$

$\text{Damaged (Skin) Region}$

$h$

$h_p$
Case where $h_p < h$

Time to the Beginning of Total System Radial Flow, $t_{brf}$

$$t_{Db} = \frac{0.000263679 \times k_z t_{brf}}{\phi \mu c_i h^2} = 0.083$$

Characteristic Dimensionless Time Based on $k_z$ and $h$

$$t_{brf} = \frac{0.083 \times \phi \mu c_i h^2}{0.000263678 \times k_z}$$

Correlation for Predicting the onset of Radial Flow based on Formation Thickness, $h$
Case 1
Limited Entry Situation

Case 2
Complete Straddle Packer

Assumes Impermeable Mud Cake

Mini DSTs

Better Arrangement

$h_p$

$h$

Shale

Formation
WFTSP Case 2 Situation

Data Edit

Storage Controlled Test (SCT)
Cased Hole Test C
Buildup 3

Log-Log Plot (using pseudo time)

Quick Match Results
Radial homogeneous
Ininitely acting
Constant compressibility

\[ C_s = 9.145 \times 10^{-7} \text{ m}^3/\text{kPa} \]
\[ k = 9.526 \times 10^{-4} \text{ md} \]
\[ k_h = 0.0029 \text{ md.m} \]
\[ S = -1.0005 \]
\[ D = 0 \text{ 1/(m}^3/\text{day)} \]
\[ P_i = 41937.7004 \text{ kPa} \]

\[ k = 0.000953 \text{ md} \]
\[ S = -1.0005 \]
\[ C_s = 9.145 \times 10^{-7} \text{ m}^3/\text{kPa} \]
\[ p_i = 41938 \text{ kPa} \]

Nonlinear Regression Automatch