“Integration of Petrophysical Data: Key to Mature Fields Rejuvenation"

HALLIBURTON

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Port Harcourt, Nigeria, March 2nd, 2017
London – 2018

USA – 2019

TBA – 2020

SPWLA 2017
58th Annual Symposium
Oklahoma City, Oklahoma

READY TO SEE OKC? MARK YOUR CALENDAR!
“Integration of Petrophysical Data: Key to Mature Fields Rejuvenation”
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Mature fields have been traditionally defined and managed from the production decline perspective with the recovery factor used as benchmark criteria. The current industry climate has forced this approach to be revised and in many cases reversed. The complexity grows with field maturation, requiring an increased skilled taskforce and a proactive approach towards use of baseline and timelapse dynamic measurements to validate and update the reservoir static models. This leads to a better understating of the uncertainty associated with the field’s economic value. Best practices indicate that integration of wellbore petrophysical data, static and dynamic, is the key for mature fields rejuvenation and to increase their recovery factor.
Keywords
- Production decline
- recovery factor
- complexity
- skilled taskforce
- economic value
- uncertainty
- integration

Mature Fields

Production Rate
- 10 Years
- 30 Years
- 50 Years
- 70 Years

Recovery Factor
- 10%
- 20%
- 30%
- 40%
- 50%
- 55%

When can/do we notice a sub-optimum Recovery Factor?
Keywords

- Recovery factor
- Production decline
- complexity
- skilled taskforce
- economic value
- uncertainty
- integration

Mature Fields

Recovery Factor

10%  20%  30%  40%  50%

At first the energy is abundant
Then we help with some energy
Then we identify unswept zones
Then we modify the behaviour of the molecules!
Mature Fields

Keywords
- Recovery factor
- Production decline
- Complexity
- Skilled taskforce
- Economic value
- Uncertainty
- Integration

Recovery Factor

<table>
<thead>
<tr>
<th>Recovery Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% 20% 30% 40% 50%</td>
</tr>
</tbody>
</table>

\[
 r(t) = \left[ \left( \frac{\gamma \lambda}{\pi^2 \eta} (t + t_0) \right)^{\frac{1}{2}} + \left( \frac{\lambda(t + t_0)}{\eta} \right)^{\frac{2}{3}} \right]^{\frac{1}{6}} + \frac{24 \rho g V^{\frac{3}{8}}}{7 \cdot 96^{\frac{1}{3}} \pi^3 \gamma_{LG}^{\frac{1}{3}}}
\]

where
- \( \gamma \) = Surface tension of the fluid
- \( V \) = Drop volume
- \( \eta \) = Viscosity of the fluid
- \( \rho \) = Density of the fluid
- \( g \) = Gravitational constant
- \( \lambda \) = Shape factor \( \lambda = 37.1 \text{ m}^{-1} \)
- \( t_0 \) = Experimental delay time
- \( r_e \) = Drop radius in the equilibrium
Sub-Optimum Recovery

• Fines Migration

Flow of Hydrocarbons (HC)

Wellbore

Damaged Zone

Crushed Zone

Fines Migration

Casing

Ideal Flow Lines
Sub-Optimum Recovery

- Water Intrusion – Channeling

Flow of HC + Water

Wellbore

Outer Cement Gap

Inner Cement Gap

Water Behind Pipe

Casing
Sub-Optimum Recovery

- Gas Blockeage

Lower Qo

Radial Distance to BubblePoint
Sub-Optimum Recovery

Reservoir   Perforations   Wellhead

Separator   ST/Pipeline

Pressure

$P_{res}$ $P_{wf}$ $P_{wh}$ $P_{sp}$ $P_{st}$
Surveillance Tools & Sensors

- Gamma Rays from Inelastic Collisions
- Gamma Rays from Neutron Activation Products
- Gamma Rays from Thermal Neutron Capture
- Inelastic $\gamma$-ray Capture
- High Energy Neutron

C/O ratio
- SS Detector
- LS Detector
- Generator

Sigma
- Capture $\gamma$-ray resulting from neutrons captured in the borehole yield decay at a rate directly proportional to the sigma of the formation

O-A
- Si-A

High Energy Pulsed Neutrons
**SCHEMATIC OF THE CHALLENGE**

- Vertical Well
- Annular Channel
- Water Entry
- Asymmetrical Water Paths
- WOC
SCHEMATIC OF THE CHALLENGE

- Water Flow
- Oil Flow
- Water Entry
- Slip Velocity: fpm
- D
- WOC
- Oil-to-Water Density Diff: g/cc
Scematic of the Challenge

Water Flow

Oil Flow

Water Entry

Oil Flow

\[ Q_{oA} = Q_{oB} \]
\[ Area_A > Area_B \]
\[ V_{oB} > V_{oA} \]

WOC
Mature Fields
Fractured heterogeneous carbonate formation

Capacitance Array Tool (CAT) / Resistance Array Tool (RAT)

SAT

Mini Spinners

Not Hidden behind Bow Spring

12 probes for each tool

CAT PROBE

RAT PROBE

Each tool
INTEGRATED WORKFLOW

Data QA/QC

PL Analysis (Standard + Array Tool)

Temp vs TVD Analysis

Match?

Water Flow Log (WFL) Analysis

Match?

Status known, Transient/ PSS?

No

Yes

Water Source Detected

Recommend Repeat Survey

No

Yes

March 5, 2017
Surveillance Tools & Sensors

Water Intrusion

Inner Cement Gap

Acoustic Signal
Fluid Unique Frequency Profile
INTEGRATED WORKFLOW

Data QA/QC

Acoustic Conformance

Temp vs TVD Analysis

Match?

Water Flow Log (WFL) Analysis

Indirect access to perforations/flow interface

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March 5, 2017
Impact of Uncertainty

Middle East Well

OH Volumetric

Water Salinity

Sw

119kppm

Fluid Volumetric

250kppm

ΔSw=35%

ΔVw=10%

65kppm

119kppm

250kppm
Integration

Asset Value
- Reserves
- Production
- Costs

Surveillance
- Behind Pipe
- Low RF
- Qo Gap

Characterization
- Saturation
- Area/Volume
- Pressure

Conformance
- Water
- Sand
- Gas

Baseline
- Fluids
- Rock

Integrity
- Scale
- Errosion
- Seal
Asset Value - Surveillance

Theoretical Flow Profile %

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Qo = 2014 BOPD
Pwf = 5697 psi

Qo = 1791 BOPD
Pwf = 5330 psi

Qo = 1098 BOPD
Pwf = 4380 psi

SPE 122199. Application of an Advanced Dynamic-Underbalance Perforating System for Improved Oil Production in Development Wells
Asset Value - Surveillance

Well Performance

Surveillance

Flowing Pressure (psi)

Oil Production (bopd)

Time (days)

Pwf (psi)

Pwf ' (psi)

Qo(BOPD)

Qo ' (BOPD)

Expon. (Pwf (psi))

Expon. (Pwf ' (psi))

Expon. (Qo(BOPD))

Expon. (Qo ' (BOPD))
Asset Value - Integration

SPE 122199. Application of an Advanced Dynamic-Underbalance Perforating System for Improved Oil Production in Development Wells
Mature Field - Integration

Well Performance

Surveillance

- Pwf (psi)
- Pwf' (psi)
- Qo (BOPD)
- Qo' (BOPD)

Expon. (Pwf (psi))
Expon. (Pwf' (psi))
Expon. (Qo (BOPD))
Expon. (Qo' (BOPD))
Integration of Petrophysical Data

Forecast Production Volumes

Cumulative Oil Production (bbls) vs. Time (years)

- Qp1 (bbls)
- Qp2 (bbls)
- XtraOil

6 MMBbls
Keywords

- Recovery factor
- Production decline
- Complexity
- Skilled taskforce
- Economic value
- Uncertainty
- Integration

Mature Fields

To improve Recovery in Mature Fields Integration of Petrophysical data (OH & CH) is mandatory, and must start immediately!

“...The best time to plant a tree was 20 years ago. The second best time is now.” – Chinese Proverb
Mature Fields
### Mature Fields

**Table:**

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<tr>
<th>FTP</th>
<th>SITP</th>
<th>CSG</th>
<th>BOPD</th>
<th>BWPD</th>
<th>NET GAS MCFPD</th>
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</table>

**Legend:**

- **Increase of 3,400 BOPD**
- **Decrease 4,900 BWPD**
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