Session I: Multiphase Flowmetering in Wells

Wanted: “Reliable & Accurate” Multiphase Flow Measurement in Intelligent Completions

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Outline

• Need for In-Well Flow Measurement

• Introduction: Optical Flow Measurement
  o The basics: what, how, and why
  o Single-phase, two-phase, and multiphase flow measurements

• Milestones & Case Histories
  o Applications

• Conclusions/Discussion
Why In-Well Flow Measurement

- Determination of in-situ and standard flow rates
- Allocation of zonal and commingled productions
- Optimization of production
- Identification and investigation of production anomalies
- Reduction of surface well tests and facilities
- Determination of productivity index and more…
Downhole Optical Flowmeter

- Integrated flowmeter and P/T gauge – all fiber-based
- Non-intrusive, non-invasive, full-bore, no pressure loss
- High turndown ratio, bidirectional
- Applicable to any pipe size
- Single-phase and multi-phase flow applications
Downhole Optical Flowmeter – Technology

- Turbulent pipe flow contains eddies (vortical structures)
- Eddies exert dynamic pressure onto pipe causing strain
- Sensors outside the pipe track eddies and sound waves
Downhole Optical Flowmeter – Technology

**Single-Phase Flows**

- Velocity $\rightarrow$ total flow rate
  
  $Q_{tot} = Velocity \times Area$

- Factory calibration (done once)
- Calibration is Re number based
  
  $Re = \frac{\rho V D}{\mu}$

- Universal behavior (G or L)
- Performance better than $\pm 1\%$
Downhole Optical Flowmeter – Technology

Two-Phase Flows

- SoS, key for phase fractions
  \[ Q_{oil} = Q_{tot} \times (1 - WLR) \]
  \[ Q_{water} = Q_{tot} \times WLR \]

- L/L curve: well-behaved
- G/L: more challenging

Performance region:
  - Gas-rich
  - Liquid-rich

- Total flow rate: ±5%
Downhole Optical Flowmeter – Technology

Three-Phase Flows

- Solution envelope (PVT)
  - SoS & density
- Contours of HL & WLR
- (HL, WLR) ← phase fractions
- (HL, WLR) → 3-phase point
- (SoS, density) → (HL, WLR)
- Velocity → total flow rate
Three-Phase Flow Measurement

- SoS and density measurement
- Vertical or near-vertical applications

\[(\Delta P)_{\text{Measured}} = (\Delta P)_{\text{Friction}} + (\Delta P)_{\text{Hydrostatic}}\]
Three-Phase Flow Performance

Flow Loop Test Results

<table>
<thead>
<tr>
<th>GVF Range</th>
<th>Total Flow Rate$^1$</th>
<th>Liquid Rate$^{1,2}$</th>
<th>Gas Rate$^1$</th>
<th>Water Fraction$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30%</td>
<td>±5%</td>
<td>±5%$^1$</td>
<td>±10%</td>
<td>±10%</td>
</tr>
<tr>
<td>30-90%</td>
<td>±5%</td>
<td>±20%$^2$</td>
<td>±10%</td>
<td>Unreliable</td>
</tr>
<tr>
<td>90-100%</td>
<td>±5%</td>
<td>±5%$^2$</td>
<td>±10%</td>
<td>Unreliable</td>
</tr>
</tbody>
</table>

$^1$Relative error, $^2$Relative error to total flow rate, $^3$Absolute error, All 95% CI (2 σ).

• Water fraction is unreliable for GVF > 30%
  ○ Flowmeter should be used in G/L mode
Historical Background

Milestones for In-Well Optical Flowmeter

• 2000 – First installation – GOM
• 2002 – First walk-away installation – Trinidad & Tobago
• 2003 – First 3-Phase Installation – North Sea
• 2005 – Surface flowmeter development (Alpha VSR)
• 2006 – Extensive multiphase flow loop tests
  o Performance envelope
• 2007 – Field-wide use of flowmeters in North sea
• 2005 – 2010 Gen-2 flowmeter development
  o Acoustic-tolerant flowmeter
• 2013 – More than 70 installations worldwide
Case History – Example 1

Two-Phase G/L Application

Mahogany Field Overview

- 45 miles off the Southeast Coast of Trinidad
- Largest gas producer in Trinidad
- Production commenced in October 1998
- Two-phase flowmeter installed in 2002
- Single-zone producer, downhole GVF > 90%
Case History – Example 1 (continued)

Story #1: Flowmeter identifies test separator error

- **Blue:** Flow rate reported by flowmeter in real-time
- **Red:** Well test results
Case History – Example 1 (continued)

Story #2: Surface instrumentation reconnects with flowmeter

Flowmeter performance (2007 – 5 years after)

- Excellent signal quality after 5 years
- Robust flow and SoS readings
- Excellent agreement with well tests (± 3%)

Ref.: 1st The Americas Workshop 2008
Case History – Example 2

Multi-Zone Injector Application

- North Sea Veslefrikk Field
- 4-zone WAG injector
- First intelligent well integrated with ICVs
- 3 single-phase flowmeters with P/T gauges
  - Installed in 2004

Objectives

- Remote control and monitoring
- Optimize water and gas injection
- Choke rates in zones with undesired water amount
Case History – Example 2 (continued)

Multi-Zone Injector Application

- Completion design
  - Zonal rates obtained by subtraction of flowmeter rates

- Some problems associated w/ high acoustics were remotely addressed w/ improved algorithms
  - Flowmeters functional at high flow rates

- No degradation in optical integrity after many years

- Value
  - Injection rates as well as cross-flow during shut-ins
  - Improved reservoir management
  - Saved well slots (i.e., allowed for additional producers)
  - Eliminated at least 1 injector (typical cost > $10 million)
  - Eliminated frequent wireline logging program
Case History – Example 3
Field-Wide L/L Application

Buzzard Field Overview

• Buzzard Field – located in the North Sea, 60 km NE of Aberdeen
• Discovered in 2001; drilling commenced in 2005; first oil in 2007
• Production is above 200,000 B/D; injection rates at 300,000 B/D
Case History – Example 3 (continued)

- N = 35 (currently)
- T = 90 sec × N

Monitoring & Field Expansion
Case History – Example 4

Service Change: Producer to Injector

- Dedicated injection well required to maintain pressure support

- Two wells identified for water and oil injection
  - Water injector: oil line removed, water line installed
  - Gas injector: gas injection feasibility study

- Wells didn’t include topside-metering solutions; utilization of downhole two-phase flowmeters was important

- Flowmeter is flexible to accommodate the service change
  - Flowmeter measurement bidirectional
  - Independent of the type of fluid
Case History – Example 4 (continued)

Results: Producer to Injector

Producer mode in 2008 & 2009

- Changing well conditions were adapted by the system
- Further optimization can be made with better SoS of injected water

Injector mode since 2011

SPE-167431
Case History – Example 5
Maximum-Contact Well – Intelligent Completion

- L/L application
- Maximum reservoir contact (>5km)
- Trilateral smart completion
- Goal → Production optimization
Case History – Example 5 (continued)

Maximum-Contact Well – Intelligent Completion

- Well → was producing at different lateral pressures
- MB → restricted to equalize pressure and allow more production from laterals at lower drawdown
  - L1 100% open
  - L2 100% open
  - MB 20% open

- Monitoring system → direct impact in optimizing production
Feedback Process: Technology Improvement

Field Test Impact on Technology

- Excessive acoustics by ICVs
  - Gen-2 flowmeter development
    - Extensive flow loop tests
    - Hardware / firmware / software
  - Acoustic-tolerant meter
    - ICVs
    - ICDs
  - Field tests scheduled

Excessive acoustics by ICVs
SPE-126741
Conclusions – In-Well Flow Measurement

Operator Perspective

• Real-time, continuous monitoring and allocation
  o Single-zone and multi-zone applications
  o Production optimization
  o Detection of production anomalies

• Reduction of well test frequency in test separator
  o Production acceleration

• “Life-of-well” solution
  o Reliability
  o Robustness
  o Accuracy
  o Flexibility
Conclusions – In-Well Flow Measurement

Technology Provider Perspective

- Multi-well, multi-sensor optical systems are proven
  - Expansion: flexible
  - Remote system access: beneficial, fast results
  - Reliability, longevity

- Adapting changing field/well conditions
  - Well service change: possible (e.g. producer-to-injector)
  - Fluid composition change: possible
  - Accuracy

- Real-time flow monitoring: a valuable tool
  - Production optimization
  - Detection of anomalies
Thank You

Questions & Discussion