OmniWell™ Production & Reservoir Monitoring

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Regional Product Line Manager (Reservoir Monitoring)

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Agenda

- Real time reservoir monitoring.

- OmniWell™ System - LxATS subsurface monitoring
  - LxATS slimline instrumentation capillary with Fiber Bragg grating (FBG) / ATS temperature and pressure real-time monitoring
  - RMS Surface data acquisition system
  - Reliability / Hydrogen darkening
  - LxATS installation methods

- Field data of real-time monitoring of SAGD in circulation & SAGD production mode
  - Efficiency metrics SOR / cSOR, local Subcool & steam chamber growth
  - Real-time, accurate and trustworthy thermal profiles
  - Manage stimulation processes in production mode
  - Lower Operational Cost and increase Production Rate

- Questions
OmniWell™ Family

Pressure
Flow
Seismic
Thermal

OmniWell Production and Reservoir Monitoring
OmniWell™ Production Optimization Solution

Field Systems
- Multiphase Flow Meters
- Monitor Water Cut
- Downhole Sensors
- Controllers
- Artificial Lift Systems

Real-Time Data Collection
- Automation & Control
- R-T Data Store
- Scorecard
- Decision Support

Engineering Analysis
- WellFlo
- PanSystem
- ReO
- ReOForecast
- PLATO

GLV Calculations
- Transfer Pressure Margins
- Design Options
- Flow Parameters
- Report Options
- Gas Lift Valve Calculations
  - Gas Passage
  - Set Pressures
  - Temperature Bias
- GLV Chokes
  - Discharge Coefficients
  - Use Catalog Discharge Coefficients
  - Use Temperature Bias
  - Use GLV Chokes
- Static Wellhead Temperature
  - °F
- Use Flowing Temp Gradient When:
  - \( P_t^{\text{static}} > P_t^{\text{flowing}} \)
  - MD > 4500 ft

Temperature Correction Calculation Method
- Rigorous
- Set Pressure Round-off 5 psi

Calculate Gas Passage Based on:
- Orifice Calculations
- True Valve Performance
- Correlation: VPC
OmniWell Integrated Optical Sensing System
Applications Experience

- Complete production and reservoir permanent monitoring solutions
  - Artificial lift.
  - Coal bed methane / coal seam gas.
  - Gas storage.
  - High temperature and pressure.
  - Heavy oil / thermal recovery.
  - Intelligent wells.
  - Sand face monitoring.
  - **Shale / multi-stage fracturing.**
  - Subsea.
OmniWell™ Technology

- **Electronic sensing systems**
  - Pressure, temperature and vibration sensing.
  - Up to $392^\circ$ F ($200^\circ$ C) and 25,000 psi (1,724 bar).
  - Over 5500 gauges installed worldwide.

- **Optical sensing**
  - Pressure/temperature gauges – Cane & LxPT.
  - Distributed temperature & Multi-point temperature arrays – DTS, DTS+, ATS * LxATS.
  - The pressure & temperature sensors operating environments include $572^\circ$ F ($300^\circ$ C) and 30,000 (2,068 bar).
  - Full bore downhole multiphase flowmeter.
  - Multi-component in-well seismic.
OmniWell The Case for Fiber Optic Sensors

• High Reliability
  – No Downhole Electronics
  – No Moving Parts
  – Minimal Part Count

• Ideally Suited For Harsh Environments
  – High Temperature Capability
  – Vibration and Shock Tolerant

• High Data Transmission Capability
  – Multiple Sensors on Common Fiber Infrastructure
  – Technological Advances Driven by Telecom

• Distributed Sensing
  – Sensing Over the Entire Length of the Fiber
OminWell Integrated Monitoring Approach

Unified Monitoring Solutions
- Pressure/Temperature Gauges
- Multifunctional Downhole Flow
- High Resolution Multi-point Temperature Sensing
- Distributed Temperature Sensing (DTS)

All Wells
- Multiphase Downhole Flow
- Tubing or casing conveyed

Actionable Real-time Data
- Temperature Correction Calculation Method: Rigorous
- Set Pressure Round-off 5 psi
- Calculate Gas Passage Based on:
  - Orifice Calculations
  - True Valve Performance Correlation: VPC

GLV Calculations
- Discharge Coefficients
- Use Catalog Discharge Coefficients
- Use Temperature Bias
- Use GLV Chokes

Transfer Pressure Margins
- Design Options
- Flow Parameters
- Report Options

Gas Lift Valve Calculations
- 0.675
- 85
- 24

Static Wellhead Temperature
°F

Use Flowing Temp Gradient When:
- \( P_t_{\text{static}} > P_t_{\text{flowing}} \)
- MD > 4500 ft
Each optical fiber can support a variety of monitoring combinations to meet application requirements.

- P/T Gauges
- ATS
- P/T + ATS
- LxATS LxT
- LxATS LxT/LxPT
- SEISMIC
- FLOW+P/T
- DTS
- DTS + P/T
- MM DTS

P/T = Pressure/Temperature; ATS = Array Temperature Sensor; LxPT/ LxT = FBG; DTS = Distributed Temperature Sensor
Optical Sensing Evolution - Weatherford

WORLD-FIRST DOWNHOLE FIBER OPTIC INSTALLATIONS:

1993 First In-well Optical P/T Gauge
1996 First Subsea Optical P/T Gauge
1999 First In-well Bragg Grating P/T Gauge
1999 First In-well Fiber Optic Seismic Accelerometer
2000 First Non-intrusive In-well Fiber Optic Flowmeter
2001 Optical P/T Gauge and DTS in Single Completion
2002 Multiple Optical P/T Gauges in Single Completion
2003 Full 3-phase Fiber Optic Flowmeter with P/T Gauges
2003 Multi-zone Optical P/T Gauges and Remote Flow Control
2004 Multiple Optical P/T Gauges and Flowmeters with Remote Flow Control
2004 Casing-conveyed, Multi-station, Seismic with P/T Gauge
2005 First Offshore Permanent Seismic Arrays interfaced to OBS Systems
2006 First SAGD LxATS Injector / Producer slimline CT deployed
2007 First Subsea Optical system for Array Temperature Sensing
2009 First LxPT installed intake pressure ESP SAGD & at Toe
2010 First combined ATS + DTS system for Sandface Monitoring
2011 First combined offshore flowmeters, P/T and Distributed Acoustic Sensing (DAS – 3rd party) monitoring.
2012 First offshore DAS (3rd party) concurrent multi-well seismic survey (Weatherford cable)
2013 First DTS, LxATS, CanePT, PDAS Thermal well s

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LxATS – High Density Array Temperature Sensing

Experiences monitoring in thermal Oil fields
LxATS & LxPT

- FBG Sensors at 300°C & 1,200 psi (8,500 kPa)
- Accurate sensing suitable for extreme High Temp
- No calibration fiber from Hydrogen
- Reliable & permanent string, > 10 years lifetime
- Multi-functional P,T in real time
- Varied monitoring spatial resolution along well
- Survives shut-ins / Thermal expansion
- Production Automation
- Detailed thermal analysis studies

<table>
<thead>
<tr>
<th>Mechanical Properties Gauge</th>
<th></th>
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<tbody>
<tr>
<td><strong>Gauge Outside Diameter (in/mm)</strong></td>
<td>0.25 (6.35)</td>
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<tr>
<td><strong>Gauge Length (in/mm)</strong></td>
<td>3.875 (98.4)</td>
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<table>
<thead>
<tr>
<th>Mechanical Properties Cable</th>
<th>1/4-in Cable (Inc 825)</th>
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<tr>
<td><strong>0.028-in wall</strong></td>
<td>Weight in air (lb/ft)</td>
<td>0.1</td>
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<tr>
<td></td>
<td>Collapse pressure (psi/bar)</td>
<td>&gt;30,000 (2,068)</td>
</tr>
<tr>
<td></td>
<td>Burst pressure (psi/bar)</td>
<td>20,000 (1,379)</td>
</tr>
<tr>
<td></td>
<td>Maximum tensile load (lb/kg)</td>
<td>1,500 (680)</td>
</tr>
<tr>
<td><strong>0.035-in wall</strong></td>
<td>Weight in air (lb/ft)</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Collapse pressure (psi/bar)</td>
<td>&gt;35,000 (2,413)</td>
</tr>
<tr>
<td></td>
<td>Burst pressure (psi/bar)</td>
<td>25,000 (1,724)</td>
</tr>
<tr>
<td></td>
<td>Maximum tensile load (lb/kg)</td>
<td>2,000 (907)</td>
</tr>
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</table>
LxATS Ultra High Temperature Monitoring

- Highest reliability and accuracy with real time sub-surface monitoring
  - First system installed Nov 2007 continuous operation in Injector
- Distributed multi-point Temperature and Pressure optical sensors
- Field proven optimization of SAGD and Steam flood recovery, reducing the operational costs & environmental footprint.
  - PID Control increases production rate by 29% lowers steam cost by 20%.

- More than 300 High Temperature/Pressure operating in Injector, Producer, infill and Observation wells (Q1 2015 – temperature range 220 – 300 C)
LxATS Systems with PID Control

✓ **Production Increase 29%**
  - Local Sub-cool measurements
  - Steam Breakthrough
  - Flow obstruction and thief zones
  - Measure and improve conformance
  - Performance of gas lift valve & ESP
  - Validate reservoir models & lifetime
  - Injection & production rates, pressures

**Results: Cumulative Oil Production**

29% Increase in Oil Production
Improved Control of Steam = More Mobilized Oil
OmniWell™ Production & Reservoir Monitoring

Local Subcool effects

SAGD Production phase

Circulation phase

Shut-in during production

Conversion from Circulation to SAGD production

Shut-in during circulation phase
Monitoring Experiences with thermal HO fields in Canada

- Nexen Pilot – LxATS installed Injector well November 2007
- Alberta Oilsands Monitoring Experiences
- LXPT optical pressure temperature gauge installed in 2009
- LxPT monitor intake pressure at ESP
Permanent Monitoring of High Viscosity SAGD Wells in Alberta Canada

- Experiences in monitoring high-viscosity oil fields Canada
- Nexen Pilot installed Injector well November 2007
- Optimize the Circulation Phase of SAGD Wells in Canada
- Optimize Production Phase of SAGD Wells in Canada

# Sensors 7200
# of Cables 171
Longest/mths 80
String Yrs 375.7
Max Depth 1960 meters
Max Temp 282º C
Monitoring Experiences with thermal HO fields in MENA

Oman:

- Qarn Alam – WFT UHT PT gauges installed (June 2012) Well under steam and Tmax = 230°C
- Qarn Alam – WFT UHT PT gauges installed in (November 2013)
- Amal west – WFT UHT-DTS and LxATS installed in 7 wells (2014)
- Amal west – WFT UHT-DTS and LxATS to be installed in another 8 wells in 2015
Real Time Reservoir Monitoring Thermal wells

Towards “Best Practices”

- Subcool measurements
- Steam Breakthrough & improve safety
- Flow obstruction and thief zones
- Tubing or casing leaks
- Reduce probability of sand production
- Reduce severity or impact of problem wells
- Completion effectiveness
- Measure and improve conformance
- Optimize surface operations duration and costs
- Optimize production & injection rates
- Performance of gas lift valve
- Validate reservoir models & reserve lifetime
- Highest and most economical recovery
- Injection & production profiles, rates, pressure

Results: Cumulative Steam-to-Oil Ratio

Feedback & Control
Data Interpretation
Surface/Process Data
Data Acquisition

20% Reduction in cSOR
Means 20% reduction in GHG Emissions
Main knob (Viscosity vs. Temperature)

At initial reservoir conditions, viscosity ~ 2+ million cP

- Steam Saturation Curve
- Athabasca Bitumen Viscosity

Target Viscosity

Pressure, kPa

Oil Viscosity, cP

Temperature, deg. C
Commercial In-Situ Recovery Process

Steam-Assisted Gravity Drainage

Chambers are Heterogeneous

Carbon Management Canada

CL Model
Oil Saturation 2008-12-26

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Monitored Data & Results

July 2012 using the WellVista™ real time software

- WellVista™ software enables processing of operational steam injection rates, surface pressures, pump variables and controls & subsurface pressures and temperature profiles

- Data from July 2012 shows local subcool at the 650 meter section as low as 15°C and instances when it drops to 10°C

- Adjustments in temperature, pressure and rate of injected steam will have a delayed impact on the production rate due to the pre-existing steam chamber

- Lifting rate has a more direct impact on the Δ T’s along the horizontal

Video of WellVista™ real-time visualization July 2012
Thank you & Questions