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13-16 November 2017

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SPE-188868-MS
Development and Field Application of a Permanent Fiberoptic Wellbore Fluid Level Monitoring System

Chris Staveley, Smart Fibres Ltd., United Kingdom
The Challenge: - Production Optimization of Fractured Carbonate Reservoirs

Current Methodology: - Periodic Wireline Gradio Surveys
- Drawbacks with Current Methodology

New Methodology: - Fiber Bragg Gratings (FBGs)
- Distributed Pressure and Temperature Sensing (DPTS) with FBGs
- Production Optimization using DPTS

Results: - Field Data
- Derived Value from Field Data

Current Status and Future Developments
THE CHALLENGE: FRACTURED CARBONATE RESERVOIRS

Typical Situation Faced by Petroleum Development Oman
• Very large reservoirs, multiple wells
• Thin oil rim with gas cap above and aquifer below
• Oil rim must align with the perforations in producing wells

But
• Oil is very mobile in carbonates – fractured / high permeability
• Leads to a dynamic oil rim

The Solution: Production Optimization
• Track the oil rim position across the reservoir
• Select which wells to produce and when
• Inject water or gas to control the oil rim position

So how to track the oil rim position?
PRODUCTION OPTIMIZATION: CURRENT METHODOLOGY

Measure fluid levels in well bores
• Indicative of levels in the reservoir if perforated well casing and fractured, permeable formation

Use a Wireline Gradio Survey
• Multiple measurand (P, T, C, ρ) tool lowered into well

Sounds good – is it Effective?
• Sometimes not…

Example Gas - Oil - Water Interface

GOC

OWC

Pressure

Capacitance

Temperature

Density
WIRELINE GRADIO SURVEY: DRAWBACKS

Data not real time
- True dynamic information missed...

Data accuracy questionable
- Differences between repeated gradio runs “orders of magnitude greater than the interpretation required” [1]

HSE Risks Involved
- Each survey requires a manned well intervention

NEW METHODOLOGY: DISTRIBUTED PRESSURE SENSING WITH FIBER BRAGG GRATINGS

• A collaborative development project:
  • Shell Global Solutions – Project Initiators and Sponsor
  • Smart Fibres – Solution Developers
  • Petroleum Development Oman – Field trial hosts and first end user

• Project Timeline:

2004
Project Start

2010
Trial Deployments

2015
System Optimisation

2016
Commercialisation

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FIBER BRAGG GRATINGS

- A Fiberoptic Sensor
- Recorded with UV laser light – changes core refractive index
- Unique Bragg wavelength $\lambda_B$ reflected according to the equation

$$\Delta \lambda_B = \lambda_B (1 - \rho_\alpha) \Delta \varepsilon + \lambda_B (\alpha + \xi) \Delta T$$

- Bragg wavelength Varies with strain and temperature

UV Laser Light

Single-mode Telecoms Optical Fibre

Alternating bands of high and low refractive index
Tuneable Laser Interrogator

Data

Processing Unit

FBG Sensors

FIBER BRAGG GRATING SENSING SYSTEM ARCHITECTURE

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PRESSURE / TEMPERATURE SENSING WITH FBGS

- 

- ¼” Control Line

- Pressure Cell

- Pressure Diaphragm

- Wellbore Pressure

- ¼” Control Line to next Gauge

- FBG Attached to Pressure Diaphragm

- FBG Attached to Temperature Coupon

- 2 Single Mode Fibers

- Sealed Vacuum

- FBG Attached to Temperature Coupon

- Internal Diaphragm

- Pressure Input Port

- ¼” Control Line to next Gauge

- Mandrel Seal (for tubing pressure)

- ¾” O.D. Gauge Assembly

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PRODUCTION OPTIMIZATION USING DPTS

Gas

Oil

Water

Pressure

Depth

GOC

OWC

Downhole PT Gauges

Pole Mounted Surface Instrument

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DPTS SPOOLED DEPLOYMENT METHOD

1. Tested DPTS gauge array delivered to well site
2. Gauge array run over large diameter sheave
3. Gauges fixed to tubing string with steel clamps
4. Solar Powered Surface instrumentation radios P/T data to PDO server
5. Software on PDO server calculates fluid interfaces
DPTS PRESSURE FIELD DATA

• Showing pressure reported from 14 deployed gauges over 5 months
• Very stable data (dP in gas phase \(\approx 1\text{kPa} = 0.15\text{psi}\))
• Relative gauge movement correlates with reported change of phase
Field Data from PDO Carbonate Reservoir, 2014/15

- Result from well with 15 Gauges deployed
- 6 months of data shown
- Oil rim disappears twice
- Gradio method would give 1 datapoint in this time window - i.e. it completely misses this behaviour

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PRODUCTION OPTIMIZATION USING DPTS: DERIVED VALUE

Improved Reservoir Understanding
- Gradio survey policy inconclusive. Real-time monitoring required

Production Improvement
- More than 100 m$^3$/d production increase estimated

Avoid Production Deferment
- e.g. prior loss of oil rim led to production loss of ~500 m$^3$/d for 6 months

OpEx Reduction
- One time cost of permanent DPTS system vs. repeated gradio survey costs

HSE Risk Reduction
- 1 well intervention for DPTS vs. repeated gradio survey interventions

System Expansion Capability
- DPTS fibre could also be used for DAS, VSP or DTS
CURRENT STATUS AND FUTURE DEVELOPMENTS

Current Status

• Numerous DPTS deployments with PDO for fluid contact monitoring in sweet and sour service fields
• Further DPTS deployments with other operators for other applications, both annular and tubing pressure measurements

Future Developments

• Increased gauge operating temperature from 400°F / 204°C to 600°F / 316°C service (for thermal recovery wells)
• Reduced gauge diameter from ¾” to ~¼” (for space critical applications)
• Integration of Quasi-Distributed Acoustic sensing (QDAS) between gauges
Acknowledgements / Thank You / Questions

Thanks to the following co-authors:
Crispin Doyle and Corne Coetzee, Smart Fibres
Andre Franzen, Hans den Boer, Arthur van Rooyen and William Birch, Shell
Ali Biderkab and Evert Moes, Petroleum Development Oman

Thanks for sponsoring the project and granting permission to publish to:
Shell Global Solutions International B.V.
Petroleum Development Oman
Sultanate of Oman Ministry of Oil and Gas