Gravimetric monitoring for existing and future use
Adrian Topham, 18th September 2020
We are a technology platform & data services company & our purpose is to solve complex challenges and create value through the application of gravity.
2 Uses of Borehole Gravity Measurements: Apparent density and Time-lapse

- **Apparent density** can represent formation bulk density: we compute an apparent density ($\rho_a$, kg/m³) of the layer of rock within the interval $\Delta Z$ as the measured difference of **single-axis vertical gravity** $\Delta g$, which is sensitive to the strata away from the borehole.

- **Time-lapse** repeated borehole gravity measurements are taken at the same locations in the well over a time period. The difference of the **tri-axial measured gravity** $\Delta g$ over time in a reservoir scenario is directly related to the time-lapse density change caused by the migration of different reservoir fluids such as oil, gas, and/or water.
4D time-lapse borehole gravity: What is the problem?

- Few techniques exist to map subsurface fluid movements (100’s ft around a wellbore)
  - Pulsed neutron immediately around a wellbore (10’s cm)
  - Sophisticated seismic surveys attempt to map deeper, costing millions of $\$, and are indirect ‘velocity’ measurements
- A gap exists between wellbore centric & 4D seismic survey data. Gravity can fill this gap.
- Huge appetite for time-lapse gravity to reduce uncertainties:
  - O&G reservoir surveillance: Flood front/coning
  - CCS: monitoring storage and CO$_2$ plume growth
  - Aquifers: Underground water movement
- Appetite for density imaging for mining and civil engineering
**Premise of a time-lapse (4D) gravity survey**

- The 3D bulk density distribution within a reservoir at any point in time consists:

  **Static element** - gross rock volume / density of solid matrix

  **Dynamic element** - saturation / density of fluids within the pore space

- Assume volume of km$^3$, within this region the mass can be measured by gravity sensor as:
  
  - Dominant “background” gravity field, (spatially constant - static)
  - “Anomalous” gravity field (spatially variable, dynamic component)

- Objective of a time-lapse borehole gravity survey is to measure this anomalous field, inferring fluid movement/substitution over time

- 3 axes will indicate spatial direction
Emerging Wireline Borehole Gravity Technology

Highly sensitive accelerometer

- MEMS technology
- Ultimate resolution of approx. Billionth Earth’s gravity
- 3-axis arrangement
- Significant size, weight & power ("SWaP"), 2-1/8” tool
- Wireline provider agnostic, full toolstring provided
- Feasibility modelling & post-acquisition Inversion

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<tr>
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<th>Target Specifications</th>
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<tr>
<td>Outside Ø</td>
<td>Slimhole OD 2-1/8” (54mm), tubing 2 ¼ ID</td>
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<tr>
<td>Temp. / Press.</td>
<td>250 °F, 125°C / 15,000 psi</td>
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<tr>
<td>Gravity Sensor</td>
<td>3-axis, resolution ~5 μGal</td>
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Northing  
N
Easting

Vertical

194845 • Three-axis Borehole Gravity Logging for Reservoir Surveillance • Lofts et al.
Inversion RESULTS

AQUIRE Gravity Log

Feasibility MODELLING

Survey plan/model

➢ saturation
➢ porosity
➢ density

gx, gy, gz (μGal)

 الوطن

➢ saturation
➢ porosity
➢ density

194845 • Three-axis Borehole Gravity Logging for Reservoir Surveillance • Lofts et al.

OTC 10.4043/30626 • Time-lapse borehole gravity survey for pre-salt reservoir monitoring • Du et al.
Vector gravity: 3-axis gravimeter measurements

Gravity anomaly is seen ‘growing from the NW
4D gravity time-lapse, Waterflood example
Onshore, Middle East

- $g_z$ provides info on vertical distribution of water; presence of water close to the well corresponds to a high gradient versus depth of $g_z$ in a zone
- Main injection interval (2260-2270 m) shown by the 2017–2018 responses
- $g_x$ shows southward movement of the water; 3-axes adds important directional information
- Measurement made in producers OR injectors...minimising lost production
4D gravity time-lapse, Waterflood example  
Libra Field, Santos Basin, Brazil

- Geophysically hard to define, sitting below the massive salt structures
- Conceptual Libra Field model built based on publicly available seismic imaging and well log data
- A clear gravity response (> 80 µGal) due to water replacing oil over 6 months of production (41 kb/d, ~7mmbbl)
- 3-axis measurement indicates direction of fluid movement 100’s of metres from wellbore

After Petersohn and Abelha, 2013

30626 • Time-lapse borehole gravity survey for pre-salt reservoir monitoring • Du et al.
4D gravity time-lapse, CO₂ Plume injection example
CCS monitoring Aquistore, Williston Basin, Canada

- Verify injection periods where sufficient injection taken place
- Feasibility model shows measurable response (~ 20 µGal) from CO₂ plume growth replacing water over appropriate time period (12 months)

Northing and Easting show increase in signal over 3 injection periods indicating NE preference.

Source: Energias Market Research
Future Value of MEMS sensors in 4D gravity time-lapse permanent sensing

- Field Demonstration of permanent borehole microgravity
- Opportunity:
  - One or two wells could monitor an entire field like Prudhoe Bay
  - Life of well monitoring of movement of fluids 100’s m from the wellbore

Reitz, 2014
Summary: 4D time-lapse gravity for Reservoir Saturation monitoring with MEMS sensors, emerging and future

- 4D time lapse gravity: deep reading time-lapse measure of fluid substitution
- 2-1/8" wireline deployed, potential for permanent completion
- Wide range of uses in reservoir management to optimize sweep
- Fill gap between near-wellbore logs and 4D seismic, cost effectively
- Commercial trials ongoing, more required to achieve commerciality in 2021

- Water/Gas
  - CCS, Canada
  - Gas field, Offshore

- Water/Oil
  - ME, US, Onshore
  - Brazil, UKCS, Offshore

- Commercial
  - Expand tool-fleet
  - Multiple operations

2020

Commercial field trials
Why now? What about oil price today?

• Our technology does this...
  • Early detection of production problems through surveillance – water breakthrough, coning, cusping etc.
  • Can reduce future infill wells / identify attic or by-passed hydrocarbons
  • Optimize well intervention through zonal isolation, production sidetracks etc.

• Opportunity to optimise reservoir surveillance programme
silicon microgravity
applying gravity to create value

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