Maximising Gas Well Potential in the Breagh Field by Mitigating Formation Damage

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When is formation damage important?

- **Prospect/development planning**
  - correct selection of field development options
  - consideration of formation damage should be an integral part of production or injection optimisation process

- **Development wells**
  - best to minimise damage
  - but can also remove damage

- **Exploration and appraisal wells**
  - formation damage mitigation is often sacrificed on the alter of drilling expediency
  - recognising and diagnosing formation damage can unlock hidden reservoir potential

- **Example - Breagh field, Southern North Sea**
  - many others exist
Breagh Field background

- Breagh located NW gas basin in Southern North Sea
- Reservoir in distributory channel, Scremerston formation sands of Lower Carboniferous age, preserved below Permian unconformity
  - poor test results – original operator relinquished licence
42/13-2 results

Reservoir properties
- 66 ft pay in 400 ft gas column
- average $\phi = 13.4\%$
- average Sw = 32\%

Core properties
- 0.5 mD to 478 mD (average ~ 10 mD)
- 3%-5% pore filling clays (kaolinite and illite)
- 36% to 45% of pore throats < 1 micron

Test results
- produced at only 3 mmscf/d
- main pressure build up was affected by changing well bore storage, masking the radial flow period
- match to log-log derivative plot of the main pressure drawdown indicated mean $kh$ of 158 mDft and damage skin (S) of +47
Reservoir exposed to heavy salt brine at around 400 psi overbalance then displaced with sea water
- 5 intervals perforated at 1550 psi underbalance using TCP-conveyed 4 ½” RDX guns
- WBM filtrate invasion between 30 – 60 inches from the wellbore (7450 ft to 7500 ft MD)
- perfs may not have penetrated beyond invaded and damaged zone
  - strong formation with coarse angular grains & high friction angle
- New operator recognised potential
  - commissioned integrated study to evaluate well results and drill and complete new appraisal well utilising best practice in well construction

Logs show deep invasion between 7450 ft and 7500 ft mD
Assess the potential deliverability of the Lower Carboniferous reservoir from an undamaged formation.

Vertical cased and perforated well

Key issues in well design:
- Could the reservoir section be drilled at minimum overbalance without compromising drilling or completion operations?
- Could the well be tested or produced without sand failure or sand production (common problem in SNS)?
- Could the well DIF be designed to prevent or minimise formation damage during conventional drilling?

Underbalance drilling had cost issues
- Drill conventionally at minimum safe overbalance (+ 0.4 ppg)

Integrated geomechanics/formation damage study
- Evaluate wellbore stability with 10.1 ppg mud
- Assess risk of sand failure and sand production during testing
- Characterise formation properties and carry out return permeability tests using water-based and oil-based DIFs
Return permeability tests on 42/13-2 core

- WB and OB DIFs formulated on basis of:
  - average formation permeability ~ 10 mD
  - clay content (3% - 5%) and pore size distribution (~40% < 0.5 micron)
- Return permeability tests at reservoir conditions
  - replicate field placement/overbalance (from 10.1 ppg mud)
    - 48 hours dynamic imbibition and 48 hours static imbibition
  - Imbibition (fluid loss)
    - Monitor DIF fluid loss (fraction of pore volume)
  - kg versus kg (reference)
    - after DIF exposure (worst case)
    - after mud cake removed (best case)
    - after remaining filtrate spun out (permanent damage)
## Return permeability test results

### Low permeability interval

- **Plug Code No.**
- **Helium Porosity (fraction)**
- **Air Permeability (mD)**
- **Reference kg at Swi (mD)**
- **Mud Type**
- **Total Filtrate Loss (PV)**
- **Return Permeability with mud cake (mD)**
- **Return Permeability w/o mud cake (mD)**
- **Return Permeability after spin down (mD)**

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**Notes:**
- * Mud cake removed manually
- ** Core extracted in centrifuge to remove remaining filtrate
Damage mechanisms

- Imbibition
  - OBM imbibition complete after ~ 25 hours
  - WBM filtrate imbibition continues unabated due to strong capillary forces
- Permeability damage
  - WBM-treated samples suffered a permanent permeability damage of 24% and 29%, compared to only 3% to 6% for the OBM-treated cores
- Damage mechanisms
  - retention of WBM filtrate in pore system reduces permeability to gas
  - filtrate invasion has dispersed, dislodged and suspended kaolinite and illite fines in the fluids
  - solids mud invasion at formation face
- Supports 42/13-2 well results

![Filtrate Loss Comparison - Low Permeability](image)

Filtrate loss curves for WBM and OBM DIFs

Cryogenic SEM shows WBM filtrate retention with filtrate draping grains and restricting pores
SPE 98110 database

Log-derived strength model

$$UCS = 1798E_c - 3574$$

$$E_c = \frac{1.34 \times 10^{10} \rho_b}{\Delta t^2}$$

$$\frac{TWC}{UCS} = 12.24UCS^{-0.4696}$$

Calibrated by tests on 42/13-2 core
- **Vertical stress**
  - density log integration 42/13-2

- **Horizontal stresses**
  - LOT, image logs in 42/13-2
  - pore pressure
  - RFT

- **SPE 98110 database**
  - stress tensors validated against offset data

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<th>Total Vertical Stress (psi/ft)</th>
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<th>Minimum Horizontal Stress (psi/ft)</th>
<th>Pore Pressure (psi/ft)</th>
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<td>1.00</td>
<td>0.80</td>
<td>0.72</td>
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Geomechanics - Results

- Wellbore stability
  - Well could be drilled with minimum overbalance without risk of collapse

- Sand production
  - No risk of sand failure at test conditions or if well produced over life of field

- Completion design simplified and failure risks minimised by avoiding sand control
42/13-3 Well Results

- Drilling and completion
  - drilled with 10.1 ppg oil-based DIF with no wellbore instability issues
- Reservoir
  - two good quality sands in Upper Breagh unit
    - 7358 ft MD to 7387 ft MD
    - 7413 ft MD to 7435 ft MD
  - 77 ft net pay in 296 ft gas column
  - Lower Breagh reservoir Unit consists of poorer quality sands and several thin limestones.
42/13-3 Well Results

Productivity
- perforated between 7340 ft and 7450 ft MD on 3 ½” OD TCP test string
- test kh ~ 237 mDft
- damage skin 0 to +2
- 17.6 mmscf/d (with no sand production) compared to 3 mmscf/d in 42/13-2
- AOF 10 times 42/13-2 AOF

Success
- well proved connectivity of channels
- 3 well field development underway
Well 42/13-5z

- Horizontal well in Breagh
  - cased and perforated completion
  - same OBM DIF as 42/13-3
  - drilled at minimum overbalance

- Tested January 2009
  - horizontal sand section 1,200 ft
  - tested dry gas at 26 mmscf/d
  - mechanical skin ~ 0
Conclusions

- Breagh field was condemned as non-viable as a result of poor well productivity rather than poor permeability or connectivity.
- Post mortem welltest and petrophysical evaluation on 42/13-2 indicated extensive formation damage through a combination of filtrate retention, fines migration and solids mud invasion.
- New operator drilled 42/13-3 appraisal well utilising best practice in well construction, drill in fluid and completion design.
- 42/13-3 produced 17.6 mmscf/d with zero to low skin. AOF increased 10 times compared to 42/13-2
- 42/13-5z horizontal well produced 26 mmscf/d with zero skin
- An integrated petrophysical, geomechanical and formation evaluation solution can recognise, diagnose and help mitigate against formation damage.
- Significant development opportunities can be realised in “uneconomic and non-viable” oil and gas fields
Observations

- In some operators, disciplinary compartmentalization and unaligned KPIs can combine to overlook or bypass viable opportunities, losing the value initially to the operator itself, and potentially to the rest of the industry.

- The key to the revival of this “toxic asset” has been the willingness of the smaller, independent operator to:
  - take calculated risks in a risk-averse climate
  - foster and encourage an integrated, multi-disciplinary approach that draws on the combined skills of geologists, petrophysicists, drilling, reservoir and production engineers.
Acknowledgements

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- MI Swaco (UK) – DIF design
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