Gas and WAG Injection in the Varg field – A Successful IOR Story
Recycled Material

Based on presentations from 2015 and 2016:

‘Increased Oil Recovery from a Mature Oil Field by Gas Injection’

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Outline

1. The Varg Field – A brief introduction

   • Water injection
   • Gas injection
   • IOR and possible mechanisms
   • Gas re-production

3. A-01 B
   • Huff’n Puff

4. Conclusion
Varg Field

- Located 200 km West of Stavanger
- First Oil 1998
- 16 slot WHP- Dry Trees
  - Not normally manned platform
- FPSO WI/GI/2 Separators/2 Flow lines
- FPSO owned and operated by TK
- Jurassic Sandstone, ‘Darcy sand’, but also moderate reservoir quality
- Light Oil, 35°API, undersaturated Pb=180-220 bar
- Stoip > 300 mmstb; produced oil 102.9 mmstb. RF varies by segment; +60%-25%
- Multiple OWC 2845-3018 m TVD SS, Multiple compartments, Faulted.
- Significant events 2014
  - Gas Export
  - New Seismic
- Talisman (Now Repsol) Operator from 2005
  - Partners Petoro as and Det norske AS (Aker BP)
- CoP 2nd of June 2016
Varg Production

- Production levels re-established as new segments are put on production
- Importance of Wag in late life
Fair reserves estimate from extrapolation
- Rate vs. Cum Reserves slightly under-predicts
- WOR vs Cum reserves slightly over-predicts
- The two methods in combination gives a fair reserves estimate.
A-10 A- A-07 C Well pair

Excellent reservoir properties and connectivity between wells

Segment is not influenced by other active wells
- Large faults to the West, Different OWC in the North, Reservoir pinches out to the East
- 3D view
Implementation of WAG

- Gas available from secondary gas cap and solution gas; gas production from A-08 A
- Gas compressor available
- Total Investment; About 1 MNOK to connect A-7 C to gas line
- For every gas/water cycle need one to two shifts to alter A07 C to water/gas injection
A-10 A Production Plot

- Increase in Oil Rate due to A07C water injection
- Decrease in WCT due to WAG injection
IOR Oil from A-10A

- Exponential decline may overestimate IOR oil
- WOR-method- Difficult to find baseline as wct is only 25%
- At least 2 mmbbl IOR oil
- (Plot also shows importance of the injector.)
WAG Saturation Development

- Oil recovered by gas/water, gas recovered by water.
- Improved sweep is main recovery mechanism for IOR

Simulation model:
- Grid sizes: x15-25m, y ~25m, z 1-2m
- Active grid cells ~120 000
- Permeability 50-1000 mD
- STOOIP in WAG area ~ 30 mill. bbl
Simulation Results from A-10 A - A-07C

Simulation of A-07C w/wo gas injection

- IOR oil 2.6 mmbbl
11.9 bcf of gas injected
13.7 bcf of gas produced since start of gas injection

- But some of that gas would have been produced during normal water injection operation

Considering only ‘excess gas’ (gas at GOR above solution GOR); 9.6 bcf is reproduced (81%)
Adding the solution gas from the IOR oil (2.6), 11.1 bcf (94%) is reproduced. => Net lost gas volume to IOR is low.
IWAG IOR Mechanisms

Microscopic displacement
- Lower Sorg than Sorw
  IOR appeared before reaching Sorw
- Increased Kro (at given Saturation)
  Slow process, observation is rapid increase in production
- Reduced krw with gas present
  Unlikely, parameter not very sensitive to history matching.

PVT
- Oil swelling for undersaturated oil
  Possible, but history match do not show sensitivity to ‘turning off PVT’
- Lower oil viscosity
  Possible, but history match does not show sensitivity to ‘turning off PVT’

Sweep
- Displacement of attic oil
  Possible, but not a significant attic volume
- Displacement of roof oil
  Possible
- ‘WAG mixing zone’
  Possible
- Better zonal displacement in ‘fining upwards sequences’
  Possible

Production issues
- Better lift performance
  Not likely: Deep gas lift installed production was not limited by lift performance in gas or water cycles
Gas Injection in A-01B

- Have drilled ~24 m MD of oil filled sand (~12 m TVD)
- Found water in the lower poorer quality part of the well
- High porosity, indicating high permeability (~500 md)
- Failed to cement well, i.e. no zonal isolation, acts like open hole
- Well came in with up to ~5000 boe/d, but rapidly declined down to ~1500 boe/d and then died due to lack of pressure support combined with a WCT around 60%.
- Failed to establish pressure communication to A-13 or any other injectors.
- What to do?
Gas injection in A-01 B using the Gas Lift System
Reduce krw selectively.
  • Gas will be dissolved faster back into oil

Displace attic oil
  • Seismic indicates sand up-dip of A-01B

Deeper Gas Lift
  • GLV at 1770 m TVD, Perf at 2800 m TVD
Production Results after ‘Huff’n Puff’

1. Inject Gas ‘slugs’ of 1 MSm³ of gas, typically 1-2 weeks
2. Rest – to allow for segregation and displacing attic oil
3. Produce, initially gas, then oil
Conclusions

- Gas injection has significantly increased late life production and reserves for the Varg Field. 3 different methods have been used to estimate incremental oil from WAG, all showing significant benefit.

- The Varg Gas injection is an example showing that IOR can be very attractive economically with short payback time, low additional investments and most of the injected gas re-produced.

- The most important recovery mechanism for IOR by WAG in A-07 C – A-10 is improved vertical sweep.

- Operational flexibility is key for successful WAG. GOR and WOR have been managed by adjusting WAG Cycle length to production responses.

- Huff ‘n Puff with hydrocarbon gas has been implemented in well A-01 B and has to date produced about 0.13 mmstb of incremental oil. Huff’n Puff has proven to be an innovative method for getting some gas injection benefits without a gas injector.

- Gas IOR can be economical even when competing with gas export.
Acknowledgements

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Thank you
Questions?
Don’t Forget the Prize!!
Varg Production 1.1.2012 – Dominated by A-10 A and A-05 A
A-10 A Scale issues

‘THE CHALLENGE OF SCALE CONTROL IN A LATE LIFE HIGH SALINITY, HIGH TEMPERATURE FIELD’

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Varg Field Introduction

Oil field south of Sleipner Øst in the central part of the North Sea. The water depth in the area is 84 metres. The field has been developed with the production vessel, “Petrojarl Varg”, which has integrated oil storage connected to the wellhead facility Varg A.

1984: Discovered by Den norske stats oljeselskap (Statoil)
1996: PDO approved (Operator: Saga Petroleum)
1998: First Production
2001: 1st cessation plan approved
2005: Talisman operatorship
2010: Production License 038 extended to 2021
A-10 A Production

Graph showing production data with various lines and markers, indicating different production rates and WOR (water to oil ratio) values.
A-10A PVT input

- Rs = 101.8
- Rs = 117.8
- Rs = 149.5
- Rs = 86.1

P @WAG = ~ 250 bar
GOR = 100 Sm3/Sm3

Liquid Formation Volume Factor, \( B_{lb, k} \) for:

- Symbol legend:
  - Oil formation volume factor (E1 HPI)
A-07C and A-10A pressure communication

A-07/A-10 pressure communication

\[ y = 0.3845x - 15499 \]

A-07 put on injection 07.07.2011