K17-FA Tight Gas Development

NAM-Shell EPE, Assen
Tight Gas in NL/NL Offshore

- Tight gas defined as reservoir properties <1mD average insitu
- TG Volumes mostly contained in Rotliegend reservoir (Slochteren Sst)
  - Tight gas properties mainly due to diagenetic impairment of reservoir sandstones by combinations of grain coating and pore-filling clay minerals and carbonates
  - Flow during well testing/production logging observed to be derived from few thin zones
  - Large lateral and vertical variation of reservoir facies, difficulty to accurately predict presence/location/orientation/dimensions of high flow features (fractures/HPS)
  - Absence or paucity of open natural fractures
  - Unusual combinations occur of low to high porosity and low permeability and limited height gas columns (often ~100m) characterised by thick transition zones and significant Sw
  - Compartmentalisation by faults common

- Well bore stability, sand production and risk of water influx are additional complications for TG field development

- Relatively modest in-place-volumes
  - Costs a major factor, cost control & reduction are a CSF
  - Ageing production systems, rising OPEX
K17-Location

- Broad Fourteens Basin
  - ~80km west of Den Helder
- Complex structural history, tight reservoir
K17-FA UBD : Background

- Main reservoir units 3 & 4
  - Thickness ~130m
  - N/G 80-100%
  - Porosity 4-26%
  - Permeability 0.01 - 200mD in-situ
  - Development – 2 horiz. wells close to existing wells

K17-FA discovered in 1972 (#2 well).
- NAM 60%, EBN 40%
- 1 Exploration and 3 Appraisal wells drilled 1977-1998
- 3D seismic;
  - Excellent to good quality. Complex overburden
- Rotliegend reservoir
  - Predominantly aeolian, with fluvial sandstones
  - Very heterogeneous
  - Paleo burial caused severe reservoir deterioration (hairy illite)
  - Poor well test results (also fracced wells) – tight reservoir
K17-FA – Location and Geological Setting

**Structural setting**

At the SW edge of the inverted Broad Fourteens Basin
Located in Erg setting adjacent to major fluvial system
Reservoir severely illitised

**Depositional setting**

**Diagenetic setting**

Fibrous Illites
**K17-FA diagenesis**

- Key reservoir issue on K17-FA: Reservoir pervasively illitised
  - No relation with
    - Structural position
    - Sedimentology
  - Permeability effect largest on poorly sorted fluvial sands

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![Image of illitised reservoir](image.png)
Rotliegend  SNS analogues
Similarities/differences

UK SNS
WELL EE  48/14-4 - Galleon
WELL SI  48/13-5 - Barque

NL SNS
WELL EE  K17+ 8

K17 vs UK Rotliegend TG
similar poroperm distribution

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<th>UK SNS analogues</th>
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Core perm: Cpor, Cperm

Rotliegend - Rotliegend
 Illite/Fibrous illite - Fibrous Illites
Core perm: Cpor, Cperm
Porosity: (5)10-26%, (5)10-22%
High permeability streaks (from PLT)
?Natural fractures/matrix (Natural) fracs/matrix

Stacked fluvial/dune sets (20-35m)
Same, but thicker dune sequence (45-60m)
Small column (> 165m)
Large column (> 250m)
UBD only tried in 1997
UBD the norm
K17-FA Main Development Risks

- Project cost
  - Drilling operations
  - Diving operations (weather risk)
  - Concurrent drilling, tie-ins, hookup & commissioning

- Well performance
  - Underbalance operations
    - Operational execution is critical (experience)
    - Relative lack of data (GR/Dir) and tool reliability
    - Well productivity prediction (initial)
      - Comparable to UK analogues?
  - Sand control required?
  - Deployment and cleanup of sand screens
  - Reservoir quality

- Pipeline & Facilities
  - Minimum facilities
K17-FA-101 plan to develop SE Block via 1700 m sub-horizontal placed in 40 m thick Unit 4

K17-FA-102: plan to develop NW Block via 1900 m sub-horizontal placed in 40 m thick Unit 4
K17 FA – Vertical facies distribution

Layer 5: 12 to 30 m, fluvio-aeolian, cemented very poor quality

Layer 4: 29 to 48 m aeolian, main target, best reservoir at base

Field wide shaly interval at base

Layer 3: 70 to 125 m fluvio-aeolian, medium quality, best reservoir at top

Layer 2: 19 to 28 m fluvial very poor to non-reservoir, vertical seal

Layer 1: 65 to 101 m sabkha-aeolian, medium reservoir, best reservoir at top
• Best reservoir across bottom half Unit 4 in line with E&A

• Difference between PIWD for Leg #1 and Leg #2 illustrates heterogeneity and benefit of long horizontal wells in TG reservoir

• No indications of natural fractures from either drilling or productivity data - but present in core

**K17-FA-101 Well Results**

- PIWD vs Depth
  - Leg #1
  - Leg #2

- PIWD = \( \frac{Q_{\text{gas}}}{(P_{\text{res}} - BHP)} \)

- Leg #1 trajectory
  - Steering problems

- Leg #2 200m short
  - Surface erosion problems

- Pres = 305 bar
- UB ~ 40 bar
- Unit 4 less clean than expected: NTG 85% vs 98% in E&A wells
- Best reservoir across bottom half Unit 4 in line with E&A data
- No indications of natural fractures from either drilling or production
- PIWD very helpful in steering well
- Shorter well than plan due to drilling difficulties
Initial Well Performance

- Very rapid clean-up – typical for UBD wells
  - Transient PI about 50% of instantaneous PI due to rapid depletion of thin high perm streaks
    - high PI’s 10-20Km3/d/bar
- Initial well performance suggests tortuous communication in reservoir
  - Corresponds with heterogeneity of reservoir
  - Connected volume increases with time
- Wellbore PI ≠ Reservoir RI
**K17-FA Hole Size**

- Average hole size 9” vs 6” gauge
- Extreme 12” hole size in K17-FA-102 sidetrack may have caused a drilling trouble spot
- Large volume of “whole grain” solids main cause of erosion of surface equipment
Comparison Against E&A Wells and Model

- Excellent inflow compared to E&A wells: horizontal & UBD success story
- Less inflow than modelled: model optimistic, impact of diagenesis difficult to model
Current View

- Biggest gain from drilling horizontals
- UBD enables horizontals in fractured reservoir
- UBD Qi benefit:
  - 1.5x-2.5x OK for damage
  - 6x-8x due to fractures
- Kill can be worse than drilling OB, in-line with general industry experience
- K17-FA performance in line with UK analogue wells
Evacuation system

K14-FA-1P/C

Dry Gas to Den Helder via K15 block

K14-FB-1

Umbilical

Wet Gas

Tie in to ONEGAS JDA LoCal evacuation system (WGT)

K17-FA-1 Monotower
Novel type of surface facilities: T2 monotower design

minimal facilities, remotely operated, 4 well slots, boat access, renewables (wind, solar) provide power
EBN/TNO Tight Gas workshop, 19Sept 2006, Utrecht

Installation

Interfacing

Drilling
K17-FA - Lessons Learned

✓ Multi-discipline, multi-functional effort with great attention to detail is critical
  ✓ To get it right-first-time is difficult
  ✓ Subsurface heterogeneity confirmed by drilling, difficult to model
  ✓ Minimum facilities - installation successful

✓ Reproduced success of horizontal drilling in UK offset tight gas fields
  ✓ Similar tight reservoir type – ‘horses for courses’ approach

✓ Maximised well capacity by underbalanced drilling (geosteering, impairment)

✓ Reaped benefits of oil-based underbalanced drilling fluid

✓ Installed sand screens underbalanced – but with a lot of difficulties/learnings

X Experienced integrity problems (BOP’s and surface erosion)

X Drilling trouble spots - need further investigation