CO2 for EOR
Ekofisk CO2 Study

FORCE - EOR Competence Building Seminar
November 2013
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Use of non-GAAP financial information - This presentation includes non-GAAP financial measures, which are included to help facilitate comparison of company operating performance across periods and with peer companies. A reconciliation of these non-GAAP measures to the nearest corresponding GAAP measure is included in the appendix.

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Agenda

- Introduction Ekofisk
- CO2 Mechanisms Subsurface
- CO2 Scenario Studies
- Summary
Ekofisk Field
Facts Ekofisk

LOCATION: CENTRAL GRABEN, NORWEGIAN NORTH
SEA
DISCOVERED: 1969
START-UP: 1971
OOIP: 7.1 MMMSTB
PRODUCED: 3.7 MMMSTB

RESERVOIR:
FRACTURED CHALK
- EKOFISK FM: DANIAN (EARLY PALEOCENE)
- TOR FM: MAASTRICHTIAN (LATE CRETACEOUS)
PAY THICKNESS: 1000 feet
DEPTH: 9500 - 10800 feet
POROSITY: 25 - 40%
PERMEABILITY:
Matrix: 3 - 10 mD
Effective: 3 - 100 mD

Ekofisk Formation
• 300 - 500 ft thick
• 2/3 of OOIP

Tor Formation
• 300 - 500 ft thick
• 1/3 of OOIP
Oil Resources and Reserves in Norwegian Fields

* Source: Norwegian Petroleum Directorate
Ekofisk EOR Target

Target for continued waterflood and EOR

Produced

2014-2028

Remaining oil after 2028

+1% incremental RF ~ 80 MMBOE
Historical Gas Based EOR Studies

![Graph showing historical gas-based Enhanced Oil Recovery (EOR) studies over time with various injection methods indicated, including Gas Injection, Water Injection, N2 Injection, HC WAG, Air Injection, and CO2. The graph includes a legend for studies, pilots, and executions.](image)
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CO2 has been extensively studied for the past 10 years

- **Subsidence & Compaction**
  - CO2 compaction impact
  - Well failure potentials
  - Full field subsidence/compaction forecast

- **CO2 Transport Mechanisms**
  - Injection schemes (Pure, WAG, Carbonated Water)

- **CO2 Displacement Mechanisms**
  - Fracture/Matrix interaction
  - Diffusion, Gravity, Viscous Displacement

- **CO2 Recovery Mechanisms**
  - Swelling, Vaporization, Miscibility

- **Other Issues**
  - CO2 Solubility in Water
  - Asphaltene formation
  - Hydrate Formation

- **Res. Simulation**
  - Model Mechanisms
  - Upscale to full field

### Project(s) Status:
- ***Completed***
- ***Ongoing***
- ***Need more work***

For workshop 6-7 Nov 2013
CO2 as an EOR Method

- CO2 can be a very efficient EOR method in homogeneous chalk
  - Potential for reducing Sor to less than 10% within 1 PV CO2 injected
- Miscible displacement can be achieved at reservoir conditions
  - Miscibility is a bigger challenge for HC- and N2-gas

**Enhanced Oil Recovery**

- Original ➔ Waterflood ➔ CO2 Flood

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**Laboratory test of waterflooded outcrop chalk with CO2 as EOR (University of Bergen)**

- a) Residual oil saturation after waterflood
- b) Residual oil saturation after CO2 injection
Most of the chalk fields are naturally fractured reservoirs
  ▪ Slower recovery and potentially higher Sor after CO2 flooding
  ▪ Early CO2 breakthrough
    ⇒ Cycling of CO2 - close to CO2 self sufficient after some years

Injection temperature
  ▪ Potential risk of losing injectivity due to hydrates
Challenges of CO2 in North Sea Chalk Reservoirs

**Compaction/Subsidence**
- Potential for increased compaction/subsidence with CO2 injection
  - Increased potential for well failures
  - Top side integrity
  - Increased risk for leakage

**Containment**
- More than 400 wells drilled during the 40 years of production
  - High potential for CO2 leakage
- Need for a safe aquifer as storage
Fractured Chalk

Fracture Corridors

Faults (offset & damage zone)

Dense Zones

Fracture network along faults (Lagerdorff)

Enhanced matrix

Etretat Chalk Cliffs (France)

porous chalk

fractured dense zone

porous chalk
Fractured Chalks: CO₂ Transfer Mechanisms?

- **Water Injection**
  - Oil – 30%
  - Water – 70%
  - Waterfilled fracs

- **CO₂ Injection**
  - Pure
  - WAG
  - CO₂/Water

- **CO₂ Transport**
  - Displace frac. water
  - CO₂ enter frac.system

- **Contact Residual Oil**
  - Diffusion
  - Gravity Drainage
  - Viscous Displacement

- **Oil Recovery**
  - Swelling of oil
  - Vaporization of light end components
  - Miscibility

- **Improved Recovery**
  - Oil
  - CO₂/Condensate Mix
  - Water/CO₂
In 2008 a larger simulation study was conducted

Full field scale CO2 injection

Two CO2 injection scenarios where evaluated
  - Continuous CO2 injection – 30MT CO2 pr year, with start-up in
    - 2020
    - 2023
    - 2028
  - CO2 WAG scenario with start-up in 2023 – 5MT CO2 pr year

Optimistic reservoir assumptions used in the simulation study.

Most knowledge of the fracture network and impact on recovery has been obtained in the past 5 years.
Simulation Study: Incremental Recovery above Waterflood

RF potential ~8-9% above waterflood. Optimistic reservoir assumptions used.
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Surface related CO2 Challenges

- **Logistics**
  - CO2 source
  - Transportation

- **Regulatory, HSE and containment**

- **High cost due to facility modifications**
  - Compression
  - Upgrade Wells for CO2 Service
  - CO2 separation
  - Pipelines
  ⇒ Expected need for a full re-development of the field

- **A multi-well pilot will be required before a full field implementation**
Value chain - 3 cost scenarios for delivered CO2

European Coal Power \rightarrow Carbon Capture \rightarrow CO2 transport pipeline \rightarrow Ekofisk CO2 EOR \rightarrow Offshore CO2 sink

(1) As-is (Base Case)
EOR project pays for full CO2 value chain and ‘receives’ carbon credits as an avoided operating cost

(2) Regulations force / incentivise power plants into CCS but they have alternative onshore storage
EOR project pays incremental transport cost to supply to Ekofisk vs onshore alternative

(3) Power plants are forced into CCS as above with no alternative storage available
EOR project gets free delivered CO2
Economical Screening of CO2 Scenarios

- High Upside Investments
- High Risk on Potential Recovery

*Even with optimistic reservoir assumptions, screening economics are not very attractive.*

NPV

- 30MT 2020
- 30MT 2023
- 30MT 2028

5MT WAG Waterflood as Base Case

Force workshop 6-7 Nov 2013
The increased revenues over waterflood are not enough to pay for the CO2 costs in the 30MT case.
Paying for the CO2 supply makes the 5MT case a marginal project under base assumptions.
Difference in value 5MT case vs continued waterflood

NPV

Base Case, Waterflood

Oil Price

Potential Waterflood Recovery

Volumetric Sweep

CO2 Cost at Source

Subsidence

Ekofisk new facility costs

Infrastructure costs

CO2 Permeability
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In un-fractured chalk, CO2 is a very effective EOR method

Key challenges (potential show-stoppers) related to North Sea chalk fields
- Most of the chalk fields are naturally fractured reservoirs
- Compaction/Subsidence
- Injection temperature
- Logistics
- Regulatory, HSE and containment
- High facility cost
- A multi-well pilot will be required before a full field implementation
Economics

- Even with optimistic reservoir assumptions, screening economics are not very attractive
- The cost of CO2 can significantly affect the economics
- The main economical uncertainties with base assumption of CO2 cost are
  - Oil Price
  - The size of the EOR target
  - Volumetric sweep efficiency
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