Improved Oil Recovery
- an overview

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The purpose of this presentation is to identify the relation between different measures and technologies in IOR
Definitions

Improved oil recovery - IOR  
(Norwegian Petroleum Directorate)  
The planning and execution of measures intended to increase or accelerate oil recovery from a hydrocarbon field in a profitable manner compared to current plans with corresponding forecasts.

Improved Oil Recovery - IOR  
(Society of Petroleum Engineers)  
Any of various methods, chiefly reservoir drive mechanisms and enhanced recovery techniques, designed to improve the flow of hydrocarbons from the reservoir to the wellbore or to recover more oil after the primary and secondary methods (water and gas floods) are uneconomic.

Enhanced Oil Recovery (EOR)  
Term normally used for the advanced chemical recovery processes, which can be part of an IOR project.

IOR in INTSOK  
’Improved Oil Recovery’ (IOR) is used for all measures which can increase or accelerate the oil recovery of a field.

There is emphasis on measures based on information gathered during production, and on measures based on advanced technology.
The unrealised potential

Produced oil end 2008
Remaining oil reserves
Remaining resources at planned cessation according to approved plans

Million scm oil

-800
-600
-400
-200
0
200
400
600

Troll
Ekofisk
Osberg
Eldfisk
Stavfiord
Vahalii
Snorre
Heidrun
Osbergs Ser
Gullfaks Ser
Brage
Balden
Gjene
Tor
Ula
Njord
Visund
Draugen
Oseberg Ost
Alvheim
Vesterklikk
Norne
Asgard
Fram
Vigdis
Gyda
Tordis
Hod
Yme
Skarv
Embla
Stafford Nord
Ur
Varg
Gulta
Albukskell
Froy
Stafford Ost
Jotun
Morvin
Mime
Gfive
Volve
Mischion
Sigma
Edda
Vollund
Vite
Ginne
Blane
Enoch

INTSOX
Norwegian Oil and Gas Partners
Reservoir Management - IOR - Success stories

Expected ultimate recovery factors

<table>
<thead>
<tr>
<th></th>
<th>1986</th>
<th>1996</th>
<th>2004</th>
<th>Current ambition</th>
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<tr>
<td>Statfjord</td>
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<td>Gullfaks</td>
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- Reservoir modelling
- Water and gas injection
- Production start
- Advanced wells and cost efficient infill drilling
- Well intervention
- 4D seismic
- Produced water management
- Top side modifications
Oseberg - continuous increase of reserves

- Postponed gas export
- Oseberg D platform 1999: Incr. gas capacity and NGL prod.
- Horizontal wells
- Multilateral wells
- Ness channel system development
  - Revised prod. mech
  - TOGI import
  - Development of northern part by Oseberg C

- Increased STOOIP
- Maturing of technical reserves

Base Reserves 1983

- New well targets
  - 20 + ?
  - 5

Dedicated Ness wells with intelligent completions 1995

First dedicated Ness well 1995

Horizontal multi-branched well 1995

Oseberg C 1991

TOGI 1991

Graph showing the increase in reserves from 1983 to 2003.
Where is the remaining oil?

Should the topside be modified?

Modeling!! Optimising Planning

Could you benefit from a sub sea solution?

Would an improved flooding process do the job?

Do you need to improve well performance?

Water management may solve the problem

Is additional drilling the thing?
Reservoir Modelling and Planning – the OIL COMPANY TASK

Recovery planning is normally based on full field or sector simulation and this is also the basis for optimised recovery.

The operating oil company is in charge, but will benefit from additional capacity and complimentary expertise.

Reservoir simulation and recovery planning
- AGR Group - Analysing IOR potential
- Aker Solutions – Consultancy in field planning, IOR studies and production technology
- IFE – Reservoir and tracer simulation tool
- IRIS – Field studies and special simulation tools and services
- Roxar – Reservoir interpretation, modelling and uncertainty. Reservoir simulation and history matching
- SINTEF Petroleum Research – full field and specialized models and simulation services
- SPT group – Reservoir and near-well simulation tools

Risk assessment and decision models
- AGR Group – Risk Assessment
- IRIS – Risk assessment models and services
Data Acquisition and Processing – full field

- Full field or regional data gathering
- Processing and analysis
- Visualization and static modelling
- Seismic surveys and interpretation
- Electromagnetic surveys and interpretation
- Tracer surveys
- Pressure surveys
Highlights of 4D seismic in Statoil

- Pioneered in Statoil since the early 1990s.
- Both towed streamers and ocean-bottom surveys (OBS) have been used.
- 4D feasibility study performed for all fields.
- Ongoing 4D projects on most fields.
- More than 40 wells drilled based on 4D seismic.
- Pilot on permanent fibre optical OBS being installed.
Data Acquisition and Processing – full field

Seismic and other full field surveys and interpretation
- Aker Solutions – seismic interpretation
- EMGS – Electromagnetic surveys
- EnVision – Visualization of pressure data (EnFind)
- Kongsberg - Visualization of reservoir and geophysical data
- NORSAR Innovation – 4D seismic modeling software and services
- OCTIO – Acquisition and processing seismic data
- READ – Down hole seismic acquisition and processing (VSP). Permanent Seismic Down hole Monitoring (PSM)

Tracer surveys
- IFE – Tracers mapping reservoir dynamics – ideal, partitioning and natural tracers, injection services and analysis. Monitoring chemical flooding.
Data Acquisition and Processing – local measurements and lab

Geo lab data and processing
Fluid lab data and processing
Sub sea monitoring
Down hole monitoring
Topside monitoring
### Data Acquisition and Processing – local measurements and lab

#### Geo & fluid lab data and processing
- APT – Biostratigrafic data based on core. Biosteering while drilling
- Aquateam - Water quality and chemicals. Lab- and pilot studies
- Fugro-Jason - Geodata acquisition and processing.
- IFE – Stable isotope data and biomarkers
- IRIS - General multifunction petroleum lab
- NGI – Rock mechanical and geophysical lab
- SINTEF Petroleum Research – Multifunction fluid lab

#### Sub sea and top side monitoring
- ClampOn – Sand detection
- Framo Engineering – Multiphase monitoring
- MPM – Subsea and topside multiphase & wetgas measurement
- ProAnalysis - Argus oil in water online monitors
- Roxar – Sub sea PT amd multiphase monitoring

#### Down hole monitoring
- READ – Multiple types cased hole data acquisition and processing
- RESMAN – Tracers for monitoring well inflow performance
- Roxar – Permanent PT Downhole Monitoring System (PDMS)
Chemical Flooding

Conventional methods
- Pressure depletion
- Water injection
- Injection of natural gas

Advanced flooding
- Polymer flooding
- Surfactant flooding
- Gel treatment
- CO₂ injection
- N₂ injection
- Water Alternating Gas (WAG)
- Foam Assisted WAG (FAWAG)
- Microbial EOR (MEOR)
- Steam injection
- Steam soak
Water injection

- Injection water for pressure maintenance
- Obtaining maximal volumetric sweep through monitoring, water shut-off and infill drilling
- Understanding remaining oil saturation after water flooding
  - Special core analysis (SCAL)
  - In situ observations
Gas injection projects in Statoil include:

- Large-scale gas flooding (miscible and immiscible)
- Gas cycling in gas condensate reservoirs
- Gas cap reinjection
- Supplementary WAG injection
- Gas diversion by foam (FAWAG)

CO2 injection

- Extensively studied for IOR
- Currently only injected for storage in aquifers (CCS projects)
CO2 for EOR in North Sea

- Challenges in the North Sea
  - Large well spacing
  - Very costly offshore modifications
  - Extensive use of gas injection and water injection – low residual saturations
  - Contamination of sales gas
  - CO2 supply/CO2 sources
  - Competition with other methods
Sleipner CO2 injection - our starting point

- Objective to reduce the CO2 content from 9% to 2.5% (sale spec.)
- The CO2 is captured by an amin plant
- CO2 storage in an aquifer
- Start up in Aug 1996
- Injection rate: ~1 mill ton CO2/yr
- Regularity: 98-99%
Chemical Flooding

R&D / assessment of chemical flooding

- AGR Group – Assess potential and decision basis for EOR projects
- Aquateam – Microbial EOR
- IFE - Broad petroleum research within recovery mechanisms and tracers for EOR operations
- IRIS – Broad petroleum research within reservoir technology, IOR & drilling
- NTNU - Broad Petroleum research
- SINTEF Petroleum Research – Broad Petroleum Research - WAG, FAWAG, polymers, surfactants, foam, CO2 sequestration, fluid flow in porous media
Drilling

Options for Improving recovery

- Conventional infill wells
- Horizontal wells
- Multilateral wells
- TTRD (Through Tubing Rotary Drilling)
- Extended reach drilling
Troll Oil

Ambition: 2 billion bbl

1 billion bbl produced in April 2005

8-13 m oil column

Increased well density

Prod. start Troll C

Prod. start Troll B

Test prod.


208 277 353 385 649 945 1164 1225 1328 1358 1408 1447 1460
Troll oil wells

- Increasingly longer well paths
- Targeting a thinner oil column
- Presently 114 horizontal wells and 33 multilateral wells
- Inflow control devices (ICD) in many wells

<table>
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<td>500</td>
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<tr>
<td>2004</td>
<td>7715</td>
<td>3 Branched well</td>
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<tr>
<td>2004</td>
<td>12679</td>
<td>5 Branched well</td>
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Drilling

Well design and planning
- add wellflow – Well planning consultancy
- AGR Group – Well planning, operations geosteering
- IRIS – research and verification of well design and down hole equipment
- SINTEF Petroleum Research – Support for well design, planning and real time analysis

Drilling technology and equipment
- AGR Group – Riserless Mud Recovery
- Geomec Engineering – Improved wellbore stability and mud loss management
- IRIS - Drilltronics
- PTC – Riser displacement cleaning tool
- Reelwell - Managed pressure drilling. Extended reach drilling

Alternative drilling and well intervention methods
- Aker Solutions – Coiled tubing. Light well intervention. Riserless well intervention
- FMCTechnologies – Riserless Well Intervention (RLWI)
- Odfjell Drilling – Snubbing
- TTS-Sense – Rack and Pinion technology

Rigs and drilling service
- AGR Group – Drilling management
- Odfjell Drilling – Rig and drilling services
- SeaDrill – Rig and drilling services
Options for improving recovery

- DIACS wells (downhole instrumentation and control system)
- Chemical treatments
- Down hole separation and injection
- Down hole pumping and compression
- Artificial lift
Using a diversity of wells

Increasing use of DIACS wells (downhole instrumentation and control system) both for injection and production

![Diagram of well setup with various components such as production packer, remotely operated valve, zone packer, and DHSV at different depths.]

**Installed DIACS wells in Statoil**

![Bar chart showing the number of installed DIACS wells from 1997 to 2007. The chart shows a significant increase in the number of wells installed after 2000, with a peak in 2004.]
Use of DIACS

With ICD

• Statoil - advanced well technology:
  – 1997: First DIACS well (Snorre A)
  – 2003: First with open-hole sand screen and swell packs (Snorre B)
  – Open-hole gravel pack and chemical injection on zonal level (Urd)
  – First with optical flow meters on zonal level in a DIACS WAG injector (Veslefrikk)
  – Technology development on Troll - a success story difficult to match
Well Technology

Well design and performance
- Geomec Engineering - Sand management, flooding optimisation
- IRIS – Research and verification of well design and down hole equipment
- Kongsberg – LedaFlow, dynamic multiphase simulations, flow assurance
- SINTEF Petroleum Research – Support on well design, planning and real time analysis, fracturing and filtercake topics
- SPT Group and IFE – Olga Rocx, well and near-well multiphase simulations

Well equipment
- AGR Group – Canseal, chemical zone isolation tool
- Aker Solutions - Wireline tractor and wireline logging services
- READ – Hydraulic expandable well systems, different kinds
- i-Tec – Equipment for smart wells
- Peak Well Solutions – Gas tight well barriers
- PTC – Equipment for Wellhead, Well intervention and completion
- SeaWell - Completion equipment and service
- TCO – Smart plugs

Artificial lift
- PTC – Gas lift equipment

Downhole separation
- READ – Flow splitter, cyclone based
Sub Sea Solutions

Options for improving recovery
- Sub sea pumping and compression
- Sub sea separation
- Sub sea power supply
Sub Sea Solutions

Pumping and compression
- Aker Solutions – Multiphase pumping and compression solutions
- FMC Technologies – Multiphase pumping and compression solutions
- Framo Engineering – Water injection pumps, Multiphase Pumps and Wet Gas Compressor
- PG Pump Solutions – Multiphase pumps
- Siemens Oil and Gas Offshore – Wet gas compressor

Separation
- Aker Solutions – Processing solutions
- FMC Technologies – Subsea separators and solutions

Sub sea power supply
- ABB – Power supply
- Siemens Oil and Gas Offshore – Power supply
Topside modifications may be needed in an IOR project – as a supplement to other measures or as Improved Recovery in itself

- Simplification, and reducing down-time
- Allowing low pressure production
- Debottlenecking - Gas processing capacity - Separator capacity - Water injection capacity - Gas injection capacity - Produced water treatment etc
Topside Modification

In-line separation
- FMC – CDS inline separation cyclone based

Process simulation
- ABB – Process simulation and control systems
- AGR – Process simulation
- Aker Solutions – Process simulations
- FMC Technologies – process simulation
- IFE – Process simulation
- Kongsberg – Process simulation and control systems, lifecycle simulation, online and enterprise simulation
- Siemens Oil and Gas Offshore - Process simulation and control systems
- SINTEF Petroleum Research – Process simulation, flow assurance
Water Management

Improving recovery

- Produced water treatment
- Reduce water production at source (well technology)
  - Isolate water producing zones
  - Intelligent completions
  - Down hole separation and reinjection
- Reinjection of produced water
Water Management

Water management consultancy
- AGR Group - Design water injection projects for IOR
- Aquateam – Consultancy and R&D for water management, operational support, monitoring and documentation
- Geomec Engineering – Rock mechanics consultancy for water injection
- NIVA - Water quality assessment and water management consultancy

Produced water treatment
- Hamworthy Gas Systems – Coalescer (VIEC)
- M-I EPCON – Produced water cleaning, Compact Flotation Unit (CFU)
- NIVA – microbial water cleaning techniques.
- ProPure – Produced water treatment – Four proprietary water treatment techniques among these C-Tour and TORR.
- Siemens Oil and gas offshore – Produced water treatment. Walnut shell filter
Statfjord drainage strategies

Early:
- Brent
- Tarbert/Ness
- Etive/Rannoch
- Dunlin
- Cook
- Statfjord
- Nansen/Eriksson
- Raude

- Water injection in Brent
- Gas injection in Statfjord fm

Later:
- Brent
- Tarbert/Ness
- Etive/Rannoch
- Dunlin
- Cook
- Statfjord
- Nansen/Eriksson
- Raude

- Development of East Flank
- Horizontal wells and ERD wells
- WAG injection in Brent
- Crestal suppl. water inj. in Statfjord fm
- In-fill wells and frequent workovers
Integration of data from multiple sources in wells and production process or from drilling and reservoir model.

Real time analysis and action

Visualisation and control room solutions

Integration of Operations
Integrated Operations

- ABB – Complete IO systems, data gathering, transfer, processing and control systems
- Abbon - Production monitoring
- AGR – Well planning and delivery process. Optimizing field operations
- Aker Solutions - Data gathering, transfer and processing
- Bjørge Naxys - Remote diagnostics software, communication systems
- EnVision – Visualisation of integrated data, mostly pressure.
- FMC Technologies – Flow management, production optimisation, software and control systems
- Framo Engineering – Integrated operation services for sub sea systems
- IFE – Integrated work processes analysis, software and consultancy. Tracer based process management
- IRIS – Integrated operation in drilling
- Kongsberg – Complete IO systems, data gathering, transfer, processing, visualization and control systems. Collaboration facilities and work process design
- Octio Geophysical – Real time decision systems
- Odfjell Drilling – Consultancy for drilling operations
- Roxar – Reservoir monitoring and data transfer.
- Siemens Oil and Gas Offshore - Complete IO systems, data gathering, transfer, processing and control systems
- SINTEF – Consultancy on IO for drilling

Research and Development

- DNV – IO in the high North – Development of standards for data representation to facilitate communication in the IO chain.
High recovery factors on Statoil-operated fields

- Strong increase in expected ultimate RF during the last decades
- Strong ambitions for further increase
- Continued and persistent efforts is the key

Expected ultimate recovery has grown by more than 4 bill bbl since 1990
Promoting Norwegian oil and gas capabilities in international markets

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