Technological challenges of shale gas exploitation

Speaker: Michael Golan, NTNU

The output of shale gas in the US has created a gas glut and depressed gas prices to the extent that conventional wisdom of near future energy scenarios starts to alter. At the same time it has triggered an investment rush to secure mineral rights in shale formations, pioneered by “independent” operators and followed by major integrated operators as Exxon, BP and Statoil.

Yet, even the successful US shale gas exploiters are operating in severe “technical fog” and in a “learn-as-you move” mode. Conventional hydrocarbon exploitation knowledge and practices are not easily transformed to shale gas. The huge scale of the underground shale bodies, coupled with nano-scale phenomena, and the mechanisms governing storage, release, and movement of shale gas exhibit new challenges.

The presentation will list some of the issues involved and address ongoing R&D efforts.

Date: Tuesday 2 November, 12.15-13.00
Place: Auditorium KJL2, Kjelhuset, Gleshaugen
Natural gas resources:
1. Conventional non-associated gas
2. Conventional associated gas
3. Tight gas reservoirs
4. Coalbed Methane
5. Shale gas

Shale formation and its organic content has been studied extensively as “source rock”. Petroleum geology and petroleum geochemistry investigates the “source rock” to conclude on the amount and type of hydrocarbons generated in the source rock and migrated to the reservoir trap. The drilling industry developed knowledge on the geomechanics aspect of shale layers penetrated during a drilling process.
Example of Kimmeridge-Bay shale in the UK which is a source rock of many North Sea fields. IPT students have annual field excursion to the area.

Kimmeridge Bay-Dorset

Basin development, rock subsidence, kerogen and hydrocarbon generation of H.C. migration.
Shale gas is defined as natural gas from shale formations. The shale acts as both the source and the reservoir for the natural gas. Older shale gas wells were vertical while more recent wells are primarily horizontal and need artificial stimulation, like hydraulic fracturing, to produce. Only shale formations with certain characteristics will produce gas. The most significant trend in US natural gas production is the rapid rise in production from shale formations. In large measure this is attributable to significant advances in the use of horizontal drilling and well stimulation technologies and refinement in the cost-effectiveness of these technologies. Hydraulic fracturing is the most significant of these.
What is the shale gas?

It is a natural gas from shale formations.

**Shale** is a fine-grained, clastic sedimentary rock, characterized by fissility.

**Fissility** refers to the property of rocks to split along planes of weakness into thin sheets.

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Conventional Reservoir vs. Shale Gas

<table>
<thead>
<tr>
<th>Conventional Reservoirs</th>
<th>Shale Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Gas Storage in Macropores; real gas law.</td>
<td>- Gas Storage by Adsorption on micropore surfaces and/or free gas.</td>
</tr>
<tr>
<td>- Production Schedule Darcy Flow of gas to the wellbore</td>
<td>- Diffusion through micropores according to Fick’s Law (Darcy Flow through Fractures or macropores)</td>
</tr>
<tr>
<td>- Gas Content as 1-SW from Logs</td>
<td>- Best Gas Content from cores.</td>
</tr>
<tr>
<td>- Gas To Water Increases in latter Stages</td>
<td>- Gas to Water increase or decreases with Production time</td>
</tr>
<tr>
<td>- Inorganic Reservoir Rock</td>
<td>- Source rock + Reservoir</td>
</tr>
<tr>
<td>- Hydraulic Fracturing may be needed to enhance flow</td>
<td>- Hydraulic fracturing required (permeability dependent on fractures)</td>
</tr>
<tr>
<td>- Permeability not pressure dependent</td>
<td>- Permeability highly pressure dependent.</td>
</tr>
<tr>
<td>- Macropore size: 1µ to 1mm</td>
<td>- Micropore size: &lt;5Å to 50Å</td>
</tr>
</tbody>
</table>

M. Kozlowski, K. Drop
The main enabler factor for shale gas production is the capability to drill long horizontal well and improve the connectivity between the wellbore and the formation by multiple frac.
The Challenge in the Shale Gas Business

Challenges in development of shale gas resources

Attractiveness of Shale Gas Prospects

How IOC (Integrated oil companies) assess attractiveness of shale gas prospect (source: Statoil)

Business Strategy of the IOCs with regards to Shale Gas Business (Statoil)

Development phases

- Early moves and land grabs
- Experimentation and growth
- Core development
- Exploitation and optimization

Subsurface potential

- Shale size, thickness
- TOC
- Gas mature
- Good shale permeability and porosity
- Frack barriers to prevent fracturing water zones
- Shallower than 4000 meters

Well cost index

- Depth
- Pressure
- Temperature
- Stratigraphy
- Water management
- HSE regulation

Market

- Market price
- Size / growth
- Supply / Demand
- Market structure
- Marketing model
- Legal frame
- Infrastructure
- Strategic fit

Business strategy of IOCs (Statoil)
What are the risks and knowledge gaps?

1. The size of the shale formation (lateral extension and thickness)
2. Heterogeneity and variations
3. The amount of organic material TOC (Total organic carbon) and the part which developed into xoren and oil and gas
4. The storage capacity, storage mechanism and hydrocarbone recovery capacity
5. Mobility of H.C from the rock to the wellbore. How much it can be enhances?
6. How to rationalized to offtake such that the initial high rate (transient) will be extended over longer period. This is primarily to rationalize sale contracts and surface facilities
7. High cost of wells and high risk in planning parameters relative to the yield.
8. Environmental issue related to the large amount of water and additives used in drilling and fracturing the wells.
TOC Variability in Exshaw Formation

SEM evidence of large portion of porosity within the kerogen
ROOKIE

Remote Operations in Oklahoma
Intended for Education

Overview

- **Monitoring & Automation**
  - Wells in Oklahoma, USA.

- **Uses:**
  - Data for PhD research on liquid-loading gas wells.
  - Student projects at IPT.
  - Teaching & exercises.
  - Multi-disciplinary.

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**Noblin**

- **Status:**
  - Monitoring and Control fully functioning.

- **Ongoing Work:**
  - Pump automation.
  - Modelling.

- **Status:**
  - Instrumentation in place.
  - Pumping unit installed.

- **Ongoing Work:**
  - Wellbore integrity.
  - Power supply.
  - Communication.

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**Anglin**

- **Status:**
  - Instrumentation in place.
  - Pumping unit installed.

- **Ongoing Work:**
  - Wellbore integrity.
  - Power supply.
  - Communication.

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**Students**

- **Coordinator:**
  - Aleks Juell (PhD)

- **GUI Development:**
  - Bjart Madsen (New Wells)
  - Maria (Documentation)
  - Farhad (Well Integrity)
  - Marwan (Coalbed Methane)

- **5th year projects:**
  - Miron (Signal Processing)
  - Tor Jørgen (New Wells)
  - Maria (Documentation)
  - Farhad (Well Integrity)
  - Marwan (Coalbed Methane)

- **Other students**
  - PhD, MS several institutes (ca 5)
User Interface (RookieGUI)

- Desktop Application
  - Historical data.
  - Real time data.
  - Video feed.
  - Control pump and choke.

- LabView
  - Created by students.

- Outlier removal.
- Denoising.
- Transient identification.
- Data reduction.
- Flow-history reconstruction.
- Behavioral filtering.
- Moving window analysis.

The oil and energy minister remotely operates the Noblin well

Production tripled within 20 minutes
Both the subsurface and the surface systems associated with fully developed shale gas fields are subject to complex decisions with many variables. The Rookie Laboratory, associated with NTNU center for integrated operation, is a natural actor in this arena.
Shale gas in US

Field Units for Gas Volumes

\[
\begin{align*}
scf &= \text{standard ft}^3 \at T_c, P_c \\
Mscf &= 10^3 \text{ scf} \quad \text{Used for well gas rates} \\
MMscf (MMCF) &= 10^6 \text{ scf} \quad 10 \rightarrow 150,000 \text{ Mscf/D} \\
bcf (Bcf) &= 10^9 \text{ scf} \quad \text{Used to define Gas Reserves, Gas in Place} \\
Tcf &= 10^{12} \text{ scf} \quad \text{(Recovered Gas)}
\end{align*}
\]

1 Tcf: Giant USA Gas Field (Marginal Norwegian Gas Field)

\(~5\text{-}10\text{ Tcf: Frigg, Sleipner, Ormen Lange}\)

\(40+\text{ Tcf: Troll Gas Field}\)

\(~900\text{ Tcf: World's largest conventional Gas Field (North Sea Field, Qatar)}\)
The nano scale of the pores in the rock and the flow permeability require a new range of tools, laboratories and methodologies.
work conducted at OU (Oklahoma University) and Norman.

Rock Tying in Gas Shales

Questions?
- Where should we land the laterals?
- Which zones are best for fracturing?
- How much vertical section are we producing from?

Pore/molecular scale processes

Molecular Transport in Organic Pores

Where is the Porosity?

Mineral grains

Crack

Organic matter

Pore/molecule scale studies

- Shale as a new location for CO₂ sequestration
- Pore-scale considerations in organic-rich shale
  - FIB/SEM image of organic pore structure
  - Effective organic pore size
- Considerations for shale gas storage capacity
- Measurement of shale gas storage capacity
- Multi-scale gas transport mechanisms
- Measurement of shale gas transport

Characteristics of Organic-rich Shale

- Sedimentary rocks with organic materials
- Trapping CO₂ in adsorbed state in kerogen
- Low permeability formations

Carbon Dioxide Storage Capacity of Organic-rich Shales

- Typical TOTC North American shale gas plays
  -pyrolyzed 4%
  - Marathon 11.12
  - Haynesville 0.8
  - Williston Basin: 5%
Fracturing operation of shale gas well. The frac job may cost 6-8 million US$.

Canadian Shale Gas Operations

Hydraulic Fracturing job scale

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>Super sized</th>
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</thead>
<tbody>
<tr>
<td>Water used [bbl]</td>
<td>~6000</td>
<td>10,000 - 12,000</td>
<td>&gt;20,000</td>
<td>To 90,000</td>
</tr>
<tr>
<td>Sand [lb]</td>
<td>100,000 - 200,000</td>
<td>200,000 - 250,000</td>
<td>300,000 - 500,000</td>
<td>Up to 1,250,000</td>
</tr>
</tbody>
</table>

Source: Canadian Society to Unconventional Gas
Shale Reservoir Permeability

- Dual porosity reservoir
- Shale porosity and permeability approximates a uniformly distributed system of natural fractures
  - Values $= 0.001$ and $0.01$ md
- Rest of shale porosity (matrix)
  - Between $0.5$ and $5\%$; permeability is between $10^{-5}$ and $10^{-9}$ md

Permeability-easiness of flow in Porous materials

<table>
<thead>
<tr>
<th>Permeability Ranges</th>
<th>Shale - Tight Gas</th>
<th>Sandstone (Carbonates)</th>
<th>Chalk</th>
<th>North Sea (West) Sandstones</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-4}$ - $10^{-2}$ md</td>
<td>$10^{-1}$ - $10^{4}$ md</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0.1$ - $5$ md</td>
<td>$10^{-1}$ - $10^{4}$ md</td>
<td></td>
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</tbody>
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| millidarcies | }
Marcellus Shale contains higher concentrations of naturally occurring radioactive materials (NORM) such as uranium-238 and radium-226 than surrounding rock formations. For years the NY Department of Environmental Conservation (DEC) has held the view that normal disturbances of NORM-bearing rock, such as mining and drilling, do not generally pose a threat to workers or the general public.

But recent tests of brine from Marcellus wells came back with levels much higher than expected. In October 2008 and April 2009 the DEC submitted 13 brine samples from twelve Marcellus wells that were actively producing gas last year. Test results show levels of radium-226 as high as 250 times the allowable level for discharge into the environment and thousands of times higher than the maximum allowed in drinking water.
Poland as an example of a new area of interest

Exploration concessions have been given to 14 operators:
- Chevron Polska Exploration and Production
- Cuadrilla Polska
- Aurelian Oil and Gas Poland
- ExxonMobil Exploration and Production Poland
- Mazovia Energy Resources
- Lublin Energy Resources
- PGNiG (biggest Polish operator)
- PKN Orlen (2nd biggest Polish operator)
- Strzelecki Energia
- BNK Petroleum (Indiana Investments, Saponis Investments)
- Lane Energy Poland + ConocoPhillips
- Lane Resources Poland
- San Leon Energy (Liesa Investments, Oculis Investments, Vabush Energy)
- Marathon Oil Poland

Source: Dan Jarvie, Energy Institute, Texas Christian University
Thank you

Michael Golan

contribution on Rookie by:
Aleksander Inel (PhD student and Rookie site manager)