Tight Oil EOR through Inter-Fracture Gas Flooding within a Single Horizontal Well

(Single Well Inter-Fracture Flooding: SWIFF)

Xuebing Fu

In Transition
This is a public forum, and your information is public. If you have confidential information to share, or intellectual property, please do so in later private meetings.

The goal of this event is to trigger interest and to encourage interested parties to connect and start a conversation.

It is our hope that the conversations will be productive.

These presentations may include forward-looking statements, which are subject to risks and uncertainties, and both financial and technical results may differ from projections.

The materials presented are for general information only, and are not intended to be complete, nor to function as operational documents. We make no warranty or representation that information is accurate, up to date or complete. We do not accept responsibility or liability to users or any third parties in relation to the use of the materials or their contents. No warranty, whether express or implied is given in relation to such materials. We shall not be liable for any technical, editorial, typographical or other errors or omissions within the information provided on this website, nor shall we be responsible for the content of any web images or information linked to this website.
US Crude Oil Production

[Graph showing US Crude Oil Production from 1945 to 2015, with bars for different regions including Tight, Alaska, and Remainder. Data source: Gail Tverberg, OurFiniteWorld.com.]
• **Primary depletion** is the standard method for shale/tight oil production, at the end of which **6~8% of the OOIP is recovered**. With the optimization of completion techniques this number may improve but still <10% OOIP in general.
Flooding Between Wells

- **Secondary Recovery** including water flooding and gas flooding between wells has been tried but with **very limited success**. Fracture communications, highly inefficient flooding pattern and/or extremely low injectivity are some major issues.
Huff-n-Puff

- **Cyclic Gas Injection (or Huff-n-Puff)** is a secondary recovery method that has gained tremendous momentum over the last few years. **Additional 30-70% over primary oil recovery** has been reported by EOG in the Eagle Ford.

- Injected gas can be methane or wet gas or $\text{CO}_2$.

1. Yu et. al, paper SPE 169575, SPE Western North American and Rocky Mountain Joint Regional Meeting held in Denver, Colorado, USA 16-18 April 2014.
Concept of SWIFF

- A continual pressure support process is usually superior to a cyclic injection process.

- An inter-fracture gas flooding process can be highly efficient due to the large surface area, uniform spacing and parallel alignment of hydraulic fractures in an ideal setting.

*Picture modified from: https://www.intechopen.com/books/effective-and-sustainable-hydraulic-fracturing/hydraulic-fracturing-mine-back-trials-design-rationale-and-project-status*
**Huff-n-Puff compared to SWIFF**

- **Huff-n-Puff**: sensitive to gas properties. The process relies heavily on good miscibility of injected gas with oil, mainly *first-contact miscibility*.

- **SWIFF**: more tolerant to lean gas and lower pressure operations. A one-dimensional miscible flooding process results in nearly 100% oil sweep efficiency; a *multi-contact miscibility* is required which is achieved at much lower pressure than first-contact.

*Picture modified from: https://www.intechopen.com/books/effective-and-sustainable-hydraulic-fracturing/hydraulic-fracturing-mine-back-trials-design-rationale-and-project-status*
Analytical Calculations

Assumptions:
Fracture half length: 350 ft
Fracture height: 300 ft
Fracture Spacing: 60 ft
Matrix permeability: 100nd
Fluid viscosity: 0.1cp
ΔP across a fracture unit: 5000psi
Steady-State Flow

\[ q_f = \frac{kA\Delta P}{\mu L} \]

\[ = \frac{0.0001md \times 10^{-15} m^2/\text{md} \times 350 ft \times 2 \times 300 ft \times 5000 psi \times 6.9 \times 10^3 \text{pa/psi}}{0.1 \text{cp} \times 10^{-3} \text{pa} \cdot \text{s/cp} \times 60 ft \times 3.28 \text{ ft/m}} \]

\[ = 20bbl/d \]

A well consisting of 50 fractures then correspond to 49 fracture units:
\[ q_{\text{well}} = 20bbl/d \times 49 = 980 \text{ bbl/d} \]
Reservoir Simulations (CMG GEM)

**Key Reservoir parameters:**
- Reservoir Model: **Single Porosity**
- Fracture Half Length: **350 ft**
- Fracture Height (thickness): **300 ft**
- Fracture Spacing: **54 ft**
- Model dimensions: **60×1020×300 ft**
- Number of Grid Blocks: **10×51×10**
- Porosity: **0.03**
- Matrix permeability: **100 nd**
- Fracture Conductivity: **10 md-ft**
- Fracture Tip Conductivity: **5 md-ft**
- Fluid Type: **Black Oil (40 API)**
- Initial Oil Saturation: **0.8**
- Reservoir Top: **12000 ft**
- Initial Reservoir Pressure: **10000 psi**

**Simulation Target:**
- **a Hydraulic Fracture Unit**

**Key Operational parameters:**
- Production Time: **20 years**
- Depletion Type: **Primary or SWIFF**
- Producer BHP: **1000 psi**
- Injector BHP: **8000 psi**
- Injected Gas: **Methane**
- SWIFF Trigger: **4 years after Primary Depletion**
- SWIFF Pattern: **Inject from the left fracture, Produce from the right fracture, with BHP kept constant at defined values**
Reservoir Simulation Results – Oil Saturation

Primary depletion:

0 years | 2 years | 4 years | 10 years | 20 years

SWIFF:

0 years | 2 years | 4 years | 10 years | 20 years
Reservoir Simulation Results – Production Rates
Reservoir Simulation Results – Cumulative Oil Production

OOIP ~ 56,000 STB

~20,000 STB
To Progress the SWIFF concept

1. Understand the feasibility of an inter-fracture gas flooding process from a reservoir point of view. Are there often communications between adjacent fractures? How do actual fracture networks compare to the ideal parallel configuration?

2. Conduct reservoir simulations to verify inter-fracture gas flooding EOR performances. What is the additional oil recovery compared to primary depletion? What is the cost? How does it compare with other EOR techniques, especially cyclic gas injection?

3. Last but most importantly, develop new downhole completion tools that can allow single-well inter-fracture gas flooding. Would it be possible to develop downhole tools that can effectively isolate different fracture zones, and can allow injection and production through a single well at the same time? Could the wellbore handle the large pressure differentials along so many sections of the well? What would be ideal fracturing designs to accommodate potential development of such downhole tools?
Contact information

• Xuebing Fu
• Email: engineerfu@gmail.com
• LinkedIn: www.linkedin.com/in/xuebingfu
  (preferred method for general inquiry)
Acknowledgement

• University of Wyoming
• Sierra Resources – Russell Greco, JC Wan
• Chevron – Soong Tam
• Noble Energy – Bo Lu, Ben Wood, Greg Synowka
• Conoco Philips – Ge Jin
• CMG – Kiran Venepalli, Bob Brugman, Vikram Chandrasekar, Jim Erdle
• Thedibia Reservoir Solutions – Jerome Onwunalu
• Mercep Corporation – Bob Merrill
• ...
Backup Slides
Limitations of Huff-n-Puff

1. **Highly sensitive to fluid properties.** The process relies heavily on good miscibility of injected gas with oil, therefore it may be only suitable for gas condensate wells with lean gas injection, or light oil wells with rich gas injection.

2. **Low recovery of the injected gas.** A cyclic process can leave a large proportion of the injected gas unrecovered. If the gas is a rich gas, the cost may be high.

3. **Only 30-70% incremental oil recovery over primary depletion.** The incremental values are significant, but still ~90% of the oil-in-place remain unrecovered at the end of cyclic gas injection. There may be room to improve upon this result.
Potential Advantages of SWIFF

1. **Lower cost.** For a flooding process, the requirement on gas miscibility is probably less rigorous than a cyclic process, as multi-contact miscibility is sufficient for a near 100% microscopic sweep efficiency. Also, a flooding process typically uses less gas per barrel of oil production than that in a cyclic process.

2. **Higher oil rate and higher recovery factor.** The large sizes of fractures along with the tight spacing expedites rates of injection/production. A flooding process provides continual pressure support for oil production. It also allows better sweep efficiency of the reservoir compared to a pressure depletion process (including the production stage of a cyclic gas injection process).
Inter-Fracture Huff-n-Puff

If Downhole tools that can isolate individual fractures and allow injection and production at the same time are difficult to develop, then a compromised solution may be an inter-fracture cyclic gas injection process.