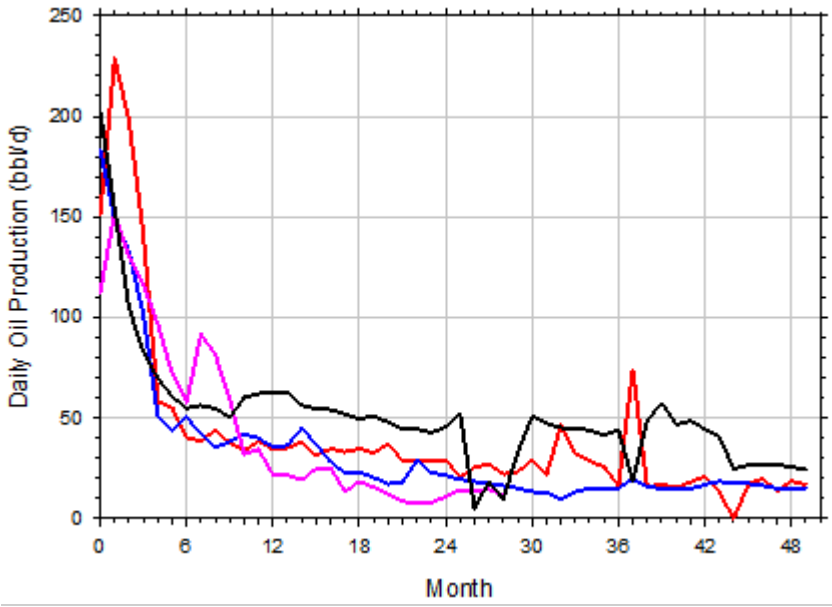
Effective EOR Technologies in Tight Bakken Oil Reservoirs:
An SRC Consortium R&D Approach

Motivation

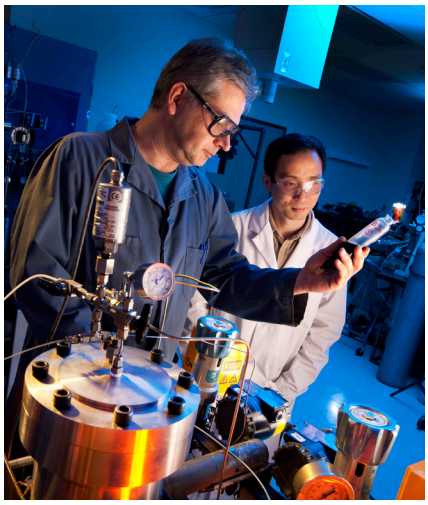
The Bakken formation which underlies much of the Williston Basin is estimated to contain up to 500 billion barrels of light oil. Application of horizontal wells with multistage hydraulic fracturing has unlocked the huge potential of this shale oil play. From 2004 to the present, Bakken production in southeast Saskatchewan rose from an average of 760 BOPD to 71,300 BOPD. Production from the Bakken as a whole (US and Canada) now exceeds 1.1 million BOPD.

While new Bakken wells are highly productive, they decline rapidly from their initial peak production, at rates sometimes in excess of 85% per year. This is because of the complex nature of the Bakken formation which consists of mainly dolomitic siltstone and sandstone with very low permeability (+/-0.01 md). The formation pore size is so small that individual pores are very poorly interconnected, dramatically limiting the flow of oil within the reservoir.

There is a major industry need to increase recovery and sustain production from new and existing Bakken wells to increase reserves and reduce costs. SRC has many years' proven expertise and experience in characterizing, screening and evaluating EOR techniques for "light and tight" reservoirs, including Bakken, particularly focused on developing waterflood and gas injection solutions for our clients.



Typical oil production decline curves for Bakken wells in southeast Saskatchewan.



SRC researchers study chemical and gas injection processes for tight oil in fully equipped laboratories.

*The **Saskatchewan Research Council** has a 30-year history of partnering with oil companies large and small to develop Western Canadian Sedimentary Basin's light oil resources. Our R&D was instrumental in the engineering design of the Weyburn field CO2 miscible flood, and we have helped other clients assess immiscible/ miscible gas injection for their holdings. SRC also has well-reputed expertise in chemical-enhanced waterflooding.*

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SRC's Approach

SRC's work in this area focuses on screening and evaluating particular EOR processes to arrest production decline rates and improve ultimate recovery in clients' Bakken reservoirs of interest. We augment experimental studies conducted in equipment specially designed for tight oil with numerical simulation to design pilot programs and understand and advance tight oil recovery.

We invite you to participate in a consortium-based program to evaluate effective EOR technologies for your Bakken oil reservoirs.

Project Objectives

- Provide a highly cost-effective route to delivering real EOR solutions through a multi-client program tailored to individual client's needs.
- Design technically viable and cost-effective EOR technologies for Bakken tight oil reservoirs.
- Apply demand-oriented R&D, helping tight oil operators tackle injection and production challenges during EOR operations.
- Ultimately, assist our clients in designing and implementing field pilot and commercial projects.

Project Scope

The entire program is designed to comprise three phases, each of which is completed in 12–14 months. The detailed work statement for each Tier-1 participant is summarized below.

Phase 1 — Fundamental Data Collection

Task 1 — Fluid and Core Characterization

(1) Fluid cleaning and characterization
- ✓ Collect field fluid samples
- ✓ Clean brine samples by filtration / prepare synthetic brine
- ✓ Measure various ion concentrations of cleaned brine along with other physico-chemical properties
- ✓ Characterize separator gas by gas chromatography
- ✓ Measure carbon number distribution, molecular weight, densities and viscosities of dead oil

(2) Core characterization
- ✓ Reservoir core plug acquisition
- ✓ Lithofacies description
- ✓ Petrophysical and petrographic measurement
- ✓ XRD (X-ray diffraction) analysis
- ✓ SEM (scanning electron microscopy)
- ✓ Capillary pressure curves
- ✓ Wettability measurement

Task 2 — Phase Behavior (PVT) Studies

(1) Live oil preparation and PVT measurements
- ✓ Reconstitute live oil with separator oil and gas
- ✓ Measure bubblepoint, density, viscosity, gas/oil ratio, live oil composition, etc., at reservoir conditions

(2) Reservoir oil–injection gas phase behavior tests
- ✓ Determine equilibrium properties of reservoir fluid mixed with different proportions of injection gas
- ✓ Measure these equilibrium properties: bubblepoint, gas/oil ratio, density, viscosity, formation volume factor, and swelling factor, etc.

(3) Reservoir oil–injection gas recovery tests
- ✓ Saturate reservoir oil with injection gas inside Bakken cores in a high-pressure visualization cell
- ✓ Deplete cell pressure at different rates/steps, measure oil recovery

(4) Minimum miscibility pressure measurements
- ✓ Rising bubble method
- ✓ Optional slim tube test at extra cost

Task 3 — Enhanced Waterflooding Studies

Various surfactant candidates and complexing agents will be evaluated for possible application of surfactant flooding at Bakken fields, through these experiments:
- ✓ Compatibility, long term stability at reservoir conditions
- ✓ Interfacial tension (IFT) reduction
- ✓ Adsorption on reservoir rocks
- ✓ Contact angle and wettability measurements
- ✓ Spontaneous imbibition test
- ✓ Geochemical modeling

Phase 2 — Core Displacement and Numerical Simulation

Task 1 — Core Displacement Tests

Two coreflood tests will be conducted for each Tier-1 participant, in reservoir core plugs that have been cleaned and aged. Based on each participant's selection, initial primary production will be followed (1) by (enhanced) waterflooding in different chemical injection scenarios, and (2) by gas flooding with different types of gas and injection schemes.

Task 2 — Coreflood History Match

First, an equation-of-state model based on measured PVT data will be built and tuned. For each coreflood, a laboratory-scale numerical simulation study will be carried out to obtain relative permeability curves that will be used in follow-up field-scale simulation. The following will be reported:

- ✓ Matched oil and water production
- ✓ Matched pressure drop along the core stack
- ✓ Oil/water and oil/gas relative permeability curves

Task 3 — Field Scale Simulation

A field-scale geological model will be generated from openhole well-logging and digitized contour maps. Field production data will be matched by adjusting the bottomhole pressures and relative permeability curves in each well region. Finally, various development strategies that include primary and EOR schemes will be investigated.

Phases 1 and 2 Deliverables

- ✓ Quarterly progress reports summarizing progress, challenges, solutions, next steps
- ✓ Semi-annual meetings presenting results and recommendations for path forward
- ✓ Comprehensive final report providing technical solutions and engineering design guidance for suitable EOR technologies at Bakken reservoirs

Cost of Consortium Participation

Cost is per Phase and two tiers of client participation are offered:

Tier-1 Participation includes: Individual client field-specific fluid and core tests; participation in meetings; access to reports and decision making: **C$80,000**

Tier-2 Participation: participation in meetings; access to all reports, data and decision making: **C$40,000**

SRC Funding Contribution:

There is a leverage fund contribution of 20% for the total program budget from the Government of Saskatchewan.

Phase 3 — Pilot Test Design and Implementation

Assist clients in applying for suitable EOR pilots.

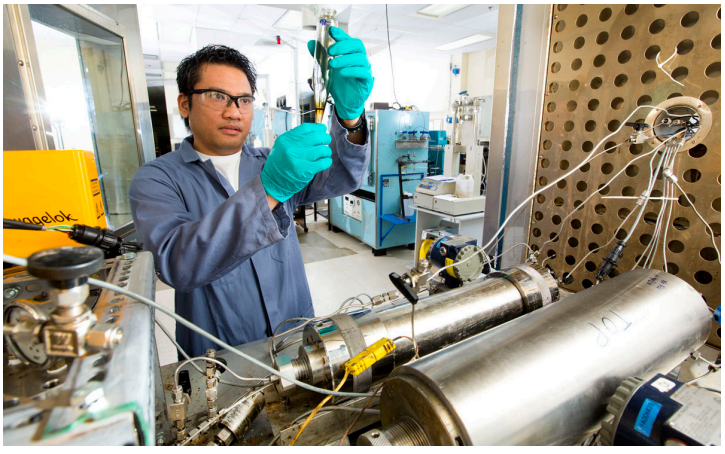
- ✓ Pilot test risk assessment
- ✓ Selection of potential pilot sites
- ✓ EOR injection scheme and production optimization
- ✓ Pilot well production monitoring and surveillance to improve production performance

Cost of Participation for Phase 3

Participation fee for Phase 3 will be determined according to specific work scope and number of participants.

Benefits of Consortium Participation

All participants will gain practical insight into the EOR processes for their Bakken oil assets. Tier-1 participants will have the Phase 1 and 2 work scope performed on their own field fluids and cores, to gain a comprehensive assessment of the suitability of that field for a particular EOR process. Tier-2 participants will benefit from internal access to all reports and data from a large multi-client, financially leveraged program.



Coreflood tests will use actual reservoir samples and different types of injectants and injection schemes.