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Viscous Oil EOR by Viscosity Reducing Immiscible (VRI) WAG Process

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Viscosity Reduction WAG: An Effective EOR Process for North Slope Viscous Oils
Outline

• Motivation
• Miscible WAG* EOR
• Viscosity Reducing Immiscible WAG
• North Slope Situation
• Closing Remarks

* Water-Alternating Gas
Motivation For Gas EOR in Viscous Oil

• Conventional technology* not applicable
  - Too deep
  - Offshore
  - Arctic

• Big projects with many high rate wells

• Available gas resource
  * e.g. Steam, Hot water flooding
Outline

• Motivation

• Miscible WAG EOR
  – Enriched Gas Drive
  – Vaporizing Gas Drive

• Viscosity Reducing Immiscible WAG

• North Slope Situation

• Closing Remarks
Miscibility Mechanism
Low Viscosity Oil – 10 cp
Pseudo-Ternary Diagram

$P_R = 2000$ PSIA

Critical point

Dew point

Bubble point

Two Phase

Single Phase
Enrichment Process

\[ P_R = 2000 \text{ PSIA} \]

Critical point

Dew point

Bubble point

Two Phase

Single Phase

Oil

\( C_H \)

\( C_L \)

\( C_1 \)
MI - Oil Miscibility

$P_R = 2000$ PSIA

- Single Phase
- Critical Composition
- Dew point
- Two Phase
- Bubble point
- Oil

$C_H$, $C_L$, $C_I$
Pressure Dependence

$P_R = 1500$ PSIA

Critical point

Single Phase

Dew point

Two Phase

Bubble point

Oil

$C_L$

$C_H$

$C_I$
Pressure Dependence

$P_R = 2500 \text{ PSIA}$
Minimum Miscibility Pressure (MMP)

\[ P_R = 2000 \text{ PSIA} \]

- Critical Composition
- Dew point
- Bubble point
- Two Phase
- Single Phase
- \( C_H \)
- \( C_I \)
- \( C_L \)
- MI
Slimtube Recovery: Miscible

MMP (Minimum Miscibility Pressure)
Miscible Displacement Process

Transition Zone

MI → Oil
Phase Viscosities in Slimtube

![Graph showing oil and gas viscosities along a slimtube](image-url)
Miscible WAG EOR Summary

- Injection gas rich in (C₂-C₄) hydrocarbons
- Fluid properties change by mass transfer
- MI composition a key design parameter
- WAG process to optimize gas sweep
Moderate Viscosity Oil – 57 cp
VRI Mechanism

\[ P_R = 2000 \text{ PSIA} \]

Critical point
1 Phase
2 Phase

VRI
(Viscosity Reducing Injectant)

Oil

\( C_H \)
\( C_I \)
Slimtube Recovery: Immiscible

Recovery @ 1.2 PV

1.0

Pressure, PSIA

2000

3500

P_R

MMP
VRI Displacement Process

VRI

Transition Zone

Viscous Oil

Reduced Viscosity Oil
Viscosity Reduction in Slimtube

Inj. ----> Distance along slimtube (Grid-block no.) Prod.

Oil Viscosity
Gas Viscosity

Oil, Gas Viscosity, cp
Viscosity Reduction in PVT Cell

![Graph showing the relationship between VRI Injected Moles/Mole and Oil Viscosity (cp)](image-url)

- **Y-Axis:** Oil Viscosity (cp)
- **X-Axis:** VRI Injected Moles/Mole

The graph illustrates a decrease in oil viscosity as the number of VRI Injected Moles/Mole increases.
VRI Reservoir Process (2D)

- Vertical injector, horizontal producer
- Waterflood, WAG simulations
- Low and Moderate Viscosity Oils
- 1:1 WAG ratio, 30% HCPV Gas Injection
Injectant Description

- Low viscosity (10 cp) oil miscible with injected gas (MI)
- The same MI immiscible with moderate viscosity (57 & 117 cp) oils
- Injectant referred to as VRI for moderate viscosity oils
Slimtube Recoveries for 2 Oils

Injected Gas
Miscible for 10 cp
VRI for 50 cp
EOR Recoveries for MI & VRI (2D)

EOR recovery similar for MI & VRI
Earlier EOR response for lower viscosity oils
VRI WAG Process

- Injectant not rich enough in $(C_2-C_4)$ hydrocarbons
- Oil viscosity reduction and swelling by mass transfer
- Improved displacement by subsequent water injection
- WAG process to optimize gas sweep
Outline

- Motivation
- Miscible WAG EOR
- Viscosity Reducing Immiscible WAG
- North Slope Situation
- Closing Remarks
Map of Alaska North Slope
Prudhoe Bay Central Gas Facility

- ~500 mmScf/d MI
NS Viscous Oil Opportunity

- Huge Resource (Tens of BSTB)
- Current development targets ~5 BSTB in W. Sak/Schrader Bluff Formation
- Low primary & waterflood recovery
- Available Gas Resource
- Prudhoe MI not miscible with moderate to high viscous oil (>15 cp)
Schrader Bluff Oil Quality Variation

C5+ fraction normalized to 100%

Miscible Target

VR-WAG Target

Mole %

Carbon Number

- 10
- 8
- 6
- 4
- 2

5 7 9 11 13 15 17 19 21 23 25 27 29

40 cp W-203 Polaris
87 cp WS 1-01 D-Sand
61 cp WSP 8i D-Sand
10 cp Orion L117 OBd
57 cp Orion Z-39 OBd
117 cp Orion Z-39 OBa
52 cp Polaris W205 OBc
11 cp Milne S-12
EOR Prediction Methodology

Phase Behavior Model
- PVT, Slimtube Data
- EOS

Reservoir Simulation
- Type patterns (based on reservoir description)
- EOR Type Curves (Oil, MI, RMI)

Field Scaleup
- Project area segments (segment PV, well allocations)
- Tank model scaleup

- Huge Development Target
- 50 mmscf/d of VRI injection
- 12 MBD EOR rate, 6% (OOIP) EOR
- MI efficiency close to classical miscible
North Slope VRI Status

- VRI project designed for Polaris & Orion fields
- IRS ruled VRI process as a qualified recovery method for EOR tax credit
- Alaska State approval to commence VRI injection in Polaris reservoir.
  - Injecting 2 mmscf/d MI in W-215
  - 6% EOR recovery from 350 MSTB OOIP
- Application for Orion VRI injection approved
  - 1,000 MSTB OOIP target with similar EOR recovery expected
Key Project Design Components

- (Lean Gas, NGIs, MI Capture)
- Surveillance (Gas Analysis, Well Intervention)
- Injectivity (Water/MI, Gas Trapping)
- Conformance (Zonal, Volumetric)
- Flood Management MI Resource (Voidage Replacement, Pressure Maintenance, WAG Ratio, MI Slug, MI Allocation)
- Asphaltenes Dropout (Reservoir & Facility)
Closing Remarks

• When conventional technology not applicable
• VRI technology can dramatically increase primary and waterflood recovery in viscous oil reservoirs
• Recovery enhancement by viscosity reduction and swelling
• Developed approach for the design, engineering, and evaluation of viscous oil gas EOR projects
Viscous Oil EOR by Viscosity
Reducing Immiscible (VRI) WAG Process

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