ADNOC · CHEMICAL EOR PROGRAM. KHALIFA UNIVERSITY

# Chemical EOR in Abu Dhabi Carbonate Reservoirs

Three studies, one chain of constraints: what it takes to move residual oil in a mature high-temperature, high-salinity carbonate, and where the margins actually sit.


PREPARED BY

**Imad A. Adel**

Senior Petroleum Research Engineer · Chemical and Petroleum Engineering, Khalifa University

01

# The asset problem

What a mature Abu Dhabi carbonate leaves behind after waterflood, and why the standard screening answer does not apply to it.

STARTING POSITION

# Waterflood leaves oil behind that is technically reachable and economically fragile

Carbonates dominate the mature Middle East resource base. Three properties of these reservoirs set the whole problem.

### TEMPERATURE

**100** °C

Reservoir conditions approach 120 °C; conventional sulfate surfactants hydrolyse in this range

### CONNATE SALINITY

**243,028** ppm TDS

With substantial hardness — precipitation risk and a narrow surfactant operating window

### WETTABILITY

**Mixed to oil-wet**

Oil retained in microporosity and continuous wetting films, not as ganglia in large pores

Sources: CDC manuscript p.1–4; screening manuscript p.1–2

THE THREE QUESTIONS

# The program answers three questions in sequence, and each one constrains the next

1

### Can the oil be moved, and at what force?

Measure the mobilization threshold in aged carbonate rather than importing it from water-wet sandstone.

$N_{t,crit}$

2

### Does a chemistry survive, and what does it cost?

Stability at temperature and salinity, then retention priced against a per-barrel screening ceiling.

$\Gamma \cdot C_{ret}$

3

### Is the result worth capital?

Carry the laboratory number through a discounted cash-flow screen to NPV, IRR and unit technical cost.

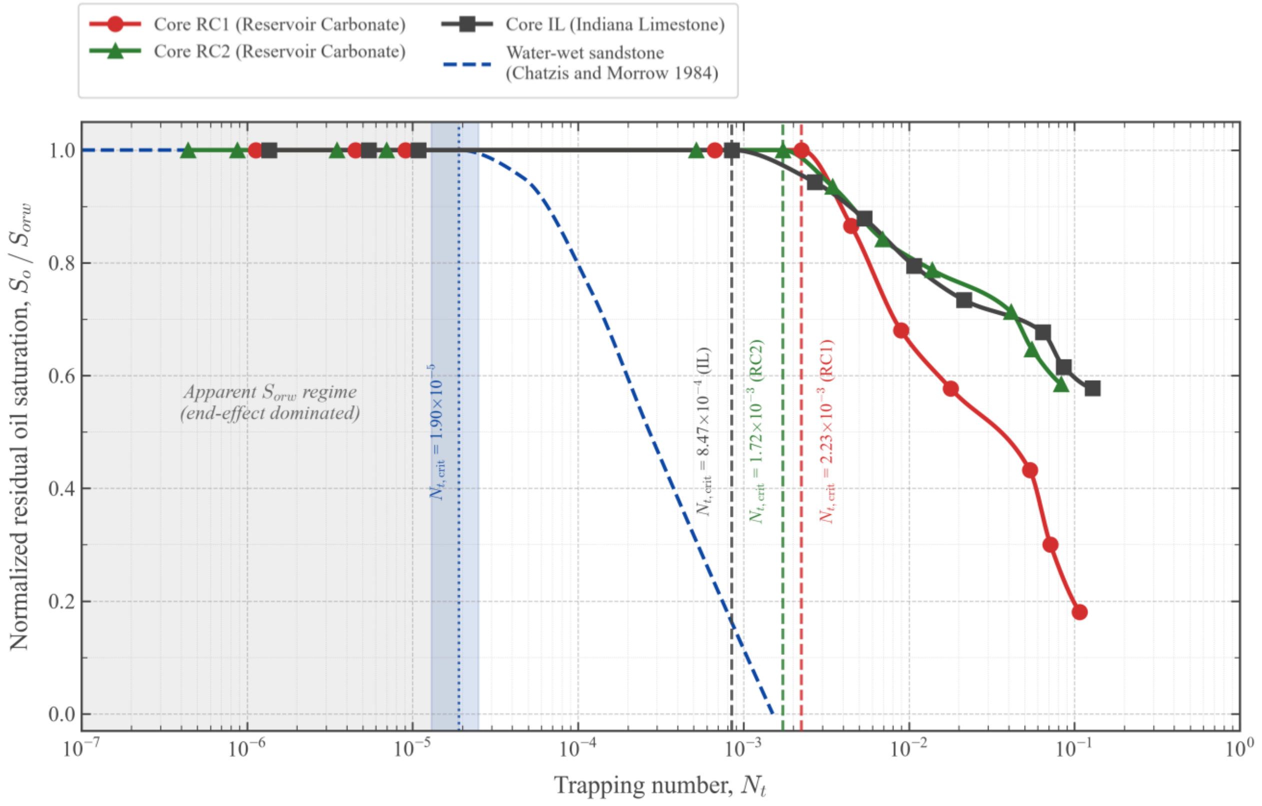
$NPV_{10} \cdot UTC$

# 02

# What was measured

Three results, each stated at the precision the measurement supports.

# The threshold in aged carbonate is two orders above the water-wet reference




*Critical trapping number for each core against the water-wet sandstone reference of Chatzis and Morrow (1984); log axis, ratios annotated. $N_{t,crit}$ is the highest tested trapping number before measurable desaturation on each plug. Core RC2 is program data completed after manuscript submission.*

## WHAT IT SHOWS

**Screening criteria carried from water-wet sandstone understate the required force by 45 to 117 times.**

- Core RC1: $N_{t,crit} = 2.23 \times 10^{-3}$, from $S_{orw} = 0.400$ to $S_{orc} = 0.072$.
- Core RC2, a further reservoir plug from a second formation: $1.72 \times 10^{-3}$.
- Outcrop analogue, Core IL: $8.47 \times 10^{-4}$.
- All three sit above the +1σ bound of the $(1.9 \pm 0.6) \times 10^{-5}$ sandstone reference, on centrifuge-conditioned baselines.

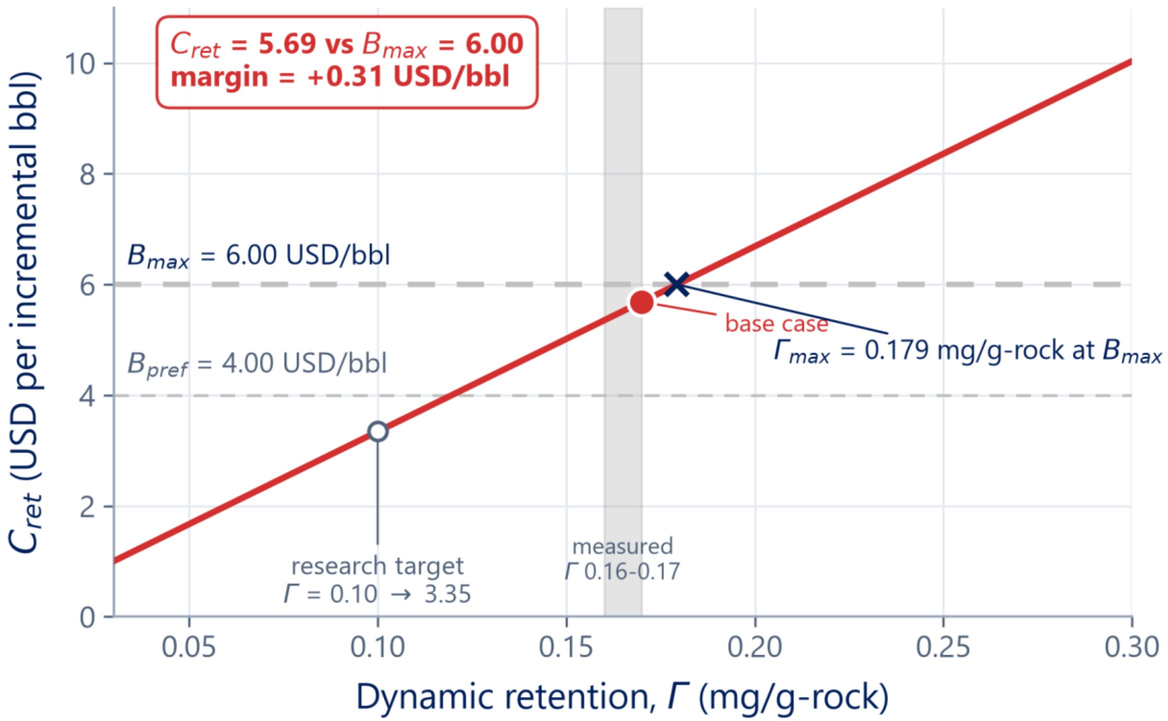
CONSEQUENCE

# At field rate the ultra-low-IFT slug alone sits on the reservoir-rock threshold, not above it.

At $u$ = 1 ft/day with $\mu_w$ = 0.40 cP and $\sigma_{os}$ = 3.07 × $10^{-3}$ mN/m, computed on each plug's own $\phi$ and $k_w$, the applied $N_t$ reaches 0.94× the onset in Core RC1 and 0.98× in Core RC2. Every reservoir plug lands on its own threshold; only the outcrop analogue clears it, at 3.06×. Viscosity is one remaining term in the calculation; the other is interfacial tension, which is where the surfactant chemistry does its work.

| ACHIEVED AT 1 FT/DAY | CORE RC1 ONSET | MARGIN | VISCOSITY TO CROSS |
|---|---|---|---|
| **2.09 × $10^{-3}$** | **2.23 × $10^{-3}$** | **0.94 – 0.98×** | **0.43** cP |
| Core RC1 | $N_{t,crit}$, measured | Across the two reservoir plugs | Core RC1, at $u$ = 1 ft/day |

# A surfactant-only formulation clears the retention cost gate by 0.31 USD per barrel



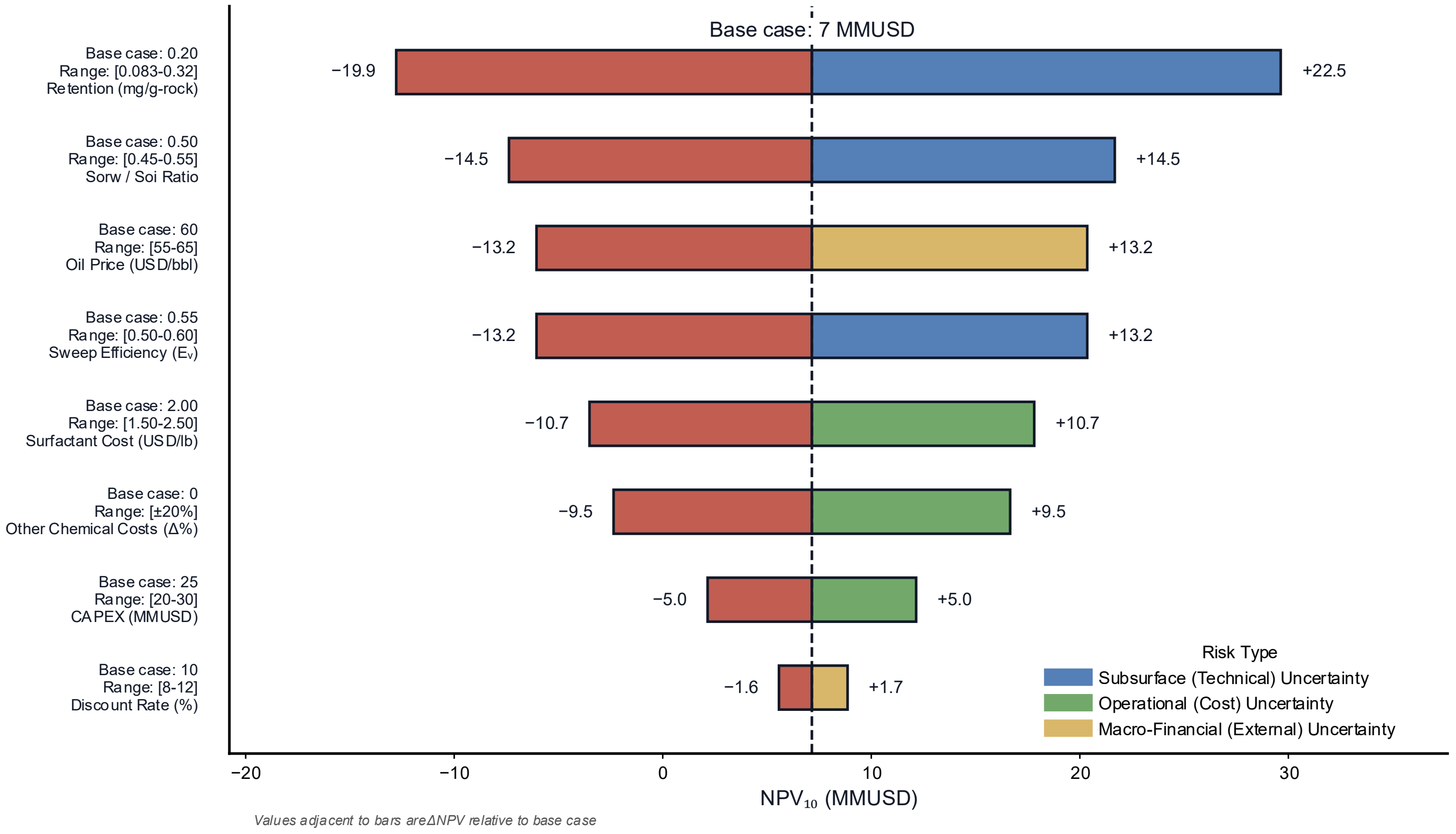

*Retained-surfactant cost per incremental barrel, $C_{ret}$, against dynamic retention Γ, with the $B_{max}$ = 6.00 USD/bbl screening ceiling and the measured Γ band.*

## WHAT IT SHOWS

**The gate passes. The margin is 0.31 USD/bbl, and retention is what consumes it.**

- Stable 30 days at 120 °C; Winsor III between 30,000 and 60,000 ppm, $S^*$ = 46,000 ppm against 43,373 ppm seawater.
- 86.4 % of $S_{orw}$ mobilized in 4.42 mD reservoir rock — no polymer, no alkali.
- Salinity-gradient post-flush brings Γ from 0.21 to 0.17 mg/g-rock.
- $C_{ret}$ = 5.69 USD/bbl against a $B_{max}$ = 6.00 USD/bbl screening ceiling.

# Retention dominates the value uncertainty, ahead of every cost and financial input

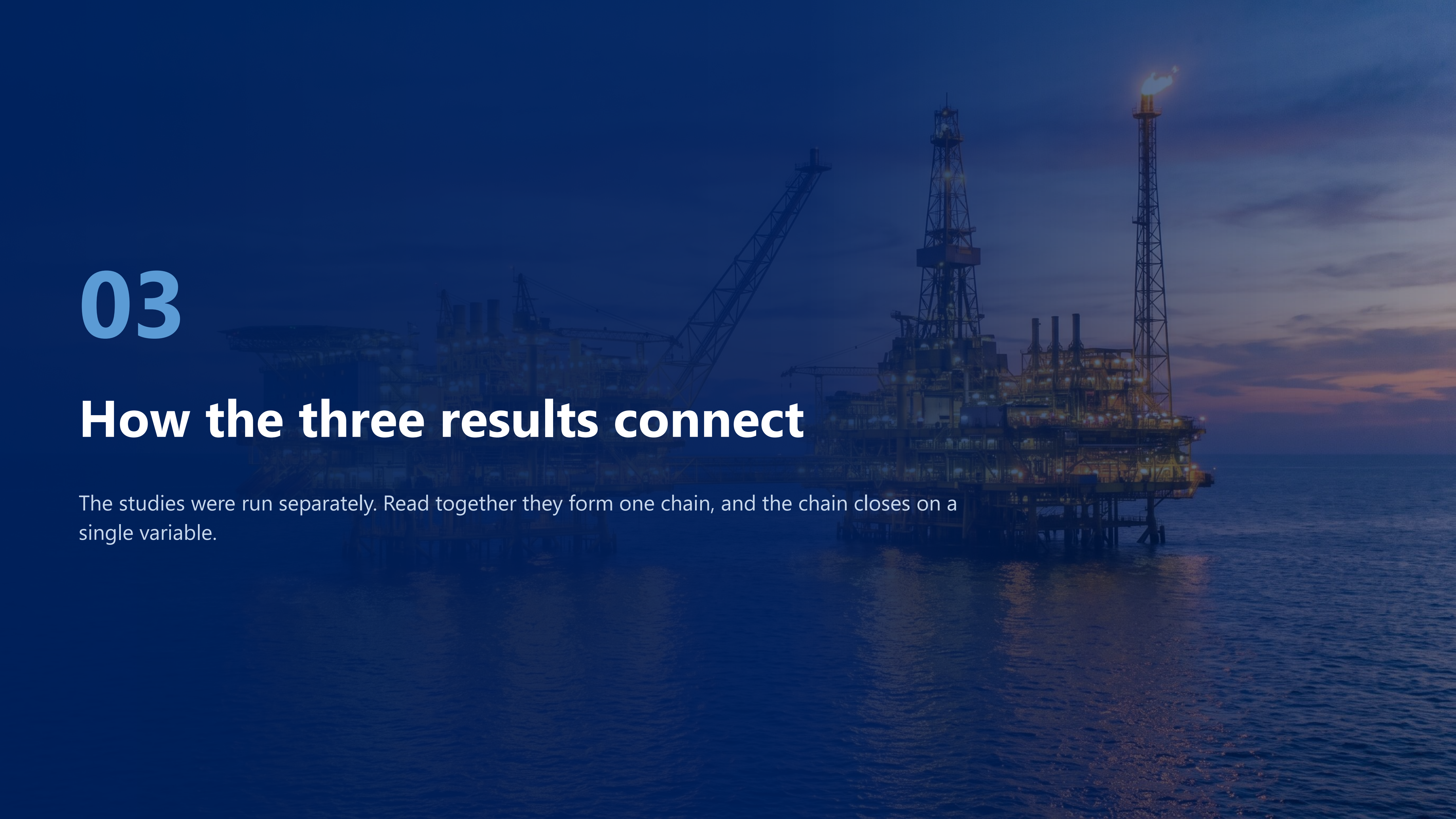



*One-at-a-time $NPV_{10}$ swing for each screening input, ranked by span; bars give the low-bound and high-bound input value against the base case.*

## WHAT IT SHOWS

**A coreflood retention measurement buys down more value uncertainty than a front-end cost estimate.**

- Base case: $NPV_{10}$ = 7.2 MMUSD, IRR = 20.7 %, UTC = 55.0 USD/bbl at 60 USD/bbl Brent.
- Retention swings $NPV_{10}$ by −19.9 / +22.5 MMUSD; CAPEX by ±5.0 MMUSD.
- Screening breakeven sits at Γ = 0.24 mg/g-rock — 0.04 above the base case.
- This screen ranks candidates and scopes pilots. It does not forecast field performance.



03

# How the three results connect

The studies were run separately. Read together they form one chain, and the chain closes on a single variable.

# Each result constrains the next, and the sequence ends on retention

1

### Force lands on the threshold

At field rate the surfactant slug reaches 0.94 to 1.01 times each reservoir plug's own onset. Viscosity is the only remaining term.

0.94 – 1.01× onset

2

### The surfactant-only path has to carry it

It does: 86.4 % of $S_{orw}$ in 4.42 mD reservoir rock, clearing the cost gate by 0.31 USD/bbl.

5.69 vs 6.00 USD/bbl

3

### And the economics sit close to breakeven

The base case is 0.04 mg/g-rock from its own breakeven, with retention the dominant value driver.

Γ 0.20 vs 0.24

# Every gate sits at its limit; the force gate sits 6.3 % under

| Gate | Requirement | Achieved | Margin |
|---|---|---|---|
| **Mobilizing force at 1 ft/day** | Core RC1 $N_{t,crit} = 2.23 \times 10^{-3}$ | $2.09 \times 10^{-3}$ | −6.3 % |
| **Aqueous stability** | 243,028 ppm formation water | 75,000 ppm limit | Seawater pre-flush required |
| **Retention cost** | $B_{max}$ = 6.00 USD/bbl | $C_{ret}$ = 5.69 USD/bbl | +0.31 USD/bbl |
| **Screening economics** | Breakeven Γ = 0.24 mg/g-rock | Γ = 0.20 mg/g-rock | +0.04 mg/g-rock |
| **Breakeven oil price** | 57.3 USD/bbl | 60 USD/bbl assumed | +2.7 USD/bbl |

Sources: CDC p.5, p.7, p.10; screening p.7, p.14; econ p.11, p.13, p.17

**Implication —** Mobilizing force is the binding gate, cleared by only 6.3 % margin; retention economics carry the next-tightest margin at +0.04 mg/g-rock.

THE PROGRAM'S ANSWER

# One measurement moves every gate at once: dynamic surfactant retention.

It sets the retained-chemical cost directly, dominates the value uncertainty budget, and is the only lever in the chain with room left in it. Moving Γ from 0.17 to 0.10 mg/g-rock releases 2.34 USD/bbl — more than the entire remaining gate margin.

| MEASURED TODAY | GATE CEILING | RESEARCH TARGET | RELEASED BY THE TARGET |
|---|---|---|---|
| **0.16 – 0.17** mg/g-rock | **0.179** mg/g-rock | **0.10** mg/g-rock | **2.34** USD/bbl |

04

# What follows

The measurements that would close the remaining gaps, in the order they pay back.

PRIORITY

# Three measurements, ranked by how much uncertainty each retires

- Retention reduction. Sacrificial agents, adsorption suppressors, softened-brine and pre-flush design — the target is $\Gamma$ = 0.10 mg/g-rock, which releases more margin than every other lever combined.
- Fracture-parting and injectivity limits at 2.24 mD. The viscosity the trapping-number calculation asks for was never tested against the pressure the formation will take.
- Sweep. $E_v$ = 0.60 is a conditional input tied to polymer-assisted mobility control, not an outcome of these corefloods. It is second only to retention in the value ranking.

Sources: CDC p.10; screening p.15–16; econ p.14, p.17; ECD §4.4

PROGRAM STATUS

# Three manuscripts, three data packages, one screening chain

- Critical Trapping Numbers and Capillary Desaturation — under review, Geoenergy Science and Engineering.
- A Retention-Controlled Screening Framework for Chemical EOR — prepared for Petroleum Exploration and Development, pending ADNOC review.
- Techno-Economic Screening under Retention Uncertainty — under review, Petroleum Research.

Imad A. Adel · Senior Petroleum Research Engineer · Chemical & Petroleum Engineering, Khalifa University

ADNOC · CHEMICAL EOR PROGRAM. KHALIFA UNIVERSITY

# Thank you


CONTACT

**Imad A. Adel**

Senior Petroleum Research Engineer · Chemical and Petroleum Engineering, Khalifa University

imad.adel@ku.ac.ae