IOR/EOR Practices for Enhanced Efficiency in the Evolving Carbon-Conscious Environment

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Challenges for Chemical EOR in Carbonate Reservoirs

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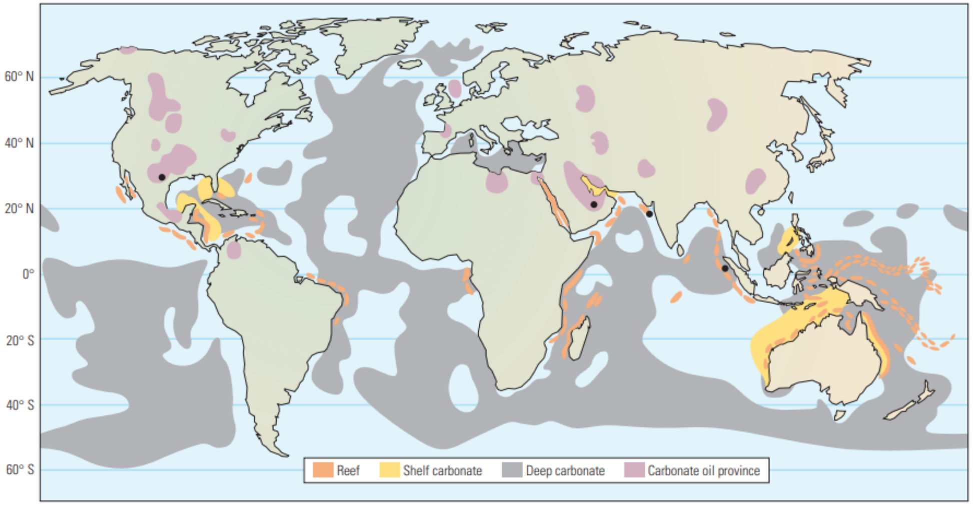
Chemical EOR in carbonate reservoirs

- Carbonate reservoirs can be found in most regions including Asia
  - >50% of world oil resources
- EOR: mostly gas (SPE-100063) so far
- Chemical EOR is challenging
  - *(Reservoir heterogeneity)*
  - High temperature, high TDS
    - not due to carbonate but often found together
  - High chemicals retention
  - Low permeability/injectivity
    - polymer mechanical degradation



(Oilfield Review Dec. 2000)

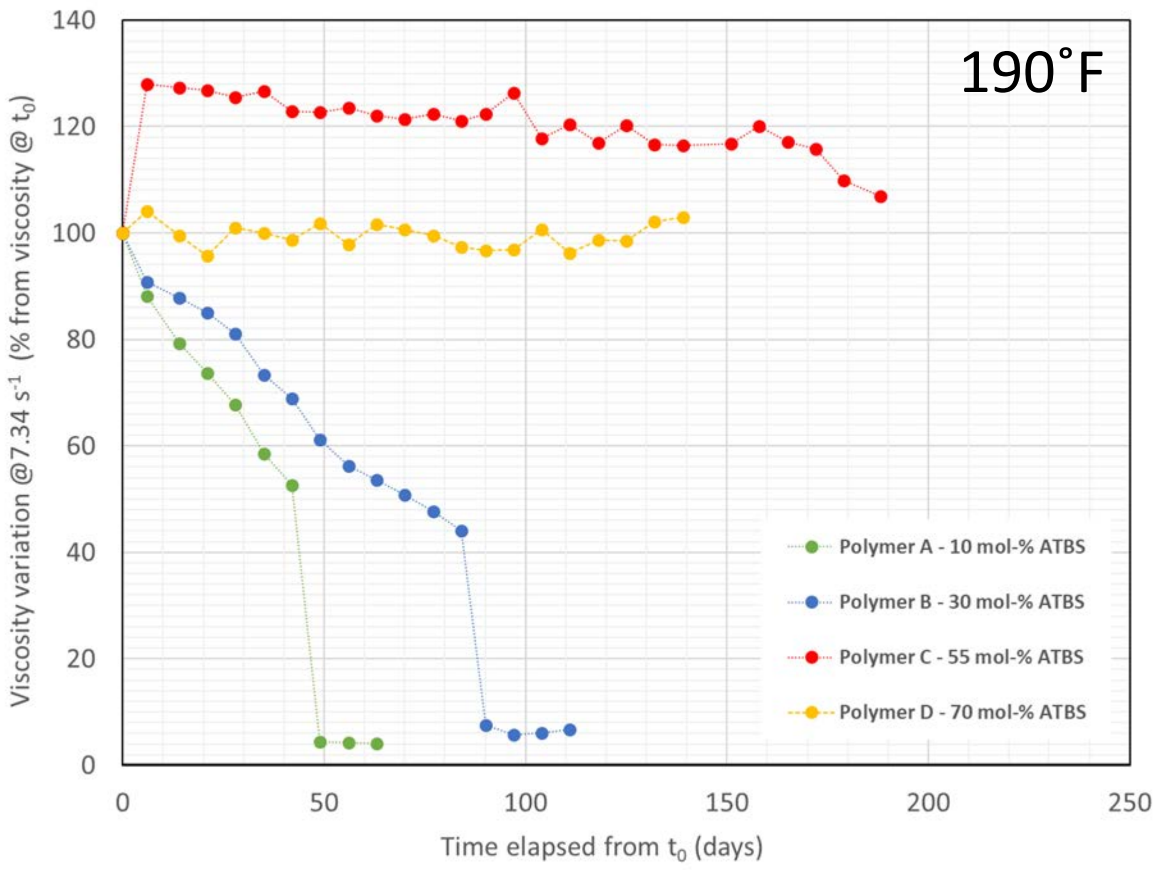
Current status of cEOR in carbonates

- Numerous old pilots mostly in US (SPE-100063)
  - Mostly polymer, poorly documented
- Few large-scale expansions
- Some recent pilots

Field	Location	Date	Lithology	Temp. (F)	TDS (g/L)	Perm. (md)	Process
Kaji Semoga	Indonesia		Limestone	122	15?	85	SP
UNKNOWN	UAE	2019-21	Limestone	250	200	10-1,000	P (IT)
Sabriyah Mauddud	Kuwait	2022	Carbonate	172	235 (soft. wat.)	7-700	ASP
Al Shaheen	Qatar	2019	Limestone	135	90-130	10-20	WA

ATBS containing polymers for harsh conditions: ME case

Long term polymer stability tests (SPE-218776)

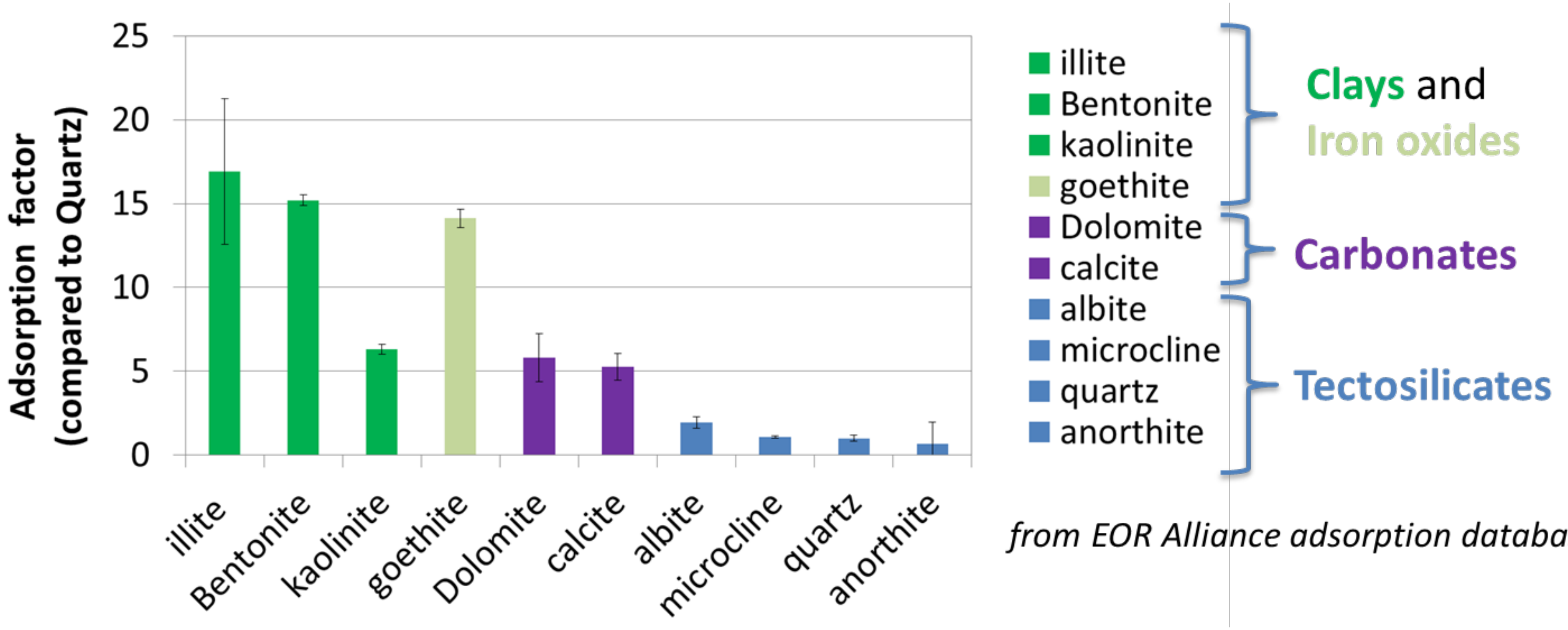


Na^+ (mg/L)	75,357
K^+ (mg/L)	3,316
Ca^{2+} (mg/L)	14,659
Mg^{2+} (mg/L)	4,777
Sr^{2+} (mg/L)	294
Ba^{2+} (mg/L)	4
Cl^- (mg/L)	159,299
HCO_3^- (mg/L)	47
TDS (mg/L)	257,753
Hardness index R^+	0.20

$$R^+ = \frac{[Ca^{2+}]+[Mg^{2+}]}{[Na^+]+[K^+]+[Ca^{2+}]+[Mg^{2+}]}$$

Impact of mineralogy on surfactant static adsorption

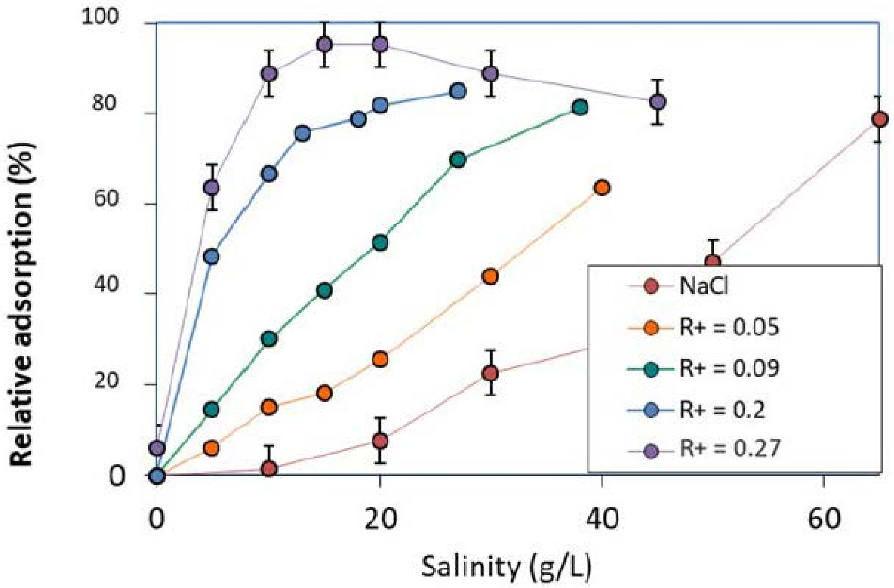
Static adsorption on controlled amount of pure minerals for classical anionic surfactant formulation (reference = quartz)



from EOR Alliance adsorption database

Impact of brine salinity and hardness on surfactant adsorption

- Same formulation, various salinities and hardness



$$R^+ = \frac{\sum DivalentCations}{\sum TotalCations} = \frac{\sum (Ca^{2+} + Mg^{2+})}{\sum (Na^+ + K^+ + Ca^{2+} + Mg^{2+})}$$

(SPE-200247)

➔Adsorption of surfactant increases with brine salinity

➔Behavior towards salinity also depends on brine hardness

Potential mitigation solutions

- Depending on field context several solutions could be contemplated
  - Brine treatment
    - Softening to remove divalent ions
    - Salinity reduction
  - Chemicals selection
    - Adapt chemical formulation
    - Do not use alkali
  - Injection process
    - ~~Add alkali~~
    - Salinity gradient
    - Adsorption inhibitors

Economics can be challenging

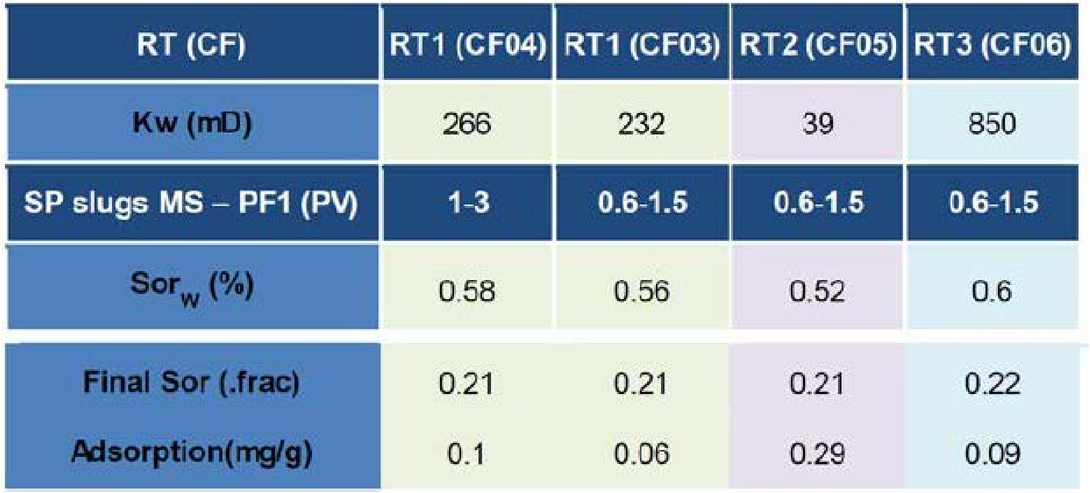
Not always technically possible,
economics can be challenging due
to high required surfactant concentration

“Traditional solutions”;
salinity gradient may require water treatment

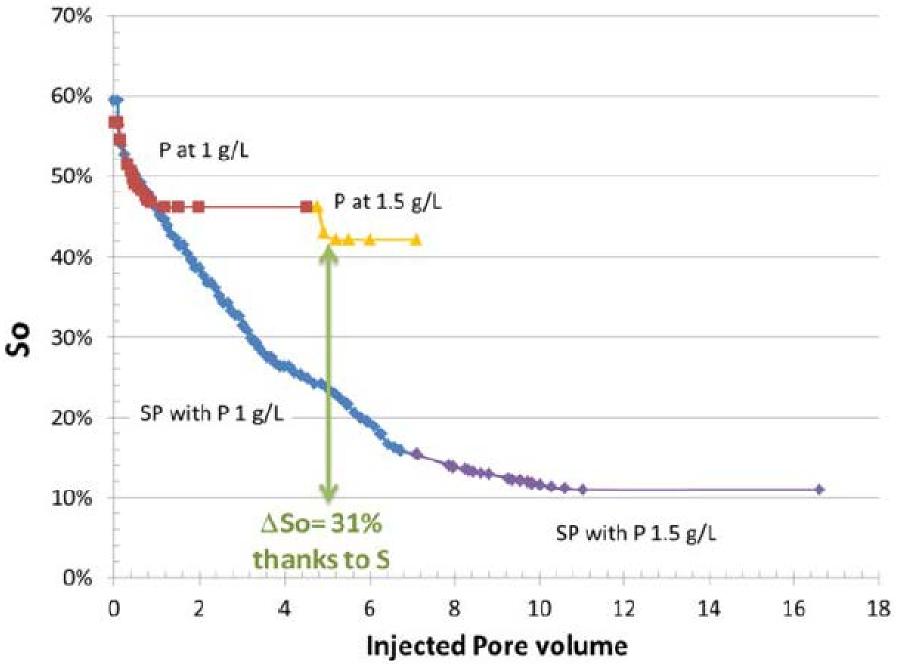
“In-house additional approach”

SP corefloods for ME carbonate case

- T = 80˚C
- Water
  - Formation 230 g/L
  - W injection seawater
    - 2 passes nano filtration
    - OR adsorption inhibitors



RT (CF)	RT1 (CF04)	RT1 (CF03)	RT2 (CF05)	RT3 (CF06)
Kw (mD)	266	232	39	850
SP slugs MS – PF1 (PV)	1-3	0.6-1.5	0.6-1.5	0.6-1.5
Sor_w (%)	0.58	0.56	0.52	0.6
Final Sor (.frac)	0.21	0.21	0.21	0.22
Adsorption(mg/g)	0.1	0.06	0.29	0.09



(SPE-197261)

Low permeability/injectivity

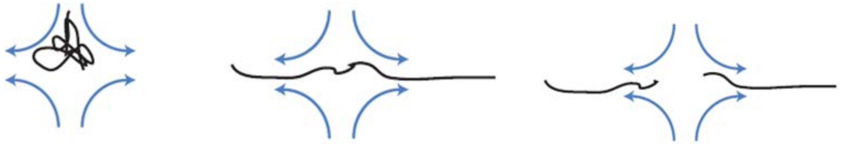
Successful polymer pilots in low permeability carbonate reservoirs (SPE 169673)

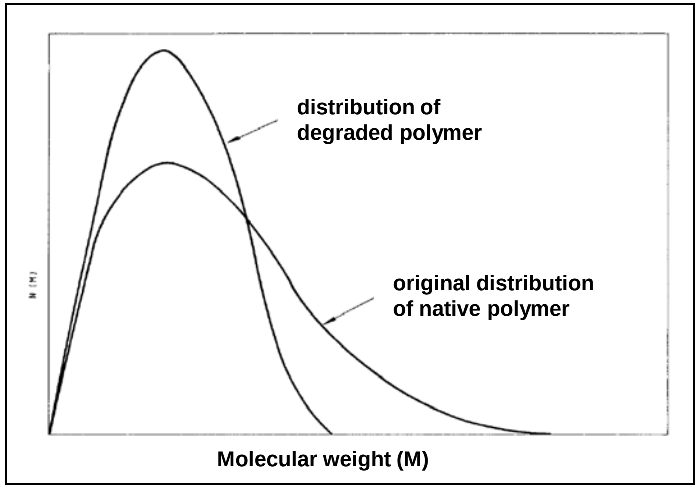
Field	Location	Date	Lithology	Temp. (F)	Porosity (%)	Perm. (md)	Process
Elliasville Caddo Unit	USA (TX)	1980	Limestone reef	34	13.2	0.1-234, avg 11	P
Vacuum (Hale/Mable Leases)	USA (NM)	1983	Dolomite	100	11.5	17.3	P
Slaughter	USA (TX)	1981	Dolomite + anhydrite	109	8-18	1-25, avg 6	SP
UNKNOWN	USA (TX)		Dolomite		11.8	3.9	SP

Mechanical degradation of polymer

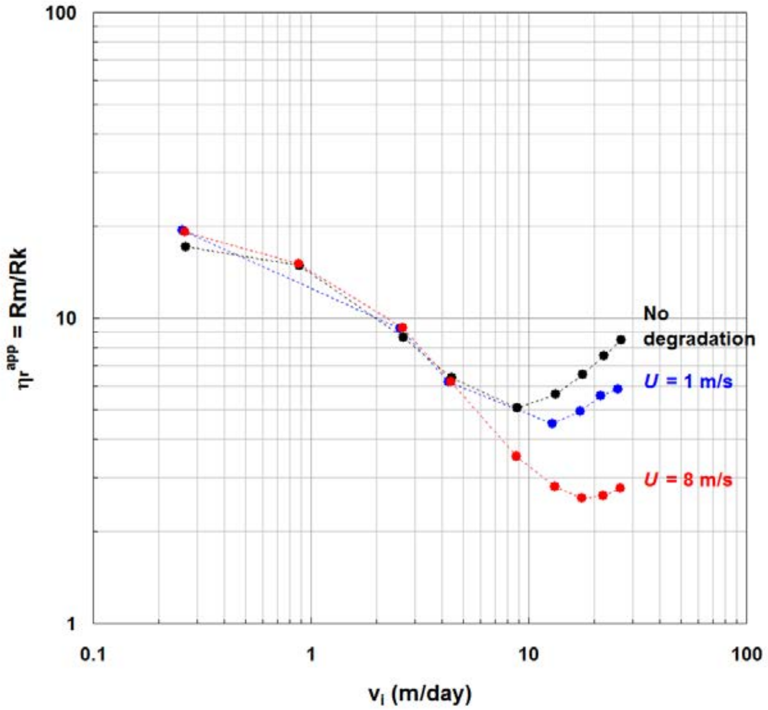
Occurs when polymer are exposed to elevated extensional strain

➔ *irreversible scission of macromolecules, viscosity loss*





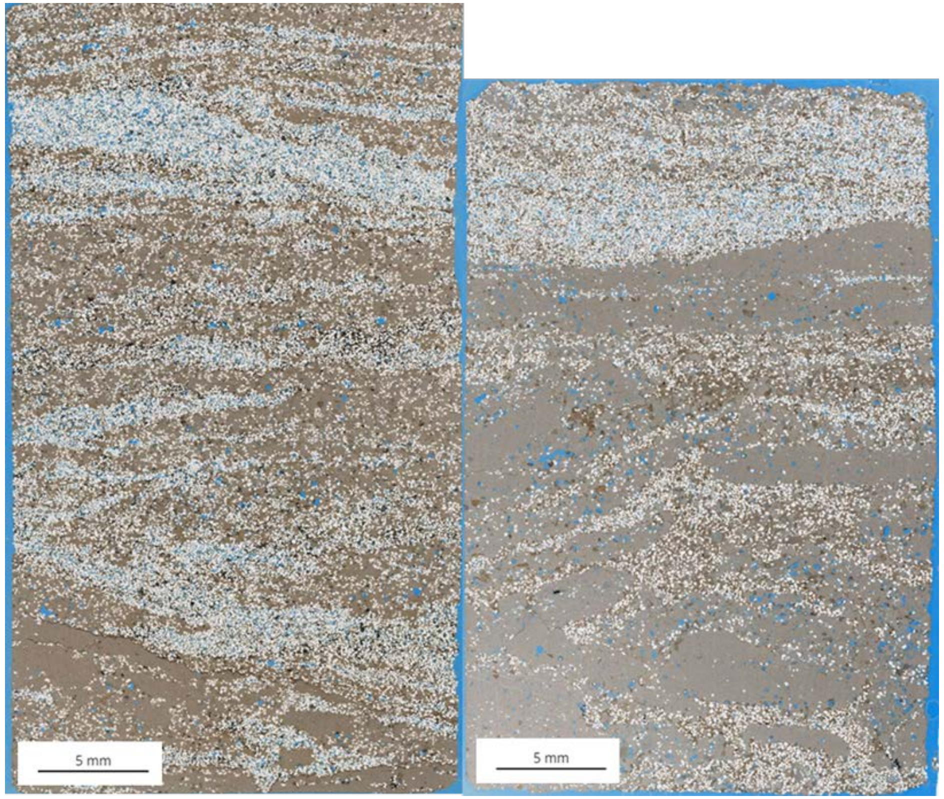
Sorbie and Roberts, SPE12654 (1984)



(SPE 164083)

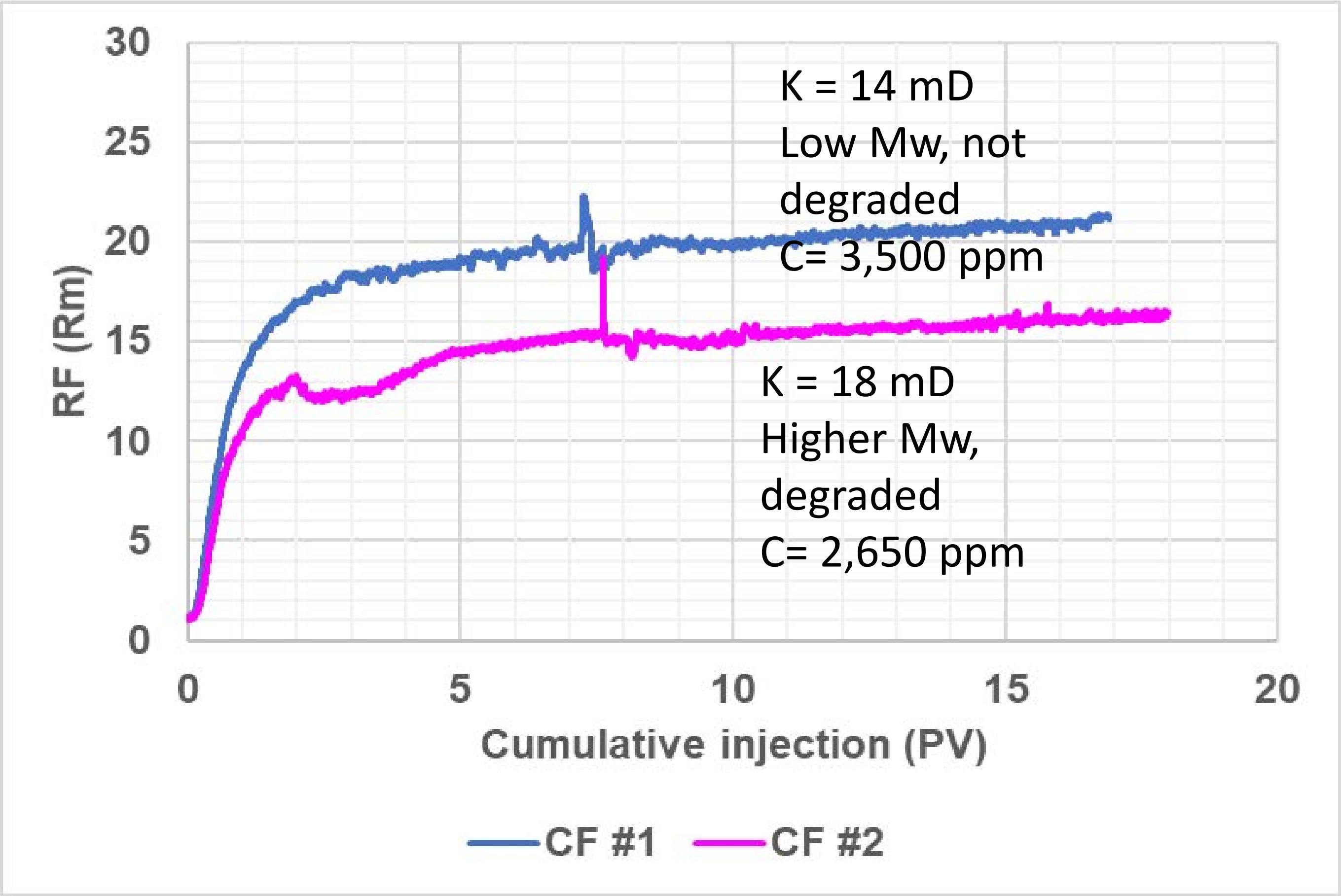
Canadian low permeability case

Reservoir temperature	55°C
Oil viscosity (@res. temperature)	11 mPa.s
Waterflood water viscosity (@res. temperature)	0.53 mPa.s
Lithology	from dolomitic quartz sandstone to sandy dolomite
Average permeability (in the target zone for polymer flooding)	30 mD (60-70% between 10 and 30 mD)
Average porosity	18%
Reservoir currently under waterflood (mix between produced water and river water) ; injectors are fractured	



Quartz grains, clay + dolomite cement

Corefloods



K = 14 mD
Low Mw, not degraded
C= 3,500 ppm

K = 18 mD
Higher Mw, degraded
C= 2,650 ppm

Conclusions

- cEOR injection in carbonates is feasible but economics challenging
- Main questions:
  - Chemicals loss
  - Permeability
- Chemical losses: challenging but potential solutions exist
- Permeability
  - 5-20 md?
  - OK in the lab but what about injectivity?
  - Pre-degradation of polymer can alleviate injectivity issues
  - More field testing required