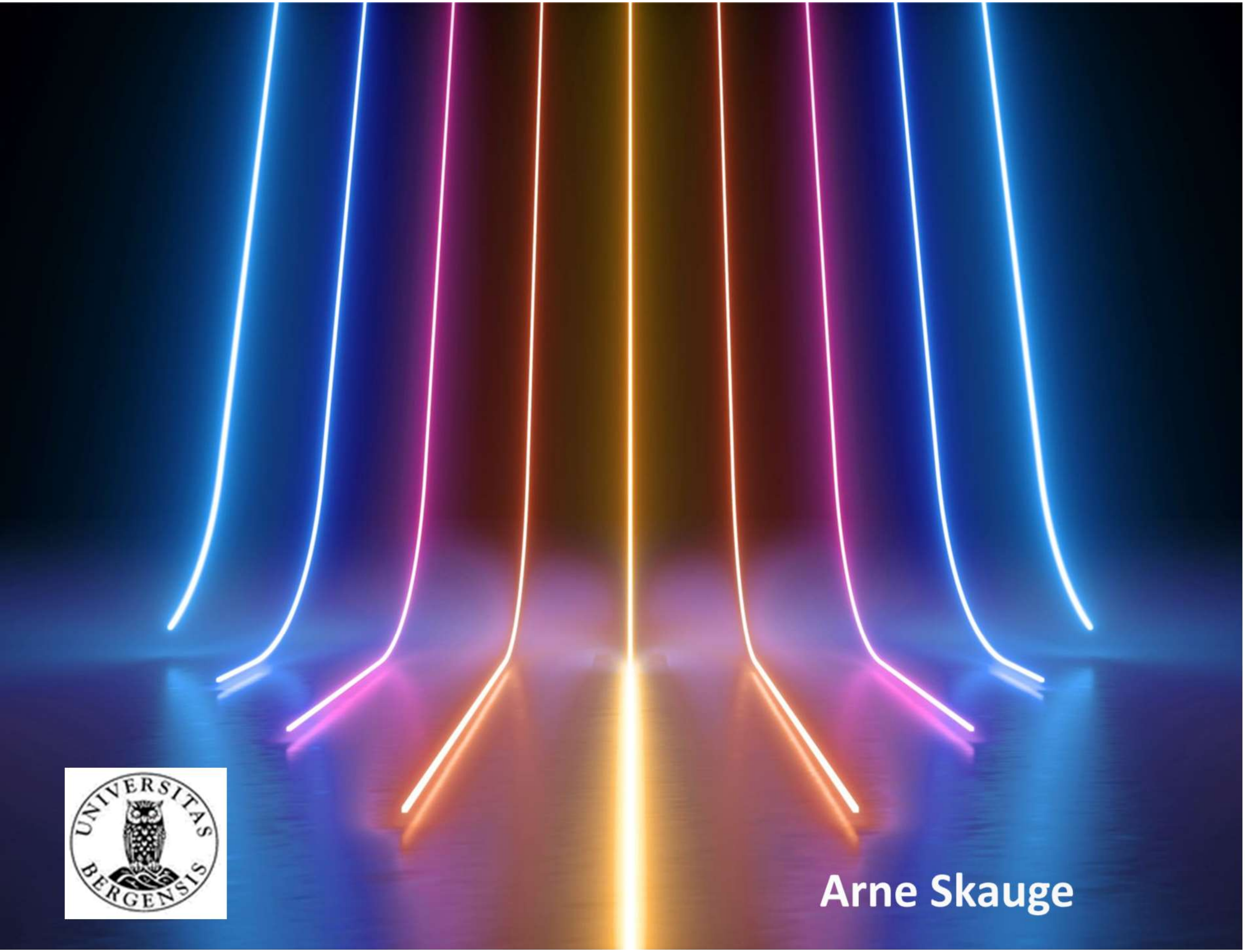


energi SIMULATION

SUMMIT

Sep 30 – Oct 1

2021

Hybrid EOR Performance; Examples of Chemical Hybrid EOR

Result of Chair Project

Arne Skauge
University of Bergen

Introduction

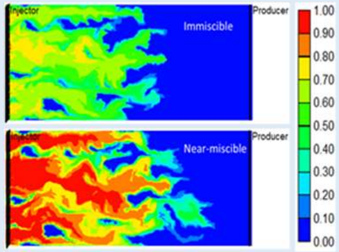
Chair research areas – Enhanced Oil Recovery (EOR)

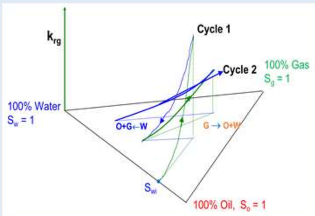
EOR can contribute towards meeting net-zero production emission target by 2050 through reducing CO2 emissions per barrel by 3-6 times.

WAG

Goal:

Completing a WAG model flexible enough to cover combination of WAG processes that range from immiscible to near miscible

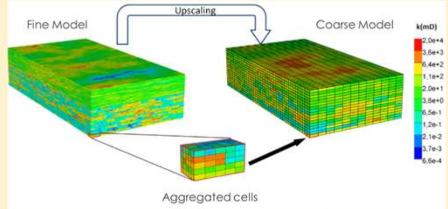


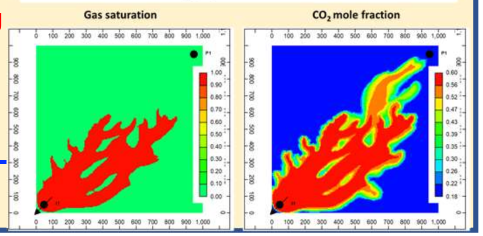


Complex Flow Upscaling

Qualify robust upscaling procedure for different complex flow processes WAG, polymer, hybrid EOR and processes involving flow at adverse mobility ratio.

Example: overcome the phase-labeling issue



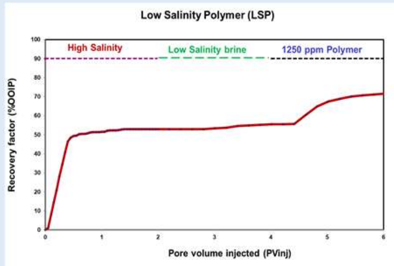


Energy Efficient Polymer Flooding

In our evaluations, polymer proves to be a low cost and high reward oil recovery method. This EOR method can <u>accelerate oil production</u>, <u>reduce water cut</u>, and <u>reduce GHG emission</u> for the production period.

Goal:

Optimize oil production and energy efficiency and also minimize emissions



Multi-Scale Oil Trapping

Quantifying remaining oil saturation is a challenge. Capillary trapped oil at the core scale may be reasonably well estimated.

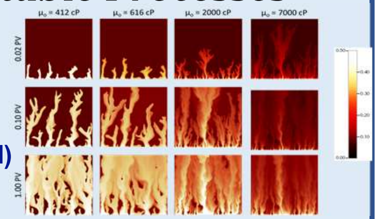
However, the local by-passed (mobile) oil at higher scale from the cm to dm to formation scales is much more uncertain and is vitally important for assessing EOR oil recovery potential.

Designing optimum solutions for these oil recovery methods, requires (i) acquiring detailed knowledge of the structure of remaining oil across many length scales, and (ii) developing sound scientific methods to recover this target oil.

Modelling Unstable Processes

Example

History match of adverse viscosity ratio experiment (water / polymer in heavy oil)



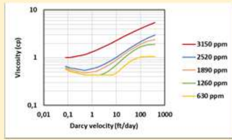
We focus on practical approaches that lead to efficient simulations, respecting the governing physics of the process so that upscaling may give results that can aid both recovery strategies and potential estimates.

We will do this by building on novel approach shown in the material recently published by this group.

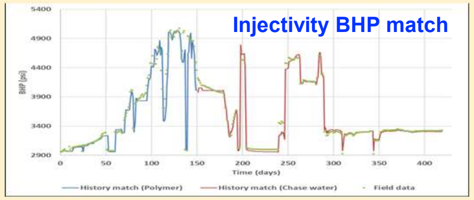
Practical Field Applications

Recent example (2021)

Polymer Injectivity Test (PIT) in Abu Dhabi



Input rheology



BHP was sufficient to obtain information about the in-situ rheology at the rate variation performed.

The non-Newtonian behavior in the near-wellbore region can clearly be distinguished by the characteristics of longer transient pressure build up due to the velocity-dependent viscosity.

Objectives

Topic. Hybrid EOR (combining two or more oil recovery processes to improve recovery response)
Why Hybrid EOR? More energy efficient recovery process (faster oil production, less carbon footprint)

FAWAG
(Foam Assisted WAG)

LSP
(Low Salinity Polymer)

Purpose of research:
Find the optimum use of hybrid EOR with a minimum carbon footprint

Examples presented here are
LSP and LSSP

PAG
(Polymer Alternate Gas)

LSS
(Low Salinity Surfactant)

LTG
(Low Tension Gas)

LSSP
(Low Salinity Surfactant Polymer)

SIMGAP
(Simultaneous inj. Miscible Gas and Polymer)

Nano-stabilized foam

SIWAP
(Simultaneous Inj. Water And Polymer)

Advantage of low salinity hybrid EOR methods

Low salinity waterflood may give only modest improved oil recovery for many reservoirs

Cost of reducing water salinity may be a showstopper for Low Salinity Waterflood

Recent research has made combined low salinity and surfactant and/or polymer flooding a way of boosting oil recovery and improve the economy of these EOR processes

Source:

Alagic and Skauge (CIPR): "Change to Low Salinity Brine Injection in Combination with Surfactant Flooding," presented at 15th European Symposium on Improved Oil Recovery — Paris, France, 27 – 29 April 2009

Alagic and Skauge, Combined Low Salinity Brine Injection and Surfactant Flooding in Mixed−Wet Sandstone Cores, *Energy and Fuels*, 2010, 24, 3551

Short Low salinity waterflooding history

- The first (?) reported observation of low salinity brine effect on oil recovery - Martin (1959)
- The first observation of improved oil recovery with freshwater injection was made by Bernard (1967)
- 1996: Yildiz and Morrow published a paper on the influence of brine composition on oil recovery
- 1997-2009: extensive research program by BP

(Tang and Morrow, 1997-1999, Webb et al., 2005, McGuire et al., 2006)

  - 20 core floods at reservoir conditions
  - 10 single well chemical tracer tests (SWCTT)

- Experimental results indicate reduction in S_{or} of 0 to 17 s.u.

Low salinity mechanisms

Mechanisms unclear, see list of suggestions

BUT a consequence of most suggested mechanisms is a destabilization of oil layers.

Can the destabilization of oil layers be utilized in combination with another chemical EOR process?

Mineral dissolution
Clay instability (fines migration)
Salinity shock (dp shock)
Release of mixed-wet particles
Particle-stabilized interfaces/lamellae
Microscopic diversion
Multicomponent ion exchange
Double-layer expansion
Wettability alteration (more water wet)
Wettability alteration (more oil wet)
Alkaline flooding effect
pH driven wettability change
Emulsification
Saponification
Surfactant-like behavior
Viscosity ratio
Osmotic Pressure
Capillary end-effects

Benefits of combining low-salinity and polymer

- Higher incremental recovery
  - Reduced Sor by LSF (improvement over polymer flooding only) and accelerated oil prod.
  - Better sweep efficiency (improvement over low salinity flooding only)

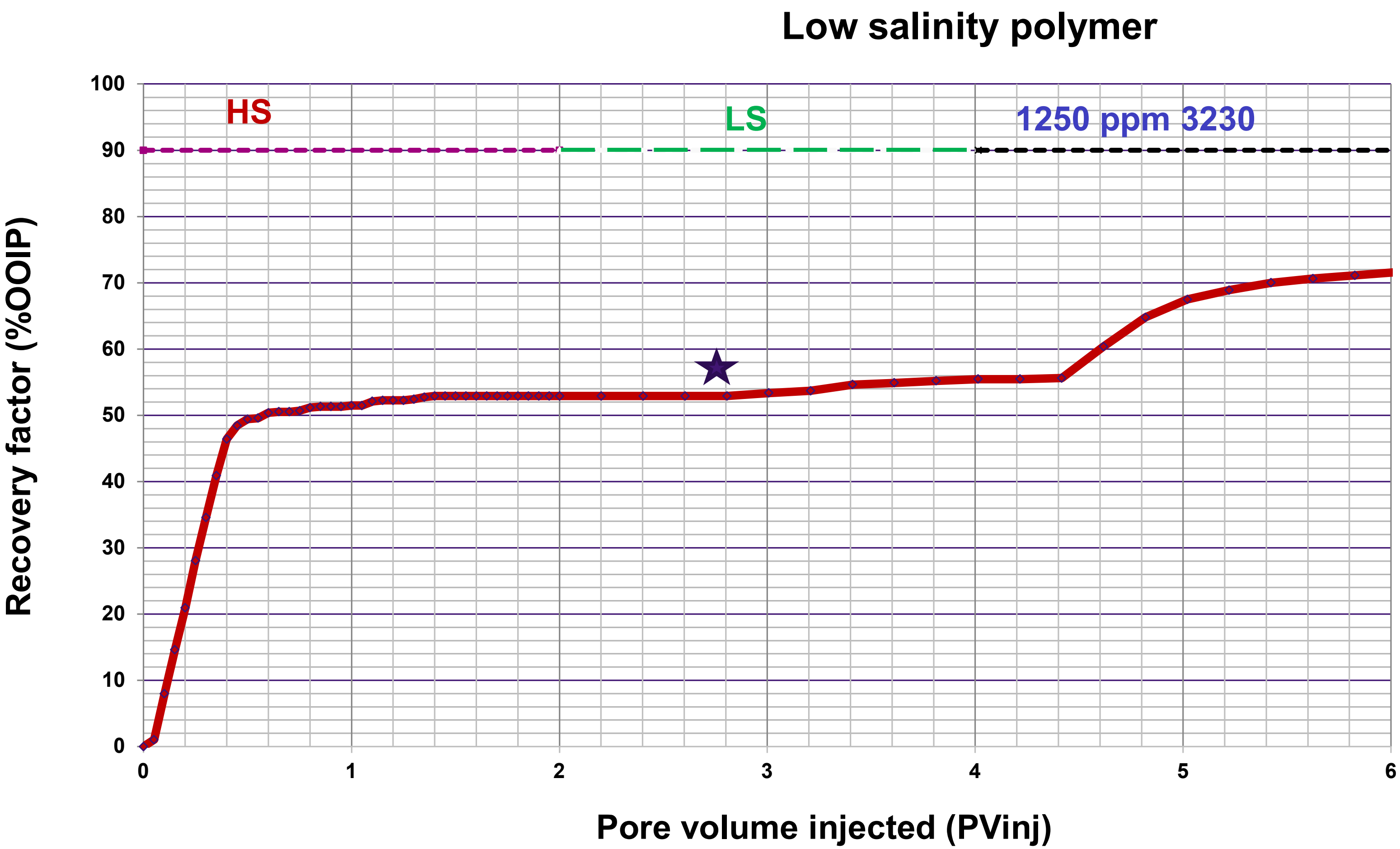
- Larger application envelope of polymer flooding
  - Low-cost polymers can be used instead of HS/HT polymer

- Lower required polymer concentration
  - Polymer swells in lower salinity brine → higher viscosity

- Lower polymer retention

- Reduced production chemistry issues
  - Scaling
  - Corrosion
  - Souring
  - Environmental impact
  - Separation of produced fluids

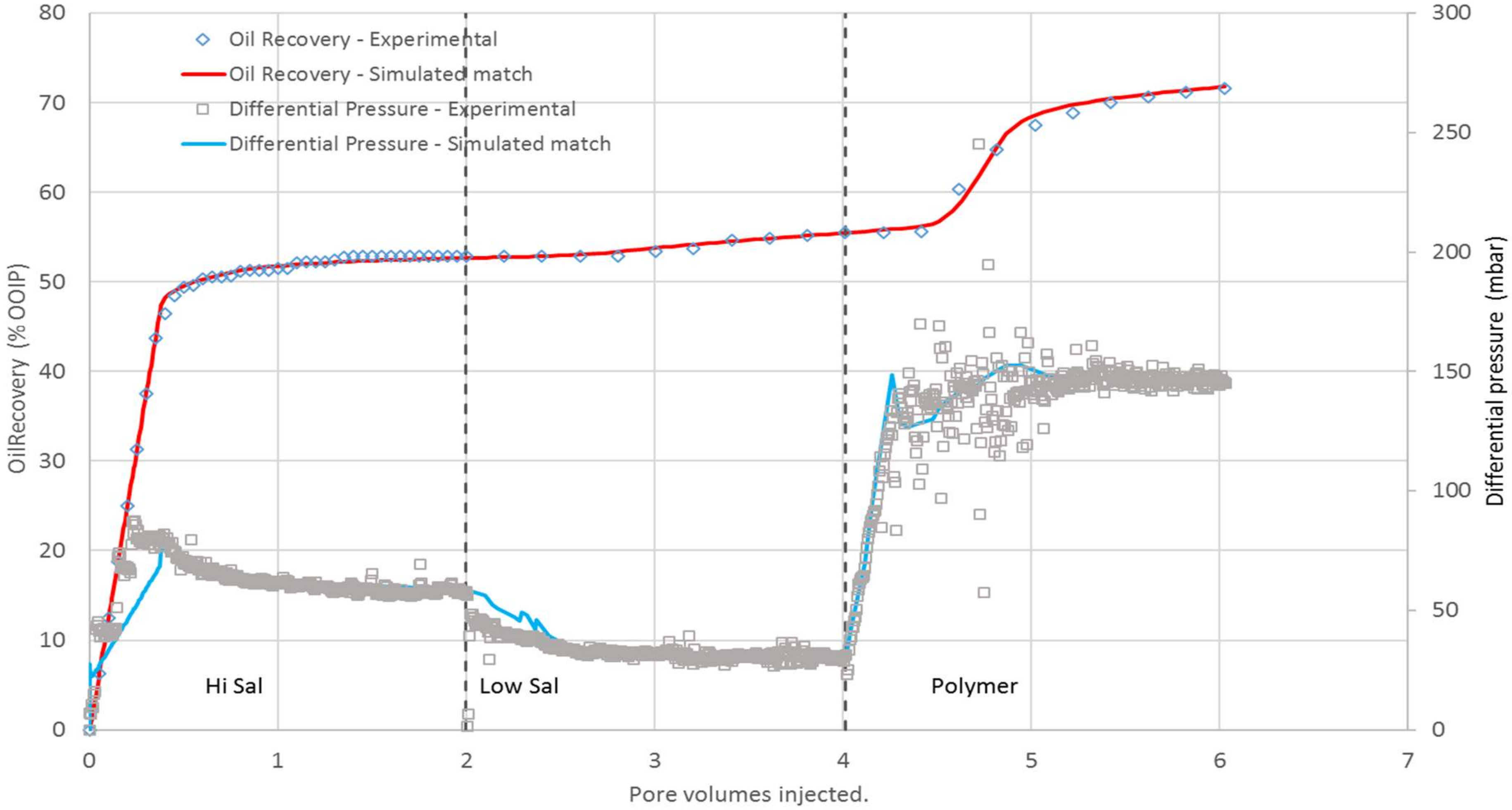
EOR for More Sustainable Future: The Role of Chemical and Hybrid EOR



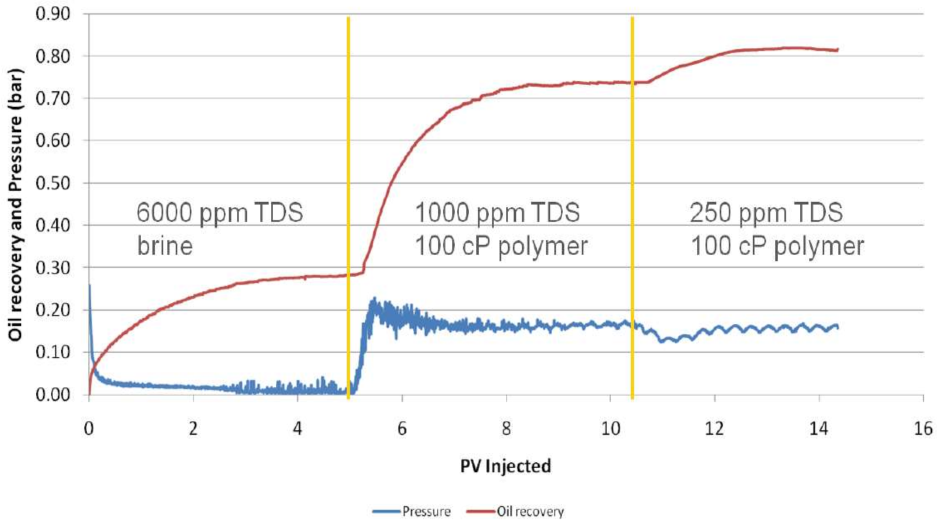
Low salinity gave only slow and very limited oil recovery

Polymer at losal condition banks oil and accelerate oil production

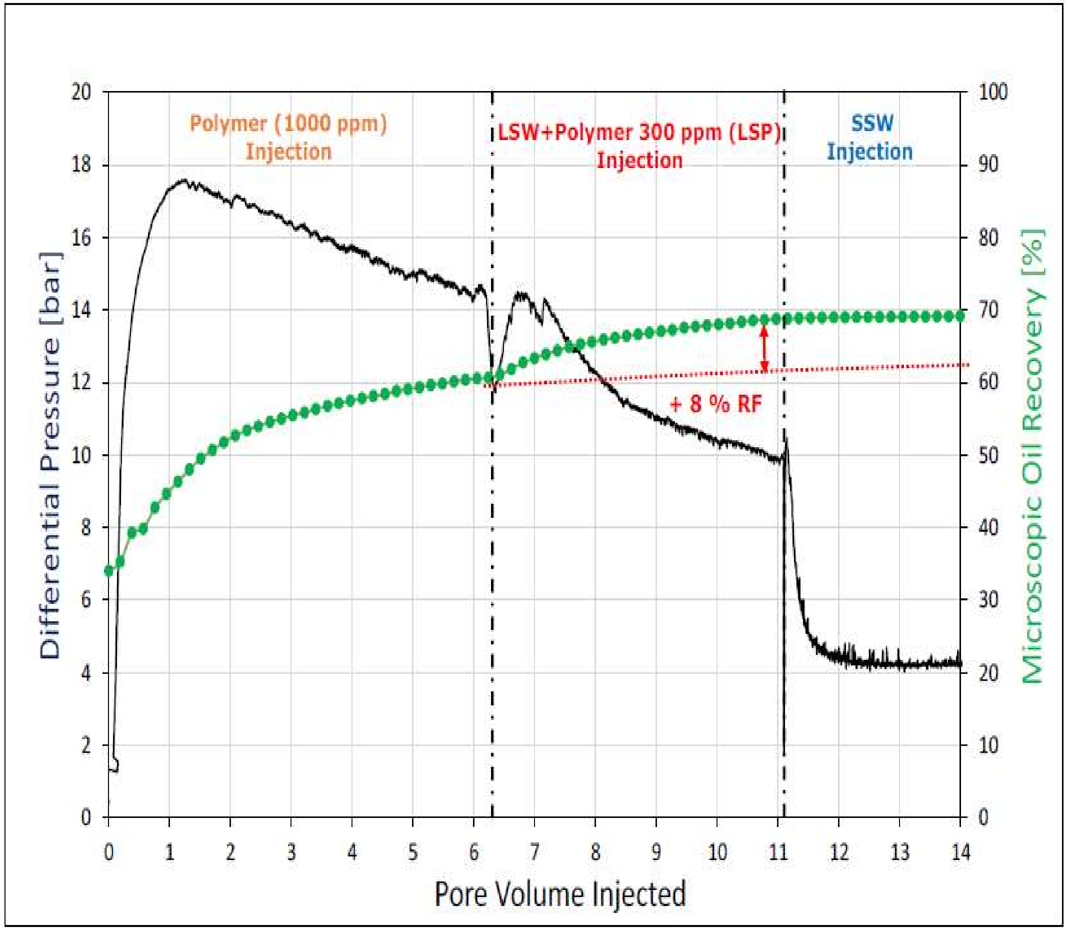
Modelling of LSP



Can we get the same oil response if we dropped the Low Salinity part ?



IPTC 17342
Low-Salinity Polymer Flooding: Improving Polymer Flooding Technical Feasibility and Economics by Using Low-Salinity Make-up Brine
Esther C.M. Vermolen, Monica Pingo-Almada, Bart M. Wassing, Dick J. Ligthelm and Shehadeh K. Masalmeh, Shell Global Solutions International B.V.
Copyright 2014, International Petroleum Technology Conference



LABORATORY INVESTIGATION ON SYNERGY EFFECT OF LOW SALINITY-POLYMER WATER INJECTION ON SANDSTONE POROUS MEDIA

L. Moghadasi, P. Pisicchio, M. Bartosek, E. Braccalenti, P. Albonico, I. Moroni, R. Veschi, F. Masserano, S. Scagliotti, L. Del Gaudio, M. De Simoni, *Eni SpA.*

This paper was presented at the 14th Offshore Mediterranean Conference and Exhibition in Ravenna, Italy, March 27-29, 2019. It was selected for presentation by OMC 2019 Programme Committee following review of information contained in the abstract submitted by the author(s). The Paper as presented at OMC 2019 has not been reviewed by the Programme Committee.

Low Salinity Polymer - LSP

Lower brine salinity reduce loss of polymer - less amount of polymer required

Lower brine salinity increase polymer viscosity – lower polymer concentration needed

LS work as an enabler for polymer flooding

Little response without low salinity prior to the polymer

Claim improved local sweep and diversion of injected fluids.

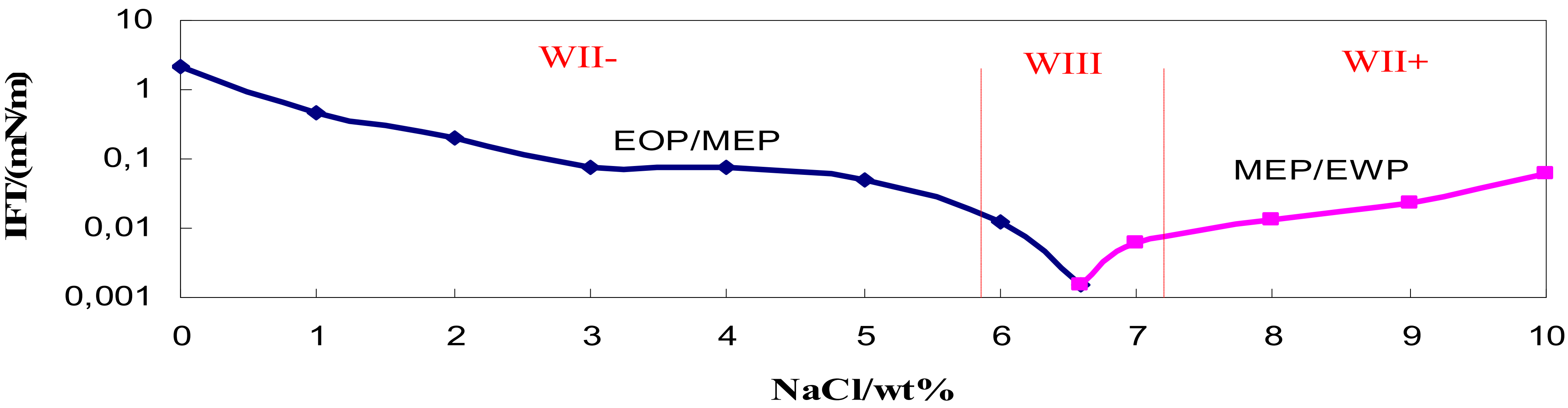
In addition, oil recovery by LS, is significant strengthen by the added polymer

Acceleration of oil production leads to lower carbon footprint

Low Salinity Surfactant Polymer

Low salinity in combination of lowering of interfacial tension and mobility control (sweep) by polymer

Phase behavior and IFT as functions of salinity



								S*				
NaCl %	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**6,6**	**7**	**8**	**9**	**10**
Phase behaviour	**II-**	**II-**	**II-**	**II-**	**II-**	**II-**	**III**	**III**	**III**	**II+**	**II+**	**II+**
IFT/(mN/m)	**2,18**	**0,46**	**0,21**	**0,075**	**0,077**	**0,05**	**~0,013**	**0,0015**	**~0,006**	**0,013**	**0,023**	**0,061**

EOP: excess oil phase
EWP: excess water phase
MEP: microemulsion phase

Phase behavior follows usual trends.

II- phase behavior gives low IFT near the three-phase region

Correlation between solubility, retention and phase behavior

NaCl wt%	0	1	2	3	4	5	6	7	8	9	10
Appearance	C	C	C	C	P	P	T	P	P	P	O
Activity	100	100	100	100	79	97	100	98	98	98	11
Retention (mg/g)		0,14		0,15			1,5			1,76	
IFT (mN/m)	2,18	0,46	0,21	0,075	0,077	0,05	0,0015*		0,013	0,023	0,061
Phase behaviour				WII-			WIII	WIII	WII+	WII+	WII+

* IFT at S* = 6.6

Novel use of surfactants for reducing IFT may be more efficient and economical than classical MPF or surfactant flooding

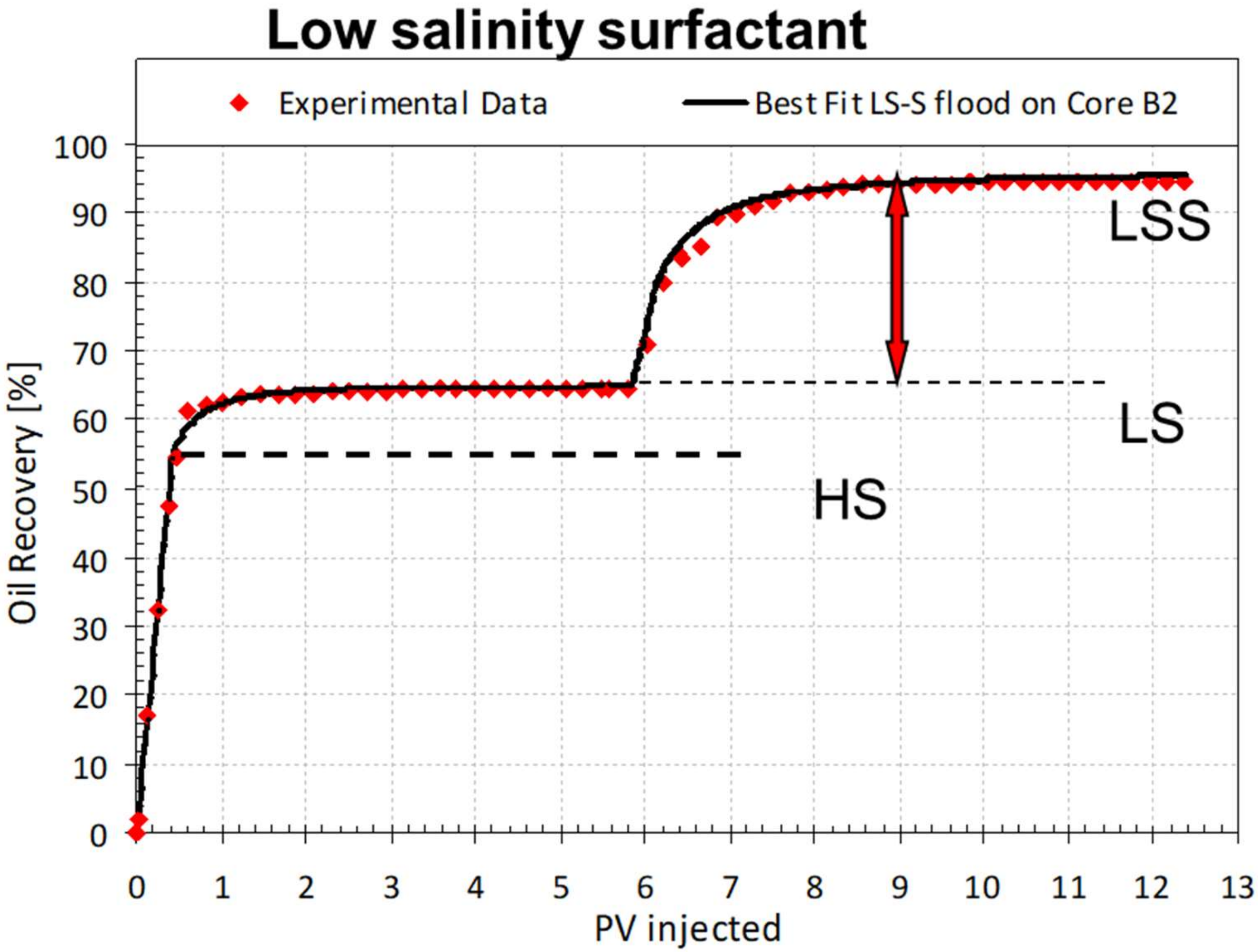
Ultralow IFT, BUT poor solution properties, high phase viscosities and high retention

Advantage of the combined EOR methods

Low salinity reduces surfactant retention

The combined process can mobilize most of the oil in place in lab core flood experiments

Low-cost surfactants can be used at these salinities



Low Salinity Surfactant – LSS(P)

In my opinion conventional MF or SF will not be a commercial process for field applications. Though, a beautiful technology, but unfortunately at too high cost.

As a Hybrid EOR process surfactant can come into commercial use.

Combination of Low Salinity and Surfactant has advantages that give the process a good potential

- Easily accessible and low-cost surfactants can be used
- Lower surfactant loss (low retention) can be achieved
- Lower microemulsion viscosity (WII- rather then WIII)
- Positive synergy between low salinity and surfactant exemplified by avoiding capillary re-trapping and easier mobilization of unstable oil layer

Conclusions & Recommendations

Low salinity is clearly an enabler for other EOR methods like polymer and/or surfactant

Low salinity polymer has recently been applied or is under planning in many oil fields (Kuwait, Africa, Venezuela, Alaska, …)

LSSP may have even higher gain, but has yet to be applied in fields

Benefit:

Lower chemical consumption

Accelerated oil production with lower water cut

Lower carbon footprint

Thank you for your time & attention

I will be happy to try to answer your questions

Acknowledgment to:

ADNOC

AkerBP

equinor

NEPTUNE ENERGY

PETROBRAS

Shell

SNF

TOTAL

wintershall dea

PETROMAKS2 The Research Council of Norway

Chair in cooperation with:

UNICAMP UNISIM

HERIOT WATT UNIVERSITY

USC University of Southern California

DTU

TU Delft Delft University of Technology