Core Flood Modelling of Ion-Exchange during Low Salinity Waterflooding*

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Abstract

The present work contains a literature review of the key and latest publications on Low Salinity Waterflooding (LSWF) since its real development in the 1990s to explain the dominant mechanisms, numerical modelling processes and requirements to apply this Enhanced Oil Recovery (EOR) technique. To-date, there is no general agreement of the dominating mechanism that rules the LSWF effectiveness. Currently, wettability alteration to a more water-wet state of the rock as a result of ion exchange and/or double layer expansion mechanism are the two most feasible and supported pore scale mechanisms. However, most of the latest published numerical modeling methods aim to represent the wettability changes only because of Multi-Ion Exchange (MIE) processes and geochemical reactions. These publications crosscheck their results with observed laboratory data and with the chemical reactions obtained from a recognized geochemical simulator, PHREEQ-C (Kharaka et al., 1988).

The present project is oriented to reproduce experimental results obtained at Heriot Watt University with PHREEQ-C to investigate the effects of concentration changes of the low salinity injection brine on the ion-exchange reactions. Later the experimental results are reproduced using industry standard reservoir simulation software to reproduce the observed data in a 1D single-phase system. The reproduction of the experimental results will be used as basis to define correlations between grid size, cation exchange capacity (CEC), selectivity coefficients, and injection rates in a Multi-Ion Exchange modelling process and as a method to estimate the type of clay present in the system through the intrinsic CEC value. In addition, a 1D two-phase system is also the set up to observe the different oil recoveries as function of the injected pore volume when using different equivalent fractions and aqueous concentrations as relative permeability interpolants.

By using these models and a model that reproduce experimental data, a correlation between the CEC and the oil recovery factor is presented which can help to understand more the modeled MIE process.

Selected References

Dang, C.T.Q., L.X. Nghiem, Z. Chen, Q.P. Nguyen, and T.B.N. Ngoc, 2013, State-of-the Art Low Salinity Waterflooding for Enhanced Oil Recovery: Society of Petroleum Engineers, SPE Asia Pacific Oil and Gas Conference and Exhibition, 22-24 October, Jakarta.

Kharaka, Y.K., L.D. White, G. Ambats, and A.F. White, 1988, Origin of subsurface water at Cajon Pass, California: Geophysical Research Letters, v. 15: doi: 10.1029/88GL03186. issn: 0094-8276.

Lager, A., K.J. Webb, C.J.J. Black, M. Singleton, and K.S. Sorbie, 2006, Low salinity oil recovery - An experimental investigation: Proceedings of International Symposium of the Society of Core Analysts, Trondheim, Norway, October, 2006.

Core Flood Modelling of Ion-Exchange during Low Salinity Waterflooding

- Nestor Vásconez (Schlumberger),
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LOW SALINITY WATER INJECTION

OBJECTIVES

- Reproduce experimental data using Geochemical & Reservoir Simulation software in a 1D single phase system
- Perform LSW in a two phase system using the matched core characteristics
- Gain more insight into modelling LSW

LOW SALINITY WATER INJECTION

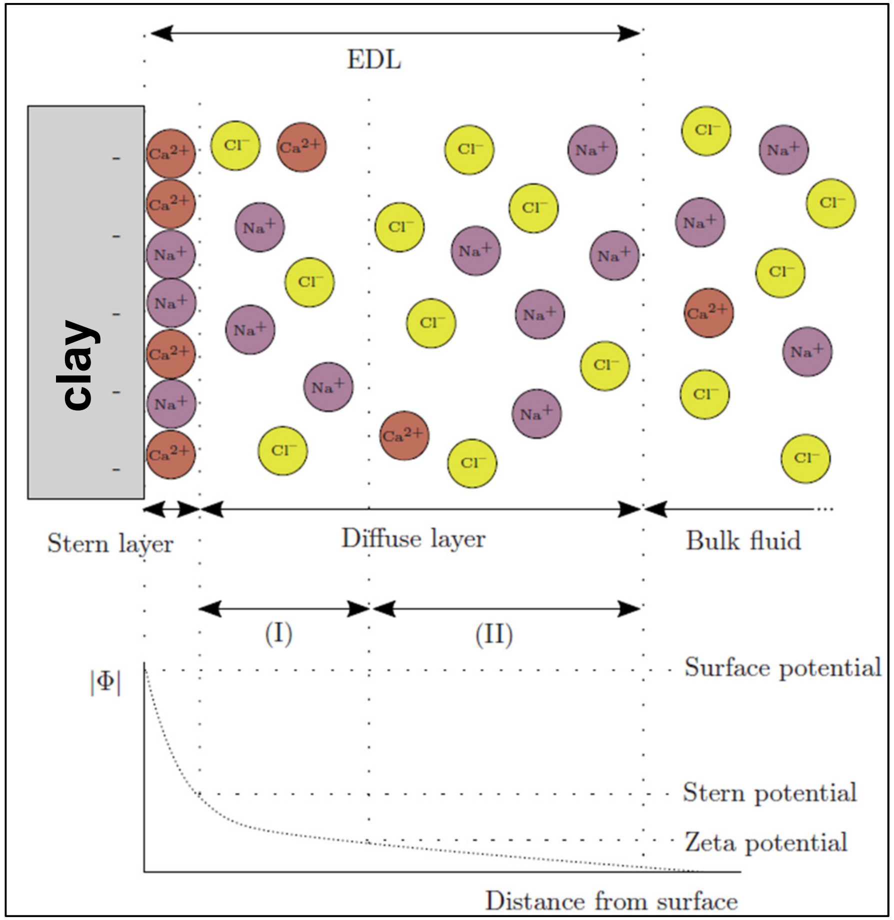
MECHANISMS

- Different mechanisms are responsible for Low Salinity Water Efficiency:
  - Electrical Double Layer Expansion
  - Multi-Ion Exchange
  - Fines Migration
  - pH increase and more
  - After 24 years: no general agreement among researchers

LOW SALINITY WATER INJECTION

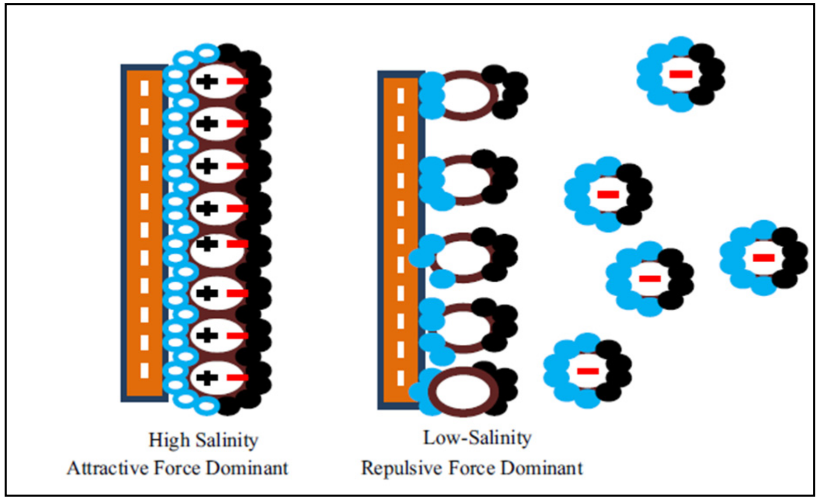
MECHANISMS

Electrical Double Layer Expansion



(De Bruin et al., 2006)

Low Salinity Waterflooding



(Aladasami et al., 2014)

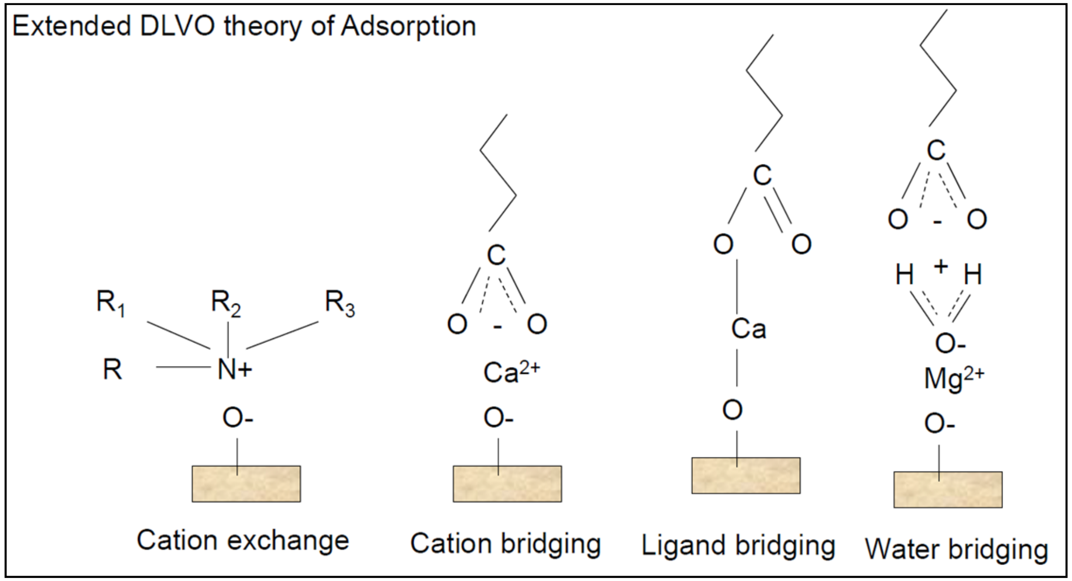
Resulting effect:

- Change in wettability
- Facilitates oil removal
- Supported by experimental observations
- Considered an effect not a mechanisms

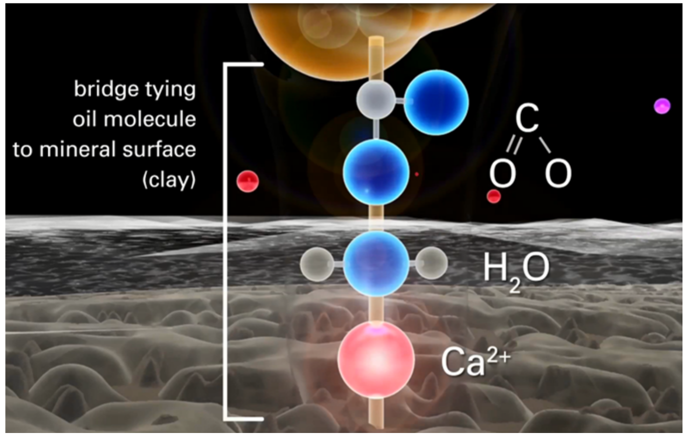
LOW SALINITY WATER INJECTION

MECHANISMS

Multi-Ion Exchange



(Lager et al., 2006)



(BP 2014)

Free monovalent or divalent cations replace the bridging cations

- Observed at core and field scale
- However, polar oil components can adsorb onto clay minerals without a bridge.

These 2 mechanisms change the wettability towards a more water wet system.

LOW SALINITY WATER INJECTION

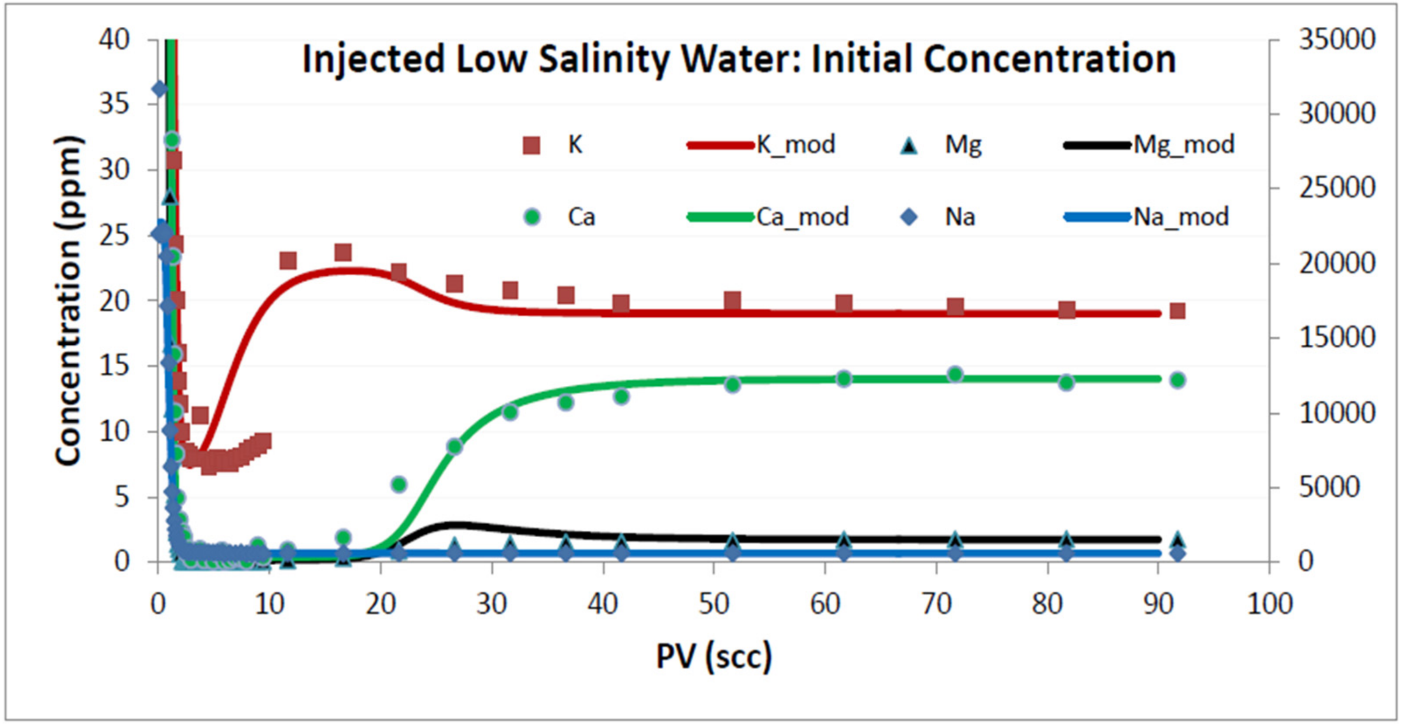
Modelling LSW

- Single phase data can be represented using a well-known Geochemical simulator
- Modelling LSW is limited in current reservoir simulators to Relative Permeability Interpolation from HS Kr to LS Kr using brine tracking.
- A compositional numerical simulator with Geochemical processes is used.
- Identify a tool for modelling LSW comparing the results with observed experimental data.

MATCHED EXPERIMENTAL DATA USING PHREEQ-C:

1D GEOCHEMICAL SIMULATOR

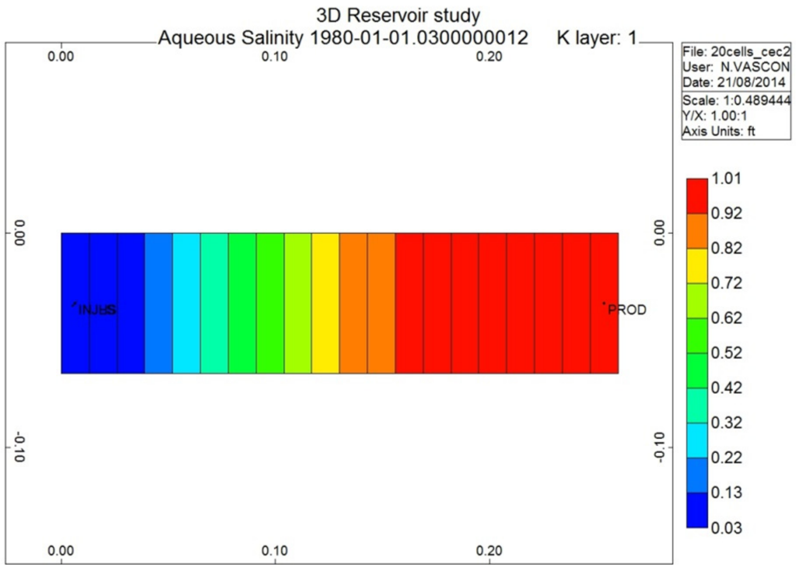
PHREEQ-C VS EXPERIMENTAL DATA (Heriot Watt University)



Brine / Ions (ppm)	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	TDS
Formation	22000	238	90	230	35500	~58058
Injection	588	14	1.75	19	941	~1563

MODELLING LOW SALINITY WATER AT CORE SCALE

MODEL	1D MODEL
CELLS	10 – 20 - 40 CELLS
SIMULATOR	GEM
PROCESS MODELED	ION EXCHANGE
DATA INPUT	
ION CONCENTRATION	FROM EXPERIMENTAL DATA
	FORMATION BRINE
	INJECTION BRINE
	EFFLUENT CONCENTRATION
PHREEQC	1D GEOCHEMICAL SIMULATOR



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MATCHING EXPERIMENTAL DATA USING GEM:

$Na^{+} + 0.5(Ca - X_2) \leftrightarrow (Na - X) + 0.5Ca^{2+}$ (1) ⟶ **S.C. 0.4**

$Na^{+} + 0.5(Mg - X_2) \leftrightarrow (Na - X) + 0.5Mg^{2+}$ (2) ⟶ **S.C. 0.4**

$Na^{+} + (K - X) \leftrightarrow (Na - X) + K^{+}$ (3) ⟶ **S.C. 0.1**

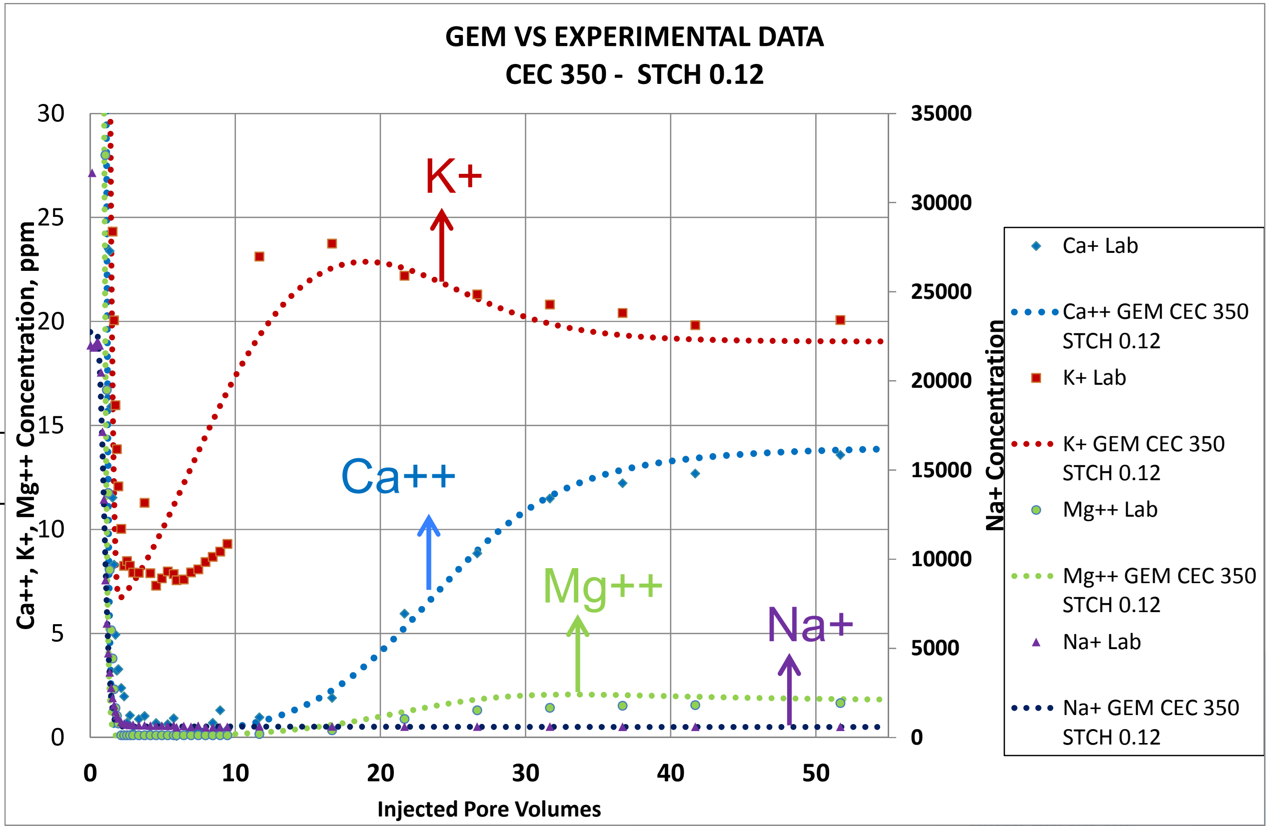
Cation Exchange Capacity: **350 meq/L**

↓

3.09 meq/(100 grams of rock)

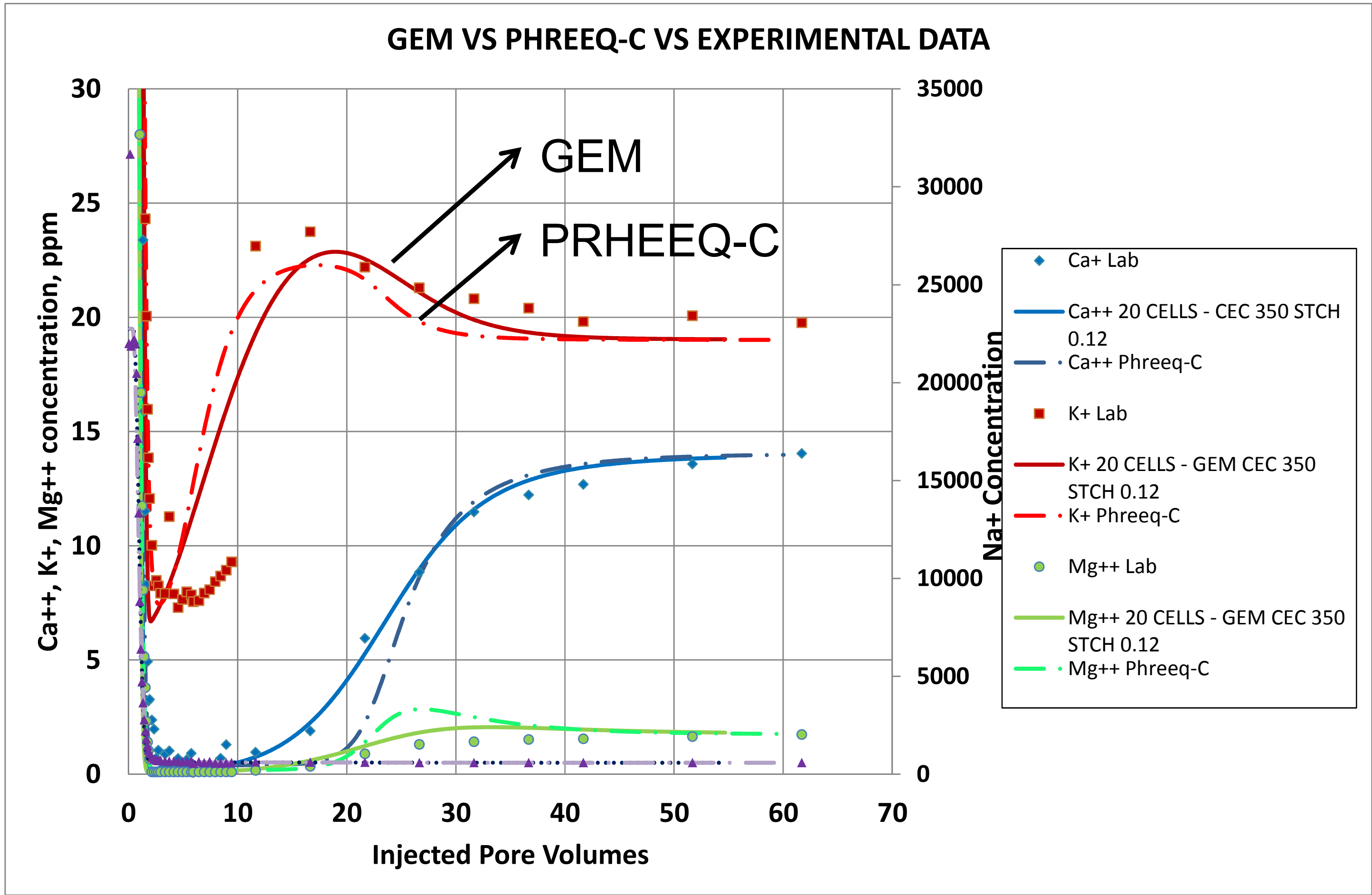
↓

Kaolinite range



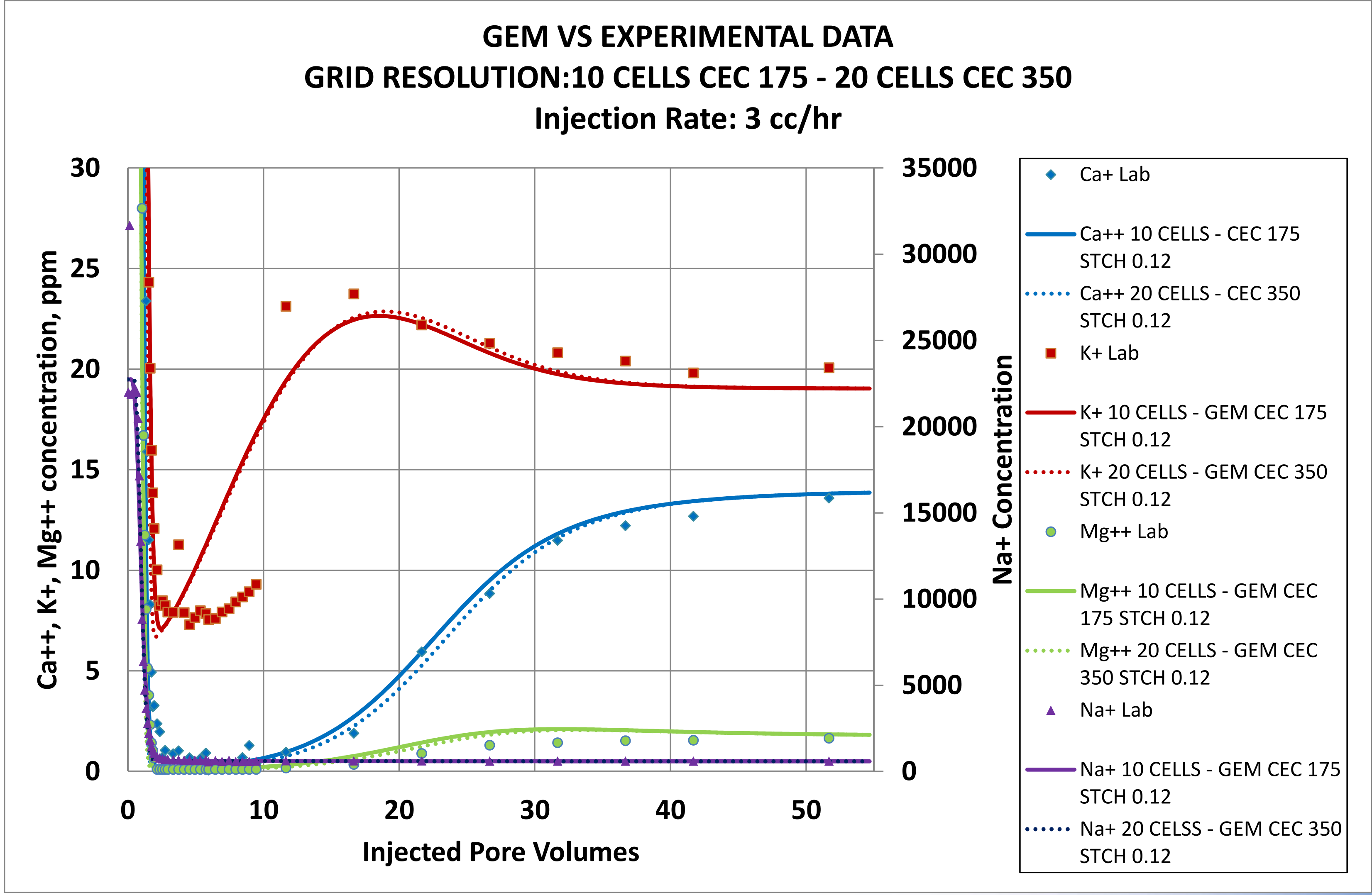
MATCHING EXPERIMENTAL DATA USING GEM:

IMPROVEMENT OVER PHREEQ-C IN MODELLING ION-EXCHANGE



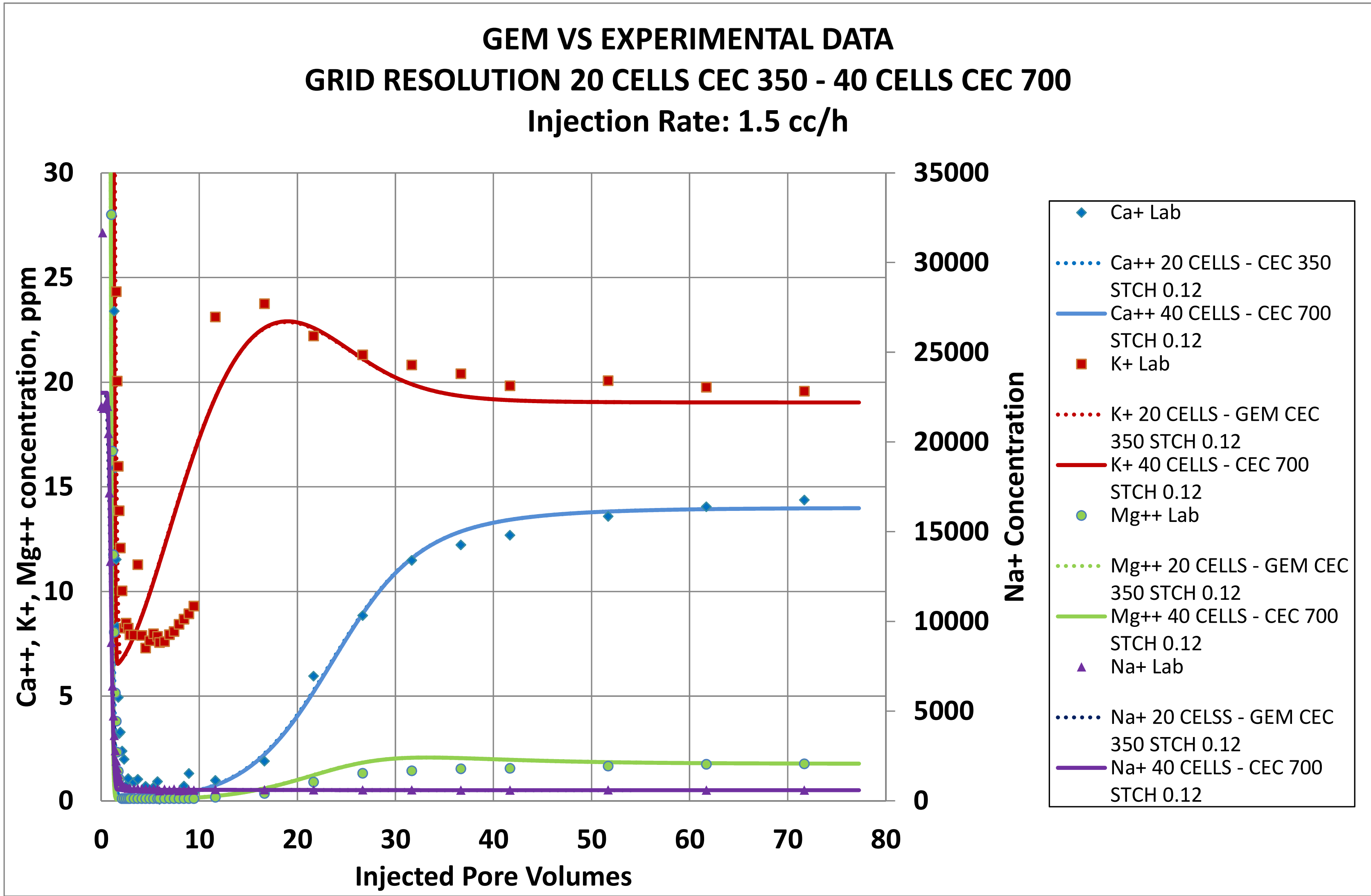
MATCHING EXPERIMENTAL DATA USING GEM:

SENSITIVITIES TO THE GRID RESOLUTION: 20 to 10 CELLS



MATCHING EXPERIMENTAL DATA USING GEM:

SENSITIVITIES TO THE GRID RESOLUTION: 40 to 20 CELLS



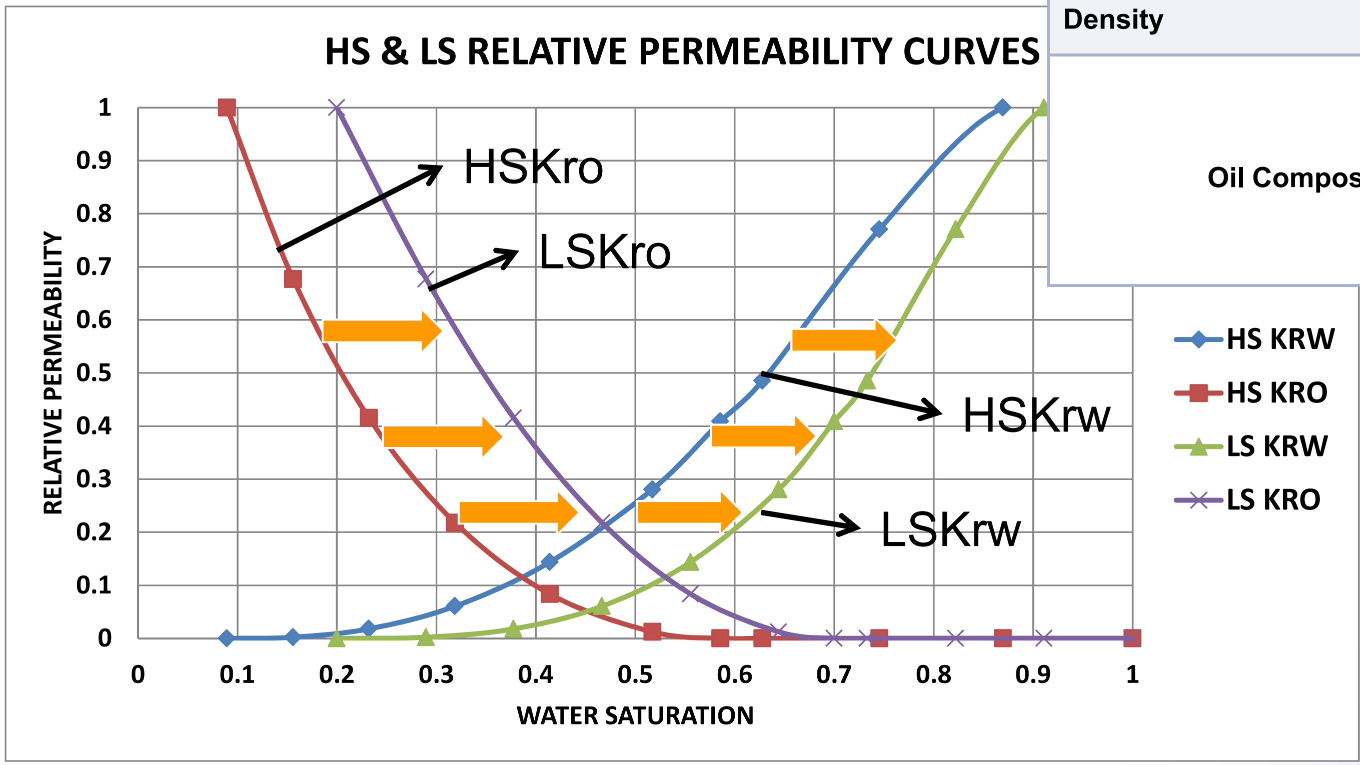
LOW SALINITY WATER INJECTION: TWO PHASES

Relative Permeability Interpolants:

1. Equivalent Fraction

2. Aqueous concentration

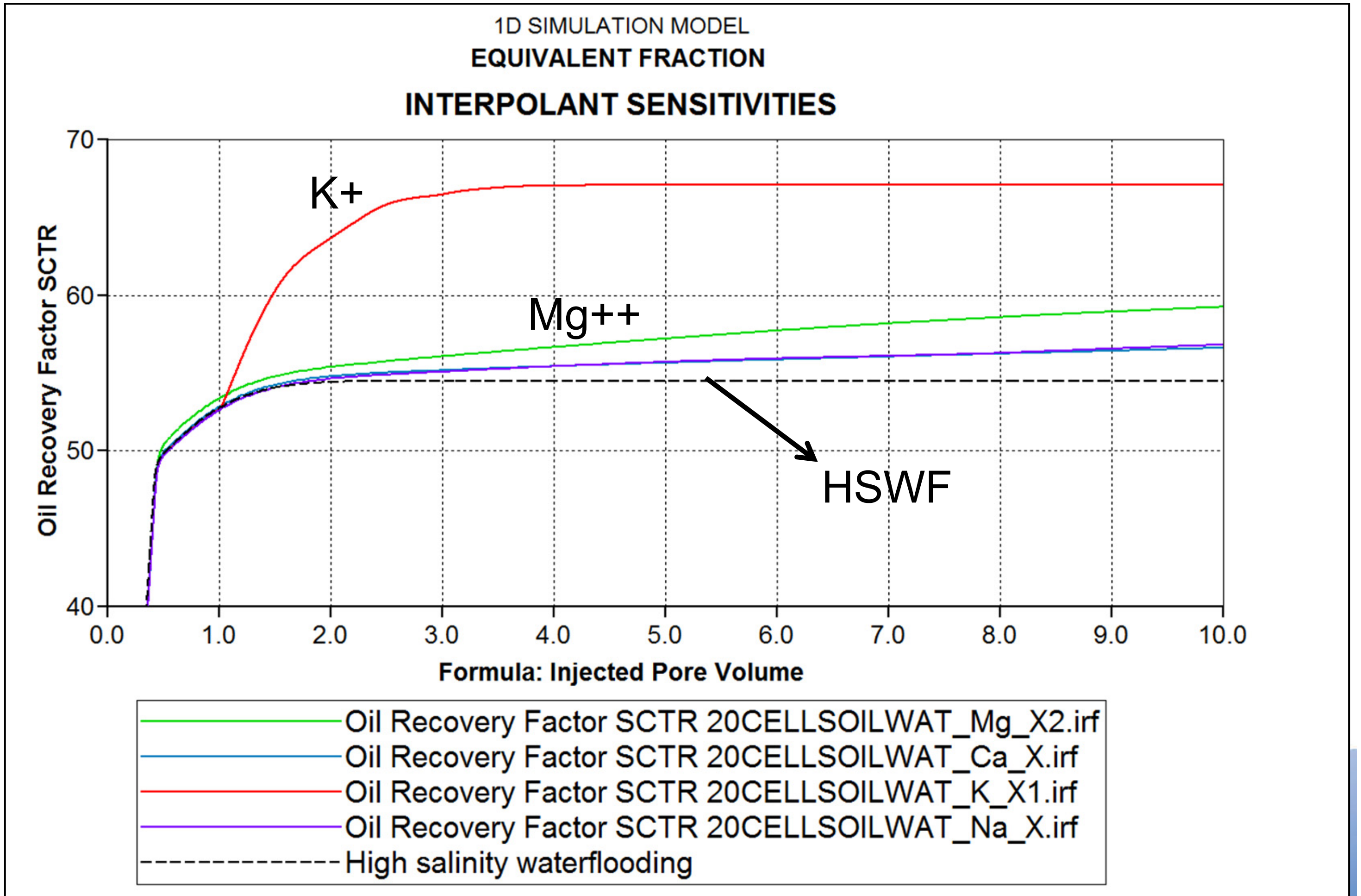
Parameter	Unit	Value
Pressure	PSIa	4500
Temperature	F	160
Viscosity @ 4500 PSIa	cP	0.42
Volumetric oil factor @ 4500 PSIa	Ad	1.17
Density	lb/cu.ft	45
Oil Composition	C1	0.2
	C4	0.2
	C10+	0.6



LOW SALINITY WATER INJECTION: TWO PHASES

1. Interpolant: Equivalent Fraction

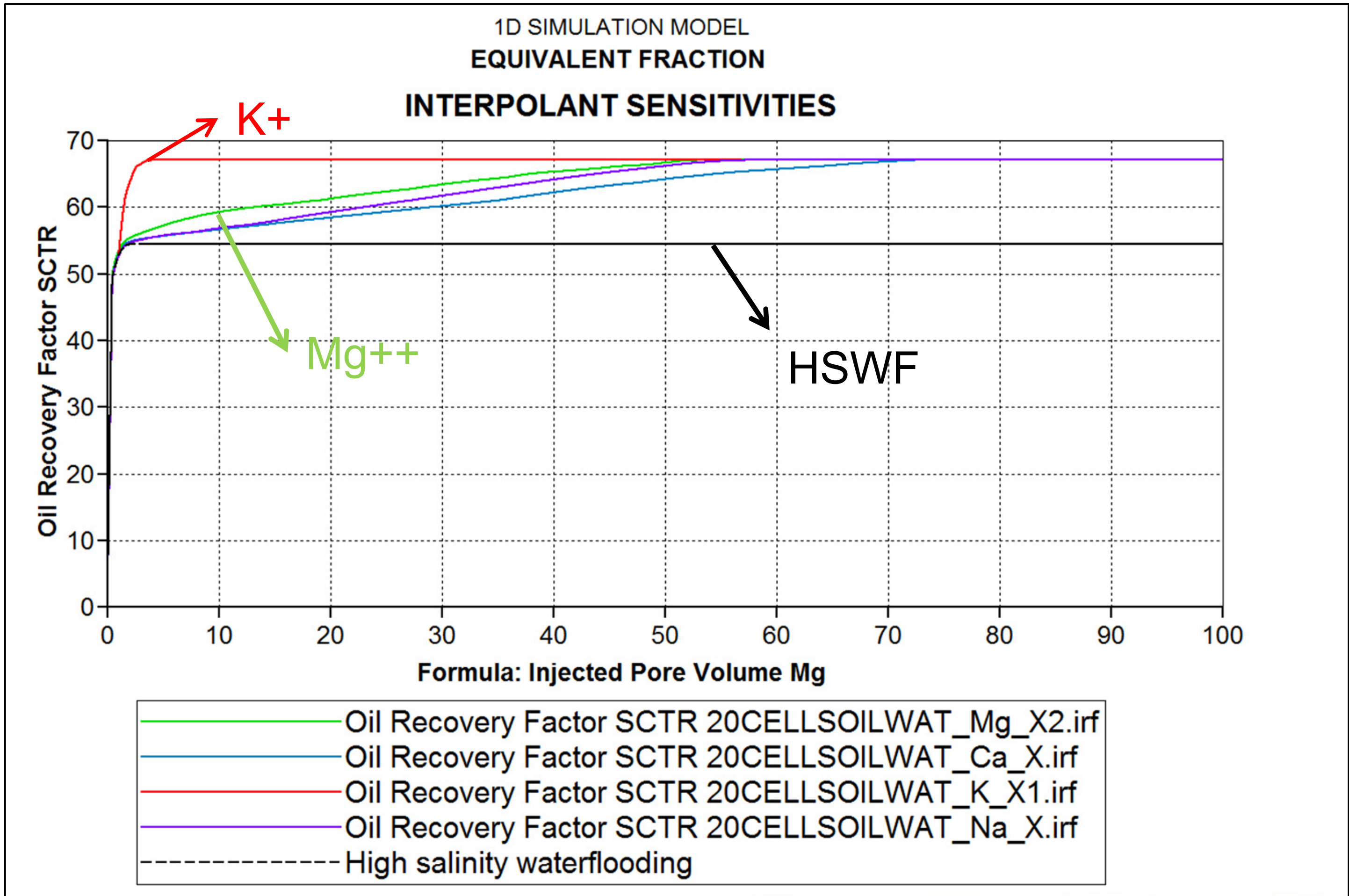
0 – 10 Injected Pore Volumes



LOW SALINITY WATER INJECTION: TWO PHASES

Interpolant: Equivalent Fraction

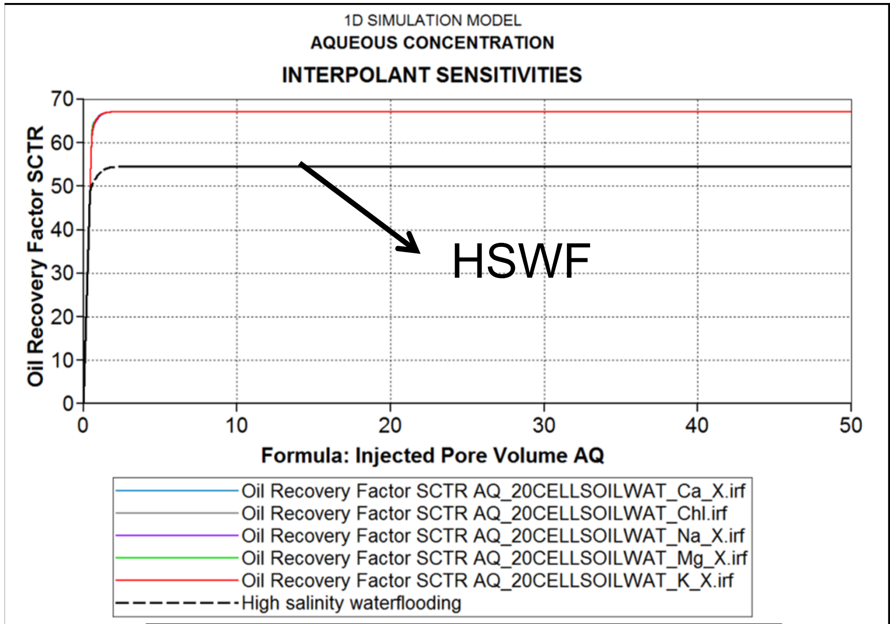
Up to 70 PV to reach equilibrium



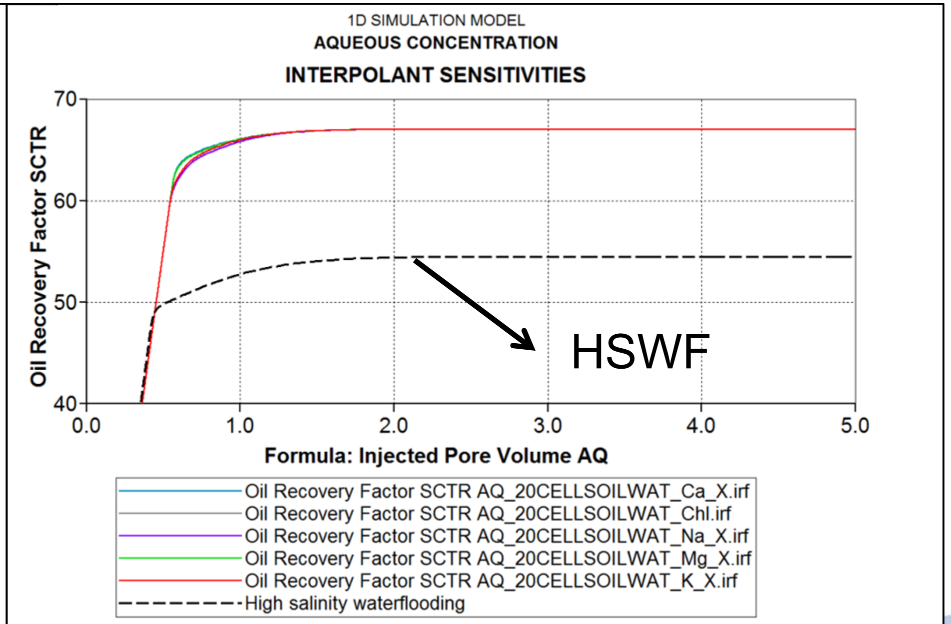
LOW SALINITY WATER INJECTION: TWO PHASES

2. Interpolant: Aqueous concentration

Early LSW effect



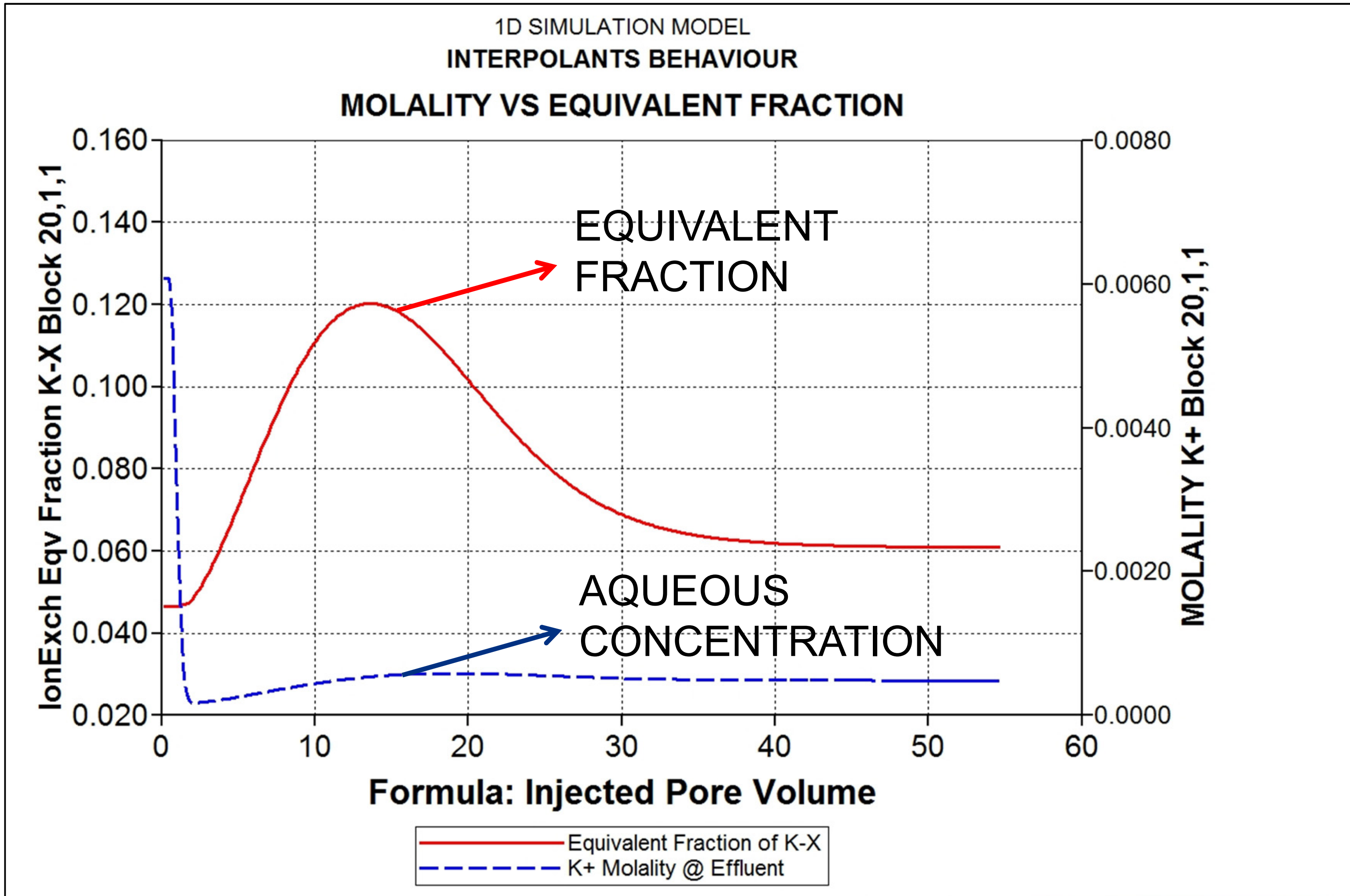
0 - 50.0 PV



0 - 5.0 PV

LOW SALINITY WATER INJECTION: TWO PHASES

Interpolant: Aqueous concentration vs Equivalent Fraction



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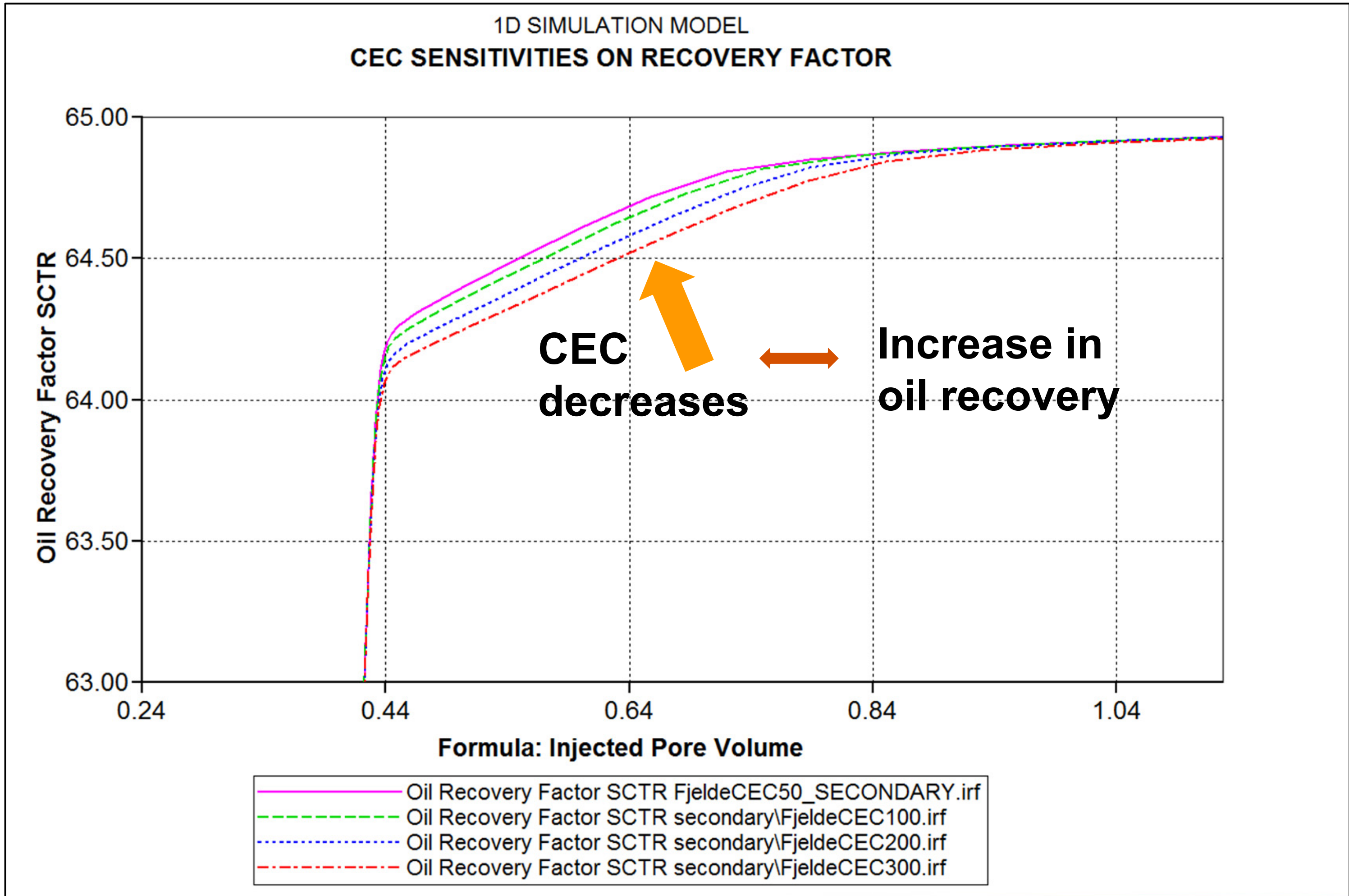
LOW SALINITY WATER INJECTION: TWO PHASES

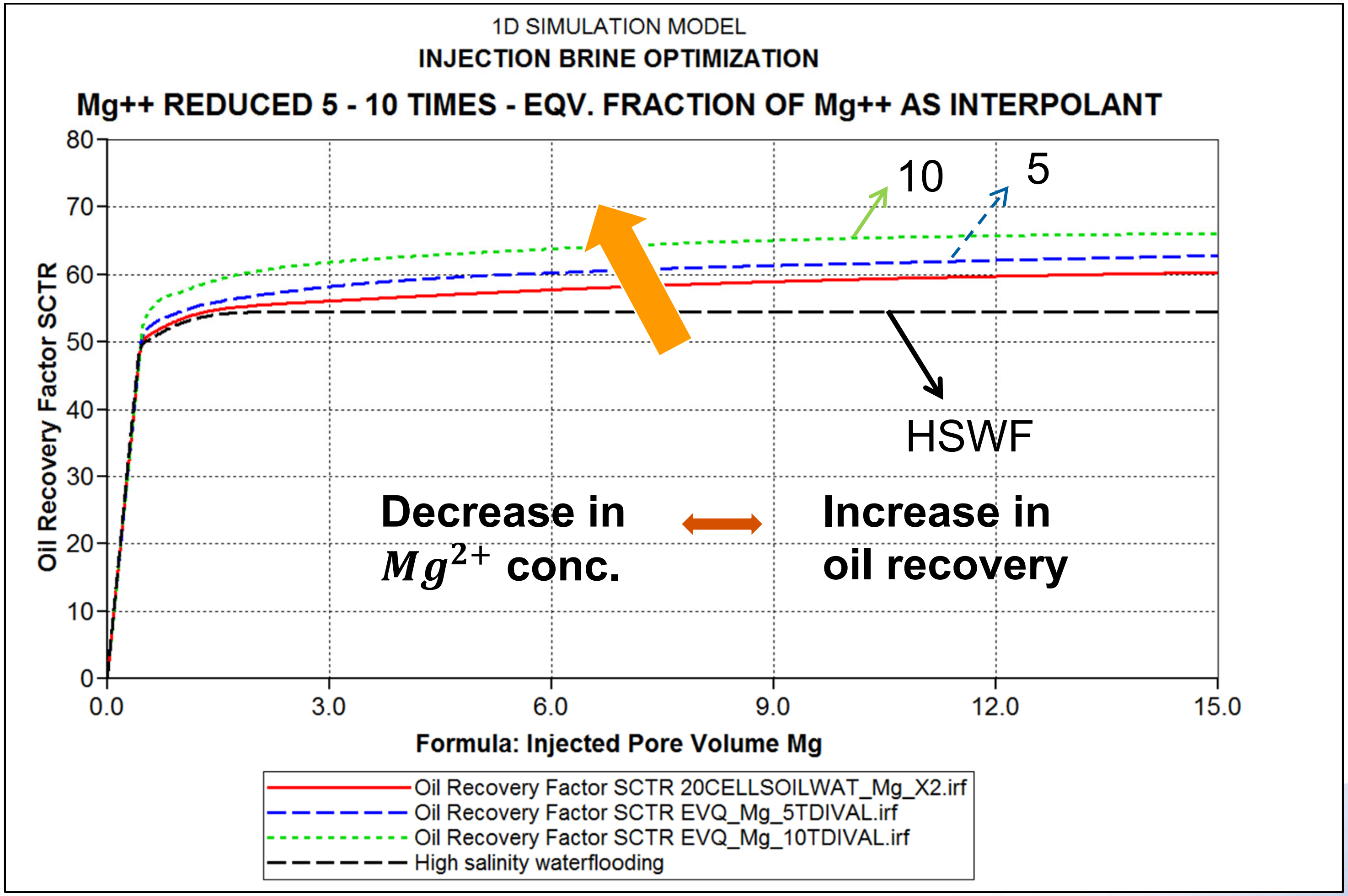
CEC effect on Oil Recovery: matched model by Dang (2013)



LOW SALINITY WATER INJECTION: TWO PHASES

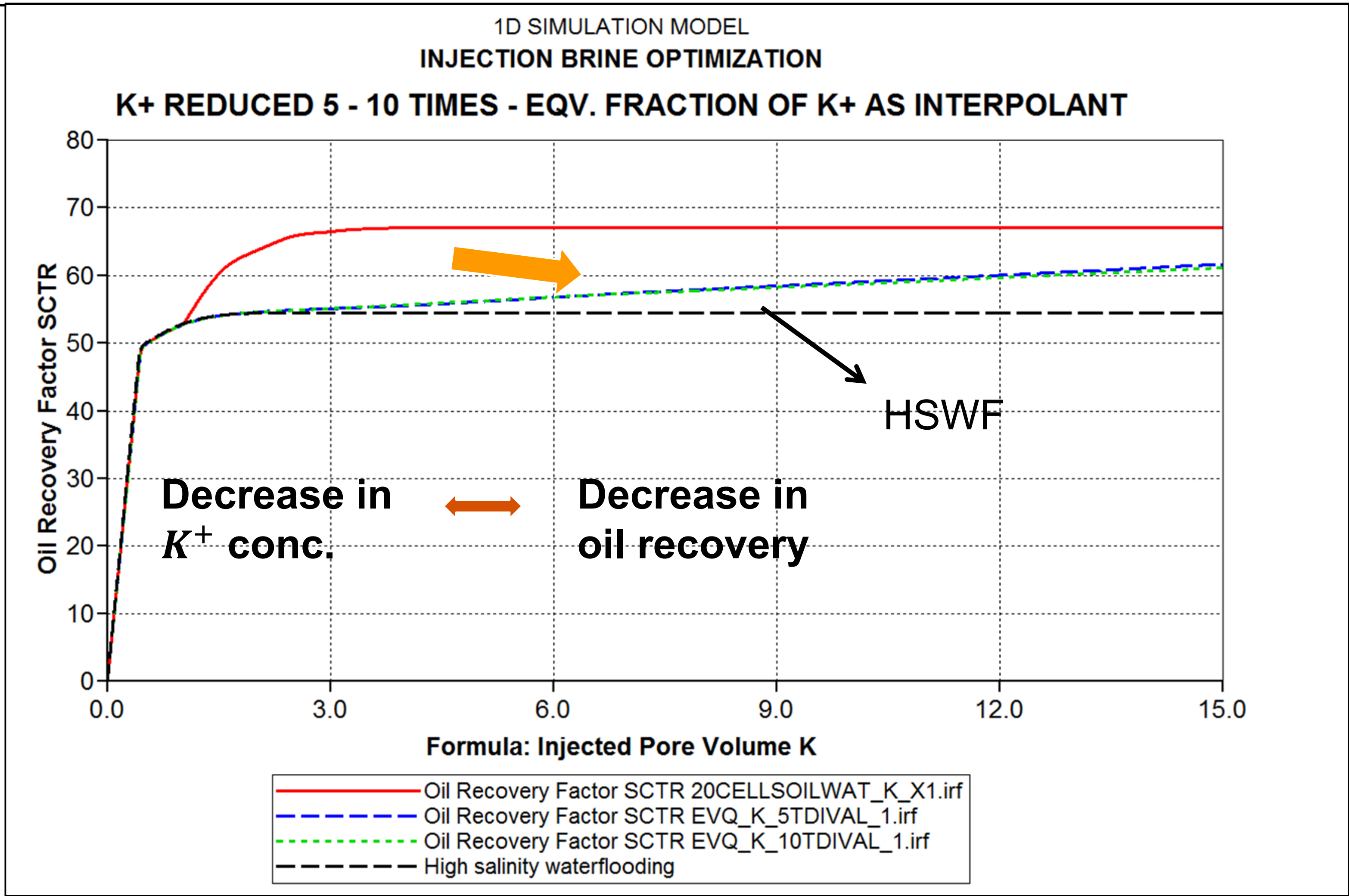
Brine Optimization

Reduction of the Ion Concentration



LOW SALINITY WATER INJECTION: TWO PHASES

Brine Optimization: 5-10 times reduction in Ion Conc.



CONCLUSIONS

- Single phase LSW can be reproduced using a 1D Geochemical simulator
- A general scaling factor to modify the CEC of the rock is presented as well as the parameters that do not interfere in the Ion-Exchange process.
- A general dependence of the rock CEC against oil recovery was found supported by a published simulation model based on experimental data.
- The sensitivities on the equivalent fraction of different ions as interpolants result in important ranges of recovery with different amounts of PV needed to reach new equilibrium conditions.
- Economical considerations are vital when deciding to implement a LSW as many pore volumes may be needed before observing a successful EOR.
- The brine optimization process performed in the current report agrees with experimental observations and requirements for LSWE.

RECOMMENDATIONS

- Inclusion of mineral reactions together with the Ion-Exchange model in order to identify the sustained behaviour of K .
- Reproduce observations that mention MIE as secondary mechanism.
- The inclusion of Kaolinite which is present in most of the reported observations is highly recommended as well as the analysis of additional variables such as pH, which can locally contribute to an increase in oil recovery at core scale.
- The inclusion of the PHREEQ-C code in open code standard reservoir simulators could lead to an important advance in terms of EOR modelling as reported in literature (Korrani et al., 2013, Korrani et al., 2014)

THANK YOU !