



Felix Feldmann (Autor)

An experimental and numerical study of low salinity effects on the oil recovery of carbonate limestone samples

An experimental and numerical study
of low salinity effects on the oil recovery
of carbonate limestone samples

Felix Feldmann



Cuvillier Verlag Göttingen
Internationaler wissenschaftlicher Fachverlag

<https://cuvillier.de/de/shop/publications/8199>

Copyright:

Cuvillier Verlag, Inhaberin Annette Jentzsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen, Germany
Telefon: +49 (0)551 54724-0, E-Mail: info@cuvillier.de, Website: <https://cuvillier.de>



Contents

List of Figures	ix
List of Tables	xiii
Glossary	xv
1 Introduction	1
1.1 Motivation	2
1.2 Production stages	3
1.3 Geology	3
1.4 Wettability	4
1.5 Low-salinity waterflooding	5
1.6 Outline	5
2 Scope & objectives	9
2.1 Experimental methodology	9
2.1.1 Spontaneous imbibition	9
2.1.2 Centrifuge method	11
2.1.3 Unsteady state coreflooding	11
2.2 Numerical methodology	12
2.2.1 Centrifuge simulation	12
2.2.2 Coreflooding simulation	13



CONTENTS

2.3	Material & equipment	14
2.4	Experimental sequence & parameter	15
3	Literature review	17
3.1	Buckley-Leverett equation	18
3.2	Spontaneous imbibition experiments	20
3.3	Coreflooding experiments	22
3.4	Low-salinity mechanisms	26
3.5	Summary & conclusions	32
I	Experimental study	35
4	Preparation	37
4.1	Fluid preparation	37
4.1.1	Brine preparation	37
4.1.2	Oil preparation	38
4.1.3	Density & viscosity	39
4.1.4	Interfacial tension	40
4.2	Core preparation	42
4.2.1	Core material	42
4.2.2	Core cleaning	43
4.2.3	Core selection	44
4.3	Connate water saturation	45
4.3.1	Core saturation	45
4.3.2	Absolute brine permeability	45
4.3.3	Nuclear Magnetic Resonance	48
4.3.4	Primary brine drainage	50
4.3.5	Effective oil permeability	52
4.3.6	Core aging	52
4.3.7	Unsteady state coreflooding samples	54



4.4	Summary & conclusions	54
5	Spontaneous imbibition	57
5.1	Theory	57
5.2	Spontaneous imbibition in carbonates	59
5.3	Methodology	60
5.4	Experimental conduction	62
5.5	Spontaneous imbibition results	63
5.5.1	Identical salinity of connate water and imbibing water	63
5.5.2	Imbibition of a low saline brine into a system at higher salinity (A)	64
5.5.3	Imbibition of a low saline brine into a system at higher salinity (B)	65
5.5.4	Imbibition of a high saline brine into a system at lower salinity	65
5.6	Contact angle	65
5.7	Zeta potential	68
5.8	Summary & conclusions	70
6	Centrifuge method	75
6.1	Theory	75
6.2	Methodology	77
6.3	Analytical centrifuge solution	78
6.4	Experimental conduction	84
6.5	Centrifuge results	86
6.5.1	Identical salinity of connate water and imbibing water	87
6.5.2	Injection of a low saline brine into a system at higher salinity (A)	88



CONTENTS

6.5.3	Injection of a low saline brine into a system at higher salinity (B)	88
6.5.4	Injection of a high saline brine into a system at lower salinity	89
6.6	Summary & conclusions	90
7	Coreflooding	93
7.1	Theory	93
7.2	Methodology	97
7.3	Experimental conduction	98
7.4	Coreflooding results	100
7.4.1	Formation-water in secondary mode	101
7.4.2	Sea-water in secondary mode	102
7.4.3	Diluted-sea-water in secondary mode	102
7.5	Summary & conclusions	103
II	Numerical study	107
8	Numerical centrifuge simulation	109
8.1	DuMu ^x	109
8.1.1	Spatial discretization	110
8.1.2	Time discretization	113
8.1.3	Newton's method	114
8.2	DuMu ^x centrifuge simulation	116
8.2.1	Boundary conditions	116
8.2.2	Fluid properties	119
8.2.3	Hydraulic properties	119
8.2.4	Flow equation	122
8.2.5	Mass balance	124
8.2.6	Time manager	124



8.3	Cydar	125
8.4	Cydar centrifuge simulation	125
8.4.1	Cydar input data	125
8.4.2	Cydar boundary conditions	126
8.5	Simulation results	127
8.5.1	History matching methodology	127
8.5.2	Forced imbibition simulation	128
8.5.3	Numerical capillary pressure	133
8.6	Summary & conclusions	134
9	Numerical coreflooding simulation	135
9.1	DuMu ^x coreflooding simulation	136
9.1.1	Boundary conditions	136
9.1.2	Fluid properties	139
9.1.3	Hydraulic properties	141
9.1.4	Flow equation	143
9.1.5	Molar balance	144
9.1.6	Time manager	145
9.2	Cydar coreflooding simulation	145
9.2.1	Cydar input data	145
9.2.2	Cydar boundary conditions	146
9.3	Simulation results	146
9.3.1	Absolute permeability matching	146
9.3.2	History matching methodology	147
9.3.3	Formation-water in secondary mode	150
9.3.4	Sea-water in secondary mode	151
9.3.5	Diluted-sea-water in secondary mode	157
9.3.6	Relative permeability and capillary pressure	158
9.4	Summary & conclusions	160



CONTENTS

10 Summary & conclusions	163
Bibliography	169
A Experimental study appendix	183
A.1 Spontaneous and forced imbibition results	183
A.2 Unsteady state coreflooding results	183
B Numerical study appendix	201
B.1 Source code excerpts - Centrifuge	201
B.2 Source code excerpts - Coreflooding	206
C Ausführliche Zusammenfassung	209
C.1 Einleitung	209
C.2 Literaturrecherche	210
C.3 Probenvorbereitung	212
C.4 Spontaneous-imbibition Tests	213
C.5 Zentrifugenversuche	214
C.6 Kernflutungsexperimente	215
C.7 Numerische Zentrifugensimulation	216
C.8 Numerische Kernflutungssimulation	217
C.9 Zusammenfassung	219