Gas Injection in Fractured Carbonate Rocks

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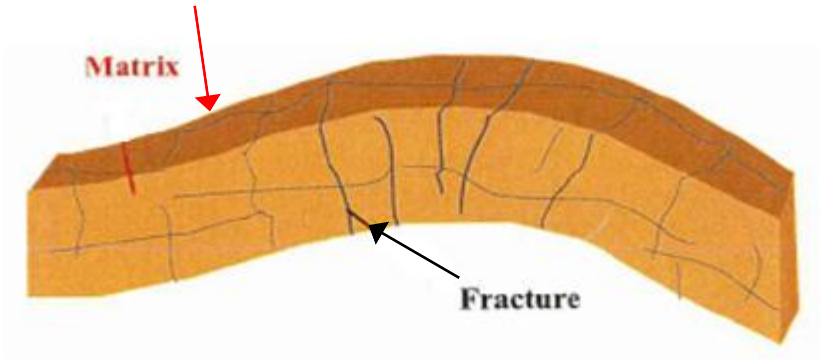

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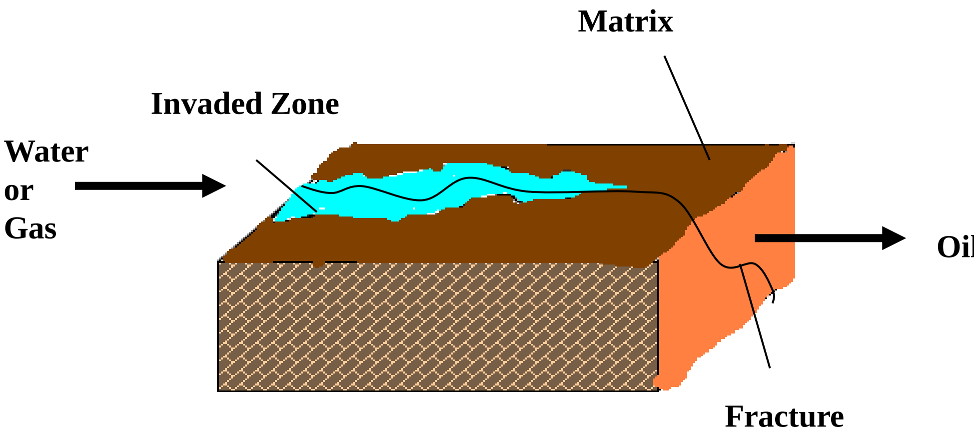
Overview

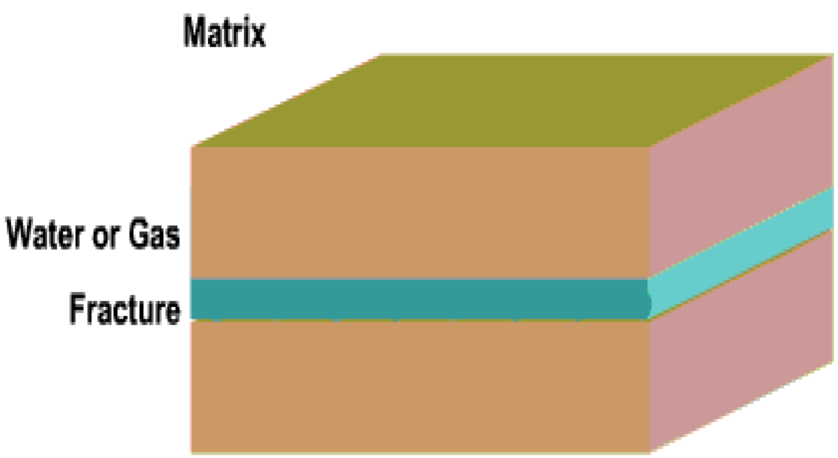
- Background
  - ✓ Matrix / fracture system in fractured reservoirs
- This research
  - ✓ Motivation and main research question
  - ✓ PVT and core properties
    - ✓ Experiments and simulation
  - ✓ Methodology
    - ✓ Experimental set-up and procedure
  - ✓ Experimental results
    - ✓ Tertiary gas-oil gravity drainage in fractured porous media
  - ✓ Conclusions

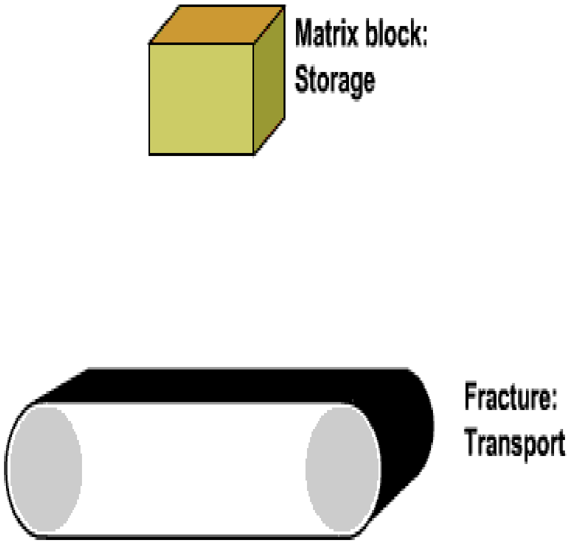
Background

- Unique feature of NFR:
  - ✓ Early breakthrough of injected fluid
  - ✓ More uniform fluid composition
  - ✓ Small pressure drop
  - ✓ Absence of transition zone



Analogue model





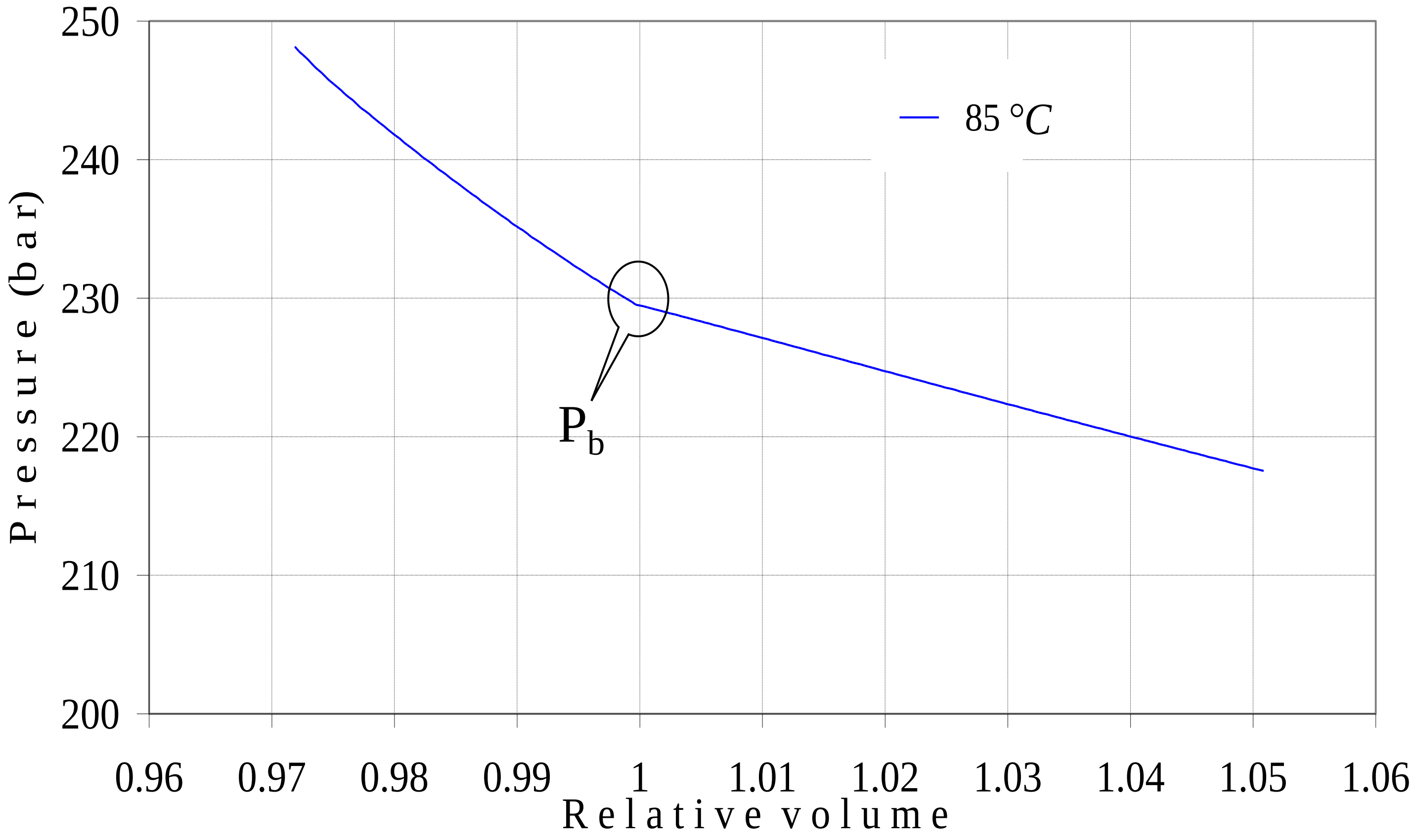
Motivation and main reserach question

- Recovering the remaining oil in the matrix after waterflooding by:
  - Equilibrium gas injection in reservoir condition
    - Tertiary case with wettability and Composition effect
    - Re-pressurization (effect of IFT reduction)
  - Non-equilibrium gas injection (CO_2 and C_1)

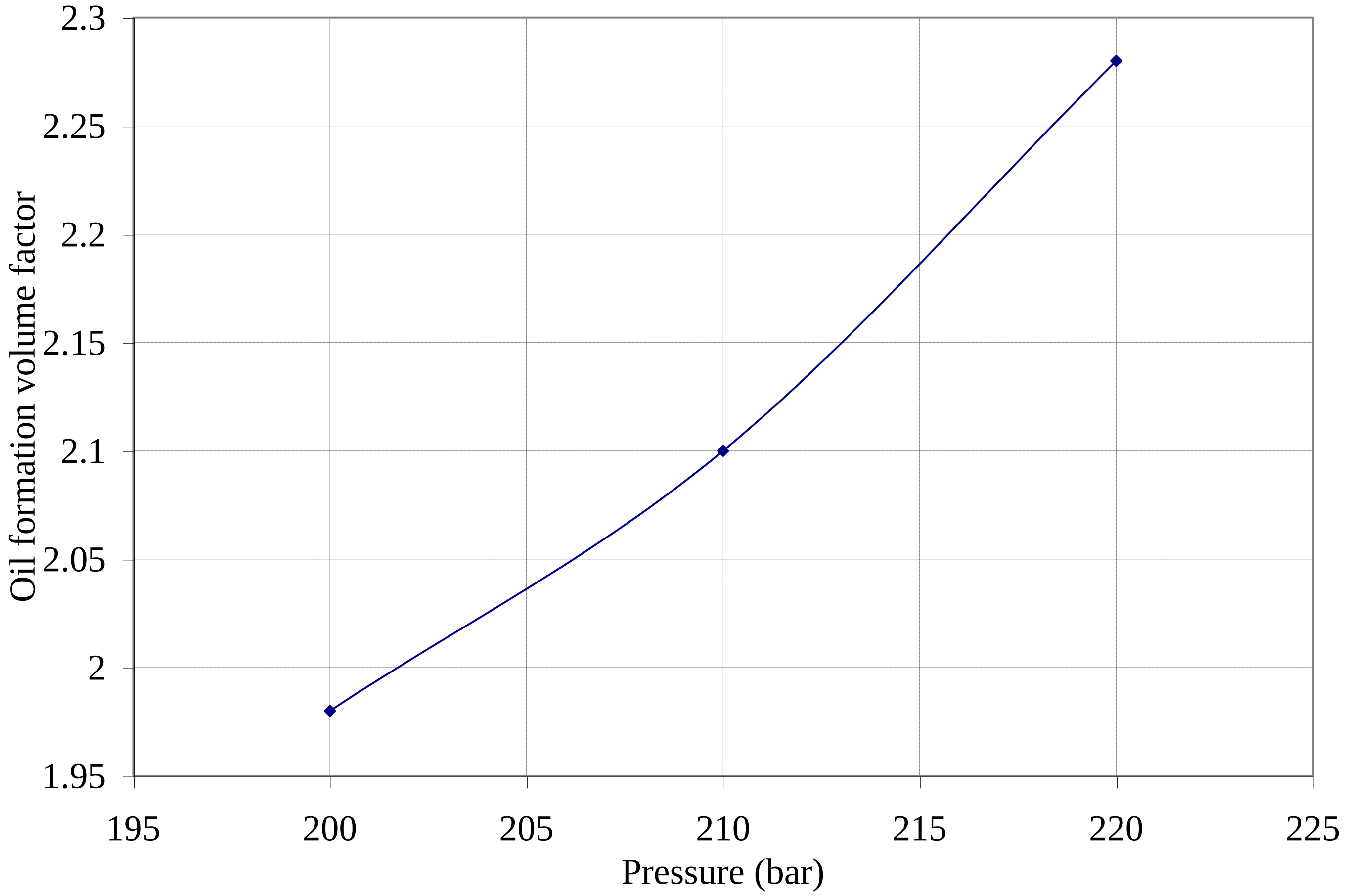
Fluid composition (85 ^{0}C)

Pressure (bar)	Oil Phase C_1	C_7	Gas phase C_1	C_7
220	0.7034	0.2966	0.8825	0.1175
210	0.6690	0.3310	0.8967	0.1033
200	0.6375	0.3625	0.9073	0.0927

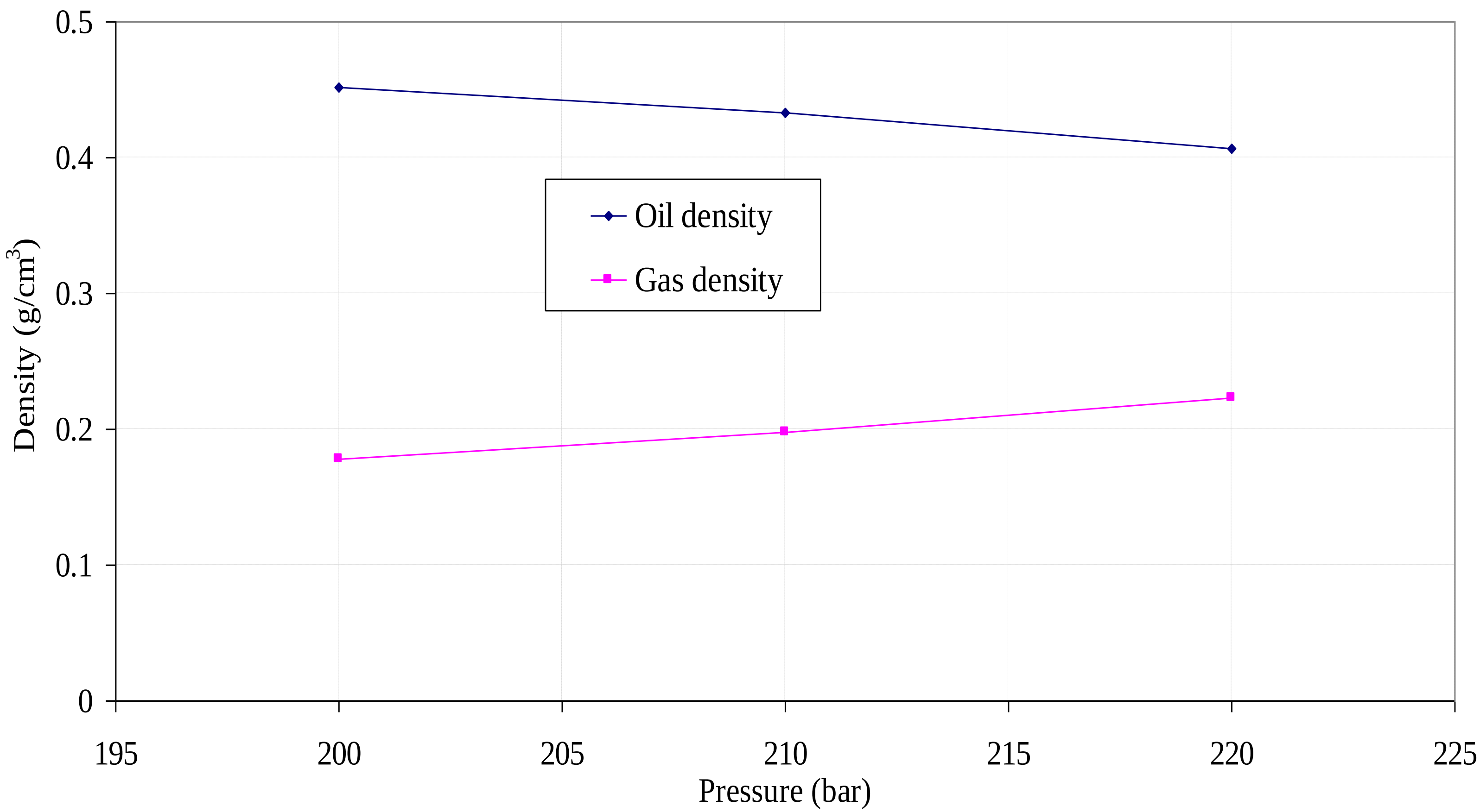
Fluid properties (PVT measurements)



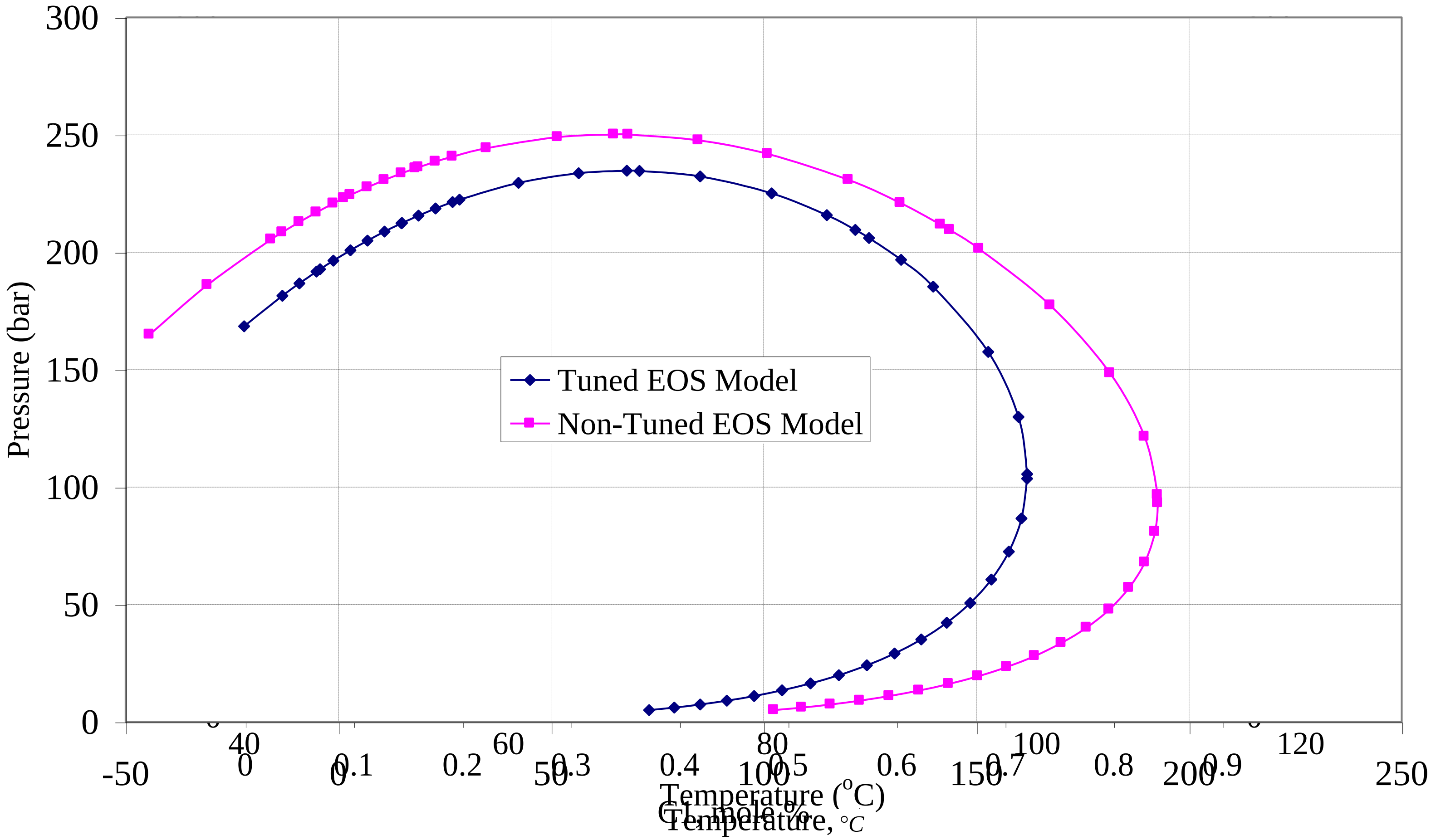
Fluid properties (PVT measurements)



Fluid properties (PVT measurements)



Fluid properties-EOS model



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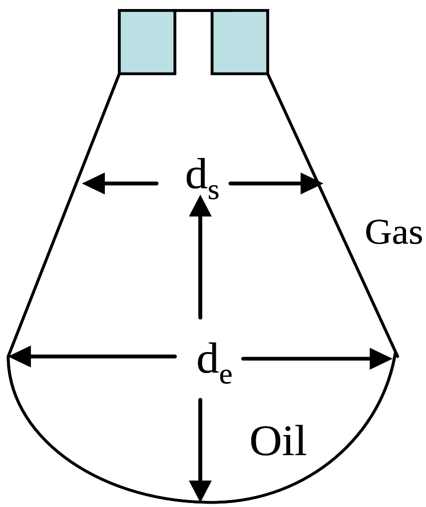
Fluid properties-IFT measurements

Pendant drop of heptane rich phase surrounded by methane rich phase

$$\sigma = \frac{g d_e^{\,2}}{l}(\rho^L - \rho^V)$$

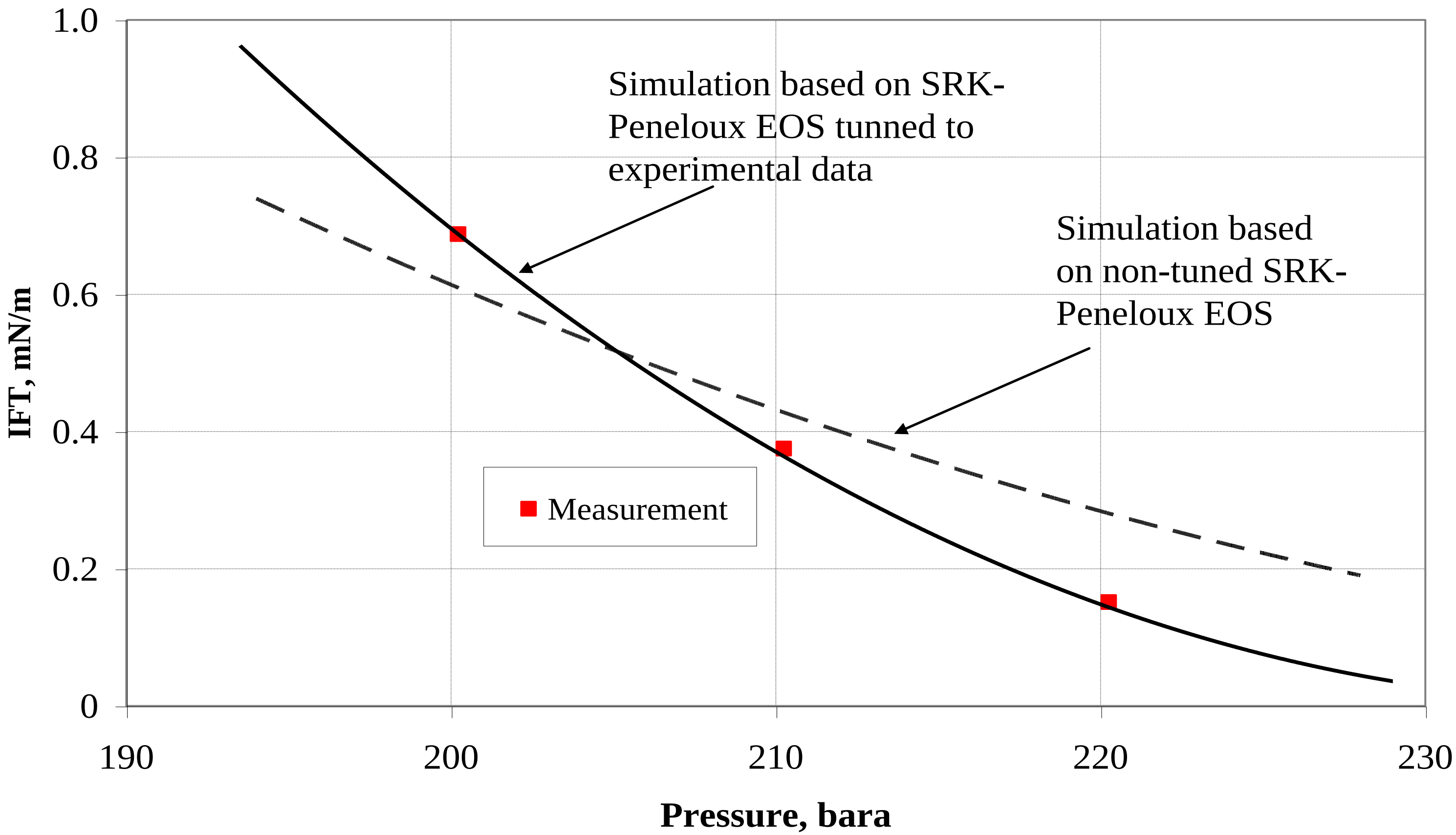
$$\Re = d_s / d_e$$

l: function of R



Pressure (bara)	220	210	200
IFT mN/m	0.15	0.37	0.68

IFT: Experiment vs. simulation



Simulation: Weinauge and Katz

$$\sigma^{\frac{1}{4}} = \sum P_{\sigma i}(x_i \rho_l - y_i \rho_v)$$

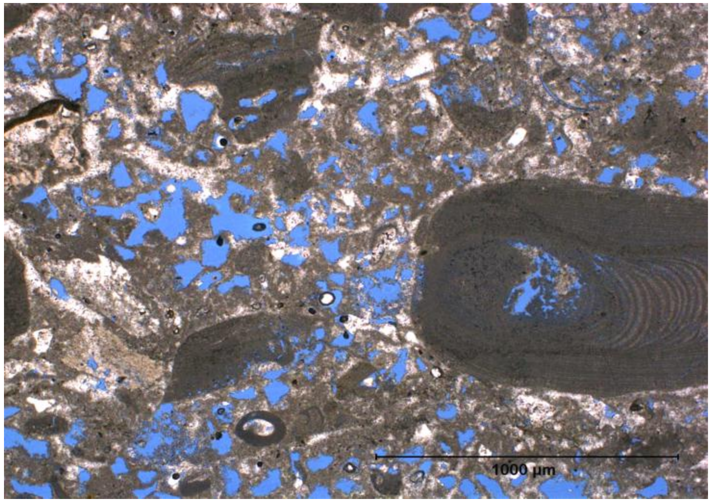
PVT properties

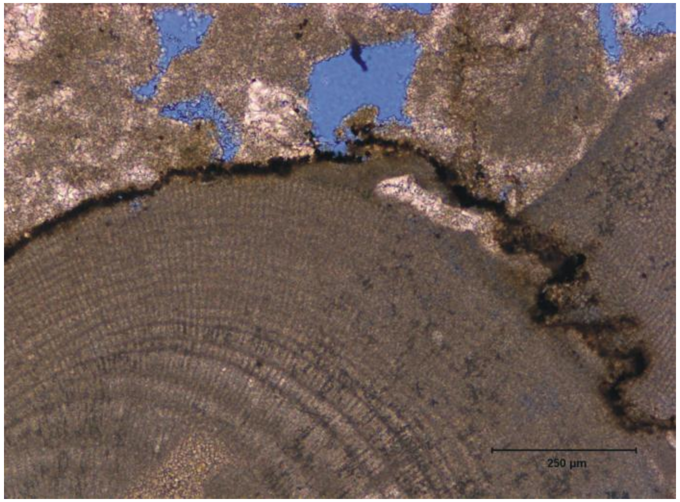
Pressure (bara)	Oil density (g/cm^3)	Gas density (g/cm^3)	B_o	IFT mN/m
220	0.407	0.223	2.28	0.15
210	0.433	0.198	2.1	0.374
200	0.452	0.178	1.98	0.686

Properties of porous media

Properties	Chalk (water wet)	Limestone (mix wet)
Permeability (mD)	5.2	14.0
Porosity %	44.0	23.0
Length (cm)	19.6	18.0-19.0
Pore Volume (cm^3)	98-99	47.0-50.0
H_c @ 0.37 mN/m	3.48 cm	4.8 cm
H_c @ 0.15 mN/m	1.41 cm	1.97 cm

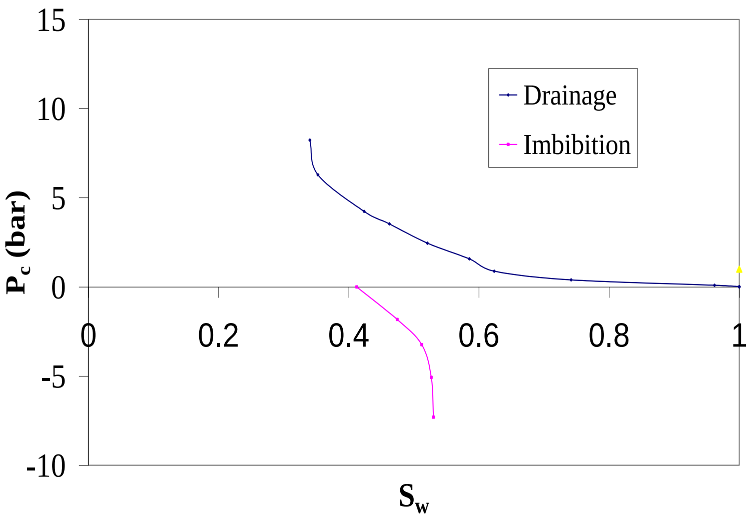
Properties of porous media





Moldic and vuggy porosity (blue)

Sparitic calcite cement (white)



Sample No.	S_{wi} %	S_{or} %	S_w @ $k_{rw} = k_{ro}$
1	15.6	24.3	33
2	25.8	31.7	46
3	18.7	32.4	34
4	18.9	32.7	40
5	20.4	31.8	39

Summary of experiments

Exp. No	Water injection	Equilibrium gas injection at 210 bar (IFT=0.37 mN/m)	Equilibrium gas injection at 220 bar (IFT=0.15 mN/m)	CO_2 injection	C_1 injection
1-Chalk (water wet)	✓.	✓.	✓.	✓.	------
2-Chalk (water wet)	✓.	✓.	✓.	------	✓.
3-Limestone (mix wet)	✓.	✓.	✓.	✓.	------
4-Limestone (mix wet)	✓.	✓.	✓.	------	✓.

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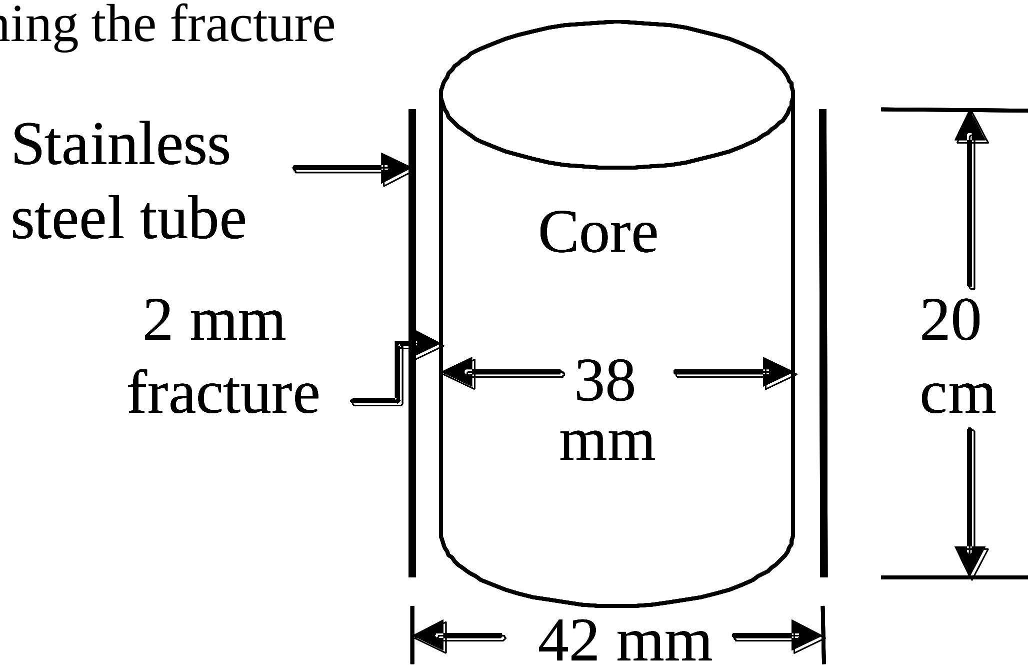
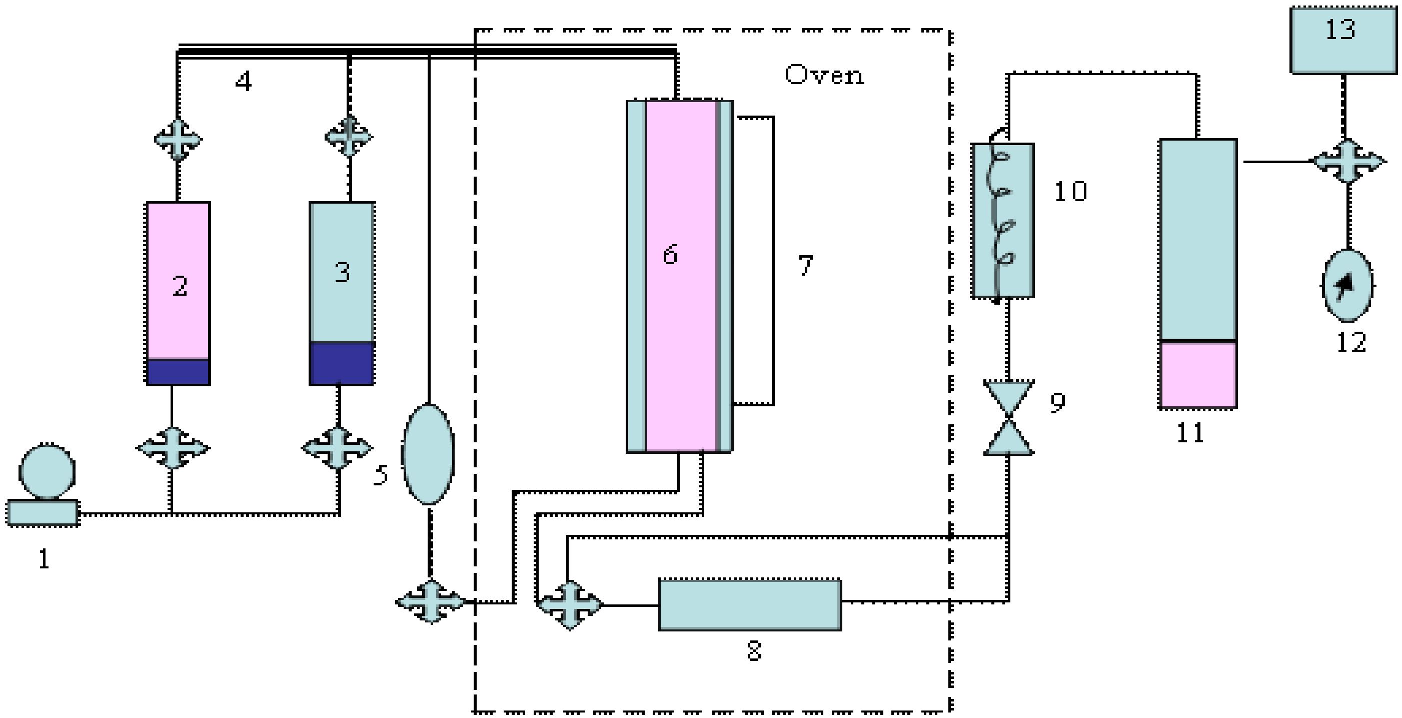
Methodology:Experimental Set-up

Methodology in gas injection experiment :

- Sealing the fracture
  - Special alloy (woods metal)
    - Melting point=67 ^{0}C
- Re-opening the fracture



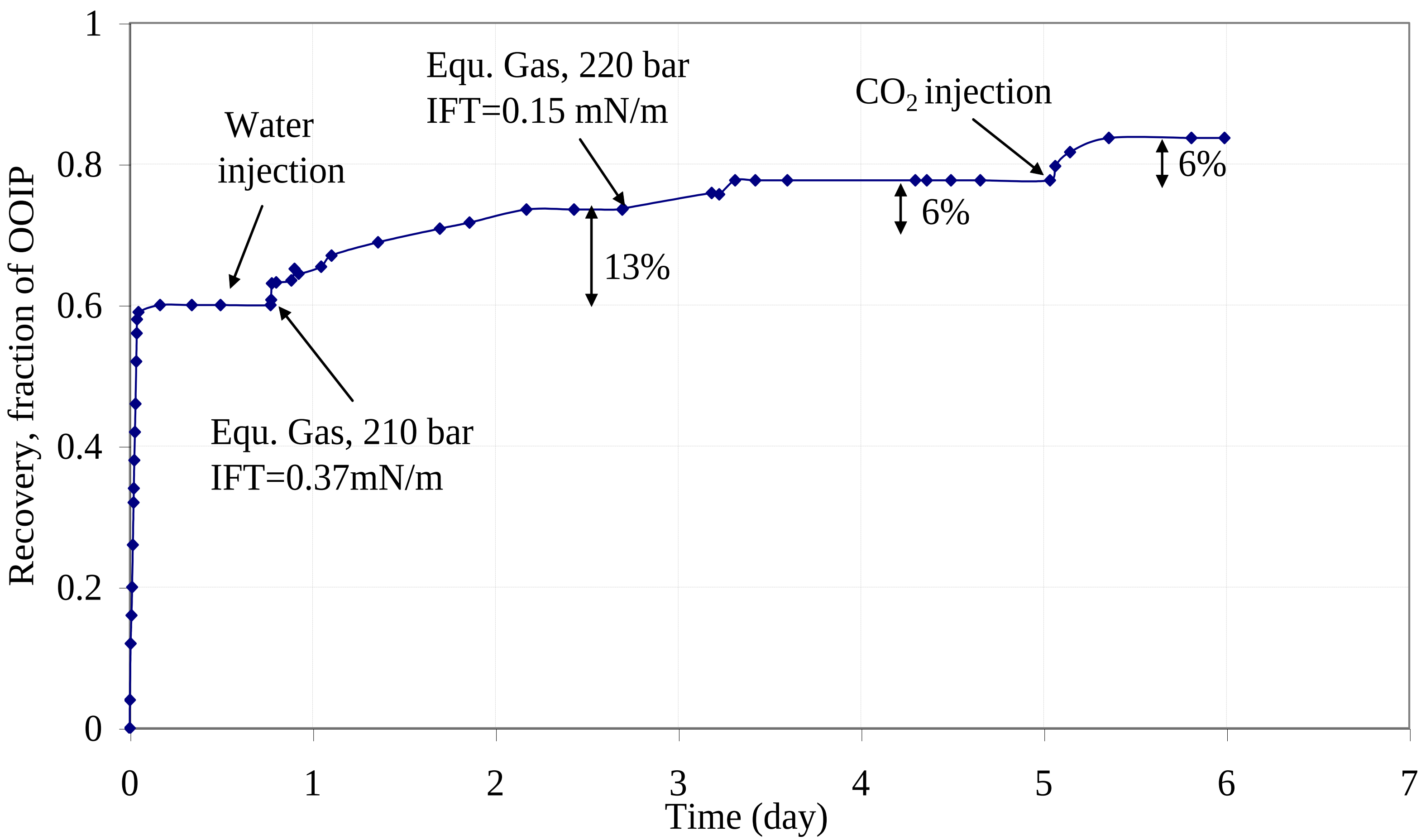
Methodology:Experimental Set-up



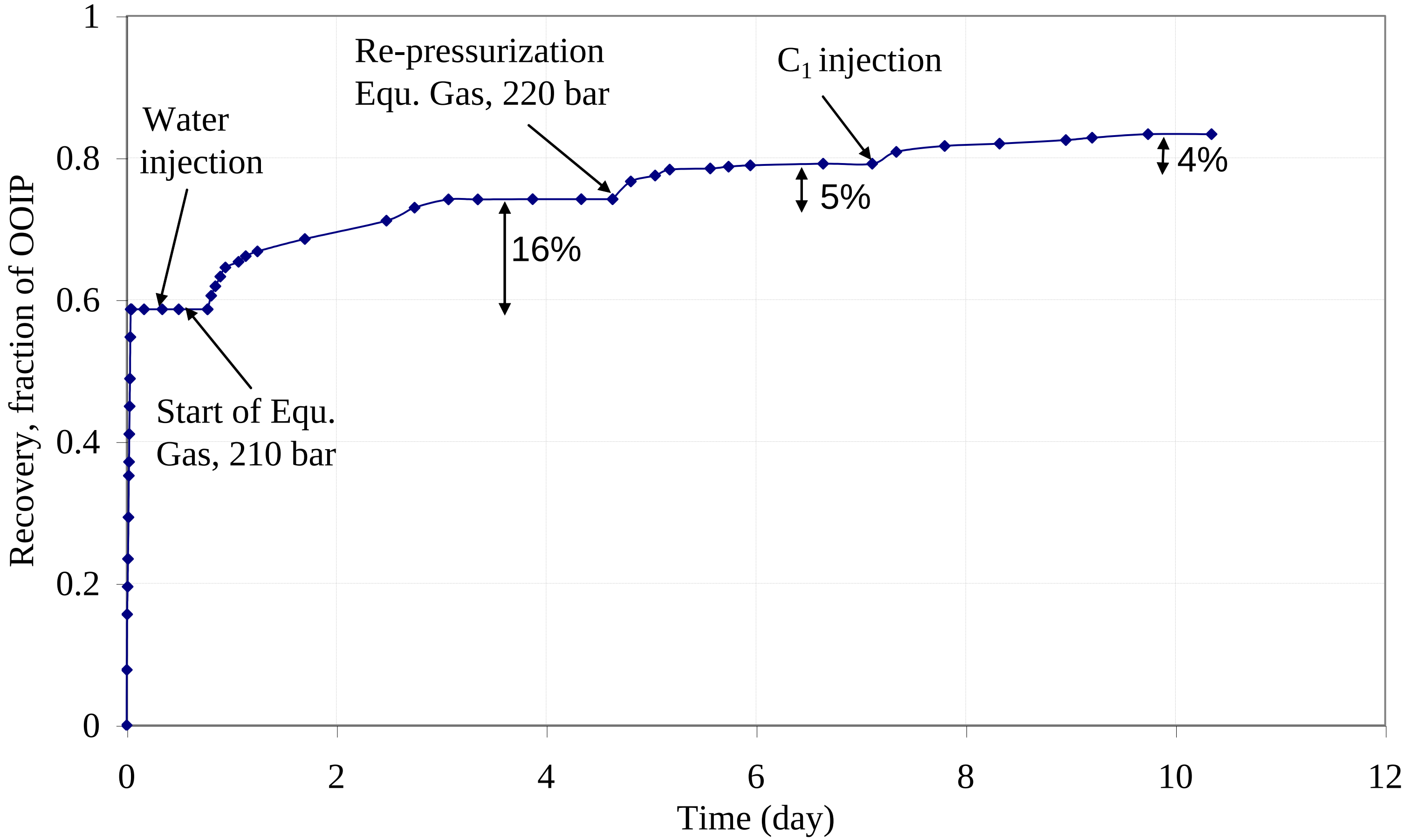
1- Quizix pump.
2,3-Isolated cells
4- Isolated constant temperature tube
5- Pressure transmitter
6-Steel tube containing matrix and fracture.
7- By-pass system

8- Sealing material accumulator
9- Back pressure regulator
10- Condenser
11-Seperator
12-Gas wet test meter
13-Gas chromatograph

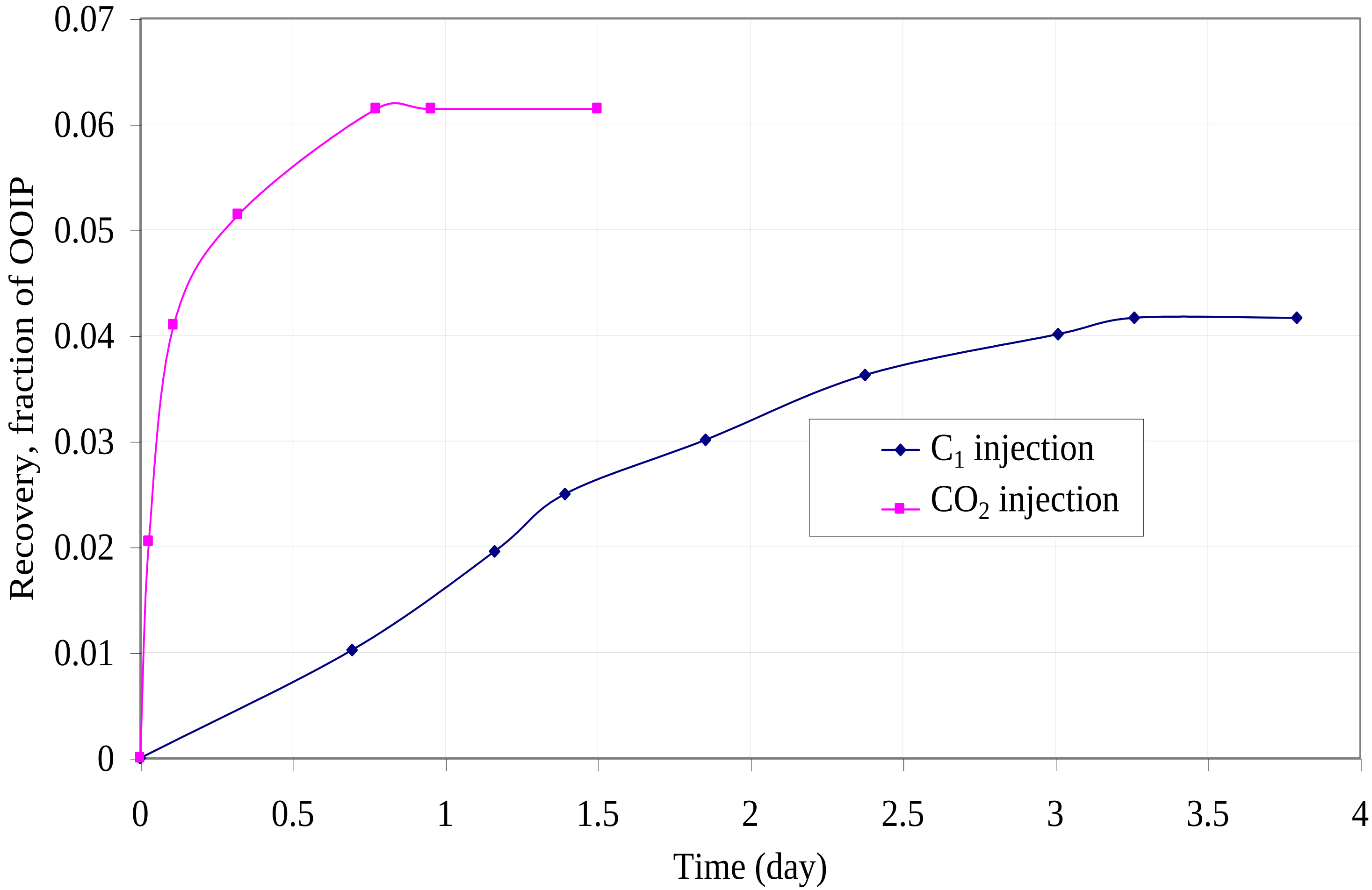
CO_2 injection in water-wet sample



C_1 injection in water-wet sample

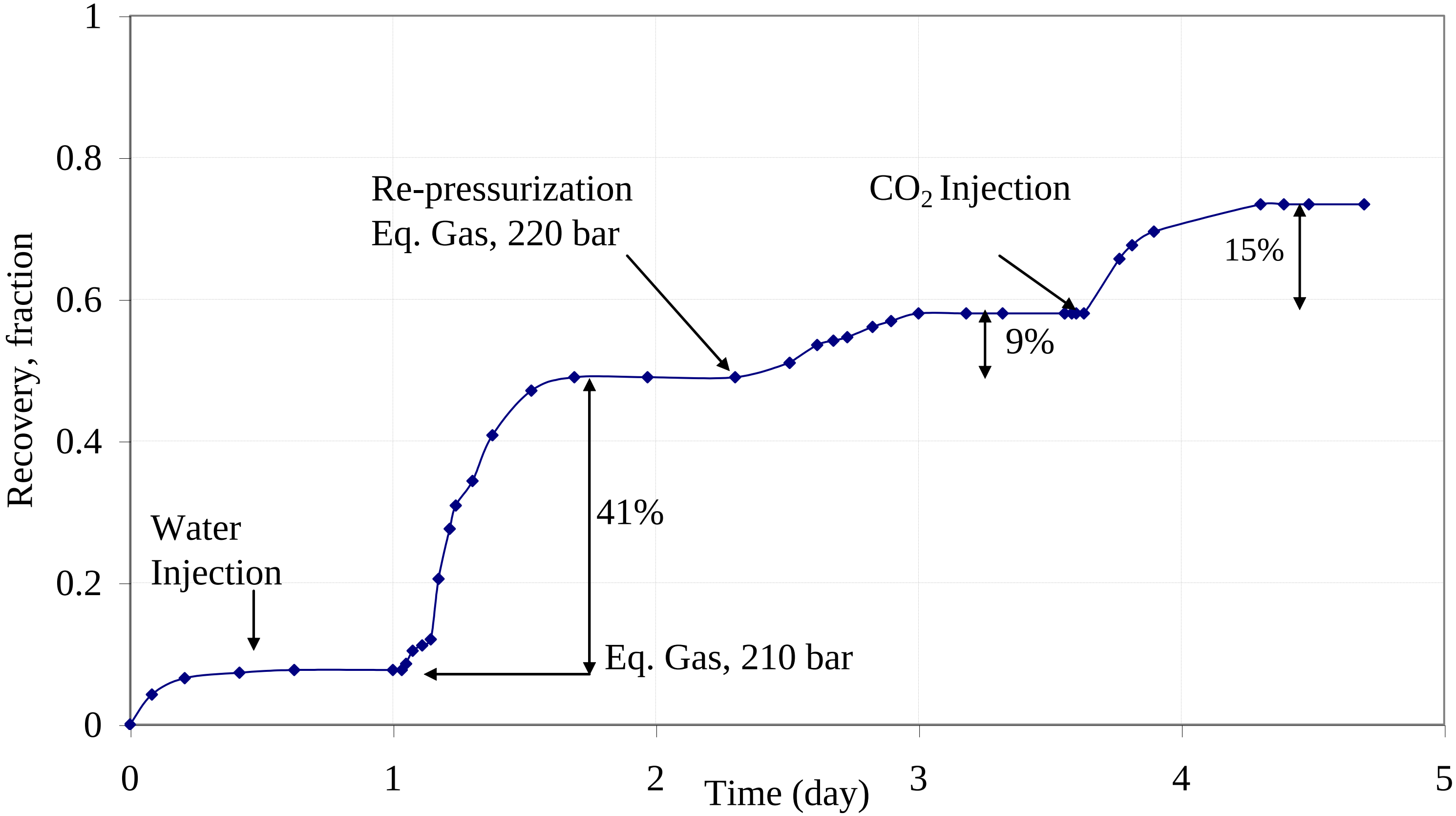


CO_2 vs. C_1

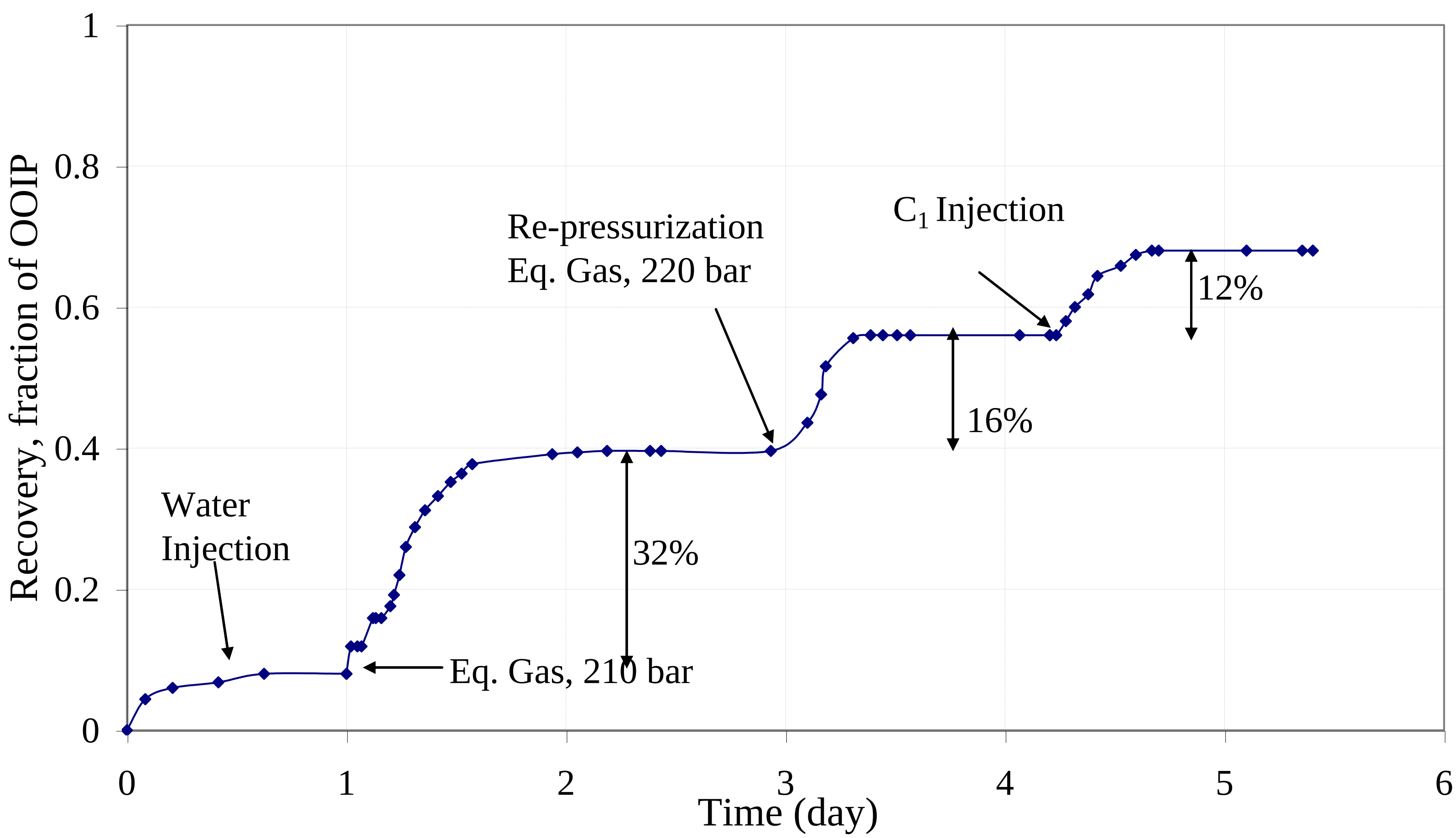


Recovery, fraction of OOIP
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (day)
C_1 injection
CO_2 injection

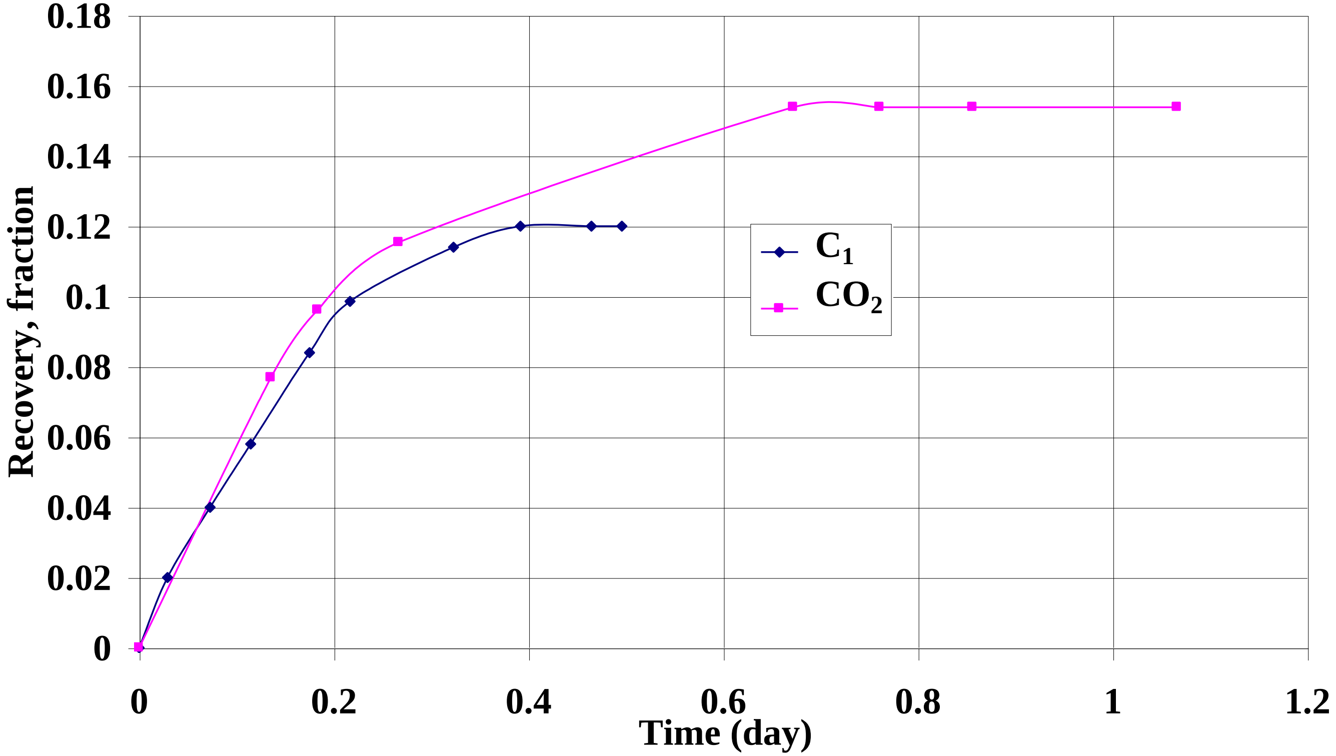
CO_2 injection in mix-wet sample



C_1 injection in mix-wet sample



CO_2 vs. C_1


0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Recovery, fraction
0
0.2
0.4
0.6
0.8
1
1.2
Time (day)
C_1
CO_2

Summary of experimental results

Exp .No	Recovery Mechanism	Wettability	Water injection R.F %	Equilibrium gas injection R.F %	Non-equilibrium gas injection R.F %
1	Tertiary (water injection +GOGD+CO_2)	Water-wet	55	19	6
2	Tertiary (water injection +GOGD+C_1)	Water-wet	60	21	4
3	Tertiary (water injection +GOGD+CO_2)	Mix-wet	8	50	15
4	Tertiary (water injection +GOGD+C_1)	Mix-wet	8	48	12

Conclusion

1- Gas-oil gravity drainage at low interfacial tension was found to be a very effective oil recovery method from mix-wet and water-wet fractured media at both secondary and tertiary injection.

2- Additional oil recovery could be obtained by injection of non-equilibrium gas, where diffusion and gravity drainage are the key factors for increased oil recovery.

3- Injection of lean gas such as C_1 can aslo improve the oil recovery significantly.

4- CO_2 injection is more efficient compare to C_1 injection in fractured carbonate rock.

References:

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- H.Karimaie and O. Torsæter. “Low IFT Gravity Drainage in Fractured Reservoirs”. Journal of Petroleum Science and Engineering (JPSE), Volume 70, Issues 1-2, January 2010, Pages 67-73.
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- A.M. Saidi,. “Reservoir Engineering of Fractured Reservoirs”. Total 1987
- T.D. Van Golf-Racht,. “Fundamentals fo Fractured Reservoirs”. Elsevier, 1982.

Thank you !

Life can only be understood backwards, but has to be lived forwards