Effect of Miscibility Condition for CO_2 Flooding on Gravity Drainage in 2D Vertical System

Oct. 28, 2014

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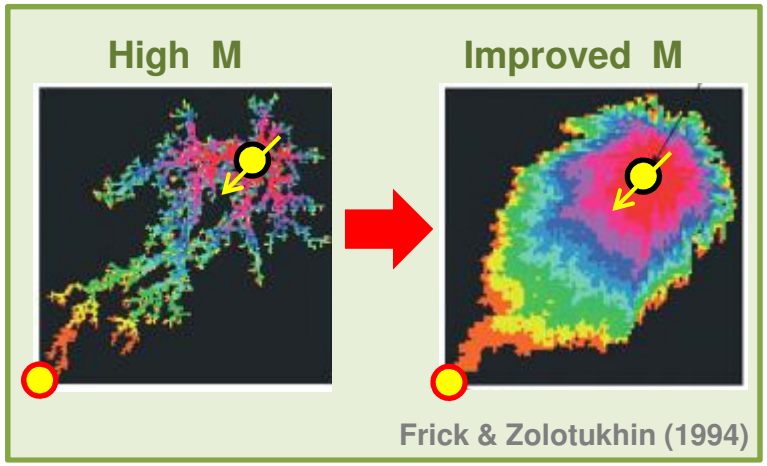
Outline

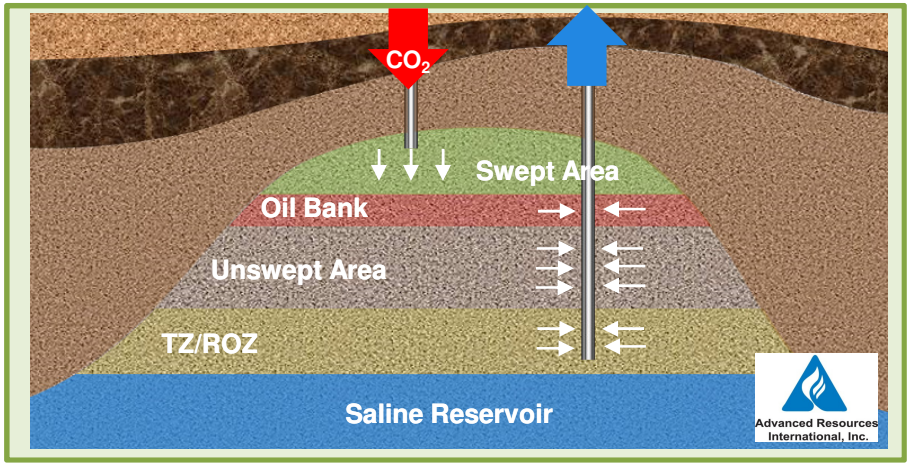
- Introduction
- Experimental System
- Results
- Conclusion

Introduction

➢ CO_2 Flooding

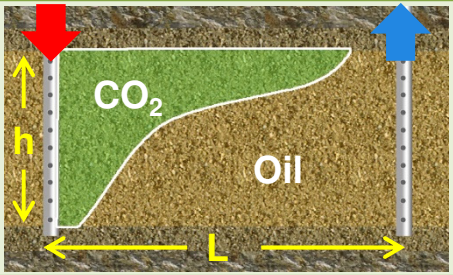
- Recently, CO_2 EOR project is increasingly growing in worldwide, because carbon capture combined with EOR is very attractive politically.
- In next generation, innovative technology for "Integrating CO_2 EOR and CCS" will bring much more CO_2 storage capacity and more recoverable oil ("Green oil").
  - Viscosity enhanced flood
  - Gravity-stable CO_2 movement control
  - Targeting main pay zone, plus TZ/ROZ and underlying saline aquifer



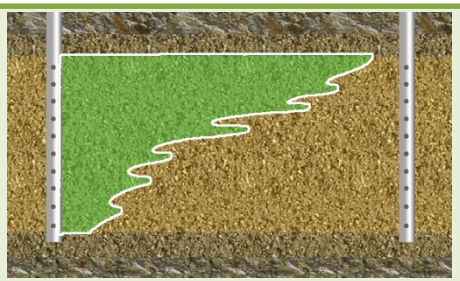


Introduction

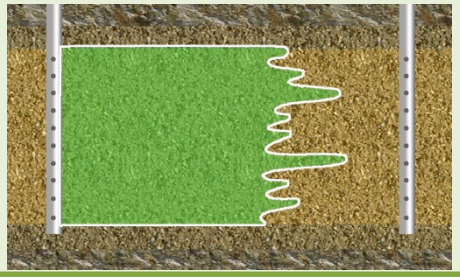
➢ Flowing Regimes in Vertical Cross-sectional System



- R: Low values
- Single gravity tongue overriding the oil
- VSE at CO_2 BT: Almost independent of R



- R: > $R_{Crit.}$
- Multiple fingers forming (growth)
- VSE at CO_2 BT: Increase sharply with increasing R



- R: High values
- Multiple fingers dominating
- VSE at CO_2 BT: Independent of R

$$R = \frac{\text{Viscous Force}}{\text{Gravity Force}} = \text{func.}[\,(Q_{CO_2})_{inj},\ \Delta\rho(P)\,]$$

Introduction

➢ Research Objectives

Previous Study

➢ **1D Core Experiment**

- No environment for viscous fingering
- No environment for gravity segregation

This Research

➢ **2D Experiment in Vertical Sandstone Slab**

- Examining oil recovery and CO_2 storage efficiency in CO_2 flooding under the environment of gravity segregation
- A series of CO_2 injection experiments:

  - Miscibility condition - CO_2 injection rate

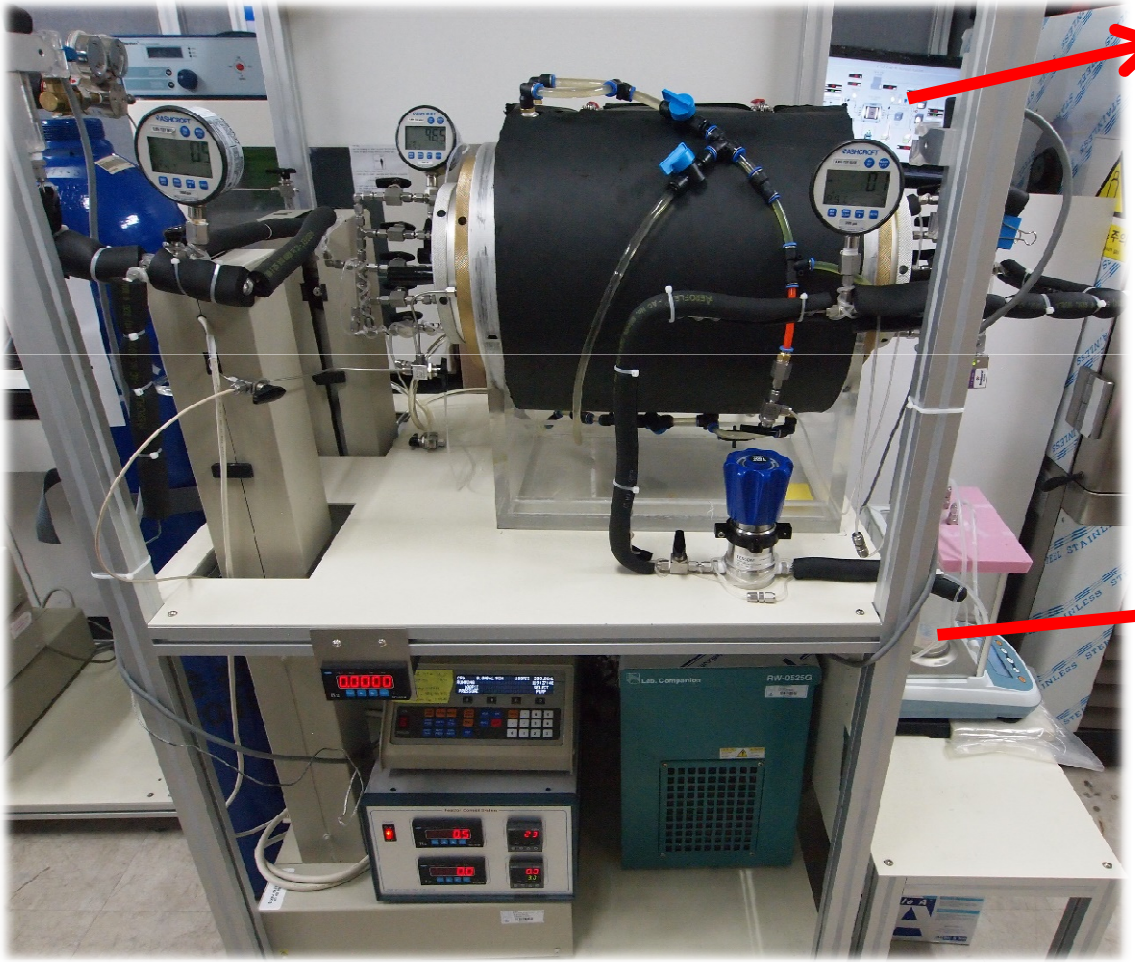
Experiment of CO_2 Flooding

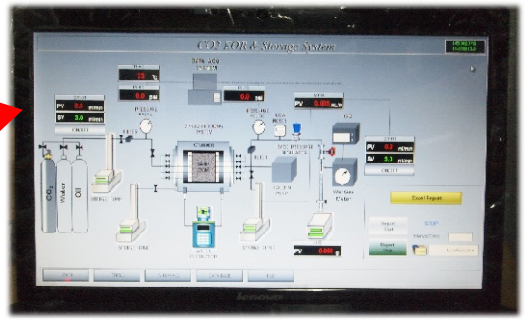
➢ Experimental System

- **Porous Media**
  - Sister Gray Berea Sandstone
  - Porosity: Standard Range 20~22%
  - Permeability: Standard Range 35~60 md
- **Fluids**
  - Oil: n-Decane
    - Density: 0.72 g/cc at 35°C
    - Viscosity: 0.74 cp at 35°C
  - Solvent: CO_2 (Purity 99.999%)

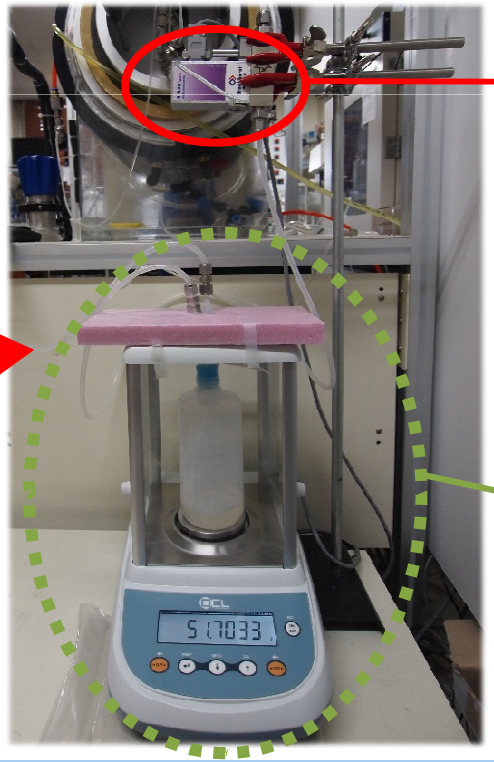
Experiment of CO_2 Flooding

➢ 2D CO_2 Flooding Apparatus





DAQ System



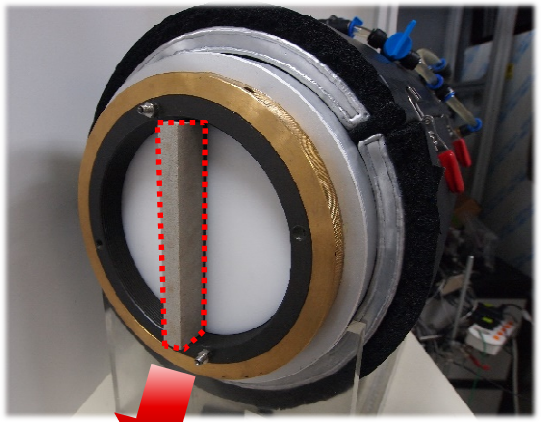
Gas MFM

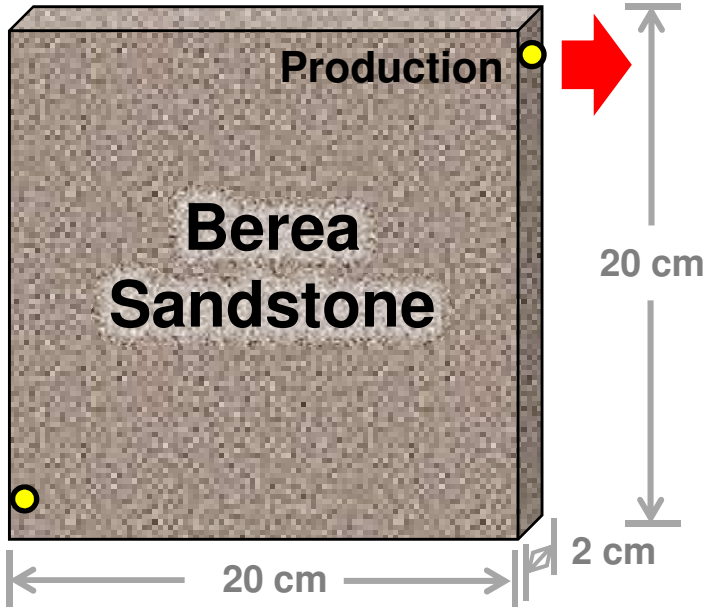
Oil Collector

Experiment of CO_2 Flooding

➢ Experimental System

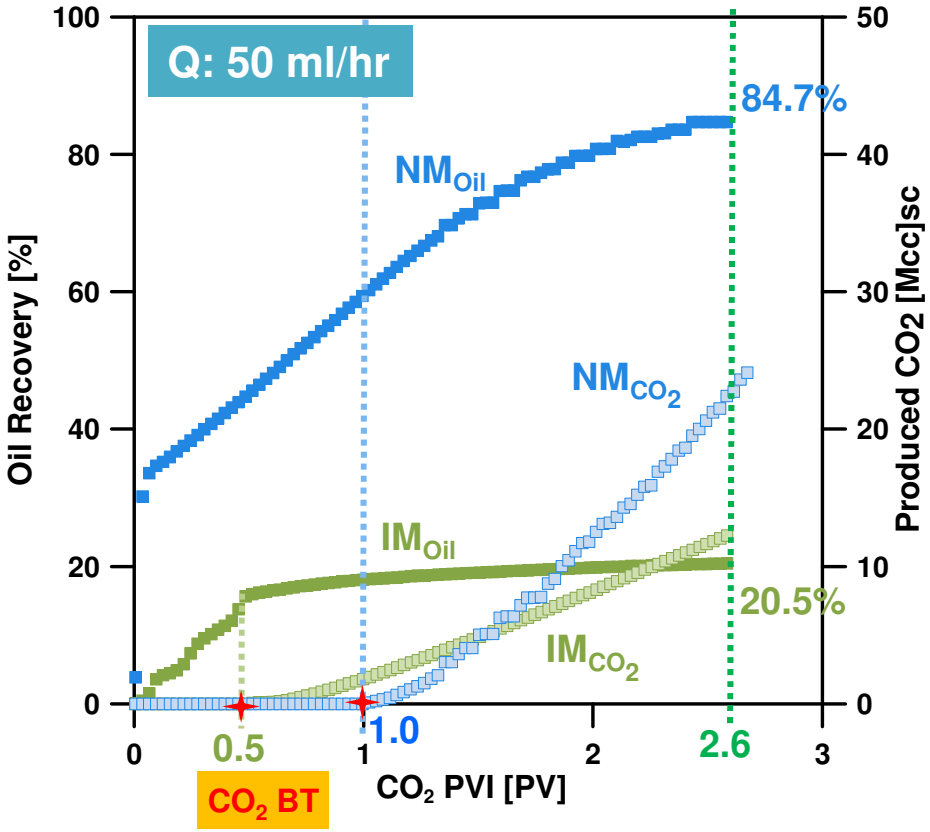
Experimental Condition	
Temperature [°C]	35
MMP @ 35°C [psia]	1,062.5
Confining Pressure [psia]	1,000~1,450
Immiscible(IM) Condition: Initial Pressure [psia]	620
Near-miscible(NM) Condition: Initial Pressure [psia]	1,020
CO_2 Injection Rate [ml/hr]	5
	30
	50

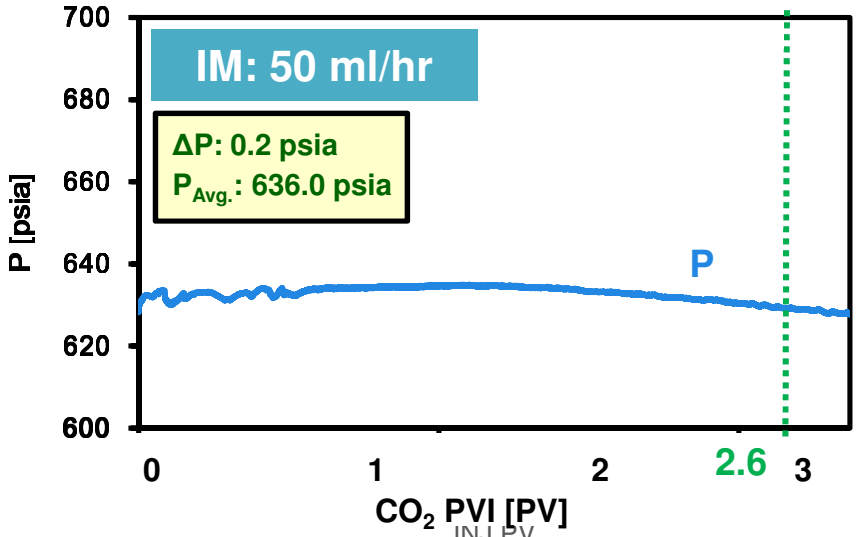


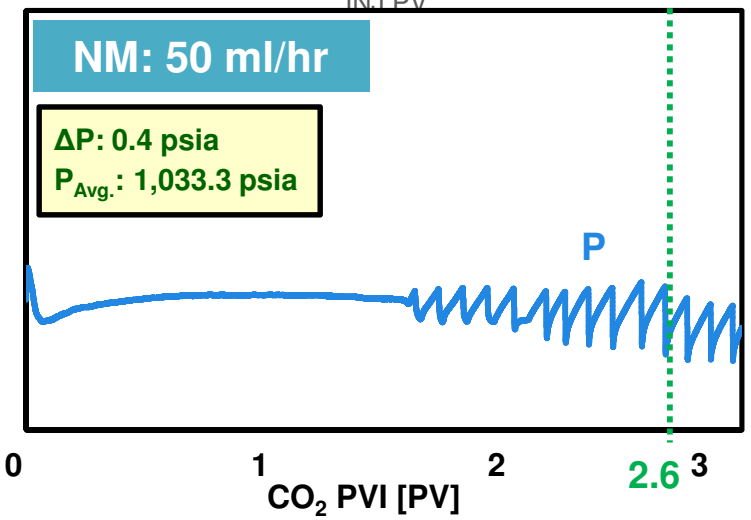


Effect of Miscibility

➢ Oil Recovery

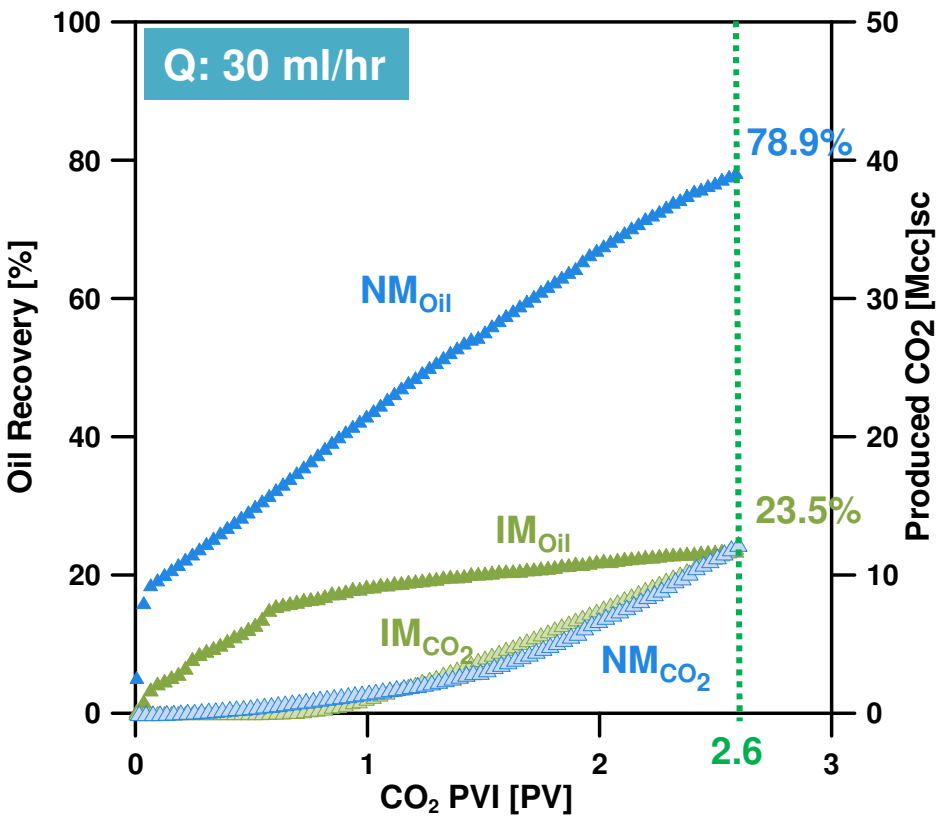


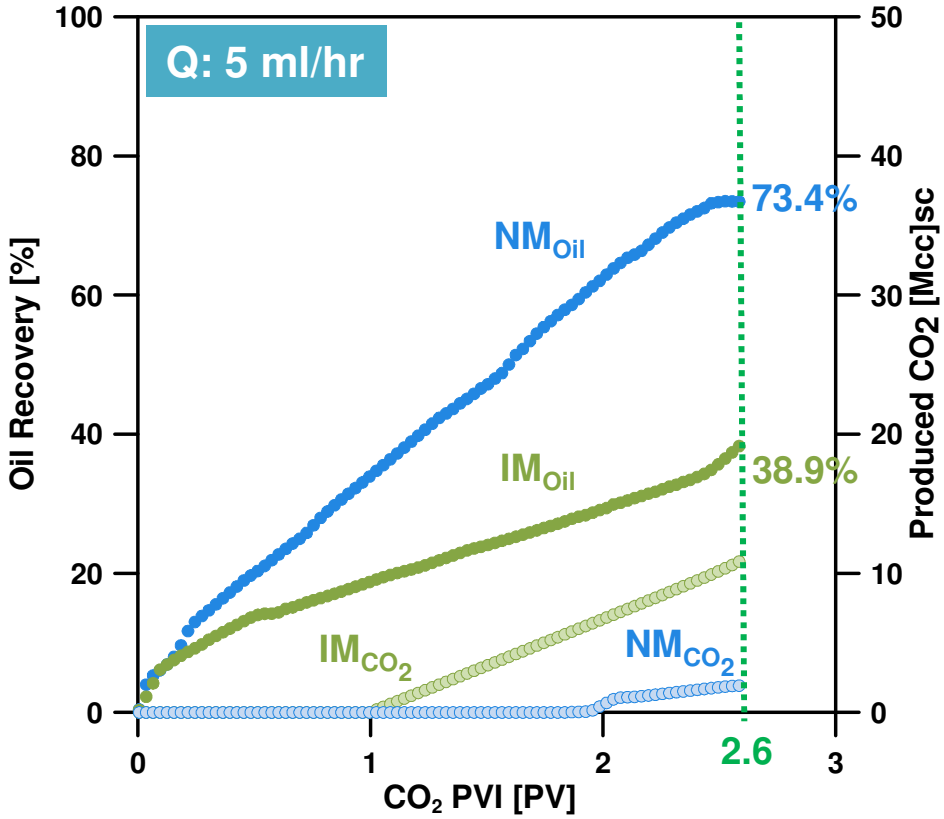




Effect of Miscibility

➢ Oil Recovery

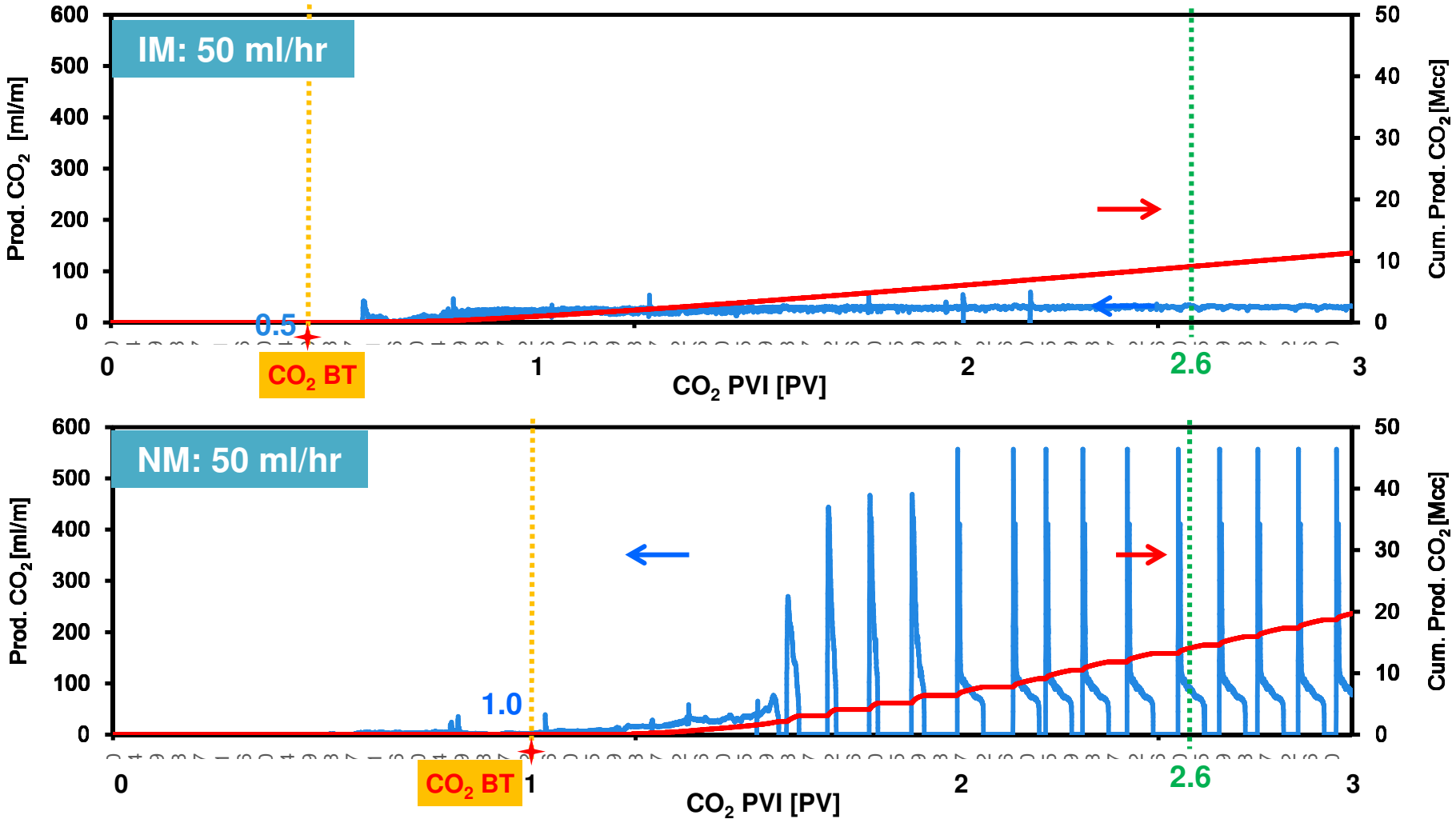




Oil recovery at **NM** is significantly larger than at **IM** regardless of CO_2 injection rate in 2D vertical system.

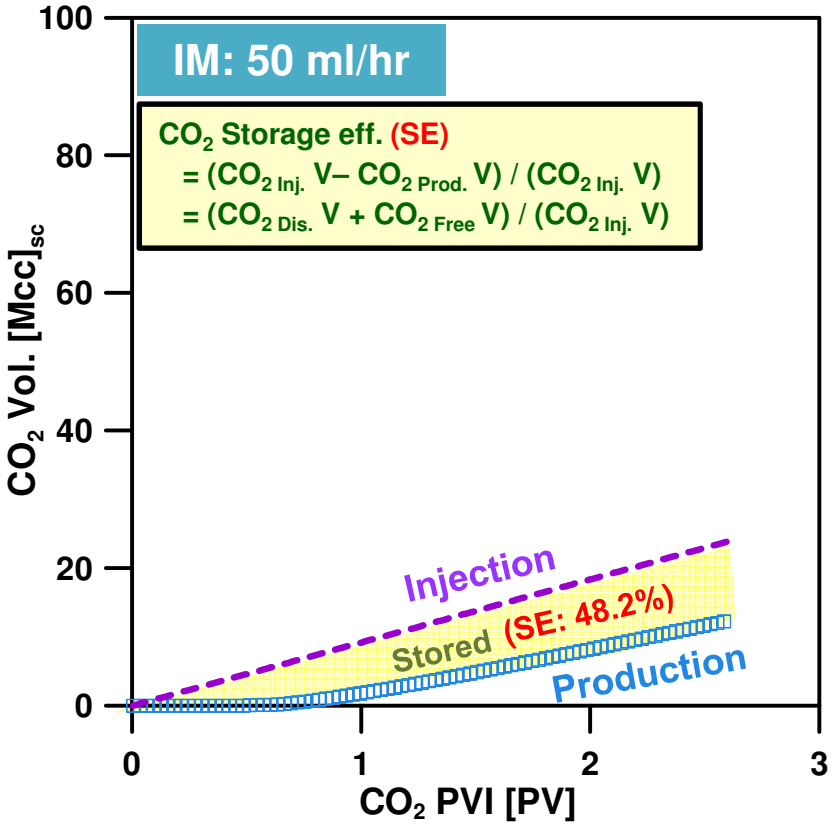
Effect of Miscibility

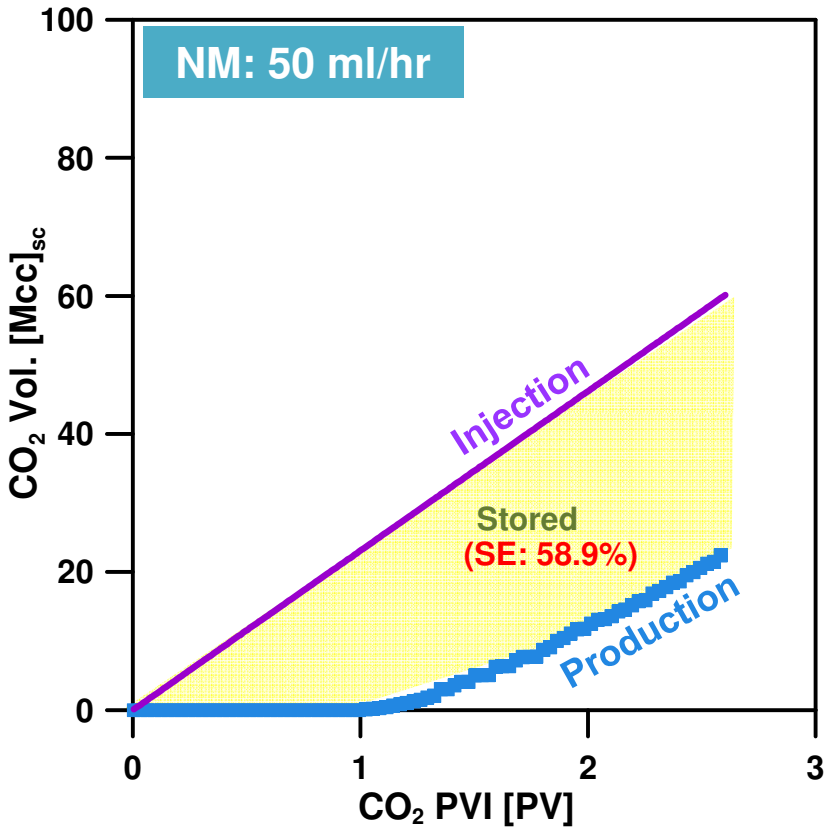
➢ CO_2 Production



Effect of Miscibility

➢ CO_2 Storage Efficiency





@ 2.6 PVI	Inj. CO_2 [cc]	Prod. CO_2 [cc]	Stored CO_2	
			Dissolved [cc]	Free Gas [cc]
IM	23,915.5	12,386.0 (51.8%)	7,628.6 (31.9%)	3,900.9 (16.3%)
NM	60,219.8	24,768.0 (41.1%)	10,104.8 (16.8%)	25,347.0 (42.1%)

Effect of Miscibility

➢ CO_2 Storage Efficiency

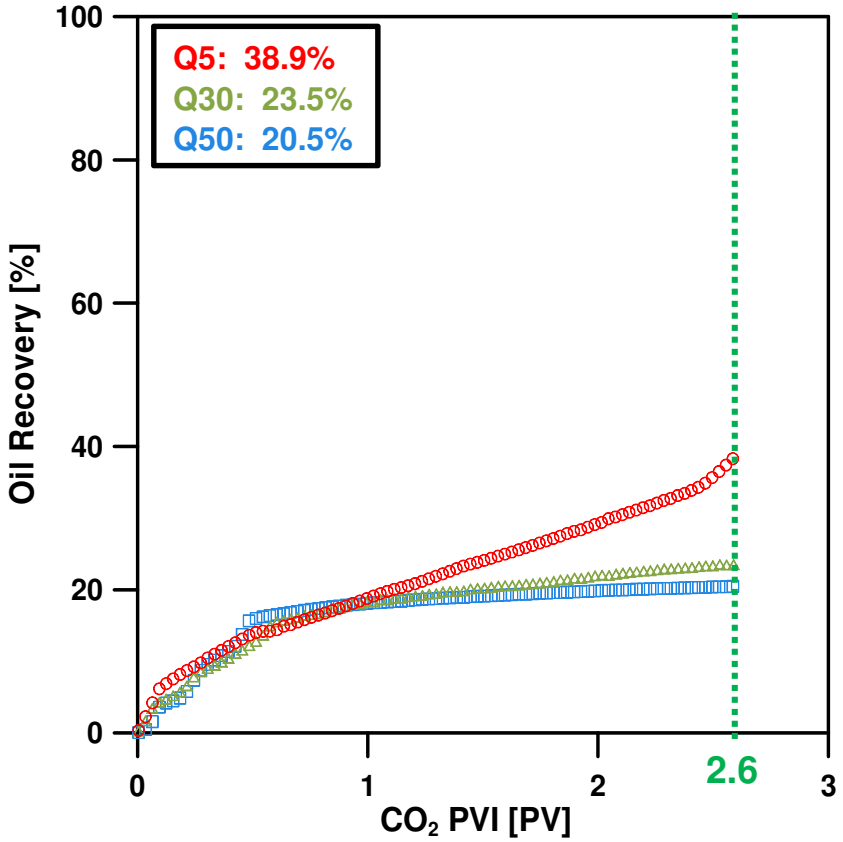
@ 2.6 PVI

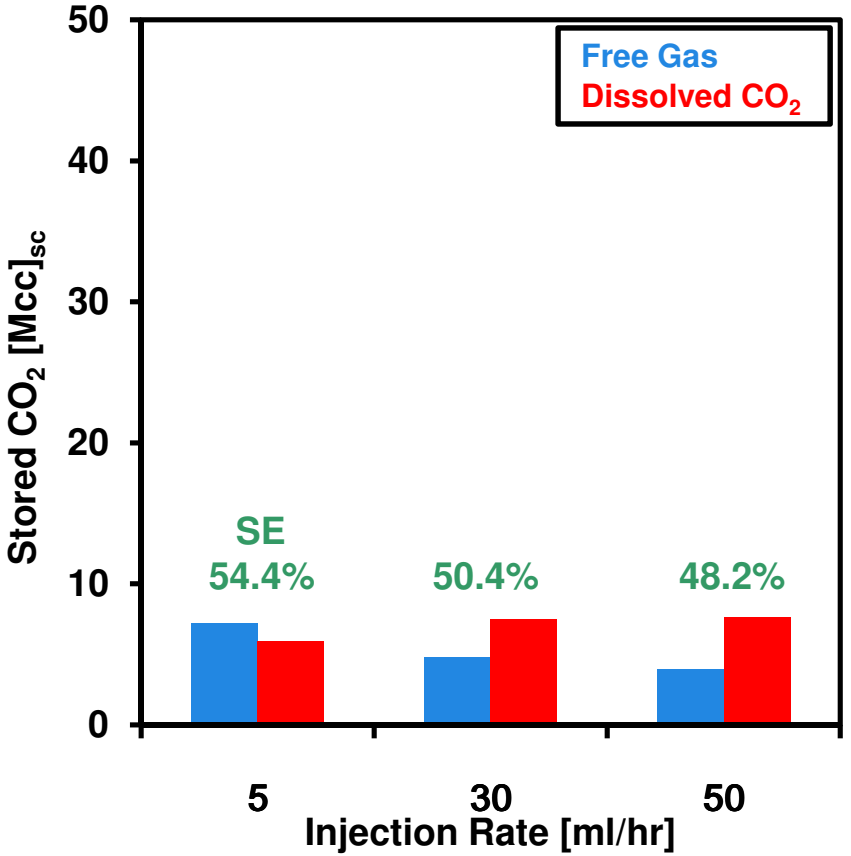
Inj. Rate [ml/hr]	Condi.	Inj. CO_2 [cc]	Prod. CO_2 [cc]	Stored CO_2		CO_2 SE [%]
				Dissolved [cc]	Free Gas [cc]	
30	IM	24,383.6	12,096.0 (49.6%)	7,487.7 (30.7%)	4,799.9(19.7%)	50.4
	NM	59,869.8	12,556.0 (21.0%)	16,003.4 (26.7%)	31,310.4 (52.3%)	79.0
5	IM	24,119.2	11,003.0 (45.6%)	5,907.2 (24.5%)	7,209.0 (29.9%)	54.4
	NM	58,014.2	1,932.8 (3.3%)	25,011.8 (43.1%)	31,069.6 (53.6%)	96.7

CO_2 storage efficiency at **NM** is more effective comparing to **IM** regardless of CO_2 injection rate.

Effect of Injection Rate

➢ Immiscible Condition

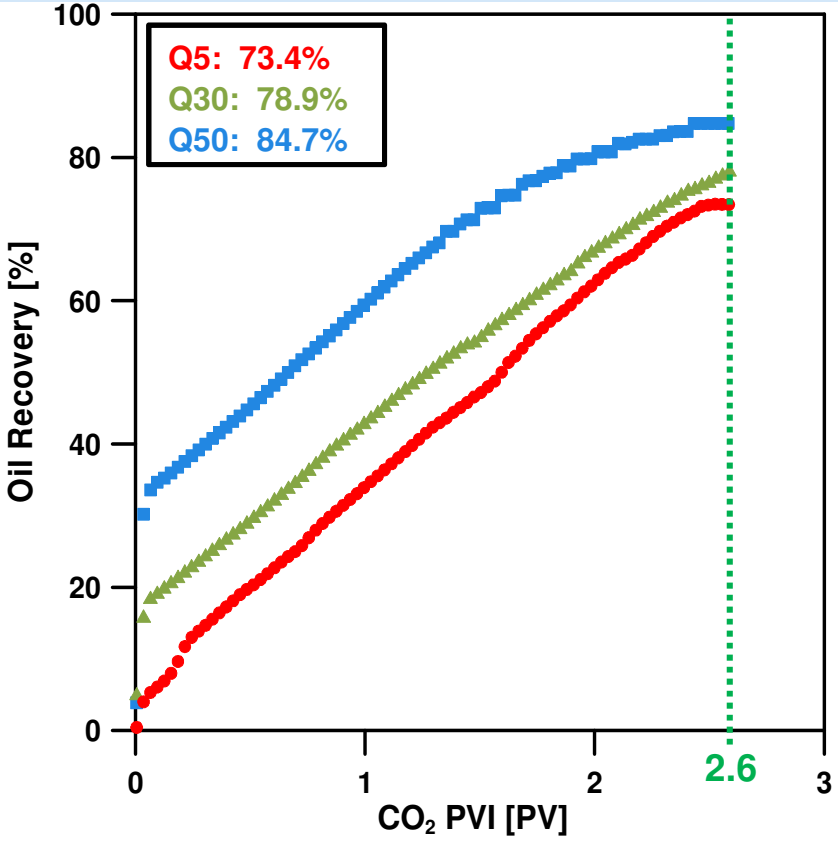


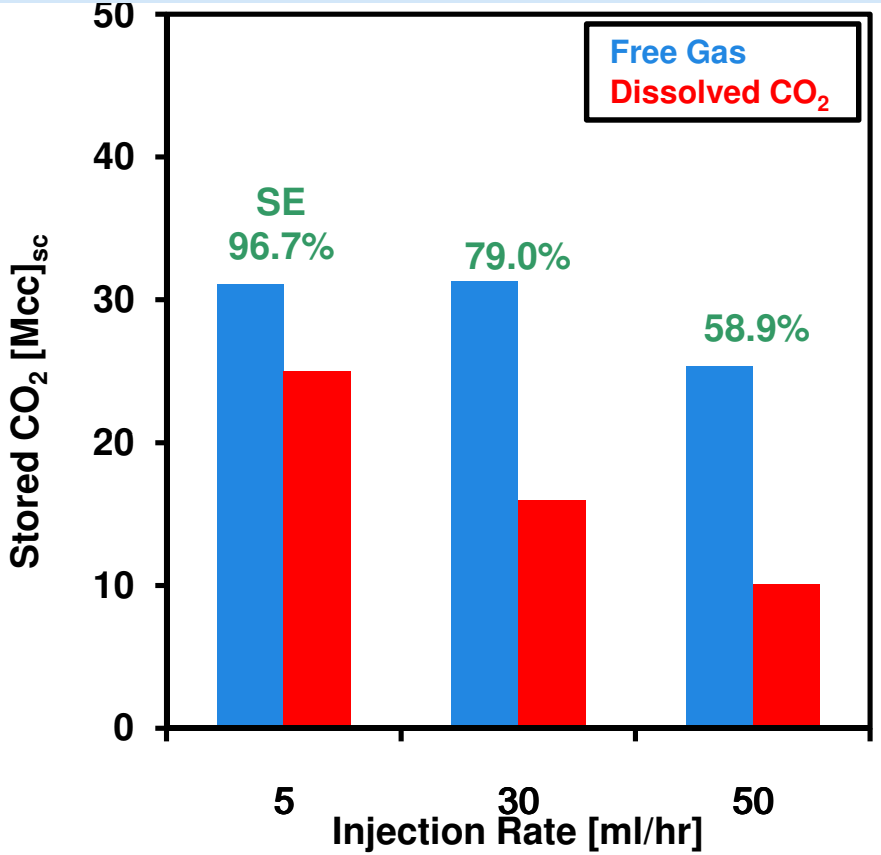


The lower the injection rate, the higher the oil recovery and the CO_2 storage efficiency. This is because when CO_2 injected at low rate, free gas state of CO_2 displaces the oil effectively with slow movement of CO_2 front, which produce more oil. Therefore, the CO_2 at lower rates was stored as free gas state more than at higher rates.

Effect of Injection Rate

➢ Near-miscible Condition

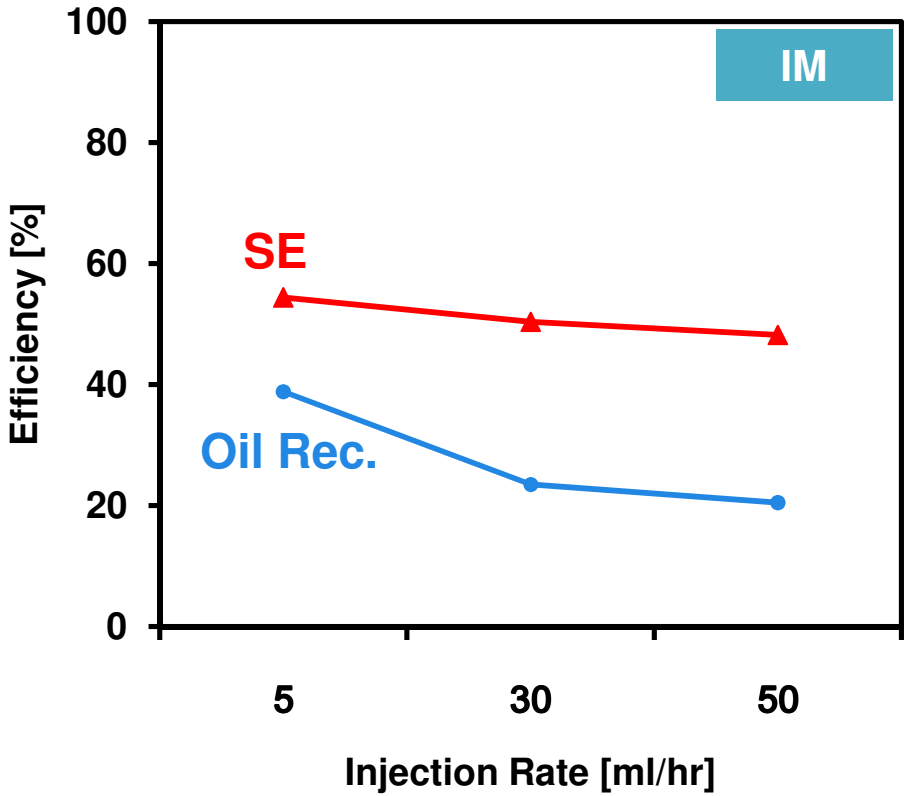


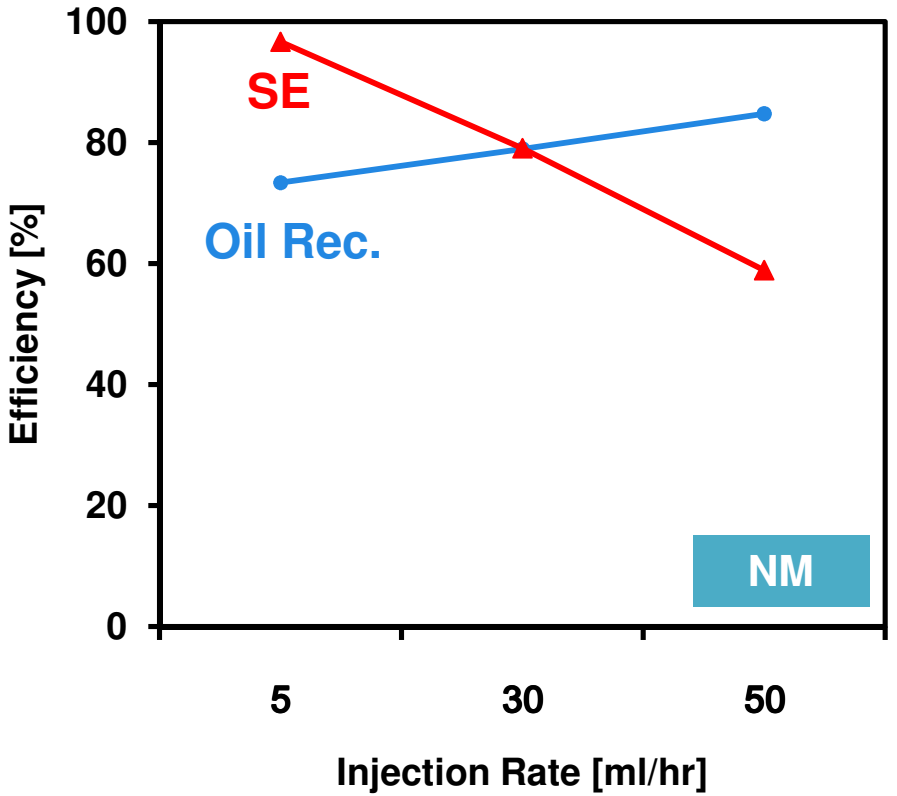


The lower the injection rate, the lower the oil recovery, but the higher the CO_2 storage efficiency. This is because slowly injected CO_2 contacts with more oil for longer time, which CO_2 diffused with oil sufficiently, which larger CO_2-oil mixing zone forms, and hence more CO_2 is stored in dissolved state than other higher rates.

Summary

➢ Oil Recovery vs. CO_2 Storage Efficiency





- ✓ **IM**: Oil recovery is **similar relationship tendency** with CO_2 storage efficiency corresponding to CO_2 injection rate.
- ✓ **NM**: Oil recovery is **opposite relationship** with CO_2 storage efficiency corresponding to CO_2 injection rate.

Conclusion

2D CO_2 Flooding Experiment in Vertical Sandstone Slab to examine oil recovery and CO_2 storage efficiency in CO_2 EOR under the environment of gravity segregation.

Effect of Miscibility Condition

- ✓ Both oil recovery and CO_2 storage efficiency at **NM** are better than at **IM** in 2D vertical system similar to 1D horizontal system.

Effect of CO_2 Injection Rate

- ✓ **IM**: The lower the injection rate, the higher the oil recovery and the CO_2 storage efficiency. This is because the CO_2 gas injected at low rate displaces the oil effectively with slow movement of CO_2 front.
- ✓ **NM**: The lower the injection rate, the lower the oil recovery, but the higher the CO_2 storage efficiency. This is because the CO_2 injected at low rate contacts with oil for longer time, which larger CO_2-oil mixing zone forms and hence more amount of CO_2 is stored in dissolved state.

Relationship between Oil Recovery vs. CO_2 Storage Efficiency

- ✓ **IM**: Oil recovery is similar relationship tendency with CO_2 storage efficiency corresponding to CO_2 injection rate.
- ✓ **NM**: Oil recovery is opposite relationship with CO_2 storage efficiency corresponding to CO_2 injection rate.

Thank you!