



Evaluation of CO₂ Flooding in Multi-Layered Heterogeneous Reservoir

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Presentation Outline

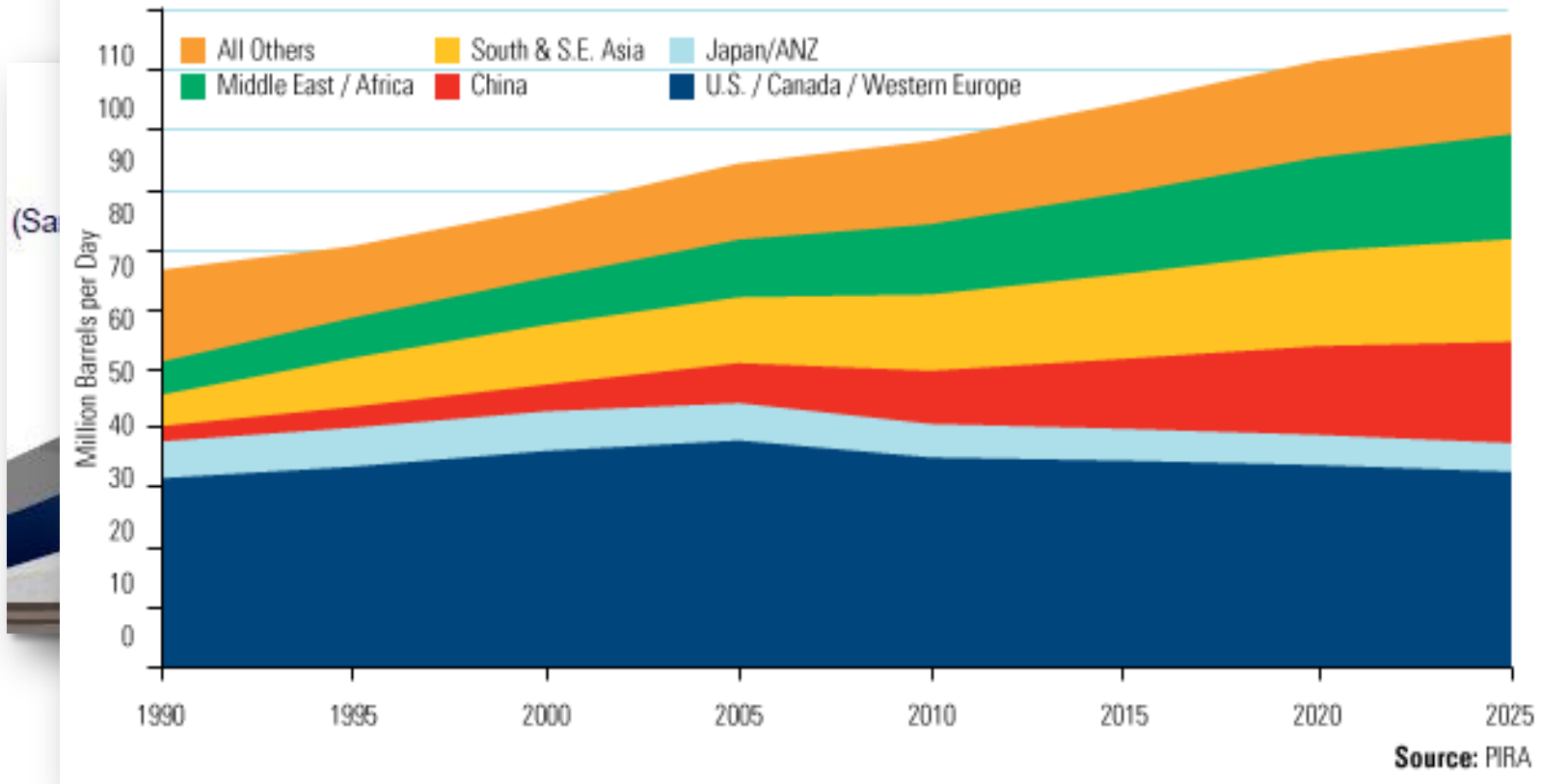


- **Introduction/ Background**
- **Reservoir Simulation Model**
 - Production and Injection Strategies
- **Results and Discussion**
 - Optimization of CO₂ Miscible Flooding Base Case
 - Effects of Study Parameters
 - Reservoir Dip Angle
 - CO₂ Injection Rate
 - CO₂ Injection Perforation Interval
 - Miscibility Formation
- **Conclusions**

Background



World Oil Demand 1990-2025



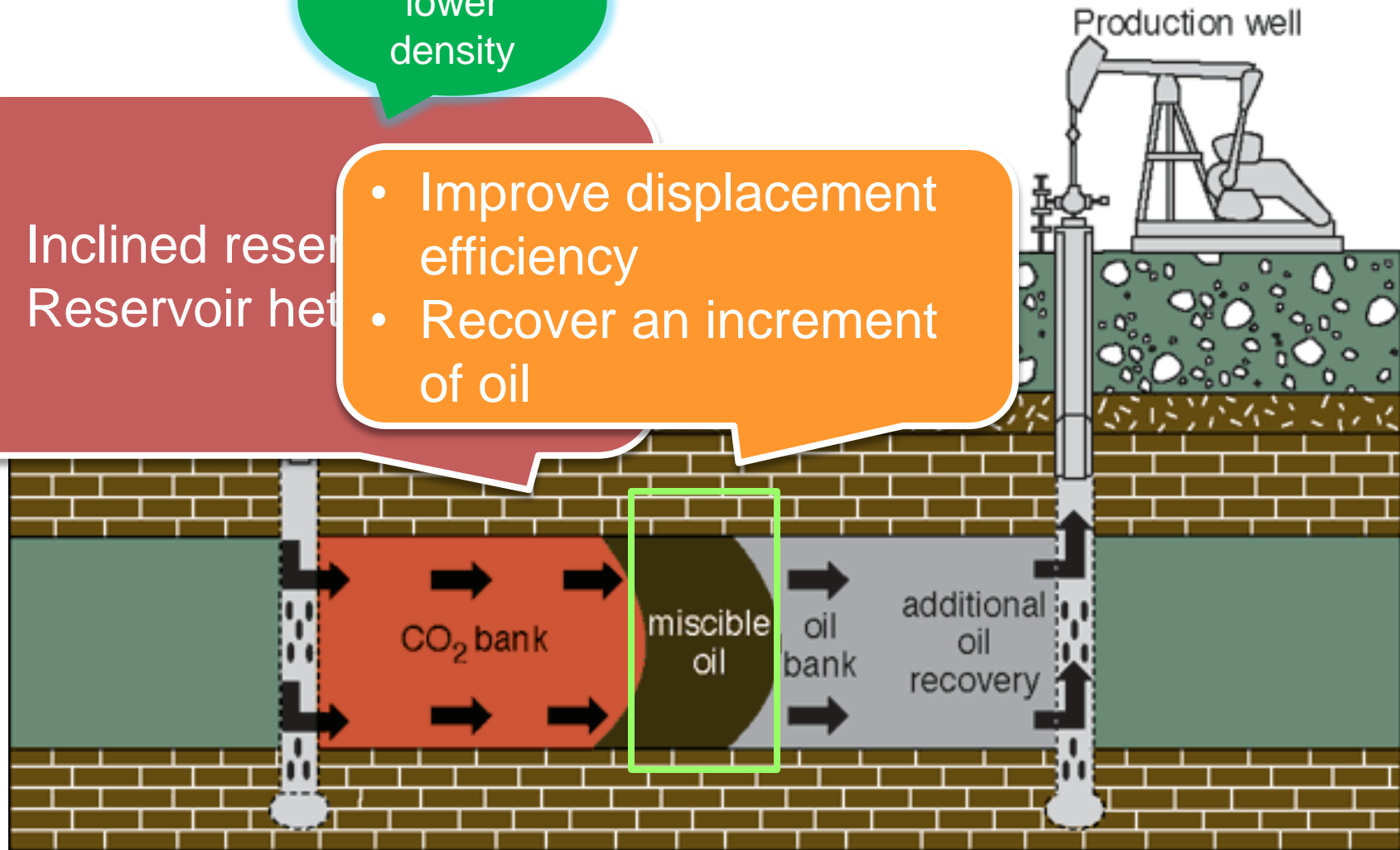
Background



CO₂ has lower density

- Inclined reservoir
- Reservoir heterogeneity

- Improve displacement efficiency
- Recover an increment of oil



Objectives



1. To study effects of uncontrollable parameters including reservoir heterogeneity, formation depositional sequence and dip angle for CO₂ miscible flooding performance.
2. To determine an appropriate value of controllable parameters which are CO₂ injection rate and CO₂ injection perforation interval when combining with uncontrollable parameters for CO₂ flooding.

Reservoir Simulation Model



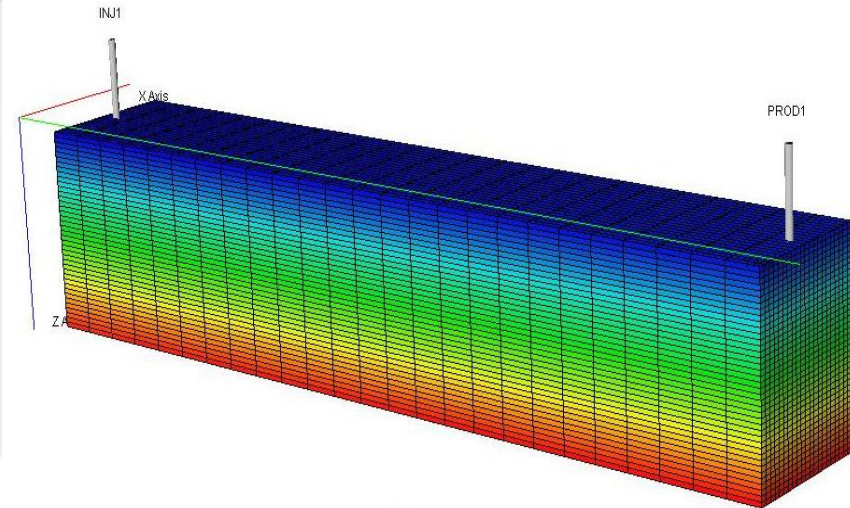
Component	Mole fraction (%)	
	Reservoir Oil	Water

Model Details

- Compositional Simulator ECLISPSE300
- 10-layer horizontal reservoir
- Total size 840x5000x200 ft in x, y, z
- Injector and Producer located at the middle of each side and opposite
- Water wetting preference

- Initial Water Saturation 28%

Heptane plus	C ₇₊	31.12
Specific gravity of C ₇₊		0.8615
Molecular weight of C ₇₊		267



Estimated Minimum Miscibility Pressure (MMP) [4][5][6][7]

3,067 psia

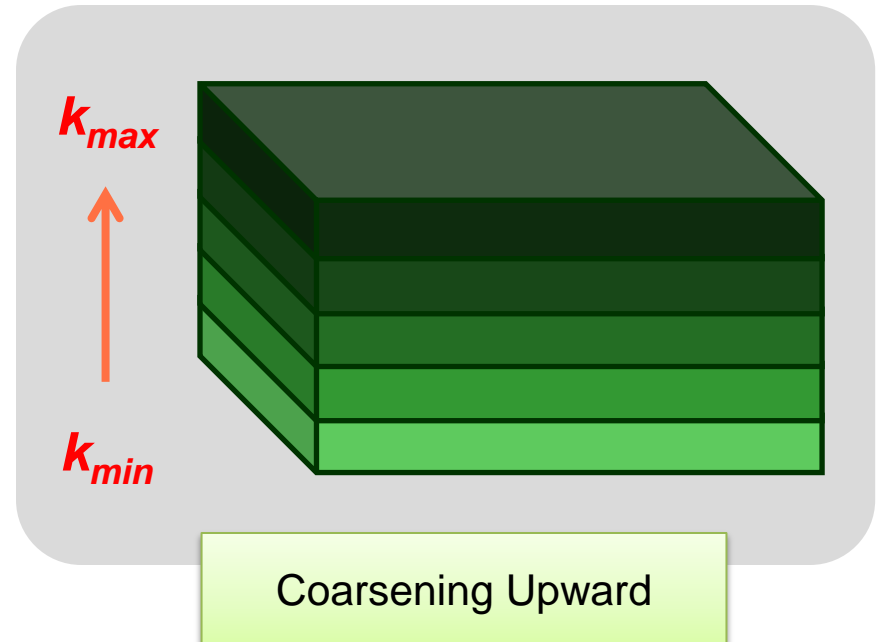
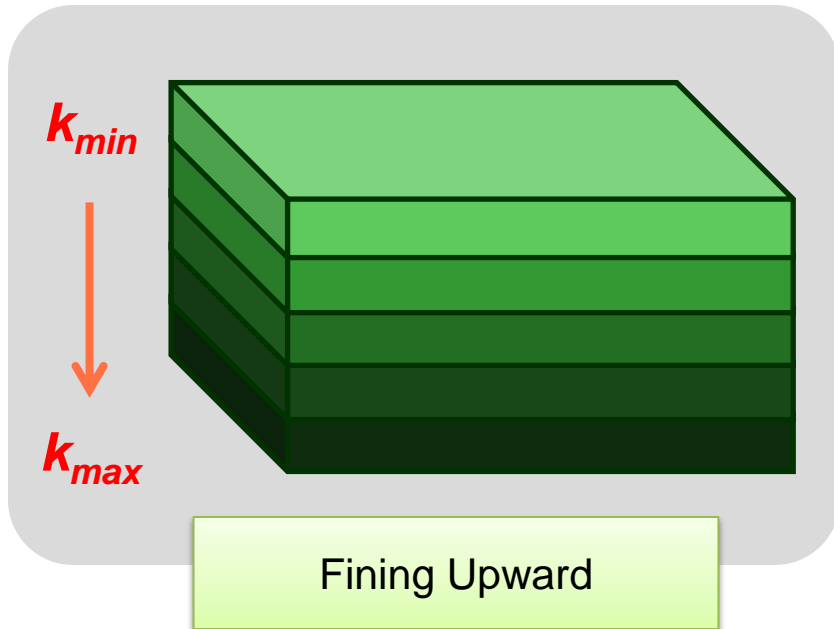
Reservoir Heterogeneity



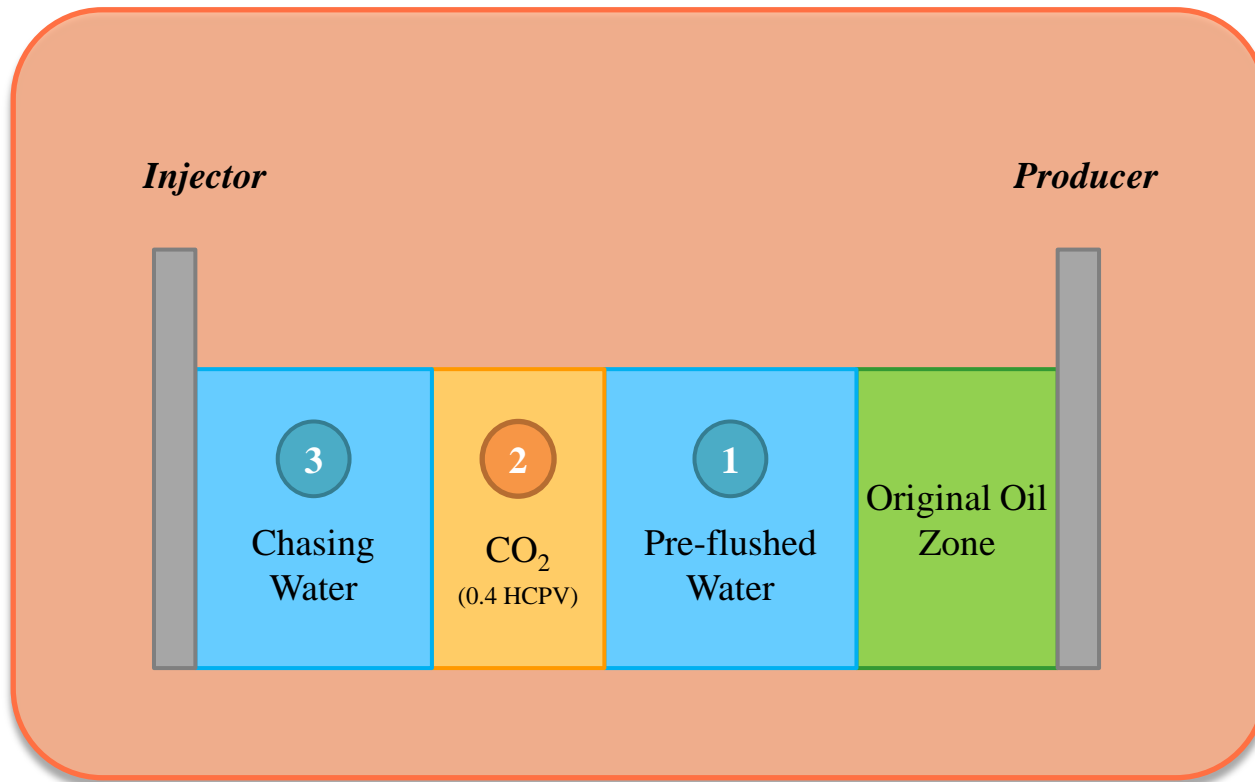
Varied permeability in vertical direction between 20-300 mD.



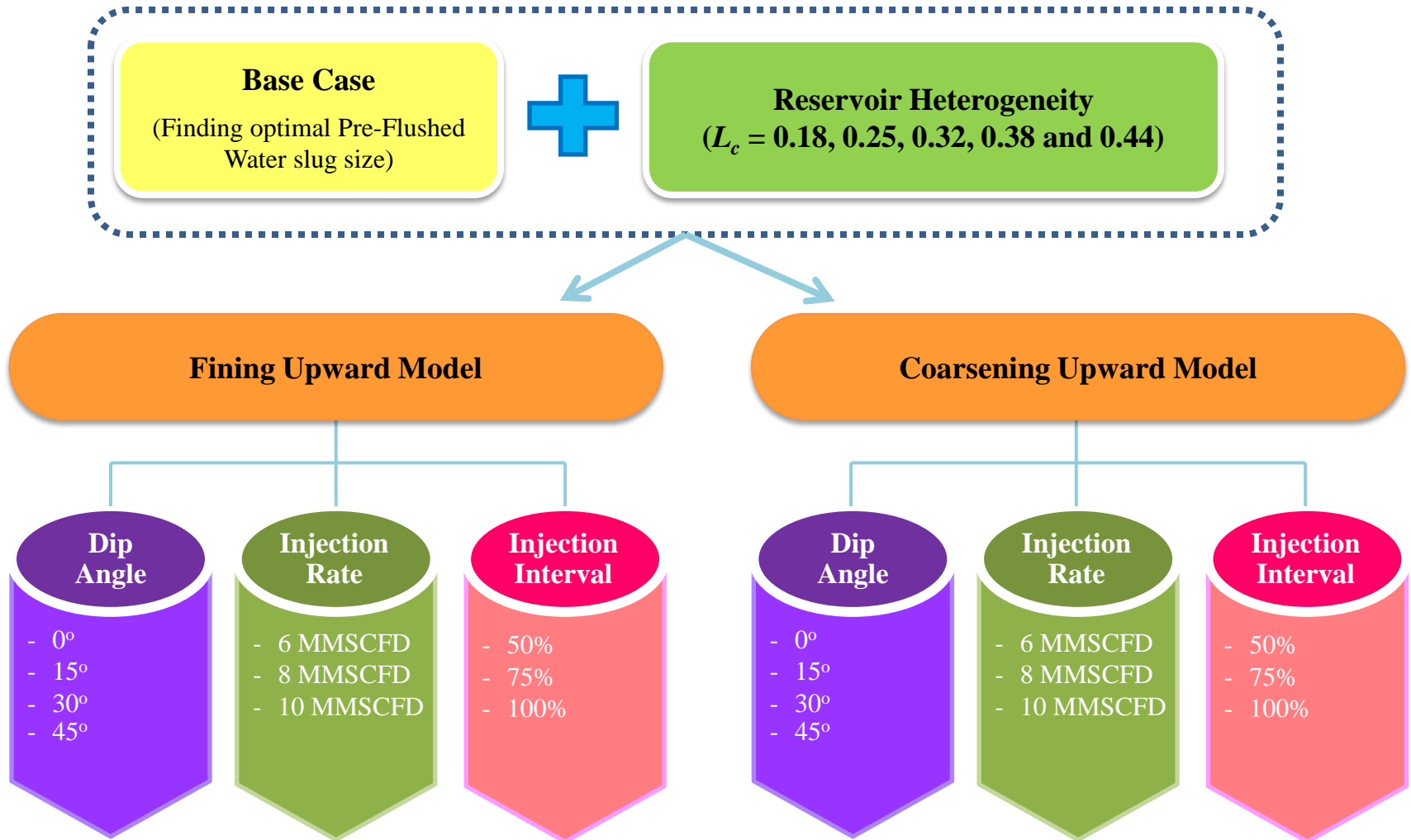
Lorenz Coefficient (L_c) = 0.18, 0.25, 0.32, 0.38 and 0.44



Production and Injection Strategies



Study Methodology



Results and Discussion



Optimization for CO₂ Miscible Flooding Base Case

- Determination of Pre-Flushed Water Slug Size

Summary table of simulation cases

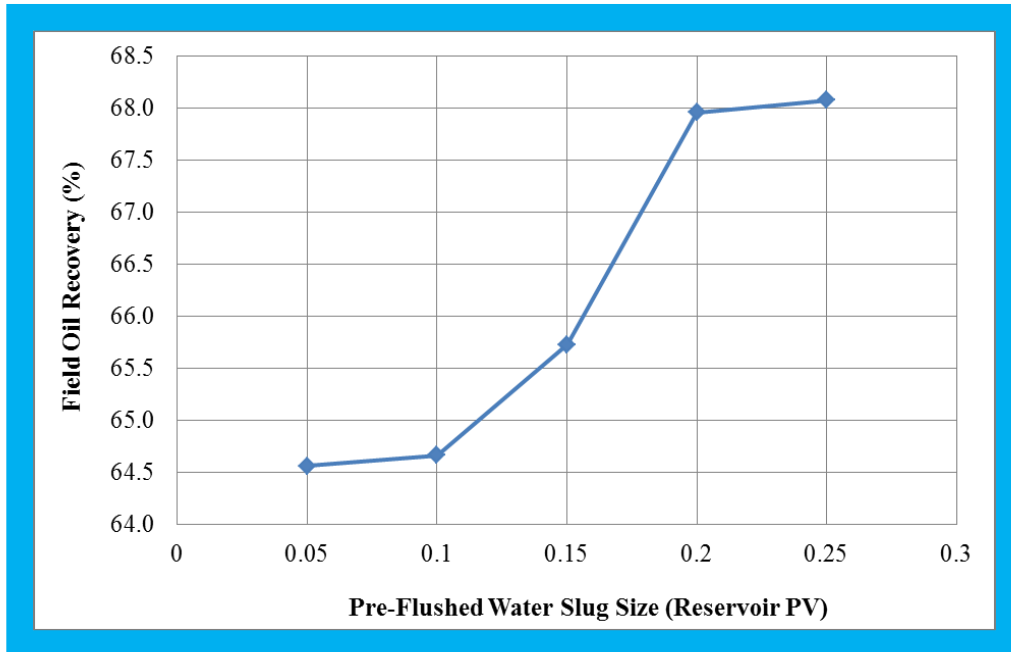
Case no.	Water Pre-flushed Slug size	CO ₂ Injection Slug Size	Water Chasing
1	0.05 PV	0.4 HCPV	Continuous injection until production meets criteria
2	0.10 PV		
3	0.15 PV		
4	0.20 PV		
5	0.25 PV		

Results and Discussion



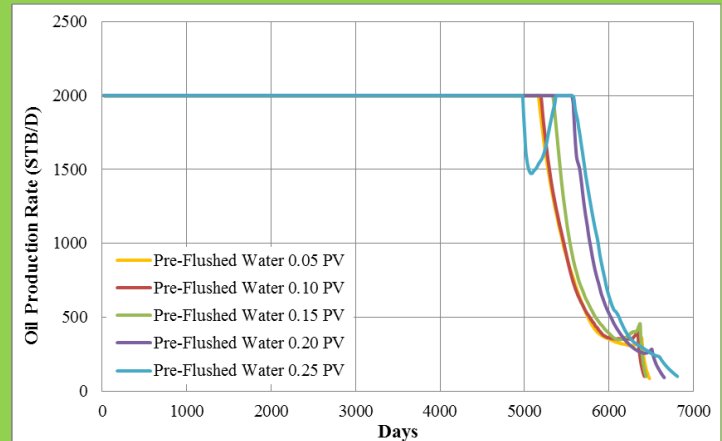
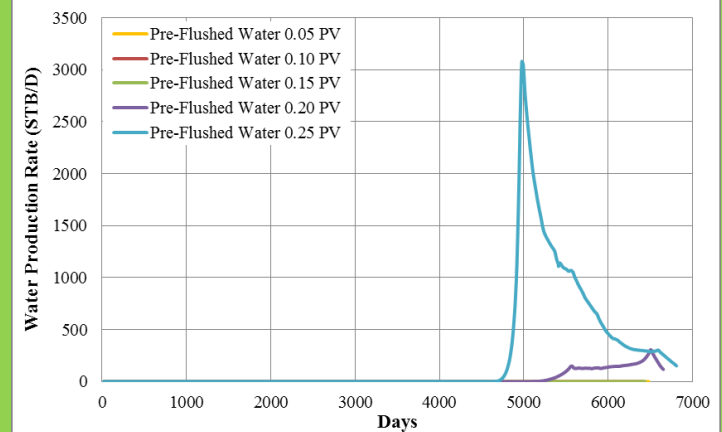
Optimization for CO₂ Miscible Flooding Base Case

- Determination of Pre-Flushed Water Slug Size



Oil recovery as a function of Pre-Flushed Water Slug Size

Water and Oil production rate



Results and Discussion



Study Parameter: Reservoir Dip Angle

Summary table of simulation cases

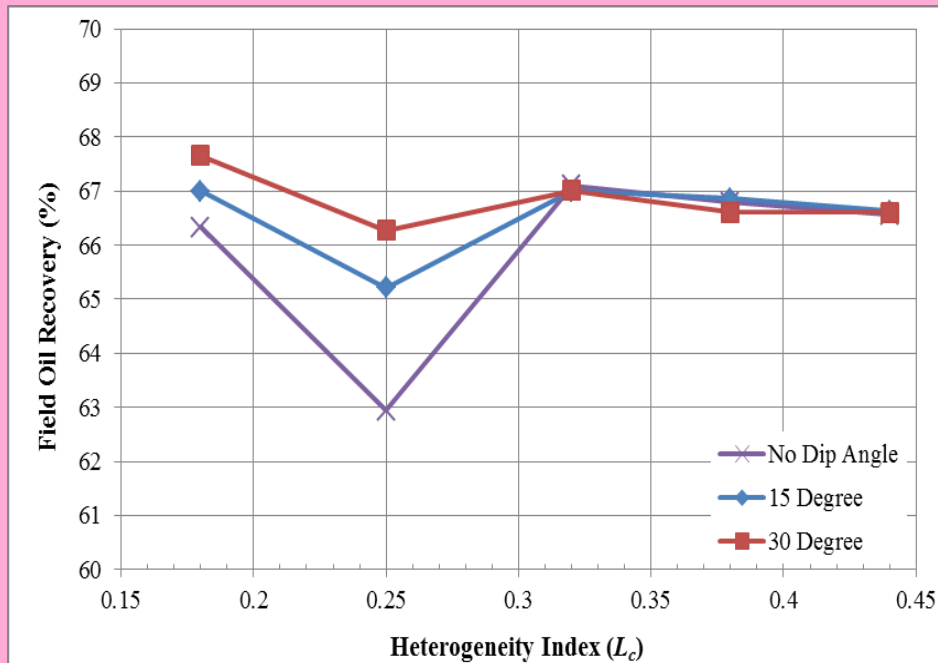
Group No.	Lithofacies	Heterogeneity Index	Dip Angle (degree)
1	Fining Upward	0.18	0, 15, 30 and 45
2		0.25	0, 15, 30 and 45
3		0.32	0, 15, 30 and 45
4		0.38	0, 15, 30 and 45
5		0.44	0, 15, 30 and 45
6	Coarsening Upward	0.18	0, 15, 30 and 45
7		0.25	0, 15, 30 and 45
8		0.32	0, 15, 30 and 45
9		0.38	0, 15, 30 and 45
10		0.44	0, 15, 30 and 45

Results and Discussion



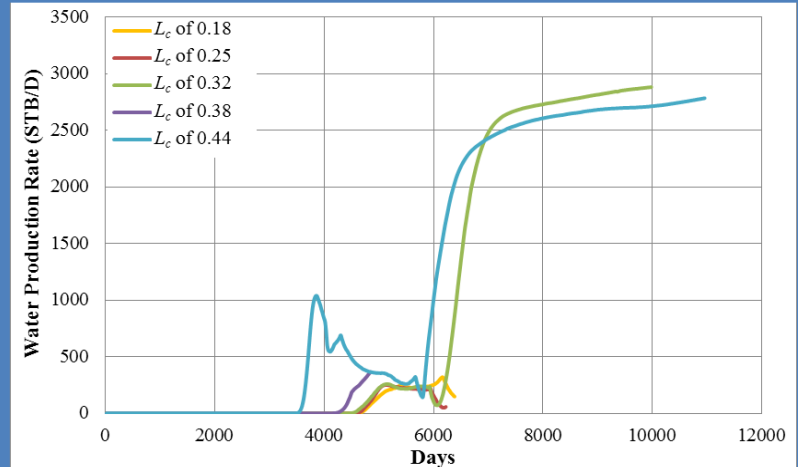
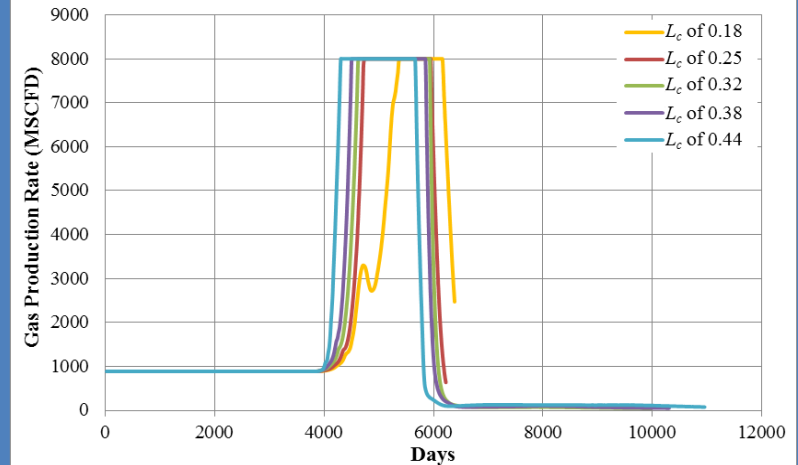
Effects of Reservoir Dip Angles

- Fining Upward



Oil recovery as functions of heterogeneity indexes and reservoir dip angles

Gas and Water production from cases without dip angle



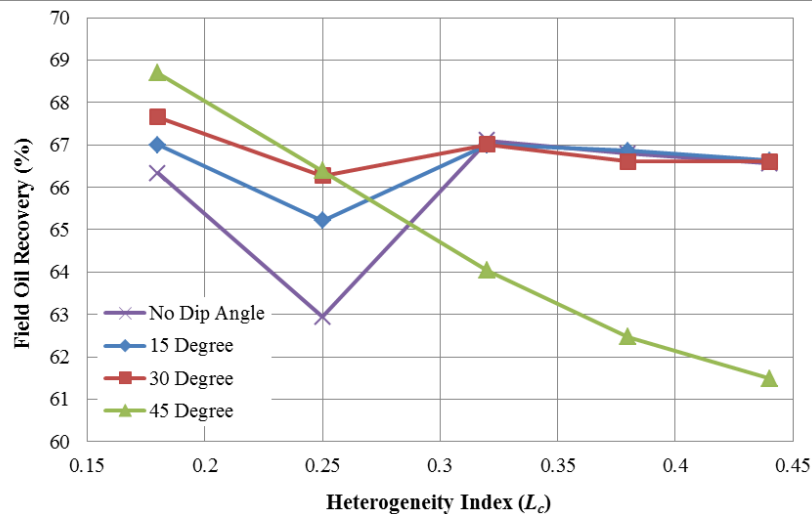
Results and Discussion



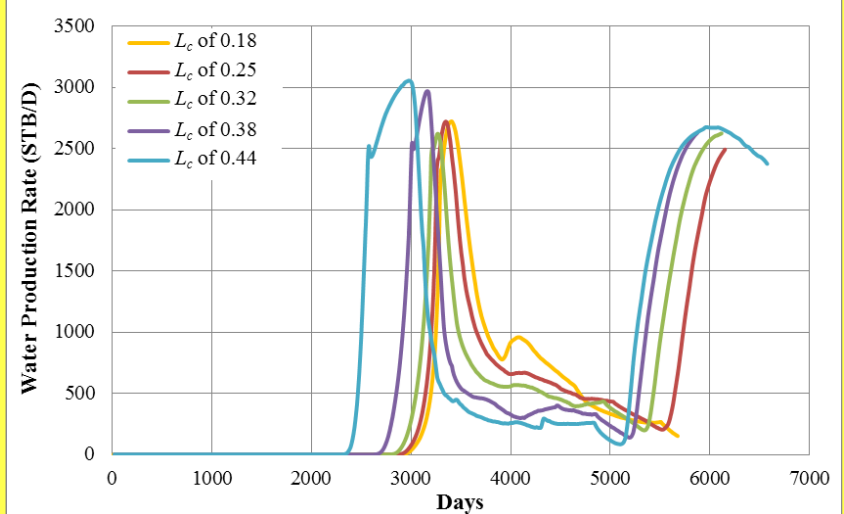
Effects of Reservoir Dip Angles

- Fining Upward

Oil recovery as functions of heterogeneity indexes and reservoir dip angles



Water production rate as functions of heterogeneity indexes for case 45° Dip Angle



45° model - influence of gravity segregation of water mainly plays a major role, leading to water tonguing downward quickly.

Results and Discussion

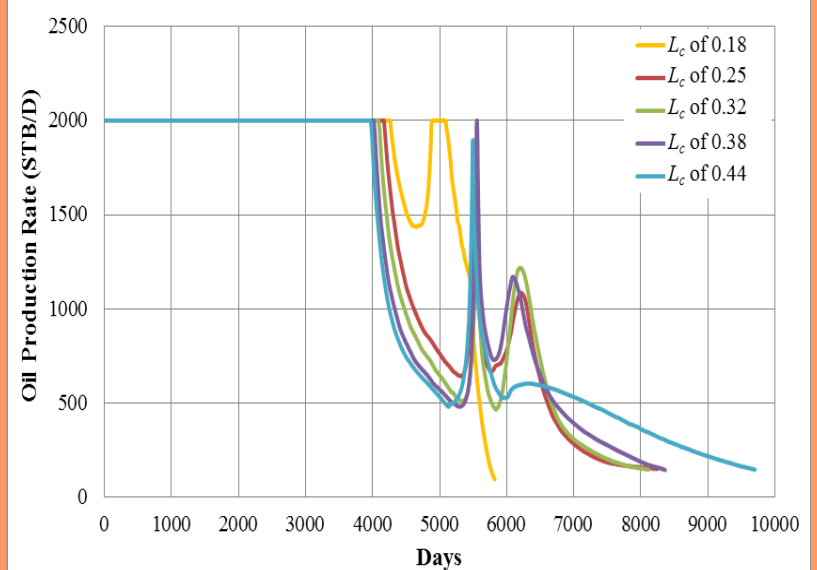
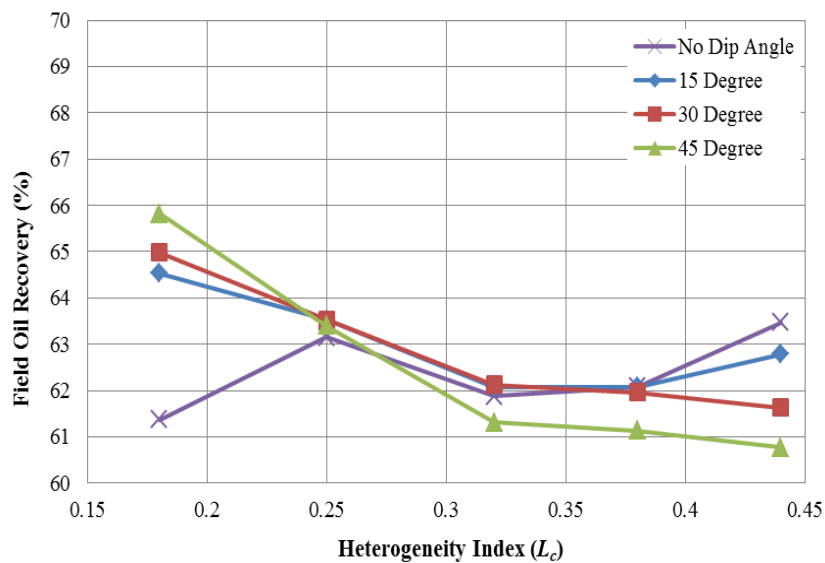


Effects of Reservoir Dip Angles

- Coarsening Upward

Oil recovery as functions of heterogeneity indexes and reservoir dip angles

Oil production rate as functions of heterogeneity indexes for case 0° Dip Angle



Results and Discussion



Study Parameter: CO₂ Injection Rates

Summary table of simulation cases

Group No.	Lithofacies	Heterogeneity Index	CO ₂ Injection rate (MMSCFD)
1	Fining Upward	0.18	6, 8, 10
2		0.25	6, 8, 10
3		0.32	6, 8, 10
4		0.38	6, 8, 10
5		0.44	6, 8, 10
6	Coarsening Upward	0.18	6, 8, 10
7		0.25	6, 8, 10
8		0.32	6, 8, 10
9		0.38	6, 8, 10
10		0.44	6, 8, 10

CO₂ slug size remains fixed at 0.4 HCPV

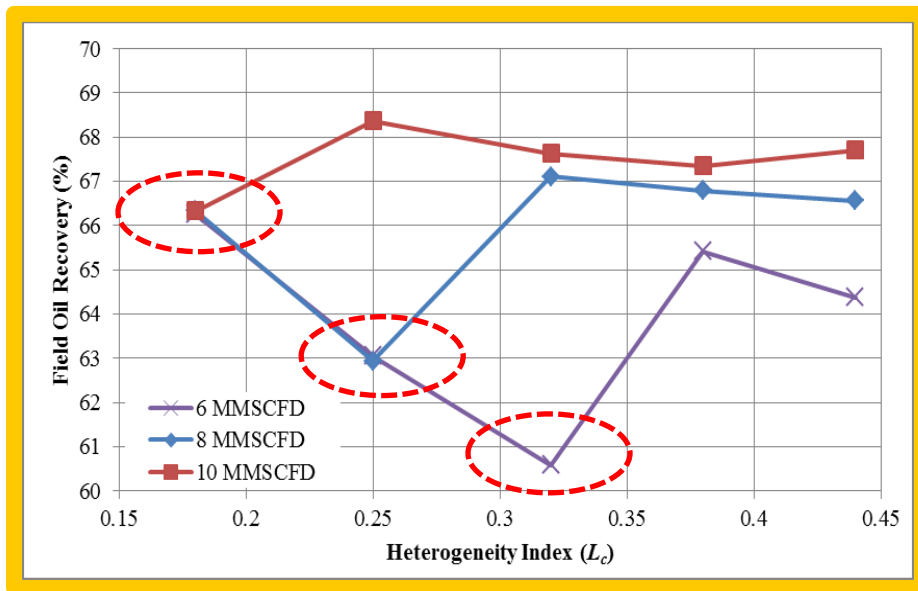
Results and Discussion



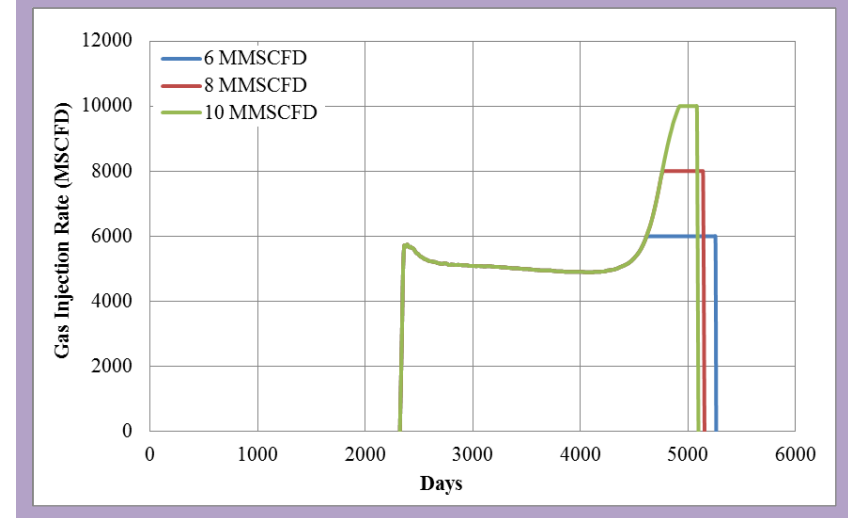
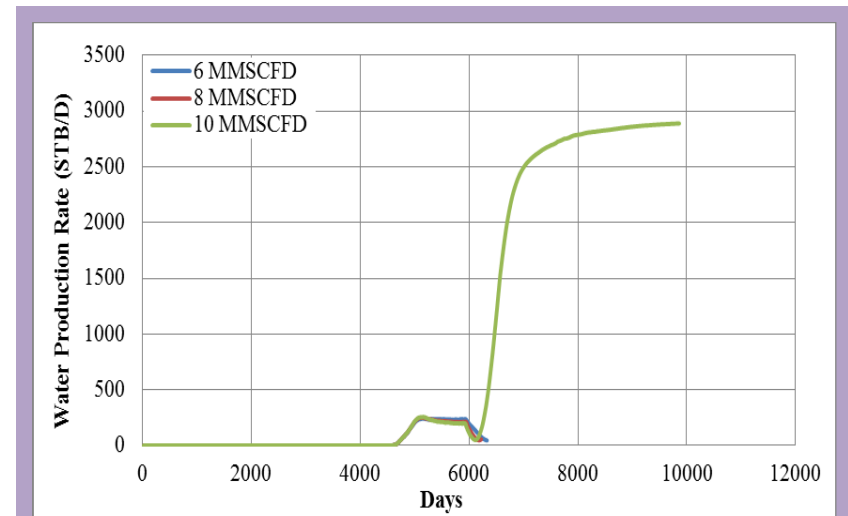
Effects of CO₂ Injection Rates

- Fining Upward

Oil recovery as functions of heterogeneity indexes and CO₂ injection rate



Water Production rate and Gas injection rate for case L_c of 0.25



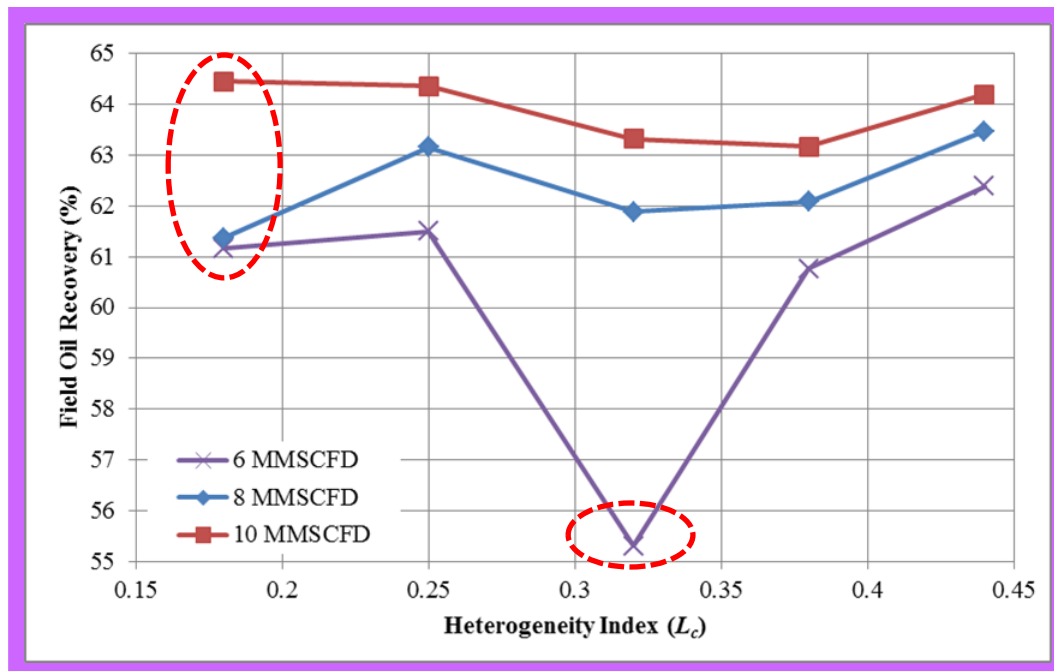
Results and Discussion



Effects of CO₂ Injection Rates

- Coarsening Upward

Oil recovery as functions of heterogeneity indexes and CO₂ injection rate



Results and Discussion



Study Parameter: CO₂ Injection Perforation Intervals

Summary table of simulation cases

Group No.	Lithofacies	Heterogeneity Index	CO ₂ Injection Perforation Interval
1	Fining Upward	0.18	50, 75 and 100%
2		0.25	50, 75 and 100%
3		0.32	50, 75 and 100%
4		0.38	50, 75 and 100%
5		0.44	50, 75 and 100%
6	Coarsening Upward	0.18	50, 75 and 100%
7		0.25	50, 75 and 100%
8		0.32	50, 75 and 100%
9		0.38	50, 75 and 100%
10		0.44	50, 75 and 100%

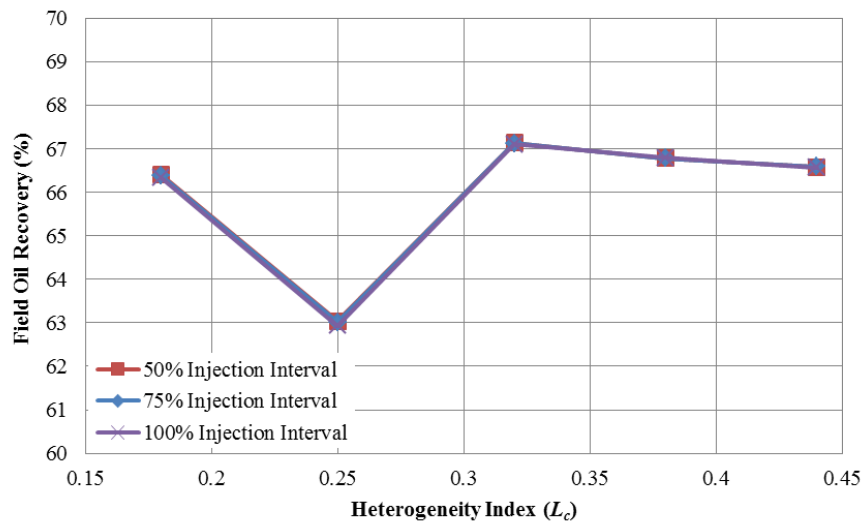
Results and Discussion



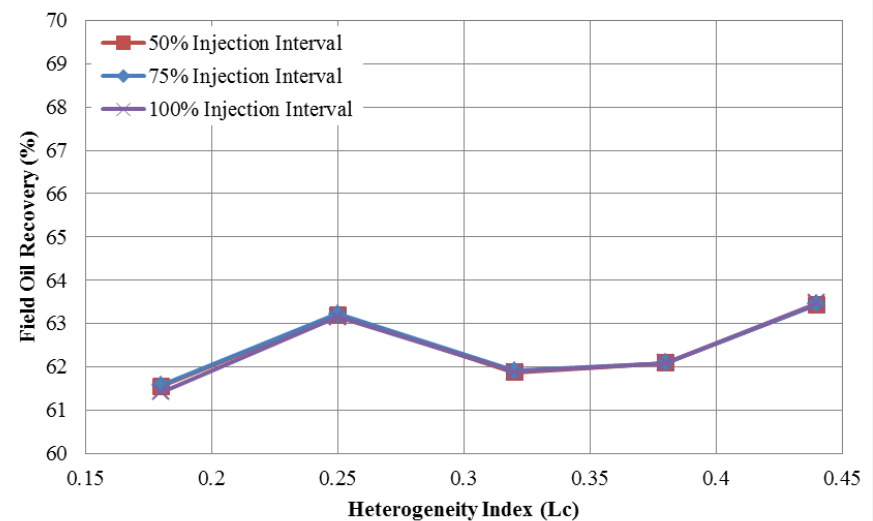
Effects of CO₂ Injection Perforation Intervals

Oil Recovery as a Function of Heterogeneity Index

Fining upward



Coarsening upward

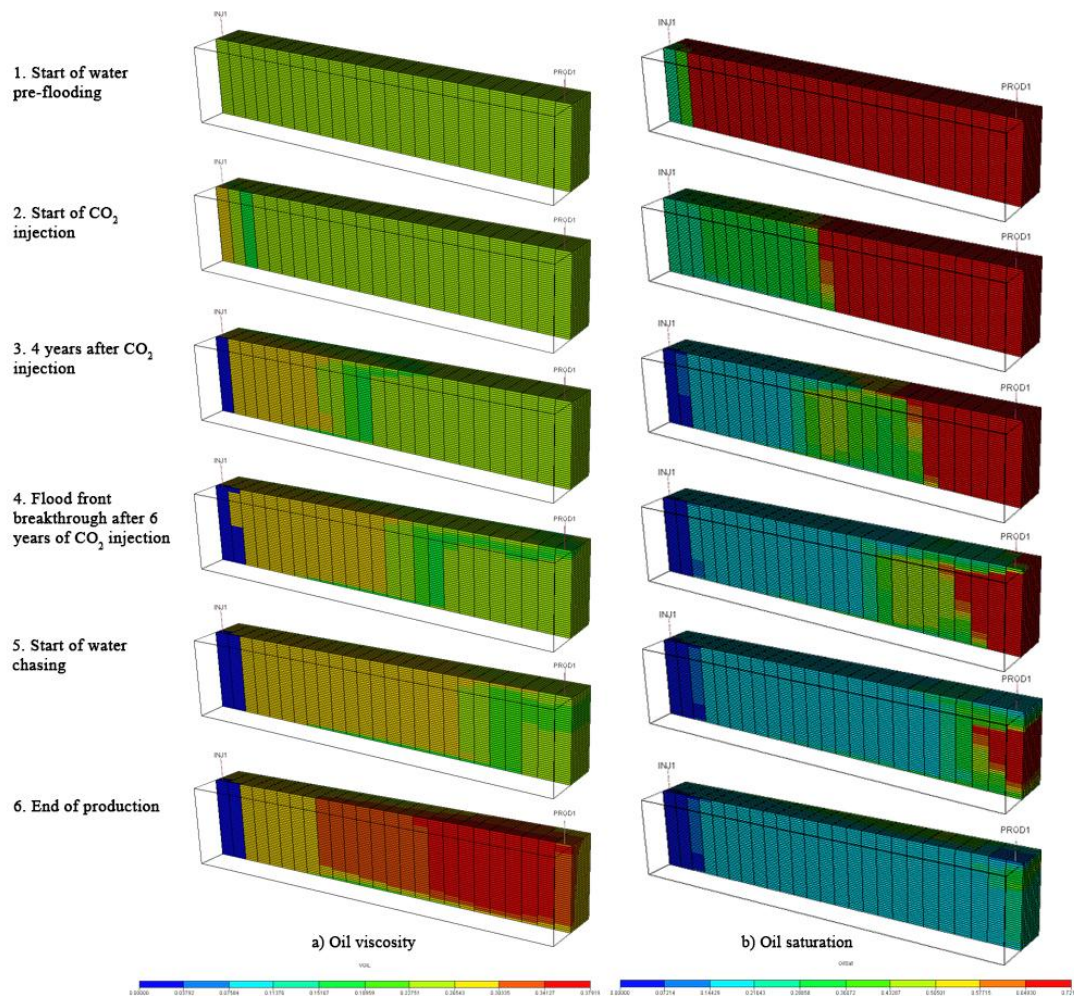


no difference on oil recovery from varying injection interval of CO₂ and varying heterogeneity index

Results and Discussion



Miscibility Formation



1. Oil viscosity is the same when reservoir is displaced with water

2. CO₂ vaporizes light hydrocarbon, leaving heavy compounds in oil phase, causing oil to be more viscous

3. Vaporized hydrocarbon obtained from contacting with CO₂ goes into gaseous phase together with injected CO₂.

Note:

Viscosity: green = initial state

Saturation: red = initial state

Conclusions



Effect of Study Parameters

Reservoir Heterogeneity



An early breakthrough of water

Slightly bouncing up oil production rate to be greater than minimum constraint



An early breakthrough of gas

a limit flow of oil to the production well.

Depositional Sequence

Coarsening upward lithofacies allows injected CO₂ to flow easily on top part of model.

Conclusions



Effect of Study Parameters

Dip Angle

Helps against gravity segregation of CO₂ by forming more stable flood front.

CO₂ Injection Rate

increasing injection rate yields benefit through accelerating completion of the CO₂ slug size

CO₂ Injection Perforation Interval

Does not show any improvement on this studied flooding.



Thank you for your attention