THE EFFECT OF FOAM STABILITY IN CO_2-FOAM FLOODING

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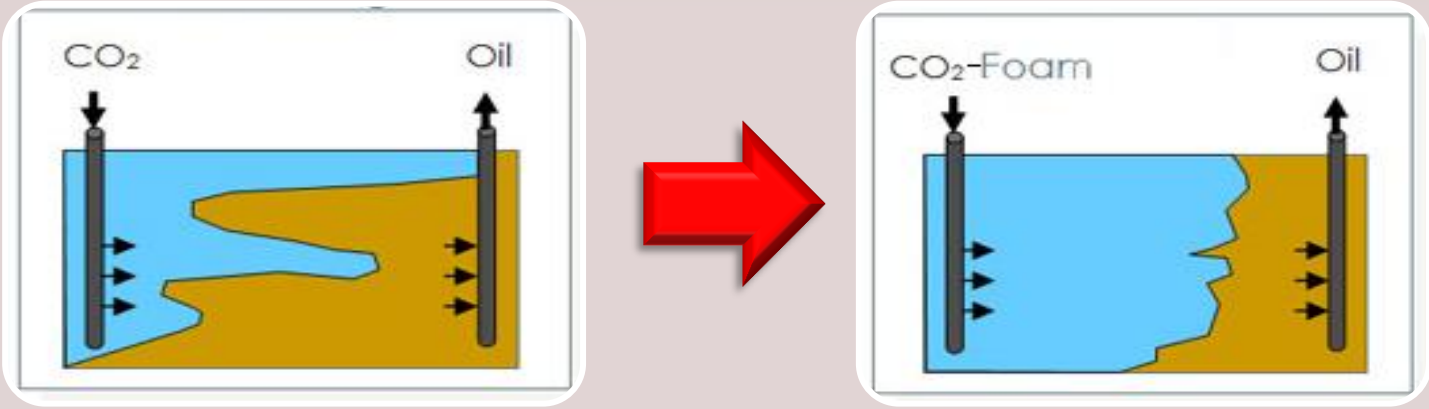
Introduction



- : CO_2 can perform both miscible and immiscible conditions.

- : Mobility of CO_2 is much higher than crude oil.

-: Gravity overiding and viscous fingering occur.

-: Finally, it leads to the early gas breakthrough.

- : Foam was used to control the mobility of gas phase and improve the sweep efficiency.

- : Foam create smoother and more stable flood front.

-: Main mechanism for oil recovery comes from CO_2 gas and displacement by foam.

-: Foam stability is a parameter that indicate foam's strength

Objectives

- To study the effects of interest parameters including wettability, hydrocarbon component and number of slug on effectiveness of CO_2-foam flooding process.

- To determine the optimal foam stability in CO_2-foam flooding process.

Methodology

1. Construct a reservoir model
2. Run CO_2 base case
3. Perform CO_2 foam flooding process
4. Vary the formation wettability
5. Vary hydrocarbon composition
6. Vary the injection slug
7. Analyze and summarize the obtained results

Parameters

Wettability

- Moderately water-wet
- Neutral-wet
- Moderately oil-wet
- Strongly oil-wet

Intermediate

- ↑ Intermediate comp. 10%
- ↑ Intermediate comp. 20%
- ↓ Intermediate comp. 10%
- ↓ Intermediate comp. 20%

CO_2 foam slug

- Double-slug (0.2 PV)
- Triple-slug (0.13PV)

Reservoir Section

- The simulator STARS will be used to evaluate the performance of CO_2-foam flooding in this study
- The studied reservoir model is created as Cartesian grid and represents homogeneous reservoir.

Property	Value
Top reservoir depth, feet	6,000
Grid block number	30 × 15 × 20
Grid size, feet	100 × 100 × 10
Thickness, feet	200
Porosity	0.25
Initial water saturation	0.28
Horizontal permeability, mD	220
Vertical permeability, mD	22
Reservoir temperature, ^oF	198
Reservoir pressure, psia	2,775

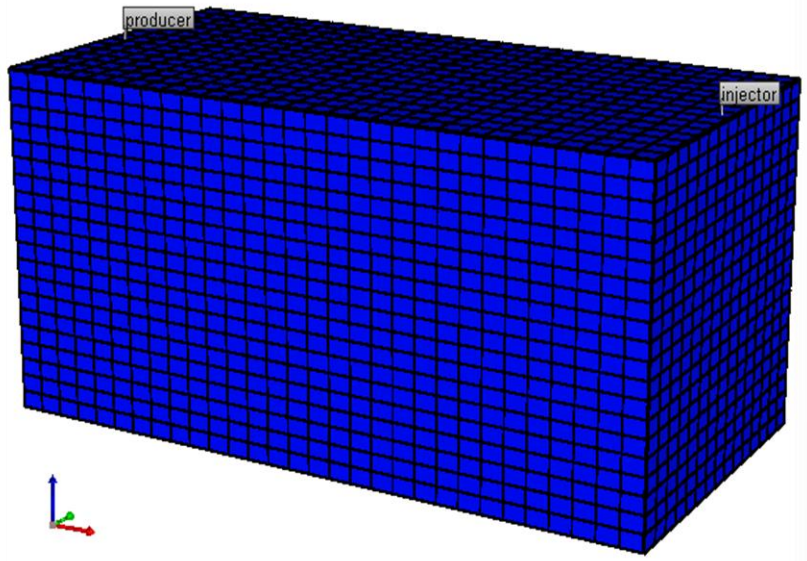
Component	Mole fraction
Carbon dioxide (CO_2)	0.0091
Nitrogen (N_2)	0.0006
Methane (C_1)	0.3383
Ethane (C_2)	0.0904
Propane (C_3)	0.0799
Isobutane (i-C_4)	0.0197
Normal butane (n-C_4)	0.0469
Isopentane (i-C_5)	0.036
Normal pentane (n-C_5)	0.0178
Hexane (C_6)	0.0501
Heptane plus (C_{7+})	0.3112

Wells and recurrent section

- The production well is located at the edge of the reservoir, while the injection well is at the edge on another side of the model

Constraints of the production well

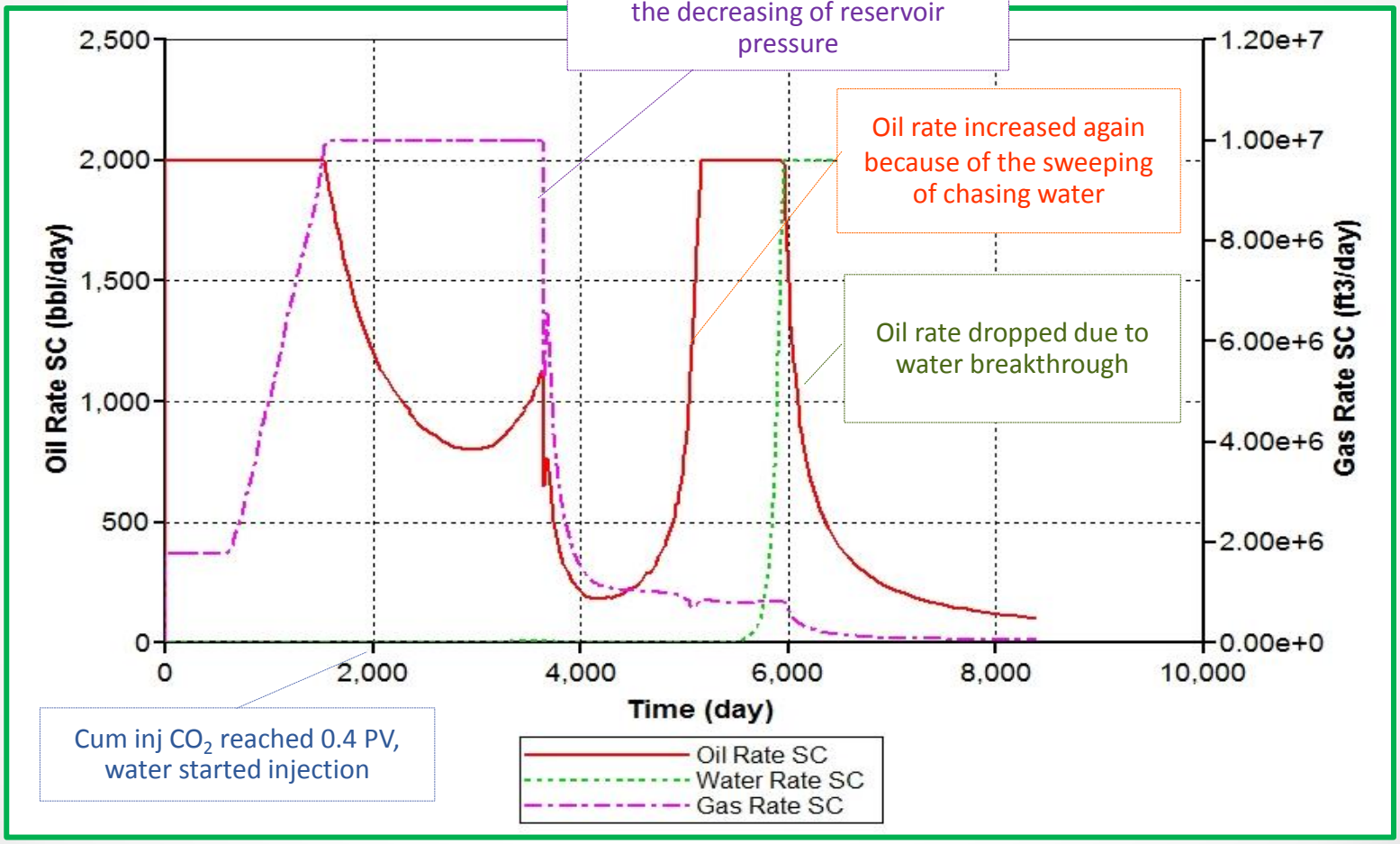
Constraint	value
Surface oil rate, BBL/D	2,000
Surface water rate, BBL/D	2,000
Surface gas rate, MMSCF/D	10
Cut-off oil production rate, BBL/D	100
Water cut, %	95



SIMULATION RESULTS AND DISCUSSION

CO_2 flooding Base Case

- Fluid injection schedule is divided in two periods, 0.4 PV of CO_2 and 0.4 PV of water

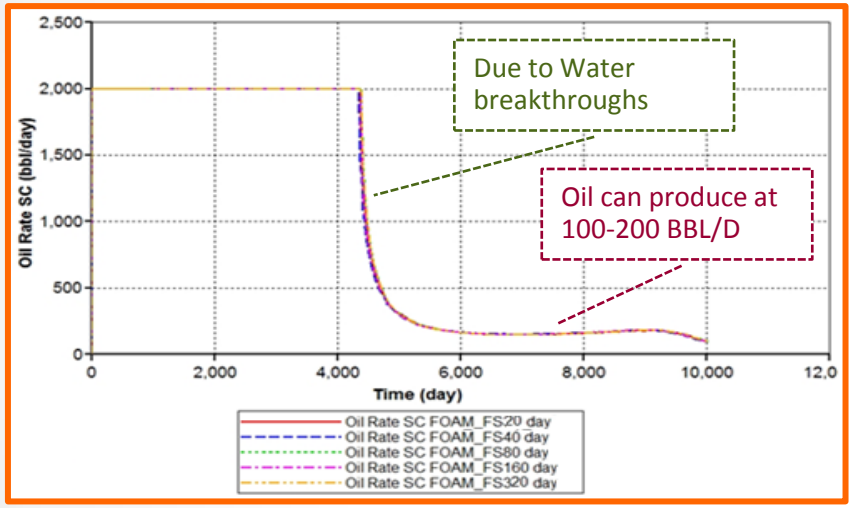


Oil, water and gas production rates

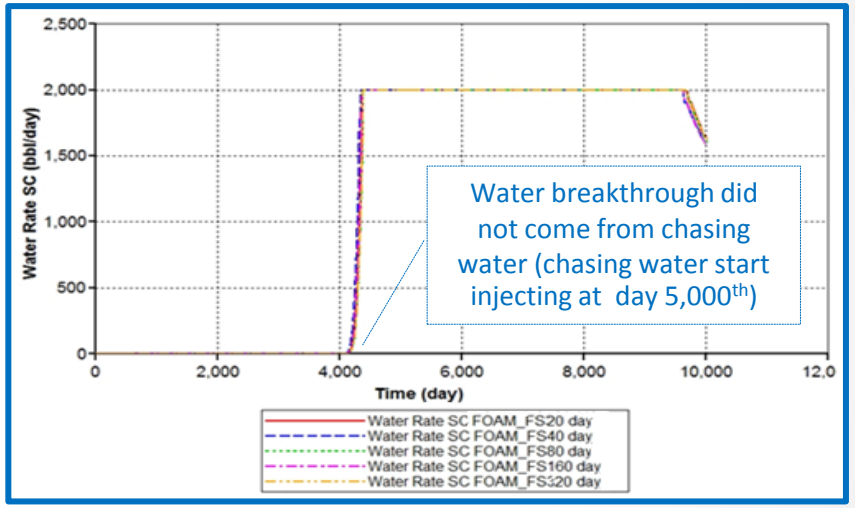
- The ultimate oil recovery factor is about 42.6%

CO_2-foam flooding base case

- The injection schemes are kept to be similar to CO_2 flooding base case
- In this study, foam stability are varied from 20 days, 40 days, 80 days, 160 days, and 320 days.



Oil production rates



Water production rates

- Water breakthrough came from the aqueous phase of foam. (when foam breaks and gas phase and aqueous phase flow separately)
- From oil production rate and water production rate, the effect of foam stability are not noticeable much.

CO_2-foam flooding base case

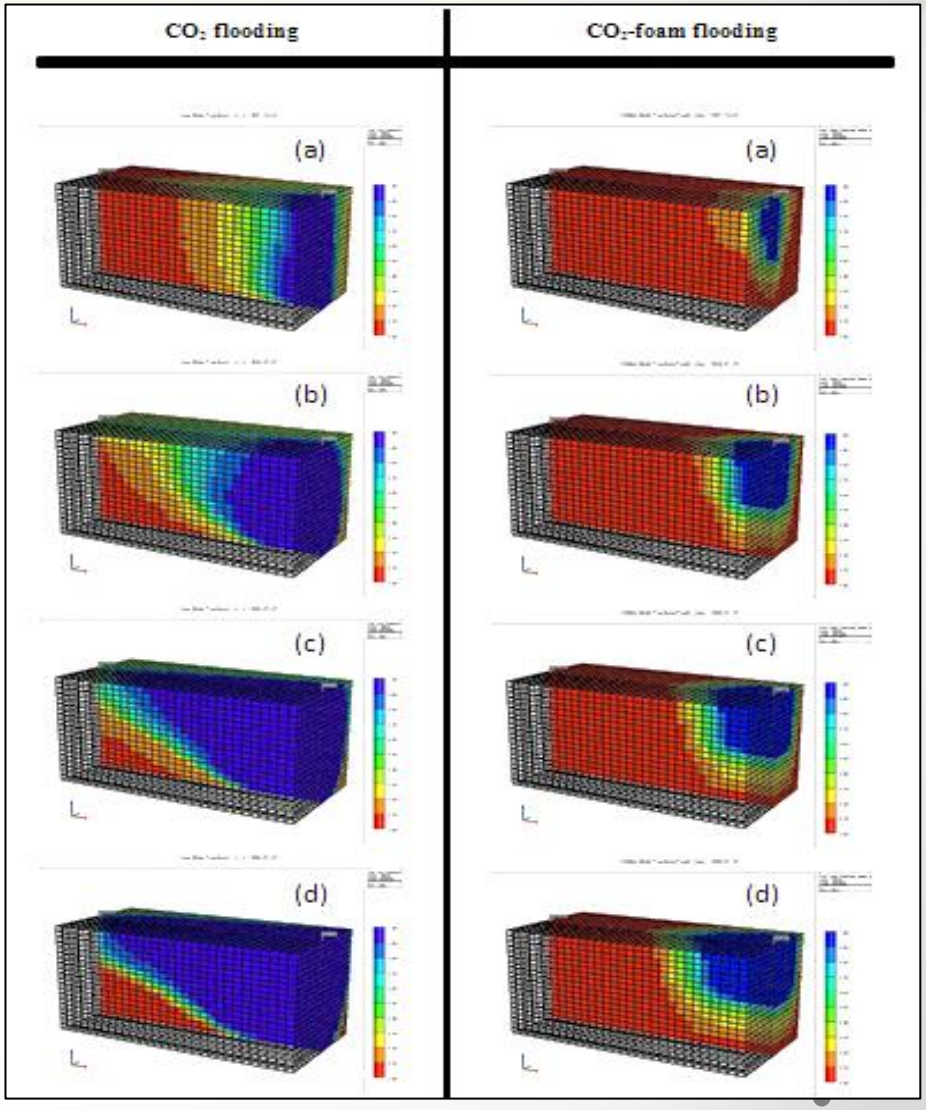
- The summary of oil production, water production, gas production and oil recovery factor

	CO_2 flooding	CO_2-Foam flooding				
		FS 20 days	FS 40 days	FS 80 days	FS 160 days	FS 320 days
Water 0.4 pore volume, day	6,350	9,796	9,673	9,801	9,755	9,801
Cumulative oil production (MMBBL)	7.91	9.94	9.87	9.96	9.91	9.95
Cumulative water production, (MMBBL)	0.98	11.00	10.83	10.98	10.94	10.99
Cumulative gas production (BSCF)	30.52	19.37	19.49	19.32	19.50	19.30
Oil recovery factor, %	42.62	55.48	55.12	55.63	55.36	55.59

This result could be from continuous injecting slug of CO_2-foam, so an effect of foam stability cannot be seen obviously.

CO_2-foam flooding base case

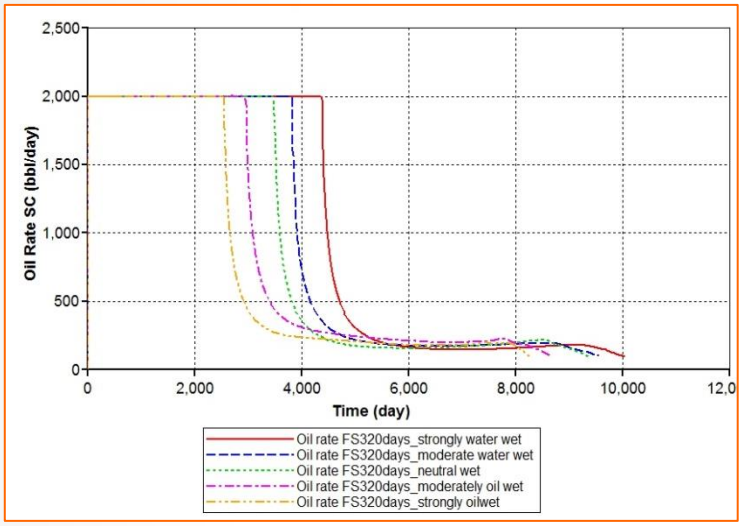
- Since foam can create the smoother flood front compared to the case of CO_2 flooding.
- The CO_2-foam flooding provides the higher ultimate oil recovery factor than CO_2 flooding about 13%



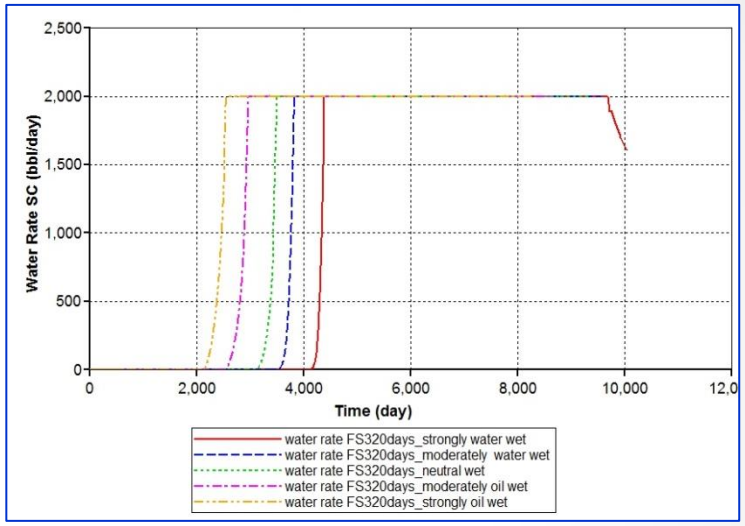
Effect of varied parameters on CO_2-foam flooding

The effect of wetting condition of reservoir rock

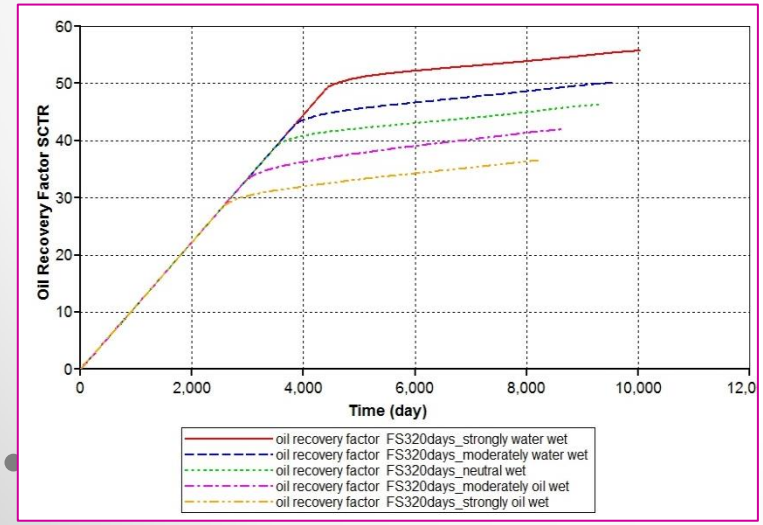
Summary of the effects of wettability



Oil production rates



Water production rates



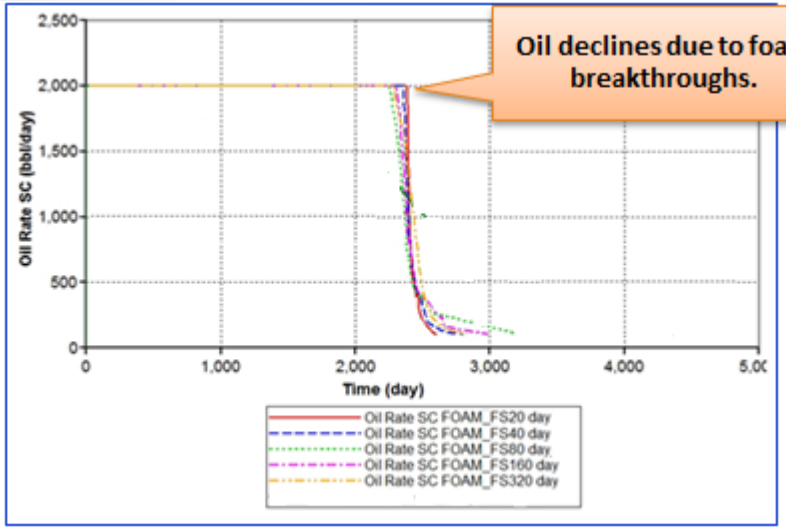
Oil recovery factor

- CO_2-foam flooding is suitable for a reservoir that its wettability is in the range of neutral-wet to strongly water-wet.
- For oil-wet formation, solely CO_2 flooding is preferable

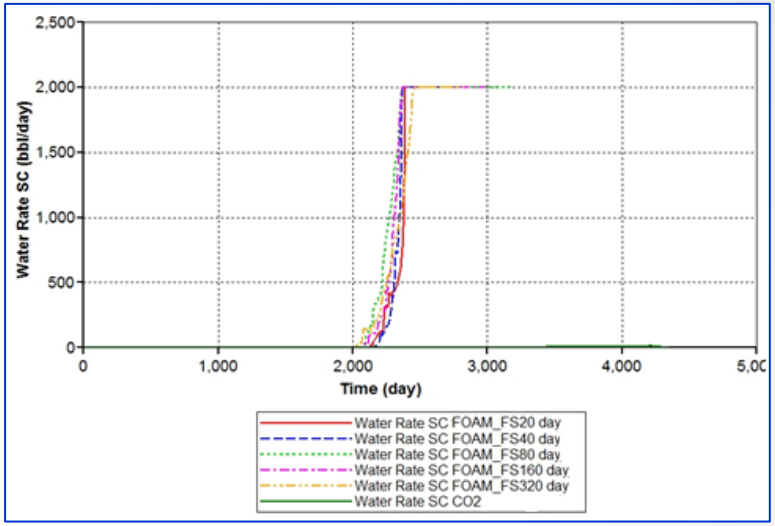
The effect of hydrocarbon compound

Increasing intermediate portion 20%

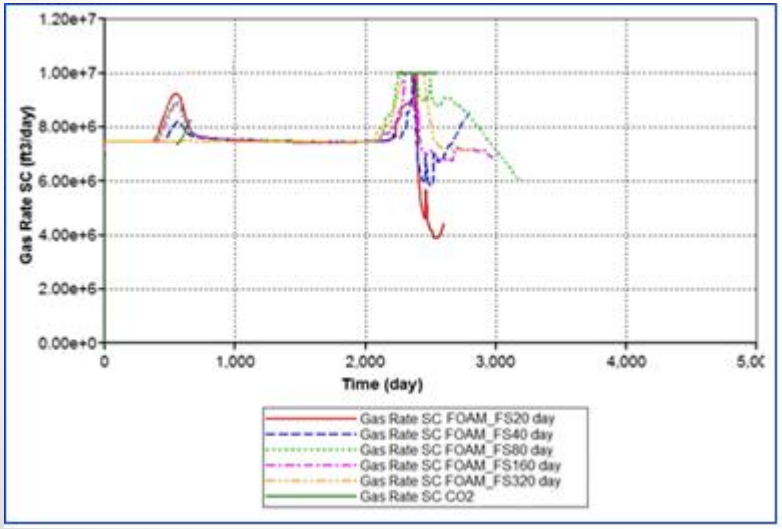
Oil production rate



Water production rate

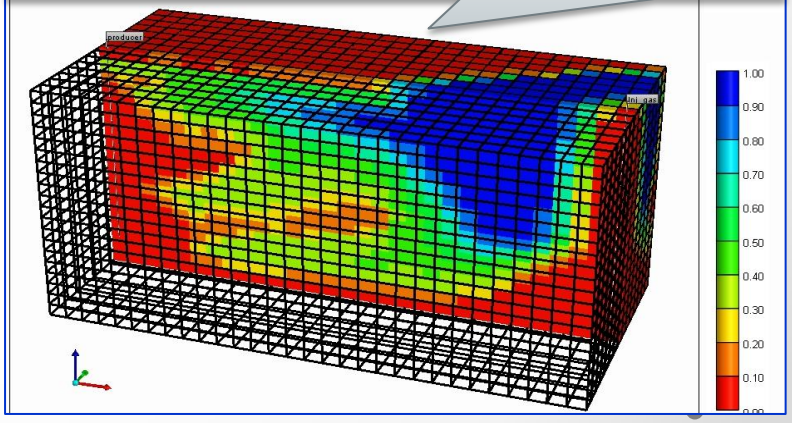


Gas production rate



CO_2-foam breakthroughs

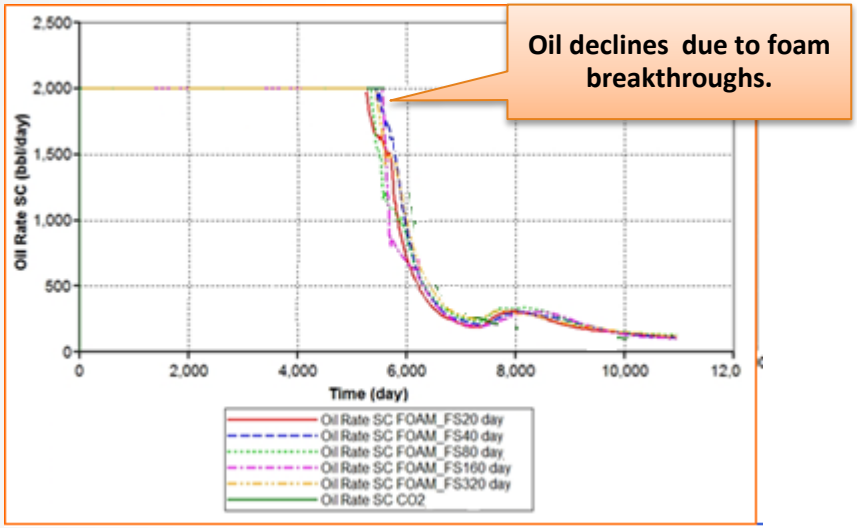
More intermediate part is vaporized ➔ S_o is reduced ➔ K_{rw} is increased ➔ foam flows faster



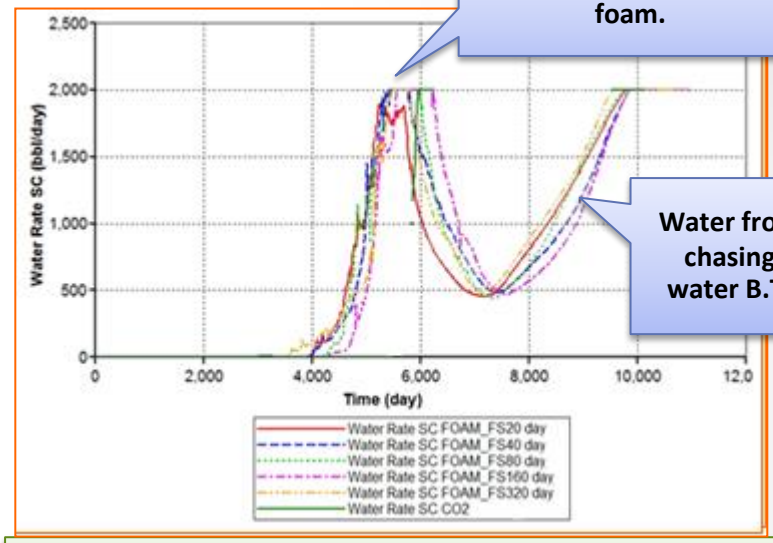
The effect of hydrocarbon compound

Decreasing intermediate portion 20%

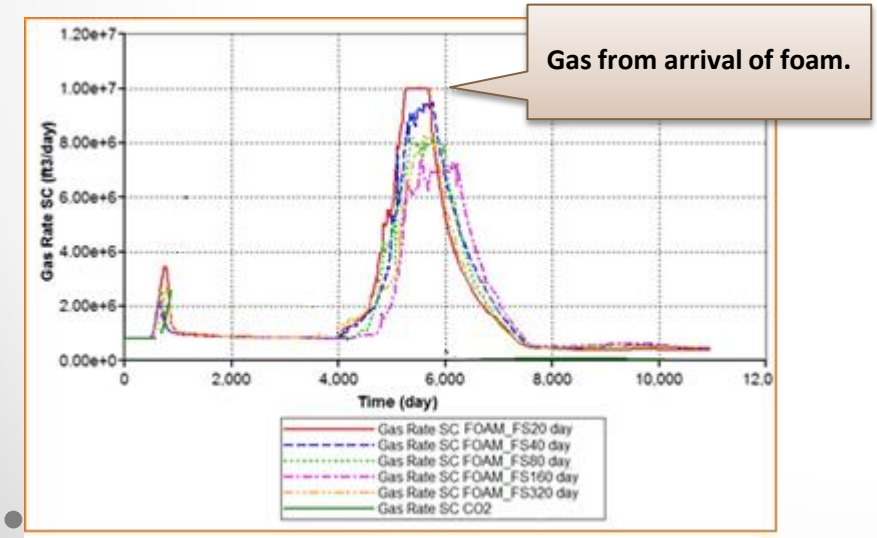
Oil production rate



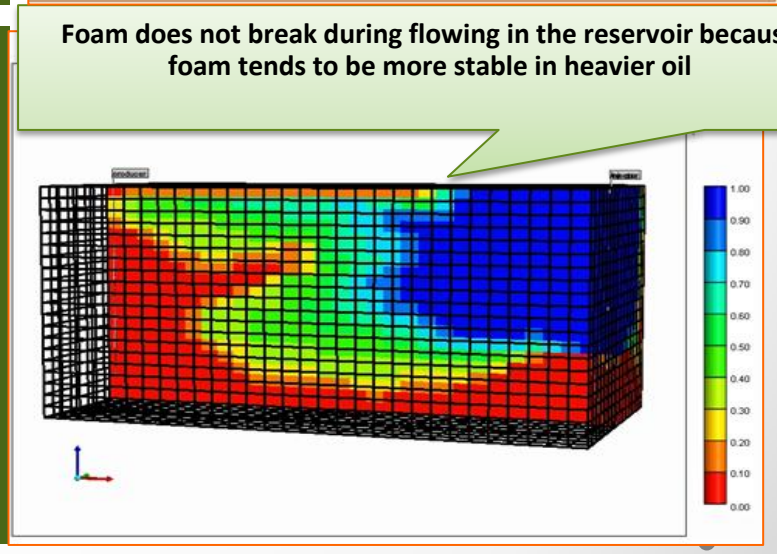
Water production rate



Gas production rate

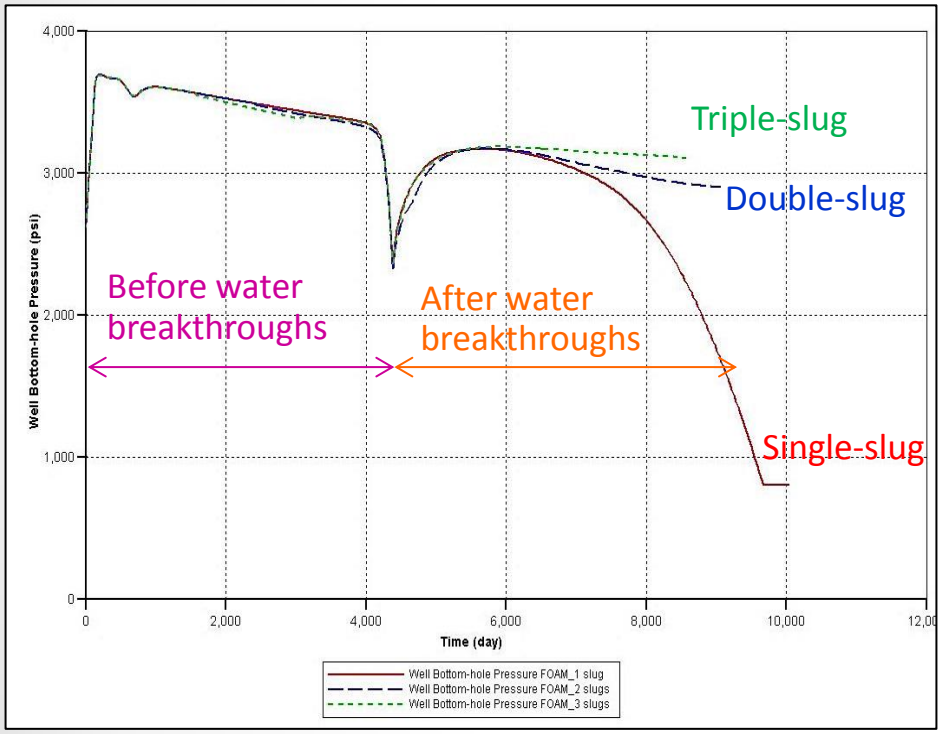


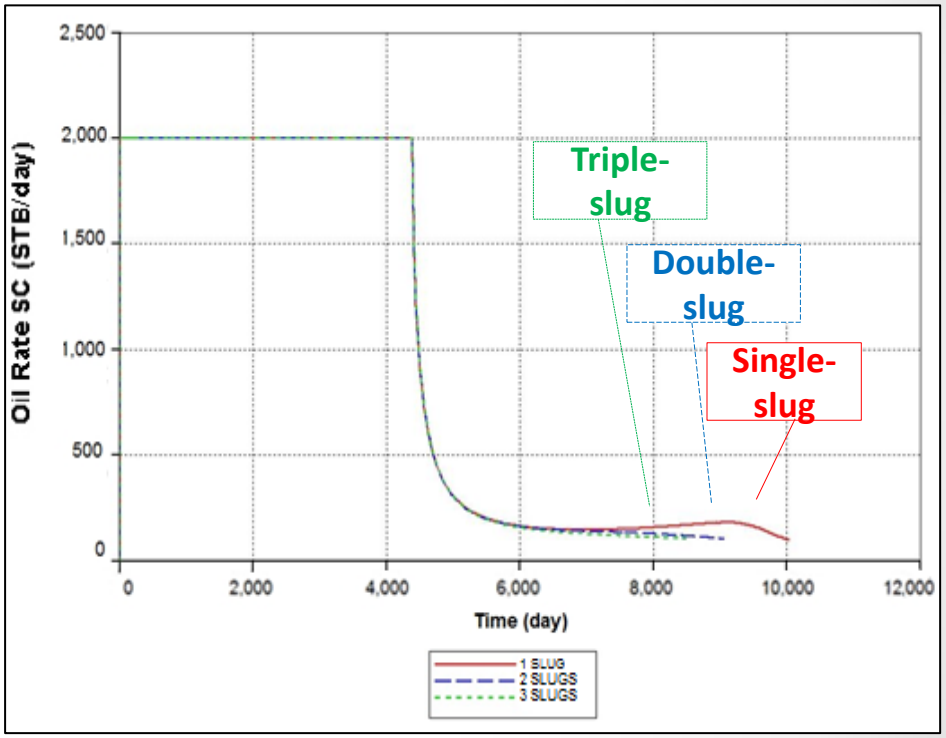
CO_2-foam breakthroughs



The effect of injection slug

- Divide foam injection from 0.4 pore volume into two slugs of 0.2 pore volume and three slugs of 0.133 pore volume. Each slug is alternated with chasing water slugs





- The injecting CO_2 foam can maintain pressure better than the injecting water
- Pressure in latter stage is more important because high pressure leads to maintaining of produced water after water breakthrough.
- The production in the cases of multi-slug were terminated because of water cut reach 95%

Conclusion

CO_2-foam flooding

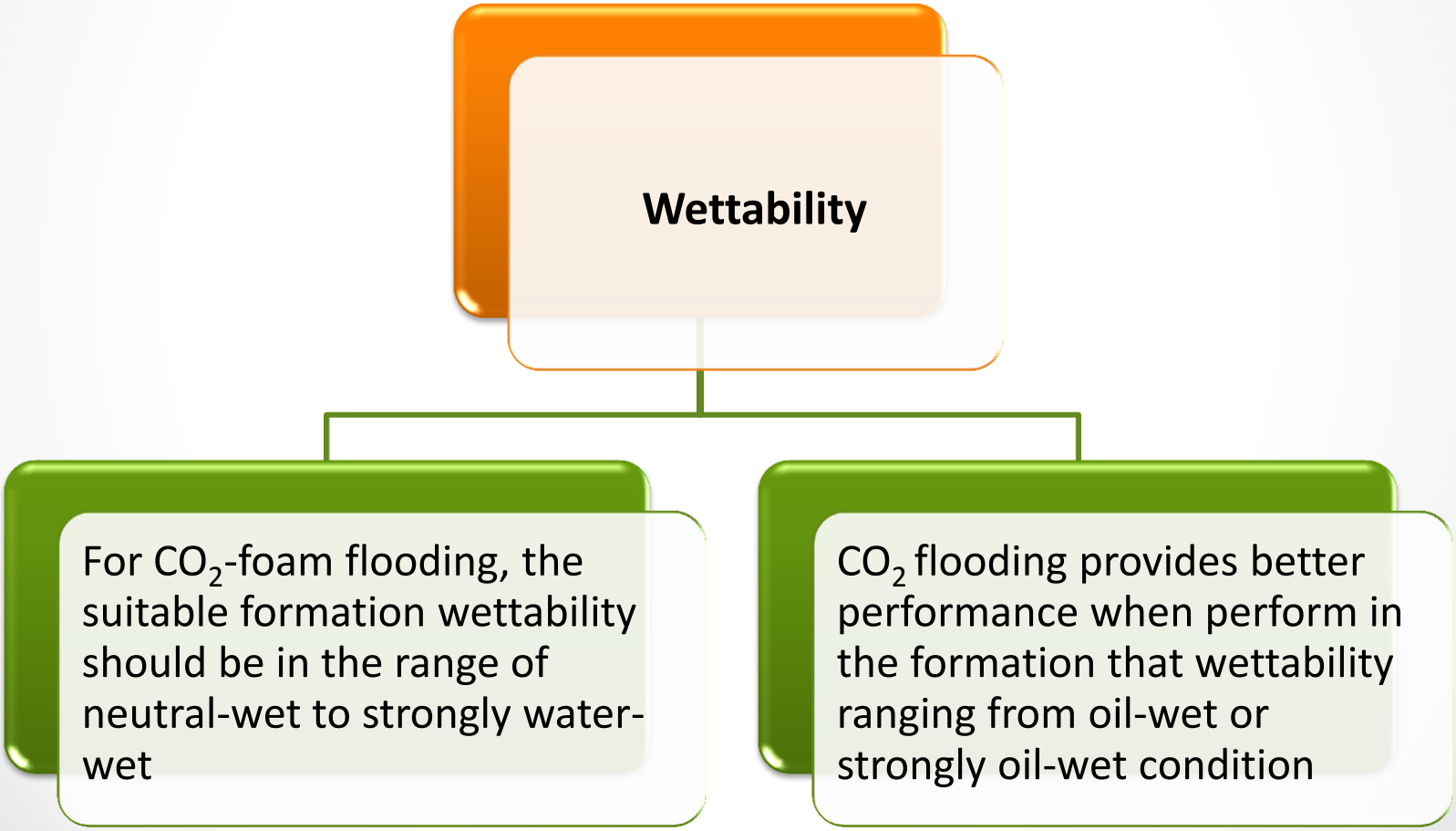
- CO_2-foam flooding cases have ability to enhance hydrocarbon recovery.
- Foam provides smoother flood front.
- Water breakthrough in CO_2-foam flooding causes the reduction of oil production rate

Foam stability

- Variation of foam stability does not significantly impact on production performance of CO_2-foam flooding
- The difference of oil recovery factors by varying foam stability is smaller than 2%
- It could be possible that there are other parameters involve, so effects of foam stability cannot be clearly seen

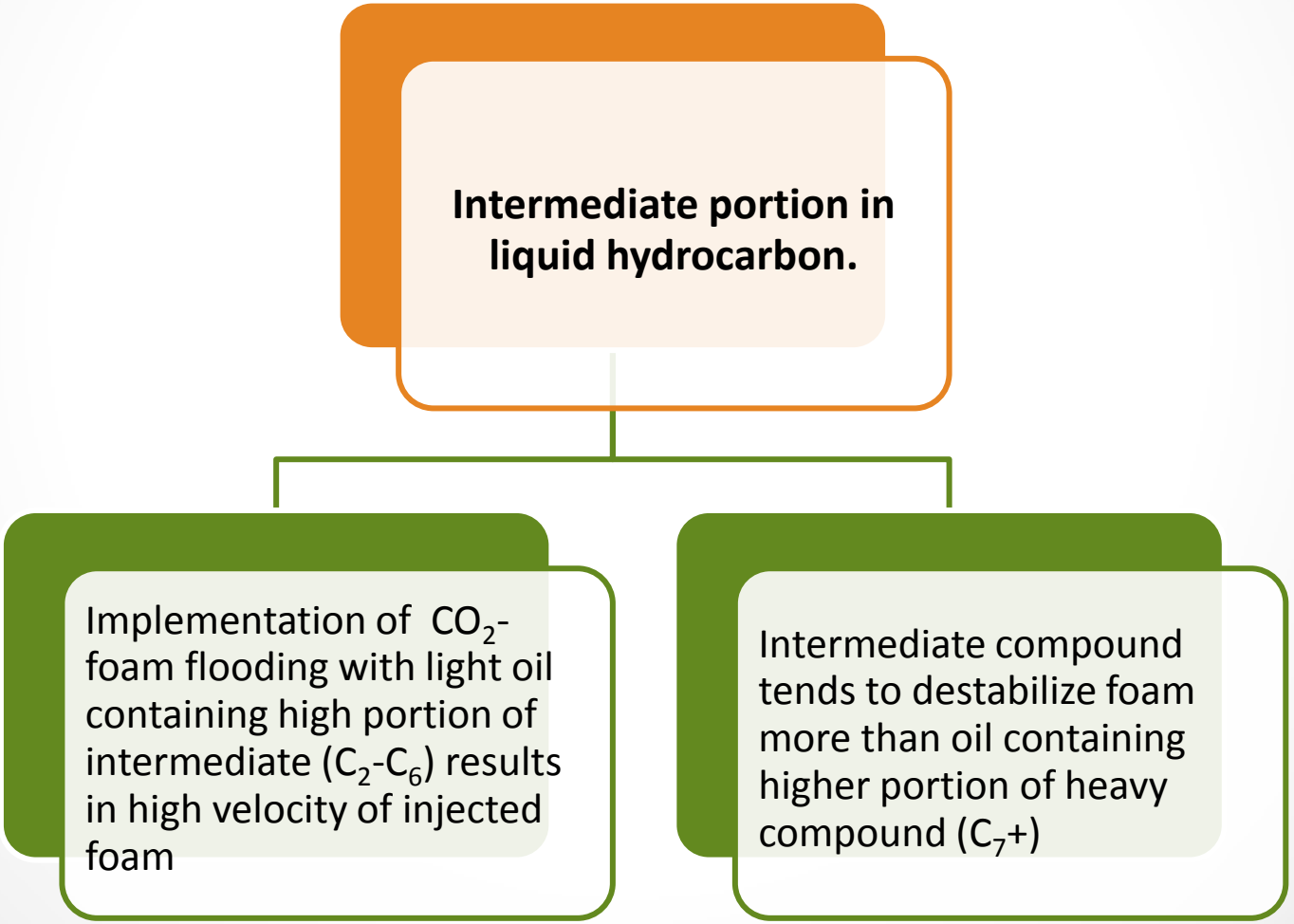
Conclusion

- The influences of wettability on effectiveness and performance of CO_2-foam flooding



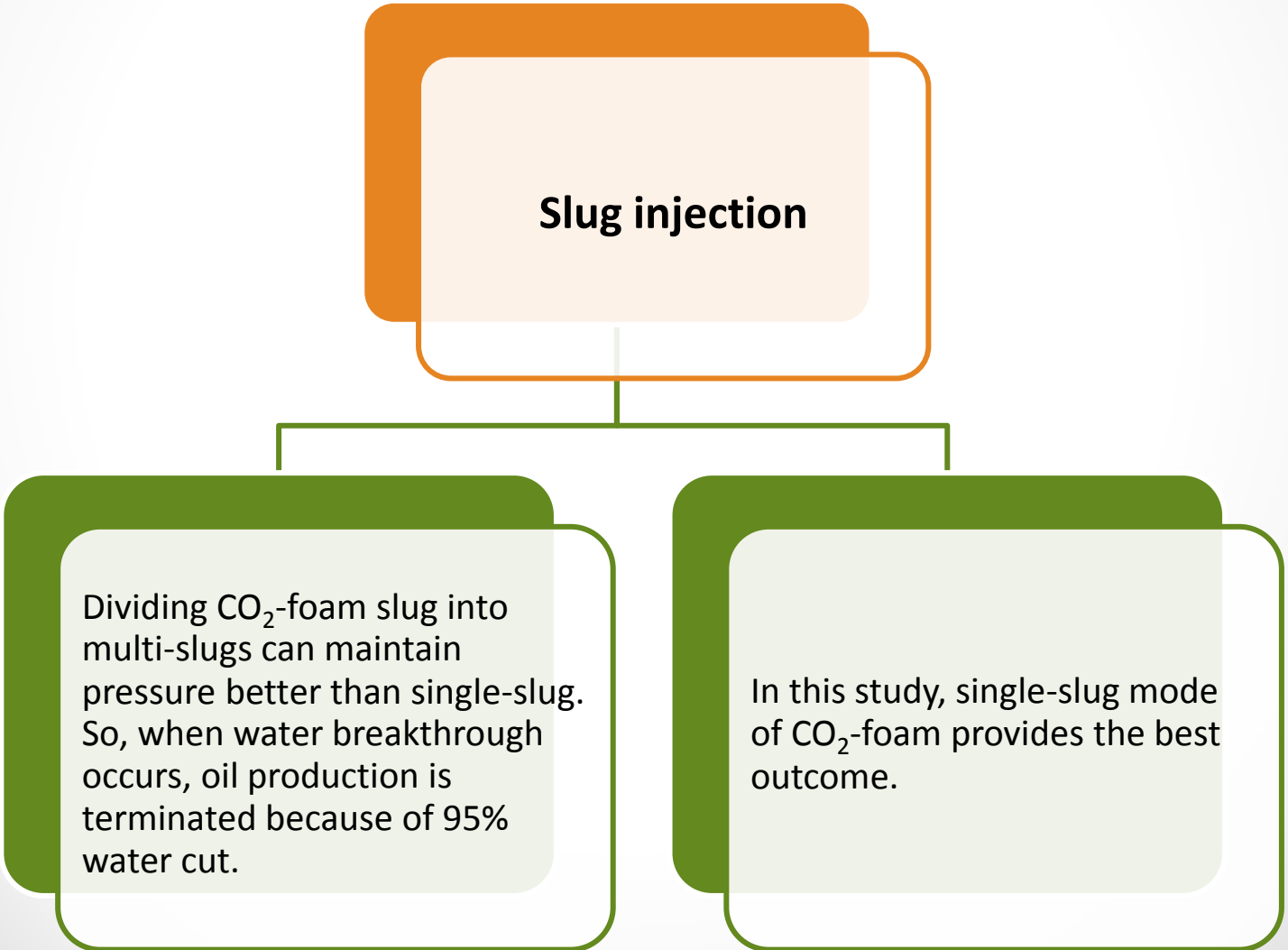
Conclusion

- The influences of intermediate compound in hydrocarbon on effectiveness and performance of CO_2-foam flooding



Conclusion

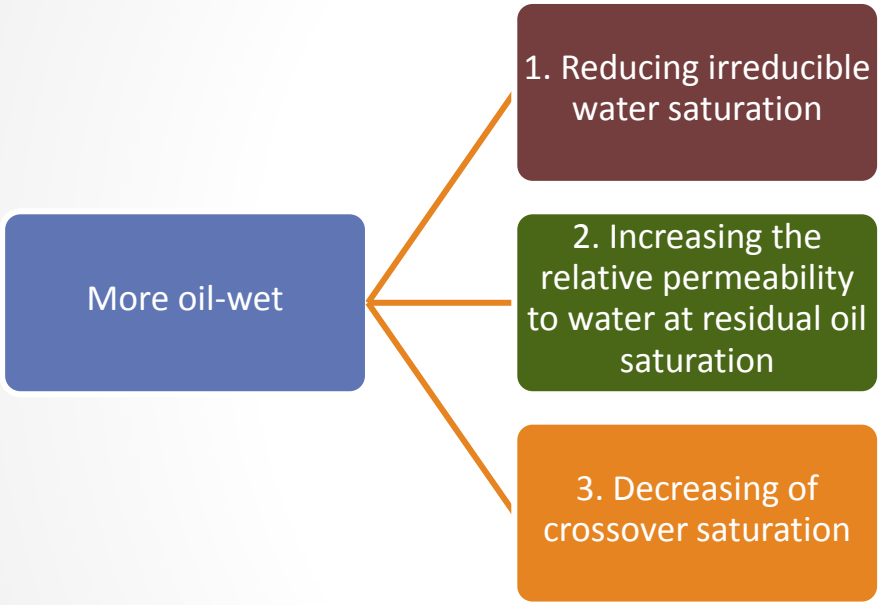
- The influences of slug injection on effectiveness and performance of CO_2-foam flooding

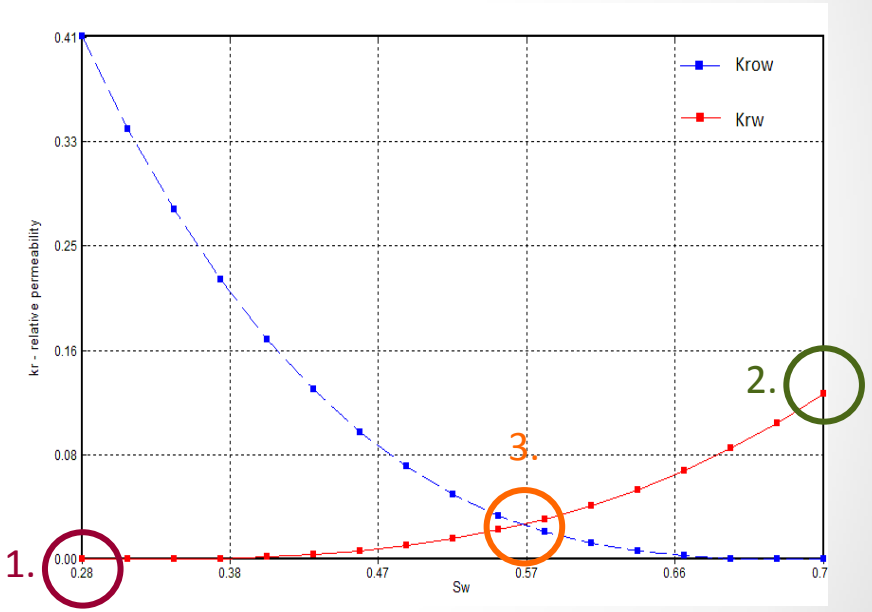


THANK YOU

The effect of wetting condition of reservoir rock

- Wetting conditions that are varied from an original value in a direction to more oil-wet.

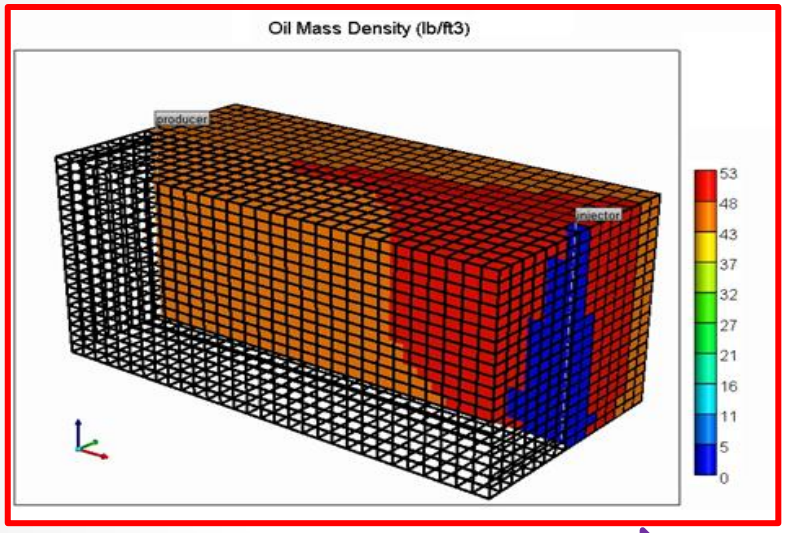




- Vary the wettability condition 4 cases
  1. Moderately water-wet
  2. Neutral wet
  3. Moderately oil- wet
  4. Strongly oil-wet

CO_2 flooding Base Case

- **Miscibility effect**

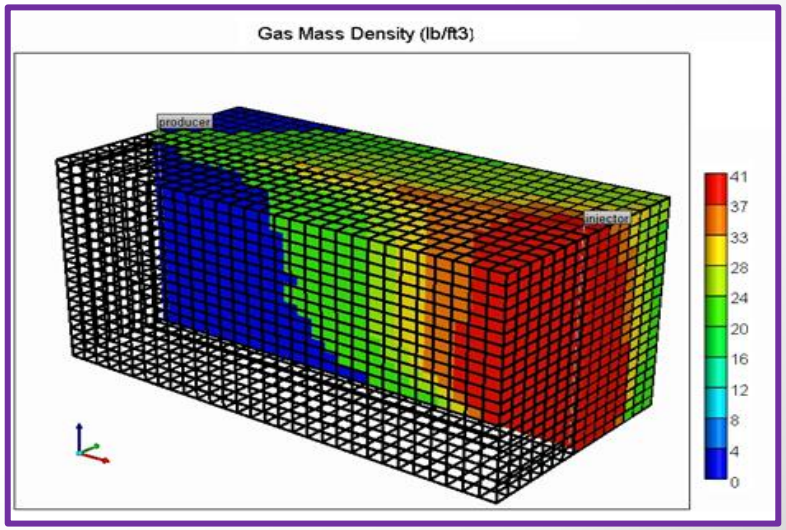


Orange zone : Initial oil density

Red zone : The left oil that cannot be vaporized by CO_2

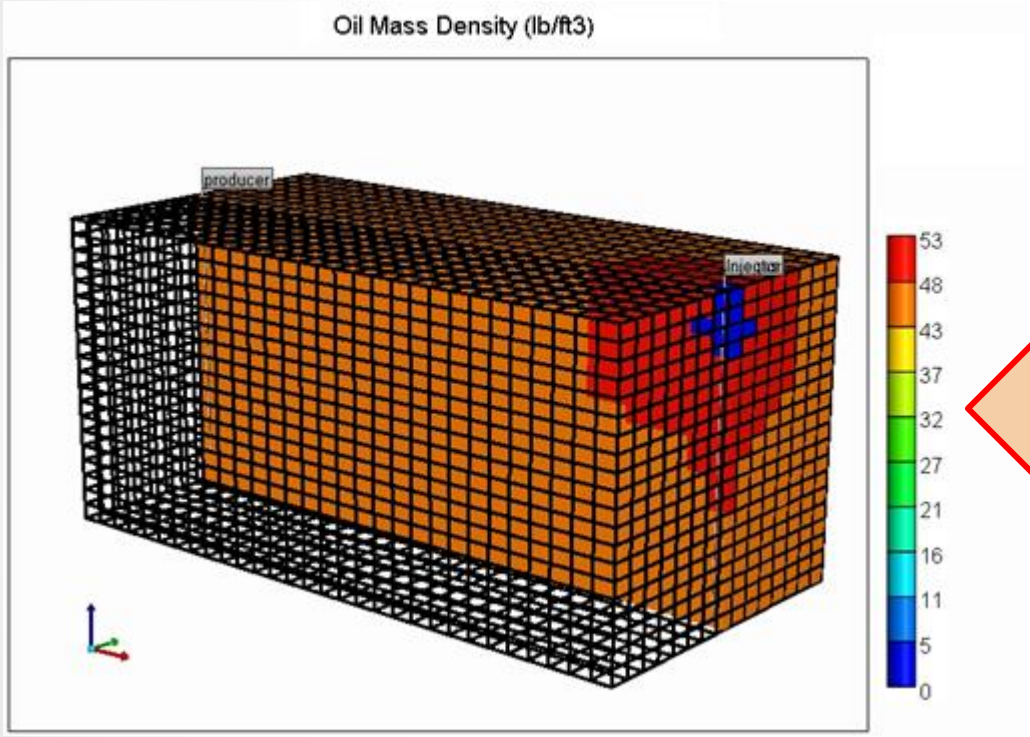
Blue zone : no oil left, pores are all occupied by CO_2

Blue zone : Initial gas density
Green Zone : gases which have lower mass density than CO_2 (CH_4)
Yellow &orange zone : mixing zone between CO_2 and vaporized intermediate
Red zone : zone of CO_2



CO_2-foam flooding base case

Miscibility in CO_2-foam flooding



Orange zone : Initial oil density

Red zone : The left oil that cannot be vaporized from contacting with CO_2

Blue zone : no oil left, pores are all occupied by CO_2

- Oil mass density changes similarly as in the case of CO_2 flooding, but due to amount of CO_2 released from foam is not as much as the case of CO_2 flooding, area of miscibility is much smaller