CO2 Trapping mechanisms assessment using numerical and analytical methods

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GCCC
GULF COAST CARBON CENTER

BUREAU OF ECONOMIC GEOLOGY

Outline

- Down-dip and up-dip stabilization of CO_2 plume in sloped formations
  - Analytical approach
    - Down-dip extent of plume can be estimated
    - Up-dip extent of plume controlled by capillary barriers (needs more work)

- CO_2 Trapping Mechanisms in SACROC Unit
  - Numerical simulation
    - WAG provides the best balance for storage and EOR

Objective and Method

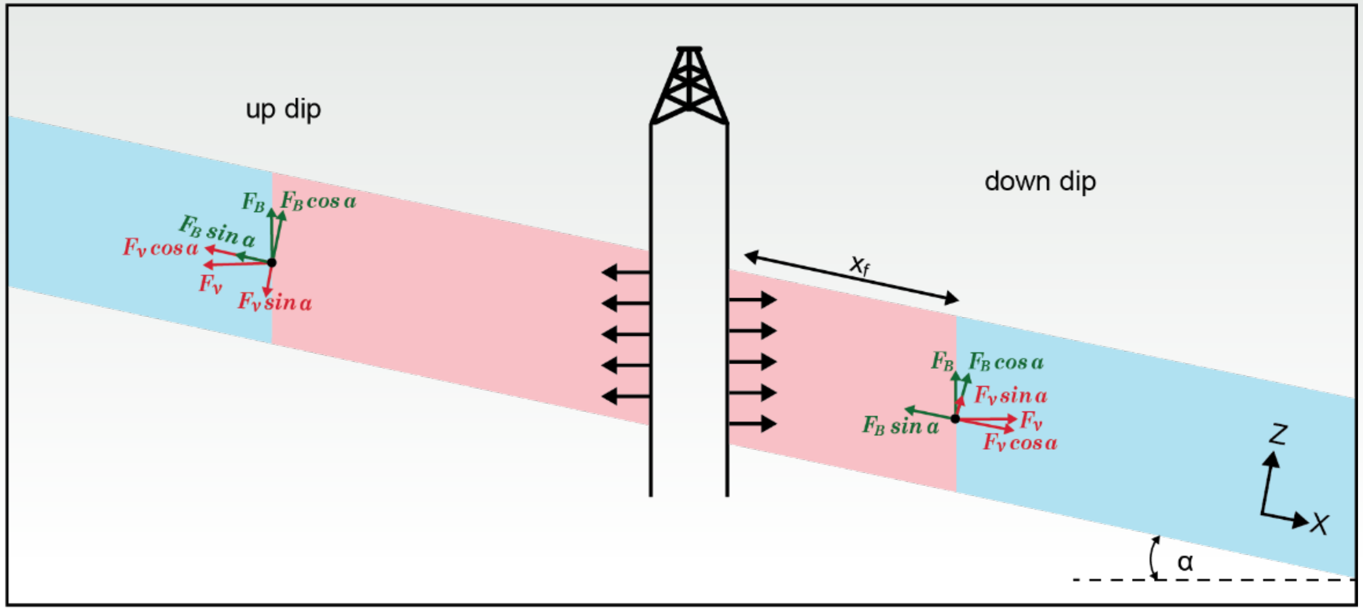
Developing an analytical solution to predict the **extent of CO_2** plume in slopping aquifers

- Assume two active forces: Buoyancy and Viscous
- Ignore capillary force and dissolution
- Homogenous properties
  - Force Balance in x-direction:
    - Up dip : $F_B \sin\alpha + F_v \cos\alpha$
    - down dip : $F_B \sin\alpha - F_v \cos\alpha$

F_B : Buoyancy Force

F_v : Viscous Force

Side View



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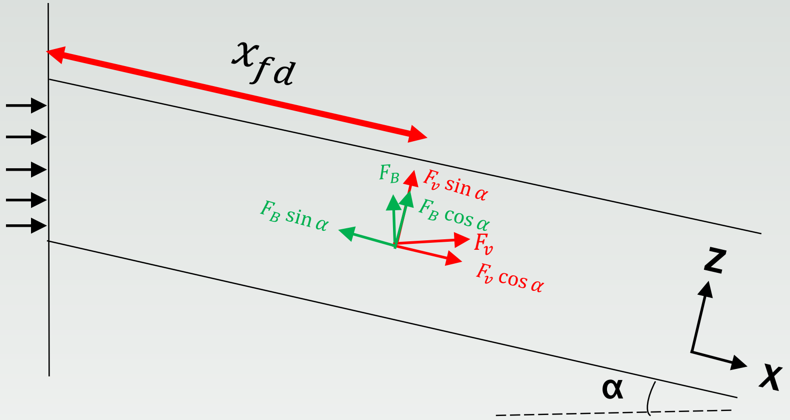
Force Balance Solution Down-dip



- Looking for the point in which x-direction force balance is zero:

$$F_v \cos\alpha - F_B \sin\alpha = 0$$

- Dividing by area:

$$P_B = (\rho_w - \rho_g)gh$$

$$P_v = Q\mu_g / kx_{fd}$$

$$\frac{Q\mu_g}{kx_{fd}}\cos\alpha - (\rho_w - \rho_g)gh\sin\alpha = 0$$

$$\boxed{x_{fd} = \frac{\frac{Q\mu_g}{k}\cos\alpha}{(\rho_w - \rho_g)gh\sin\alpha}}$$

Q : CO_2 Injection Rate

μ_g: CO_2 Viscosity

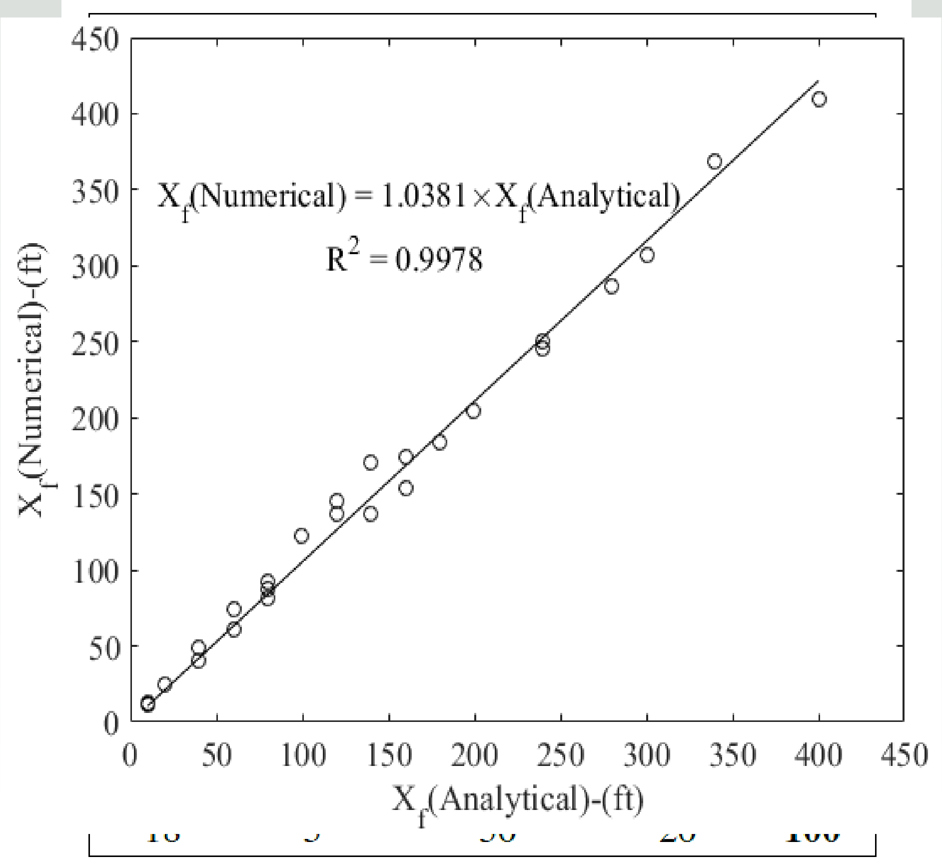
k : Permeability

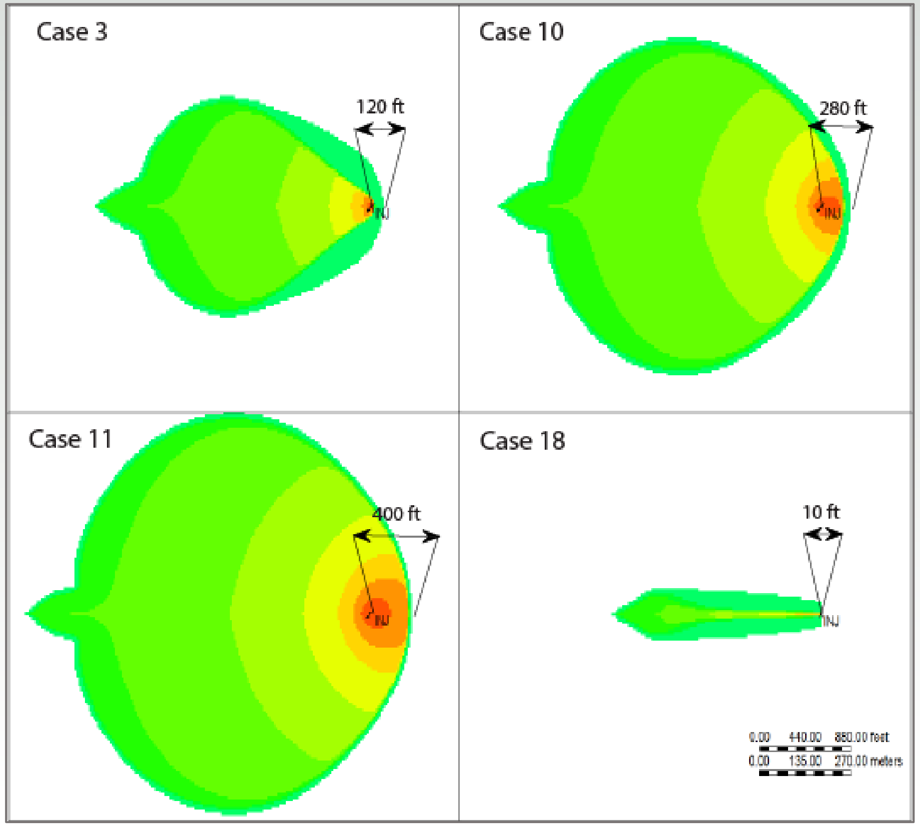
ρ_w : Water Density

ρ_g : CO_2 Density

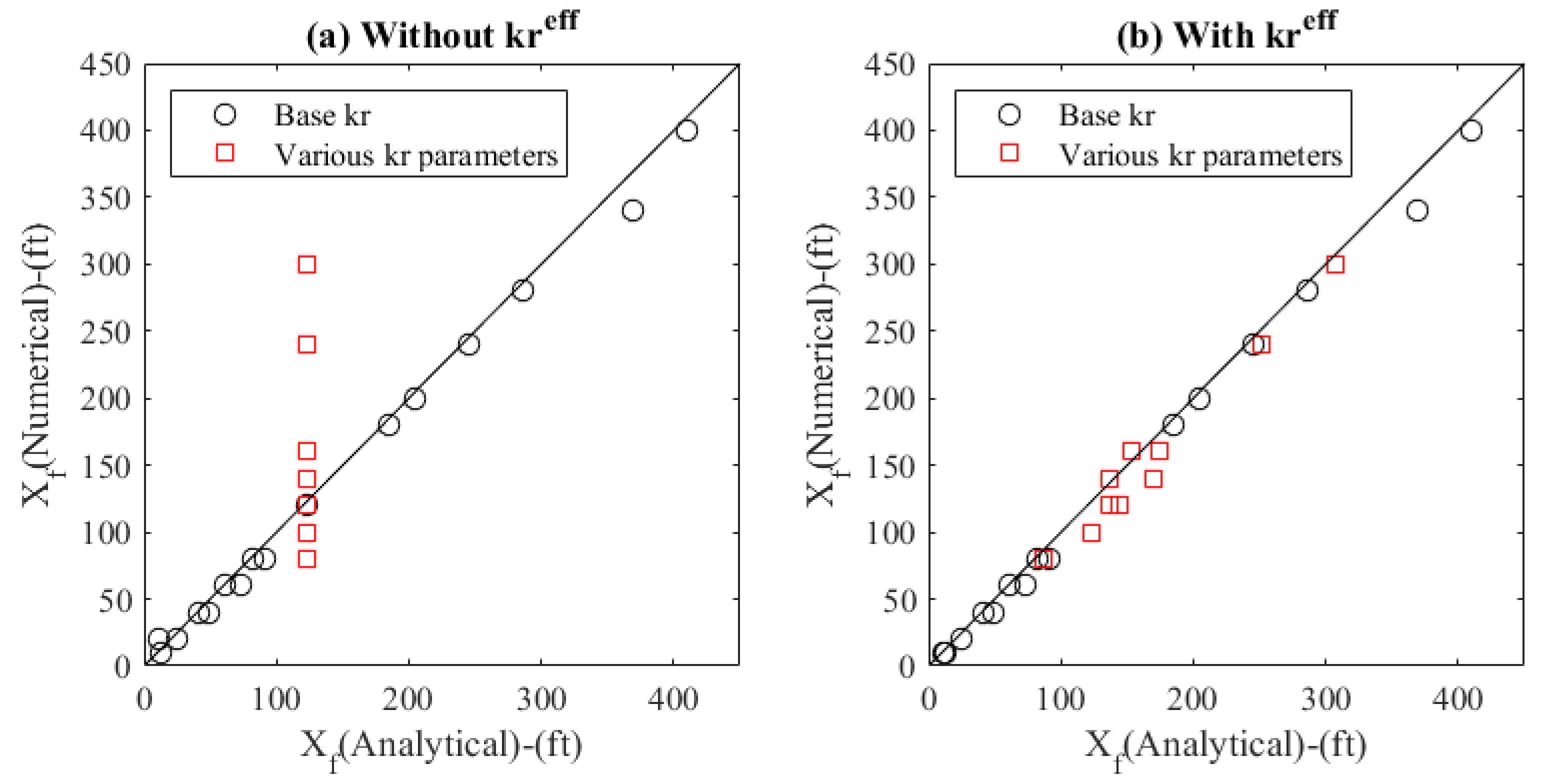
h : Thickness

Effective Relative Permeability





Relative Permeability Impact

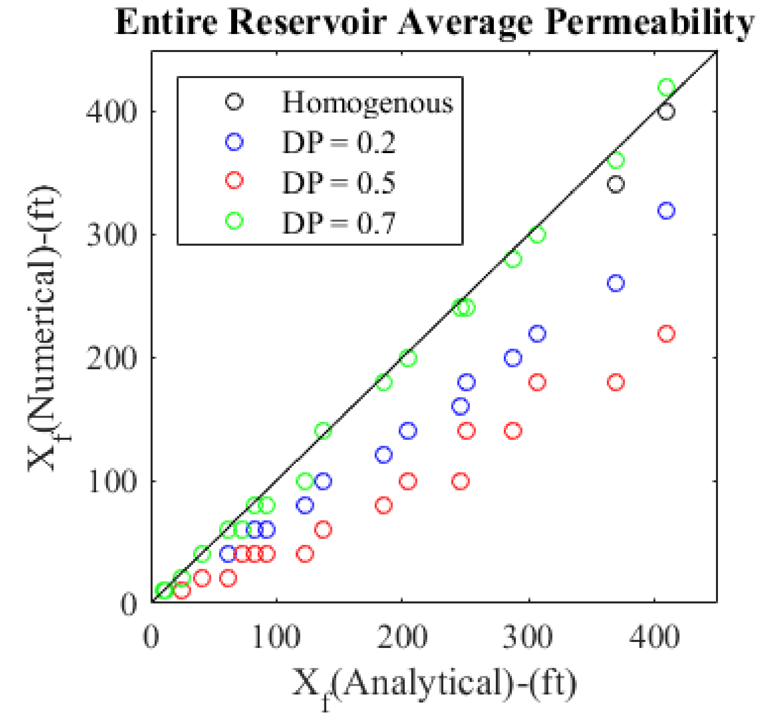


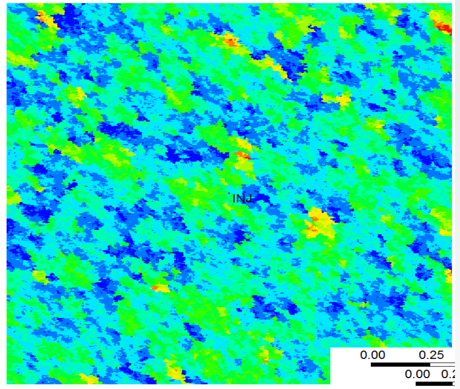
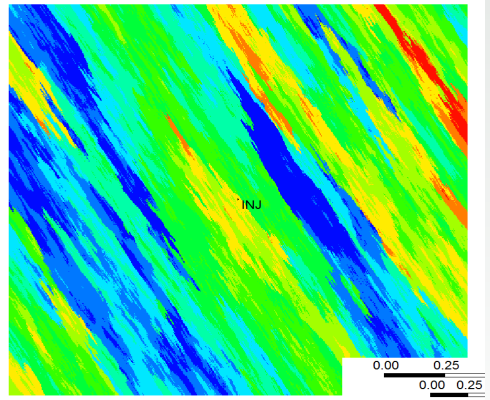
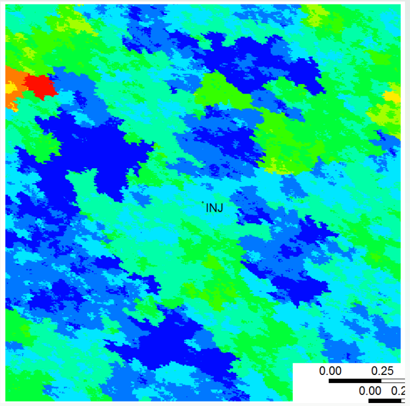
$$x_{fd} = \frac{\frac{Q\mu_g}{k}\cos\alpha}{(\rho_w - \rho_g)gh\sin\alpha}$$

$$x_{fd} = \frac{\frac{Q\mu_g}{k k_r^{eff}}\cos\alpha}{(\rho_w - \rho_g)gh\sin\alpha}$$

$$k_r^{eff} = 2 \times \sqrt{k_r^{cross}}$$

Heterogeneity

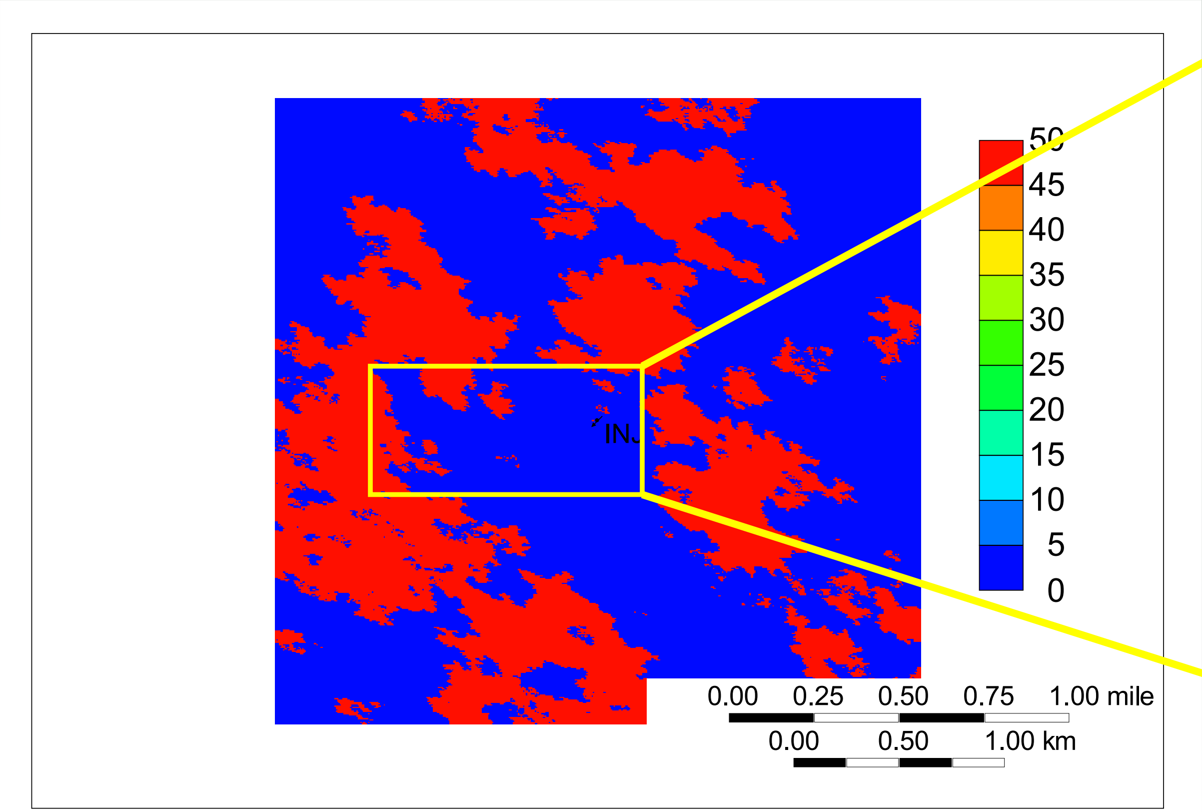


Dykstra Parson Coefficient = 0.2	Dykstra Parson Coefficient = 0.5	Dykstra Parson Coefficient = 0.7
		

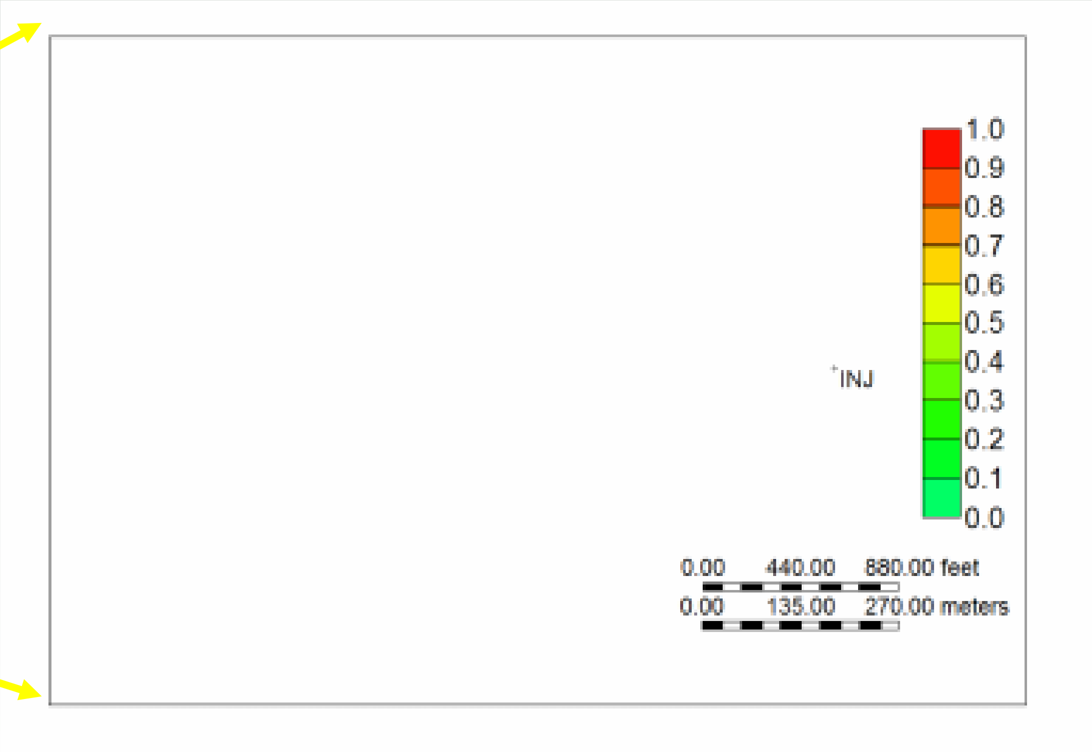
$$x_{fd} = \frac{\frac{Q\mu_g}{kk_r^{eff}}\cos\alpha}{(\rho_w-\rho_g)gh\sin\alpha}$$

Up-dip trapping

Capillary Pressure (psi)-Top View



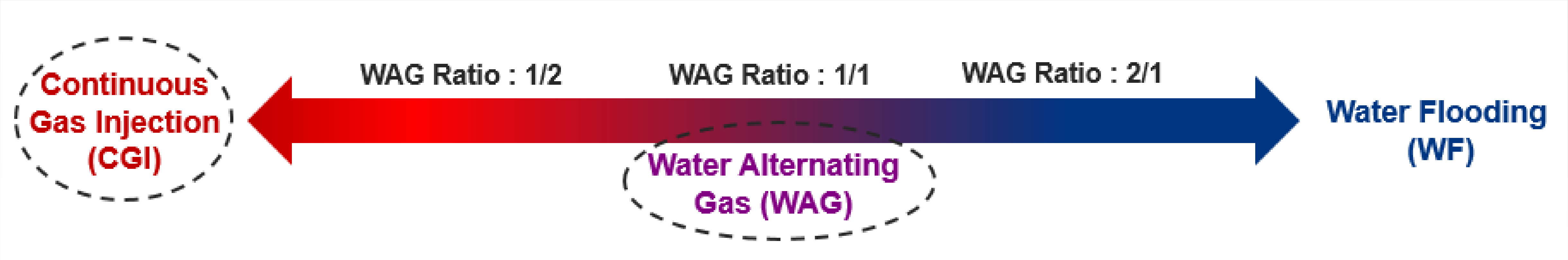
CO_2 Saturation



CO2 Trapping Mechanisms in SACROC Unit

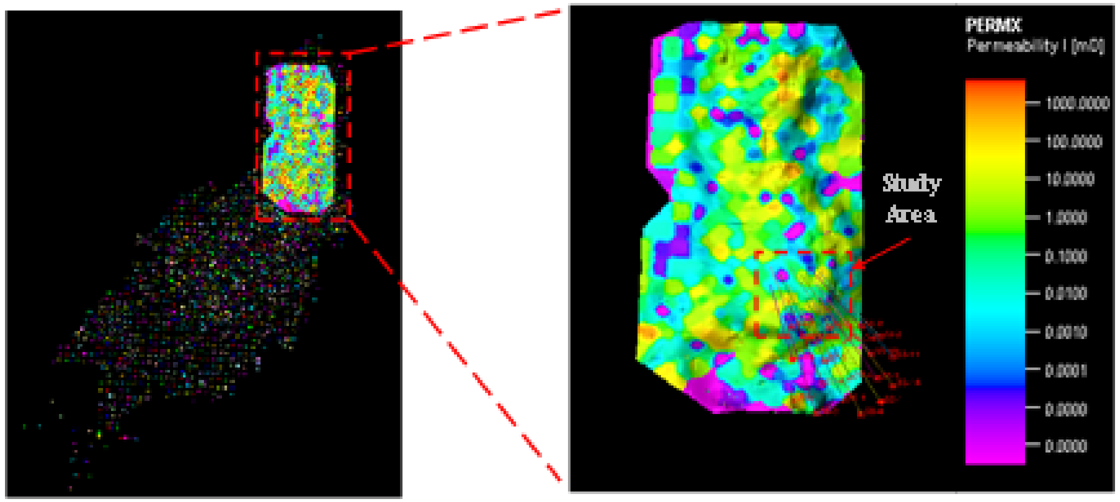
- The contribution of trapping mechanisms to CO_2 storage depends on various reservoir's parameters.

- An intelligent selection of CO_2 injection strategy improves the incremental oil recovery, CO_2 storage capacity, and CO_2 utilization ratio (UR).



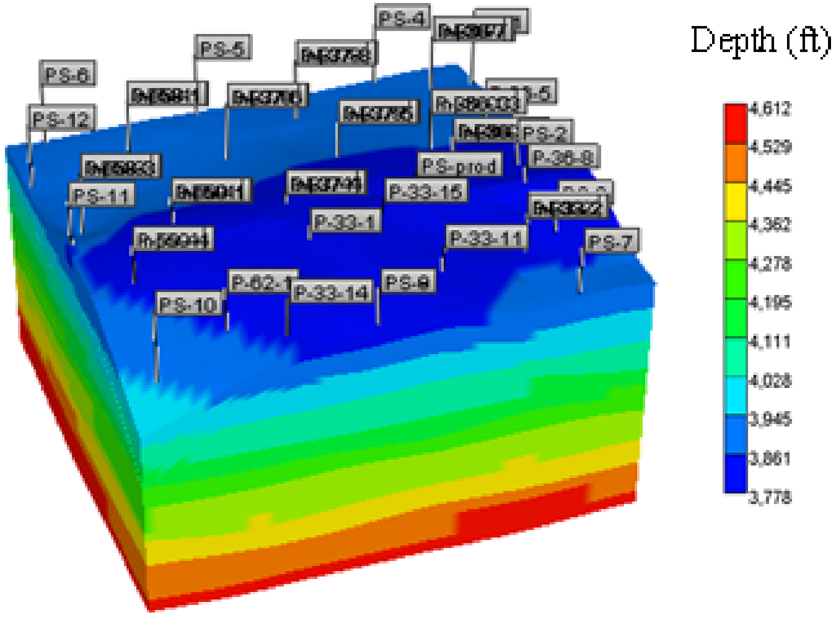
Reservoir Model

Maximum Permeability: 500 mD



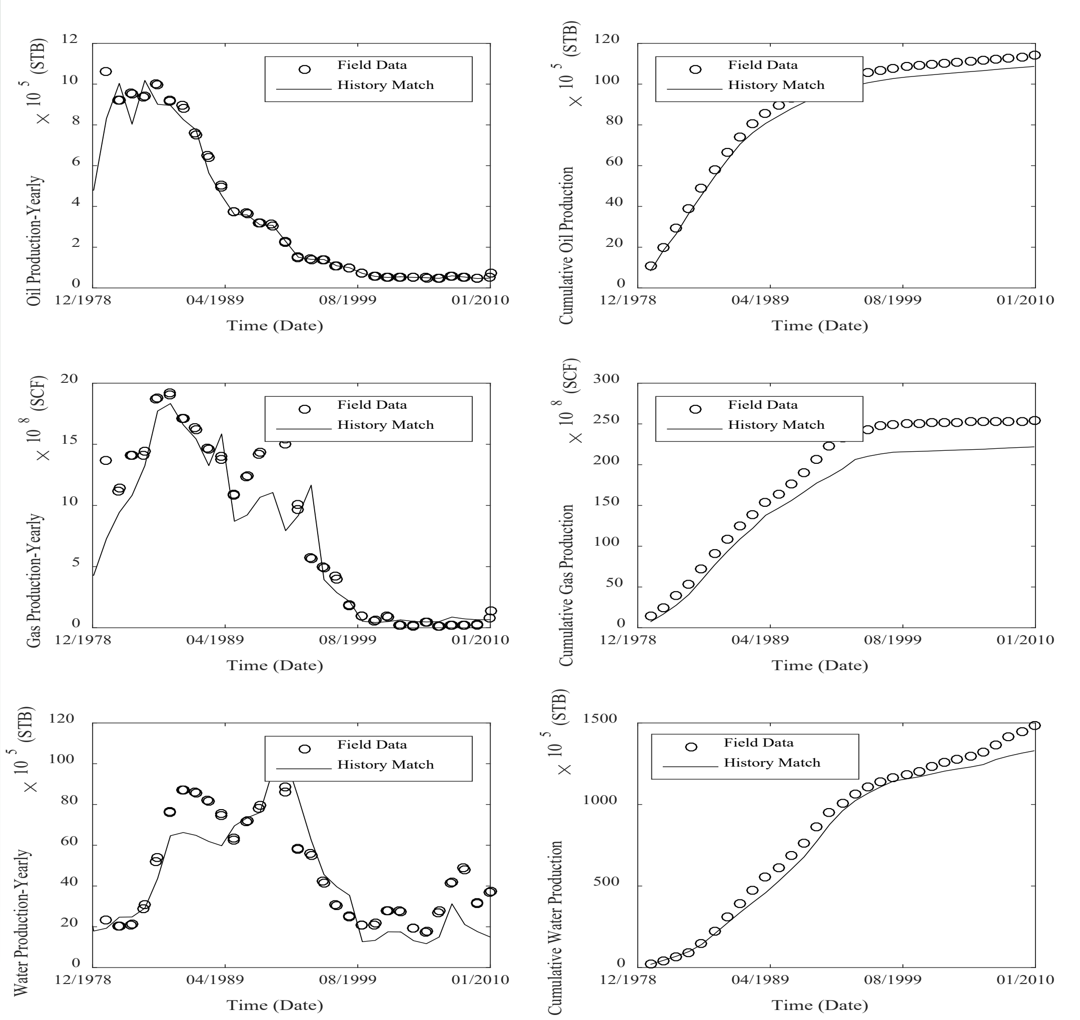
SACROC unit **Northern platform and study area**

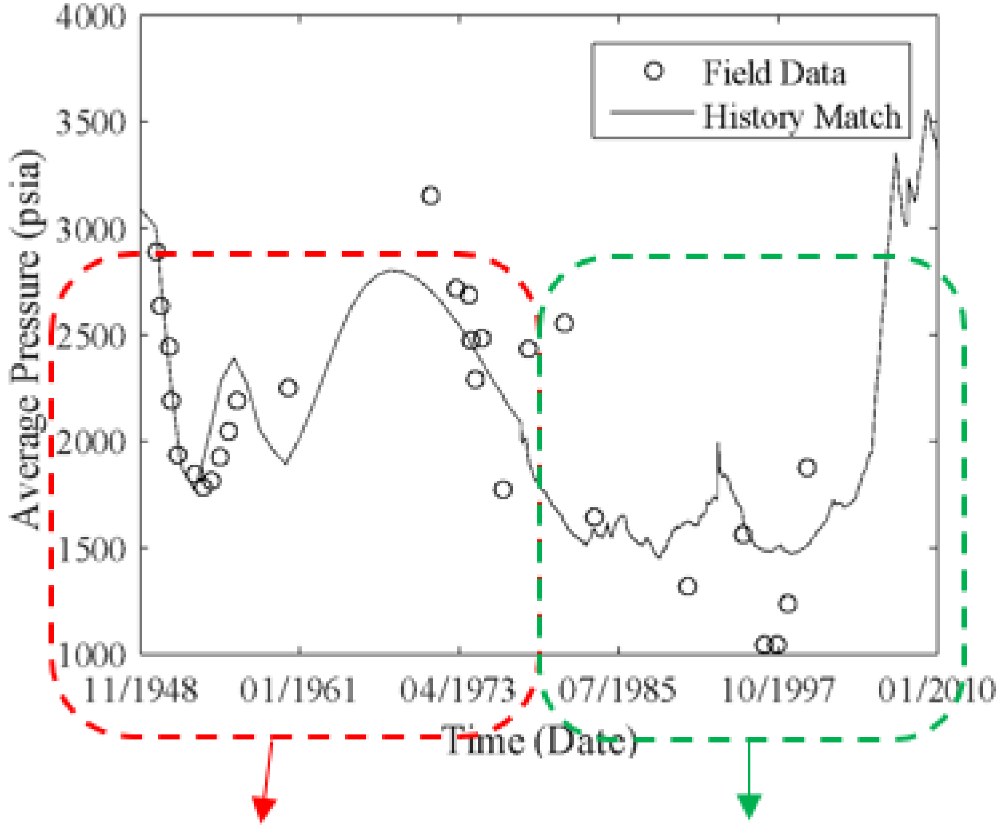
9,450,623 grid blocks



✓ **The study area includes 19 production wells. 12 wells have been converted to injection wells for waterflooding. Out of these 12 wells, 10 have undergone CO_2 flooding.**

Pressure-Production History Matching

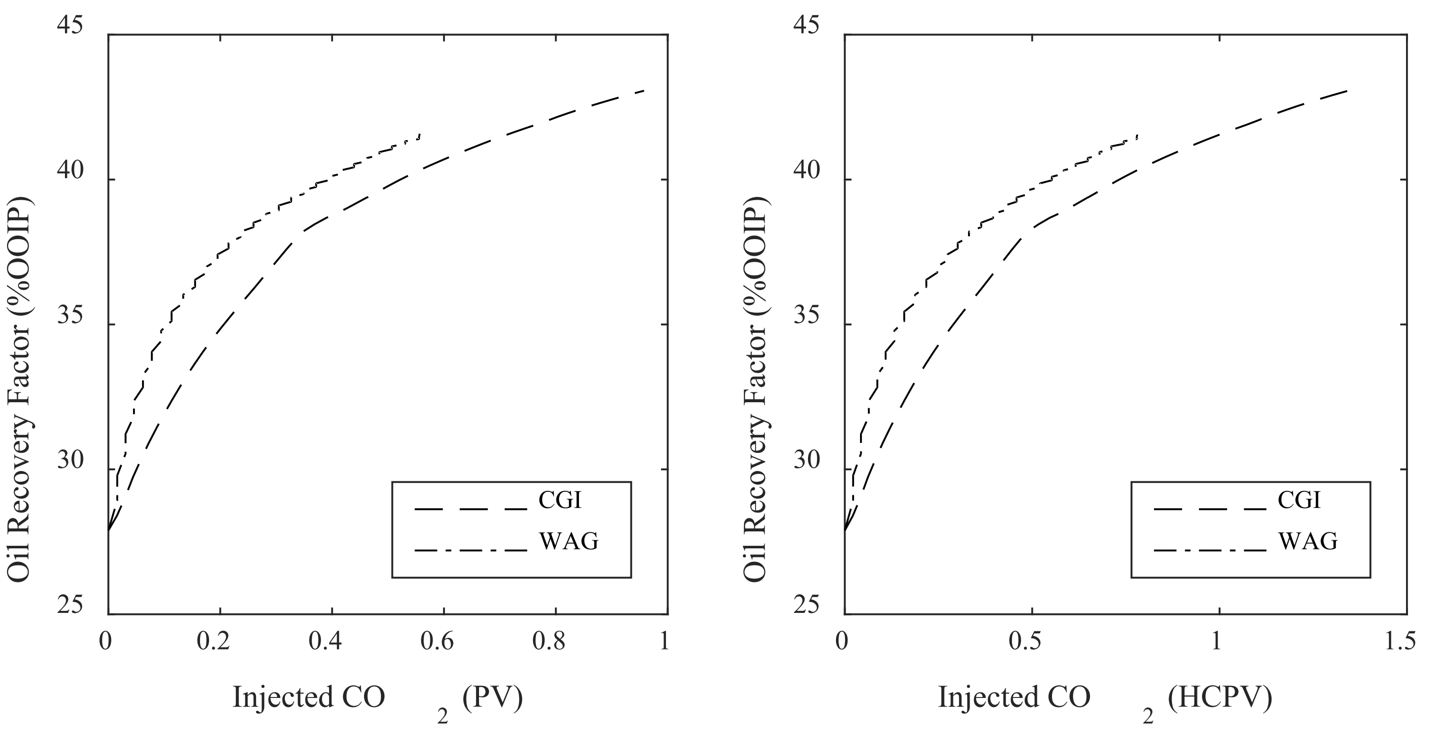




U.S. Department of Energy report (1948–1978)

We had access to the data for the period from 1978 to 2010.

Difference Between WAG and CGI



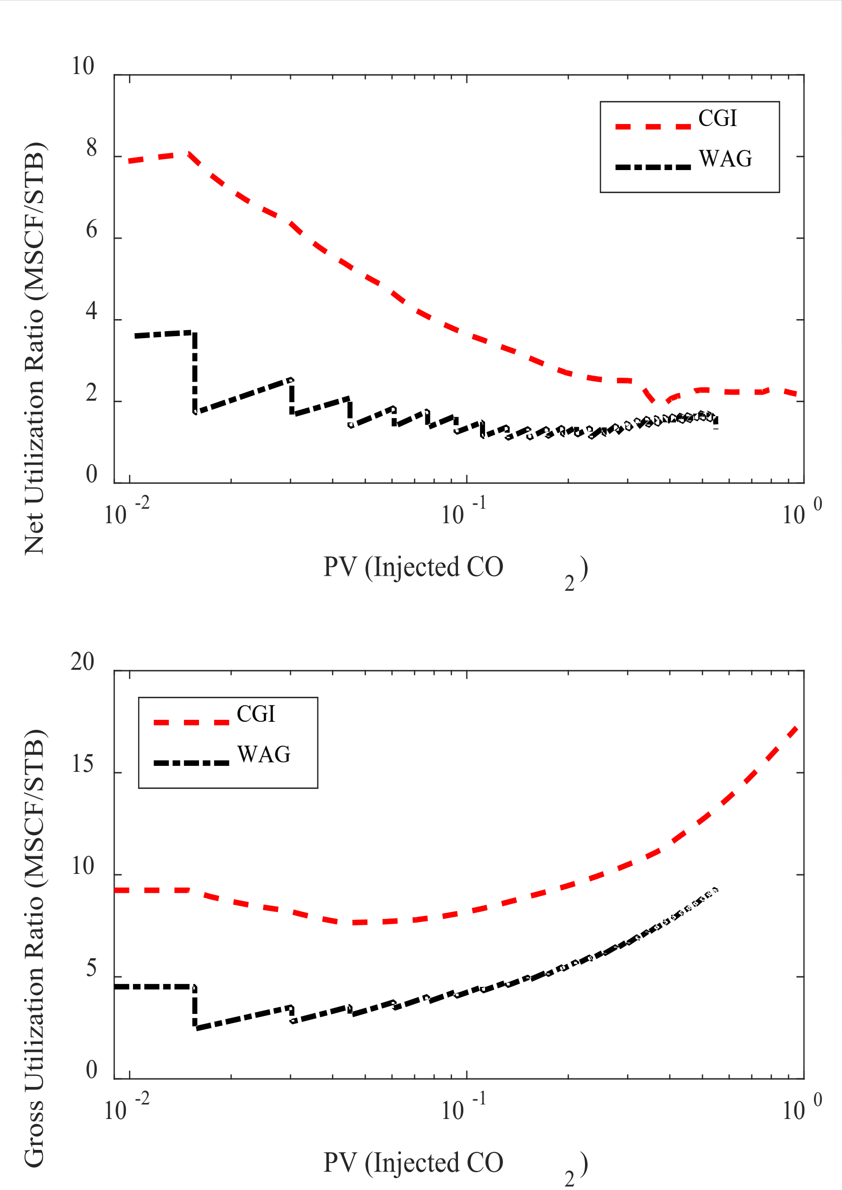
- ✓ **Although the total oil recovery factor is higher in CGI (around 43%), the recovery factor for the same amount of injected CO_2 is higher in WAG scenario**

CO2 Utilization Ratios

- WAG shows much lower utilization ratios in comparison with CGI.
- Utilization ratio is not a constant number and is highly dependent on the time of CO_2 injection.

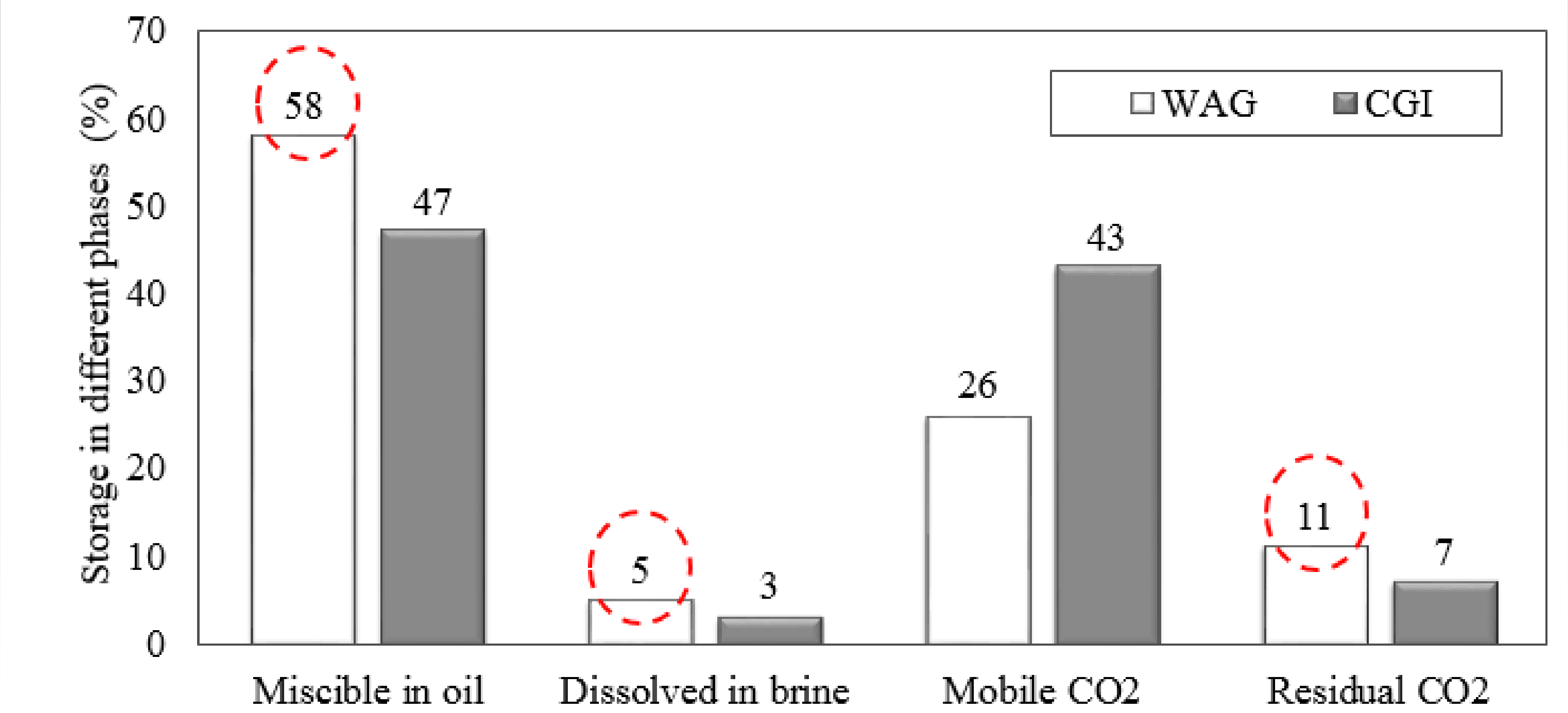
$$Net\ UR = \frac{Injected\ CO_2 - Produced\ CO_2}{Produced\ Oil}$$

$$Gross\ UR = \frac{Injected\ CO_2}{Produced\ Oil}$$

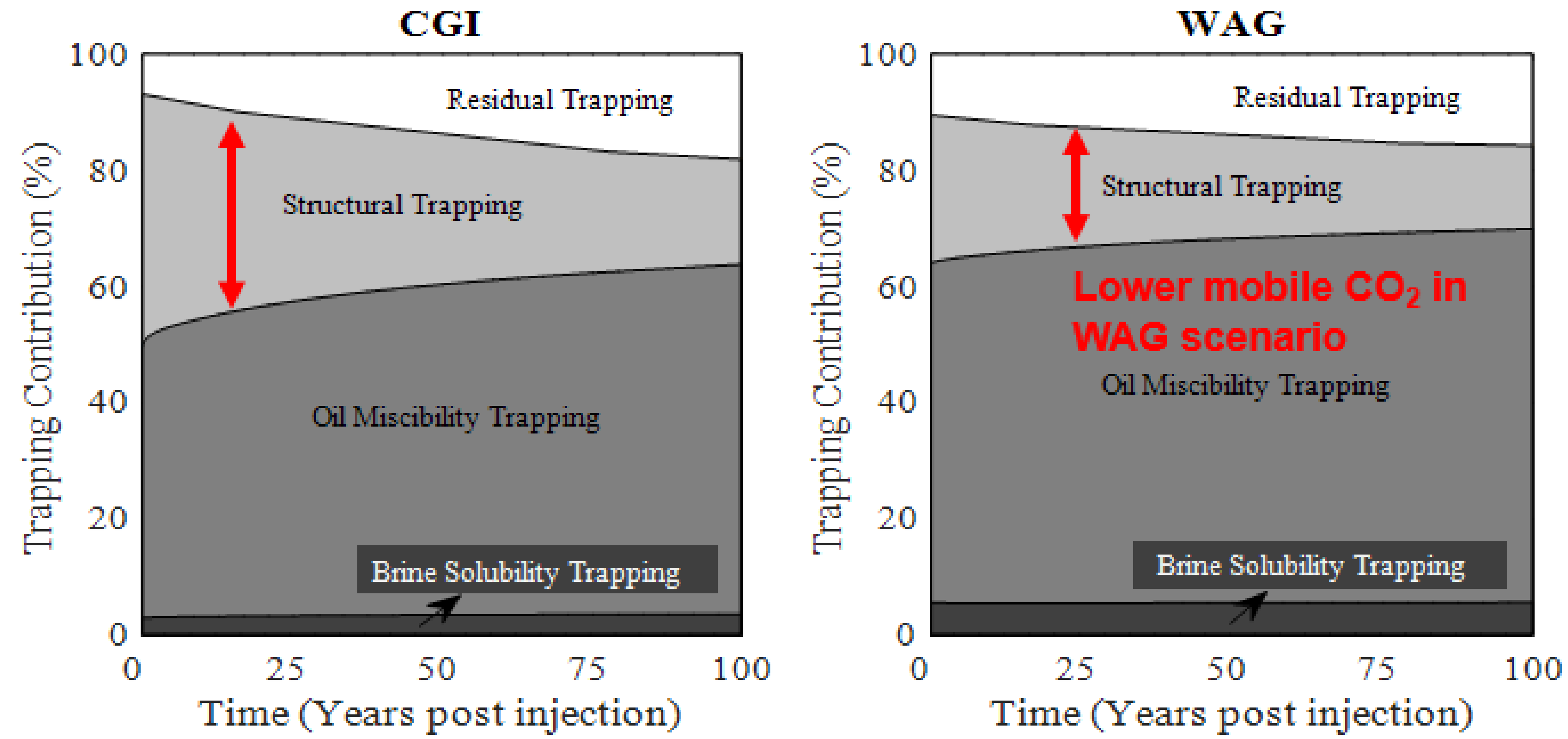


Trapping Mechanisms Contribution

End of CO_2 injection period (01/2010)



Trapping Mechanisms Contribution



Lower mobile CO_2 in WAG scenario

Dissolution Trapping = Oil Miscibility + Brine Solubility

Conclusions

1. **WAG shows a good balance between maximizing oil production and CO_2 storage with a lower utilization ratio compared to CGI.**

2. **We have more free phase CO_2 in the reservoir in CGI while more CO_2 in dissolved and trapped form in WAG.**

3. **CO_2 net and gross utilization ratios are not constant but evolve during the injection period.**

Extra slides

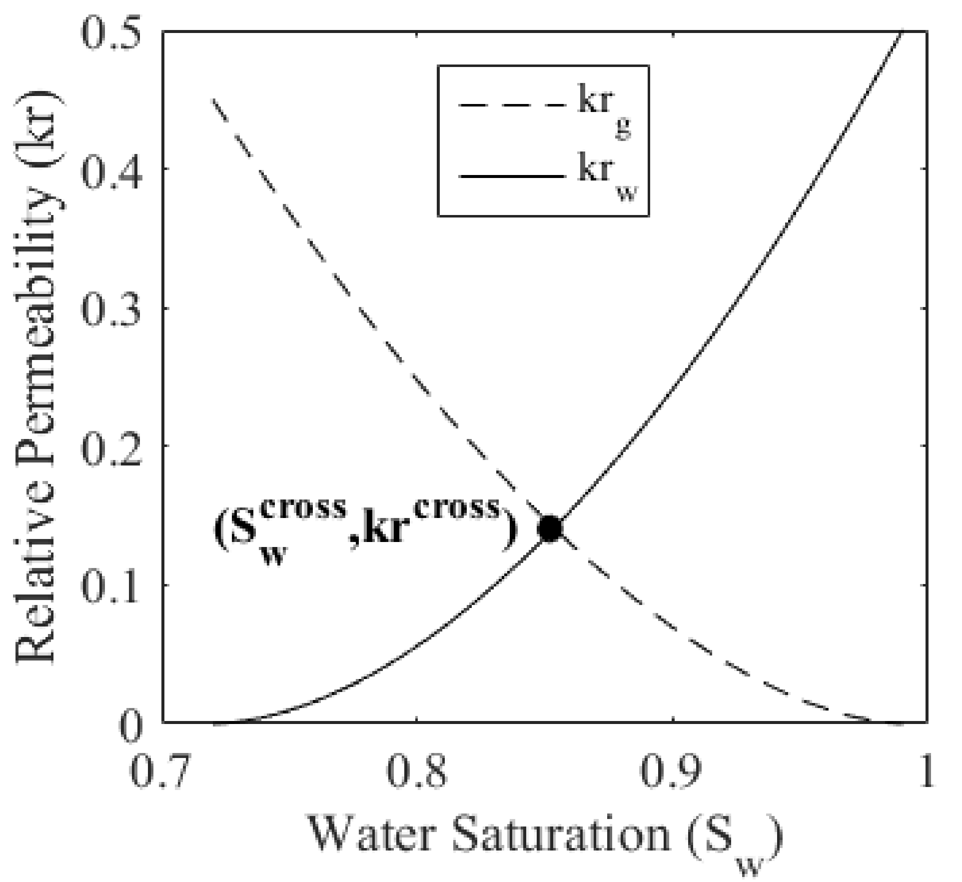
Effective Relative Permeability

- ☐ We found the effective relative permeability based on several simulation cases that we conducted.

$$\boxed{k_r^{eff} = 2 \times \sqrt{k_r^{cross}}}$$

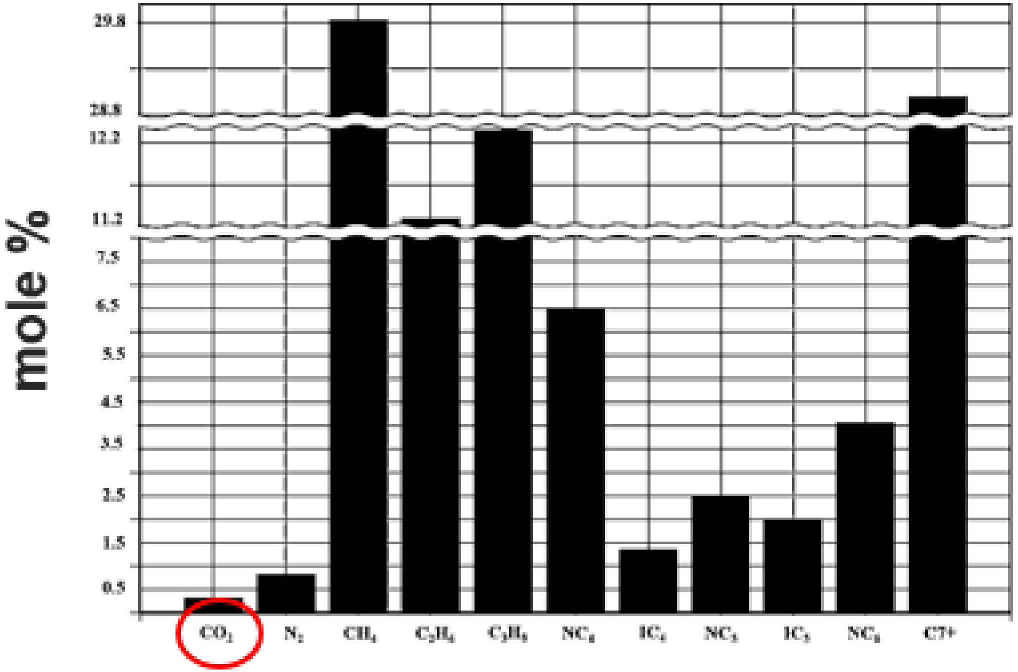
- ☐ We modify the equation:

$$\boxed{x_{fd} = \frac{\frac{Q\mu_g}{kk_r^{eff}}\cos\alpha}{(\rho_w - \rho_g)gh\sin\alpha}}$$

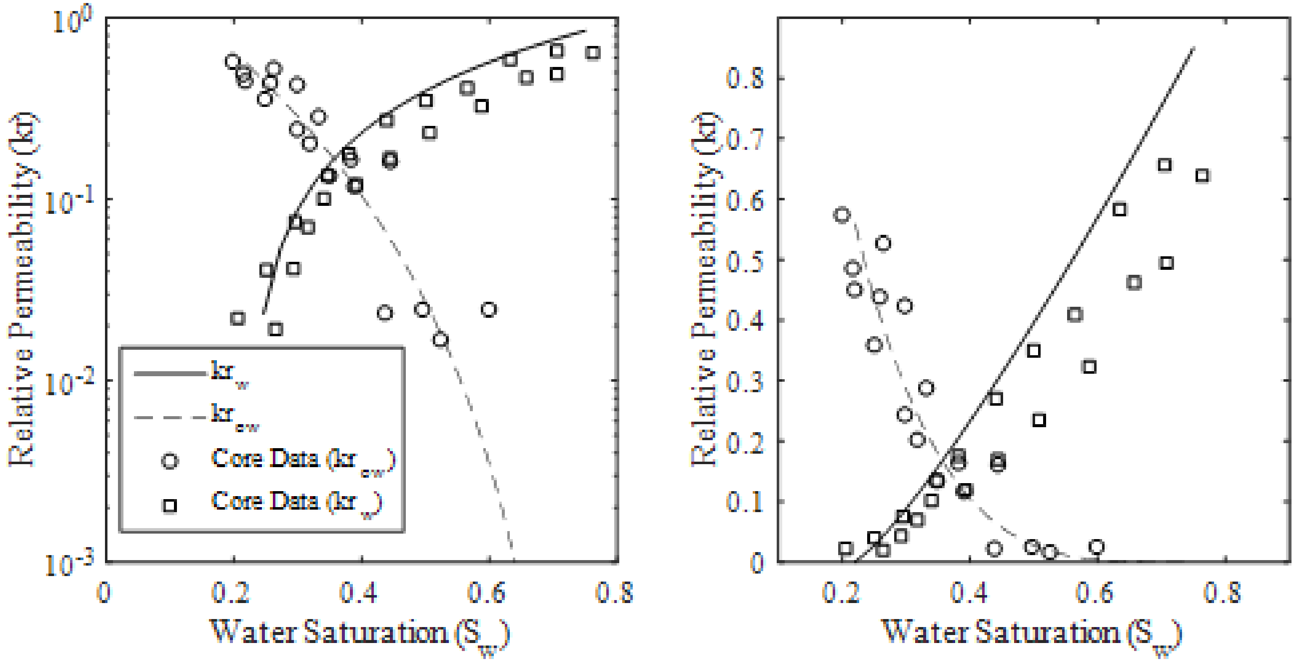


Phase Behavior & Relative Permeability

- ✓ Reservoir fluid viscosity at bubble point pressure (1,820 psia): 0.38 cp
- ✓ Composition: based on measured data



11 components



- ✓ History matching is achieved with relative permeability curves which are in good agreements with core data.

Trapped CO_2 Calculation

- ✓ **Material balance:**

$$M_{CO_2}^{Injected} = \overbrace{M_{CO_2}^{oil} + M_{CO_2}^{brine}}^{\text{Dissolution Trapping}} + M_{CO_2}^{residual} + M_{CO_2}^{Structural} + \boxed{M_{CO_2}^{mineral}} \xrightarrow{\text{Negligible}} + M_{CO_2}^{produced}$$

$$M_{CO_2}^{residual} = \sum_{i=1}^{n} V_{m,co2}(i) \times f_{CO2}(i) \times S_{CO2,r}(i) \times PV(i)$$

M_{CO_2} : Mole CO_2

$V_{m,g}$: molar density of gas phase

f_{CO2}: CO_2 mole fraction

$\boxed{S_{CO2,r}}$: residual CO_2 saturation

PV: net pore volume

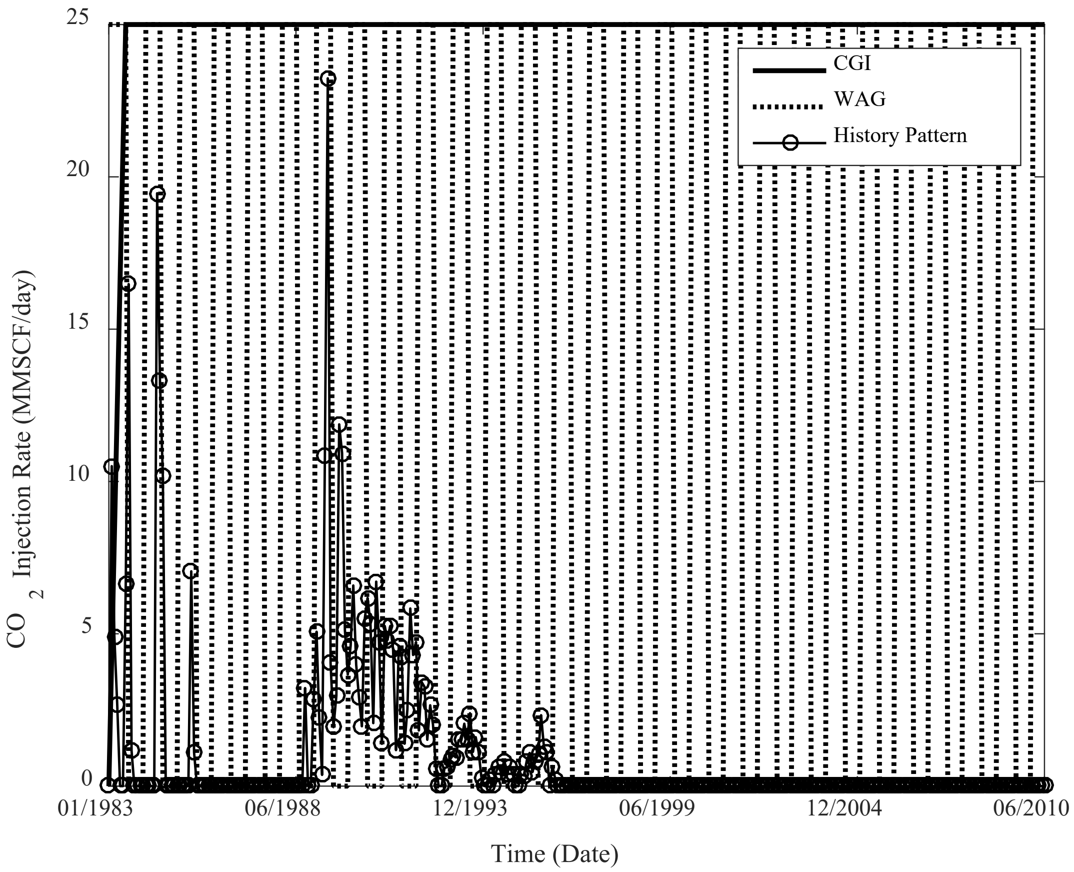
Calculated using Land's (1968) equation

Land, C.S., 1968. Calculation of imbibition relative permeability for two- and three-phase flow from rock properties. Society of Petroleum Engineers Journal 1942

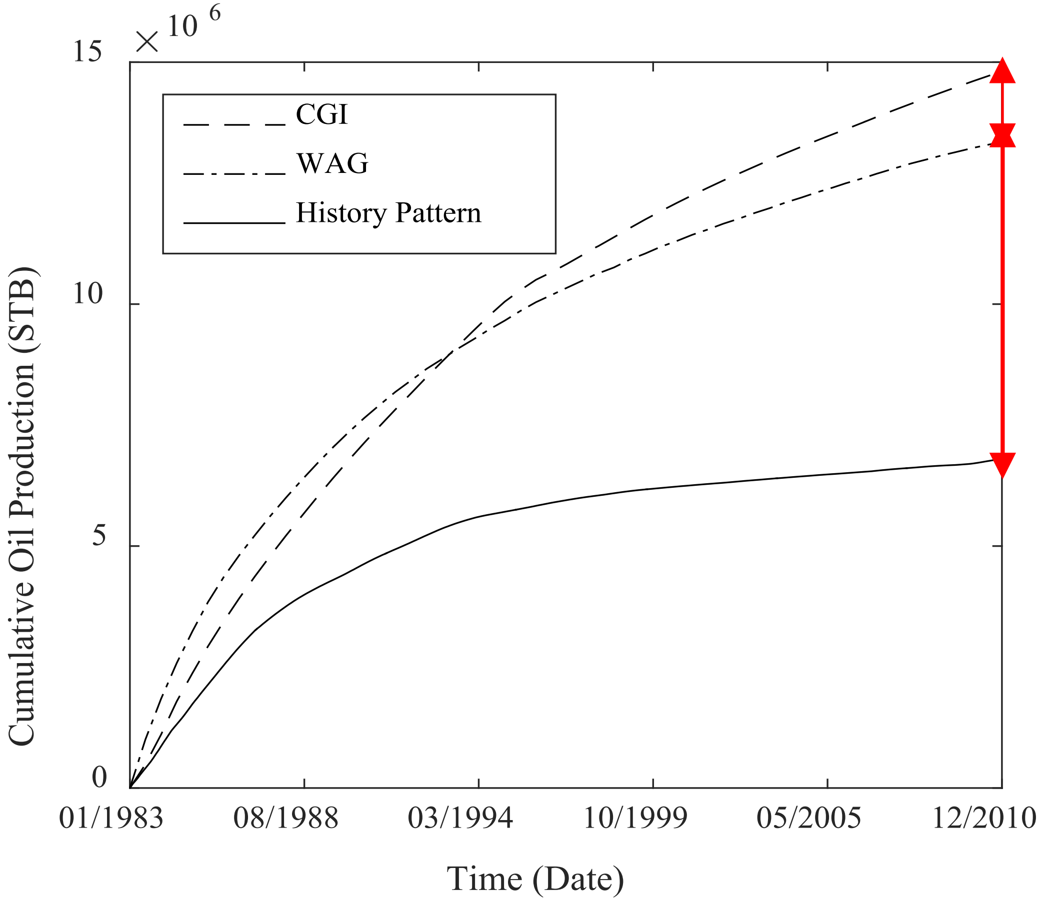
Scenarios Design

- After a comprehensive history matching:

1. Scenarios are designed for the period that the average reservoir pressure was available (1983-2010).
2. We designed the CO_2 injection rates by assuming the same average reservoir pressure for all scenarios.
3. WAG ratio : 1/1, cycle of 6 months.
4. CGI injection rate: 25 MMSCF/day
5. Low CO_2 injection rate in the history of the field, the field was mostly waterflooded.



Incremental Oil Recovery



- ✓ **If the operators would perform CO_2 injection (WAG or CGI), oil recovery could be 50% greater.**

- ✓ **The difference between incremental oil recovery in WAG and CGI is insignificant.**