# Effect of Pseudo-Component Selection on the Simulation of a $CO_2$ Gas Injection Process

Folake Ogunbanwo

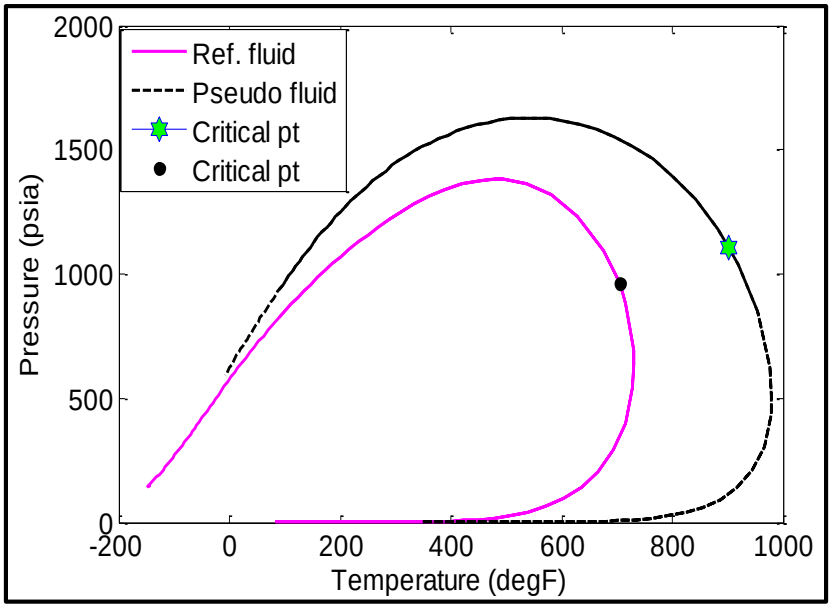
May 21st, 2014

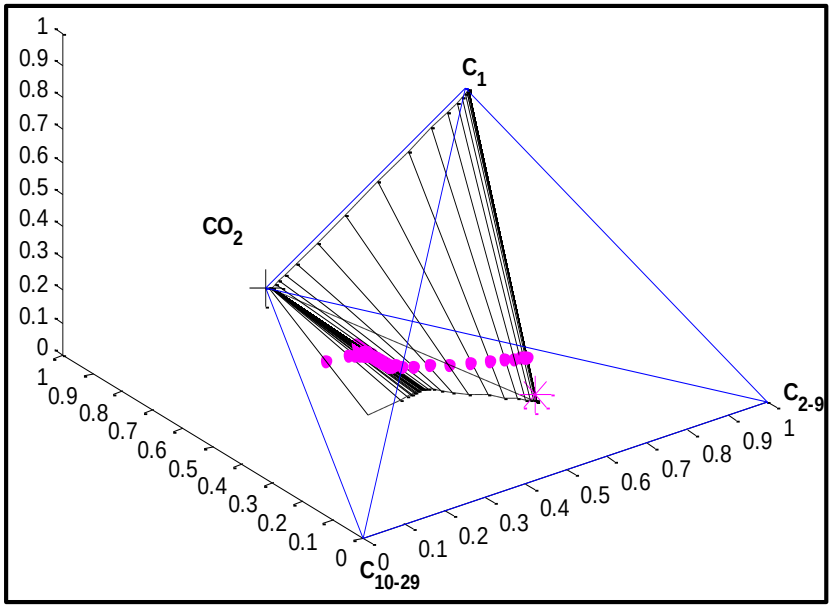
# Outline

- Objective
- Introduction
- Literature Background
- 1-D Simulation results
- Conclusions
- Future work

# Objective

Capture the flow dynamics and phase behavior of multi-component fluids undergoing $CO_2$ EOR using pseudoized components.



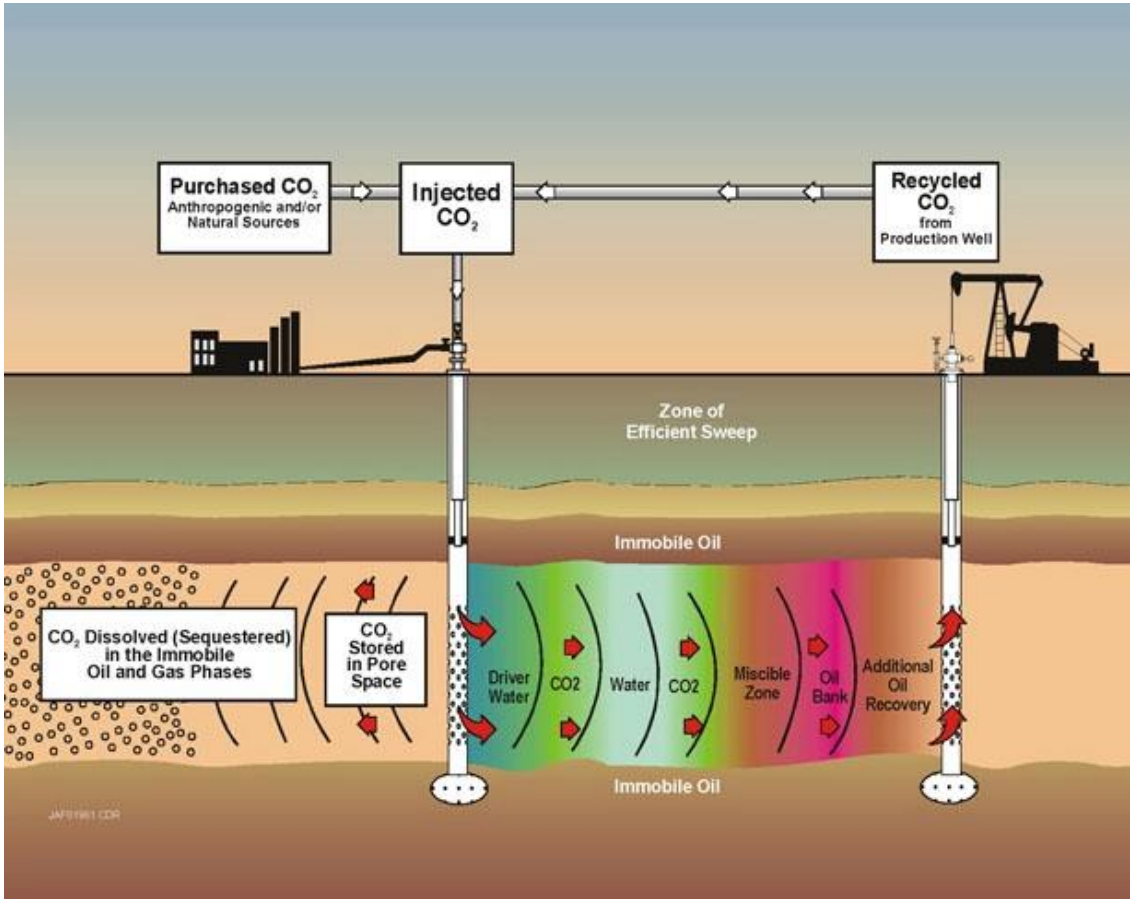

## MOVE FROM

A static approach of selecting pseudo-components using phase diagrams

## TO

A dynamic selection based on the path of the reference fluid in compositional space

# Typical $CO_2$ injection process




http://www.globalccsinstitute.com/publications/global-technology-roadmap-ccs-industry-sectoral-assessment- $CO_2$ -enhanced-oil-recovery-3

# Compositional Simulation Challenges

- Reservoir fluids contain a large number of components ($C_1$------$C_{30+}$)
- Mass conservation and phase equilibria calculations have to be solved at each time step
- Large number of iterative flash calculations required
- Increased computer storage and simulation run time

# Solution –Pseudocomponents

Lumping :

$C_1, C_2, C_3, \ldots\ldots\ldots\ldots, C_N$

$C_a, C_b, C_c, \ldots, C_n$

- Where n is less than N.
- Each component has the following properties:

  $P_c$, $T_c$, $V_c$, ω, Mw and $\delta_{ij}$

Two main issues arise :

- Grouping scheme: What components should be lumped together?
- Mixing rules: How do we assign properties to the pseudo -components?

# Literature Background

- Lumping schemes have been proposed based on the
  - Mass fractions (Whitson, 1980)
  - Boiling point range (Lee et al., 1981)
  - Saturation pressure (Mehra, 1982)
  - K-value similarity (Lee, 1985)
  - Flow based lumping using K value variation (Rastegar, 2009)

# Mixing Rules

- Weighted arithmetic averaging is the method generally used such that

$$\mathrm{Pr}_s = \sum_{i \in s} x_i \, \mathrm{Pr}_i \Big/ \sum_{i \in s} x_i$$

- $\delta_{ij}$ is calculated using

$$\delta_s = \frac{\sum_{i \in s} \sum_{j \in t} x_i x_j \delta_{ij}}{\sum_{i \in s} \sum_{j \in t} x_i x_j}$$

- EOS-$T_{cs}$ [1] is calculated by

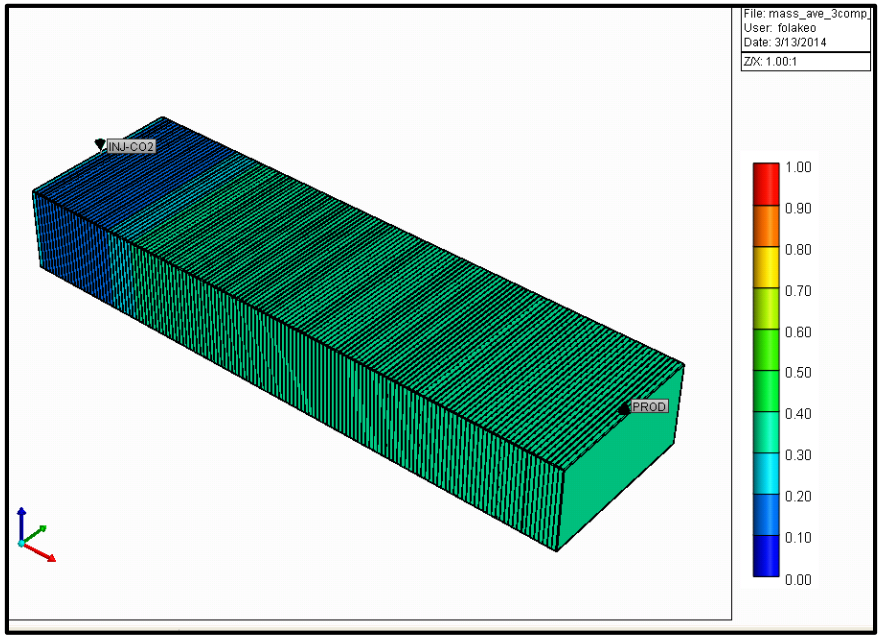
$$T_{cs} = \frac{\sum_i \sum_j x_i x_j (T_{ci} T_{cj})^{1/2} (1 - k_{ij})}{x_s \sum_s x_i T_{ci} \Big/ P_{ci}}$$

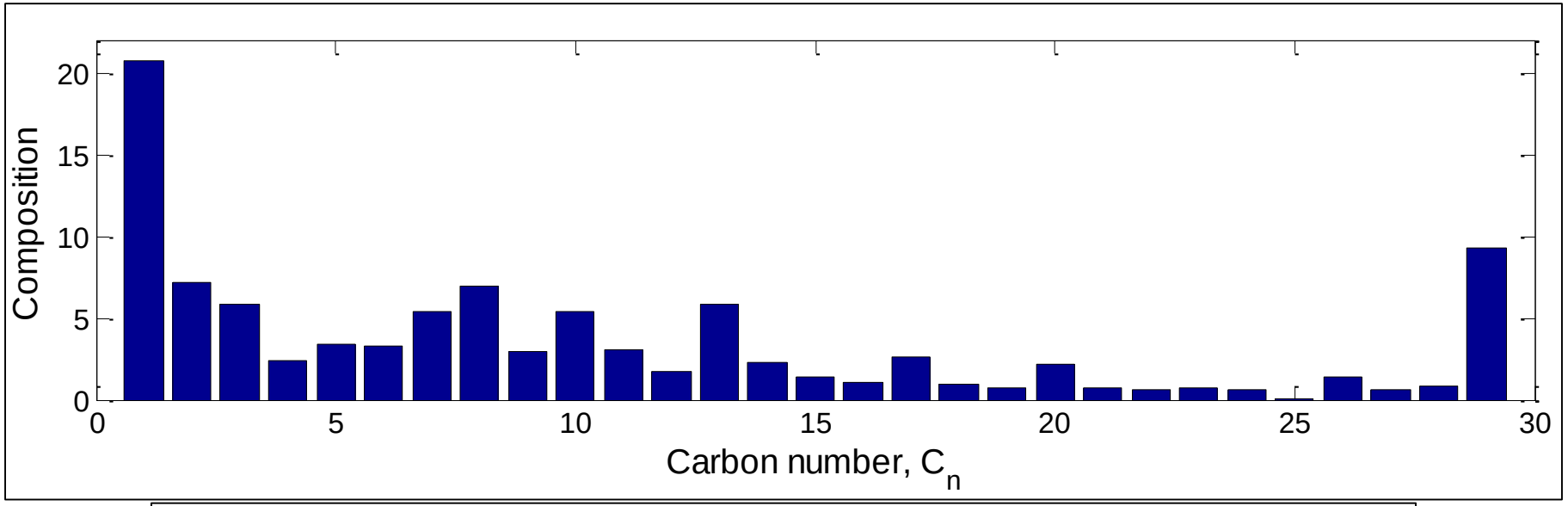
- Factors used as weights include
  - Molar[2] and Mass[3] fractions, $V_c$ [4] and $P_c$[5]

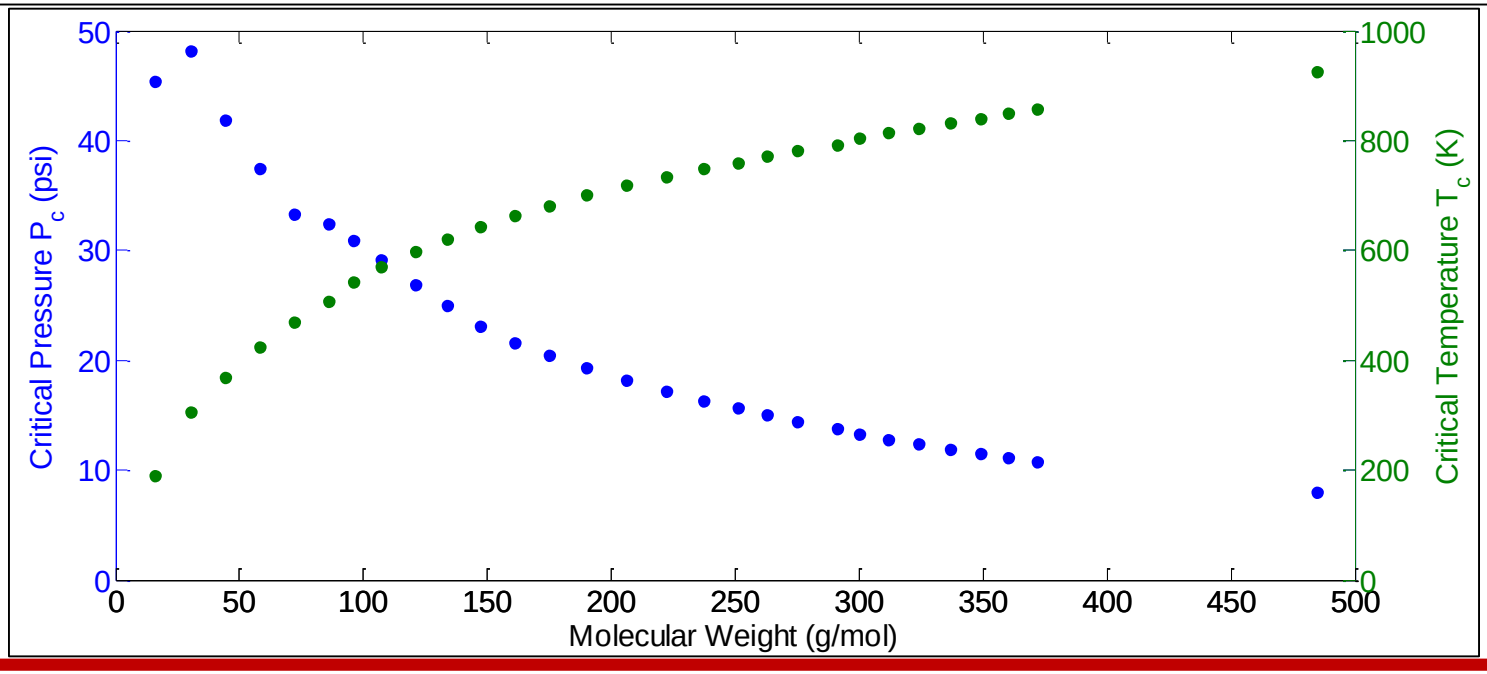
[1] Reid (1977), [2] Kay (1938), [3] Pedersen et al.(1985), [4] Hong (1982), [5] Lee (1981)

# Simulation Set up in CMG GEM

- Synthetic fluid containing $C_1$-$C_{29+}$ generated using WinProp
- 1-D Cartesian grid of 140*1*1 (0.05ft*2ft*1ft)
- K = 200 md, ϕ =30 %
- T = 90$^o$F, P = 800 psi
- Gas injection rate = 500 scf/d






# Physical Properties of Reference Fluid

# Lumping using Whitson's rule

$$N_g = Int\left[1 + 3.3 * \log_{10}(N - n)\right]$$

$$M_I = M_n \left\{\exp\left[\left(1/N_g\right) * \ln\left(M_N / M_n\right)\right]\right\}^I$$

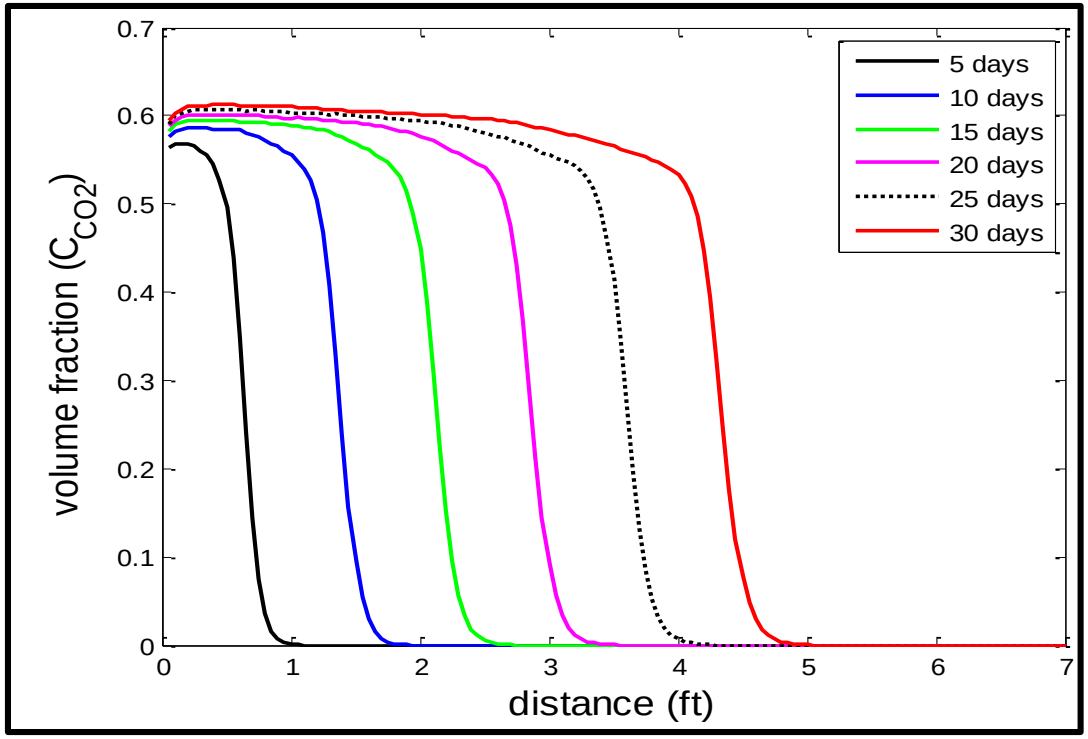
$C_1$, $C_2$, $C_3$,……,$C_{29+}$

$C_1$, $C_{2\text{-}10}$, $C_{11\text{-}29+}$

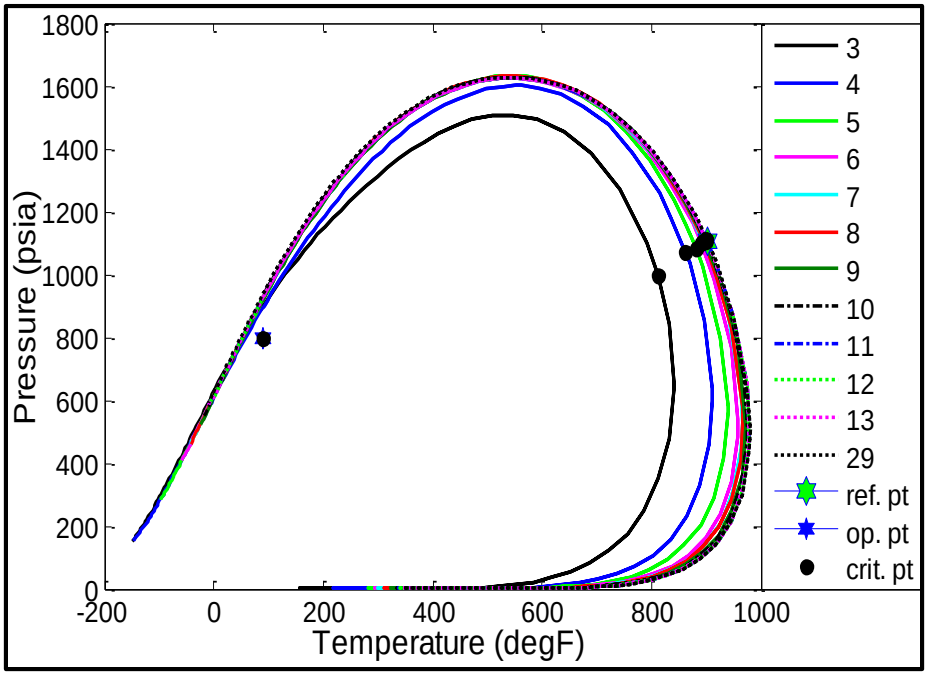
light, intermediate and heavy fractions

- The multi-component mixture was lumped gradually into a pseudo-component fluid
- By rule of thumb, $C_1$ is not lumped

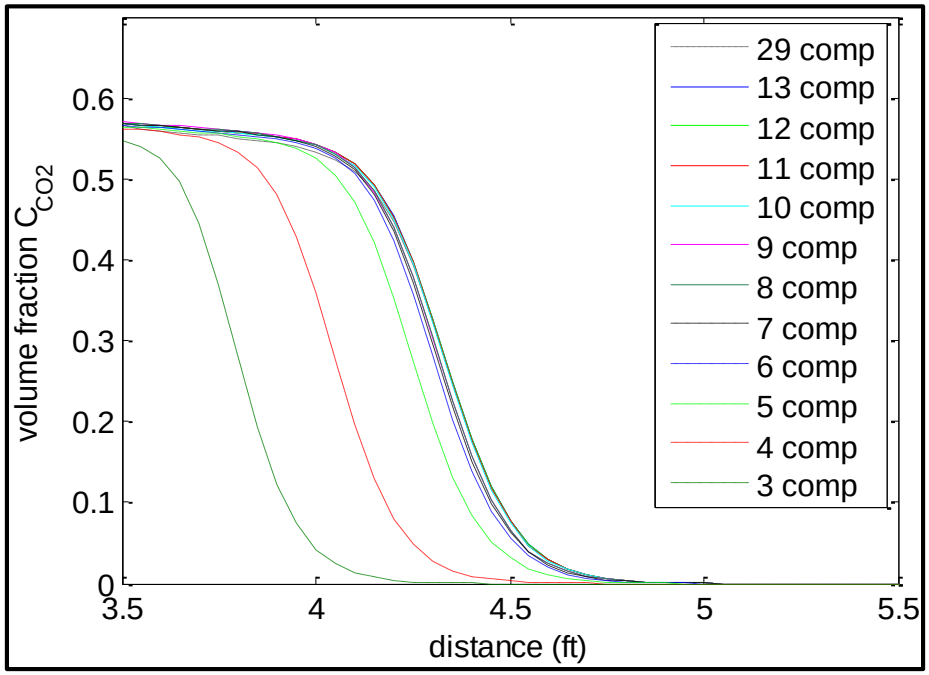
# Results


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
volume fraction ($C_{CO2}$)
0
1
2
3
4
5
6
7
distance (ft)
5 days
10 days
15 days
20 days
25 days
30 days

# Molar Weighted Pseudocomponents



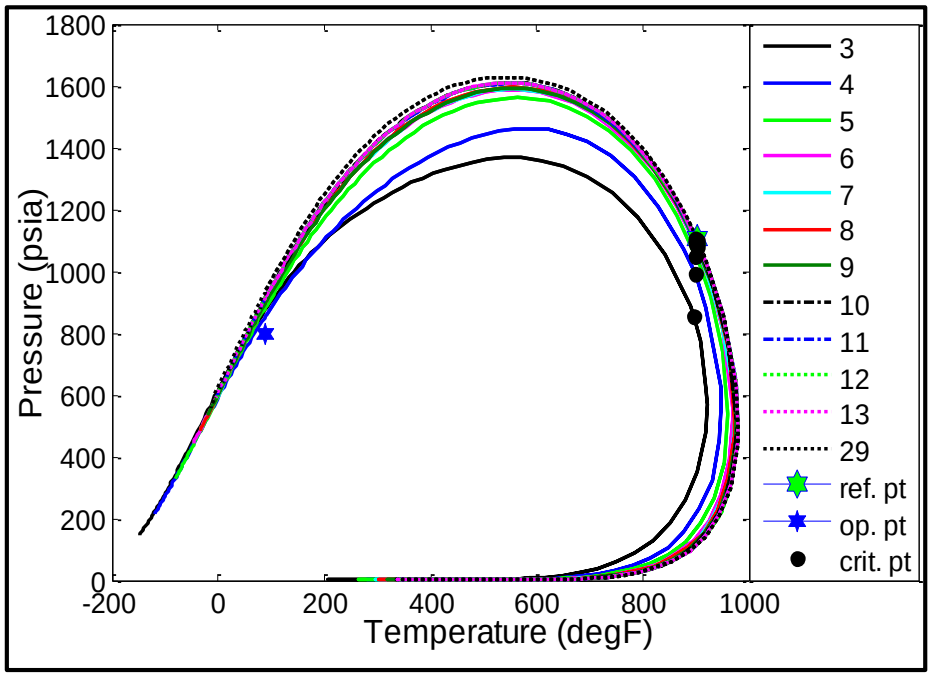

P-T diagram for Pseudoized Fluids



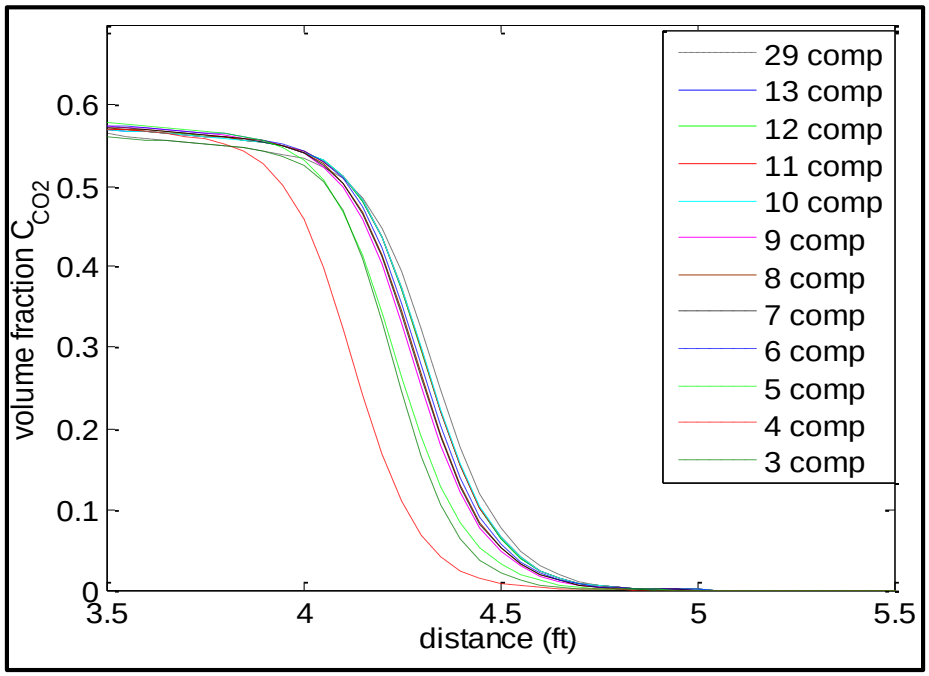

$CO_2$ front after 29 days of injection

- The phase diagram shrinks with lumping and the errors introduced in the front propagation increases.

# Mass Weighted Pseudocomponents



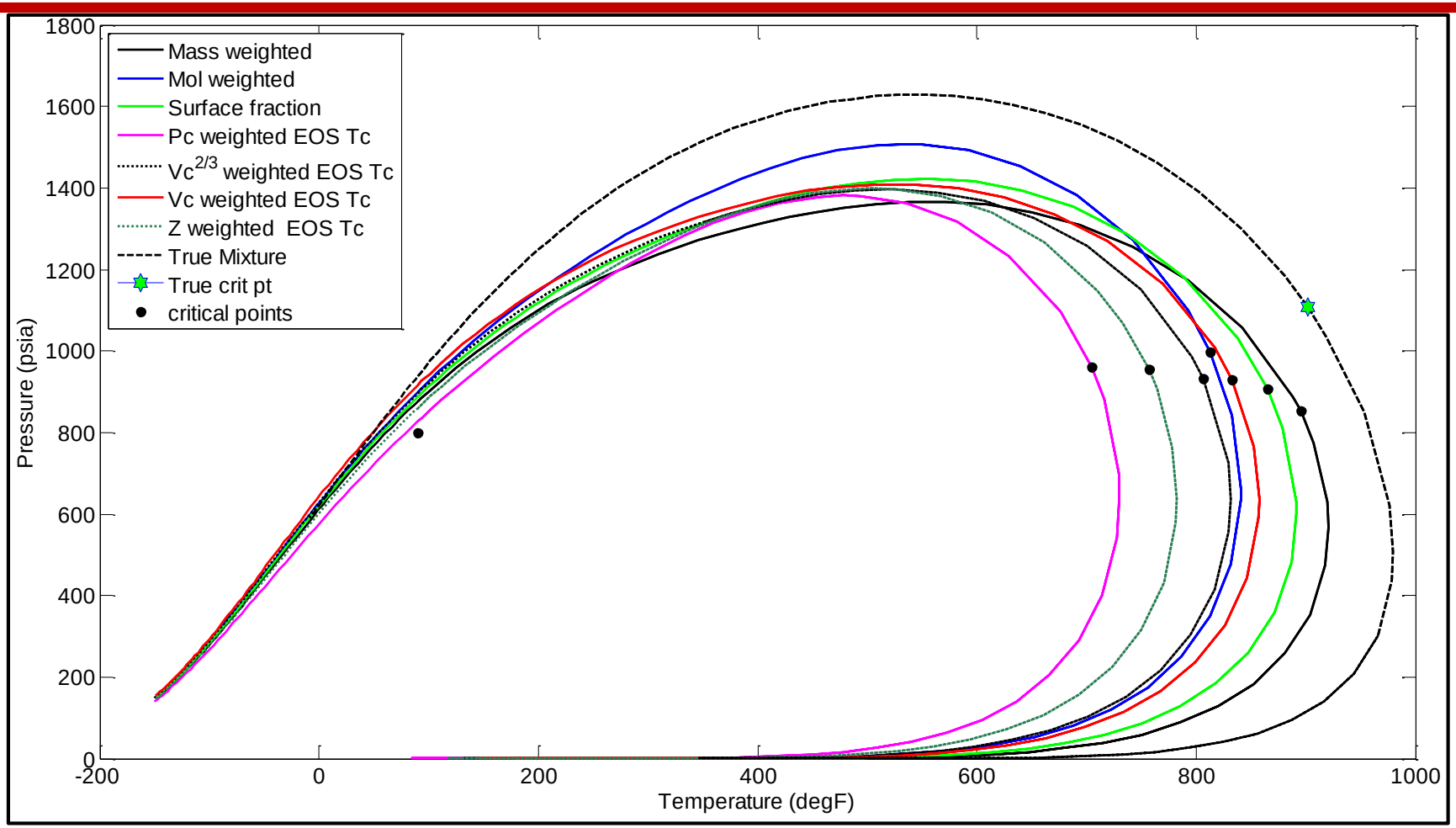

P-T diagram for Pseudoized Fluids




$CO_2$ front after 29 days of injection

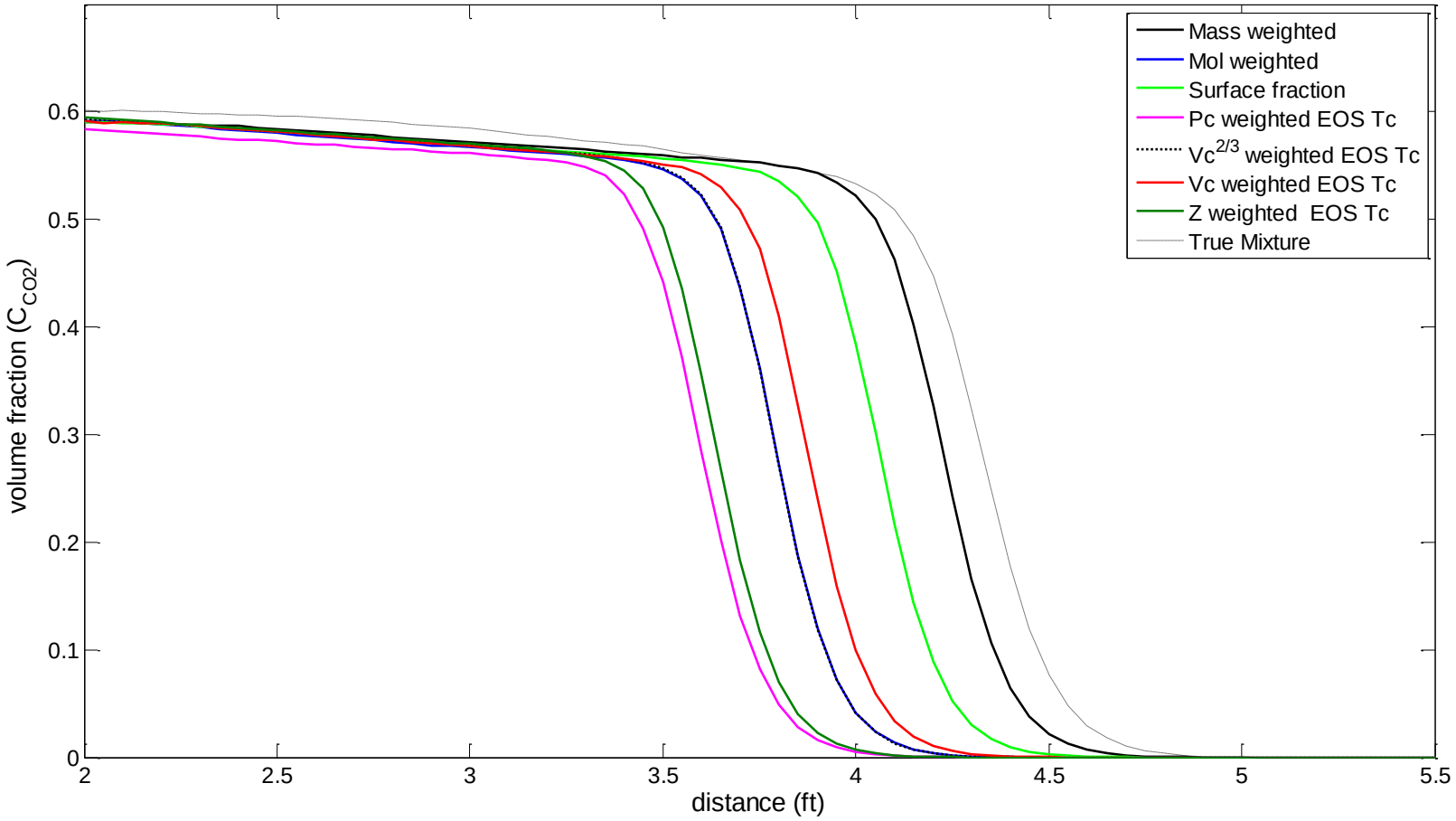
- The phase diagram shrinks with lumping.

# Mixing rule effect



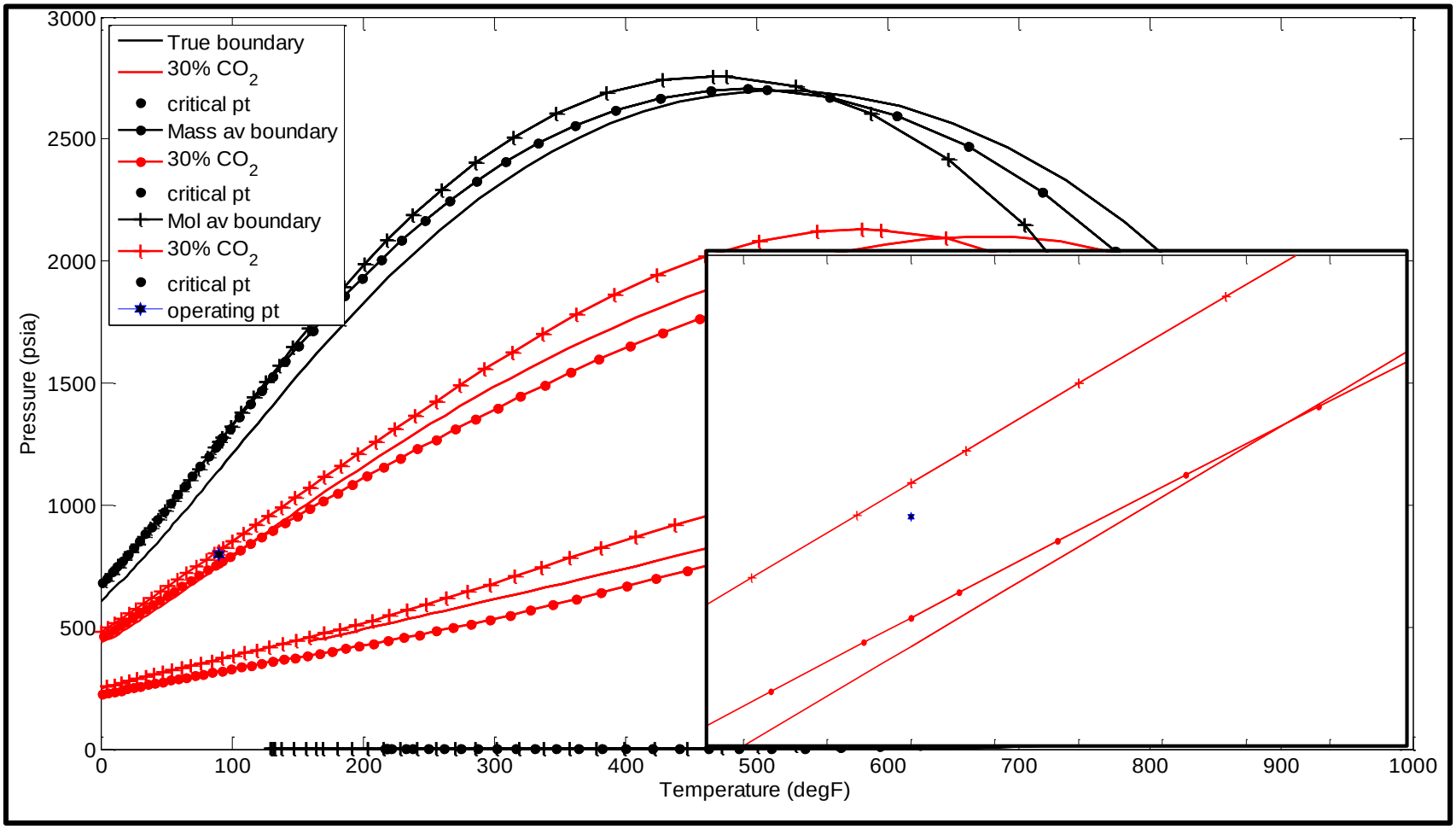

P-T diagram for a 3 – pseudocomponent mixture using different mixing rules

# Mixing rule effect




$CO_2$ front after 29 days of injection using different mixing rules on a 3 pseudocomponent mixture

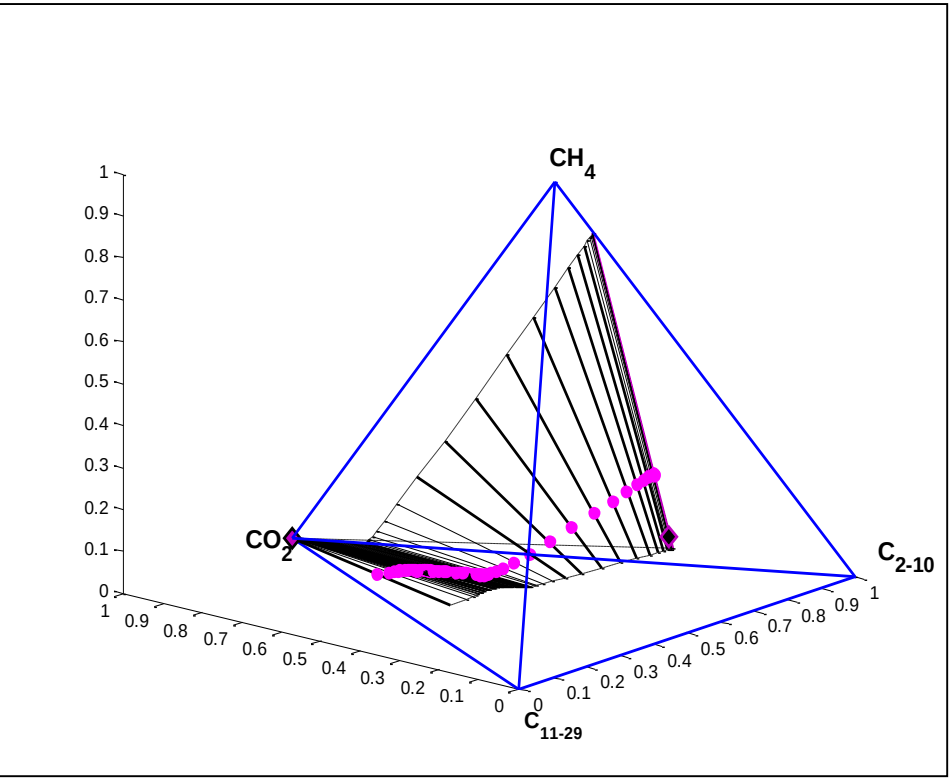
# Lines of Constant Volume fraction Vapor



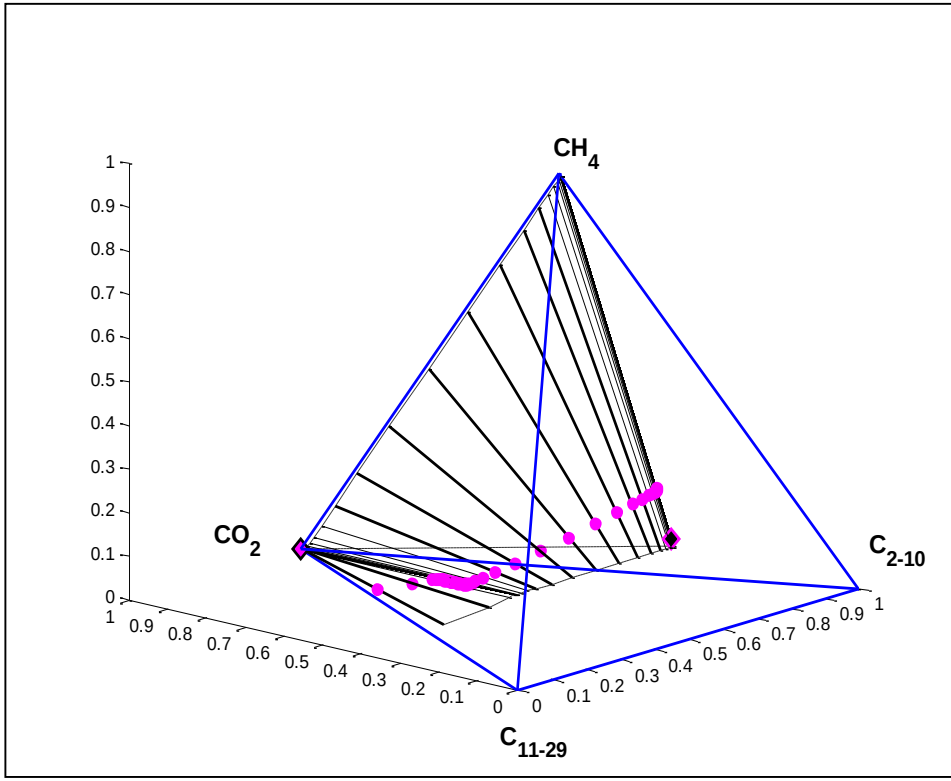

Phase Diagrams for 70% Primary fluid and 30 % $CO_2$ mixture

# Comparing Paths on Quaternary Plots

## Path of Reference fluid




## Path of Pseudoized fluid




Path in quaternary diagram after 29 days of $CO_2$ injection into the reservoir

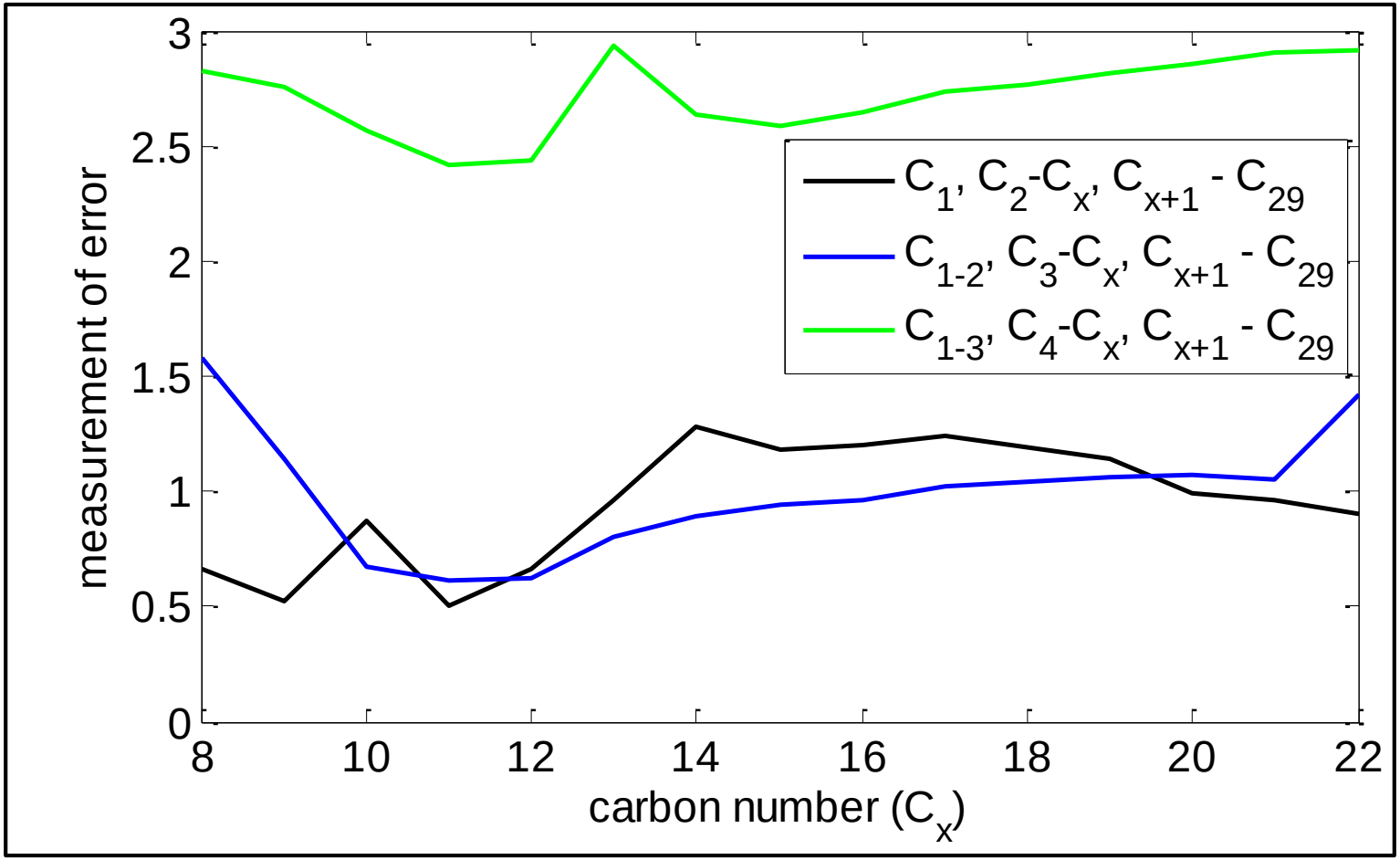
# Determining Best Lumping Scheme

- Run fully descriptive model and obtain $Z_{ref}$ at all time steps
- Run simulations using different grouping schemes
- Get composition of pseudoized fluid per time step ($Z_{ps}$)
- Determine the error using $L^2$ norm:

$$error = (L^2 norm(Z_{ref} - Z_{PS}))^2 = (\left\| Z_{ref} - Z_{PS} \right\|_2)^2$$

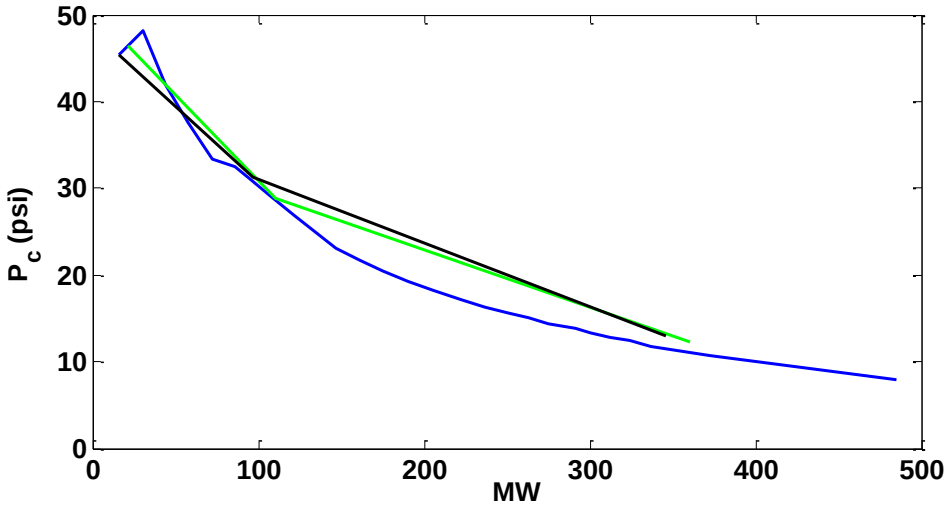
- Select group with the least error

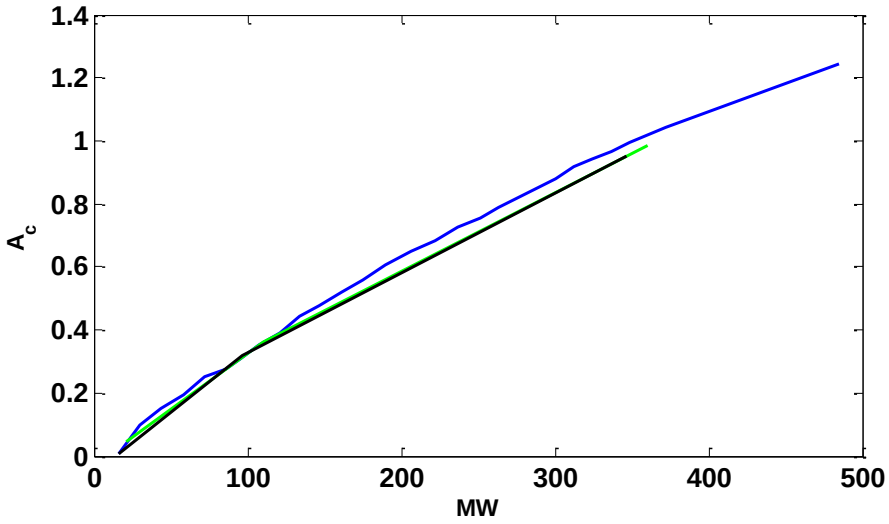
# Plot of Error vs Grouping Scheme

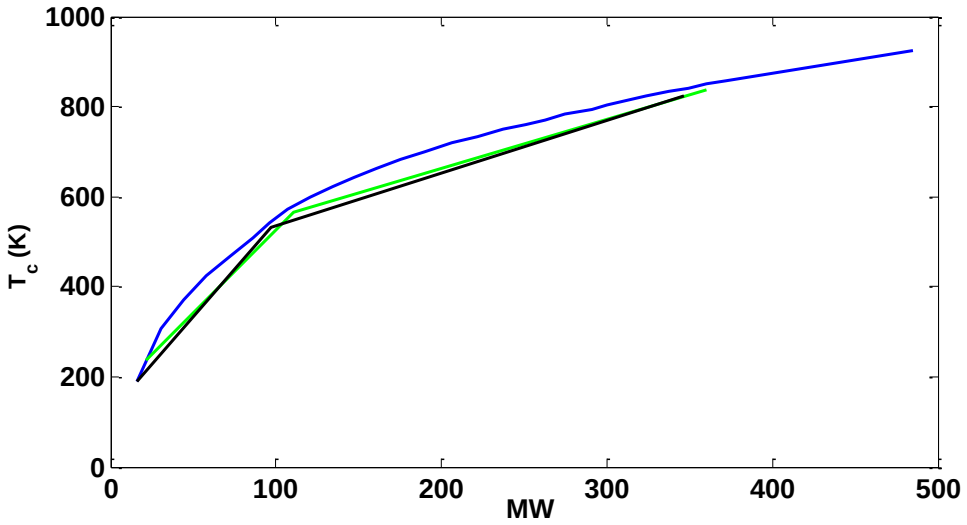


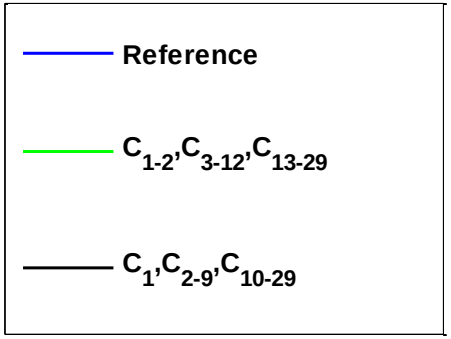

$C_1$, $C_{2\text{-}9}$, $C_{10\text{-}29}$ and $C_{1\text{-}2}$, $C_{3\text{-}12}$, $C_{13\text{-}29}$ have the lowest errors

# Properties Plot of Pseudoized Fluids

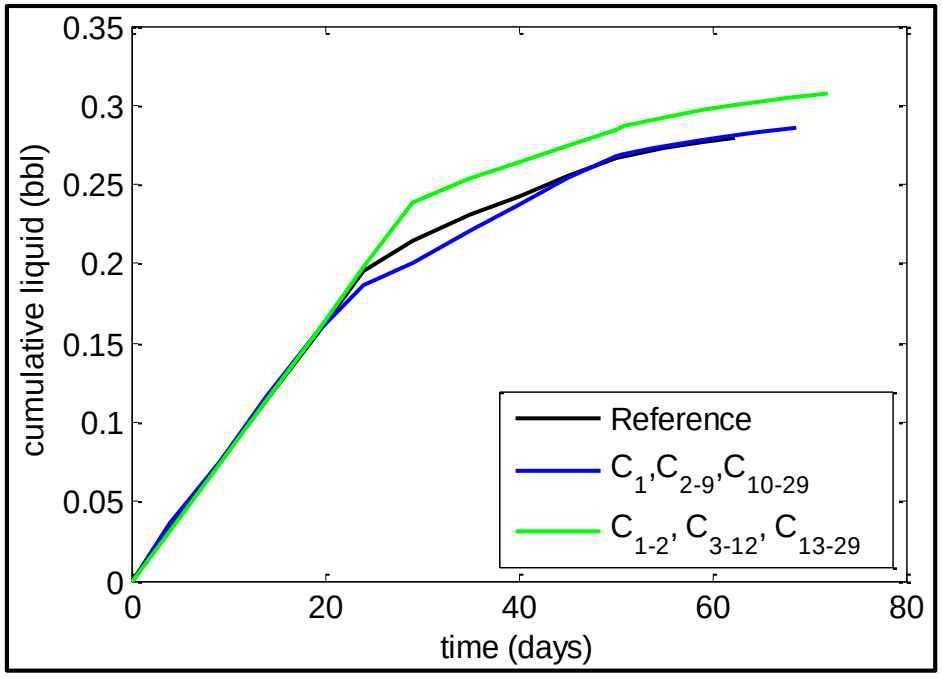


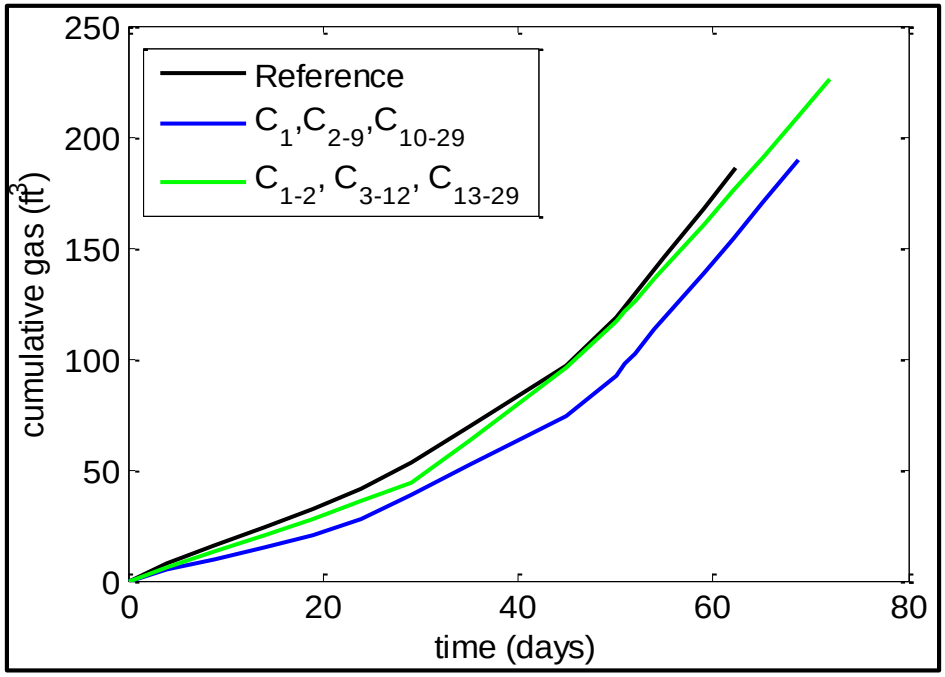



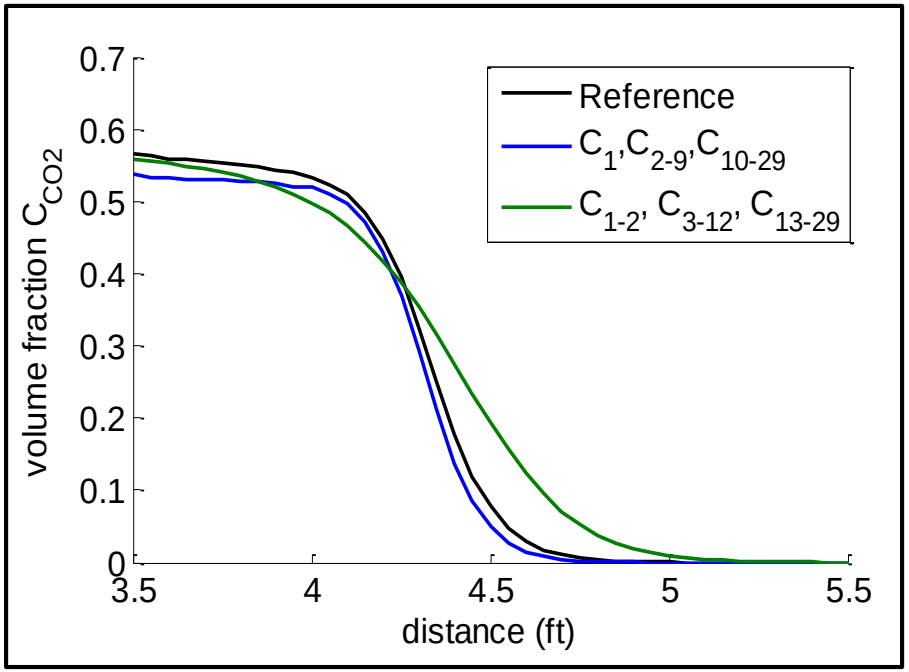
# Results



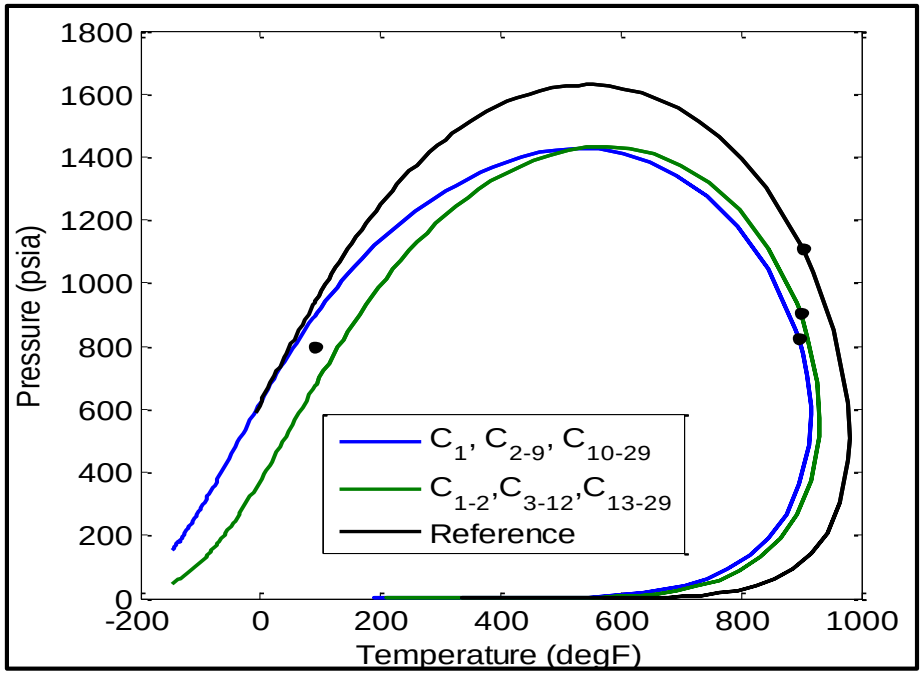




| Fluid | Simulation Time (S) |
|---|---|
| Reference | 12165 |
| $C_1$, $C_{2-9}$, $C_{10-29}$ | 117.453 |
| $C_{1-2}$, $C_{3-12}$, $C_{13-29}$ | 234.53 |

# Results



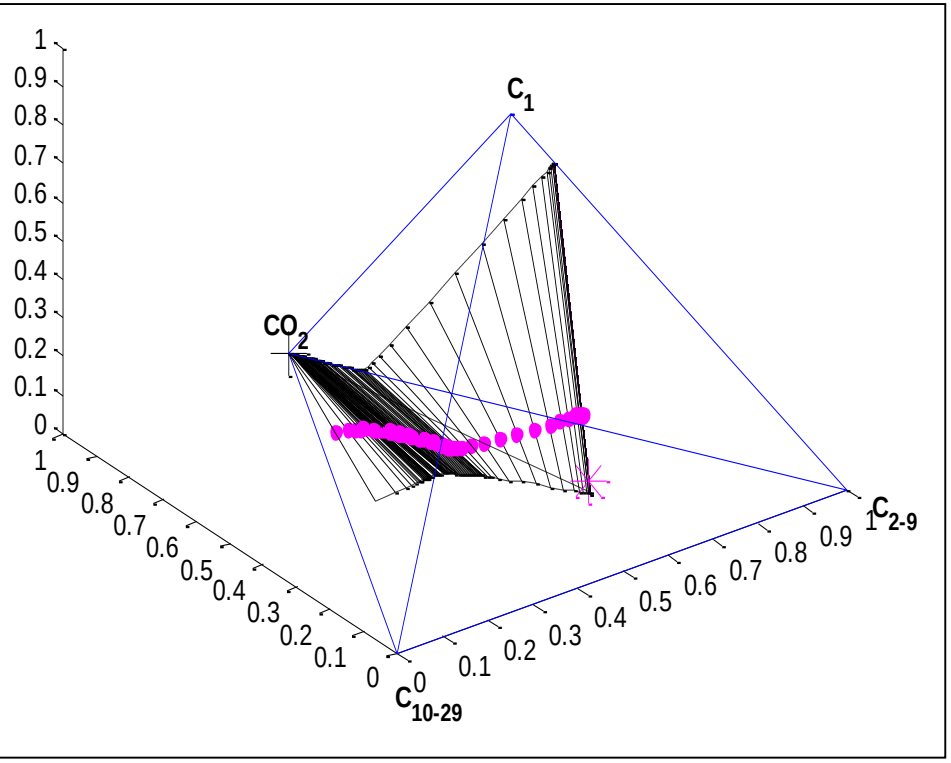

$CO_2$ front after 29 days of injection



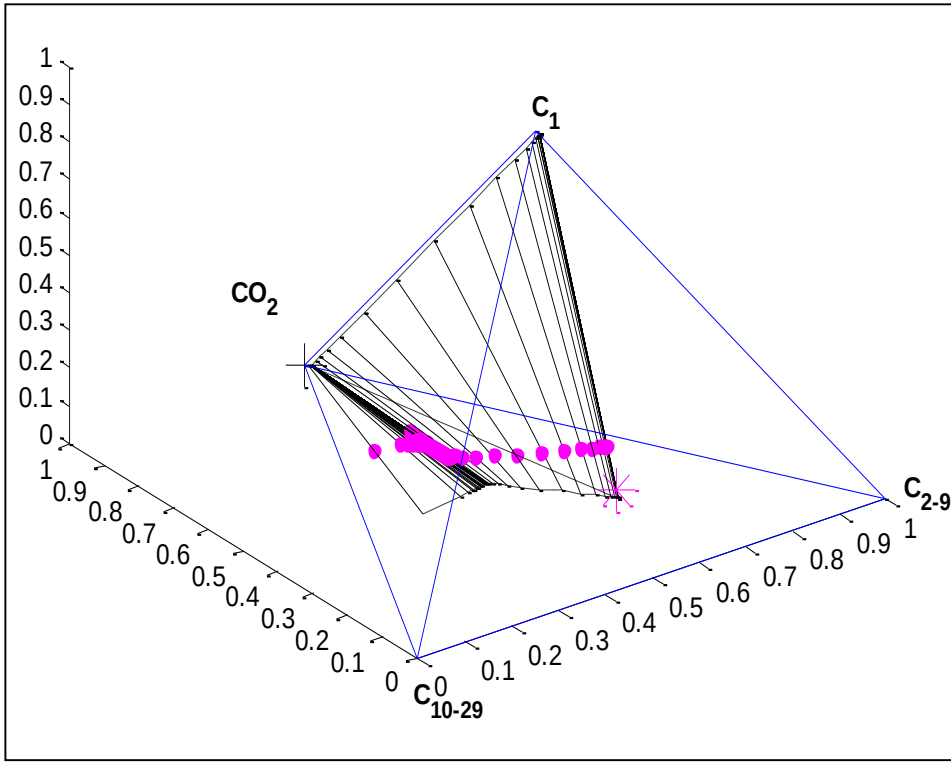

P-T Diagram for pseudoized fluid

# Comparing Paths on Quaternary Plots

## Path of Reference Fluid




## Path of Best Pseudoized Fluid



# Conclusion

- The grouping scheme and mixing rule used for assigning properties to the pseudo-components are important.

- Matching the path in compositional space can be used to group a large number of components into pseudo-components for faster simulations

# Future Work

- Tune pseudoized fluid parameters by matching the path in compositional space.
- Run simulations at other operating conditions.
- Use a different fluid
- Check the effect on viscosity