Impact of Three-Phase Relative Permeability and Hysteresis Models on CO_2 Sequestration in CO_2-EOR

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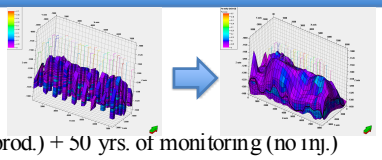
Introduction

- **Problem:** CO_2 sequestration with enhanced oil recovery (CO_2-EOR) includes complex multiphase flow processes. Two of the most important factors are three-phase relative permeability and hysteresis effects, both of which are difficult to measure and are usually represented by numerical interpolation models.
- **Goal:** Quantify impact of three-phase relative permeability model and hysteresis model on CO_2 sequestration in CO_2-EOR, using a generalized CO_2-EOR reservoir simulation model.

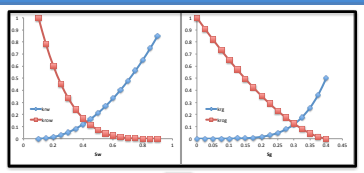
Generic CO_2-EOR Simulation Model



- 8283m × 3908m × 239m;
- 34×16×25=13600 cells;
- 23 prod. wells, 22 inj. wells;
- 30 yrs. of CO_2-EOR + 20 yrs. of post-EOR CO_2 inj.(no prod.) + 50 yrs. of monitoring (no inj.)
- 45 synthetic well observation datasets used for Sequential Gaussian Simulation (SGS)
- 50 heterogeneous realizations $c(\varphi,k)$ from SGS

Method

Two-phase (water-oil, oil-gas) relative permeability data:



4 three-phase relative permeability models to calculate k_{ro}:

- R1 (Stone I model)

$$k_{ro} = \frac{k_{row} k_{rog} S S_o}{k_{rocw}(1-SS_w)(1-SS_g)}$$

- R2 (Stone II model)

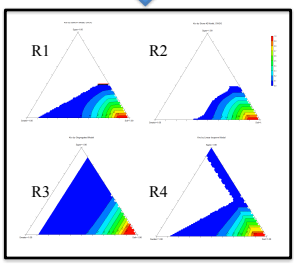
$$k_{ro} = k_{rocw}\left[\left(\frac{k_{row}}{k_{rocw}} + k_{rw}\right)\left(\frac{k_{rog}}{k_{rocw}} + k_{rg}\right) - k_{rw} - k_{rg}\right]$$

- R3 (Segregated model)

$$k_{ro} = \frac{(S_w - S_{wco})k_{row} + S_g k_{rog}}{S_w + S_g - S_{wco}}$$

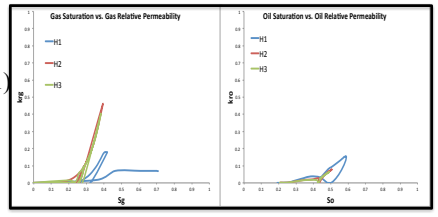
- R4 (Linear IsoPerm model)

$$k_{ri} = \frac{(S_i - S_{ic})k_{rli} + (S_j - S_{jc})k_{rij}}{(S_i - S_{ic}) + (S_j - S_{jc})}, \text{where } l \neq i \neq j$$



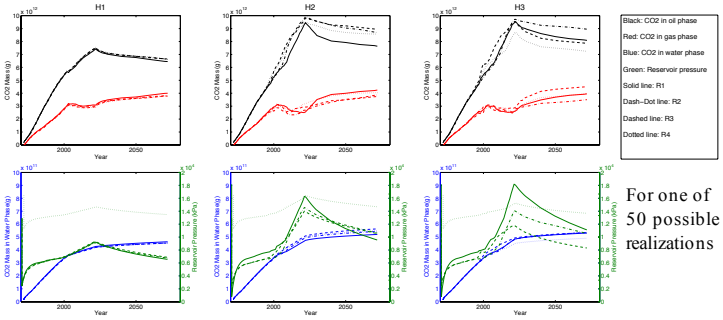
3 hysteresis models:

- H1 (three-phase WAG model)
- H2 (Carlson & Land model)
- H3 (Land model)



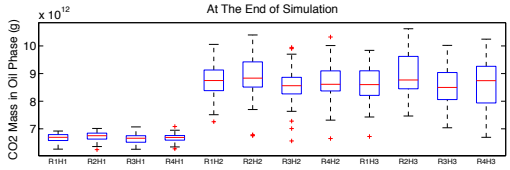
Results & Discussion

Net CO_2 Storage and Reservoir Pressure



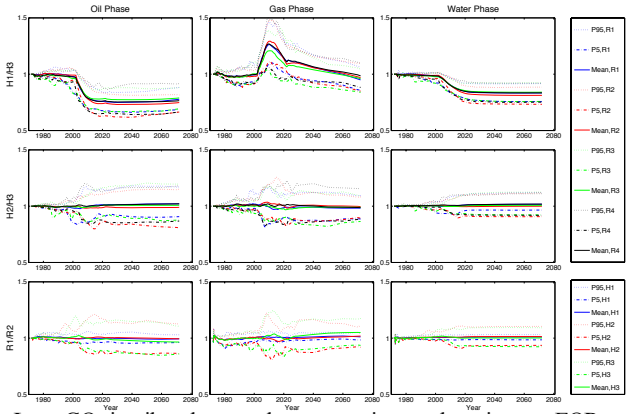
For one of 50 possible realizations

Comparison of Net CO_2 Storage in Oil Phases



Ratios of Net CO_2 Storage in Three Phases

$$\frac{H_i}{H_3}(c_k,t)_{o,g,w} = \frac{Mass_{CO_2(o,g,w)}(H_i,R_j,c_k,t)}{Mass_{CO_2(o,g,w)}(H_3,R_j,c_k,t)}, \quad \frac{R_j}{R_2}(c_k,t)_{o,g,w} = \frac{Mass_{CO_2(o,g,w)}(H_i,R_j,c_k,t)}{Mass_{CO_2(o,g,w)}(H_i,R_2,c_k,t)} \quad i=1\sim3, j=1\sim4, c=1\sim50$$



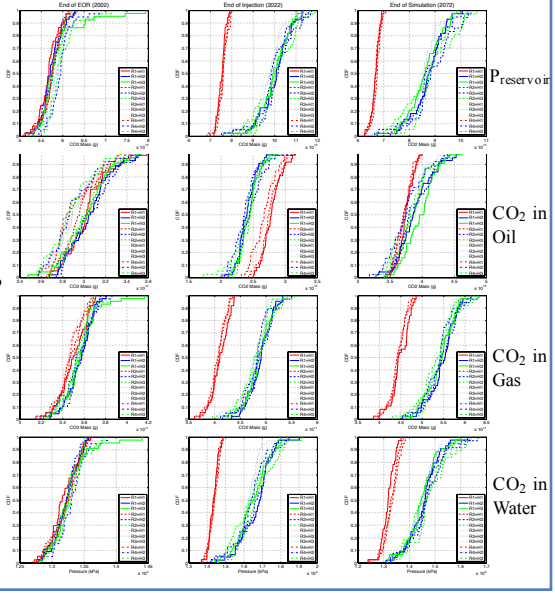
- H1: Less CO_2 in oil and water phase, more in gas phase in post-EOR and monitoring period.
- H2: similar with H3
- R1, R3, R4: similar with R2

Risk Assessment of Net CO_2 Storage and Reservoir Pressure

At the end of CO_2-EOR (left), all R and H modes predict similar results

At the end of post-EOR (middle), H1 predicts **lower reservoir pressure**, **lower** CO_2 storage in **oil** and **water** phases, **higher** in **gas** phase

At the end of simulation (right), H1 predicts slightly **lower** CO_2 storage in **gas** phase



Conclusion

- The choice of three-phase relative permeability model and hysteresis model critically impacts CO_2 sequestration simulation forecasts;
- Influences of both relative permeability and hysteresis are observed in all realizations;
- The specific choice of hysteresis model appears to be somewhat more important relative to the choice of three-phase relative permeability model, especially with respect to predicted uncertainty.

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