

Characterizing sub-core hysteretic relative permeability and capillary pressure for accurate imbibition coreflood modeling

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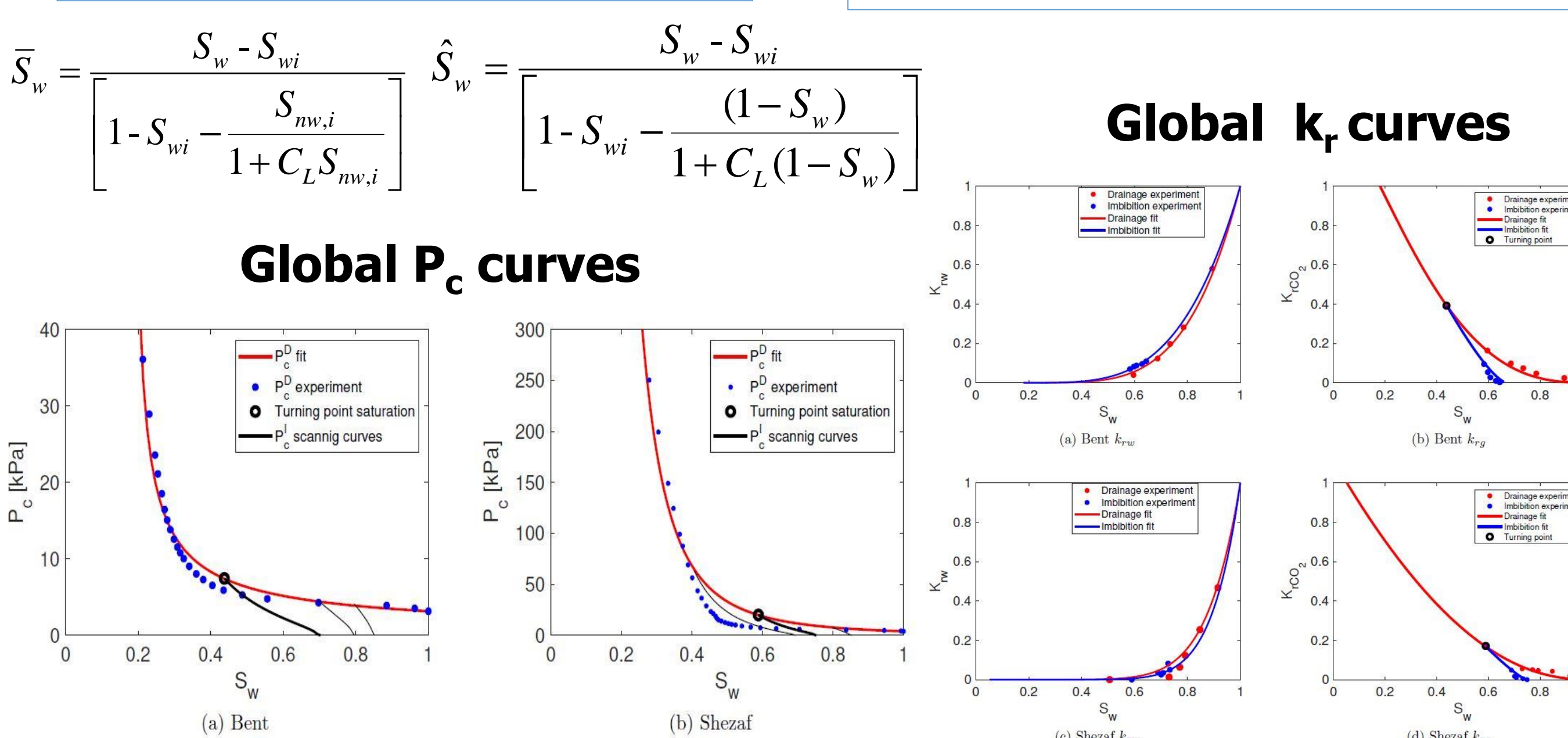
Summary

- Drainage and imbibition coreflooding experiments were conducted on two core samples along with X-ray CT imaging resulting in detailed sub-core saturation distributions.
- Previous work estimated drainage relative permeability (k_r), capillary pressure (P_c) and 3D permeability distribution (k).
- In this work we characterize hysteretic sub-core k_r and P_c in order to accurately model imbibition coreflooding.
- We first adopt the methods of Pini and Benson (2017) for sub-core capillary pressure modeling and that of Dury et al. (1999) for relative permeability modeling, however, we find that these are not sufficient for accurate modeling of core saturation distribution.
- The models are improved using unique Land trapping coefficients for each mm-scale grid block in our model and also by calculating new imbibition characteristic relative permeability curves based on a procedure developed in Anto-Darkwah et al. (2020).
- Results show improvements in matching experimental data.

Experimental Data

- Corefloods were conducted at the Benson Lab in Stanford Univ.
- For drainage, P_c^D is obtained by MICP and fitted by:
$$P_c^D(S_w) = P_e \cdot (\tilde{S}_w)^{-1/\lambda}$$
, $\tilde{S}_w = (S_w - S_{wi})/(1 - S_{wi})$, $\tilde{S}_{w,m} = 1 - \tilde{S}_{nw,m}$
- Imbibition P_c^I is modeled by: $P_c^I(S_w) = P_{c,i} \cdot (\tilde{S}_{w,m}^{-1/\lambda} - 1)$
$$\tilde{S}_{nw,m} = \frac{1}{2} \left[(\tilde{S}_{nw} - \tilde{S}_{nw,r}) + \sqrt{(\tilde{S}_{nw} - \tilde{S}_{nw,r})^2 + \frac{4}{C_L} (\tilde{S}_{nw} - \tilde{S}_{nw,r})} \right]$$
, $C_L = \frac{1}{\langle S_{nw,r} \rangle} - \frac{1}{\langle S_{nw,i} \rangle}$
 $P_{c,i} = P_e \cdot (1 - \tilde{S}_{w,i}^{-1/\lambda})^{-1}$
 C_L - global land trapping coefficient
 $P_e, P_{c,i}$ - drainage and imbibition entry pressures
 $\tilde{S}_{nw,i}, \tilde{S}_{nw,r}$ - turning point and residual saturations

$$k_{rcO_2}^I = (1 - \tilde{S}_w)^C (1 - \tilde{S}_w^A)^B \quad \text{Drainage} \quad k_{rcO_2}^D = (1 - \hat{S}_w)^C (1 - \hat{S}_w^A)^B$$



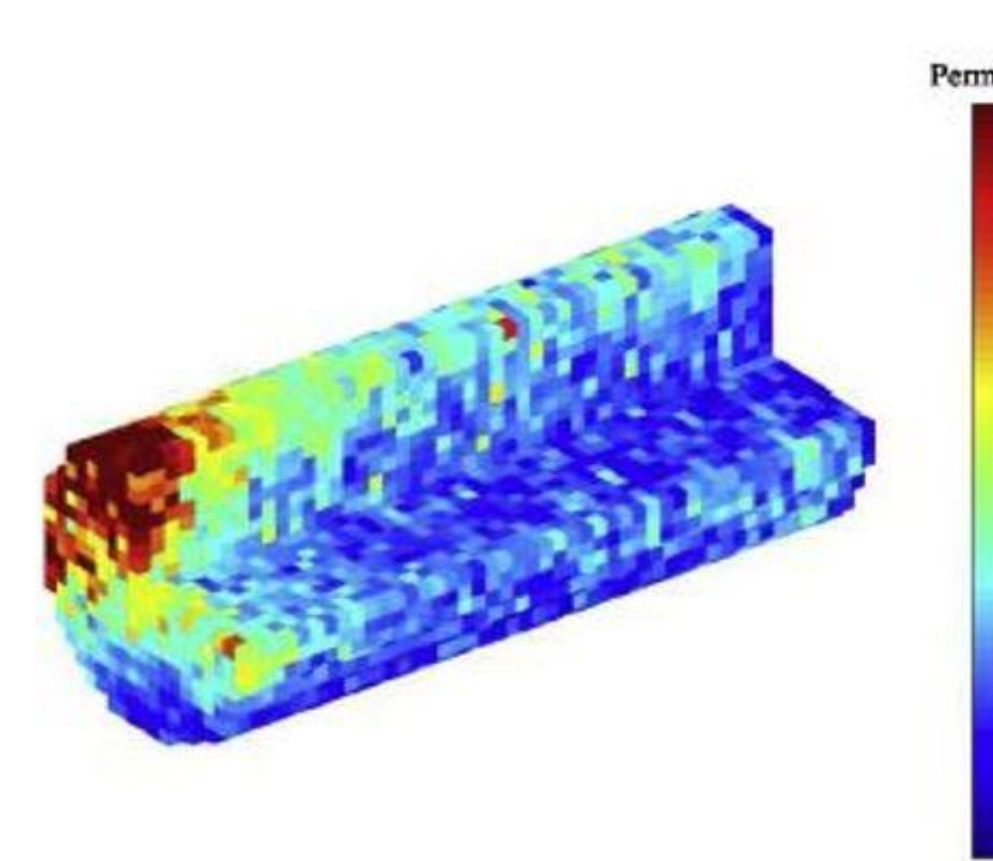
- A, B and C are fitting parameters obtained from simultaneous fitting of $k_{rcO_2}^D, k_{rcO_2}^I$ curves

Rock	λ	A	B	C	C_L	n_w	P_e (kPa)	$S_{nw,i}$ (Global)	$S_{nw,r}$ (Global)
Bent	1.35	1.78	0.329	1.06	1.236	3.79	3.14	0.561	0.331
Shezaf	0.35	0.76	0.001	1.19	1.496	9.10	3.89	0.411	0.254

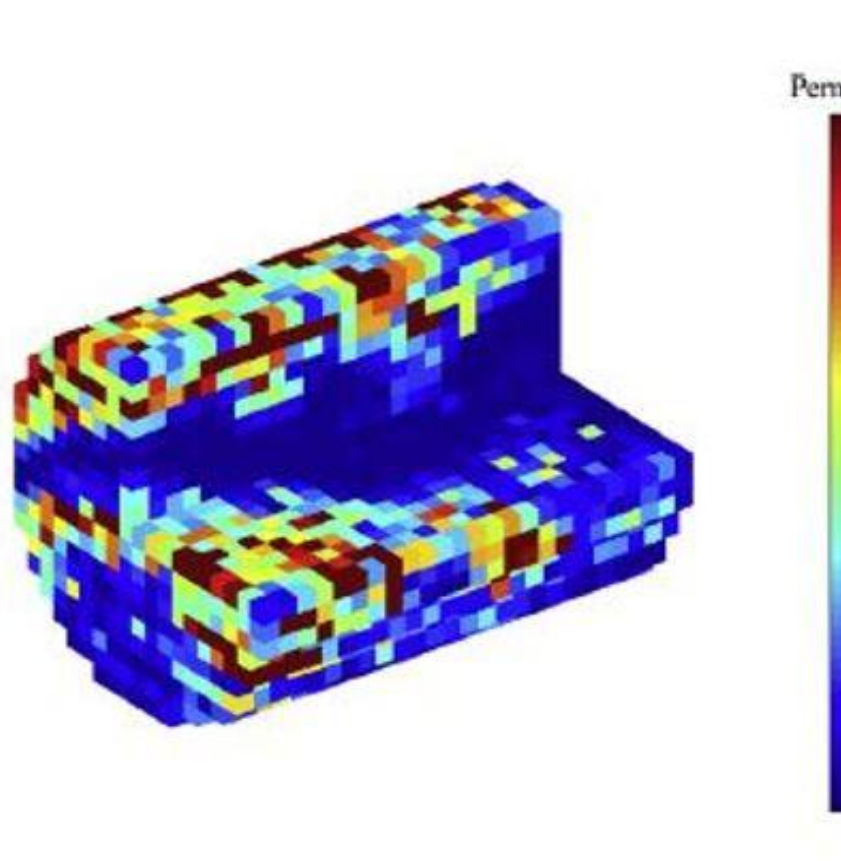
Permeability estimation

- Permeability distributions $k(x, y, z)$ were previously obtained from drainage experiments (Anto-Darkwah et al. 2020)

Bentheimer rock permeability



Shezaf rock permeability



Sub-core scale imbibition $k_{rcO_2}^{b,I}, P_c^{b,I}$ curves

- We used the previous equations for $k_{rcO_2}^I, P_c^I$ however, grid block values: $C_L^b, \tilde{S}_{nw,i}^b, \tilde{S}_{nw,r}^b$ are used as opposed to global values
- Grid block land coefficients were calculated as: $C_L^b = \frac{1}{S_{nw,r}^b} - \frac{1}{S_{nw,i}^b}$

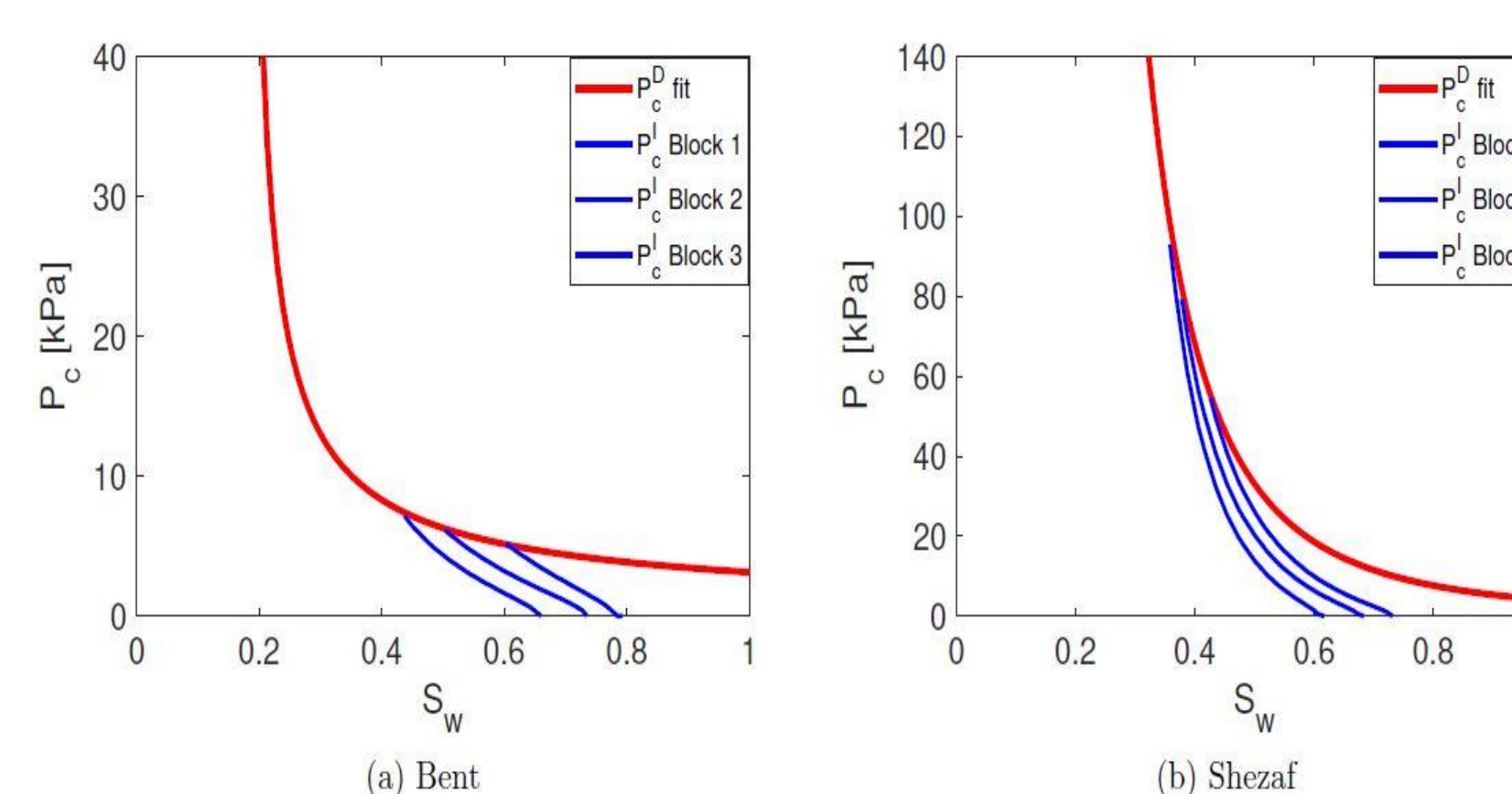
Imbibition characteristic k_{rj}^{char} curves

$k_{rcO_2}^{I, char}(\tilde{S}_w^b)$ curves changes with each grid block

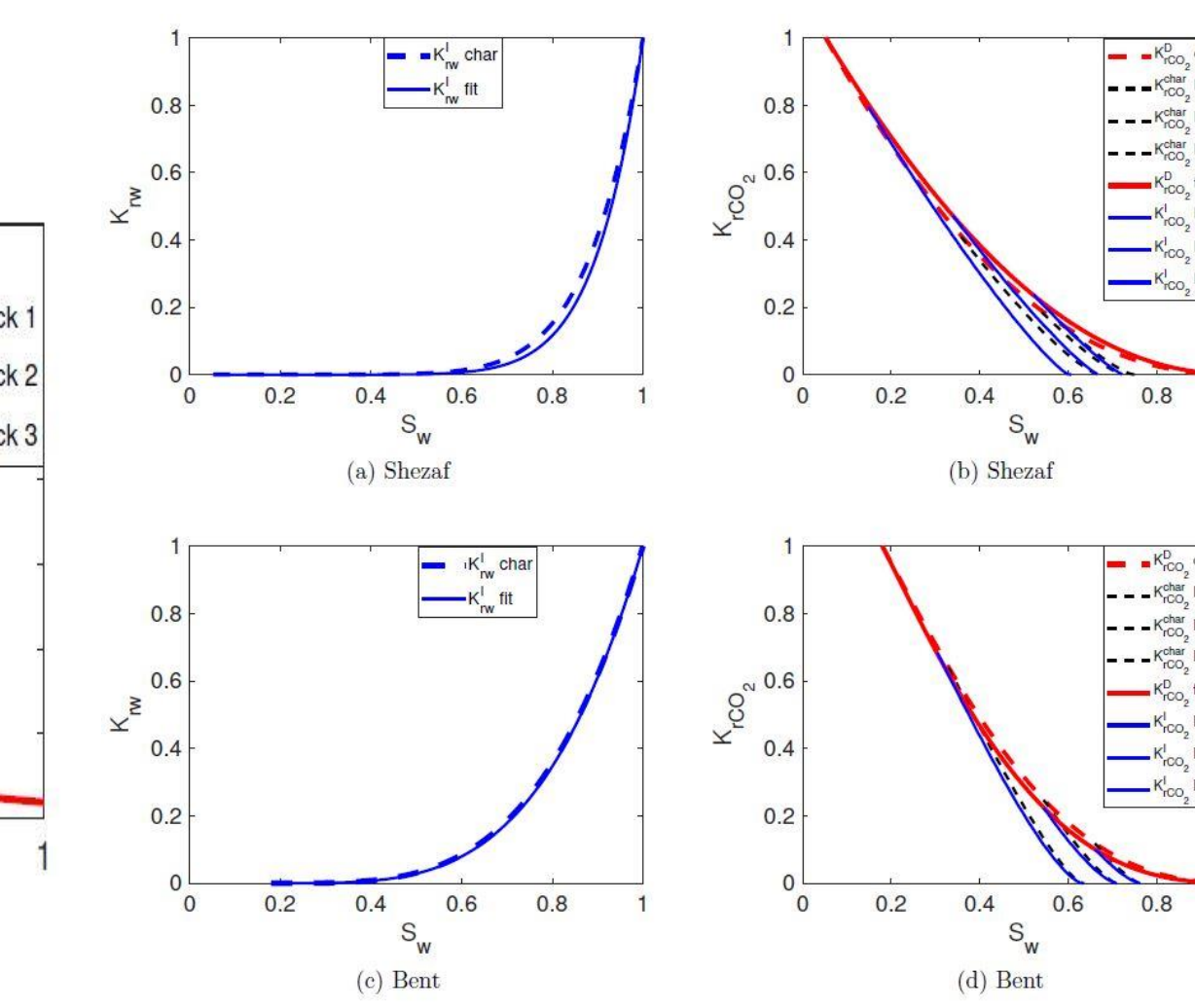
$A^{char}, B^{char}, C^{char}, n_w^{char}$ are optimized so core effective rel perm matches the experimental measured values

Rock	A^{char}	B^{char}	C^{char}	n_w^{char}
Bent	1.792	0.319	0.992	3.70
Shezaf	0.775	0.049	1.238	7.75

Block by block P_c curves



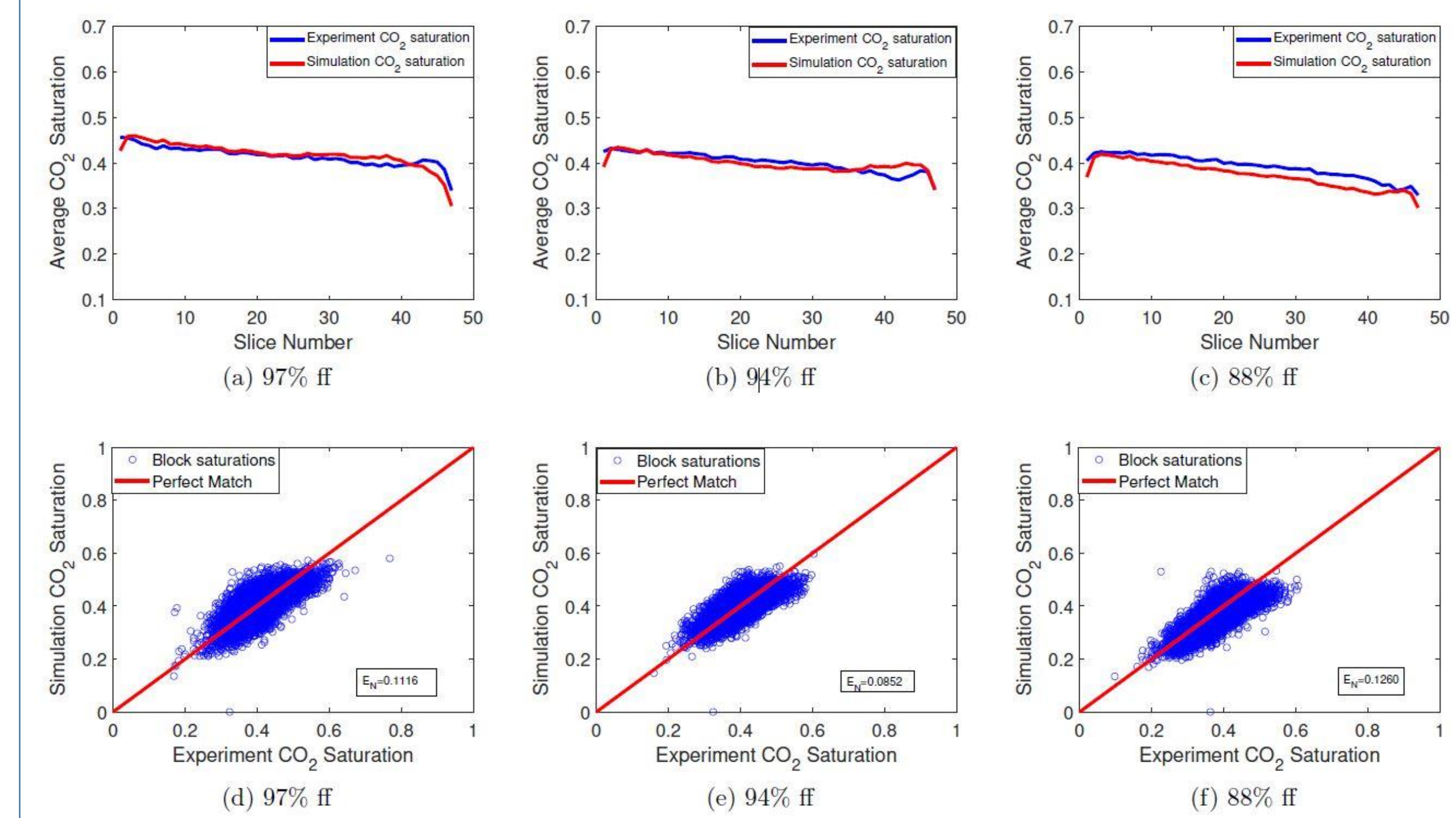
Block by block k_r curves



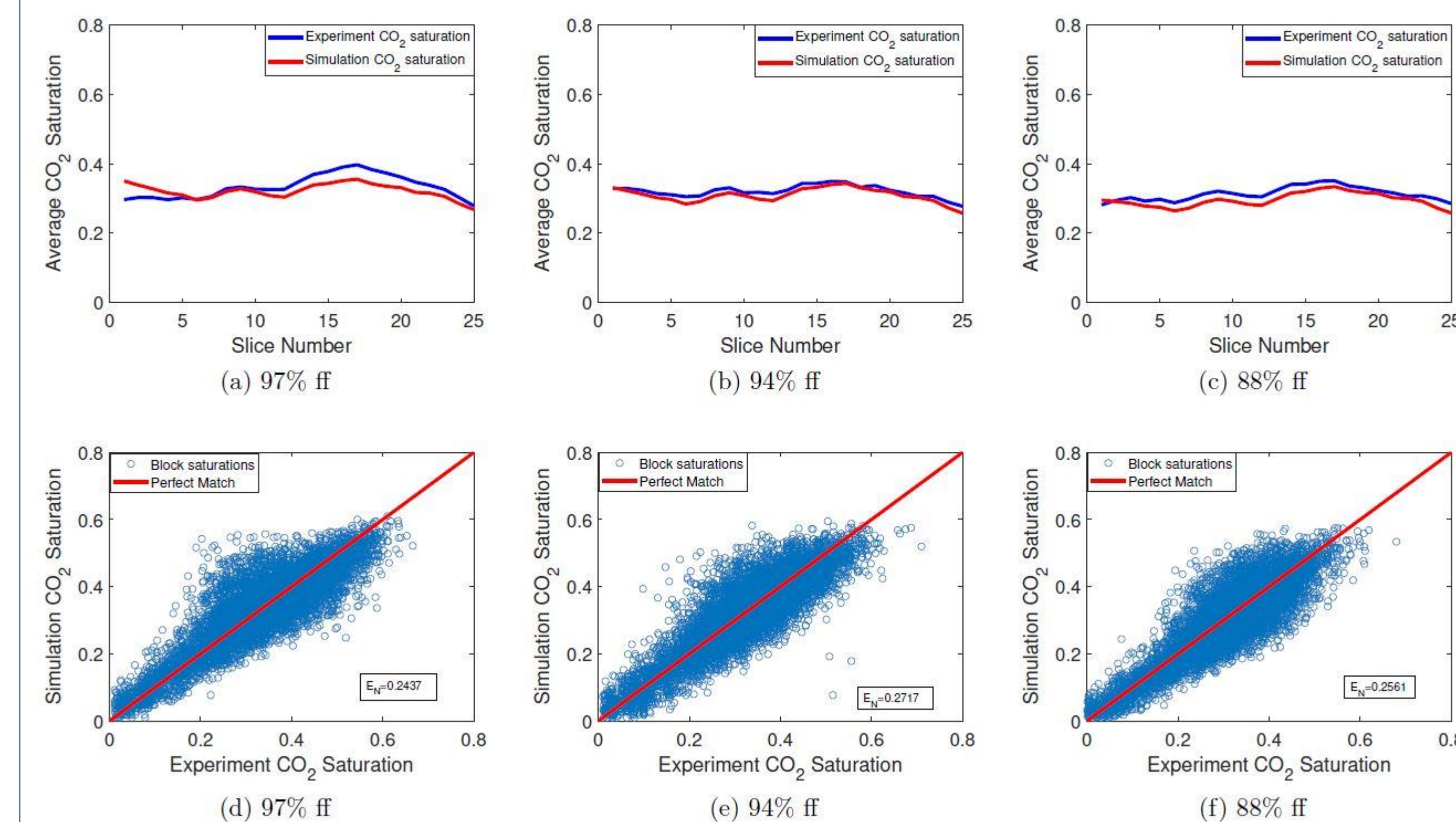
Results

- Flow simulations are conducted with the new sub-core scale $k_{rj}^{I, char}, P_c^{I, char}$ as input

Bentheimer saturation comparisons



Shezaf saturation comparisons



Relative permeability comparisons

