A fractal effective permeability model for dual-wet porous media

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Appendix A. Values of parameters used in Eq. (12)

Previous studies (Lan et al., 2015; Yassin et al., 2016; Yuan et al., 2019) have discussed the dual-wettability behavior of the selected 13 pairs of rocks. Table A1 lists all determined values of parameters in Eq. (12). As discussed in **Section 4**, $\lambda_{maxMICP}$ is obtained from available MICP data and λ_{max_hl} and λ_{max_hb} are assumed to be equal to $\lambda_{maxMICP}$. λ_{min_hl} and λ_{min_hb} are calculated by Eq. (12) and ϕ_{hl} and ϕ_{hb} are obtained from equilibrated imbibed volume of water and oil. D_{hl} and τ_{hl} are obtained by fitting water imbibition data and D_{hb} and τ_{hb} are calculated by solving Eqs. (17) and (18) simultaneously. Once τ_{hl} and τ_{hb} are specified, ϕ'_{hl} and ϕ'_{hb} are determined by Eqs. (14) and (15), respectively.

Table A1. The values of parameters used in Eq. (12).

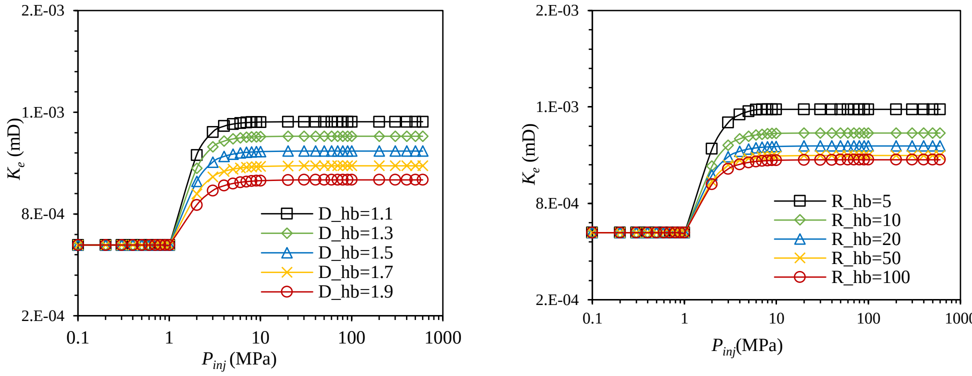
Sample ID	$\lambda_{maxMICP}$ (nm)	λ_{min_hl} (nm)	λ_{min_hb} (nm)	Φ_{hl} (fraction)	Φ_{hb} (fraction)	τ_{hl}	τ_{hb}	D_{hl}	D_{hb}
UMT1	131.0	12.50	5.34	0.019	0.030	2.19	2.63	1.52	1.57
UMT2	131.0	28.00	6.36	0.015	0.028	2.72	3.21	1.78	1.82
UMT3	368.0	10.50	6.30	0.020	0.036	2.81	3.19	1.90	1.87
UMT4	262.0	14.70	3.02	0.026	0.029	1.99	2.08	1.68	1.73
UMT5	131.0	4.35	3.08	0.016	0.023	2.28	2.73	1.42	1.98
GMT1	190.0	9.78	3.77	0.011	0.034	2.82	3.16	1.65	1.94
GMT2	110.0	6.21	3.78	0.015	0.029	2.65	3.10	1.58	1.98
GMT3	300.0	7.82	2.25	0.016	0.051	3.01	3.31	1.61	1.67
GMT4	260.0	6.82	3.15	0.019	0.048	2.98	3.22	1.52	1.73
LMT1	14.6	2.19	1.75	0.006	0.021	2.52	2.04	1.94	1.91
LMT2	37.8	2.15	1.73	0.005	0.019	2.19	2.40	1.92	1.98
LMT3	21.6	5.18	1.85	0.007	0.032	2.28	2.48	1.87	1.88
LMT4	57.6	2.02	1.82	0.005	0.032	2.14	2.17	1.90	1.92

Appendix B. Sensitivity analysis on the effect of PSD$_{hb}$ on effective permeability

On the basis of fractal theory, PSD$_{hb}$ is mainly controlled by three key parameters: λ_{max_hb}, λ_{min_hb} and D_{hb} (Shi et al., 2019). In this section, we keep PSD of hydrophilic pores (PSD$_{hl}$) to be the same and investigate the effect of PSD$_{hb}$ on K_e by changing D_{hb} and the ratio of $\lambda_{max\_hb}/\lambda_{min\_hb}$. ϕ_{hl} and ϕ_{hb} are kept to be constant to isolate the effect of porosity on permeability.

Fig. A1a shows K_e versus P_{inj} for different values of D_{hb}. Eq. (12) is used to calculate K_e by using the parameters listed in Table 4 except D_{hb}. All the curves are overlapped when P_{inj}<1 MPa, which indicates K_{hl} is not affected by D_{hb}. When P_{inj}>200 MPa, under which the rock is 100% water saturated, K_e decreases as D_{hb} increases. Our previous work (Shi et al., 2019) showed that the rock with higher value of D has larger volumetric fraction of small pores and smaller volumetric fraction of large pores. Compared with large pores, small pores have larger surface area per unit of volume, which in turn requires more energy to sustain the same flow rate (Peters, 2012a). In other words, given the same porosity, the rock with small pores has lower K_e compared with the rock with large pores. Thus, the higher volumetric fraction of large pores results in higher K_e.

Fig. A1b shows K_e versus P_{inj} for different ratio of $\lambda_{max\_hb}/\lambda_{min\_hb}$ (R$_{hb}$). Table 4 is used to calculate K_e except λ_{min_hb}. Here, we keep λ_{max_hb} to be 131 nm while changing R$_{hb}$. Five values of R$_{hb}$ (5, 10, 20, 50 and 100) are selected and the values of λ_{min_hb} corresponding to the five ratios are 26.2, 13.1, 6.55, 2.62 and 1.31 nm. As R$_{hb}$ increases, λ_{min_hb} decreases and the PSD$_{hb}$ profile becomes wider. ϕ_{hb} is kept to be constant. Similar to Fig. A1a, Fig. A1b shows that K_{hl} remains the same when R$_{hb}$ changes. When S_w=100% is achieved, K_e decreases as R$_{hb}$ increases. The negative correlation between K_e and R$_{hb}$ can also be explained by the fact that the rock with relatively more small pores has lower K_e compared to the rock with less small pores.



(a) (b)

Fig. A1 K_e versus P_{inj} for (a) difference values of D_{hb} and (b) different ratios of $\lambda_{max\_hb}/\lambda_{min\_hb}$ (R_hb)