PS Relative Permeability Parameter Estimation for Laboratory-Formed Hydrate-Bearing Sediments*

Yongkoo Seol[1] and Timothy J. Kneafsey[2]

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[1]National Energy Technology Laboratory, Morgantown, WV (yongkoo.seol@netl.doe.gov)
[2]Lawrence Berkeley National Laboratory, Berkeley, CA

Abstract

Relative permeability is an essential parameter governing flow of water and gas through hydrate bearing sediments during gas production, and has not been extensively examined. We formed methane hydrate in three different kinds of silica sand (Korean sand, F110 sand, and a mixture of F110 sand and fine silt). Hydrate formation and phase saturation were monitored using temperature and pressure measurements as well as x-ray computed tomography (CT). The van Genuchten model relative permeability parameter, m, (van Genuchten, 1980) was estimated using differential pressure (ΔP) across the sand column under steady state flow and average hydrate saturation measured with CT images. We compared the estimated parameters in terms of hydrate saturations (20-35%) and sand types. Further estimations of the relative permeability parameter are underway using numerical inversion of transient CT measured water saturation data and independently measured capillary pressure.

Reference

van Genuchten, M.T., 1980, A closed-form equation for predicting the hydraulic conductivity of unsaturated soils: Soil Science Society of America Journal v. 44/5, p. 892-898.

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HYDRATES-20E

Relative Permeability Parameter Estimation for Laboratory-Formed Hydrate Bearing Sediments

[1]Yongkoo Seol and [2]Timothy J. Kneafsey
[1]National Energy Technology Laboratory, Morgantown, WV
[2]Lawrence Berkeley National Laboratory, Berkeley, CA

ABSTRACT: Relative permeability is an essential parameter describing flow of water and gas through hydrate bearing sediments during gas production, and we have measured it under steady state. We formed methane hydrate in three silica sands (Korean sand, F110 sand, and a mixture of F110 sand and fine silt). Hydrate formation and phase saturation were monitored using temperature and pressure measurements as well as x-ray computed tomography (CT). The van Genuchten model relative permeability parameter, *m*, (van Genuchten, 1980) was estimated using differential pressure (ΔP) across the sand column under steady state flow, and average hydrate saturation was measured with CT images. We compared the estimated parameters in terms of hydrate saturations and sand types. Further estimations of the relative permeability parameter are underway using numerical inversion of transient CT measured water saturation data and independently measured capillary pressure.

CONCLUSION

- The presence of hydrate in sands significantly changes the relative permeability (k_r) and residual saturations, and the extent of changes were varied with the type of sands
- Large ΔP (and k_r) variation on Ksand may be caused by irregular grain shape, and the pressure is more predictable in Fsand (+silt) with regular grain shape
- The estimated parameters can be used for validation or prior information for transient-state relative permeability estimation method

CT measured Saturation and Differential Pressure under Steady State | Transient State-CT measured Saturation and Numerical Inversion | Capillary Pressure Measurement

Darcy's Equation :

$$Q(s) = -K(s)\cdot A\cdot\left(\frac{dh}{dl}\right) = -k_r(s)\cdot k_i\cdot\left(\frac{\rho g}{\mu}\right)\cdot A\cdot\left(\frac{dh}{dl}\right)$$

$$k_r(s) = -\frac{Q(s)}{k_i\cdot\left(\frac{\rho g}{\mu}\right)\cdot A\cdot\left(\frac{dh}{dl}\right)}$$

Van Genuchten Relation :

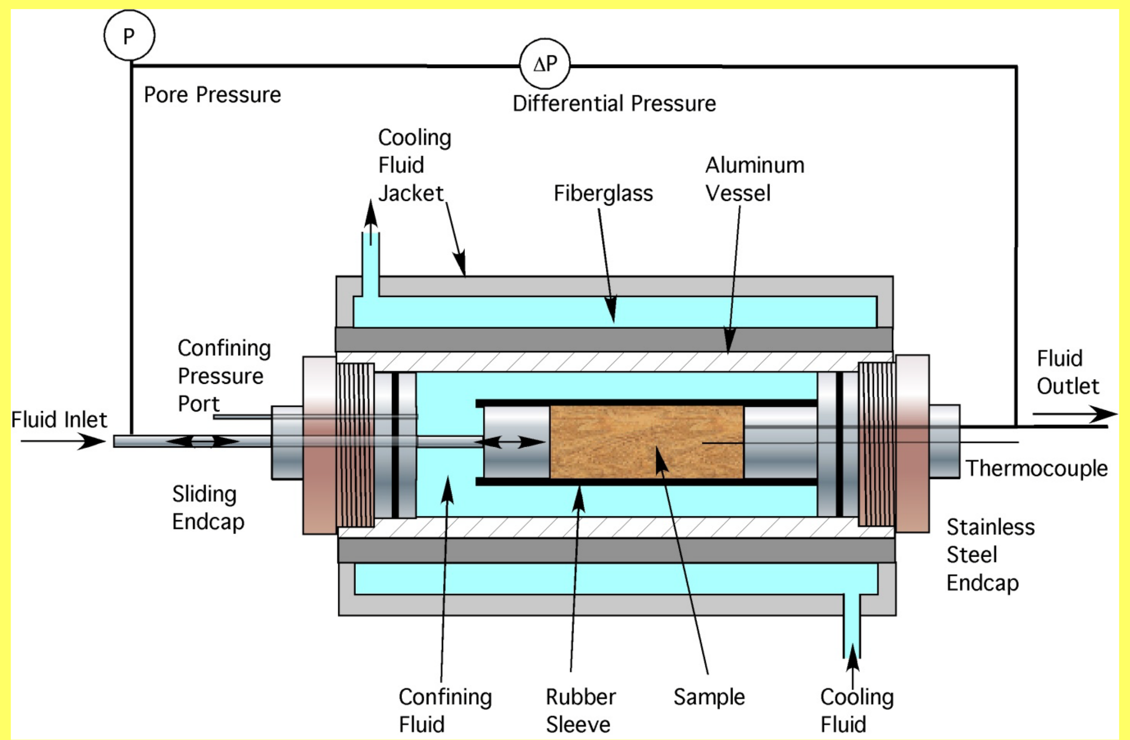
$$K(s) = K_S\sqrt{S^*}\left[(1-(1-S^{*1/m})^m\right]^2$$

$$k_r(s) = \sqrt{S^*}\left[(1-(1-S^{*1/m})^m\right]^2$$

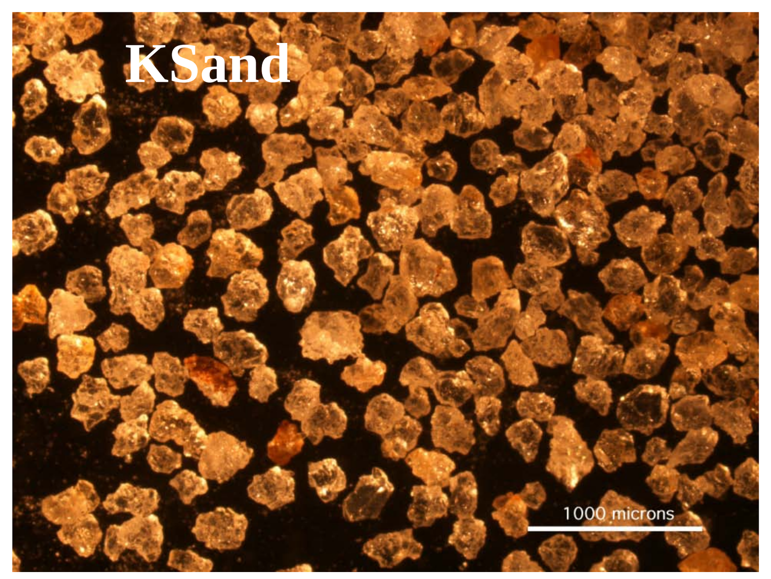
$$S^* = (s-s_r)/(s_s-s_r)$$

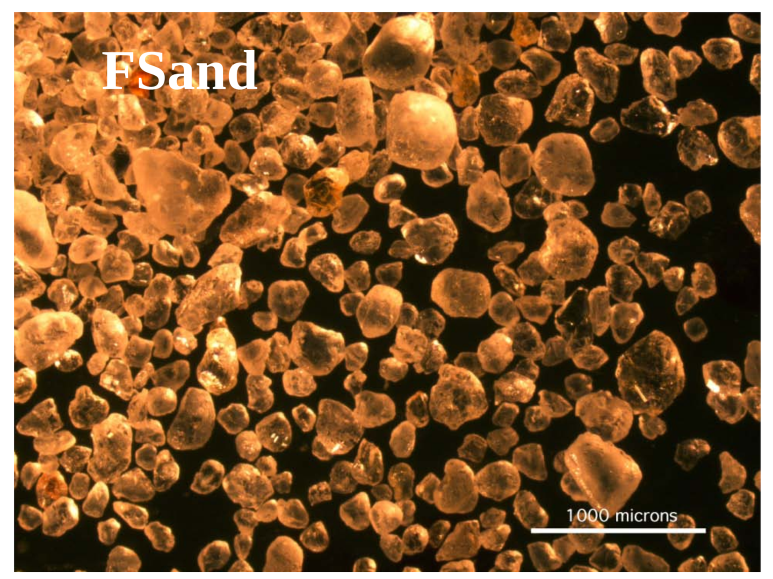
$$k_r(s) = K(s)/K_S$$

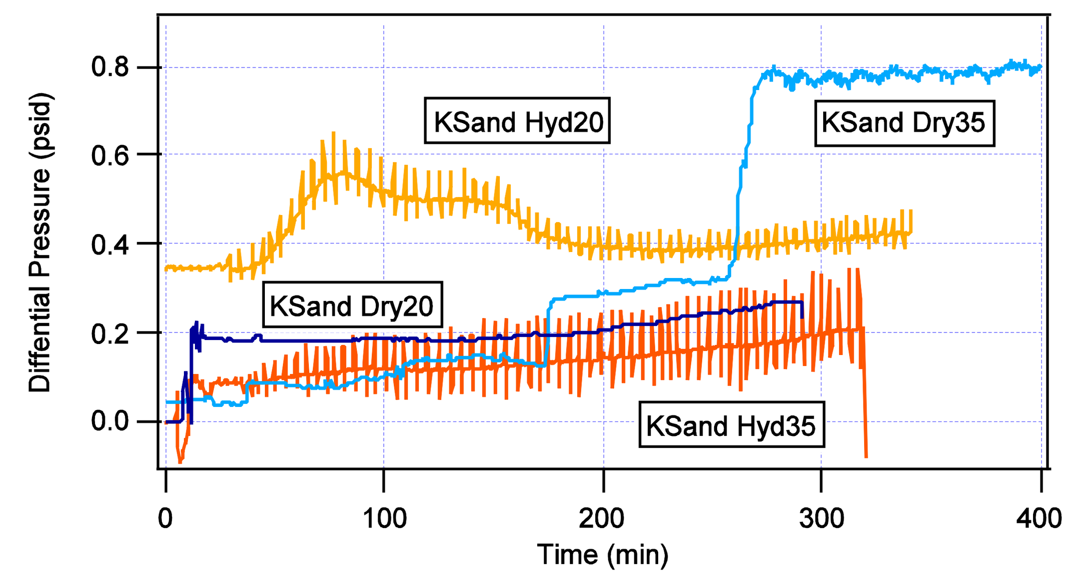
- Moisten sands (Korea sand, F110 sand, F110 sand+silt mixture, initial water saturation=20-45%)
- Hydrate formation (~700 psig at 4 ˚C with 1200 psig confining pressure)
- Water flooding with constant flow rates (0.1 to 2 mL/min)
- Measure differential pressure
- X-ray CT scan for water saturation
- Assume/estimate residual saturations
- Calculate relative permeability with Darcy's equation
- Estimate 'm' for van Genuchten Parameter

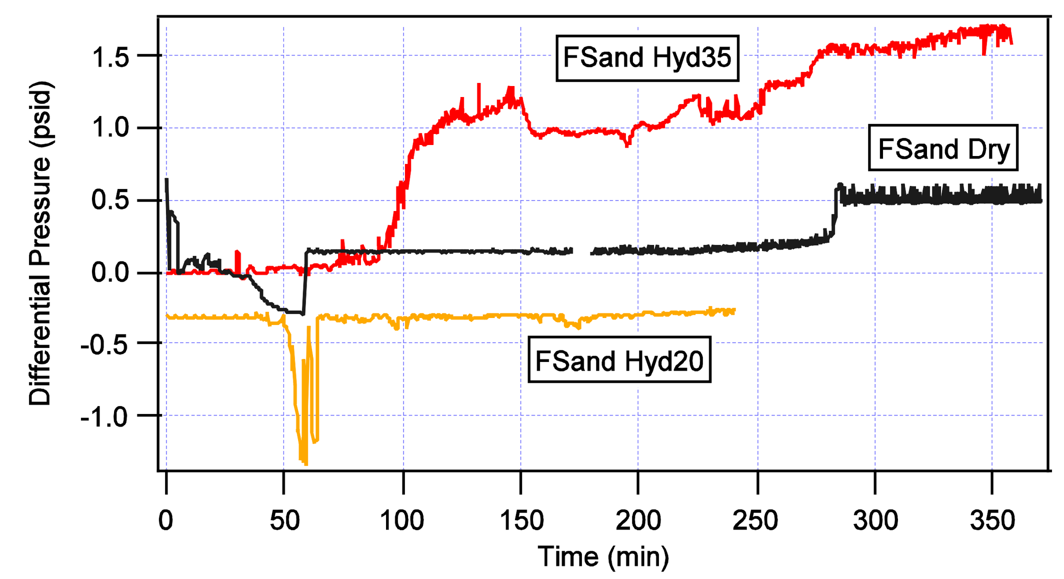


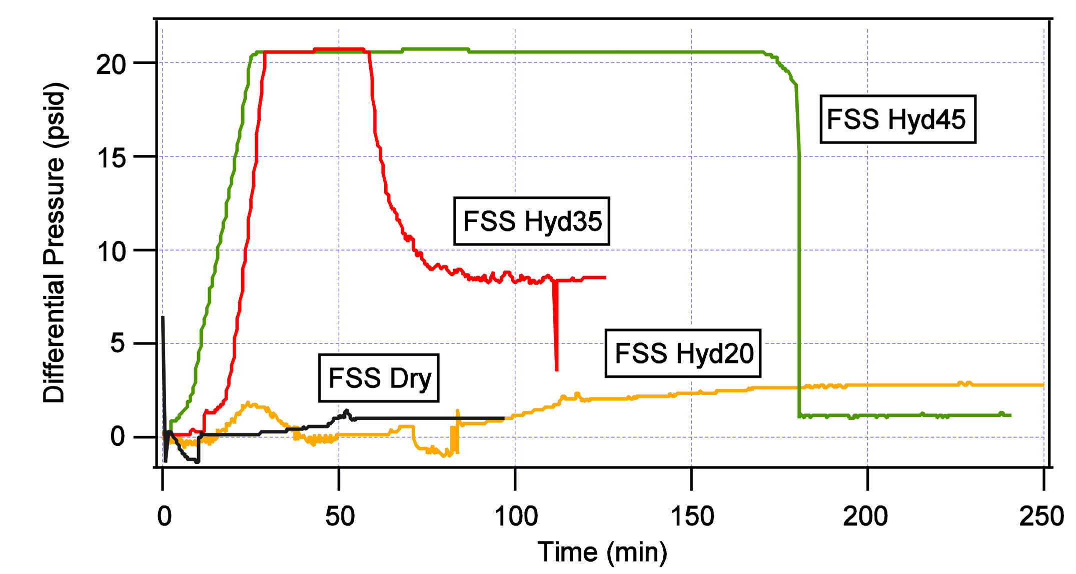
Parameters	K20Dry	K35Dry	K20Hyd	K35Hyd	F20Dry	F20Hyd	F35Hyd	FS10Dry	FS20Hyd	FS35Hyd	FS45Hyd
φ	0.37	0.38	0.37	0.38	0.31	0.31	0.31		0.33	0.30	0.30
Sh	0.00	0.00	0.21	0.31	0.00	0.35	0.47	0.00	0.26	0.43	0.49
Q (ml/min)	0.5	1.0	0.5	0.5	1.0	0.3	0.3	2.0	2.0	0.1	0.1
ki (m^2)	2.90E-12	2.70E-12	1.35E-12	2.25E-12	2.40E-12	1.40E-12	8.40E-13	8.40E-13	1.06E-12	1.71E-13	6.18E-14
A (m^2)	2.72E-03	2.62E-03	2.72E-03	2.62E-03	2.16E-03	2.16E-03	2.32E-03	2.30E-03	2.19E-03	2.30E-03	2.30E-03
ΔP (psig)	2.80E-01	2.58E-01	5.30E-01	2.40E-01	5.08E-01	2.66E-01	1.57E+00	9.70E-01	2.75E+00	1.13E+00	8.44E+00
(-ΔP)	1.80E-01	8.60E-02	4.30E-01	1.30E-01	4.50E-01	1.76E-01	7.50E-01	8.70E-01	2.50E+00	1.00E+00	7.50E+00
(+ΔP)	6.00E-01	2.97E-01	8.00E-01	5.40E-01	5.50E-01	3.17E-01	1.70E+00	1.07E+00	3.00E+00	1.25E+00	9.30E+00
L (cm)	35.6	36.0	35.6	36.0	36.5	36.5	38.5	13.6	13.3	13.6	13.6
Sw	0.75	0.78	0.97	0.94	0.82	0.82	0.85	0.90	0.98	0.99	0.99
Slr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sls	0.90	0.90	0.98	0.98	0.90	0.90	0.94	0.92	0.99	0.99	0.99
S*	**0.83**	**0.87**	**0.99**	**0.96**	**0.91**	**0.92**	**0.90**	**0.98**	**0.99**	**1.00**	**1.00**
Kr (s)	**2.22E-01**	**5.44E-01**	**2.52E-01**	**3.51E-01**	**3.82E-01**	**3.75E-01**	**1.04E-01**	**4.01E-01**	**1.15E-01**	**8.45E-02**	**3.13E-02**
(+Kr (s))	3.46E-01	1.63E+00	3.11E-01	6.48E-01	4.31E-01	5.67E-01	2.18E-01	4.47E-01	1.27E-01	9.55E-02	3.52E-02
(-Kr (s))	1.04E-01	4.72E-01	1.67E-01	1.56E-01	3.53E-01	3.15E-01	9.61E-02	3.63E-01	1.05E-01	7.64E-02	2.84E-02

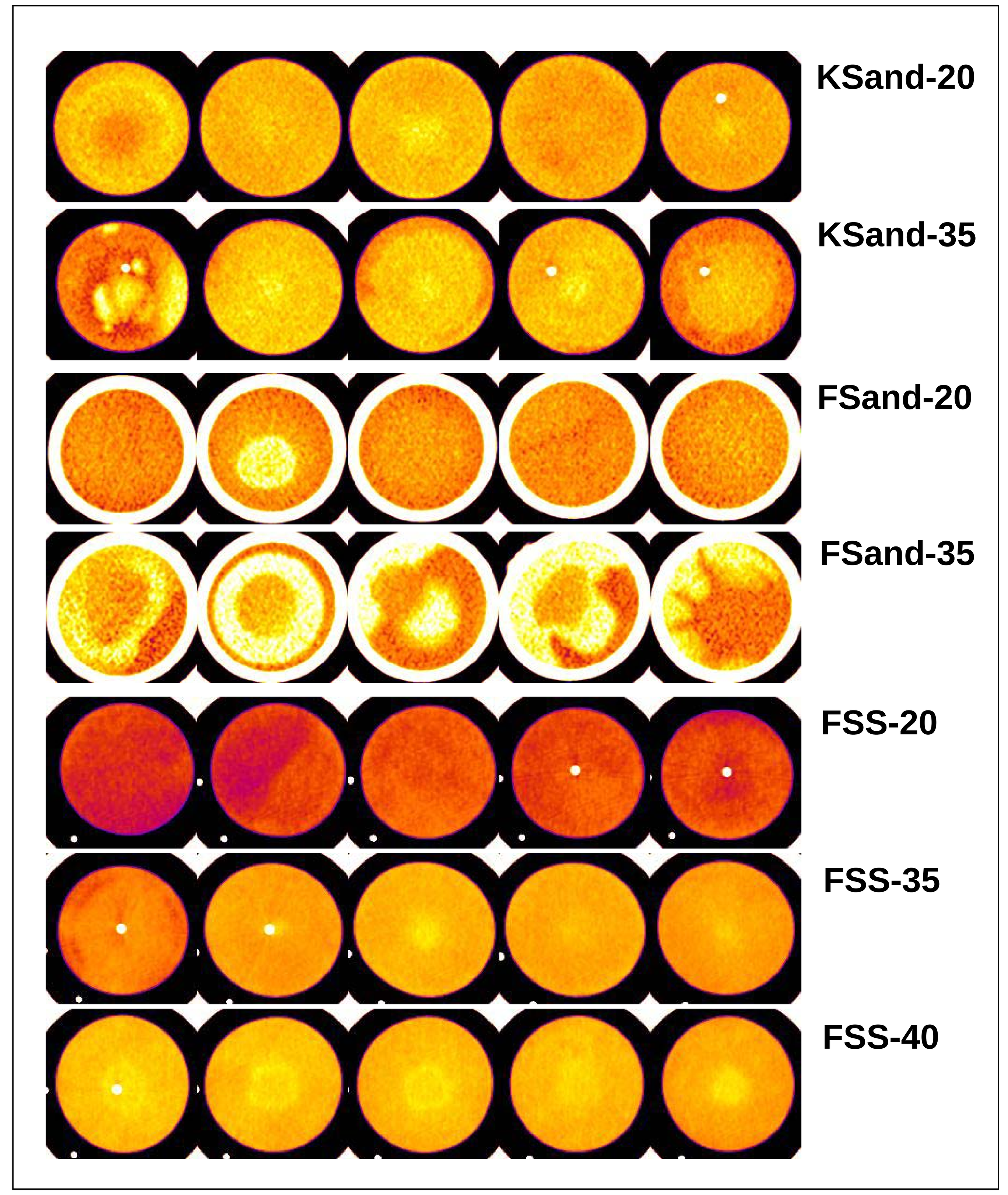


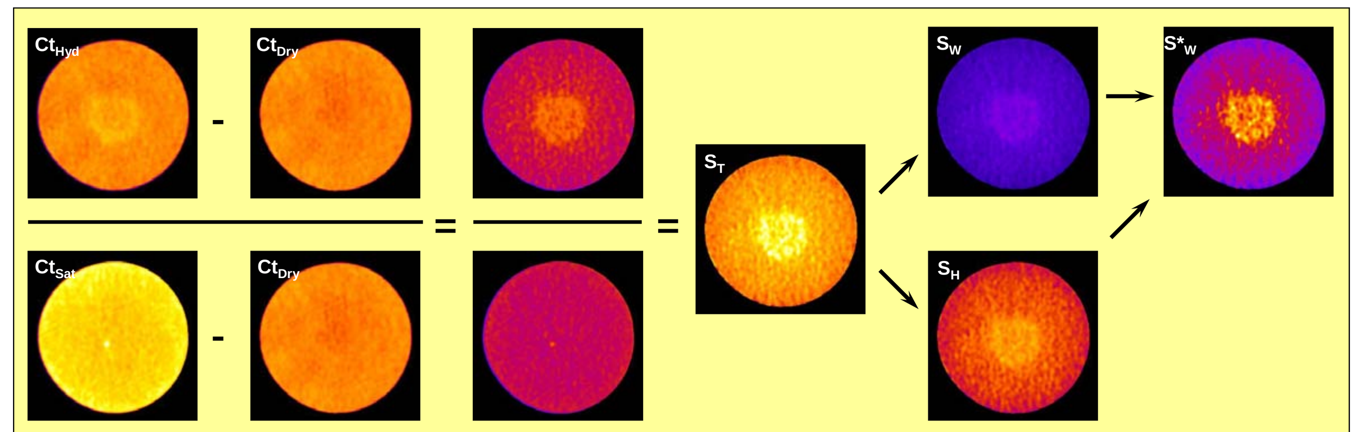












$$S_T = \frac{Ct_{Hyd}-Ct_{Dry}}{Ct_{Sat}-Ct_{Dry}} \quad S_W = \frac{S_T}{1+\frac{xf}{1-x}} \quad S_H = \frac{S_T/\rho_H}{\frac{1-x}{xf}+1} \quad S_W^* = S_W\cdot\frac{1}{1-S_H}$$

x : hydrate conversion factor, f : expansion factor (1.155), ρ : density (0.917), S^*_w : water saturation (hydrate as solid)