1 Supplementary Information

Table S1: Hot Rod sensor array positions. Heating elements were set at 65, 140 and 215 mm depth along the central carbon fibre rod below the base plate and are referred heat injection depth R1, R2 and R3, respectively.

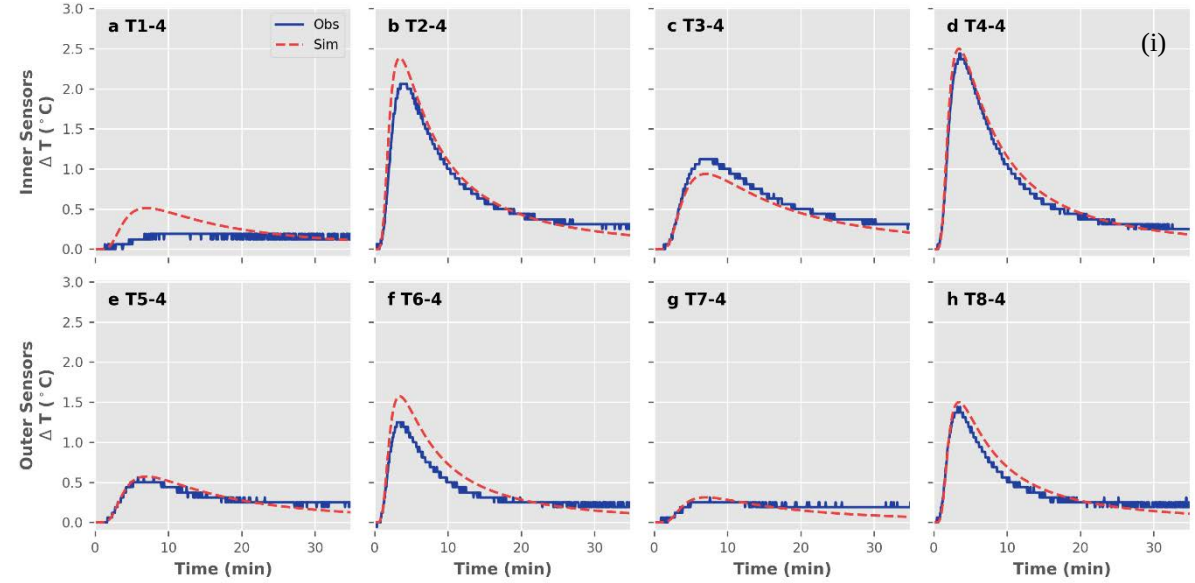
Thermistor depth below base plate (mm)	Thermistors sticks at 28 mm spacing from centre	Thermistors sticks at 47 mm spacing from centre
44	T1-1, T3-1, T5-1, T7-1	T2-1, T4-1, T6-1, T8-1
82	T1-2, T3-2, T5-2, T7-2	T2-2, T4-2, T6-2, T8-2
120	T1-3, T3-3, T5-3, T7-3	T2-3, T4-3, T6-3, T8-3
158	T1-4, T3-4, T5-4, T7-4	T2-4, T4-4, T6-4, T8-4
196	T1-5, T3-5, T5-5, T7-5	T2-5, T4-5, T6-5, T8-5
234	T1-6, T3-6, T5-6, T7-6	T2-6, T4-6, T6-6, T8-6
272	T1-7, T3-7, T5-7, T7-7	T2-7, T4-7, T6-7, T8-7

5

Table 2: Calculated flux magnitude, q_{mag} , and the fluxes q_x, q_y and q_z in each direction, optimised thermal conductivity, κ_0 and volumetric heat capacity, ρc at the three heat injection depths (R1= 65 mm, R2= 140 mm and R3 = 215 mm) for each of the flow scenarios and flow conditions. Horizontal_45 is when the Hot Rod sensor array was orientated 45 degrees to the direction of flow. Two values for the Darcy Flux (q) are shown. Darcy Flux- measure was calculated from the saturated hydraulic conductivity of the sand and the hydraulic gradient and Darcy Flux- calculated was based on the average value from the ultrasonic flow meter that was used in the sand tank to measure discharge. O/R stands for out of range.

Scenario and heat injection depth (R1, R2 & R3)	Darcy Flux- measured, q (m s^{-1})	Darcy Flux- calculated, q (m s^{-1})	q_{mag} (m s^{-1})	q_x (m s^{-1})	q_y (m s^{-1})	q_z (m s^{-1})	κ_0 (W m^{-1} ^{o}C^{-1})	ρc (J m^{-3} ^{o}C^{-1})
Horizontal R1- low		2.80E-05	2.76E-05	1.12E-05	-2.02E-06	2.51E-05	3.93	3.72E+06
Horizontal R2- low	1.23E-05	2.80E-05	1.69E-05	1.27E-05	-2.33E-06	1.09E-05	3.96	3.68E+06
Horizontal R3- low		2.79E-05	1.90E-05	1.89E-05	-1.76E-06	5.78E-08	3.93	3.59E+06
Horizontal R1- mod		4.33E-05	5.18E-05	4.20E-05	5.36E-06	-2.99E-05	3.96	3.71E+06
Horizontal R2- mod	4.50E-05	4.38E-05	2.29E-05	2.01E-05	-2.06E-06	-1.08E-05	3.52	3.43E+06
Horizontal R3- mod		4.39E-05	5.20E-05	5.17E-05	-3.73E-06	3.31E-06	4.14	3.81E+06
Horizontal R1- high		8.87E-05	7.43E-05	7.39E-05	-8.21E-07	7.47E-06	3.78	3.72E+06
Horizontal R2- high	7.88E-05	8.89E-05	6.97E-05	6.91E-05	8.08E-06	4.85E-06	3.97	3.86E+06
Horizontal R3- high		8.95E-05	1.08E-04	1.07E-04	-1.07E-05	7.48E-07	4.17	3.94E+06
Horizontal_45 R1- low		1.14E-05	1.77E-05	1.40E-05	8.12E-06	-7.05E-06	4.02	3.95E+06
Horizontal_45 R2- low	1.23E-05	1.13E-05	5.22E-06	2.16E-06	3.48E-06	3.24E-06	3.92	3.63E+06
Horizontal_45 R3- low		1.13E-05	1.28E-05	7.41E-06	1.04E-05	1.09E-06	4.08	3.70E+06
Horizontal_45 R1- mod		4.75E-05	3.44E-05	9.74E-06	9.11E-06	3.17E-05	4.16	3.94E+06
Horizontal_45 R2- mod	3.27E-05	4.17E-05	1.76E-05	7.80E-06	-7.86E-06	1.37E-05	3.91	3.69E+06
Horizontal_45 R3- mod		4.71E-05	3.61E-05	1.96E-05	2.55E-05	1.64E-05	4.25	3.93E+06
Horizontal_45 R1- high		9.54E-05	8.89E-05	6.66E-05	5.84E-05	7.47E-06	3.73	3.87E+06
Horizontal_45 R2- high	1.04E-04	9.51E-05	7.58E-05	5.66E-05	-5.02E-05	3.79E-06	4.03	4.01E+06
Horizontal_45 R3- high		9.49E-05	1.11E-04	7.60E-05	-8.11E-05	4.97E-06	4.24	4.04E+06
Diagonal R1- low		3.40E-05	3.23E-05	2.78E-05	-9.61E-07	1.63E-05	3.92	3.80E+06
Diagonal R2- low	5.42E-05	3.34E-05	2.83E-05	2.05E-05	8.25E-07	1.95E-05	4.07	3.51E+06
Diagonal R3- low		3.27E-05	2.86E-05	2.04E-05	-5.70E-07	2.00E-05	4.19	3.77E+06
Diagonal R1- mod		5.72E-05	4.89E-05	4.54E-05	-3.00E-06	1.77E-05	3.85	3.76E+06
Diagonal R2- mod	9.66E-05	6.16E-05	4.39E-05	3.15E-05	1.17E-06	3.06E-05	3.85	3.43E+06
Diagonal R3- mod		5.91E-05	5.26E-05	4.07E-05	1.56E-06	3.33E-05	4.25	3.91E+06
Diagonal R1- high		7.57E-05	5.97E-05	5.59E-05	2.74E-06	2.06E-05	3.89	3.71E+06
Diagonal R2- high	1.39E-04	7.48E-05	5.99E-05	4.55E-05	1.38E-06	3.89E-05	4.22	3.63E+06
Diagonal R3- high		7.52E-05	6.82E-05	5.19E-05	-3.32E-07	4.42E-05	4.25	3.99E+06
Upward R1- low		1.42E-05	1.35E-05	1.15E-05	5.82E-06	4.16E-06	4.25	4.12E+06
Upward R2- low	2.49E-05	1.61E-05	7.46E-06	-2.80E-06	-3.20E-06	6.13E-06	4.25	3.70E+06
Upward R3- low		1.81E-05	1.34E-05	-1.62E-06	-1.40E-07	1.33E-05	1.75	1.42E+06
Upward R1- mod		7.01E-05	6.72E-05	1.91E-05	-3.72E-06	6.43E-05	4.25	4.25E+06

Upward R2- mod	3.74E-05	7.03E-05	7.75E-05	-4.27E-06	2.39E-08	7.74E-05	4.25	3.89E+06
Upward R3- mod		6.78E-05	7.82E-05	-8.48E-06	-3.78E-06	7.77E-05	4.10	3.84E+06
Upward R1- high	5.36E-05	2.60E-04	2.64E-04	1.57E-05	-1.14E-05	2.64E-04	1.93	4.12E+06
Upward R2- high		2.55E-04	3.11E-04	-4.92E-06	-5.02E-06	3.11E-04	4.25	4.19E+06
Upward R3- high		2.72E-04	8.86E-05	-9.24E-06	-2.02E-06	8.81E-05	1.75	1.25E+06
Downward R1- low	4.61E-05	1.92E-04	5.95E-05	6.83E-06	4.01E-06	-5.90E-05	4.25	4.17E+06
Downward R2- low		1.92E-04	5.52E-05	2.57E-06	-3.76E-08	-5.51E-05	4.25	3.90E+06
Downward R3- low		1.91E-04	6.13E-05	-5.59E-06	6.31E-06	-6.07E-05	4.25	4.24E+06
Downward R1- mod	1.30E-04	2.69E-04	1.96E-04	3.18E-06	8.46E-06	-1.96E-04	4.25	4.25E+06
Downward R2- mod		2.47E-04	1.98E-04	6.51E-06	4.23E-06	1.98E-04	4.25	4.25E+06
Downward R3- mod		2.10E-04	1.79E-04	-8.11E-06	1.07E-05	-1.79E-04	4.25	4.25E+06
Downward R1- high	2.84E-04	3.96E-04	O/R	O/R	O/R	O/R	O/R	O/R
Downward R2- high		3.98E-04	O/R	O/R	O/R	O/R	O/R	O/R
Downward R3- high		4.01E-04	O/R	O/R	O/R	O/R	O/R	O/R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c T3-4
d T4-4
(i)
Obs
Sim
Inner Sensors
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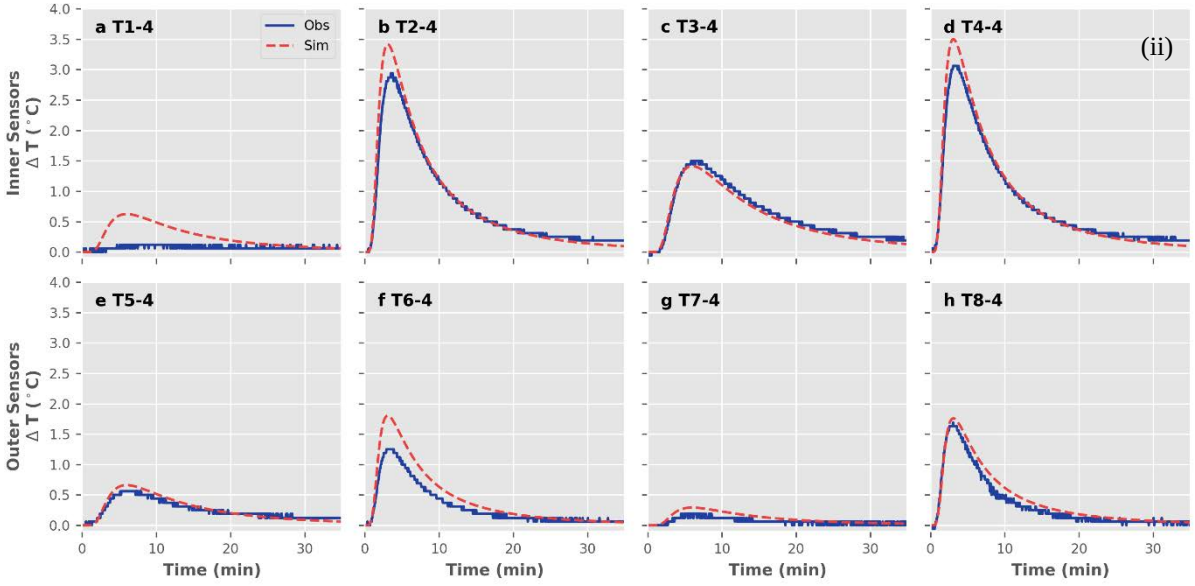
f T6-4
g T7-4
h T8-4
Outer Sensors
Δ T (° C)
Time (min)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(ii)
Obs
Sim
Inner Sensors
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Outer Sensors
Δ T (° C)
Time (min)

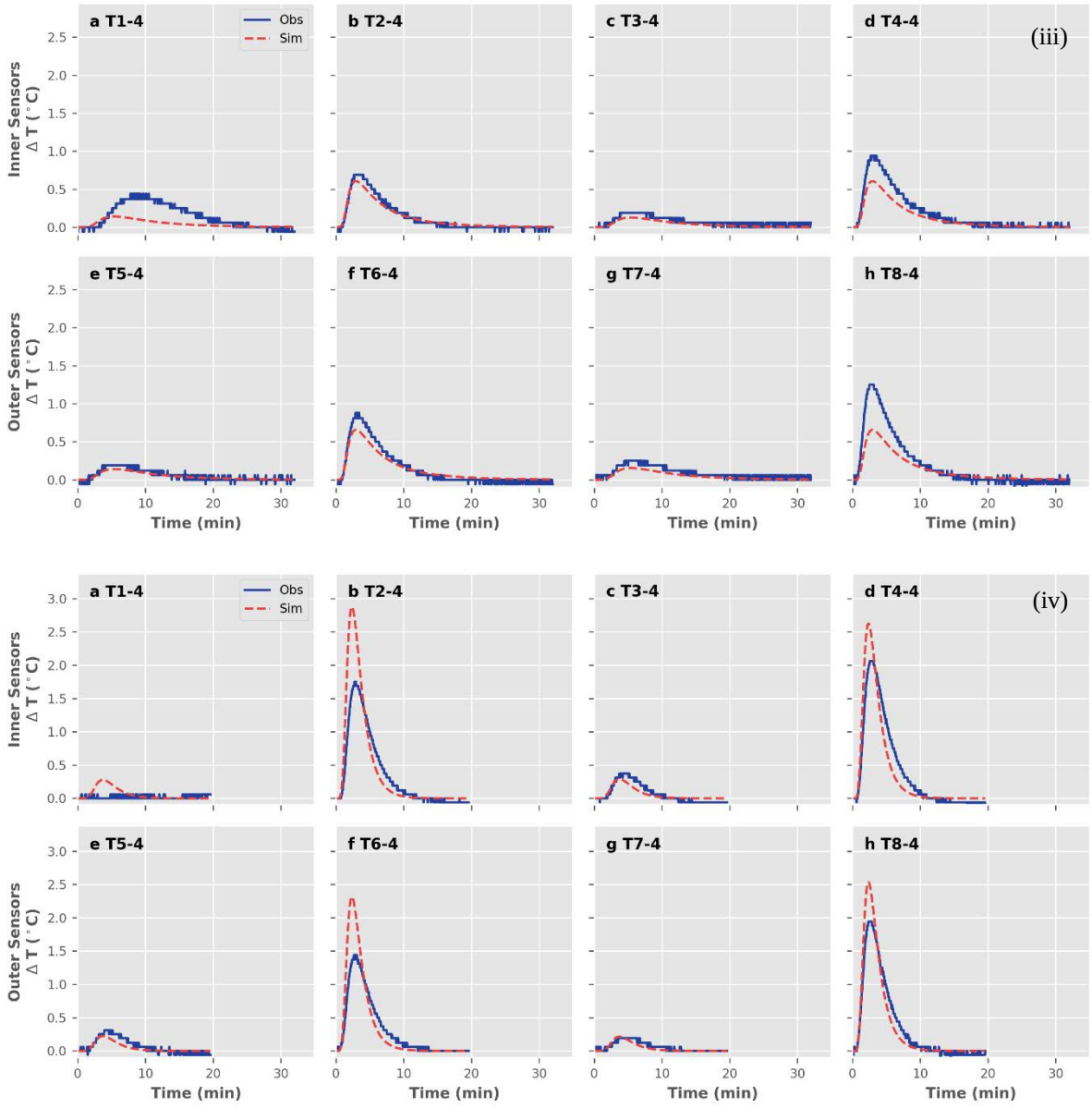
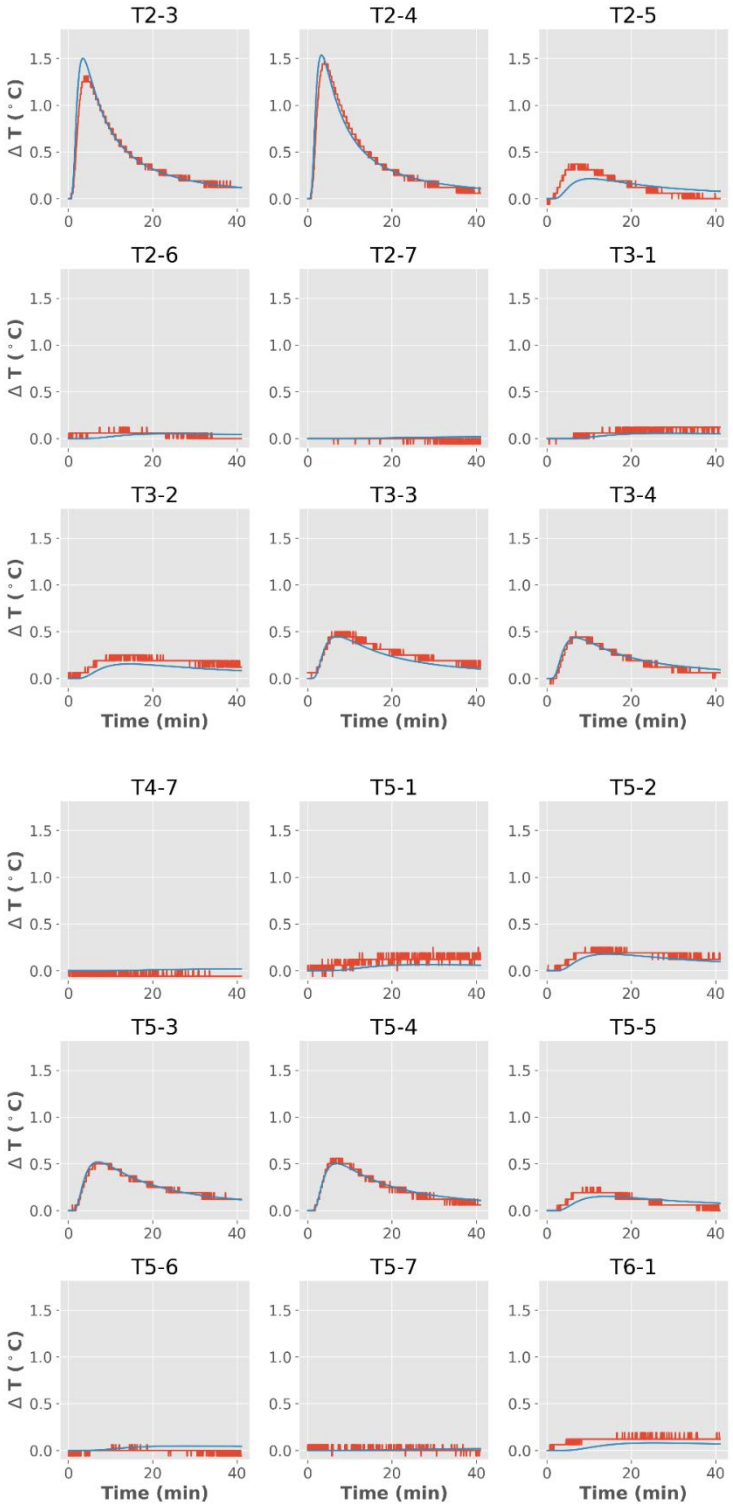


Figure S1: Selected measured and modelled breakthrough curves are shown of the 4th vertical thermistor (158 mm depth) from each radial sensor location for the (i) horizontal, (ii) diagonal, (iii) upward, and (iv) downward flow scenarios. Solid blue lines are observed and dashed red lines are modelled.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T2-5
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T5-7
T6-1
Δ T (°C)
Time (min)

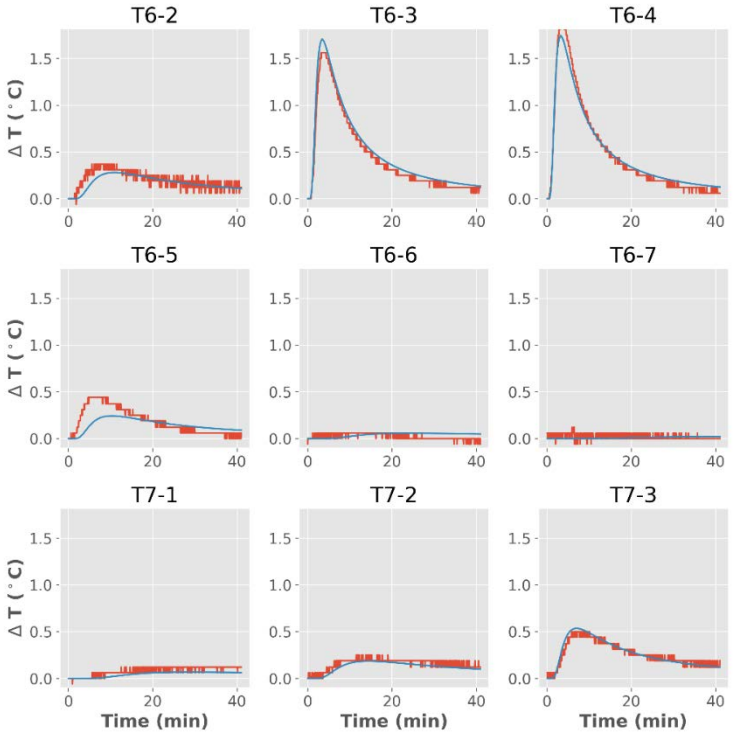

Figure S2: Selected measured and modelled breakthrough curves for the no-flow scenario from heat injection depth R2.

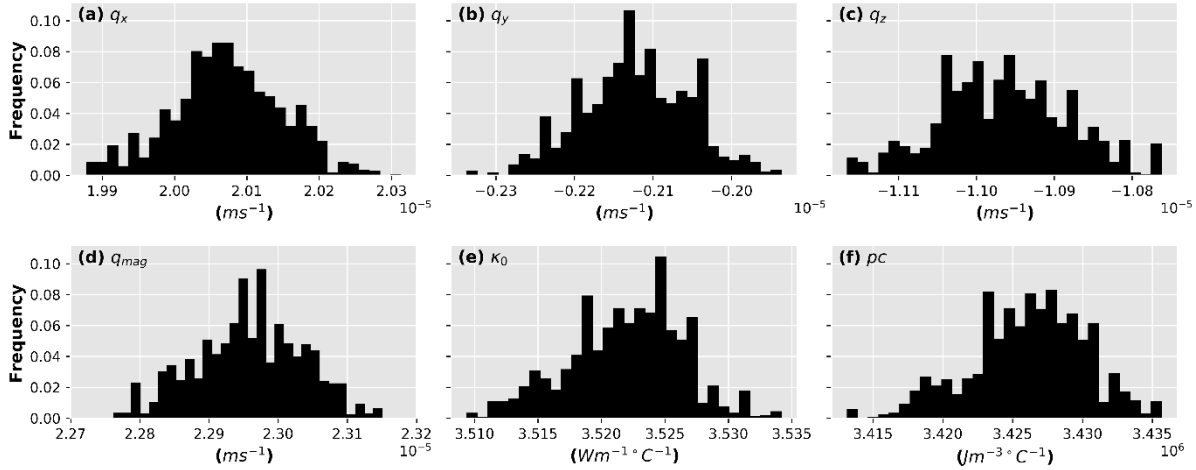

Figure S3: Histogram showing the output from the DREAM algorithm for the flux magnitude, q_{mag}, flux components, q_x, q_y, q_z, thermal conductivity, κ_0 and volumetric heat capacity of water, ρc for the horizontal flow scenario with moderate flow at heat injection depth R2.

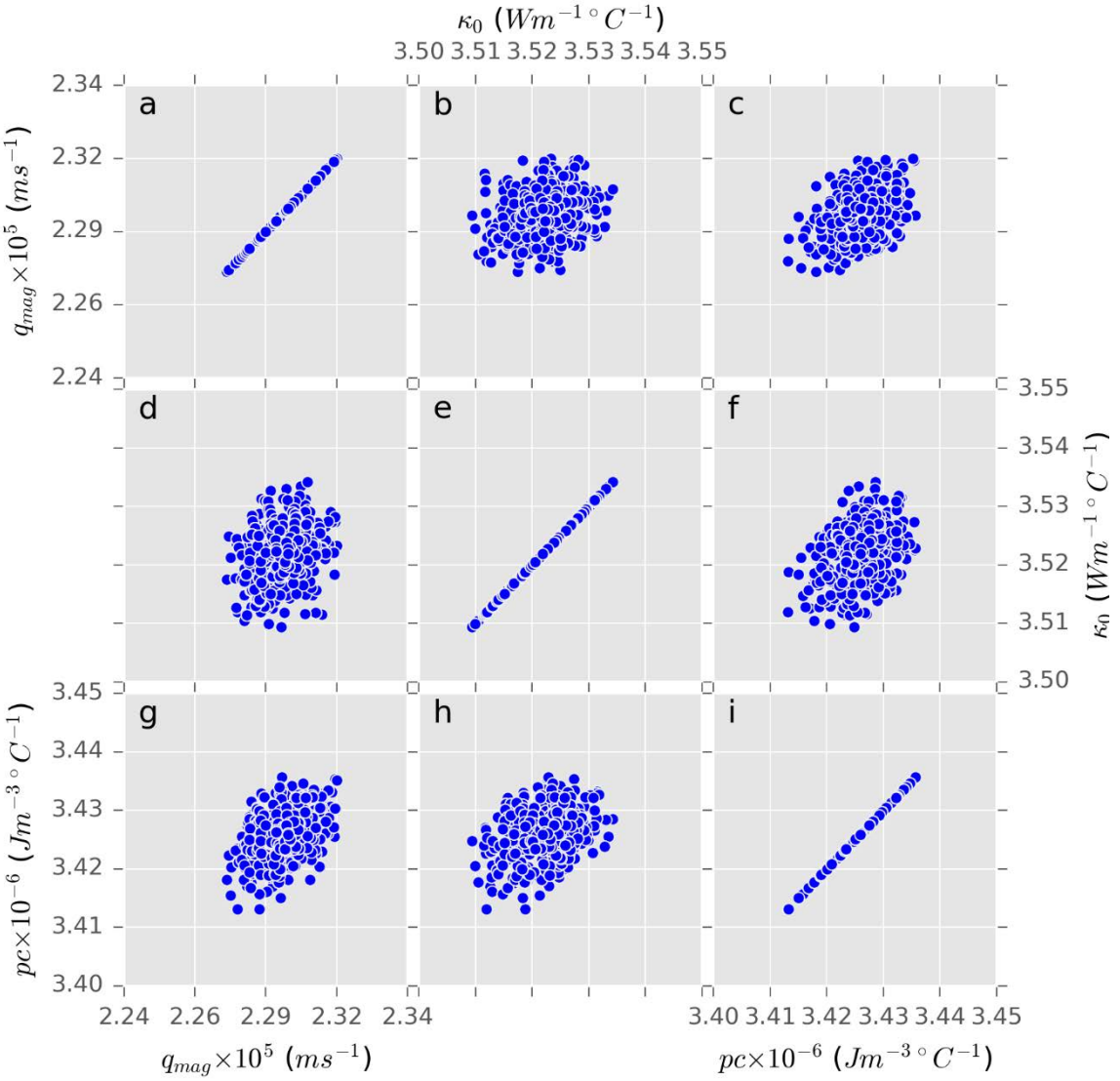

Figure S4: Correlation plot of the flux magnitude, q_{mag}, thermal conductivity, κ_0 and volumetric heat capacity of water, ρc for the horizontal flow scenario with moderate flow at heat injection depth R2.

Please refer to the Hot Rod time series animation video of the four scenarios. File name: Banks_etal_2017_Hot Rod sand tank.mp4