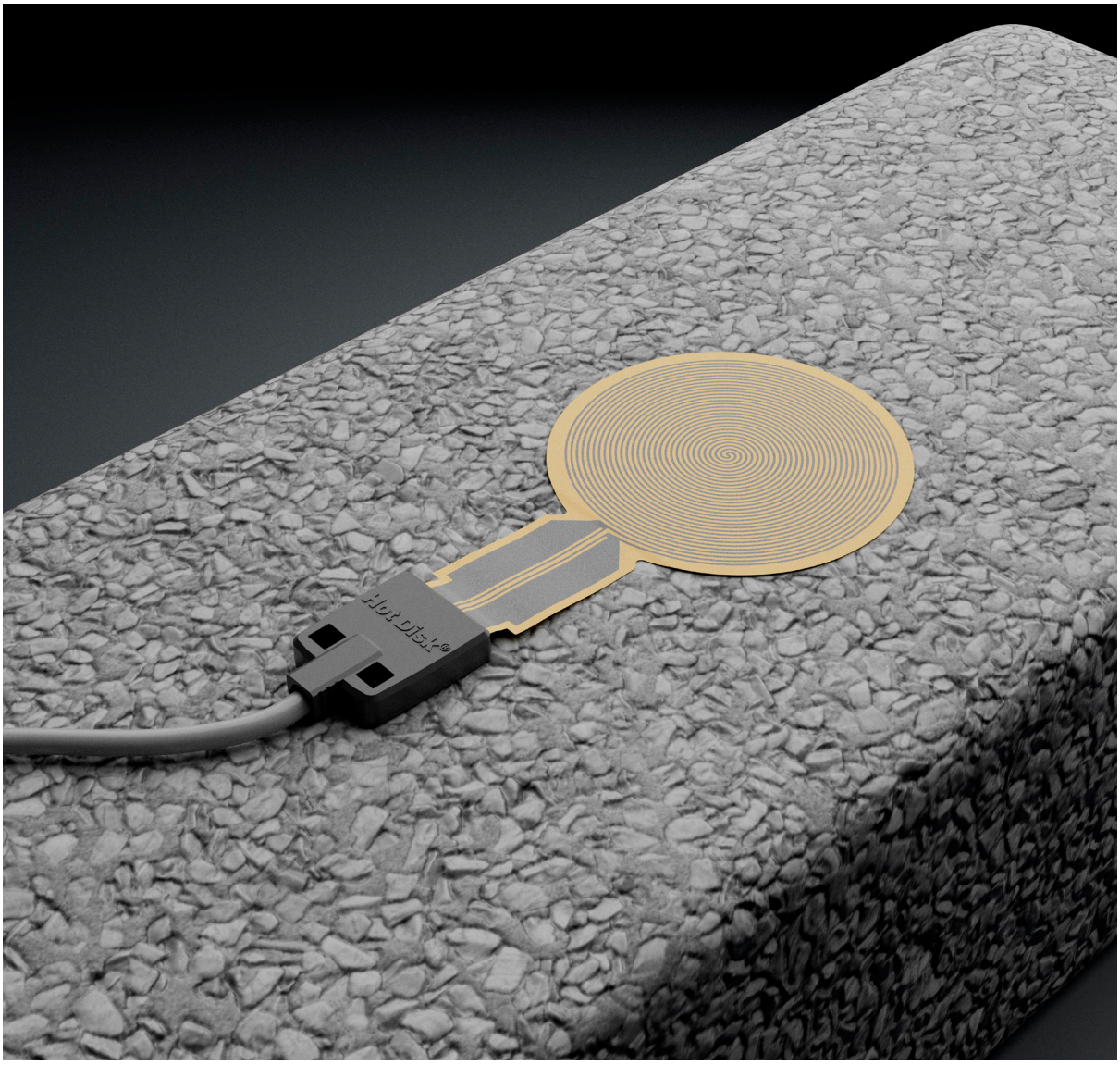
Hot Disk® Instruments

Application Note

Large Diameter Hot Disk® Sensors Enabling Thermal Conductivity Measurements of Aggregates and Particulates

Besira Mihiretie, Ph.D.



Larger Sensors for Representative Bulk Measurements

This application note presents Hot Disk® sensors with diameters of 120 and 180 mm for measurements over larger sample areas and volumes. Sampling a larger portion of a heterogeneous material can help the measured thermal properties represent the bulk material, rather than an individual pore, particle, inclusion, or local region. This enables testing of aggregate and particulate materials such as gravel, expanded clay aggregate, light weight concrete, and asphalt used in construction.

55.0 L

Maximum probed sample volume
For the 180 mm Hot Disk® sensor, using the maximum targeted probing depth with the Hot Disk® measurment sensitive region

254 cm^2

Hot Disk® sensor-to-sample contact area
The 180 mm diameter sensor covers 36 times the area of a 30 mm diameter sensor, nine times that of a 60 mm diameter sensor, and 2.25 times that of a 120 mm diameter sensor

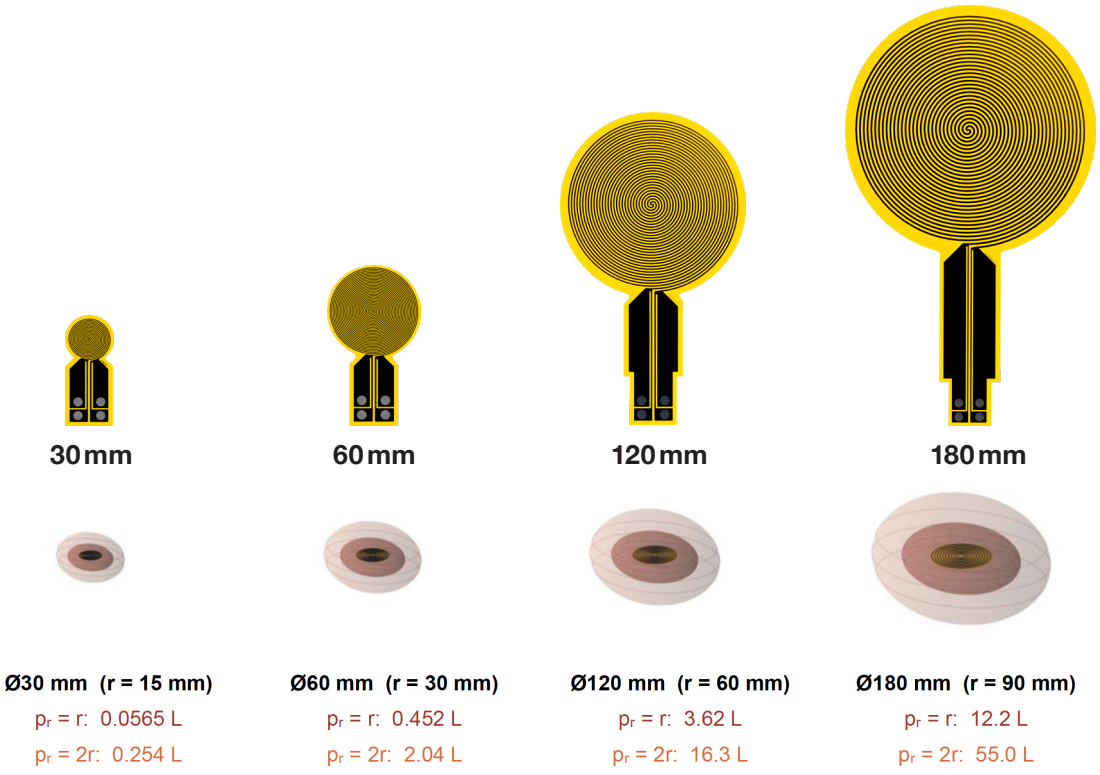


Figure 1. (Top) Applied Hot Disk® sensors arranged by diameter (2r) size: 30, 60, 120, and 180 mm, and (Bottom) the respective thermally probed volume. Illustrated is the volume corresponding to the targeted probing depth (p_r) range for maximum sensitivity of a Hot Disk® measurement.

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Why Sensor Size Matters

The Hot Disk® technique determines thermal conductivity, thermal diffusivity, and volumetric heat capacity from the temperature response of a plane double-spiral element that acts as both a transient heat source and a resistance thermometer[1]. For homogeneous materials, different sensor diameter sizes can provide comparable results when the experimental conditions satisfy the Hot Disk® model. In coarse or heterogeneous materials, a small diameter sensor may sample too few structural features to represent the component as a whole. A larger diameter sensor samples more particles, pores, flakes, or aggregates and can therefore improve the representativeness of the effective bulk properties.

In a double-sided Hot Disk® measurement, heat from the double-spiral element propagates into both sample halves. The thermally probed region can be approximated by an oblate spheroid. Here, r is the sensor radius and p_r is the thermal probing depth measured from the sensor plane into each sample half and radially beyond the sensor edge. The equatorial and polar semi-axes are $a = r + p_r$ and $c = p_r$, respectively. The estimated volume is:

$$V = \frac{4}{3}\pi(r + p_\mathrm{r})^2 p_\mathrm{r}$$

$$p_\mathrm{r} = 2r \quad \Rightarrow \quad V = 24\pi r^3$$

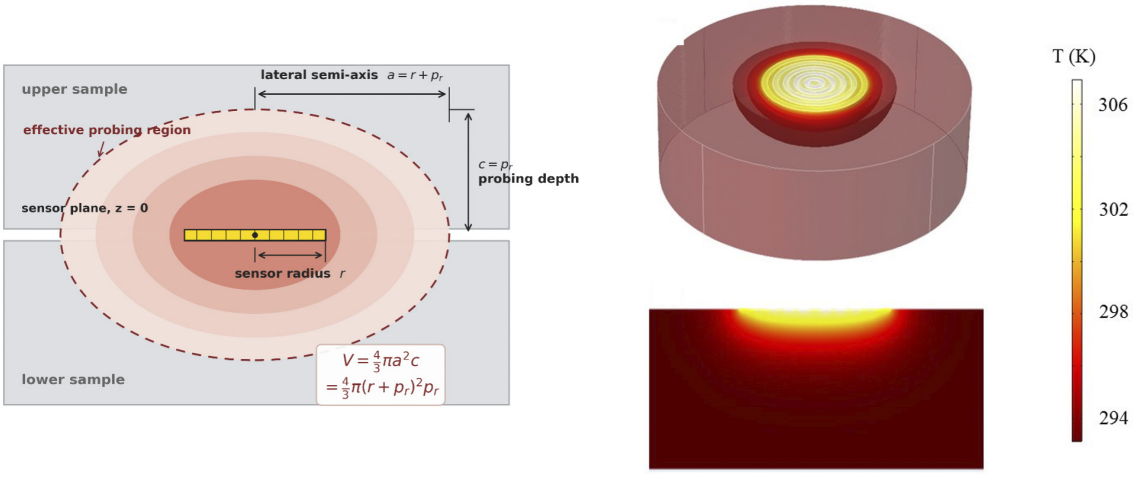


Figure 2. Left: Cross-sectional schematic defining the Hot Disk® sensor radius r, probing depth p_r, and semi-axes of the oblate spheroid used to estimate the probed volume. Right: Simulated temperature field showing heat propagation from the sensor double-spiral into the surrounding sample[2], with a three-dimensional distribution above and a two-dimensional view below.

For particulates and strongly heterogeneous materials, a sensor radius rule-of-thumb of $r \geq 10d_{max}$ provides a guide to sensor selection, where d_{max} is the largest relevant particle or structural-feature dimension. The thermal probing depth should of course also be within the specimen or loose-material assembly. Larger radius sensors increase the range of feature sizes and sample volumes that can be investigated.

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These materials, like lightweight concrete construction blocks and expanded clay pellets, contain pores, particles, and interparticle voids. A larger measurement region includes more of these features and can reduce sensitivity to sensor position, in other words it can provide a more representative bulk value.

Materials and Measurement Configuration

Test set 1: Comparing measurement results from using different sensor diameter. Expanded polystyrene (EPS), expanded glass beads, and compressed graphite were measured with Hot Disk® sensors of diameter 30, 60, and 120 mm. The tests compared Hot Disk® Instruments newly introduced 120 mm diameter sensor with their established smaller diameter sensors across a thermal conductivity range spanning more than three orders of magnitude. The purpose of these tests is to verify the performance of the newly introduced 120 mm diameter sensor.

Test set 2: Measurements of aggregate and particulate samples of large particle feature size. A lightweight concrete construction block measuring 580 × 240 × 180 mm and expanded clay pellets with particle sizes of 8–12 mm were measured using newly introduced Hot Disk® sensors of diameter 120 and 180 mm. The clay pellets were filled into a cylindrical container of diameter 280 mm and height 240 mm, with the sensor positioned at the midpoint along its height.

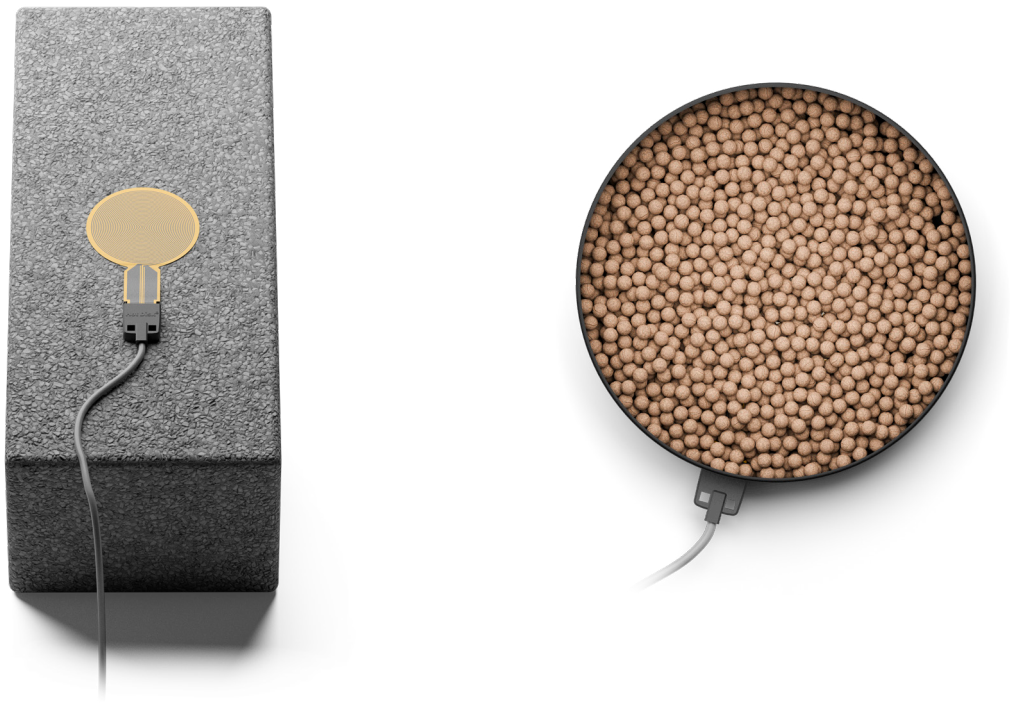


Figure 3. Left: Lightweight concrete construction block (580 × 240 × 180 mm) with the Hot Disk® sensor on its surface. During single-sided testing, the exposed side of the sensor is thermally insulated. Right: Expanded clay pellets (8–12 mm) in a cylindrical container of diameter 280 mm and height 240 mm; the Hot Disk® sensor is positioned at the midpoint along the height of the container.

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Sample	Material form and dimensions	Hot Disk® sensor diameter (mm)	Measurement power (mW)	Measurement duration (s)
Expanded polystyrene (EPS)	Porous cellular solid	30	25	80
		60	50	160
		120	150	320
Expanded-glass beads	Loose beads; particle size ≈1 mm	30	30	640
		60	70	1280
		120	200	2560
Compressed graphite	Compacted flakes	30	7500	2.5
		60	7500	3
		120	7500	3
Lightweight concrete construction block	Porous block; 580 × 240 × 180 mm	120	800	640
		180	800	640
Expanded clay pellets	Pellets: 8–12 mm; holder: Ø280 × 240 mm	120	600	640
		180	800	1256

Table 1. Samples, sensor diameters, heating powers, and measurement durations. The tests were performed using a Hot Disk® instrument model TPS 1000 at ambient laboratory temperature. Heating power and measurement duration were selected for each sensor–sample combination to provide a sufficient temperature rise while limiting thermal penetration through the specimen.

For the test set 1 measurements, a double-sided measurement set-up was implemented. For the test set 2 measurements, the expanded clay pellets surrounded the sensor in a loose-material assembly, whereas the lightweight concrete construction block was tested in a single-sided configuration, with the sensor against one face of the block and insulation on the opposite side of the sensor.

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Measurement Results

Temperature-rise transients and thermal-property results are presented below.

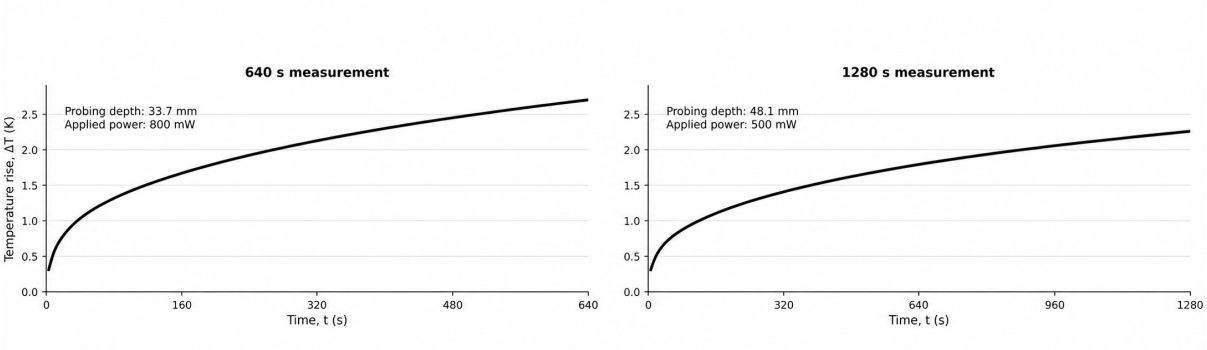


Figure 4. Temperature-rise transients measured in the construction block using a Hot Disk® sensor of 120 mm diameter. Measurement durations were 640 and 1280 s, with calculated probing depths of 33.7 and 48.1 mm, respectively.

Sample	Sensor diameter (mm)	Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	Thermal diffusivity ($mm^2 \cdot s^{-1}$)	Volumetric heat capacity ($MJ \cdot m^{-3} \cdot K^{-1}$)
EPS	30	0.030 ± 0.0004	1.30	0.023
	60	0.033 ± 0.0005	1.68	0.020
	120	0.034 ± 0.0004	1.69	0.020
Expanded-glass beads	30	0.080 ± 0.001	0.34 ± 0.025	0.23
	60	0.080 ± 0.004	0.34 ± 0.011	0.24 ± 0.07
	120	0.090 ± 0.006	0.39 ± 0.078	0.25 ± 0.05
Compressed graphite	30	188.8 ± 1.7	119.5 ± 2.9	1.58 ± 0.05
	60	184.0 ± 1.2	133.4 ± 10.9	1.39
	120	181.0 ± 4.8	147.8 ± 11.3	1.23

Table 2. Measurement results of test set 1, i.e. comparing Hot Disk® sensors of different diameter size.

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Sample	Configuration	Sensor diameter (mm)	Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)
Lightweight concrete construction block	Single-sided	120	0.46 ± 0.003
	Single-sided	180	0.459 ± 0.08
Expanded clay pellets	Loose-material assembly (double-sided)	120	0.21 ± 0.007
	Loose-material assembly (double-sided)	180	0.23 ± 0.001

Table 3. Thermal-conductivity measurements on the construction block and expanded clay pellets using the 120 and 180 mm Hot Disk® sensors.

Conclusions

The newly introduced 120 and 180 mm diameter Hot Disk® sensors extend thermal property measurements to larger sample areas and volumes, enabling characterization of materials with coarse particles and structural features. The 180 mm sensor provides a contact area of 254 cm^2 and, in a double-sided configuration, can probe volumes of up to 55 litres

Measurements on three materials spanning more than three orders of magnitude in thermal conductivity confirmed the performance of the 120 mm sensor compared with smaller Hot Disk® sensors. Further measurements on lightweight concrete blocks and expanded clay pellets demonstrated the benefits of the larger sensors for porous bulk and granular materials.

For the lightweight concrete blocks, the thermal conductivity values obtained with the 120 and 180 mm sensors differed by only 0.22%, demonstrating excellent agreement. This also indicates that both sensors fulfil the rule of thumb of having a radius larger than ten times the structural features in the porous block sample. For the expanded clay pellets, the 180 mm sensor gave a 9.5% higher thermal conductivity than the 120 mm sensor. This difference reflects the influence of local particle packing and interparticle voids when relatively large 8–12 mm particles are measured. By sampling a larger number of particles, the 180 mm sensor can provide a more representative estimate of bulk thermal conductivity.

Overall, the results demonstrate the practical value of large Hot Disk® sensors for characterizing porous solids and coarse granular materials.

References

1. S. E. Gustafsson. “Transient Plane Source Techniques for Thermal Conductivity and Thermal Diffusivity Measurements of Solid Materials,” Review of Scientific Instruments 62(3), 797–804 (1991).

2. B.M. Mihiretie, D. Cederkrantz, A. Rosén, H. Otterberg, M. Sundin, S.E. Gustafsson, and M. Karlsteen, “Finite Element Modeling of the Hot Disc Method,” International Journal of Heat and Mass Transfer 115, 216–223 (2017). https://doi.org/10.1016/j.ijheatmasstransfer.2017.08.036

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