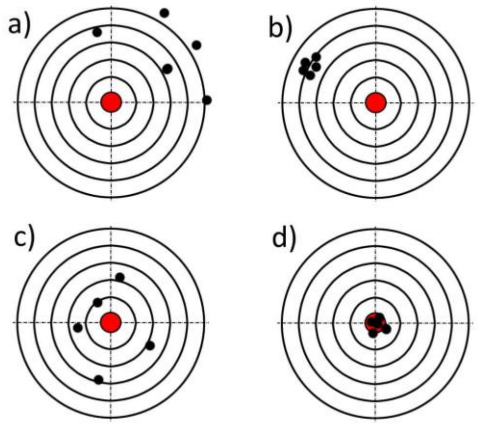
APPLICATION NOTE (C3 #7675) ____

Measurement Accuracy and Thermal Conductivity of Water

Two figures of merit are commonly used to describe how "good" an analysis technique is. One is Accuracy, telling how correct the measurement is, the other is Precision, telling how well a result is reproduced. This application note deals with the accuracy of thermal conductivity measurements, utilizing water to exemplify how the quality of a Hot Disk measurement can be assured.

In the literature there are numerous published values of Thermal Transport Properties of many materials, some dating back as far as the 19th century. All these data are based on measurements, as there is no baseline material for thermal conductivity. In the best of cases, the published results are compiled from many measurements with different techniques under controlled conditions, so called Round Robin tests. If so, the mean of all measurements is probably a fair estimate of the true value, but will never the less contain errors and deviations, and to what magnitude being unknown.



Bad accuracy and precision. b) Bad accuracy but good precision. c) Good accuracy (average is close to bulls-eye) but bad precision. d) Good accuracy and precision.

Linking Specific Heat and Thermal Conductivity

The one exception to the above is related to the heat capacity of water. One calorie is per definition the amount of energy needed to increase the temperature of one gram of water with one degree Celsius at 20 °C. In SI units the C_p of water is thus 4.18 J/g K at 20 °C. As this is the definition of specific heat, it is accurate and correct. Knowing that the specific heat per unit volume (density multiplied with C_p) is equal to Thermal Conductivity divided by Thermal Diffusivity, we have a good chance of testing Accuracy by simultaneously measuring conductivity and diffusivity of water. At 20 °C the density of pure water is 1.00 g/cm^3 and thus the specific heat per unit volume will be 4.18 MJ/m^3 K.

Testing Water

To measure water some precautions must be taken: The water needs to be distilled, to get rid of all ions. It must also be degassed and kept in a sealed container, to remove dissolved gases and prevent new uptake in contact with air. A sample of water prepared this way was enclosed in a vessel with a Hot Disk sensor and tested accordingly.

For the analysis a TPS 2500 S instrument following ISO 22007-2 was utilized. In this case a sensor with radius of 3.2 mm was employed, with a heating power of 25 mW and a 3 s measurement time.

Results

Thermal Conductivity of water between 0 and 100 °C, as measured with a Hot Disk TPS 2500 S.

Temp. [°C]	λ [W/m K]	Std.	κ [mm²/s]	Std.	ρC_p [MJ/m³ K]	Std.
0	0.5864	0.009	0.133	0.005	4.41	0.11
20	0.6075	0.028	0.147	0.018	4.18	0.33
40	0.6691	0.038	0.173	0.026	3.94	0.47
60	0.7310	0.027	0.200	0.021	3.68	0.27
80	0.7938	0.028	0.239	0.025	3.35	0.22
100	0.8580	0.017	0.268	0.022	3.21	0.17
20	0.6270	0.012	0.158	0.008	3.97	0.13

The water was initially measured at 20 °C and the results then showed a C_p of 4.186 MJ/m³ K. Testing was then performed at 0 °C and at every 20 °C step up to 100 °C, and then finally at 20 °C again. As the sample starts do dissolve gases from the surrounding air, the C_p value gradually decreases, as seen in the values acquired at 20 °C.

Five measurements were performed at each temperature and standard deviation calculated at each temperature to evaluate the precision of the test. Standard deviation is also used to calculate confidence levels, so that small variations can be judged to be real or random. In these experiments all standard deviations were proved within the 2σ level.

Conclusion

With the Hot Disk method, both Conductivity and Diffusivity are measured simultaneously. From these measured values, the specific heat capacity per unit volume is calculated. No calibration nor any comparison to standards are used or needed. The Hot Disk method is absolute. The agreement with expected specific heat is excellent and as a result it can be concluded that Conductivity and Diffusivity are accurate with very high certainty. The risk of conductivity and diffusivity being incorrect in such a way that the calculation of specific heat nevertheless yields the theoretical value is negligible.

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