APPLICATION**NOTE**

Penetration Model in the NETZSCH LFA Software – Porous Materials Finally Handled Properly!

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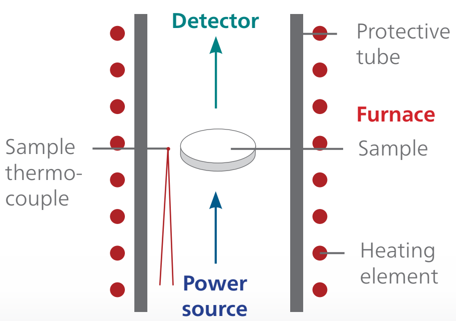
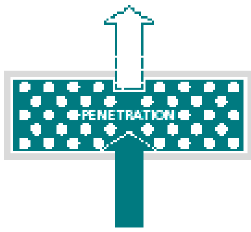
Introduction

Since the development of the laser flash method by Parker et al. in 1961 [1], various improvements have been made to this method for the non-contact, non-destructive determination of the thermal diffusivity. Nowadays, hardware and software should allow for measurements on different sample geometries, shapes and forms. It became necessary for the laser/light flash apparatus (LFA) to be able to test not only solids, but also powdery, liquid, crumbled and porous specimens. For this reason, certain hardware prerequisites such as specific sample holders must be provided. In addition, software models that consider the influence of the shape and form of the specimen are becoming increasingly important for the precise determination of the thermal diffusivity (a), thermal conductivity (λ) and specific heat capacity (c_p).

In recent years, NETZSCH has continuously improved and developed calculation models, corrections and mathematical operations taking into account heat loss in combination with pulse correction, radiation, multilayer systems, in-plane tests, baseline corrections, etc. This application note presents the *Penetration* model based on McMasters [2] for measurements on porous materials.



1 Diagram of LFA method



2 *Penetration* model implemented in the NETZSCH *Proteus®* LFA software

Porous Materials Are a Challenge – But Not for the *Penetration* Model

For standard flash measurements, the front face of the specimen absorbs the total energy. A thermal wave will then travel through the specimen's thickness before reaching the rear face (figure 1). For porous materials, NETZSCH has now introduced the *Penetration* model (figure 2) that includes the following considerations:

- Absorption of the pulse energy is no longer limited to the front face
- Absorption is extended over a thin layer into the specimen's thickness
- Absorption layers can be handled as the mean free path in the material

Taking these aspects into account results in an exponentially decaying initial temperature distribution within the specimen. Applying this approach, which accounts for the porosity of the material, results in improved accuracy and precision of the thermal diffusivity, thermal conductivity and specific heat capacity values determined.

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Measurement Conditions

A graphite felt insulation was measured between room temperature and 90°C with the NETZSCH LFA 427 and, for purposes of comparison, with the NETZSCH heat flow meter HFM 436 *Lambda*. The specimen thicknesses amounted to 5.4 mm and 20 mm, respectively. The density was determined to be 0.082 g/cm^3 at 20°C.

Measurement Results

Figure 3 depicts: a) the LFA measurement results demonstrating the course of the monitored thermal diffusivity based on the *Penetration* model, b) the literature data of the specific heat capacity of POCO graphite, and c) the calculated thermal conductivity based on the equation:

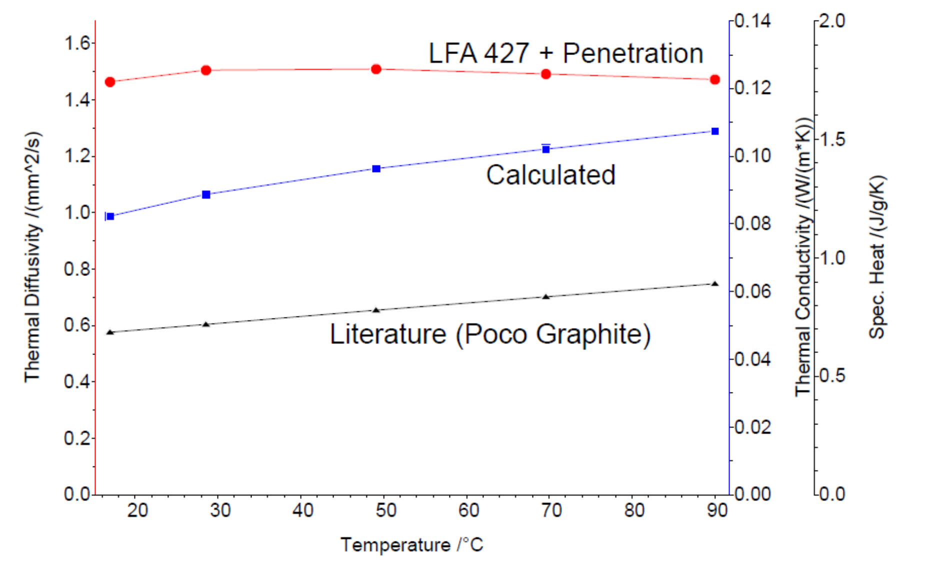
$$\lambda = a \cdot \rho \cdot c_p$$

with λ = thermal conductivity
α = thermal diffusivity
ρ = density
c_p = specific heat capacity

The LFA measurement was first evaluated with the standard model (Cowan, [3]) and a second time with the *Penetration* model. Figure 4 clearly shows that the same measurement yields different thermal conductivity results when using different calculation models. The question as to which is the better result can be answered by checking the signal increase (figure 5).

Figure 5 shows the rise of the detector signal. The left plot depicts the use of the standard model. It clearly indicates that the standard model yields an insufficient model fit. In this case, the thermal diffusivity is determined to be 0.753 mm^2/s – a value too high for the investigated material. However, an excellent model fit results when using a fit based on the *Penetration* model (right plot). The resulting thermal diffusivity value, a = 0.626 mm^2/s, is approximately 17% lower and, due to the improved fit, far more reliable than the one achieved with the standard Cowan model.

The thermal conductivity is proportional to the thermal diffusivity and therefore the values are higher for standard materials, too. The reliability of the results obtained with the *Penetration* model is confirmed by HFM measurements on the same material. LFA and HFM results are in good agreement; the maximum deviation is less than ±6% (figure 6).



3 LFA measurement on the graphite felt insulation along with literature data on the specific heat capacity for Poco graphite

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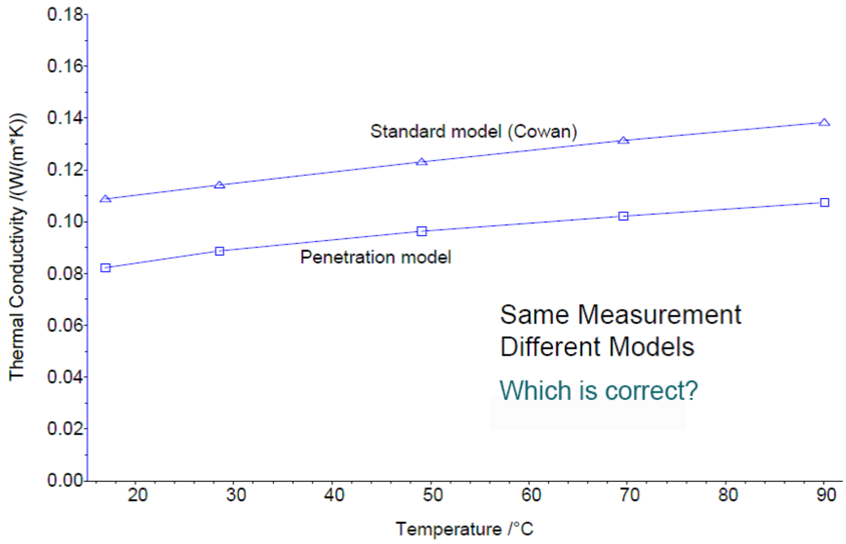
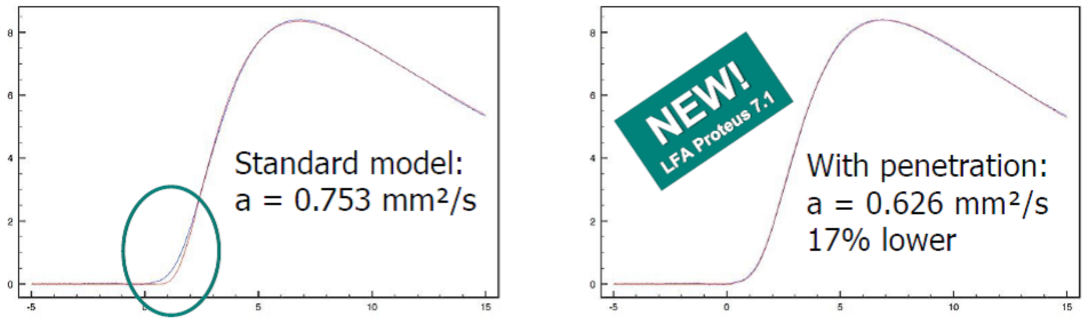
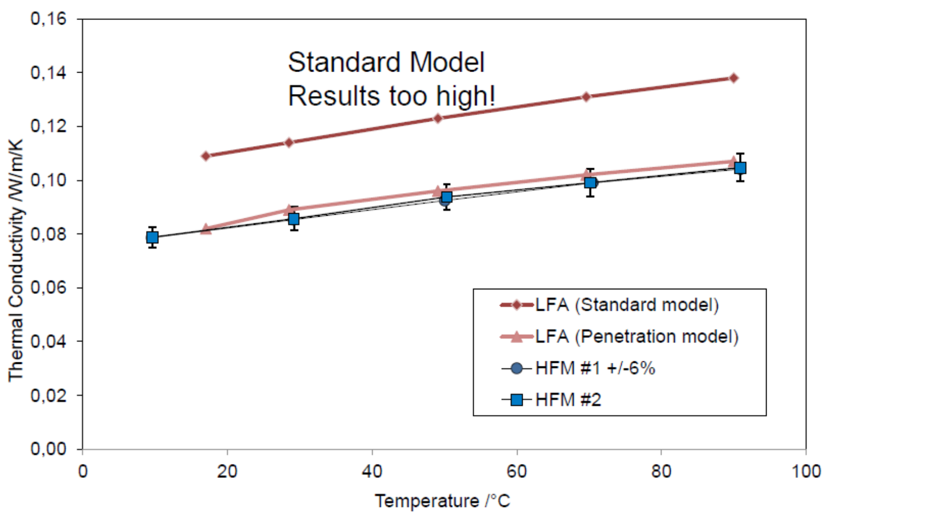


4 LFA measurement on the graphite felt insulation along with literature data on the specific heat capacity for Poco graphite



5 Laser shot without penetration: 0.753 mm²/s

Laser shot with penetration: 0.626 mm²/s



6 Thermal conductivity determined by means of LFA using the standard and *Penetration* models(red curve) and HFM (blue curve)

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Conclusion

Along with the various classical models (e.g., Cowan 5 / 10, Parker, improved Cape-Lehman, etc.), the NETZSCH LFA *Proteus*® software includes many different calculation models, corrections and mathematical operations. One of them is the *Penetration* model, which is suitable specifically for porous materials and materials with a rough surface. This special feature of the LFA *Proteus*® software involves the penetration of the light flash into the specimen beyond the actual heated surface. It accounts for the specimen's porosity, which causes a portion of the light flash energy to be deposited inside the specimen. This means the *Penetration* model takes into account absorption of the pulse energy over a thin layer into the specimen's thickness. Other reliable methods such as Heat Flow Meter (HFM) confirm the LFA results obtained by applying the *Penetration* model for calculation of the thermal diffusivity/conductivity.

Literature

[1] W.J. Parker; R.J. Jenkins; C.P. Butler; G.L. Abbott (1961). "Method of Determining Thermal Diffusivity, Heat Capacity and Thermal Conductivity". *Journal of Applied Physics*. 32 (9): 1679.
[2] McMasters, Beck, Dinwiddie, Wang (1999): "Accounting for Penetration of Laser Heating in Flash Thermal Diffusivity Experiments", *Journal of Heat Transfer*, 121, 15-21
[3] Cowan, Robert D.; *Journal of Applied Physics*, Vol. 34, Number 4 (Part 1), April 1963

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