Testing Multi-Layer Samples Using the Flash Diffusivity Method

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Overview:

Experimental Method

Mathematical Models

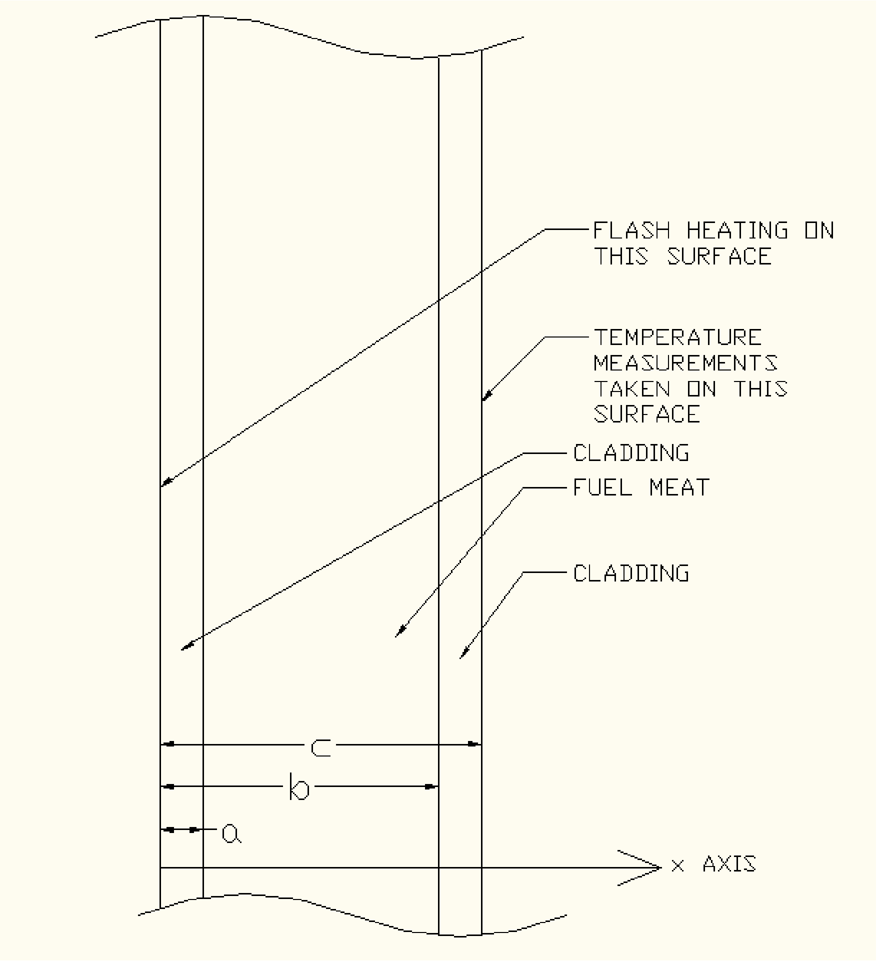
Insight from sensitivity coefficients

Insight from Residuals

Results

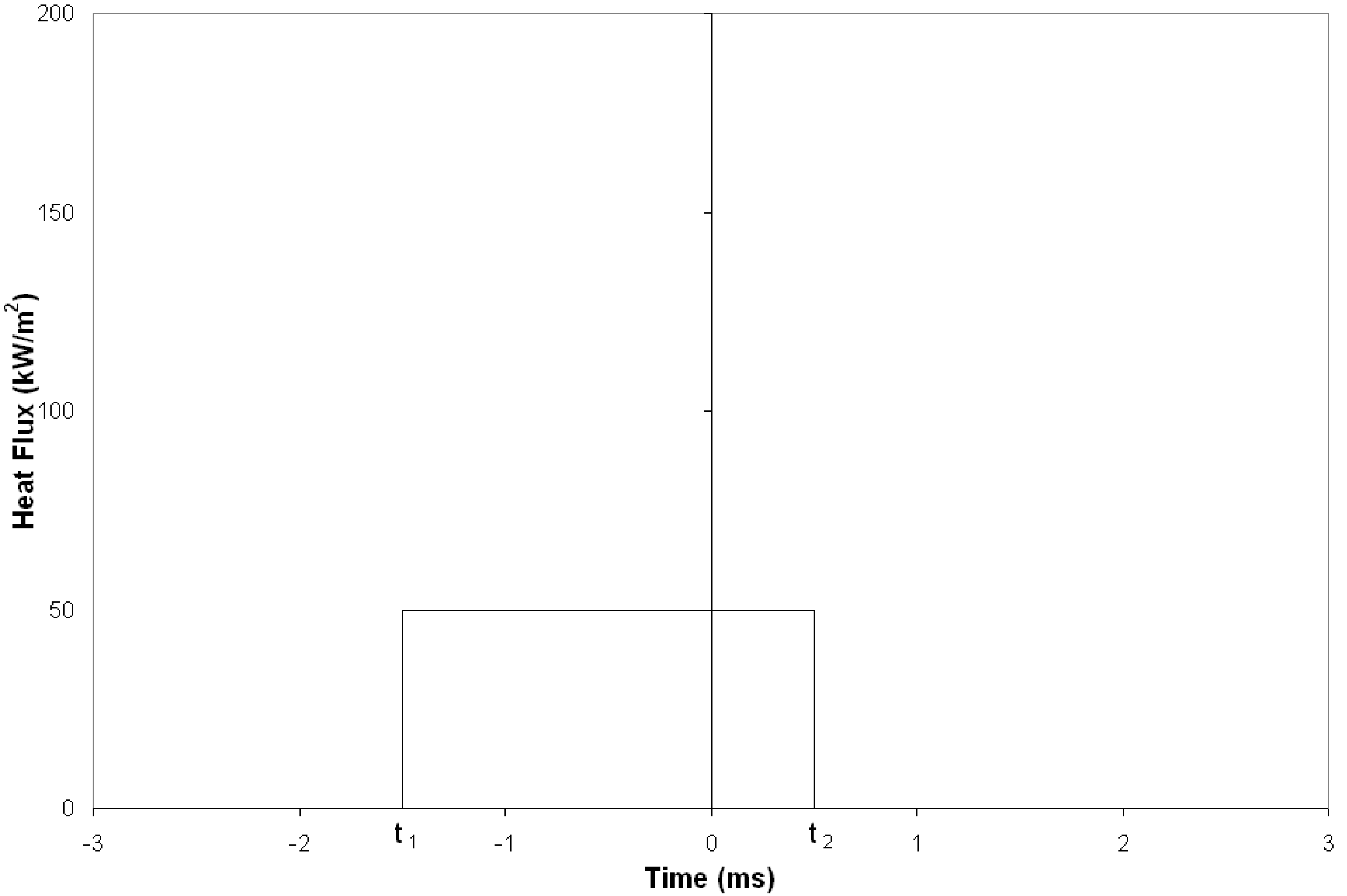
Parameter Optimization Method

Experimental Method



- Three layers
- Highly radioactive material
- Non-contact method
- Conductivity of fuel expected to rise over time due to accumulation of fission products

Assumed Pulse Shape



Mathematical Model:

Temperature response on the unheated surface from a heat pulse of magnitude q_o (in Joules per square meter). This assumes pure Fourier diffusion of heat with a convective surface on each face.

Five parameters: k_2, q_o, h, t_1, t_2

Three differential equations:

$$k_1 \frac{\partial^2 T_1}{\partial x^2} = \rho_1 c_{p1} \frac{\partial T_1}{\partial t} \quad \text{and} \quad k_2 \frac{\partial^2 T_2}{\partial x^2} = \rho_2 c_{p2} \frac{\partial T_2}{\partial t} \quad and \quad k_3 \frac{\partial^2 T_3}{\partial x^2} = \rho_3 c_{p3} \frac{\partial T_3}{\partial t}$$

Mathematical Model (cont.):

Two boundary conditions:

$$-k_1 \frac{\partial T_1}{\partial x}\bigg|_{x=0} = h(T_\infty - T_1) + q_o \delta(t) \quad \text{and} \quad -k_3 \frac{\partial T_3}{\partial x}\bigg|_{x=c} = h(T_3 - T_\infty)$$

Four interface conditions:

$T_1(x=a) = T_2(x=a)$ $\qquad$ $T_2(x=b) = T_3(x=b)$

$$k_1 \frac{\partial T_1}{\partial x}\bigg|_{x=a} = k_2 \frac{\partial T_2}{\partial x}\bigg|_{x=a} \qquad k_2 \frac{\partial T_2}{\partial x}\bigg|_{x=b} = k_3 \frac{\partial T_3}{\partial x}\bigg|_{x=b}$$

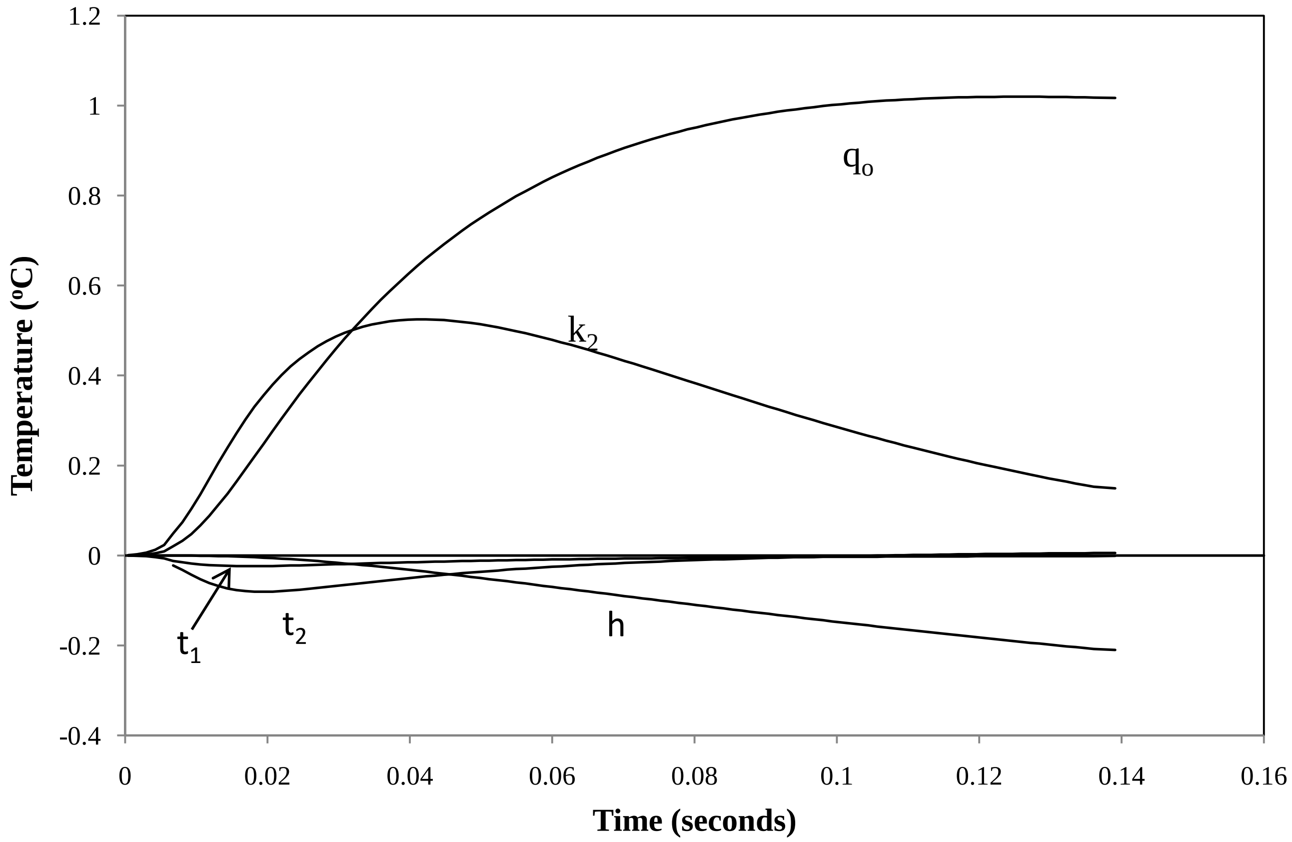
Three initial conditions:

$T_1(t=0) = 0$ $\qquad$ $T_2(t=0) = 0$ $\qquad$ $T_3(t=0) = 0$

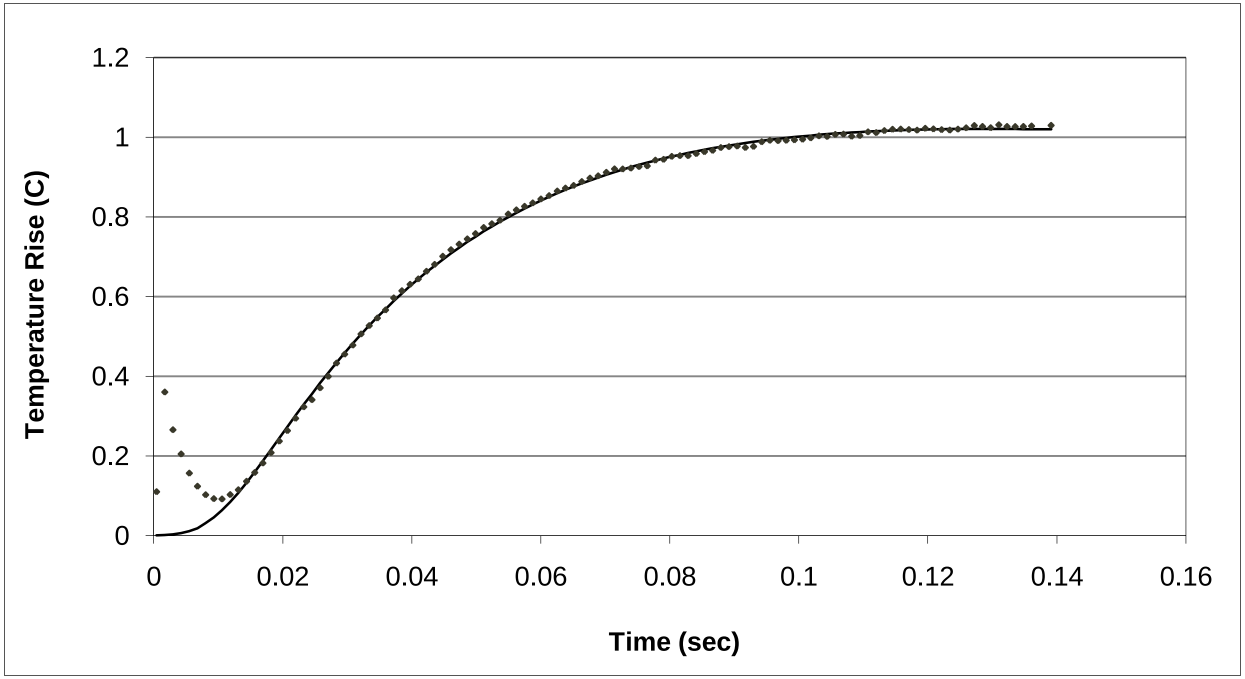
Sensitivity coefficients:

- Derivative of temperature with respect to the parameters

- Plot with respect to time for insight into experiment design

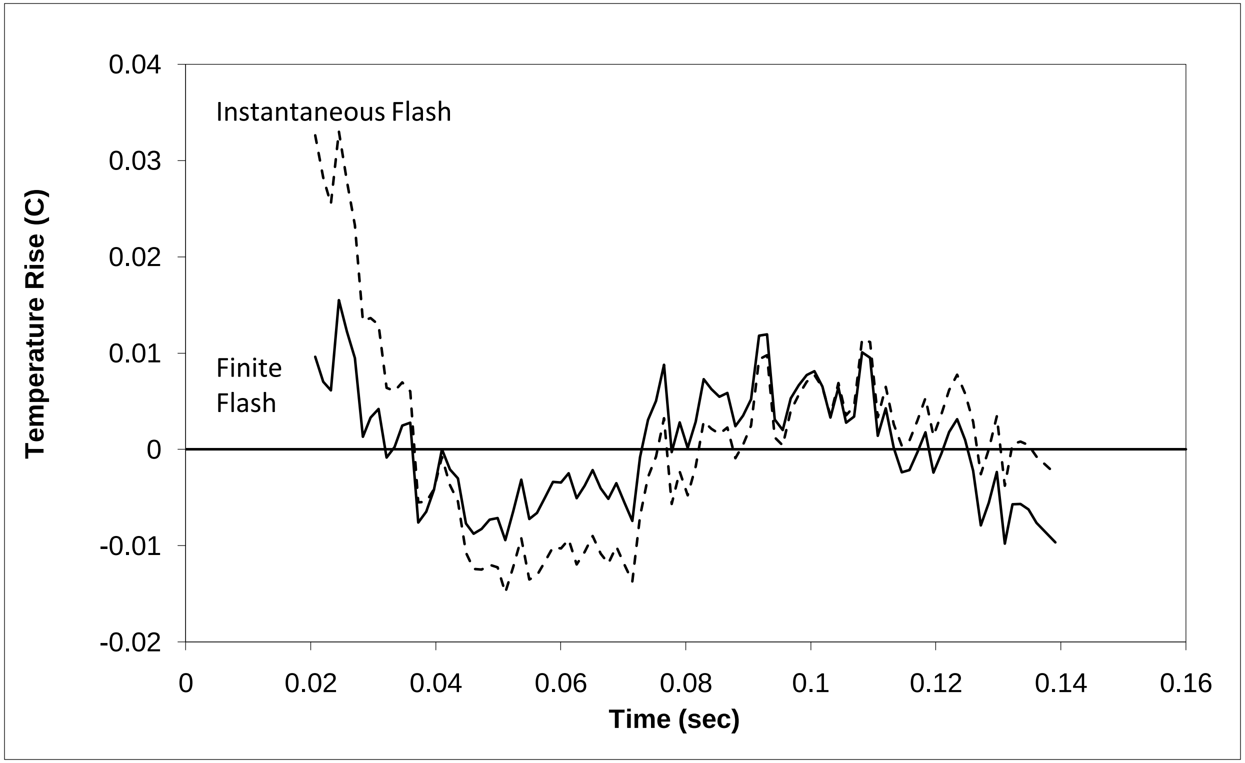


Fitting the Experimental Data



An initial spike in the detector signal from inadequate masking. This mandated a selective use of data.

Residual Signatures



Instantaneous Flash: $k = 6.77$ W/m-K, $\sigma = 0.01038^{o}C$

Finite Flash: $k = 7.40$ W/m-K, $\sigma = 0.00595^{o}C$

$t_1 = -1.91$ ms, $t_2 = 7.69$ ms

Results

Cladding: Aluminum

$k = 167$ W/m-K, $\rho c = 2419$ kJ/m^{3}K,

$L_1 = 0.559$ mm, $L_3 = 0.483$ mm

Fuel: Molybdenum

$k = 139$ W/m-K, $\rho c = 2560$ kJ/m^{3}K,

$L_2 = 0.381$ mm

Results from Analysis

$k = 7.40$ W/m-K

This indicates a large contact resistance.

Using Excel for Analysis

- Excel is a common tool for data acquisition and storage
- Custom-made post-processing tools added
- Numerical solution placed in macro
    - Activated by button
    - Function was tried
    - Function was too slow for “Solver”
- Optimization placed in a macro – activated by button

Conclusions

- Three-layer highly-conductive material
- Conductivity of center layer found – high contact resistance
- Finite pulse duration a significant effect (8.5% difference on k)
- Excel used in fitting mathematical model – demonstration following