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https://hdl.handle.net/2324/1566251

出版情報：MI lecture note series. 67, pp.1-3, 2016-02-05. 九州大学マス・フォア・インダストリ研究所
バージョン：

Fires in stored materials — assessment of risk

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The classical theory of thermal condition has been developed using the stationary theory for a nonlinear heat conduction equation. The ignition threshold is then obtained as a bifurcation point in parameter space. This is well-suited for obtaining the critical storage conditions in steady ambient conditions, or its critical thermal properties above/below which it will/will-not catch fire. This theory was applied successfully in a substantial legal investigation of a fire on the container vessel Aconcagua (Figure 1) which severely damaged the vessel. The fire occurred on 30th December 1998, in the Pacific Ocean resulting in extensive damage to vessel and cargo on board. The source of the explosion was immediately identified to be a container loaded with 334 kegs (plastic drums, known as quadritainers) of calcium hypochlorite shipped by a major shipper. Ten years later the English courts found the shipper liable to the carrier under the bill of lading contract for shipping dangerous goods in breach of the Hague Rules, with an initial judgment amount in the sum of USD 27.75 million, and further extensive quantum issues still to be resolved. The evidence provided was based on the theory described here.

FIGURE 1. Fire on the container vessel Aconcagua

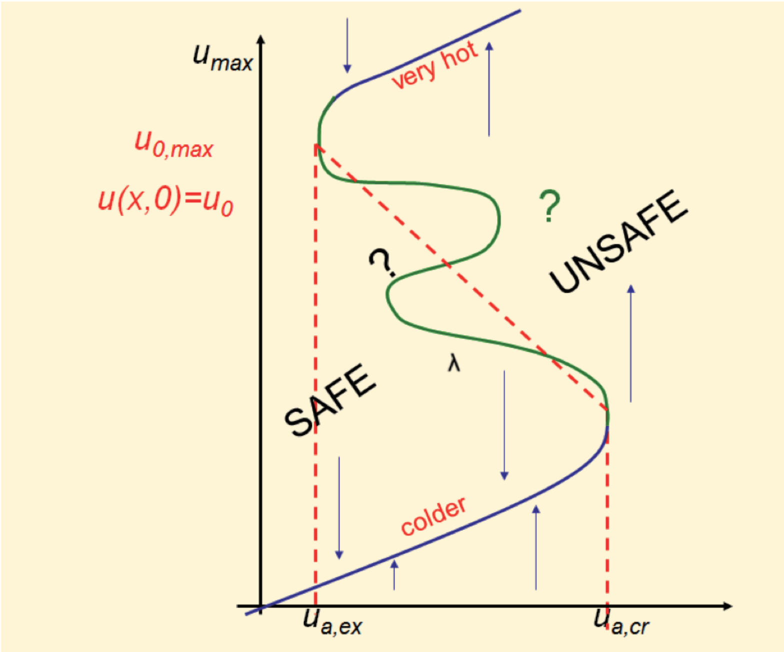

FIGURE 2. Schematic bifurcation diagram for steady-state nonlinear heat conduction

This stationary theory is captured in the steady-states of the nonlinear heat conduction equation

$$\Delta u + \lambda \exp(-1/u) = \frac{\partial u}{\partial t} \quad \text{in the region} \quad \Omega, t > 0;$$

with a (say Dirichlet) boundary condition $u = u_a$ on the spatial boundary $\partial\Omega$. Here u is a measure of the dimensionless temperature, and λ is a measure of the exothermicity of the material. Here we have neglected the effect of reactant consumption and mass transfer, which is a reasonable assumption for many ignition events.

A schematic representation of the resulting bifurcation diagram, using u_a (a measure of the ambient stored temperature) as the distinguished parameter and λ as a co-parameter is shown in Figure 2.

The number of intermediate solutions is dependent on the geometry and λ. It is known that, in general, only the smallest and highest solutions are asymptotically stable and therefore attracting with time t. Some actual computed bifurcation diagrams are shown in Figure 3. Here U is the ambient temperature, $n = 0, 1, 2$ are the infinite slab (one-dimension), infinite circular cylinder, and unit sphere respectively. The highest stable solution is not shown as it is much larger. Of those that are shown, only the smallest is stable.

Recently a raft of consulting problems have arisen where the ignition is triggered by “super-critical” initial conditions — that is, the material stored in safe ambient conditions, but is assembled too hot. This suggests the existence of a nonlinear manifold $\{u(x, 0)\}$ of critical initial conditions. Similarly, situations are now arising in applications where the variations in the ambient temperature can trigger a thermal

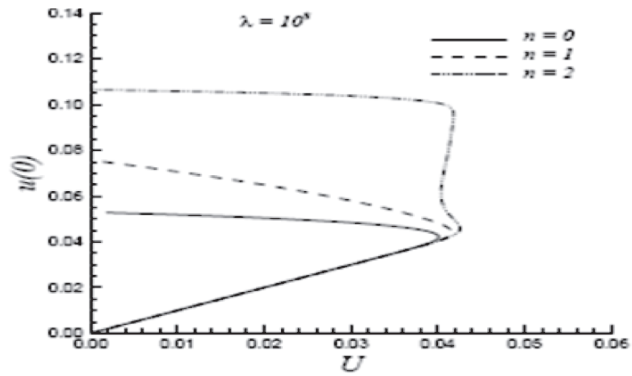

FIGURE 3. Path-following outputs; Stationary solutions

spontaneous ignition, while the average suggests that the material is sub-critical. Thus new algorithms are needed to determine critical thresholds for both these transient scenarios to provide under-pinning decision support for legal assessments.

Numerical procedures have been developed for this purpose for defining the thresholds for thermal ignition for both of these scenarios. These are used commercially to assist assessment of new ignition scenarios. The shape of the initial temperature profile is also investigated, using the moments of the profile. Recently a coal mine disaster in New Zealand, where a "flashover event" was deemed to be part of the tragedy which cost 29 miners their lives, gave rise to a mathematical investigation involving non-local calculus, where cause and event are spatially separated. This situation will be illustrated on a video clip.

References

[1] Boddington T., P. Gray, and G. C. Wake, "Criteria for thermal explosions with and without reactant consumption", Proc. Royal. Soc. Lond. Series A 357, 1977, pp. 403–422.

[2] Gong R., J. G. Burnell and G. C. Wake, "Modelling spontaneous combustion in wet lignite", Combustion Theory Modelling 3, 1999, pp. 215–232.