FIRE GROWTH RESEARCH AT VTT: EXPERIMENTS AND MODELING

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Introduction

The goal of VTT's research on fire growth has been a) to develop methods for testing and ranking of linings, furniture and other products, and b) to be able to assess the contribution of these products to fire development. Characteristic to our work has been to concentrate on phenomenological 'thermal' models of fire growth and to large-scale validation of these models. Recently, fire growth modeling using CFD models has been started, e.g. in co-operation with NIST. This paper will review some of the key findings of the work during the past years

Thermal model of flame spread

Wind-aided flame spread can be described by a one-dimensional differential equation [1]

$$\frac{dx_p}{dt} = \frac{x_f - x_p}{\tau_{ig}} \qquad (1)$$

where x_p is the distance of the ignition front from the base of the fire, x_f is the flame height and τ_{ig} is a characteristic ignition time at an irradiance level corresponding to the heat flux from the flame to the unignited surface.

The flame spread problem can be reduced to the mathematical problem of finding the solution $x_p(t)$ of the initial value problem [2]

$$\frac{dx_p(t)}{dt} = \frac{x_f(t) - x_p(t)}{\tau_{ig}}, \quad \mathrm{t} > 0 \qquad (2)$$

$$x_p(0) = x_{p0}, \quad \mathrm{t} = 0$$

$$x_f(t) = k_f \left[\dot{Q}(t)\right]^n, \quad t > 0,\ n > 0,\ k_f > 0$$

where n and k_f are constants and x_{p0} is the initial pyrolysis height at the moment of ignition. The total rate of heat release $\dot{Q}(t)$ is calculated as the sum of the contributions of the burner and the material ($\dot{Q}_0$ and $\dot{Q}_{mat}$, respectively) as follows:

$$\dot{Q}(t) = \dot{Q}_0(t) + \dot{Q}_{mat}(t), \qquad (3)$$

$$\dot{Q}_{mat}(t) = x_{p0} w \dot{q}''(t) + w \int_0^t \dot{q}''(t-\tau) \frac{x_f(\tau) - x_p(\tau)}{t_{ig}} d\tau$$

where w is the width of the pyrolysis area, assumed constant in the one-dimensional model, and $\dot{q}''(t)$ and t_{ig} are the rate of heat release curve and the ignition time, respectively, at a relevant the heat flux level. The input data is usually determined by the Cone Calorimeter.

The origin of time in the calculation is the moment when the specimen exposed by a burner flame, and the ignition delay is taken into account as a time shift afterwards. It has been shown that the pair of equations (2) and (3) can be solved analytically if the flame length x_f is assumed to depend linearly on the rate of heat release (n=1), and if the rate of heat release per unit area is assumed to decay exponentially as a function of time. Analytical solutions can be found also for some other analytical expressions of $\dot{q}''(t)$ [3, 4].

Application 1: Prediction of upward spread on a wall

The first application of the thermal model at VTT was study of upward flame spread on wooden surfaces. A series of large-scale tests were made [5]. After an adjustment of the empirical parameters, a reasonable fit with experiments was achieved [2].

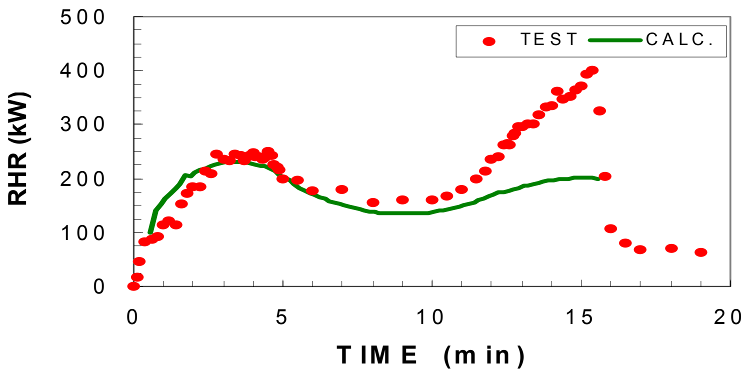


Fig. 1. Heat release rate in a wall fire ignited by a 1.2. m wide and 0.1 m deep gas burner with a heat output of 100 kW.

Application 2: Prediction of the results in the SBI Test

In a recent study, the same approach was taken to predict the fire growth [6]. In the SBI test lateral flame spread may occur, too. The model was found to work reasonably well for products with minor or moderate lateral flame spread. The European FIGRA classification was predicted correctly for 90% of the products which is about the same success rate as in interlaboratory round robin tests.

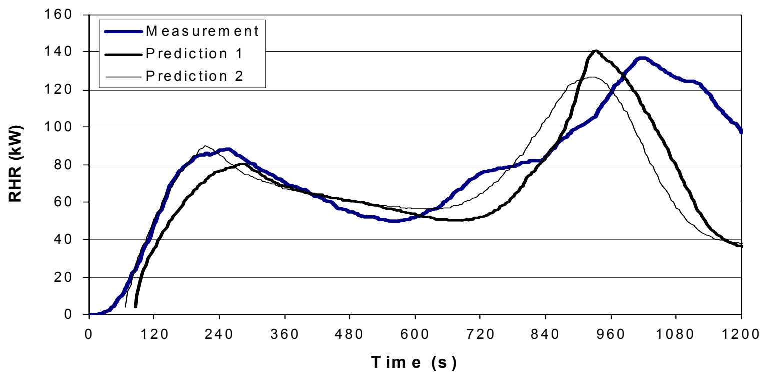
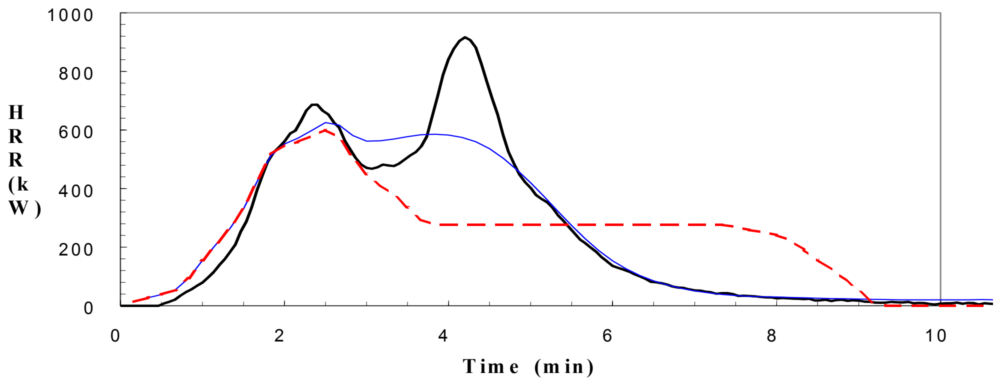


Fig. 2. Comparison of measured and predicted RHR curves of SBI test of medium density fibreboard M25 as an example of basic wood products.

Application 3: Prediction of lateral flame spread on a mattress

In the case of lateral flame spread, the spread mechanism may be completely different due to heat transfer at the flame front. However, in large scale like a full-scale mattress burn, the radiation from the pool fire may heat up the surface around to a longer extent. The length of the heating region depends on the size of the pool fire (i.e. heat release rate). Mathematically, the same equations as above can be applied although with a different interpretation. The work done in connection with the CBUF project showed that the heat release rate curve of a burning mattress may be predicted with a reasonable



accuracy [7].

Fig. 3 Measured and calculated heat release rates for furniture item 1:21 (120 mm polyether foam, cotton/viscose fabric). Measured data depicted by two-peaked solid curve, calculation with simple thickness scaling as dashed line calculation with exact thickness scaling as a solid line with lower peaks.

Challenges to thermal flame spread models

The examples shown above indicate that the one-dimensional thermal flame spread model based on the use of the Cone Calorimeter data can be calibrated or tuned into various fire scenarios. The model is, however, always limited to one specific scenario only. There are also a number of empirical parameters which must be fitted with care. Although the tuning of the model may be base don one test only, increased confidence requires validation against a larger set of independent data. For the purposes of developing more simple correlations between the Cone and a specific larger-scale test scenario these models have proved to be powerful, cf. [8]. Since heat release rate as a function of time is one of the model outputs, the methods could be applied, e.g., in connection with zone models.

In real fires, the burning objects may have a very complicated texture. For example, in the case of wooden facades, the fine details of fixing the boards may influence the fire spread [9]. At least so far, large scale experiments are required to study the fire behavior those kinds of objects.

Ongoing work at VTT on fire in cavities or concealed spaces has shown that CFD models like FDS have great potential to become a practical tool for fire safety assessment. Calculations by using FDS1 have extremely well reproduced fire growth in experiments in a few meters long cavities with internal dimensions of the order of 0.5 to 1 m. [9].

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