# DEVELOPMENT OF FDMS TOOLS TO GENERATE DATA FOR FIRE SAFETY ENGINEERING AND MODELING

**Marc L. Janssens**
**The University of North Carolina at Charlotte**
**Charlotte, NC, USA**

## INTRODUCTION

The main limitation of current compartment fire models is that they generally are not capable of predicting fire growth, but are only suitable to calculate the consequences of a user-specified fire [1]. An extensive database of fire curves would alleviate this problem, but the development of an exhaustive database of fire curves is not feasible. A more practical approach involves the use of correlations and sub-models, so that fire curves can be constructed for a variety of geometries and configurations on the basis of material properties from small-scale fire test data.

Methods have been developed to predict the heat release rate vs. time of objects that are common in residences such as chairs and TV sets [2-7]; and large objects such as automobiles and railcars [8]. However, the most common geometry for which predictive sub-models have been developed is the room/corner test [9-26]. Standard room/corner test protocols have been developed domestically (e.g., NFPA 265 and NFPA 286) as well as internationally (ISO 9705).

Many sub-models require that the fire performance of materials be characterized on the basis of a number of fundamental material properties. For example, Quintiere's room/corner test model requires that the following properties be specified [18]:

- Ignition properties: surface temperature at ignition $T_{ig}$, critical heat flux for ignition $\dot{q}''_{cr}$, and thermal inertia $k\rho c$.
- Flame spread properties: flame heating parameter $\phi$ and minimum temperature for spread $T_{s,min}$.
- Heat release rate properties: heat of combustion $\Delta H_c$ and heat of gasification L.

Different procedures have been developed to obtain these properties from small-scale fire test data.

## PROCEDURES TO OBTAIN IGNITION PROPERTIES

Ignition properties are determined on the basis of ignition data, i.e., the time to ignition measured for a range of heat fluxes. Janssens published an extensive survey of procedures to analyze ignition data in terms of material properties [27]. Although the focus of this paper was on wood products, most procedures are applicable to materials in general.

The majority of the procedures described in [27] consist of two steps. The first step is to determine the critical heat flux for ignition, i.e., the heat flux below which ignition is not possible, even for long exposure times. This can be done experimentally by lowering the heat flux in small increments between subsequent tests until ignition no longer occurs. The critical heat flux value obtained via this "bracketing" method is sometimes referred to as the minimum heat flux for ignition. The second approach consists of plotting a function of the ignition time (typically $1/\sqrt{t_{ig}}$) obtained over a range of exposure conditions versus the heat flux, fitting a (typically straight) line through the data points, and extrapolating the line to $t \rightarrow \infty$ (or $1/\sqrt{t_{ig}} \rightarrow 0$). The intercept with the abscissa is the critical flux estimate, because it corresponds to an ignition time of infinity, at least theoretically. Both methods often give very similar results, but the minimum flux is sometimes much higher than the critical flux. The relationship between the critical heat flux and the surface temperature at ignition is given by:

$$\varepsilon \dot{q}''_{cr} = h_c (T_{ig} - T_a) + \varepsilon\sigma\left(T_{ig}^4 - T_a^4\right) \quad (1)$$

where

| | | |
|---|---|---|
| $\varepsilon$ | = | surface emissivity |
| $\dot{q}''_{cr}$ | = | critical heat flux for ignition ($kW/m^2$) |
| $h_c$ | = | convection coefficient ($kW/m^2 \cdot K$) |
| $T_{ig}$ | = | surface temperature at ignition (K) |
| $T_a$ | = | ambient air temperature (K) |
| $\sigma$ | = | Boltzmann constant ($5.67 \cdot 10^{-11}$ $kW/m^2 \cdot K^4$) |

The second step is to determine the thermal inertia, usually from the slope of the regression line through the data points.

Most procedures assume that the surface emissivity is 1.0, although the real value may be lower. A recent study indicates that the convection coefficient is not constant in the Cone calorimeter or LIFT apparatus as commonly assumed, but varies as a function of the heat flux [25]. Other investigators have questioned the findings of this study, and more extensive and detailed measurements are clearly needed. Data for the vertical orientation are also needed.

Finally, most procedures were developed for thermally thick materials, i.e., assuming that ignition always occurs before the thermal wave hits the back surface of the specimen.. Grenier et al. developed a procedure to deal with thermally intermediate and thermally thin materials [28]. Unfortunately, this procedure did not appear to work very well for a set of materials in a recent study [25].

**PROCEDURES TO OBTAIN FLAME SPREAD PROPERTIES**

Opposed-flow flame spread properties are usually determined from data obtained in the LIFT apparatus. According to deRis' formula, the flame spread rate at a particular location is proportional to the flame heating parameter and is also a function of the ignition properties and the surface temperature when the flame front reaches that location:

$$V_p = \frac{\phi}{k\rho c\left(T_{ig} - T_s\right)^2} \quad (2)$$

where

| | | |
|---|---|---|
| $V_p$ | = | opposed-flow flame spread rate (m/s) |
| $\phi$ | = | flame heating parameter ($kW^2/m^3 \cdot$) |
| $T_a$ | = | surface temperature ahead of the flame front (K) |

The surface temperature can be calculated, and $\phi$ can therefore also be determined from flame spread rate measurements. The procedure is described in detail in the LIFT standard ASTM E 1321. However, there is some disagreement about the preheating period that is required in the standard, because it seems to adversely affect the performance of FR treated materials.. In fact, some investigators feel that there may be a strong correlation between ϕ and other fire properties, so that measuring opposed-flow flame spread properties may not be necessary.

## PROCEDURES TO OBTAIN RELEASE RATE PROPERTIES

The heat release properties are the heat of combustion and the heat of gasification. The former is the amount of heat that is released per mass unit burnt. The latter is the amount of energy that needs to be supplied to the solid to convert one mass unit to volatiles. The heat of combustion is included in a standard Cone calorimeter report. A single average value is most often used for modeling. This may not be appropriate for layered or charring materials. A single value for the heat of gasification is also most commonly used. It is determined as the inverse of the slope of a straight-line fit through peak or average heat release rate data points plotted as a function of incident heat flux. It has been shown that a single value obtained in this manner may not be suitable for FR treated or charring materials [21]. A better approach for such materials is to use a time-varying value expressed as a function of a progress variable, for example mass loss at a given time as a percentage of the total mass loss over the entire flaming period [29].

Other important release rate properties are the yields of smoke and toxic products of combustion. Average yield values are invariably reported and used, although they may also not be suitable for layered or charring materials.

## NIST GRANT RESEARCH AT UNC CHARLOTTE

A three-year research program was initiated at UNC Charlotte in September of 2001 under a grant from NIST. The program consists of three tasks:

1. Development of software tools to calculate ignition, flame spread, and release rate properties on the basis of small-scale fire test data. (Year 1).
2. Development of algorithms and corresponding computer programs to calculate the fire curve for wall sections and possibly some other types of fuel packages (Year 2).
3. Evaluation of the predictive capability of these sub-models based on a comparison between calculated and measured fire curves (Year 3).

Task 1 will be discussed in detail at the workshop, and is briefly described below.

A literature survey is currently being conducted of previously developed methods to determine ignition flame spread and release rate properties on the basis of small-scale fire test data. A set of algorithms will be selected or developed from the literature survey and will be coded in the form of Visual Basic or VBA programs. Many of the challenges identified in previous sections will have to be addressed in the process. For example, experiments and calibrations will be conducted to obtain more accurate values for some of the parameters in the algorithms, such as the convection coefficient in the Cone Calorimeter and the LIFT apparatus. The software tools that result will be supplemented with Cone Calorimeter and other small-scale test data in FDMS format to serve as input to the algorithms.

## REFERENCES

[1] Babrauskas, V., *Journal of Fire Protection Engineering*, Vol. 8, pp.97 96, 1996.
[2] Babrauskas, V., and W.D. Walton, *Fire Safety Journal*, 11:181-192, 1986.
[3] Babrauskas, V., and J.F. Krasny, *Fire Safety: Science and Engineering*, ASTM, STP 882, ASTM, Philadelphia, PA, 268-284, 1987.
[4] Dietenberger, M.A., NIST-GCR-91-589, NIST, Gaithersburg, MD, 1991.

[5] Sundström , B., *Fire Safety of Upholstered Furniture - The Final Report on the CBUF Research Programme*, Interscience Communications, London, UK, 1995.
[6] Ohlemiller, T.J., *Proceedings of the First International Conference on Fire Research and Engineering*, Society of Fire Protection Engineers, Boston, MA, 1995.
[7] Hirschler, M.M., *Proceedings of the Second International Conference on Fire Research and Engineering*, Society of Fire Protection Engineers, Boston, MA, 1997.
[8] Ingason, H., *ASIAFLAM '95*, Kowloon, Hong Kong, Interscience Communications, pp. 77-86, 1995.
[9] Steckler, K.D., NBSIR 83-2765, National Bureau of Standards, Gaithersburg, MD, 1983.
[10] Quintiere, J.G., *Fire Safety Journal*, 3:201-214, 1981.
[11] Janssens, M.L., *Fire and Flammability of Furnishings and Contents*, ASTM, STP 1233, ASTM, Philadelphia, PA, 169-185, 1994.
[12] Magnusson, S.E., and B.E. Sundström, *Fire Safety: Science and Engineering*, ASTM, STP 882, ASTM, Philadelphia, PA, 45-69, 1984.
[13] Wickström, U., and U. Göransson, *Journal of Fire and Materials*, 16:15-22, 1992.
[14] Östman, B.A.-L., and R.M. Nussbaum, *Fire Safety Science: Proceedings of the Second International Symposium* , Hemisphere Publishing Co., New York, NY, 823-832, 1989.
[15] Östman, B.A.-L., and L.D. Tsantaridis, *Fire Safety Journal*, 17:27-43, 1991.
[16] Karlsson, B., Ph.D. Dissertation, Report TVBB-1009, Lund University, Lund, Sweden, 1992.
[17] Karlsson, B., *Fire Safety Journal*, 20:93-113, 1993.
[18] Quintiere, J.G., *Fire Safety Journal*, 20:313-339, 1993.
[19] Janssens, M.L., M.A. Dietenberger, O. Grexa., and R.H. White, *Proceedings of the 4th Fire and Materials Conference*, Interscience Communications, London, England, 73-83, 1995.
[20] Janssens, M.L., *Abstracts of the Annual Conference on Fire Research*, NISTIR 5904, National Institute of Standards and Technology, Gaithersburg, MD, 87-88, 1996.
[21] Janssens, M.L., P.D. Dissertation, University of Gent, Gent, Belgium, 1991.
[22] Wade, C., M.S. Thesis, Worcester Polytechnic Institute, Worcester, MA, 1996.
[23] Opstad, K., Ph.D. Dissertation, MTF-Rapport 1995:114(D), University of Trondheim, Trondheim, Norway, 1995.
[24] Yan, Z., and G. Holmstedt, *Fire Safety Journal*, 27:201-238, 1996.
[25] Janssens, M., and S. Dillon DOT Report No. CG-D-22-99, Appendix A, US Coast Guard R&D Center, Groton, CT, 1999.
[26] Grenier, A., S. Dillon, and M. Janssens, *Fire and Materials '01, 7th International Conference and Exhibition, January 22-24, 2001, San Francisco, CA*, Interscience Communications Ltd., London, England, pp. 351-362, 2001.
[27] Janssens, M., *Journal of Fire and Materials*, Vol. 15, No. 4, pp. 151-167, 1991.
[28] Grenier, A., and M. Janssens, *23rd International Conference on Fire Safety, Millbrae, CA, January 13-17, 1997*, Product Safety Corporation, Sunnyvale, CA, pp. 253-264, 1997.
[29] Janssens, M., *Interflam '93, 6th International Fire Conference, March 30-April 1, 1993, Oxford, England*, Franks, C., Editor, Interscience Communications Ltd., London, England, pp. 549-558, 1993.