2009 BFRL Project Description

Project Title: Predicting Material Decomposition in Fires

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BFRL Program: Reduced Risk of Fire Spread in Buildings

Objective: To develop the ability to predict pyrolysis product generation rates from a range of solid materials (that relate to building contents) when subjected to a radiant heat flux, using experimental parameters from appropriate tests, together with analytic or numerical modeling.

Problem:

What is the problem? Performance-based design for fire safety requires an ability to predict fire behavior based on the building configuration and contents; mathematical descriptions of fire are increasingly being used for this purpose. The most important parameter in fire modeling is the rate of fuel addition to the fire (which occurs from heat feedback to materials, followed by their decomposition). Great strides have been made in understanding the gas-phase behavior of the fire; whereas, the modeling of the condensed phase is in earlier stages. There exists a need for the knowledge of the physical behavior of decomposing materials subjected to high heat fluxes typical of a fire, with particular emphasis on identifying the physical parameters necessary for accurate prediction of the material decomposition. For example, for fire modeling of real materials, it is essential to be able to predict the effect of a material composition change on the full-scale fire behavior; however, this is not presently possible.

Why is it hard to solve? The problem is hard to solve since computer fire calculations and present computers do not have the resolution or the computational speed to treat the solid phase in detail from first principles. The phenomena involved in material mass loss are complicated, and include partial transmission of radiant heat, heat conduction, melting, dripping, thermal decomposition or reaction, bubble formation, gas-phase transport through the material, char formation, gasification, and other physical phenomena. Hence, some empirical simplification is required, yet finding common ways to treat the wide range of materials and conditions, and defining the appropriate parameters as input are difficult.

How is it solved today, and by whom? In previous work at universities and research laboratories, there has been much fundamental work on flame spread over condensed-phase materials, including a simplified description of the solid phase. The domain for these tests, however, has been of the order of centimeters to decimeters, and the range of materials (and their behavior) has been extremely small (typically filter paper or PMMA). For large fire calculations used to describe very specific scenarios, the problem of material burning has often been solved

by using test results from full-scale experiments tracking the burning rates of real objects. The range of objects it too large, however, for this to be a generally useful, broadly applicable tool. Hence, smaller-scale tests are often performed on representative materials using a cone calorimeter, or a similar device, to extract more fundamental (but often still empirical) parameters which are then applied in a sub-grid model of burning in the larger fire code. Unfortunately, ways to describe the relevant physics of the material decomposition and burning process have only been developed for the simplest materials under limited conditions. Further, the data obtained from cone calorimeter-type tests often lump several parameters together, so that the individual parameters are still unavailable. Work is continuing here at NIST, as well as at other US, and European, universities and government research laboratories to understand the physics and develop modeling approaches. Researchers at the FAA Technical Center are doing related work.

Why NIST? The ability to predict the fire size of burning materials is essential for the use of performance-based fire codes, which are expected to reduce costs and increase fire safety, and are part of the BFRL mission and vision. The project directly contributes to two of the BFRL strategic priorities (Measurement Science for Innovative Fire Protection, and Measurements Science for Sustainable Infrastructure Materials), as well as two of the five BFRL core competencies (Fire Protection and Fire Spread within Buildings and Communities, and Performance, and Durability and Service-Life Prediction of Building Materials). BFRL is the appropriate organization to do this work because we have a one-of-a-kind apparatus (the gasification device), unique expertise, and the task is both too broadly applicable and too long-term to be taken on by industry.

Approach:

What is the new technical idea? To improve the ability of fire models to predict the gas-phase fuel species generation from room contents, the problem must be simplified and the parts analyzed and developed. The simplification in the proposed work is to look only at the solid phase (i.e., not the flame, convective hot gases, or gas-phase reactions), subjected only to radiative heating, and begin to understand and quantify the parameters responsible for decomposition and fuel generation from the materials. An apparatus available for this approach is the NIST gasification device, which measures the mass loss rate of a sample, which is exposed to radiative fluxes of 35 kW/m^2 to 70 kW/m^2 (the cone calorimeter with air or N_2 will also be used as required). The NIST gasification device exposes a sample to a radiant flux, in a controlled atmosphere. Since there is no flame, the uncertainty in the heat flux and chemical environment due to the flame is removed, and the behavior of the solid phase itself is more clearly examined.

Why can we succeed now? In order to implement Performance-Based Design in the fire protection community, there is a pressing need for the ability to predict the burning rate of materials exposed to a fire. New computational approaches have recently been developed, and there is a growing international effort to model solid material decomposition in fires.

What is the research plan? The present series of experiments and finite-element modeling for thermoplastics (in coordination with FAA)[1] will be completed and written up. We will then select a new set of materials with more complicated behavior (for example, composites or wood). The mass-loss experiments will be conducted in the gasification device, and the material properties necessary for modeling (for example the: reflectance of IR, surface emissivity, decomposition kinetic parameters heat of decomposition, specific heat, thermal conductivity, and transmission of infrared, etc.) will be measured, or obtained, using: thermogravimetric devices (TGA), differential scanning calorimetery (DSC), combined DSC and TGA, transient line source method for thermal conductivity, and the cone calorimeter (or NIST gasification device). Increasingly complex materials will be selected for study and modeled in FY2010 and FY2011. We do not have, in-house, the capability for some of these. As a first step in this process, we will search for standard tests to measure the parameters, and identify NIST facilities available for the measurements. We will coordinate with others who have the test devices (e.g., other NIST divisions, FAA), develop them, contract out measurements, or use simplified methods (e.g., extracting the numbers from the cone) when the more fundamental methods do not exist or are too hard to develop.

After the conclusion of a test series on a class of materials, the results will be written up. Finally, we will contribute, as appropriate, to the materials decomposition chapter in the Standard Guide for Obtaining Data for Fire Models.

Recent Results:

Output:

- Established a research collaboration on solid-phase combustion with the FAA Technical Center.
- Linteris, G.T. and Rafferty, I.P., "Flame Size, Heat Release, and Smoke Points in Materials Flammability," *Fire Safety Journal*, 43(6):442-450 (2008).
- Linteris G.T., Rafferty I.P. "Scale Model Flames for Determining the Heat Release Rate from Burning Polymers." in "Progress in Scale Modeling." Ed.: F.A. Williams, T. Takeno, Y. Nakamura. Tokyo, to be published, July 2008.

Outcomes:

- New technical expertise or capabilities: new instrumentation method for assessing flammability of materials (flame-size based heat release rate measurement).

Standards and Codes:

The development of measurement tools and the validation of numerical modeling techniques are expected to promote improved standards for the use of fire codes for assuring fire safety in buildings. The project will provide input to into an ASTM standard committee on the use of input parameters for fire models.

[1] Stoliarov, S.I., Lyon, R.E. "Thermo-Kinetic Model of Pyrolysis," FAA Technical Center Report, June 2008.

Outcome:
The results of this project will feed into the development of fire models, leading to improved predictive capabilities of fire models such as FDS.

Impact:
Better performing consumer goods based on NIST measurement science work (less flammable and environmentally friendly polymers).