SOLID INFLAMMABILITY BOUNDARY AT LOW-SPEED (SIBAL)

J. T'ien[*#], K. Sacksteder[+], P. Ferkul[#], R. Pettegrew[#], K. Street[+], A. Kumar[*], K. Tolejko[*], J. Kleinhenz[*], N.Piltch[+]
[*]Case Western Reserve University [+]NASA Glenn Research Center
[#]National Center for Microgravity Research on Fluids and Combustion

This research program is concerned with the effect of low-speed flow on the spreading and extinction processes over solid fuels. The project has passed the Science Concept Review and the experiment is currently scheduled to be performed in the ISS Combustion Integrated Rack. We present an overview of recent and ongoing experimental and theoretical efforts.

(1) Measurement and Evaluation of the Radiative Properties of a Thin Solid Fuel [1]

Surface radiation has a significant role in the combustion of solid fuels. This process contributes not only to the overall heat loss of the system, but also to the interaction between the gaseous flame and the solid fuel. Radiative effects are amplified in microgravity flames because of the decrease of convection. Accurate modeling of combustion systems requires not only the gas-phase but also the surface radiative properties during burning conditions. Effects of heat treatment on spectrally resolved radiative properties of thin solid fuels are described in order to simulate different degrees of pyrolysis and to supplement earlier spectrally resolved data on virgin fuels. An example of spectral absorptance is shown in Fig. 1. The total temperature dependence of total emittance of these solids is evaluated assuming the spectral emission data are independent of temperature. In addition, the total absorptance of the solid is evaluated using simulated gas phase spectra at a specified flame temperature as the incident radiation source. The total emittance and the total absorptance are found to be quite different in value. The two effects, the inequality of emittance and absorptance and the temperature dependence of the total emittance, are manifestations of the non-gray nature of these solids. This has implications for the flame modeling work, which conventionally assumes equal and constant values of emittance and absorptance.

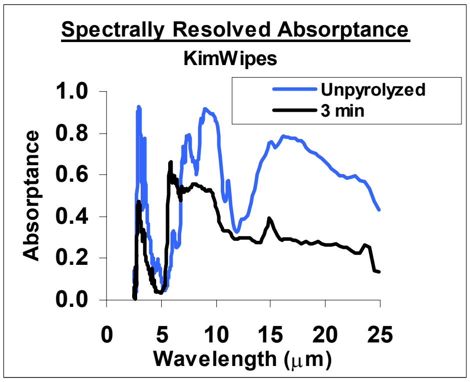

Fig. 1: Specrtally resolved absorptance for unpyrolyzed Kimwipes and Kimwipes subjected to 3 minutes heating in a 300 °C oven (area density reduced by 60%).

(2) Infrared Imaging Diagnostics for Flame Spread over Solid Surfaces [2]

Solid surface temperature measurements are important to solid-fuel flame spreading experiments. The measured variation of surface temperature distributions have been used to deduce flame spread rates and pyrolysis lengths, and are a key link between experimental results and theoretical predictions. Thermocouples or thermocouple arrays have often been used to obtain histories of temperature at discrete locations on the fuel surface, but such measurements are intrusive and may alter the local surface temperature, perhaps sufficiently to quench a weak but otherwise viable flame. Additionally, thermocouple measurements cannot provide the time-varying two-dimensional temperature distributions that are needed for three-dimensional or transient flame spread studies.

A non-intrusive alternative is to use radiometric infrared imaging of thermal radiation emissions from the burning fuel surface. A narrow band pass filter centered at 3.8 μm is used to reject emissions from CO, CO_2, and H_2O in the flame. Broadband emission from soot cannot be removed entirely by spectral filtering, but an experimental and algebraic method has been developed to estimate its contribution to the imaged radiance. A method has also been developed for determining fuel surface emittance as a function of temperature in the narrow imaging pass band.

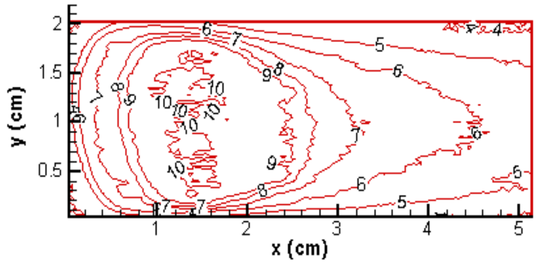

Fig. 2: Surface temperature (non-dimensionalized by 100K) of a downward spreading flame over a 2-cm wide cotton/fiberglass fabric in 11 psia, 25% O_2 atmosphere.

In [2], the application of infrared imaging to the study of flame spreading is illustrated using two distinct fuels in different spreading modes and environments. One fuel is thin cellulose tissue that is normally consumed completely in the flame. The other is a cotton-fiberglass composite from which the cotton is consumed leaving the fiberglass matrix after the flame passage. Surface temperature distributions of a downward spreading flame for the cotton/fiberglass fuel obtained with the infrared imaging method is shown in Fig. 2 using the spectral emittance at 3.8 μm determined in [1].

(3) A Comparison of Extinction Limits and Spreading Rates in Opposed and Concurrent Spreading Flames over Thin Solids [3]

Flame spread phenomena over thin solids are investigated for purely forced opposing and concurrent flows. A two-dimensional opposed-flow flame spread model, with flame radiation, has been formulated and solved numerically. In the first part of this work, flammability limits and spread rates in opposed flow are presented using oxygen percentage, free stream velocity and flow entrance length as parameters. The comparison of the flammability boundaries and spread rate curves for two different entrance lengths exhibits a crossover phenomenon (Fig.3). Shorter entrance length results in higher spread rates and lower oxygen extinction limit in low free-stream flow velocities; but lower spread rates and higher oxygen extinction limit in high free-stream velocities. The entrance length affects the effective flow rate the flame sees at the base region. This affects the radiation loss and gas residence time in an opposing way to cause the crossover. Radiation also affects the energy balance on the solid surface and is in part responsible for solid-fuel non-burnout phenomenon. In the second part of this work, a comparison of flammability limits and flame spreading rates between opposing and concurrent spreading flames are made; both models

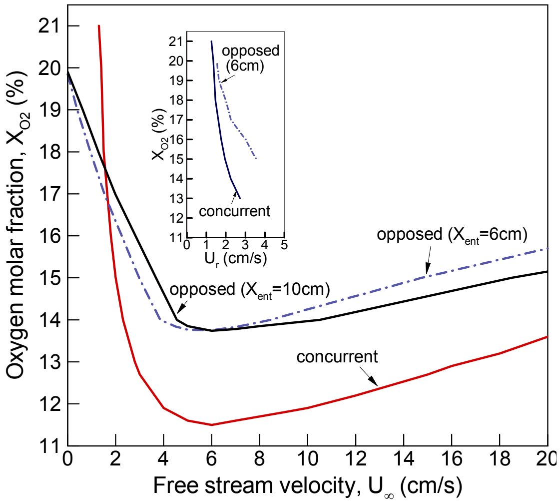

Fig. 3: Comparison of extinction boundaries of opposed flow flame spread with concurrent-flow flame spread

contain the same assumptions and properties. While the spread rate in concurrent spread increases linearly with free stream velocity, the spread rate in opposed flow varies with free stream velocity in a non-monotonic manner, with a peak rate at an intermediate free stream velocity. At a given free stream velocity, the limiting oxygen limits are lower for concurrent spread except in the very low free stream velocity regime where spreading flame may be sustainable in opposed mode and not in concurrent mode (Fig.3). The crossover disappears if the two spread modes are compared using relative flow velocities with respect to the flames rather than using free stream velocities with respect to the laboratory as shown in the inset in Fig.3.

(4) A Computational Study on Flame –Solid Radiation Interaction in Flame Spread over Solid-Fuel [4]

A detailed numerical study has been made on the interaction of gas-phase flame radiation with a thin solid fuel in flame spread in quiescent microgravity and in normal gravity environments. The computations are performed using a 2-D opposed flow flame spread model in which gravity, solid total emittance (ε) and total absorptance (α) can be varied as independent parameters. The radiative transfer equation is solved using S-N discrete ordinates method to obtain the gas phase radiation loss to the ambient and heat feed back to the solid. Fig. 4 shows that while flame radiation has only a minor role in downward flame spread in normal gravity (see inset), radiation (gaseous and/or surface) plays an important role in the micro-gravity flames. Both flame-spread rate and low oxygen limit or index (LOI) are sensitive to the radiation parameters. For example, a non-emitting and full absorbing solid (ε = 0, α = 1) can spread faster than the adiabatic case (no radiation). The full emitting and absorbing case (ε = α =1) will spread faster than the adiabatic case in high oxygen environment and slower than the adiabatic case in low oxygen environment. This reversal phenomenon is due to the shifting relative weight between flame radiation and solid emission. Flame radiation increases at high oxygen environment due to higher flame temperature while surface temperature remains little changed.

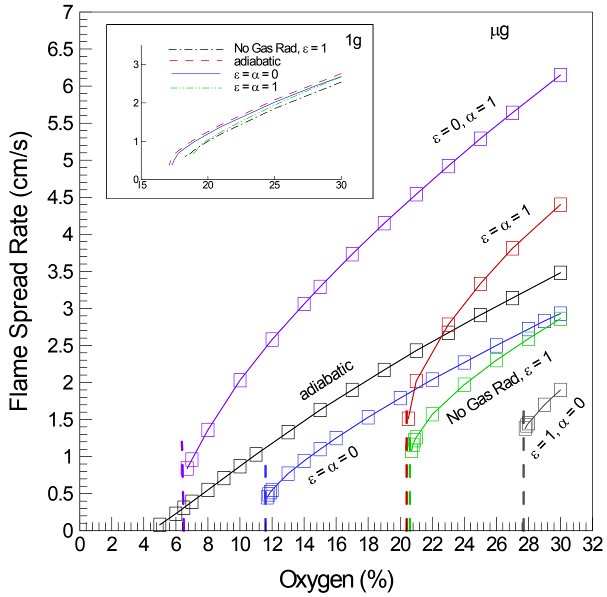

Fig. 4: Parametric study of flame surface interaction in μ*g* self propagating flame. Inset shows equivalent curves for *1g* flame.

A computational experiment [5] has been performed to test the assumption of constant emittance vs. varying emittance as a function of temperature and area density (or degree of pyrolysis). Fig. 5 shows the solid profiles using the variable emittance obtained in [1] while Fig. 6 shows the results assuming a uniform emittance equals to the value of the unpyrolyzed Kimwipes at ambient temperature. There are substantial differences between the two results- one solid burned out with a short pyrolysis length while the other solid does not burn out. These computations have been carried out in two dimensions. Three dimensional calculations for opposed-flow flame spread and extinction in mixed buoyant and forced flow is underway [6].

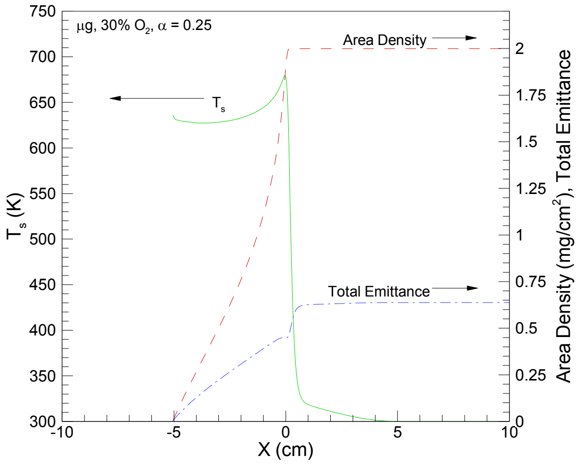

Fig. 5: Total emittance, area density and solid temperature in microgravity at 30% O_2, α = 0.25 and variable total emittance

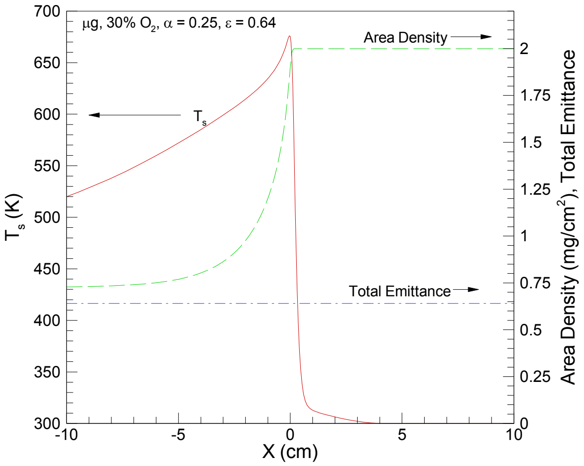

Fig. 6: Total emittance, area density and solid temperature in microgravity at 30% O_2, α = 0.25 and ε = 0.64

References:

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