Effect of Longitudinal Oscillations on Downward Flame Spread over Thin Solid Fuels

Vedha Nayagam and Kurt R. Sacksteder, NCSER/NASA Glenn Research Center, Cleveland, Ohio

Abstract:

Downward flame spread rates over vertically vibrated thin fuel samples are measured in air at one atmospheric pressure under normal gravity. Unlike flame spread against forced-convective flows, the present results show that with increasing vibration acceleration the flame spread rate increases before being blown off at high acceleration levels causing flame extinction. A simple scaling analysis seems to explain this phenomenon, which may have important implications to flammability studies including in microgravity environments.

Introduction:

Understanding the mechanisms of opposed-flow flame spread over solid fuels is of fundamental as well as practical interest in the area of fire safety. In the past the effects of buoyancy [2], forced flow velocities [1,3], and fuel thickness, among others, on flame spread rates against an opposing flow of oxidizer have been investigated both experimentally and theoretically. It has been observed that for thermally thin fuels the flame spread rate remains independent of the external flow velocity, naturally induced or forced, up to a certain value then begins to decrease with increasing flow speed eventually leading to flame extinction due to finite rate chemical kinetic effects. Here we study the effects of longitudinal oscillations of the fuel sample on flame spread rates.

Experiments:

Thin strips of ashless cellulose filter papers (Whatman #44) mounted on a metal sample holder are vibrated vertically at various frequencies and acceleration levels and ignited on top. The vibration frequencies varied in the range 0 to 65 Hz and the acceleration levels g/g0 in the range 1 to 32, where g0 is the earth normal gravitational acceleration. The RMS acceleration and frequencies are measured using an accelerometer. Video images of the vertical downward flame spread process are recorded and an average spread rate for a flame travel of 10 cm is measured and reported here.

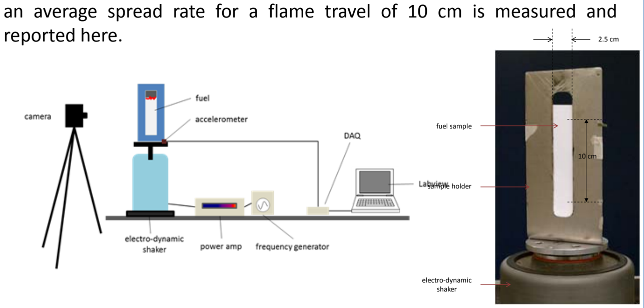
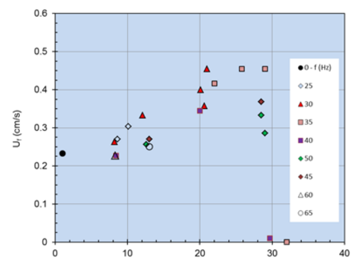


Figure 1. Schematic illustration of the experimental setup and a photograph of the fuel sample mounted on the shaker.

Results:

Based on the experimental results three different flame spread regimes can be identified (Fig.2):

a) Natural convection dominated regime,
b) Vibration dominated thermally controlled regime, and
c) Vibration dominated chemically controlled regime.



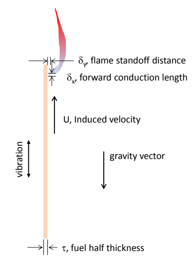


Figure 2. Flame spread rate as a function of acceleration for various vibration frequencies.

Natural convection regime:

For low acceleration levels (g/g_0 < ~ 8) the flame spread rate is relatively independent of the acceleration or frequency values. In this regime the gas-phase flow is still dominated by the buoyancy induced flow and the fuel surface oscillations do not alter the boundary layer substantially.

Vibration dominated thermally controlled regime:

As the vibration acceleration (g) increases beyond certain level the flame spread rate increases. For a fixed acceleration in this regime the spread rate slightly decreases with increasing frequency. Note that the characteristic velocity of the fuel plate is ~ g/ω and unlike flame spread against an opposing forced flow the measured spread rate increases with increasing plate velocity (see, Fig. 3).

Vibration dominated chemically controlled regime:

When the fuel surface velocity (g/ω) becomes sufficiently high, finite-rate chemical kinetic effects become important and the flame is eventually extinguished due to insufficient residence time for heat release. Figure 3 shows the present spread rates plotted as function of effective fuel surface velocity (g/ω) along with the forced flow results from [1, 3]. It is interesting note that extinction occurs around the same velocity range of 120 cm/s as in [3] where the same fuel was used. Hirano and Sato [1] used somewhat thicker samples. In this regime close to extinction it is difficult to ignite the sample, the flame spread become unsteady and unstable [1] and considerable scatter in the experimental data occurs.

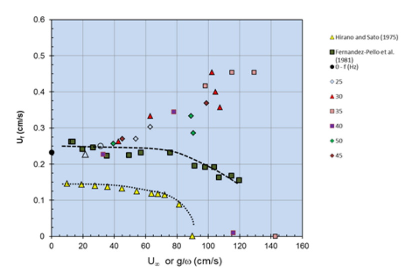
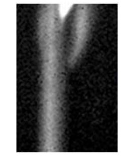


Figure 4. Flame spread rate as a function of velocity for various frequencies.

Scaling:

For thermally controlled regime a simplified energy balance at t leading edge of the fuel sample yields:

$$\rho_s c_s U_f \tau (T_v - T_\infty) = k_g \delta_x \frac{(T_f - T_v)}{\delta_y}$$



Streamwise length scale is the amplitude of vibration:

$$\delta_x = x_0 = \frac{g}{\omega^2}$$

Normal length scale (Stokes thickness):

$$\delta_y = 2\sqrt{\frac{2\nu}{\omega}}$$

Spread rate then becomes:

$$U_f \approx \frac{g}{\omega^{2/3}}$$

Figure 4 shows U_f plotted against ($g/\omega^{2/3}$). As seen in Fig. 4 t correlation is improved in the thermally controlled regime, but close extinction further analysis is necessary.

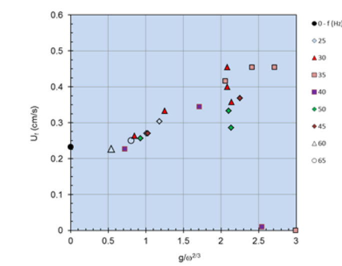


Figure 4. Flame spread rate as a function of ($g/\omega^{2/3}$) for various vibrati frequencies.

Conclusions and future work:

It is shown that the nature of the gas-phase velocity profile significant influence on the flame spread rate even for thermally t fuels. Unlike forced or natural convective flow, the vibration indu flow leads to substantial increase in spread rate for a fixed ambi oxygen concentration. High speed photography of the leading edge the flame is currently underway and analysis of the video images sho provide further insight into the flame spread process. Dimension correlation of the spread rate against a suitably defined Damkol number is also being considered.

References:

1. Hirano. T., and Sato, K., "Effects of radiation and convection on gas velocity an temperature profiles of flames spreading over paper," *Proceedings of the Combustion Institute*, Vol. 15, 1975, pp. 233-241.

2. Altenkirch, R.A., Eichorn, R., and Shang, P.C., "Buoyancy effects on flames spreading down thermally thin fuels," Combustion and Flame, Vol. 37, 1980, pp.71-83.

3. Fernandez-Pello, A.C., Ray, S.R., and Glassman, I., "Flame spread in an oppose forced flow: The effect of ambient oxygen concentration, *Proceedings of the Combustion Institute*, Vol. 18, 1981, pp. 579-589.