SESSION VI

BLAST/FIRE AND RELATED TOPICS

BLAST/FIRE INTERACTION SCALING

by

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ABSTRACT

Hypotheses are formulated of the process of interaction between an airblast and fires supported by liquid fuels and wood cribs. A map of blast weakness versus fire strength is conceived on which the regime of fire extinction by the blast can be delineated from the regime where the fire will sustain the blast. The fire strength is described for liquid fuels primarily by the heat of combustion; and for wood, it is mainly described by the preburn time. The concept is substantiated by the SRI shocktube data.

INTRODUCTION

Thermal radiation from the fireball would cause spontaneous ignition of various combustibles at all stations where the fluence of energy is sufficiently high. As the thus started fires grow, the blast wave would arrive to perturb the fires with its associated transient pressure, flow and temperature disturbances. The purpose of the research synopsized in this paper is: to develop scaling rules governing the behavior of the blast-impacted-fires; to apply these rules to the available experimental data on blast/fire interaction; and to thus elicit upon the nature of this interaction. A synopsis as this paper is, complete details are available in (1).

Fires supported by hydrocarbon liquid fuel pools (known as Class B fires) and by charring solid fuels such as wood (known as Class A fires) are of specific interest in this study. Since the wood pyrolyzates are composed mostly of a variety of gaseous hydrocarbons, the wood flame combustion chemistry characteristics are expected to be essentially similar to those of liquid hydrocarbon flames. Additionally, however, if the flame were annihilated to permit approach of oxygen to the hot char surface of wood, glowing combustion would ensue. Thus, a scrutiny of blast effects on flames and on glowing surfaces constitutes the essential scientific content of this study.

BLAST INTERACTION WITH FLAMES

A steadily burning pool fire is disturbed by a blast wave through the manifestation of one or more of the following phenomena.

(a) Annihilation of spacial gradients of species, temperature and velocity by the increased molecular and turbulent transport is expected to lead to excessive thermal as well as species dilution in the reaction space.

(b) Energy feedback from the flame to the condensed phase fuel will be reduced due to physical displacement or deformation of the flame resulting in both a decay in fuel vapor supply to the gas phase and a reduction of the temperature of gas phase near the fuel bed. The chemical kinetic rate is drastically reduced as a result.

(c) If the wind is feeble, energy feedback to the fuel bed may be augmented by the wind bringing the flame closer to the surface so that the blast imposition would augment the fire intensity contrary to the consequences of (a) and (b) above.

(d) Energy feedback to the fuel bed will be enhanced due to flame-holding in the recirculatory zones.

(e) The fuel bed may be mechanically broken up to possibly aggrevate the fire in intensity by transforming the bulk fuel into a spray. Fragmentation of the fuel bed might also aid to dissipate the energy content of the fuel in the tray to an ineffectually low average level.

(f) Pressure change will result in a shift in combustion chemical kinetics. The kinetic rate for combustion of hydrocarbons in air varies nearly as proportional to the square of pressure. The pressure change also alters the fluid dynamics to increase the coefficients of heat and mass transfer. The net effect of these two opposing actions of increased pressure can not be drawn without a detailed study. Additionally, since the pressure rise associated with a blast wave is temporally variant, arguments based on static imposition of a pressure rise might become invalid in the dynamic behavior of a blast-impacted flame.

(g) The shockwave is also associated with a temperature rise due to isentropic compression of air. This too is a transient phenomenon which may exert some effect on the chemical kinetic aspects of the flame.

(h) In all practical situations of blast wave generation by the explosion of a weapon, a thermal radiation pulse is involved which would promote continued vaporization of the fuel bed even as the energy feedback is mitigated from the disappeared flames. Even more important is the thermal radiation pulse from subsequent weapon bursts. The issue of multibursts is ignored here.

Inasmuch as most of the above-enumerated effects can be condensed, they fall into one or more of the three global altercations: thermal dilution, fuel vapor dilution and oxygen enrichment of the gas phase space where once the flame stood. The dilution effects figure dominantly in the fate of flaming while the oxygen enrichment has a role to play in glowing combustion of charcoal.

Based on an algebraic analysis of the fuel species and energy conservation, the following relation is derived in (1) to relate the gas temperature θ to the energetic strength q^* of the flame, blast weakness P^*, and fuel surface temperature θ_i.

$$P^* = \frac{(\theta-\theta_i)\exp(1/\theta)}{q^*-(\theta-\theta_i)} \qquad (1)$$

where $\theta \equiv RT/E$, $\theta_i \equiv RT_i/E$, $P^* \equiv k_0\ell/u$ and $q^* \equiv Rh_cY_{Ai}/EC_{pg}$. (E/R, k_0, h_c and T respectively are the activation temperature, preexponential factor, enthalpy of combustion and temperature of the flame reaction. Y_{Ai} and T_i are mass fraction of fuel and its surface temperature. C_{pg} is gas specific heat; ℓ is fuel bed dimension and u is blast-induced velocity.) Equation (1) indicates that there exists a P^* for any given q^* and θ_i at which the reaction can not sustain itself, i.e., θ falls catastrophically to result in extinction. The higher the q^* (i.e., the more stronger the flame is energetically), the lower is P^* (i.e., the stronger is the blast wave) to cause extinction. Figure 1 shows the P^* vs q^* map in which fires and blasts corresponding to the area under the curve are expected to represent extinguish-

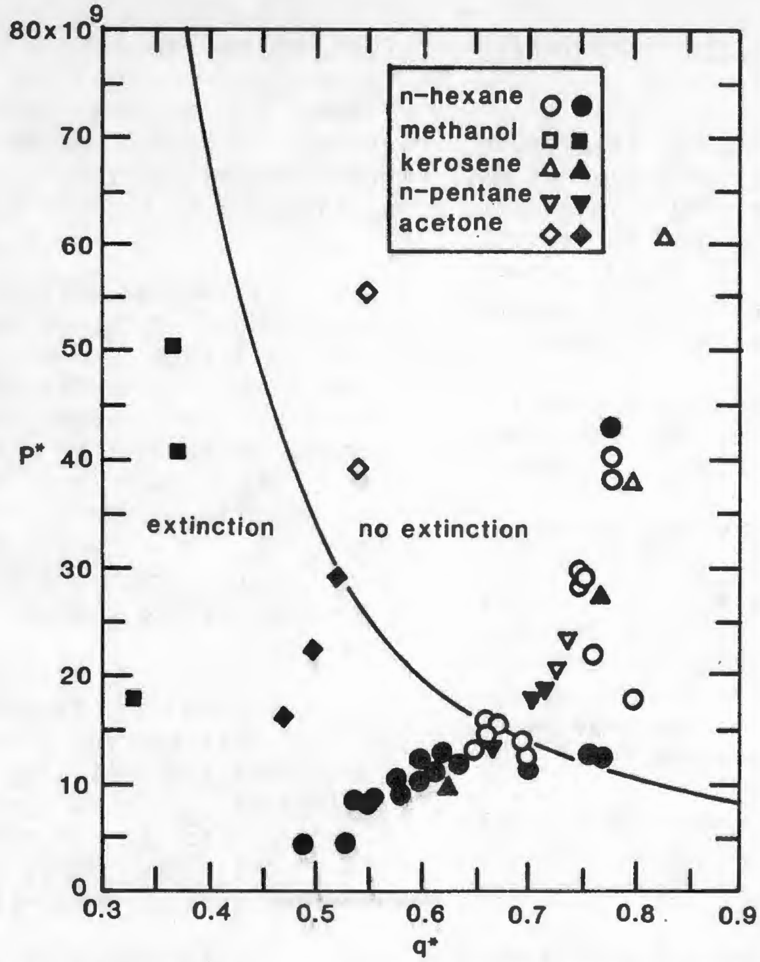
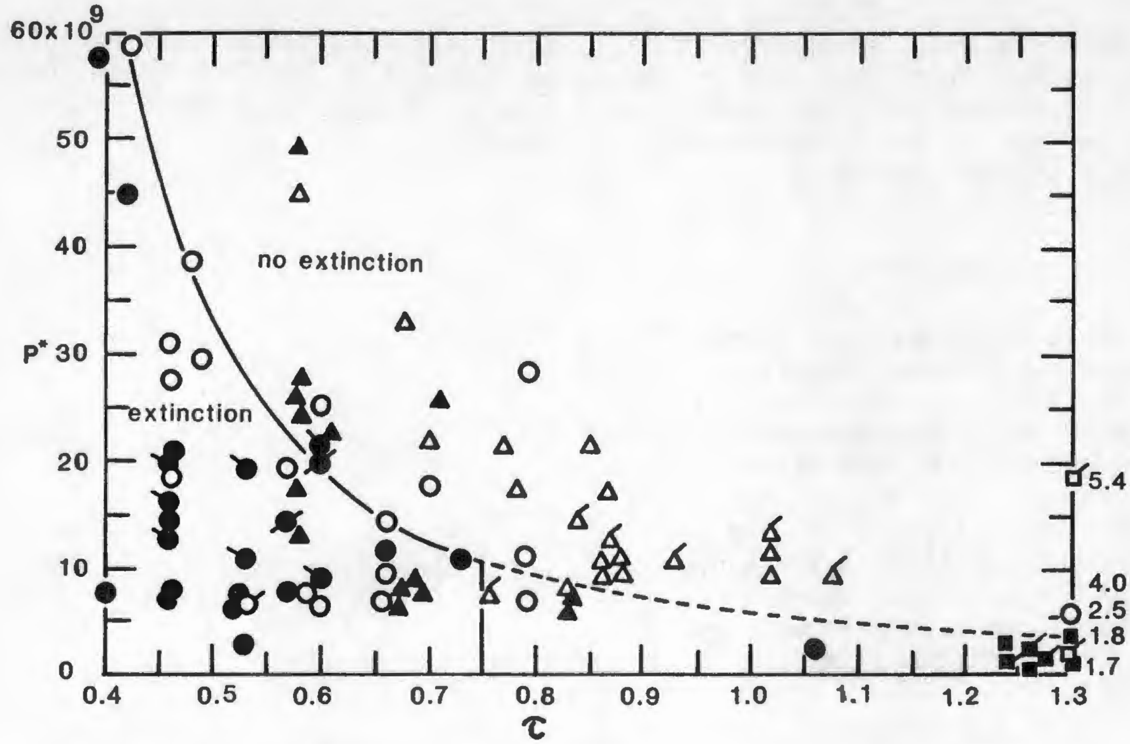


Figure 1: Extinction (filled symbols) - No Extinction (open symbols) Correlation for Class B Fires with No Barriers.

ment. The shock-tube (Class B, no-barrier) fire data obtained by Martin and Backovsky (2-4) are shown in this figure (open and closed symbols respectively for unextinguished and extinguished fires) to demonstrate that the extinction regime can indeed be delineated according to our hypothesis. Upstream barriers, behind which recirculation of flow is possible, are shown in (1) to render the fire more blast resistant.

BLAST INTERACTION WITH WOOD FIRES

Whereas the flaming combustion of wood cribs follows the same patterns as described above, there are at least two special features to be noted. It is known that the longer a wood crib fire burns, the more established it becomes, mainly due to the transient conductive heating and pyrolysis. Based on analyses of transient pyrolysis of wood sticks (5), the characteristic time to completely burn a stick of wood of thickness b is given by $t^{\circ} = Ab + Bb^2$ where the A is a function of pyrolysis energetics and kinetics, heating rate and wood specific heat and B is essentially the inverse thermal diffusivity of wood. Typically, A ≈ 260 sec/cm and B ≈ 30 sec/cm^2. The fire strength then can be expressed as a ratio of (pre)burn time t to the characteristic time t°. Since the wood flames appear to be similar to hydrocarbon flames, we expect the blast interaction with wood flames to obey the same rules as Class B fires on a blast weakness P* versus fire strength q* map provided $q^* \equiv \tau$ is



3/4" stick cribs: ● extinguished. ○ sustained. (marked ●) extinguished, glows, no reflash. (marked ●) extinguished, close to reflash. (marked ○) reflashed.

3/8" stick cribs: ▲ extinguished. △ sustained. (marked △) reflashed.

shredded paper trays: ■ extinguished. □ sustained. (marked □) rekindled. (marked ■) rekindled upon blowing air.

Figure 2: Extinction- No Extinction Correlation of Class A Fires.

taken to be proporational to t/t°. With τ = 2.7 t/t°, the shock-tube data of (3) and (4) are shown in Fig. 2 to demonstrate that weak, short-preburn, fires impacted by strong blasts are prone to extinction.

SRI experiments also indicate that beyond a critical preburn time of about 170s, the crib fire becomes altogether blast-proof. Based on wood pyrolysis kinetics literature, the time taken for complete charring of a wood element surface is shown in (1) to be also about 170s under conditions typical of crib burning. Beyond this time: (a) the pyrolysis process will become completely submerged within the solid, less vulnerable to any extinguishment actions in the gas phase; and (b) the surface char is so richly carbonaceous as to effectively glow with the oxygen attacking it after the flame is extinguished. This intense glowing maintains or even accelerates the subsurface pyrolysis. As the blast effects subside and glowing tends to cease, the system passes through the flaming ignition state at which a reflash is imminent. If, on the contrary, the preburn time is short, the surface would be only partially charred; the resultant glowing, being less intense, fails to perpetuate the pyrolyzate production; the flaming ignition state is not encountered as the system cools down; and the reflash is absent. Based on this description, for τ exceeding that corresponding to preburn time = 170s, the fire is to become blast-proof. Figure 2 shows this critical fire strength parameter to be τ = 0.75.

Such factors as recirculation of flow behind the sticks within the crib to stablize the flame are discussed in (1) as the reasons underlying the scatter in Fig. 2.

CONCLUSION

The scaling approach appears to provide a systematic framework with which an improved understanding of the blast/fire interaction mechanisms can be gained from the experimental observations. The influence of blast on both Class B fires with and without barriers and Class A fires over a range of preburn times appears to be describable on a blast weakness P* versus fire strength q* map.

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