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Louis Leblanc; Maha Manoubi; Kadeem Dennis; Zhe (Rita) Liang; Matei I. Radulescu

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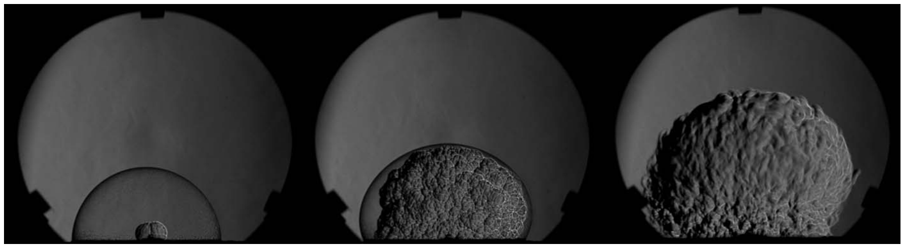

FIG. 1. Schlieren photographs illustrating the ignition and subsequent flame propagation in a $12\%H_2 - Air$ mixture contained in a soap bubble; for reference, the field of view is 30 cm in diameter. The thermal-diffusive cellular instabilities developed on the flame structure are clearly discernable (enhanced online) [URL: http://dx.doi.org/10.1063/1.4820018.1].

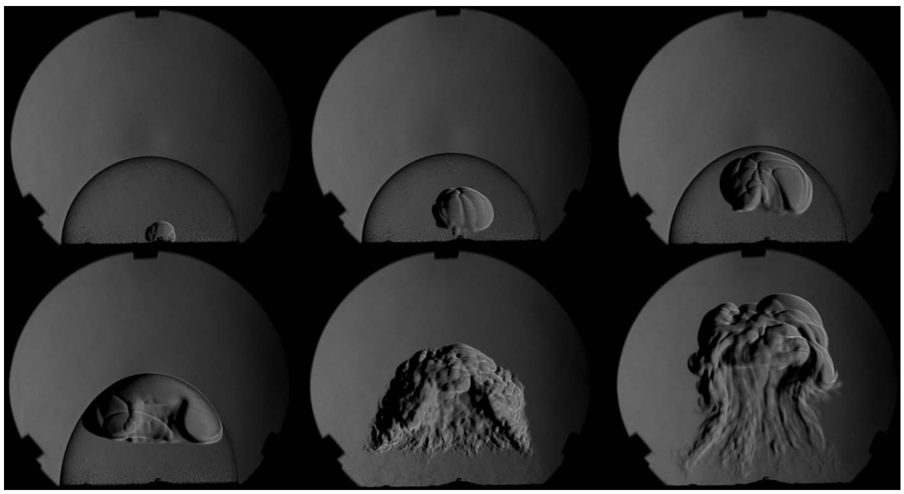

FIG. 2. Schlieren photographs illustrating the ignition and subsequent flame propagation in a $9\%H_2 - Air$ mixture contained in a soap bubble (enhanced online) [URL: http://dx.doi.org/10.1063/1.4820018.2].

Dynamics of unconfined spherical flames: Influence of buoyancy

Louis Leblanc,[1] Maha Manoubi,[1] Kadeem Dennis,[1] Zhe (Rita) Liang,[2] and Matei I. Radulescu[1,a)]
[1]Department of Mechanical Engineering, University of Ottawa, Ottawa K1N6N5, Canada
[2]Atomic Energy Canada Limited, Chalk River, Ontario K0J 1J0, Canada

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Unconfined deflagrations occur at nearly constant pressure. Constant pressure conditions can be obtained using the soap bubble technique.[1] A soap bubble can be filled with a reactive mixture, which is then ignited. The present study addresses the dynamics of such weakly confined deflagrations, focusing on the effect of buoyant forces. We wish to verify experimentally the scaling laws suggested by Babkin *et al.*[2] and Zingale and Dursi[3] for determining the flame size at which buoyant effects become important.

a)Electronic mail: matei@uottawa.ca

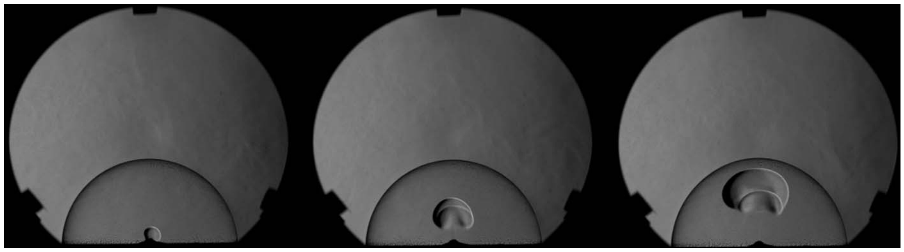

FIG. 3. Schlieren photographs illustrating the ignition and subsequent flame propagation in a 7%$H_2 - Air$ mixture contained in a soap bubble (enhanced online) [URL: http://dx.doi.org/10.1063/1.4820018.3].

For relatively fast burning flames, the flame takes on a spherically symmetric structure, as shown in Fig. 1. Buoyancy forces do not have time to operate. For weaker mixtures, i.e., mixtures characterized by relatively low flame speeds, we find that the flames remain spherical initially, but begin to rise, as shown in Figs. 2 and 3. This phenomenon is due to the gravitational acceleration (buoyancy forces) preferentially accelerating the light combustion products contained inside the flame kernel.

The characteristic flame size for which buoyancy is expected to play a role can be obtained by equating the characteristic time for flame growth by diffusive-convective effects (as in the absence of gravity) and the time scale for buoyancy effects.[3] The time scale for the flame to grow to a characteristic dimension R is $t_{burn} = R/\dot{R} = (R/S)(\rho_u/\rho_b)^{-1}$, where S is the laminar flame speed, ρ_u/ρ_b is gas expansion ratio, and the subscripts b and u refer, respectively, to the burned and unburned gases. The time scale for buoyancy forces to displace the flame bubble the same characteristic distance R is $t_{rise} = R/V_{rise}$, where V_{rise} is the characteristic rise speed of the bubble due to buoyant forces. The latter can be estimated as being the terminal velocity of a non-reactive buoyant bubble, where the inertia dominated drag force balances the buoyant force.[3,4] Adapting the result of Davies and Taylor[4] to a bubble with non-negligible density, we obtain $V_{rise} = 2/3\sqrt{Rg(1-(\rho_u/\rho_b)^{-1})}$.

The ratio of the time scales for burning and flame kernel advection becomes

$$\frac{t_{burn}}{t_{rise}} = \frac{2}{3}\frac{1}{S}(\rho_u/\rho_b)^{-1}\sqrt{Rg(1-(\rho_u/\rho_b)^{-1})}. \tag{1}$$

Without the 2/3 factor, it is the square root of the Richardson number.

Setting this time scale ratio to unity provides an estimate of the critical flame dimension in which buoyant forces will begin to play a substantial role:[3]

$$R_* = \frac{9}{4}\frac{S^2}{g}\left(\frac{\rho_b}{\rho_u}\right)^{-2}\left(1-\frac{\rho_b}{\rho_u}\right)^{-1}. \tag{2}$$

We can compare the above criterion with the experiments shown in Figs. 1–3. For a 12%H_2 flame, we predict a detaching flame radius of 70 cm, larger than the field of view (Fig. 1). On the scale of the visualization, the flame does not rise noticeably. For the 9%H_2 and 7%H_2 flames, the predicted critical radii are 10 cm and 3 cm, respectively. This is in good agreement with our experiments, where flame kernels of characteristic dimensions comparable to these estimates detach from the bottom wall (Figs. 2 and 3).

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