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Planar, cylindrical, and spherical flame propagation in closed vessels with nonuniform composition and temperature

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Flame propagation in enclosed mixtures is accompanied by a continuous pressure rise, leading to an increase in temperature. Because of the temperature dependence of the chemical reactions controlling fuel oxidation, this temperature rise enhances the burning rate as the flame advances through the vessel. As demonstrated by Sivashinsky in his seminal work on the subject [1, 2], the problem admits a simplified description due to the presence of disparate scales. Specifically: (i) since the deflagration thickness is typically orders of magnitude smaller than the characteristic vessel dimension, the flame can be approximated as a thin layer separating the chemically frozen reactant mixture from a hot equilibrium region; (ii) the pressure, which increases over time, remains uniform in the first approximation because the flame front propagates at a velocity much lower than the speed of sound; and (iii) while molecular transport plays a crucial role in determining the internal structure and propagation velocity of the flame, it is negligible in the external regions, where the flow dynamics is governed by the Euler equations.
This paper aims to extend the hydrodynamic theory of flame propagation in closed vessels [1, 2] to configurations where the initial temperature and composition of the reactant mixture are nonuniform–an aspect of the problem with significant implications for both technological applications and accidental scenarios. For instance, many modern gasoline direct injection engines operate in a stratified mode to enhance fuel efficiency, with a locally richer mixture near the spark plug. Similarly, stratified reactant mixtures can form due to buoyancy following hydrogen release during severe accidents in nuclear power plants. The associated issue of flame acceleration in nonuniform hydrogen-air mixtures is of critical interest for assessing the risks of deflagration-to-detonation transition. Simplified flame-propagation models like the one presented here can be useful in enabling rapid assessment of flame acceleration under various stratification conditions.

References

[1] Sivashinsky, GI. On propagation of a flame in a closed vessel. *Isr. J. Technol.* 1974;12:317–321.

[2] Sivashinsky, GI. Hydrodynamic theory of flame propagation in an enclosed volume. *Acta Astronautica* 1979;6:631–645.