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Water spray mitigation of H2/air detonations: Impact of droplet size and pathological regimes

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Detonations of reactive mixtures, such as hydrogen and air, pose significant safety risks due to their supersonic speeds and high pressures. Mitigation strategies using water spray have been proposed as an effective mean to attenuate or quench these waves [1]. Building upon a previous numerical model developed for liquid-fueled detonations [2], this study investigates the impact of water droplet size on the effectiveness of mitigating H2/air detonations. Using a one-dimensional, steady-state, two-phase model, the interaction between the reactive gas and a diluted mono-disperse spray is analyzed, incorporating interphase mass, momentum, and energy exchanges, and detailed chemical kinetics.

The results reveal that droplet size significantly impacts detonation behavior. For small droplets, water vaporization occurs relatively quickly behind the leading shock wave and the detonation speed can be predicted by a global energy balance, accounting for the latent heat of vaporization, aligning with the Chapman-Jouguet (CJ) theory where a sonic condition is reached at the equilibrium state. However, for droplets exceeding a critical diameter, pathological detonation regimes [3] can be identified. In this regime, the sonic condition occurs within the non-equilibrium region, decoupling part of the endothermic vaporization and exothermic heat release from the detonation-driving mechanism. In these cases, the detonation speed is determined as an eigenvalue of the governing equations, rather than an overall balance. Very large droplets, by contrast, vaporize too slowly to meaningfully attenuate the detonation, resulting in speeds close to that of the pure H2/air mixture.

These findings underscore the need for precise control of droplet size in spray-based mitigation systems and highlight the critical role of two-phase dynamics in predicting detonation behavior.

References

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