Accurate determination of syngas flame speeds at high pressures and temperatures by using spherical flames

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Objectives

The purpose of the present study is to develop a rigorous method for accurate measurement of syngas flame speeds at high pressures and temperatures by using a spherical bomb. The flame speed data are used to assess the performance of kinetic and transport mechanisms for synthetic gas combustion at pressures and temperatures typical of gas turbine engines.

Accomplishments to Date

Laminar flame speeds for syngas mixtures of various compositions up to 20 atm are measured with outwardly propagating spherical flames at constant pressure using more restrictive measures for data reduction that consider deviation from the ideal flow field caused by a non-spherical confinement. In the present study, as in earlier high pressure study of flame speeds, a recently developed constant-pressure approach that utilizes a cylindrical test chamber is applied. For the first time, the effect of flow field on flame speed measurements is addressed in detail for these non-spherical constant-pressure chambers. The results from experiments and analysis indicate that deviation from the assumed flow field causes significant errors in instantaneous flame speed measurement, which are amplified in the extrapolation to zero stretch rate. A simple model is developed to study the effect of flow disturbance in cylindrical confinements. In cylindrical chambers, where the flow is typically most constrained in the plane of measurement (radial direction), failure to consider this effect results in lower values for the measured flame speed.

Laminar flame speed measurements are reported for $H_2/CO/CO_2$ mixtures varying in equivalence ratio from 0.6 to 4.0, pressure from 1 to 20 atm, and CO_2 dilution from 0 to 25%. The corrected data range ($0.6\text{ cm} < r < 0.30R_w$ where R_w is the chamber wall radius) is seen to raise the extrapolated burning velocity by as much as 6% from the burning velocity found from extrapolation over a wider range ($0.6\text{ cm} < r < 0.54R_w$), which is more strongly influenced by flow field deviations. The experimental measurements are compared with experiments from McLean et al., Sun et al., and Hassan et al. (where applicable) and planar calculations using the kinetic mechanisms of Li et al., Davis et al., and Sun et al. While the experimental data and predictions for burning velocity agree reasonably well at lean conditions, large discrepancies occur at rich conditions. The substantial variation in the available stretch-corrected flame speed data indicate that significantly more data and more rigorous calculations of uncertainty are necessary before quantitative conclusions can be made and the performance of kinetic mechanisms can be properly assessed.

The effects of flow compression and flame stretch on the determination of flame speeds using spherical bombs under constant-pressure and constant-volume conditions are studied theoretically and numerically. A time-accurate and front-adaptive numerical algorithm is developed to simulate the outwardly propagating spherical flame in a closed chamber for a broad range of pressures and equivalence ratios. The results show that both flow compression and flame stretch have significant impacts on the accuracy of measured flame speeds. For the constant-pressure method, a new expression is presented to calculate a compression corrected flame speed (CCFS). Likewise, for the constant-volume method, a new expression is presented to calculate a stretch corrected flame speed (SCFS). The results demonstrate that the present CCFS and SCFS methods not only greatly improve the accuracy of the flame speed measurements but also extend the valid parameter range of experimental conditions. These findings and techniques will be implemented in future work for the determination of syngas flame speeds at elevated pressures and temperatures in a preheated spherical bomb.

Future Work

Syngas flame speeds at elevated pressures and temperatures will be measured in a preheated counter-flow flame burner and/or preheated spherical bomb.

Journal Papers Published

1. Z. Chen, Y. Ju, “On the accurate determination of flame speeds by using a spherical bomb: the effect of compression and stretch”, *Combustion and Flame* (2007) Submitted.
2. Z. Chen, Y. Ju, “Combined effects of curvature, radiation, and stretch on the extinction of premixed tubular flames”, *Combustion and Flame* (2007) Submitted.
3. Z. Chen, X. Qin, B. Xu, Y. Ju, F. Liu, “Studies of radiation absorption on flame speed and flammability limit of CO2 diluted methane flames at elevated pressures”, *Proceedings of the Combustion Institute* (2007) 31: 2693-2700.

Conference Presentations

1. Z. Chen, X. Qin, Y. Ju, “Burning properties of dimethyl ether/methane/air mixtures at normal and elevated pressures,” 18th International Symposium on Transport Phenomena, Daejeon, Korea, August 2007.
2. Z. Chen, Y. Ju, “On the accurate determination of flame speeds at normal and elevated pressures by using a spherical bomb: the effect of compression and stretch (detailed chemistry)”, 6th Asian-Pacific Conference on Combustion (ASPACC07), Nagoya, Japan, May 2007.
3. M.P. Burke, X. Qin, Y. Ju, F.L. Dryer, “Measurements of Hydrogen Syngas Flame Speeds at Elevated Pressures,” 5th US Combustion Meeting, San Diego, California, USA, March 2007.
4. Z. Chen, Y. Ju, “The effects of flow compression on the determination of flame speeds using propagating spherical flames at normal and elevated pressures”, 5th US Combustion Meeting, San Diego, California, USA March 2007.
5. Z. Chen, Y. Ju, “Combined effects of radiation, stretch and curvature on the extinction of premixed tubular flames (one-step chemistry)”, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, USA, January 2007. No. 2006-0175.
6. Z. Chen, Y. Ju, “On the accurate determination of flame speeds at normal and elevated pressures by using a spherical bomb: the effect of compression and stretch”, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, USA, January 2007. No. 2006-0378.

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