Numerical simulation of hydrogen-air turbulent diffusion flame

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Problem description

Figure 1 presents a schematic of the computational domain shown in side and rear views. A mixture of hydrogen and nitrogen with a mole ratio of 1:1 is used as fuel. The fuel enters the domain with a velocity of 29.2 m/s. The fuel jet accelerates in the fuel pipe and ejects with a velocity close to 34.8 m/s, which is the burner exit velocity measured in the experiment. The co-flow air velocity is fixed at 0.2 m/s. The ambient air inlet is also given an air inflow boundary condition (with inlet velocity of 0.2 m/s). The pressure and temperature are maintained at 1 bar and 300 K respectively.

* Thinned down to 0.25 mm at lip
Dimensions are in mm

Figure 1. Schematic of the computational domain

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Computational details
Compressible real gas Navier Stokes equations are solved using a pressure-based approach to obtain the flow field. The realizable k-epsilon turbulence model is employed to model the effect of turbulence. A 9 species and 18 step H2-O2 reaction model [2] is used to model chemical reaction. Figure 2 shows the computational domain and the mesh. There are 0.823 million cells in the domain. The mesh is clustered in the region where the flame gets stabilized. Temperature–velocity inflow/ pressure outflow boundary condition$^2$ is applied at the three, inlet regions. Inlets are set to 300 K temperature, 101325 Pa pressure, and velocity of 29.2 m/s at fuel inlet and 0.2 m/s at co-flow and ambient air inlets are used. Pressure temperature using inside velocity boundary condition$^3$ with a pressure of 101325 Pa and temperature of 300 K is applied at exit. The fuel and co-flow pipe walls are set as adiabatic viscous walls. The side-wall is maintained as inviscid. Symmetry boundary condition is maintained at the symmetry faces. First-order to second-order discretization blending technique was employed to expel initial transients from the system during computation. Multigrid technique was used for convergence acceleration. In the computations, the residuals came down by six orders of magnitude.

Figure 2. Computational domain

Results and discussion
Figure 3 shows the temperature contours over the symmetry plane. From the figure, we can see the presence of high temperature region around the reaction zone. We can also see that the flame has its base positioned at the fuel pipe wall lip. In the experiments [1], Laser-Doppler-Velocimeter was used to obtain the three velocity components simultaneously. Spontaneous Raman-Rayleigh spectroscopy (SRRS/Raman) and Coherent Anti-Stokes Raman spectroscopy (CARS) techniques were separately used to measure temperature. SRRS was used to measure mixture fraction.

$^2$ This BC can act as both inflow and outflow. For subsonic inflow, the temperature and velocity are prescribed and the pressure is taken from the interior. For subsonic outflow, the pressure is prescribed, and the temperature and velocity are taken from the interior.

$^3$ This is a reservoir type BC, but also allows for a reverse flow. For inflow, a user-specified stagnation pressure and temperature are imposed. For outflow, the input pressure is imposed as back-pressure.
Figure 4 shows the plot of temperature along the axis obtained in experiments and computation. The peak temperature in the computation is about 16% higher compared to the experiment but the prediction of peak temperature location is close to the experiment (x/d 35-40).

Figure 5 shows the plot of axial velocity decay along the axis. We observed a good match between experiment and computation at lower x/d, but for x/d > 65 it is slightly under-predicted.

Figure 6 shows the plot of mixture fraction along the axis showing a good match between experimental and computational values.
Figure 5. Axial velocity decay along the axis

Figure 6. Mixture fraction along the axis

References