Quenching, Blowoff, and Spontaneous Ignition Limits of Hydrogen Flames and Jets

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Motivation

- Hydrogen presents unique flame hazards:
  - Very dim flames
  - High leak propensity
  - Wide flammability limits (4 – 75%)
  - Steel embrittlement
  - Small ignition energy
  - Small quenching distance (0.2 mm)

- A hydrogen vehicle could develop a small fuel leak supporting an undetected flame.

Background

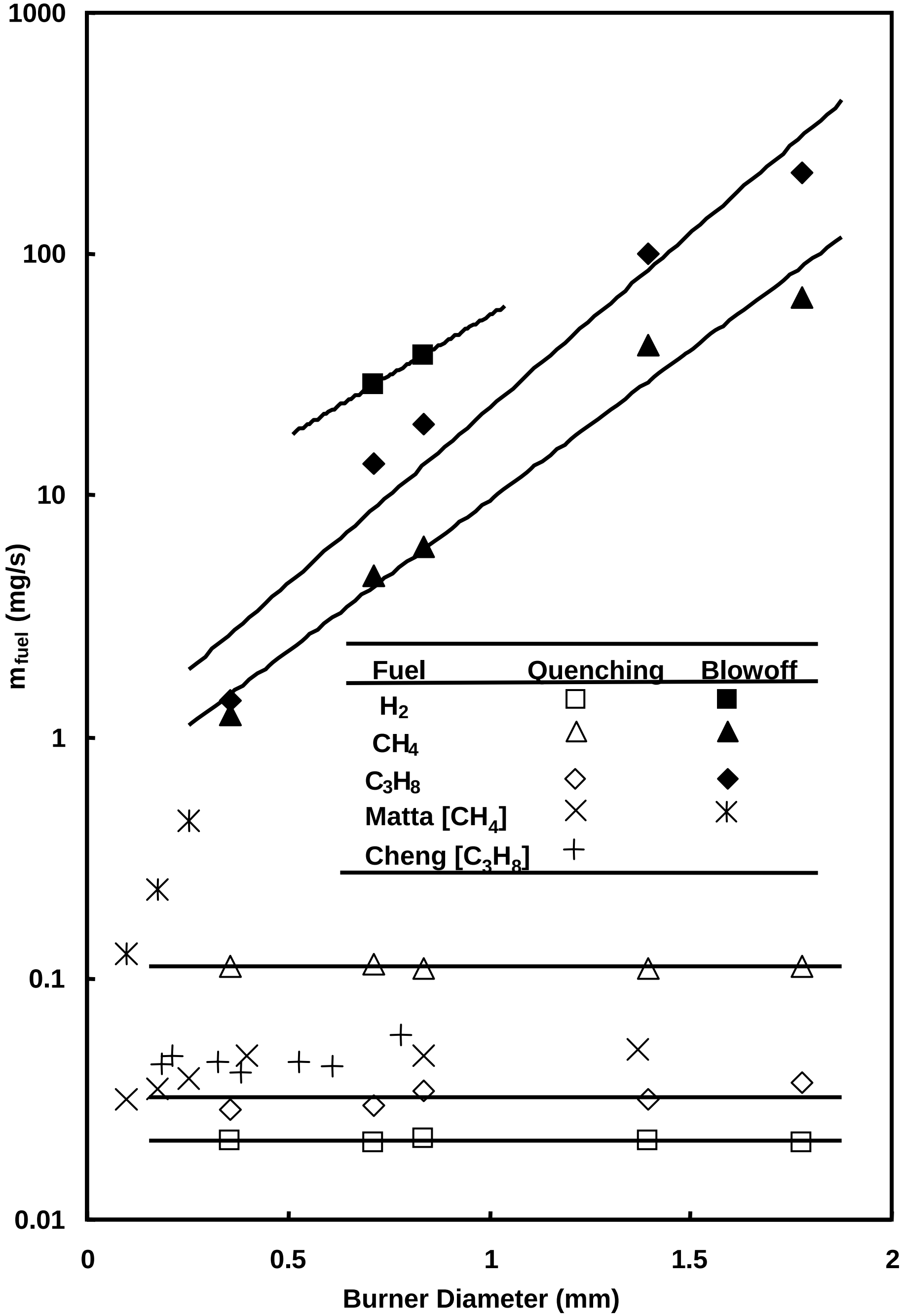
- Swain and Swain (1992) modeled and measured H_2, CH_4, and C_3H_8 leak rates at low pressures.
- Quenching and blowoff of CH_4 and C_3H_8 flames were measured by Matta et al. (2002) and Cheng et al. (2006).
- Utgikar and Thiesen (2005) considered the effects of H_2 on materials at ambient temperature.
- An investigation of different combustion regimes by AEA in a stagnant mixing layer was performed by Lee and Chung (1996).

Objectives

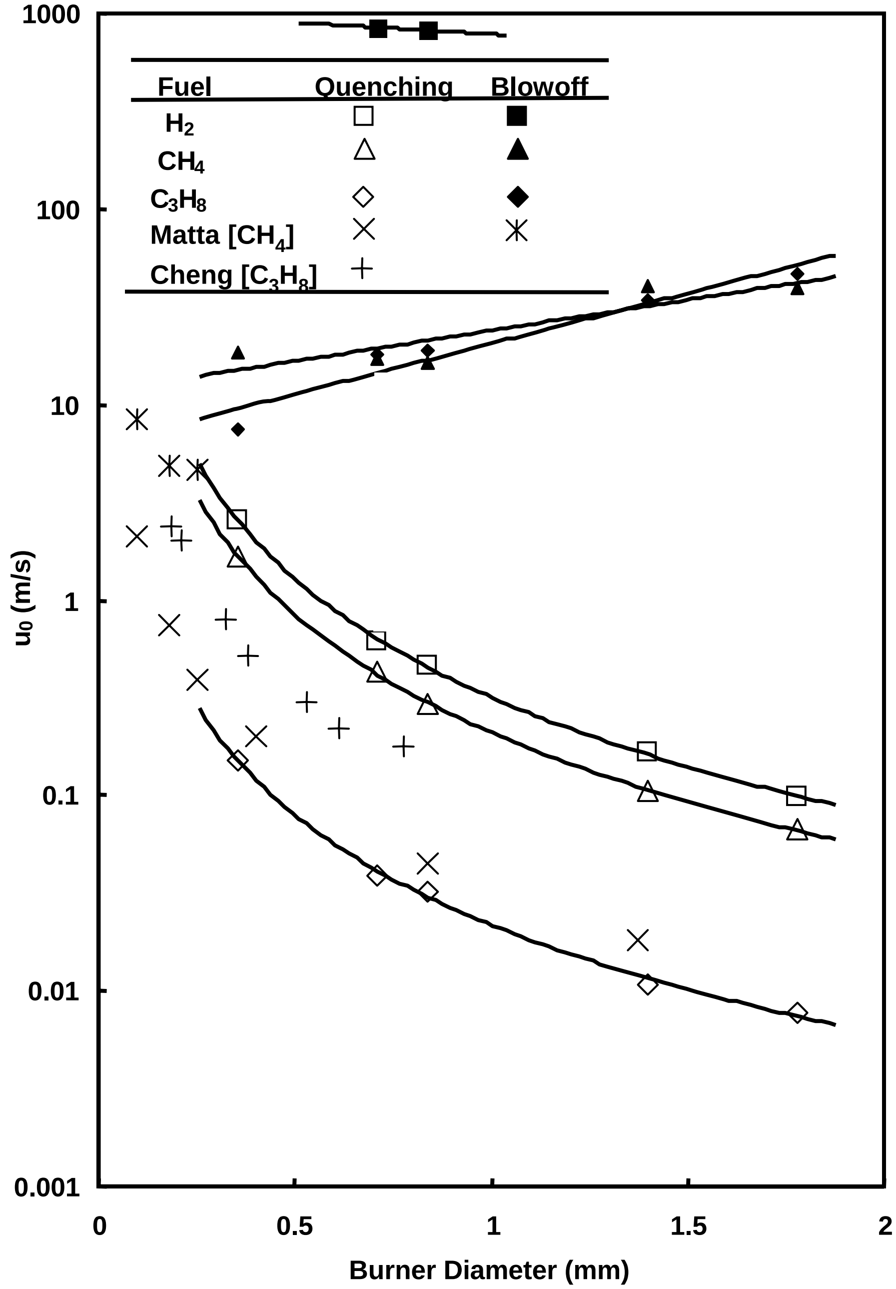
- Measure quenching and blowoff limits for H_2, CH_4 and C_3H_8 on small round burners.
- Examine material degradation arising from exposure to H_2 and CH_4 flames.
- Perform asymptotic analysis on spontaneous ignition of hydrogen jets.
- Perform detailed computations of H_2 flames.

Experimental

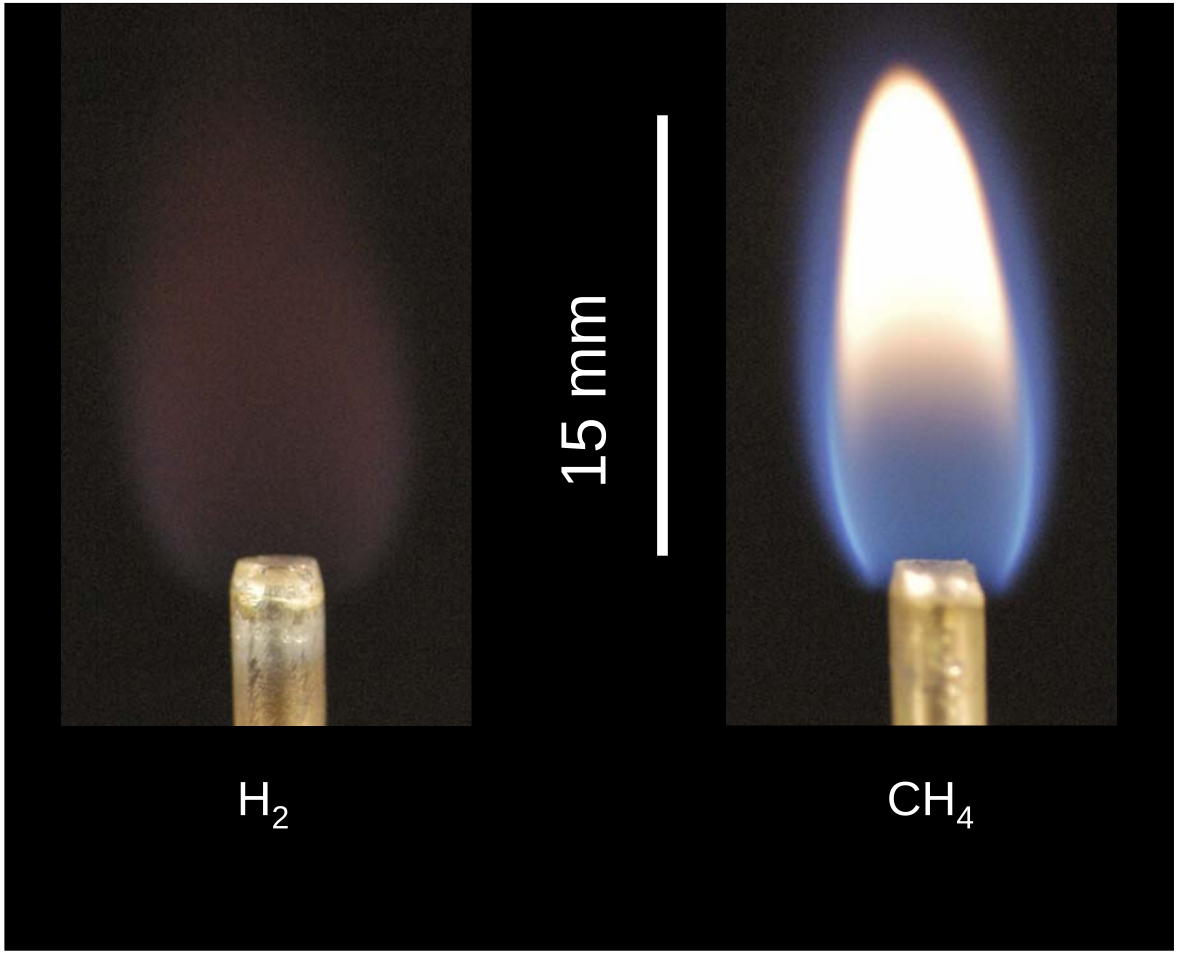
- Quenching and blowoff limits
  - Fuels: H_2, CH_4, and C_3H_8
  - Diameters: 0.4, 0.7, 0.8, 1.4, 1.8 mm
- Materials degradation
  - Fuels: H_2 and CH_4
  - Materials: aluminum alloy 1100, galvanized steel, stainless steel, SiC
  - Test times: up to 300 hours



- Quenching limit is independent of *d*.
- H_2 has the lowest quenching limit and the highest blowoff limit.

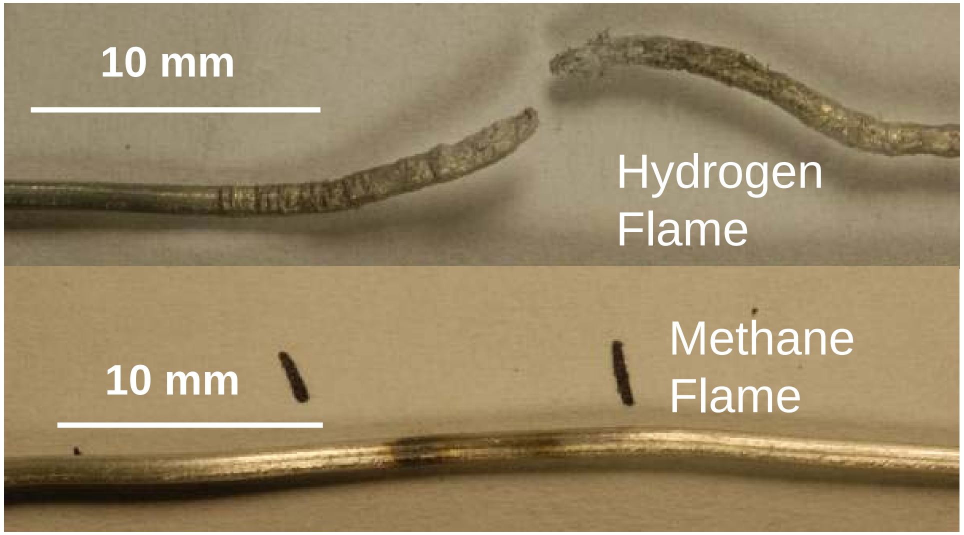

1000
100
10
1
0.1
0.01
0.001
0
0.5
1
1.5
2
Fuel
Quenching
Blowoff
H_2
CH_4
C_3H_8
Matta [CH_4]
Cheng [C_3H_8]
u_0 (m/s)
Burner Diameter (mm)

Materials Degradation



Materials Degradation

- Al wire failed in H_2 flame at 8 hours:

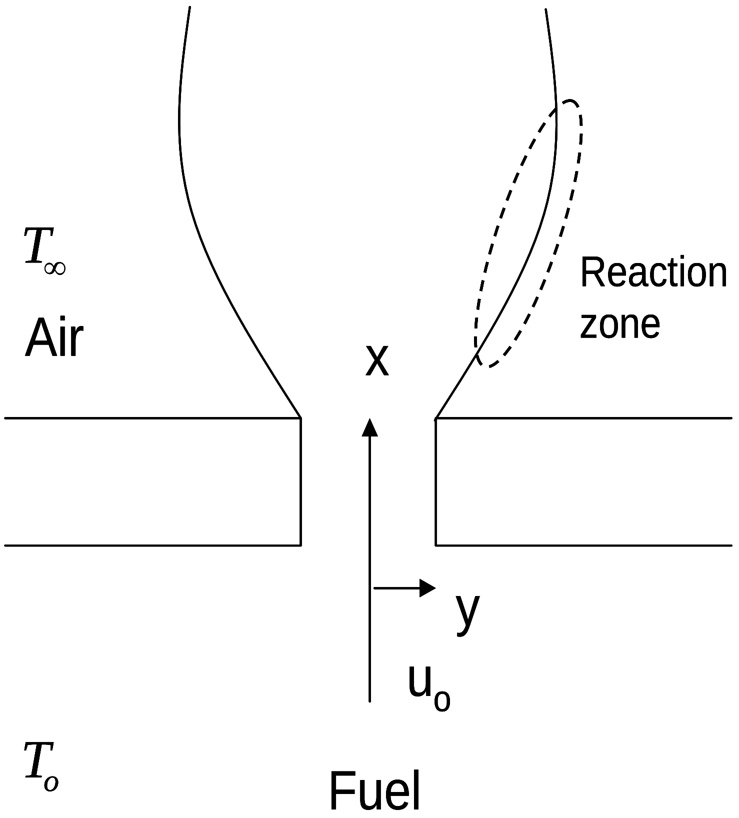


- SiC filaments failed at 15 minutes (H_2 flame) and 116 minutes (CH_4 flame).

Ignition Analysis

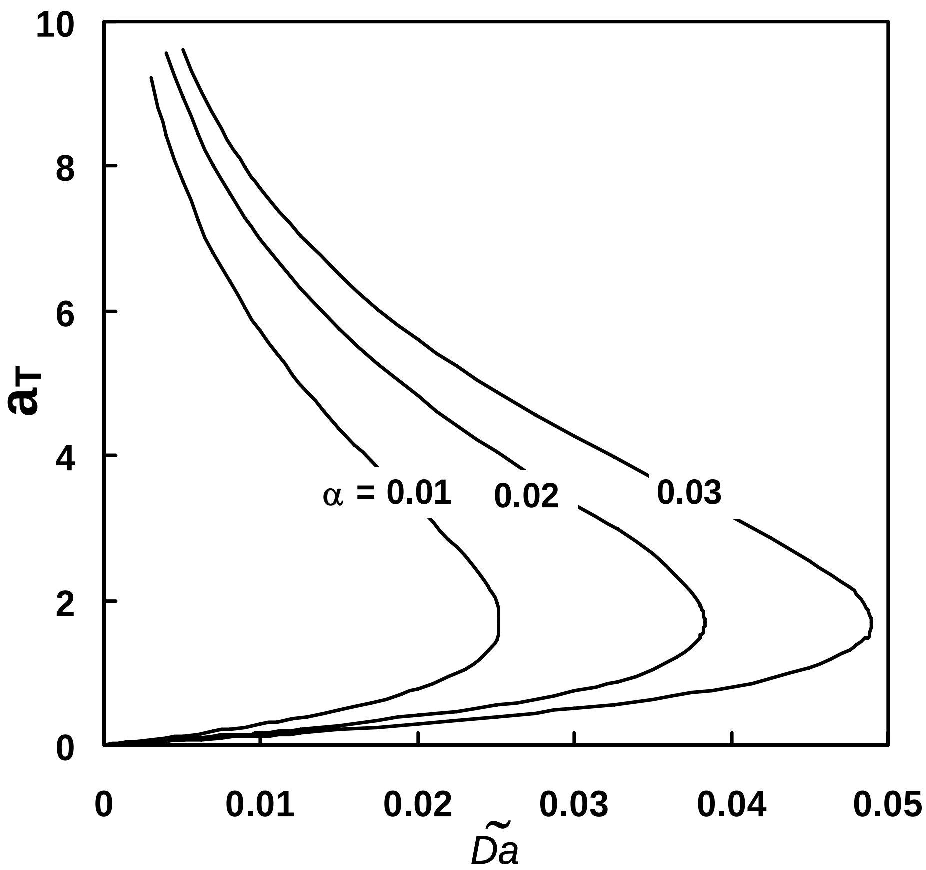
- Consider a steady laminar jet of fuel at T_0 issuing from a rectangular slot into an oxidizing environment at T_∞ .

- Spontaneous ignition is predicted when T_0 or T_∞ is sufficiently high.

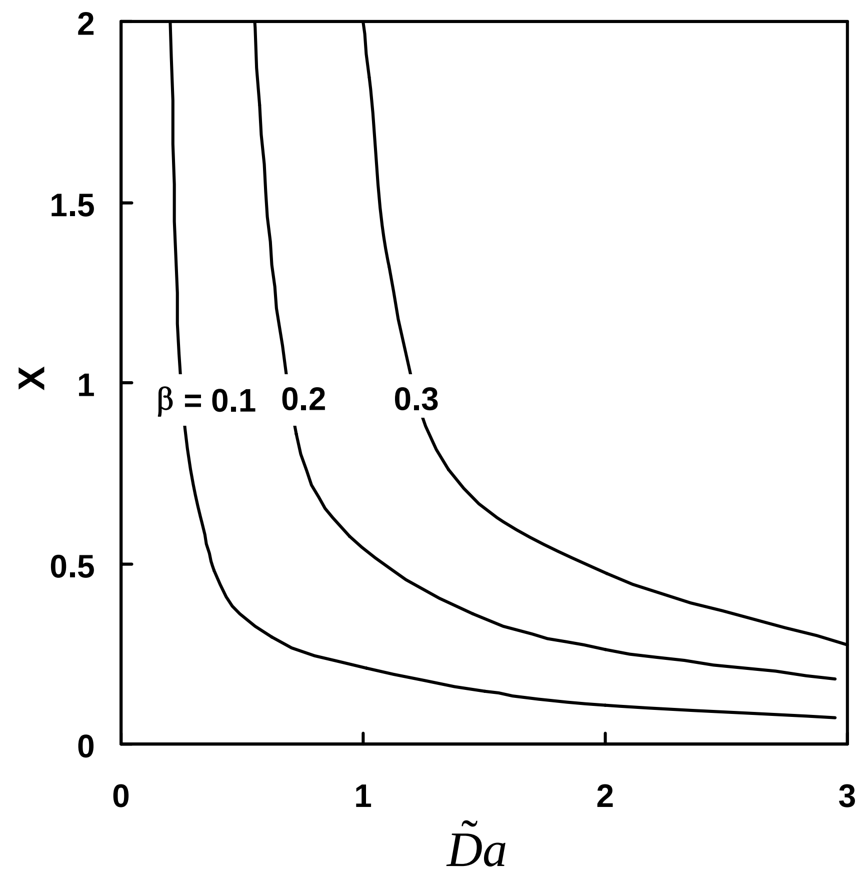


Ignition Analysis

Hot ambient

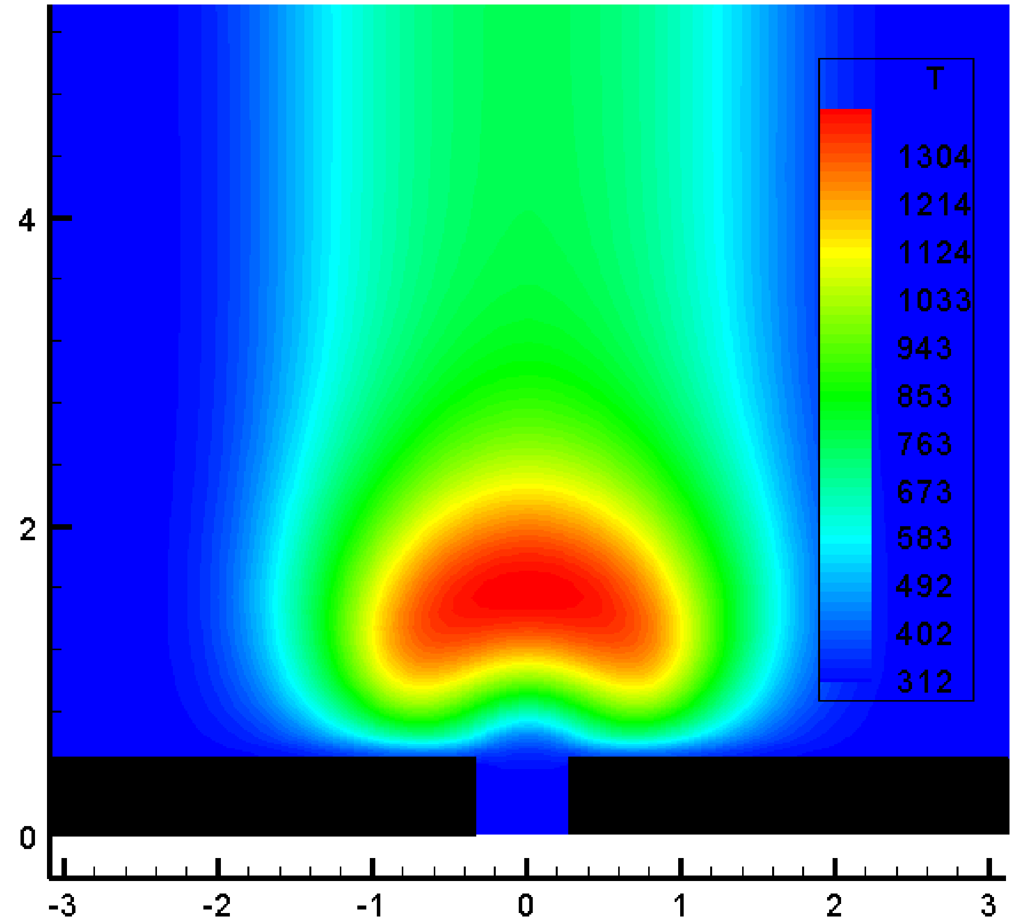


Hot jet



Computations

- Unicorn code of V. Katta.
- 2D laminar axisymmetric flames.
- Detailed H_2/air chemistry (73 reactions, 13 species) and transport.
- Optically thin radiation.



Simulation of an H_2/air diffusion flame, v = 20 cm/s, d = 0.80 mm. Number of grids is 201 x 71 .

Conclusions

- Fuel mass flow rate at quenching is independent of burner diameter.
- H_2 has a lower mass flow rate at quenching and a higher mass flow rate at blowoff than either CH_4 or C_3H_8.
- H_2 flames caused faster corrosion than methane flames on aluminum and SiC fibers.
- Limits of spontaneous ignition were found as functions of w, m, Le_F, Le_O, T_0, and T_∞.

Future Work

- Extend quench, blowoff, and degradation measurements.
- Consider high-pressure leaks.
- Perform AEA for round holes and extinction.
- Extend numerical work.
- Include metal surface chemistry.