Determination of Laminar Burning Velocity of H_2-CO fuel with high diluent content

Professor Anjan Ray
Department of Mechanical Engineering
Indian Institute of Technology Delhi
New Delhi 110016 INDIA
Email: raya@mech.iitd.ernet.in

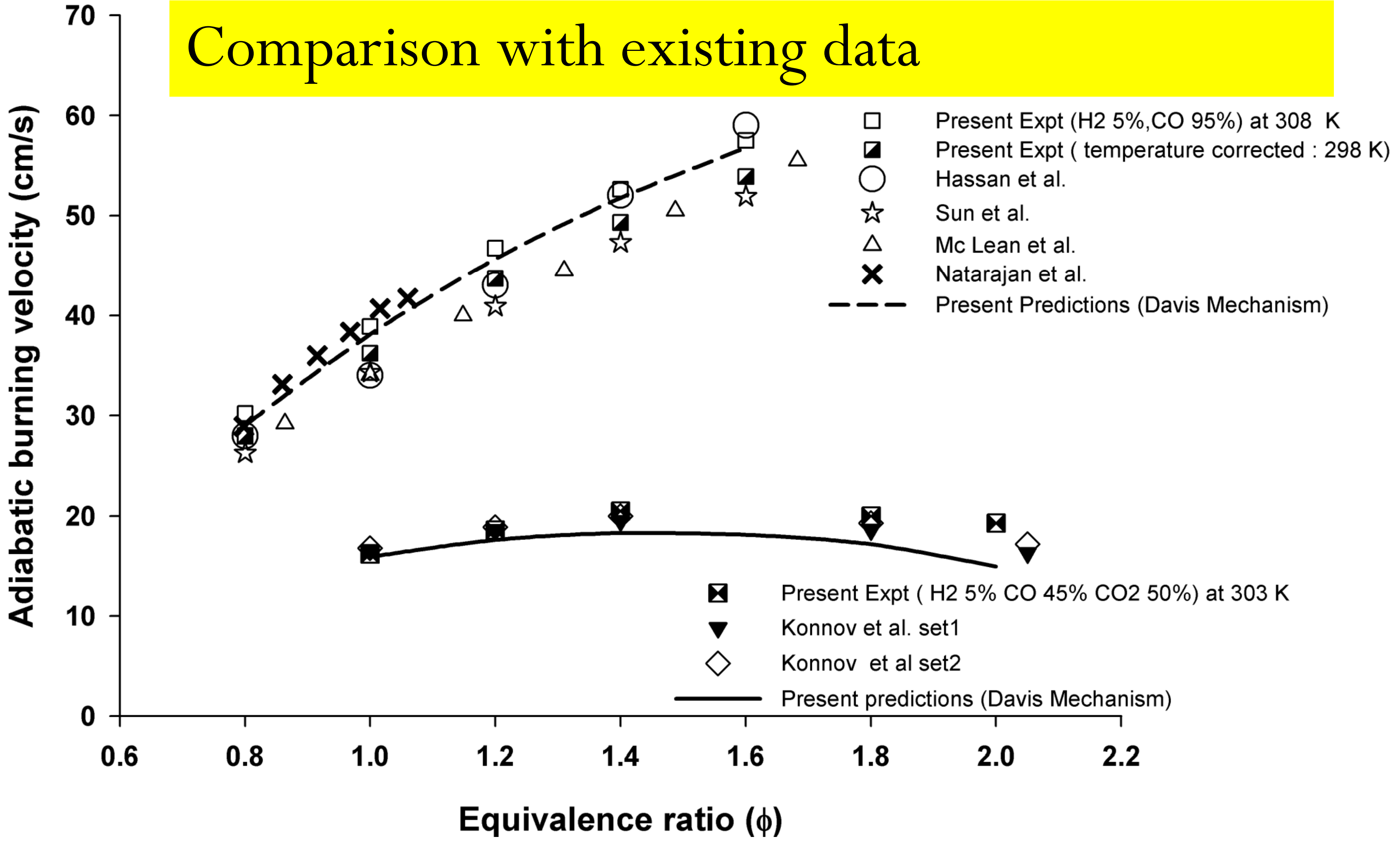
Background

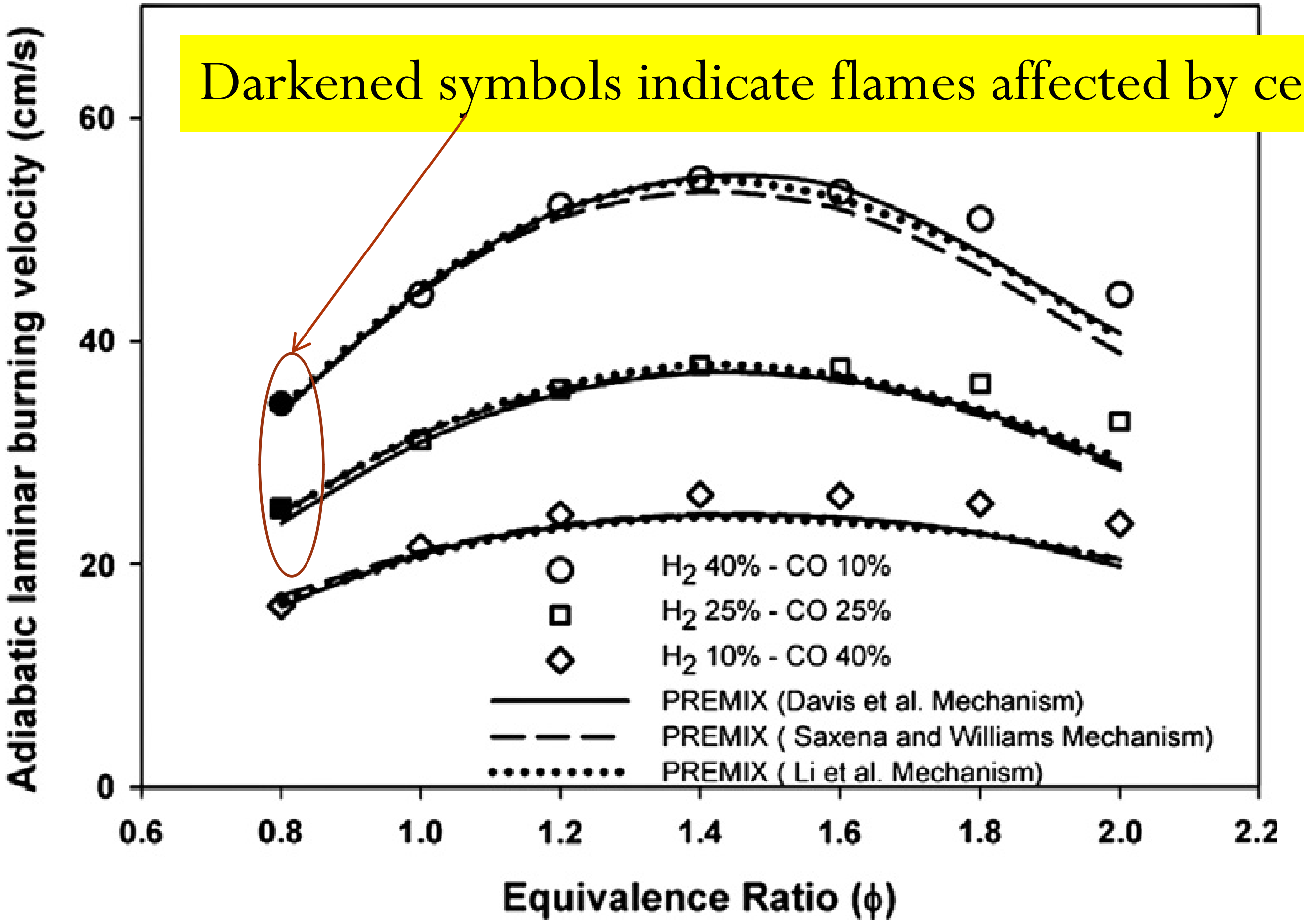
- Syngas composition can be 30-60% (H_2+CO), the rest being N_2+ CO_2 and moisture;
- High diluent content and a lot of variability in the composition;
- It is thus of interest to determine laminar burning velocity of syngas-air mixtures when CO_2 content is high and for various H_2:CO ratios.

Objectives

- Experimental determination of Syngas AULBV with high levels of CO_2 dilution for varying H_2/CO ratios
- Investigation of Cellular flame structures on a porous burner for such mixtures.

Comparison with existing data

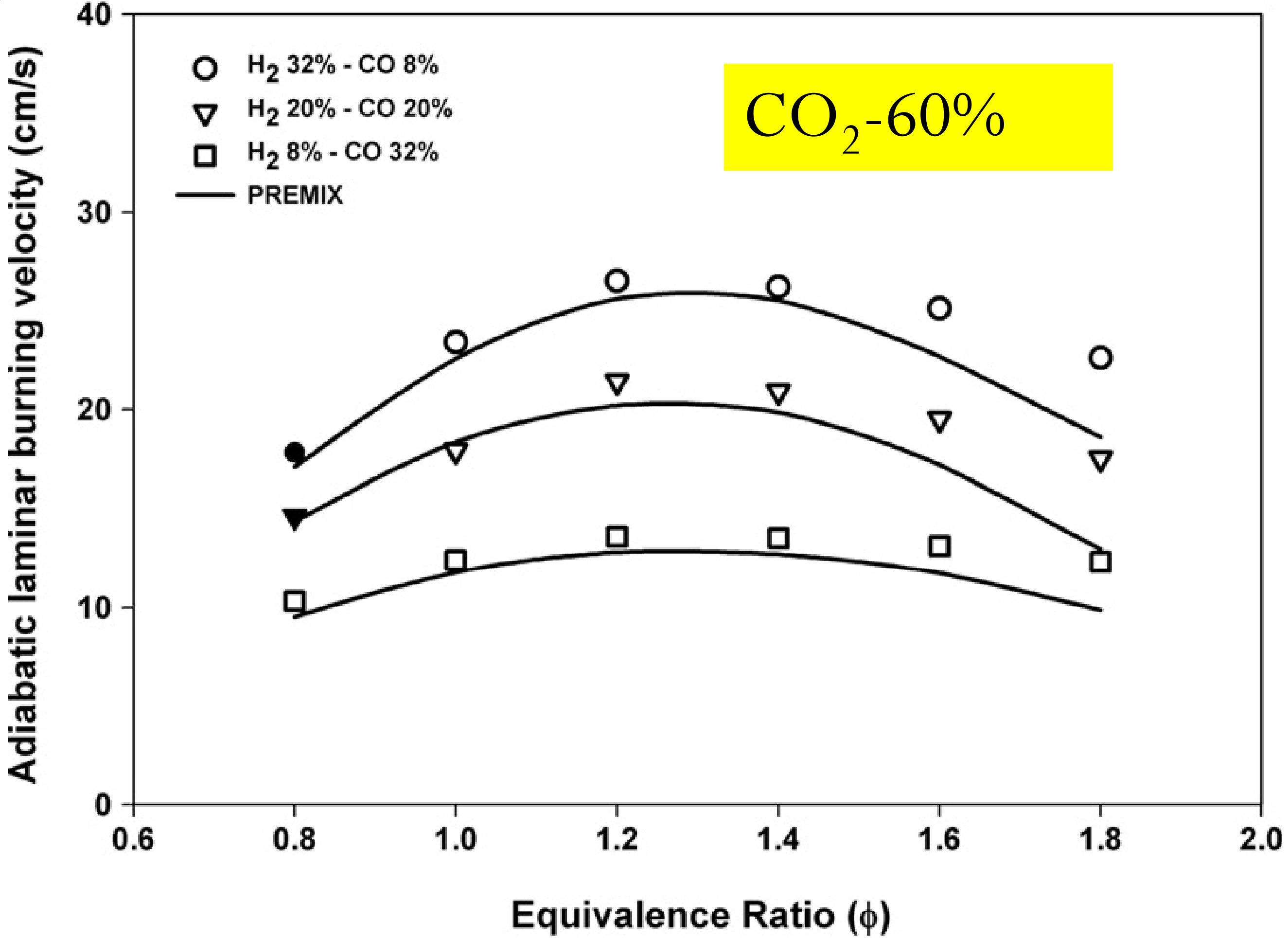




Darkened symbols indicate flames affected by cellularity

CO_2-50%

1. Increased H_2 concentration in the fuel results in high values of AULBV.
2. The mechanisms are not very successful for very rich mixtures.
3. AULBV peaks at approximately 1.4 equivalence ratio.

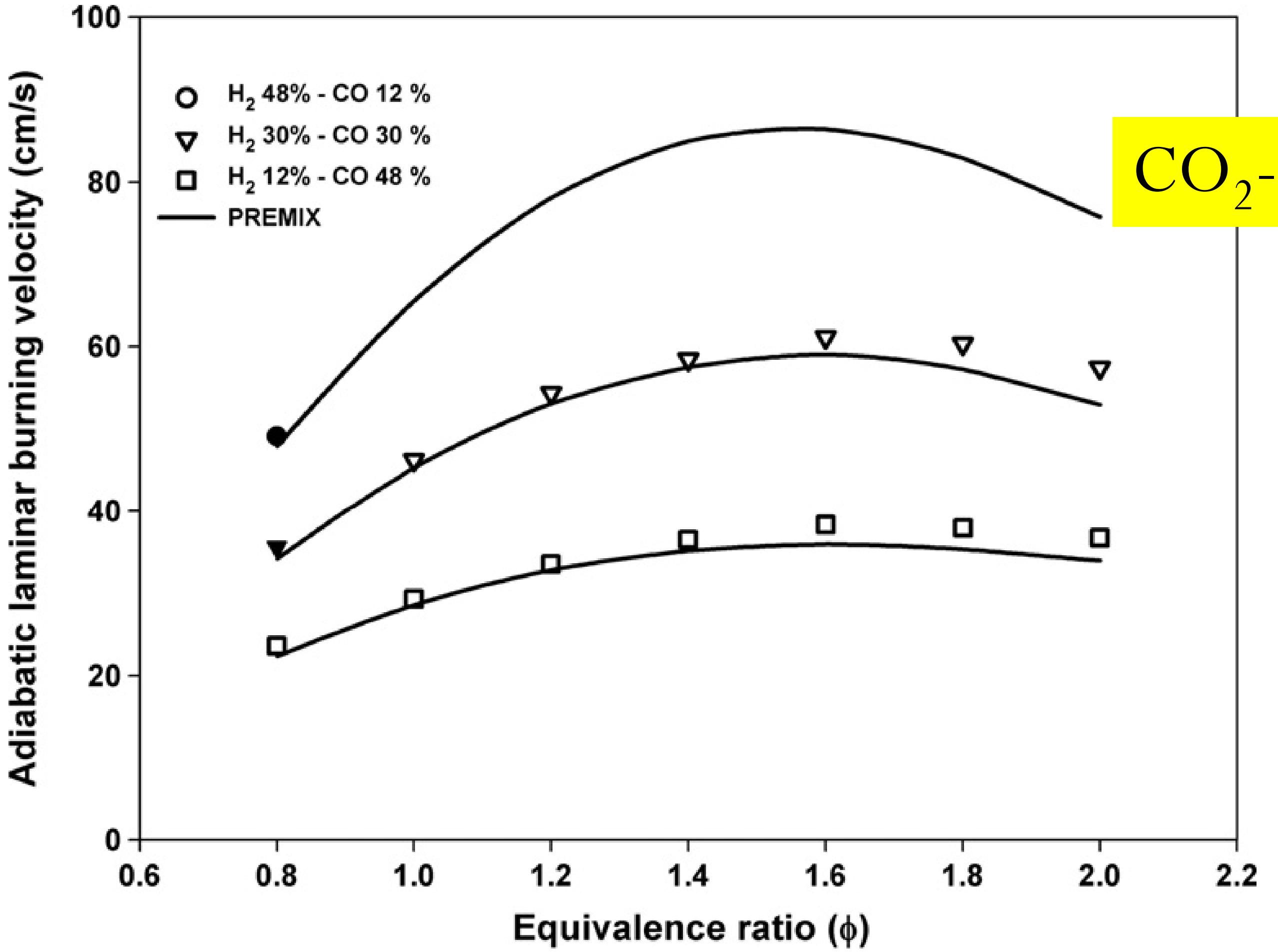


CO_2-60%

Very significant discrepancy for very rich mixtures.

The peak is at about equivalence ratio 1.2

Dilution with CO_2 results in reduced ALBV.



CO_2-40%

Shift in location of the peak AULBV from ϕ = 1.6 for 40% CO_2 to ϕ = 1.2 for 60% CO_2

Summary

- LBV increases with H_2 content in the fuel.
- CO_2 dilution results in very significant reduction in LBV.
- Location of peak LBV shifts from $\phi = 1.6$ for 40% CO_2 to $\phi = 1.2$ for 60% CO_2.
- The mechanism of Davis et al predicts LBV well except for significantly rich conditions.

Cellular Flames

- For lean mixtures with H_2/CO ratios of 4:1 and 1:1, at all levels of CO_2 dilutions studied, cellular flames were observed.

- Cellular flames were studied using **steady-state three-dimensional simulations** to understand the effect of stretch and preferential diffusion in various areas of the flame.

Mechanism of cellular flame formation

- In lean mixtures of syngas, the diffusion of very light H_2 dominates over conduction of heat from the flame region;
- This results in formation of cellular structures due to diffusive-thermal instability;
- Brighter, hotter cells are separated by darker, cooler folds that point upward, away from the burner.

Simulations

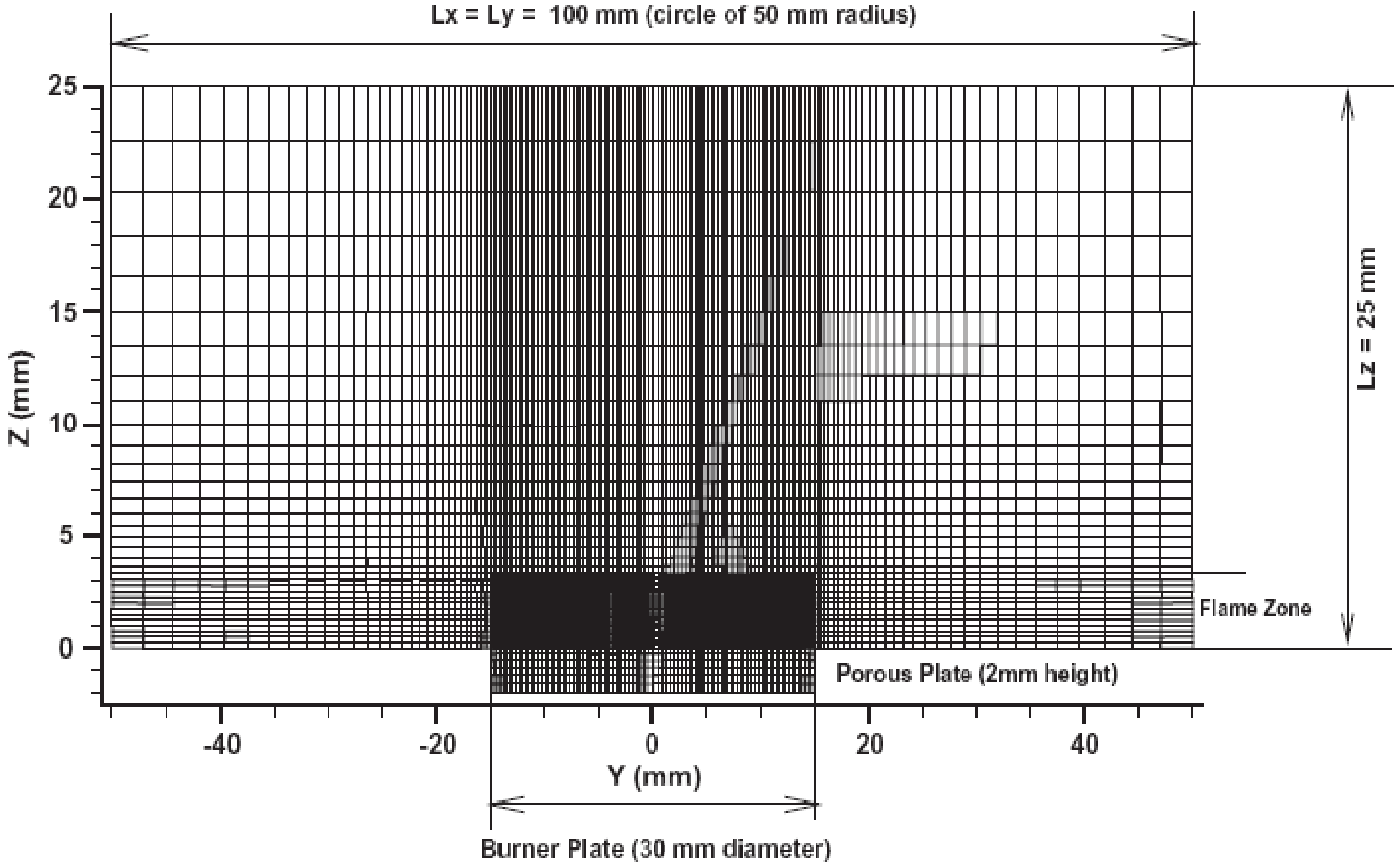
- The simulations were carried out using the CFD software FLUENT;
- An unstructured grid was used,
- The numerical noise generated on using an unstructured grid was sufficient to generate cellular structures.
- A full CFD has the advantage (over K-S equation) that it is not based solely on diffusive-thermal instability theory;
- It also gives all physical variables in contrast to just predicting the flame topography.

Modeling and Boundary Conditions

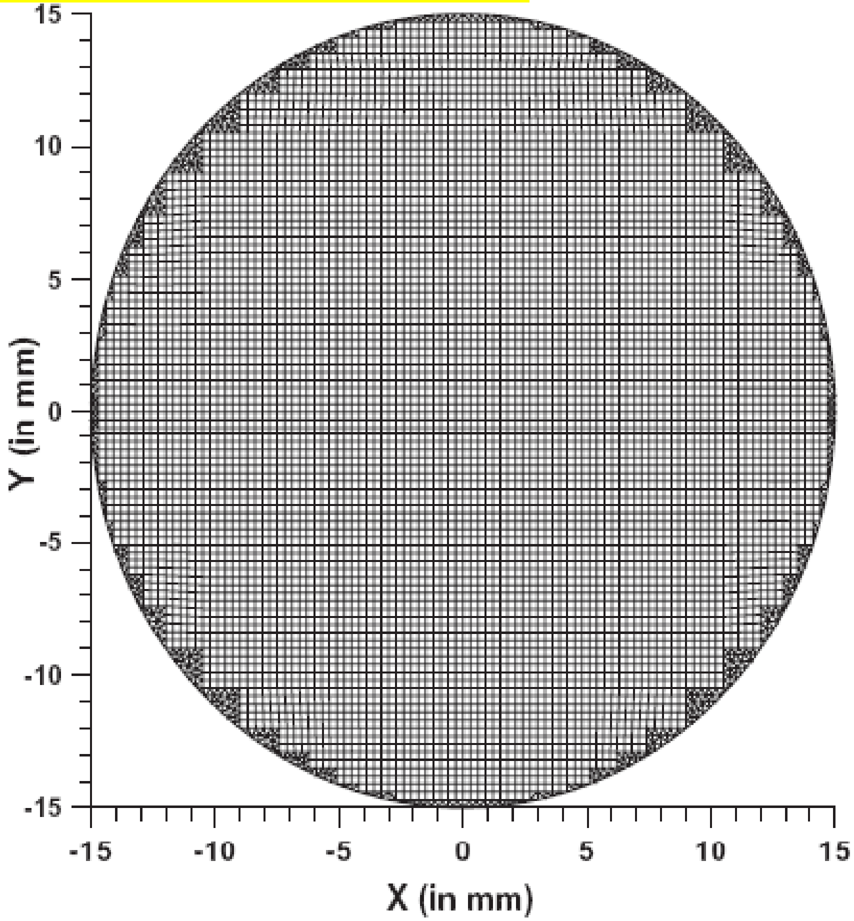
- The burner plate was modeled as a porous zone with a porosity equal to that of the actual plate;
- The burner plate rim was treated as a convective boundary;
- Uniform velocity and species mass fraction profiles were assumed at the inlet to the porous plate;
- The inlet temperature was taken to be 300 K;

Modeling and Boundary Conditions

- Along the cylindrical far-field boundaries as well as along the bottom surface of the domain outside the burner plate, the stagnation pressure was set equal to the local ambient pressure.
- At the top plane of the computational domain, static pressure was set equal to the local ambient pressure.

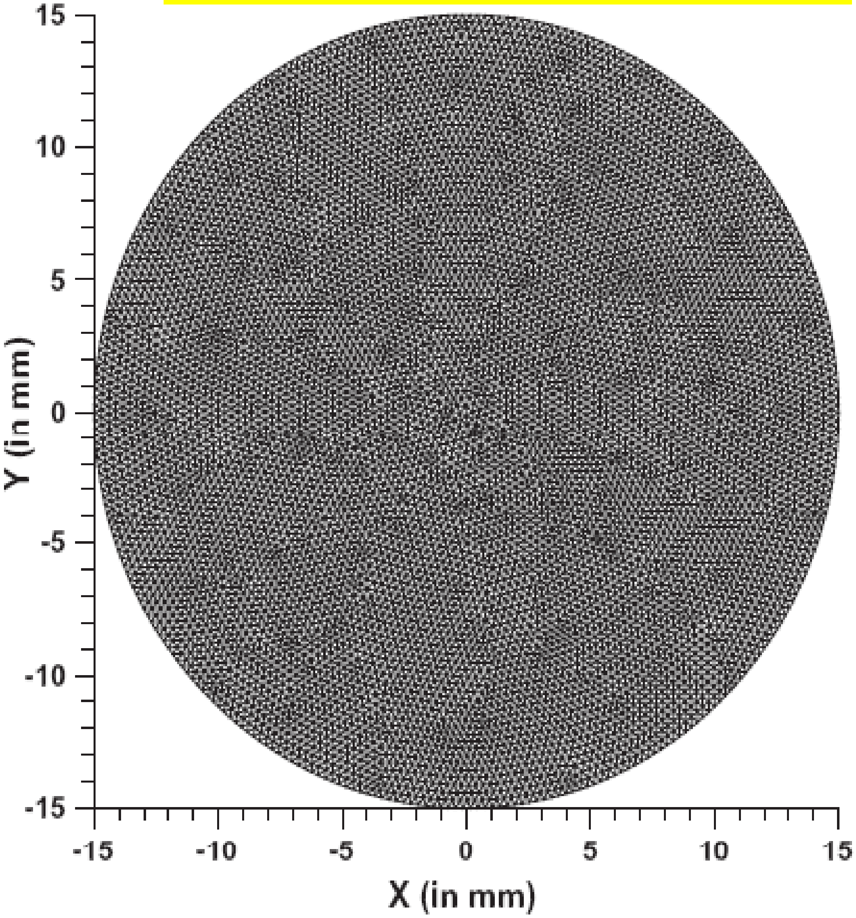

Lx = Ly = 100 mm (circle of 50 mm radius)
Lz = 25 mm
Z (mm)
25
20
15
10
5
0
Flame Zone
Porous Plate (2mm height)
-40
-20
0
20
40
Y (mm)
Burner Plate (30 mm diameter)

Structured grid

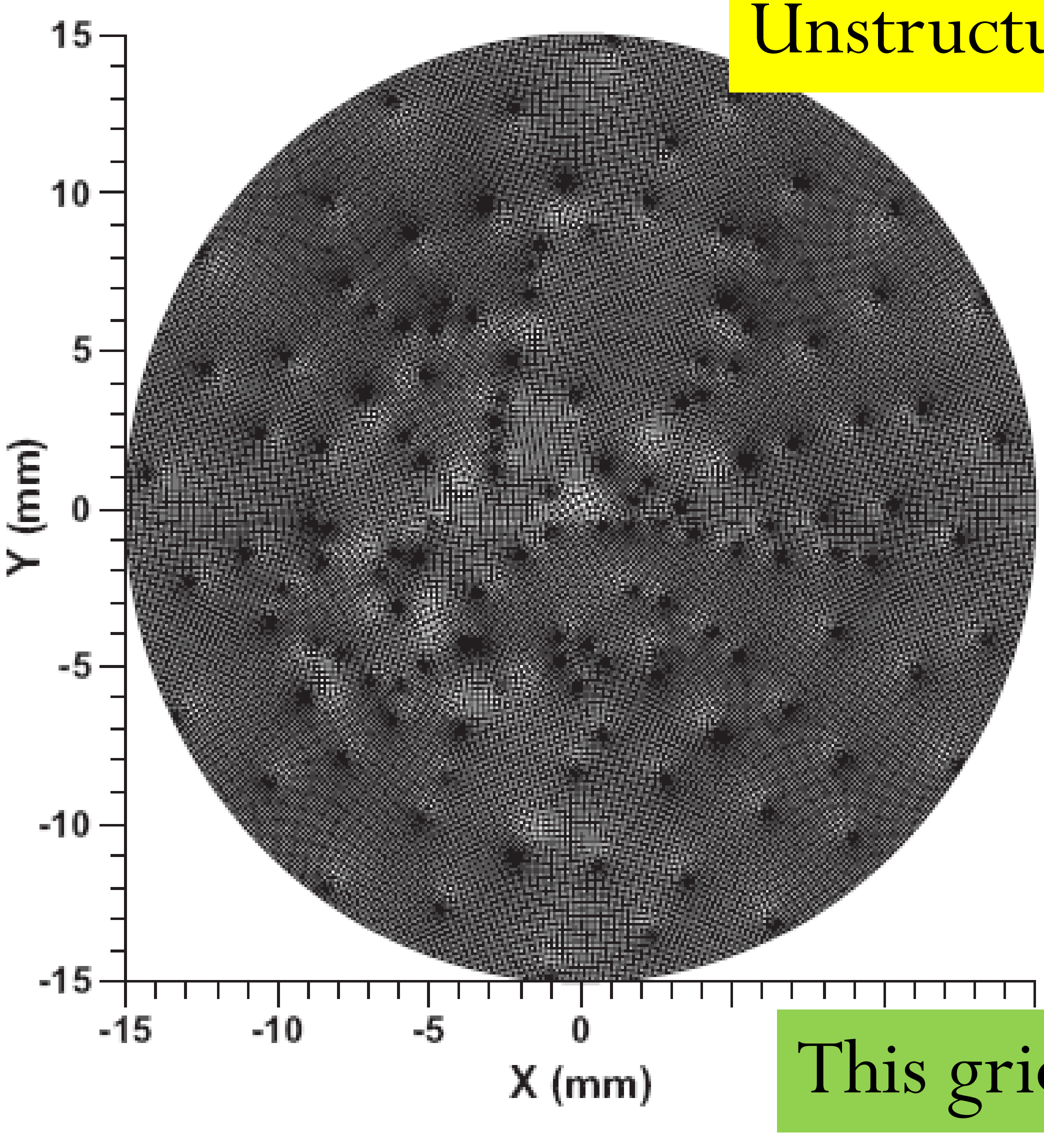


(a) hexahedral grid

Unstructured grid



(b) tetrahedral grid



Unstructured grid

This grid was used

(c) quadrilateral-pave grid

CFD Simulation for a flat flame

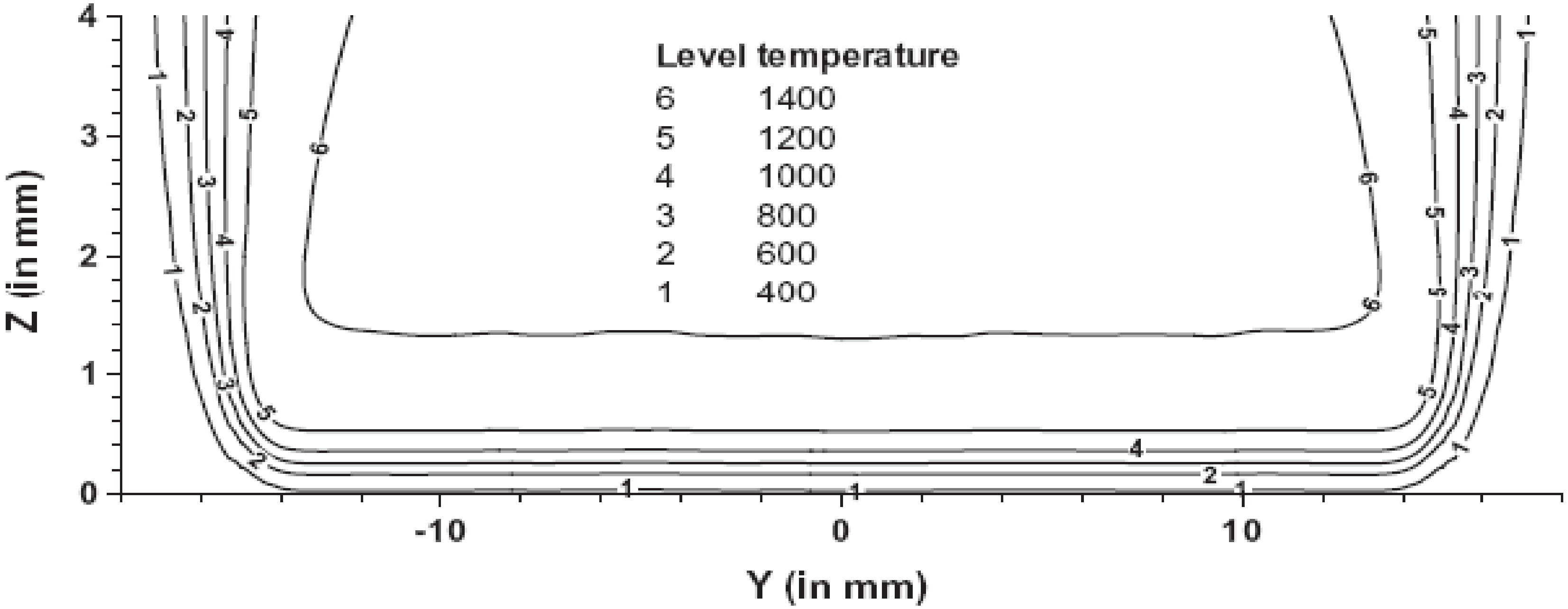
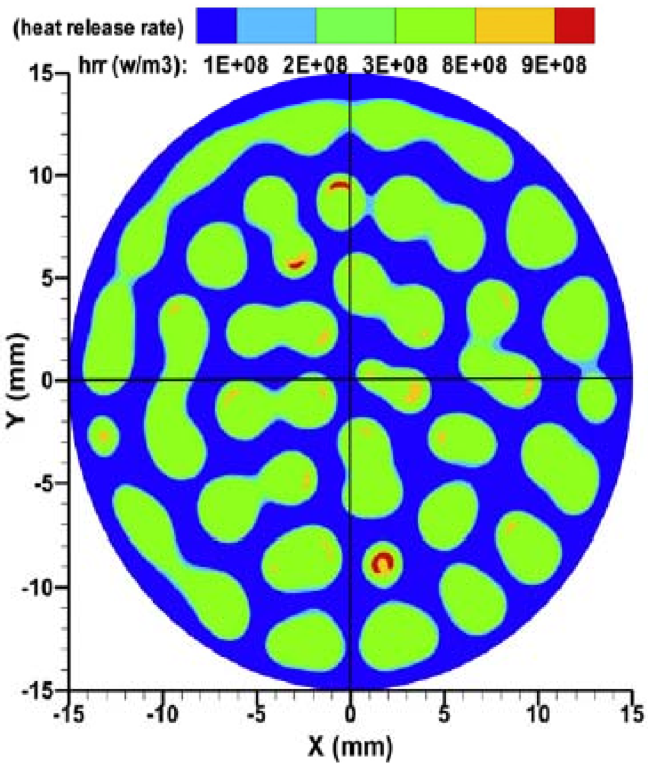
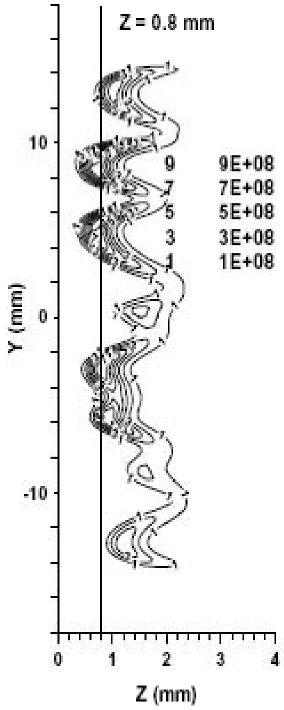


Fig. 13. Temperature contours in YZ plane showing that flat flame stabilized over porous burner plate.

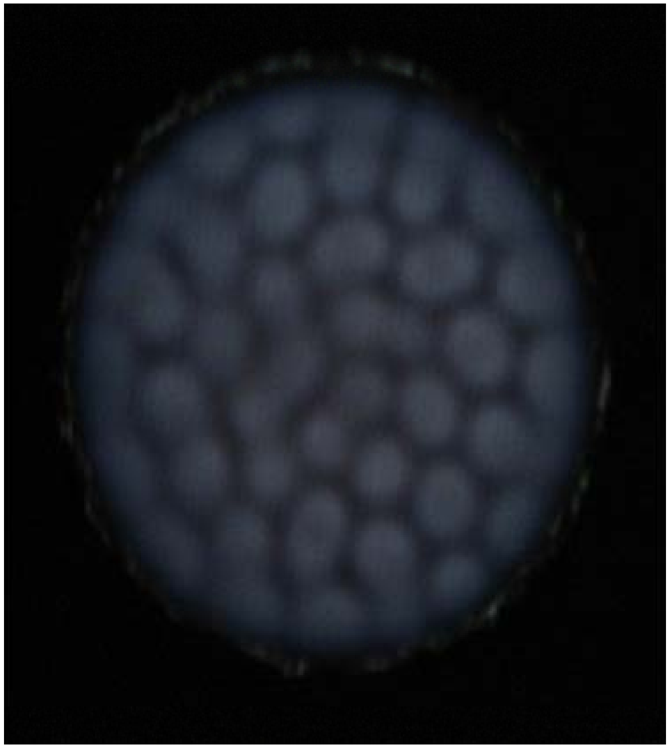
H_2-25%, CO-25%, CO_2-50%-air mixture, equivalence ratio 1.8



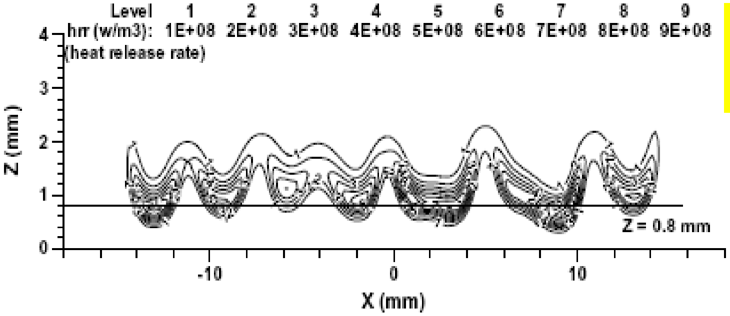
(a) at Z = 0.8 mm



(b) Y-Z plane at X = 0.0 mm



(c) ϕ =0.6

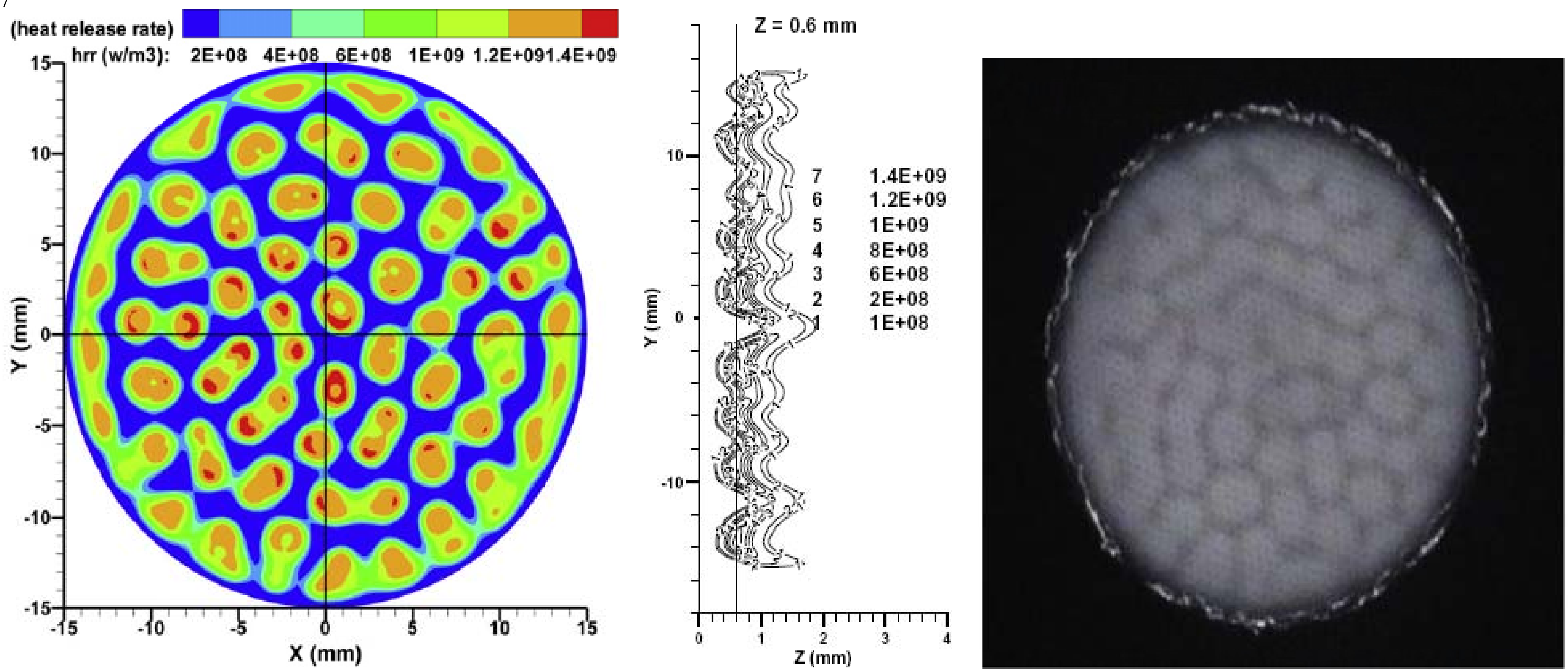


(d) X-Z plane at Y = 0.0 mm

Volumetric heat release rate contours

$\phi = 0.6$

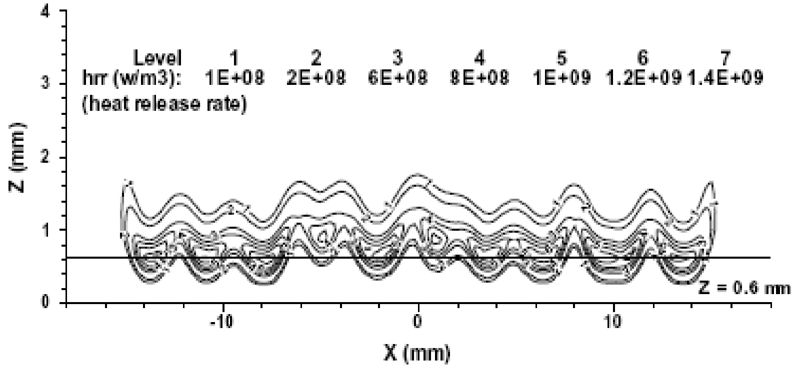
H_2-25%, CO-25%, CO_2-50%-air mixture



(a) at Z = 0.6 mm

(b) Y-Z plane at X = 0.0 mm

(c) ϕ =0.8



(d) X-Z plane at Y = 0.0 mm

$\phi = 0.8$

Percentage extinction area is less in this case

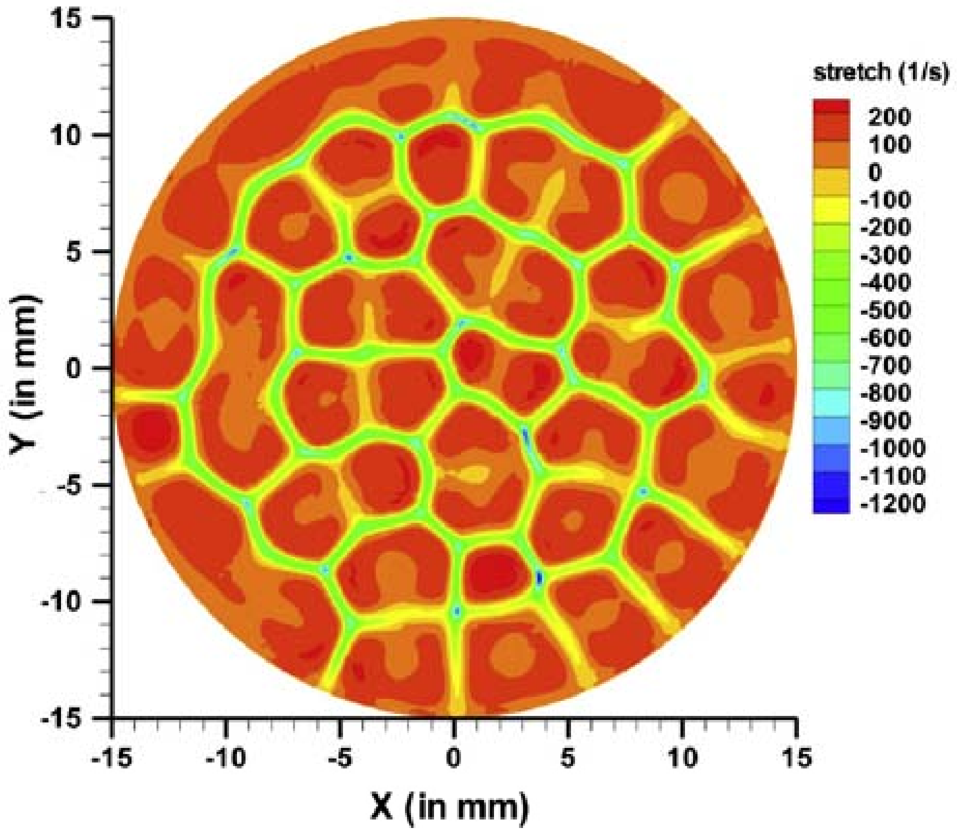


Fig. 17. Stretch rate on the 400 K isotherm of H_2 (25%)–CO (25%)–CO_2 (50%)–air flame for $\phi = 0.6$.

Extinction regions exhibit negative stretch and in the brightly burning regions, stretch is positive.

Summary

- Cellular flame structures were observed for lean mixtures when the H_2:CO ratio was 1:1 or 4:1, for all CO_2 dilution levels studied.
- Three-dimensional CFD simulations predict the cell count very well.
- Volumetric heat release rate was used to identify cells in simulations.
- Computed stretch rates were positive in the regions of intense burning and negative in the regions of low heat release rates.
- Various reaction rates and species consumption rates were analyzed in different regions of cellular flames to understand these flames better.

The team

- The work was done by Dr V Ratna Kishore (his PhD work)
- Co-workers: M R Ravi and Anjan Ray

Adiabatic burning velocity and cellular flame characteristics of H_2–CO–CO_2–air mixtures, V Ratna Kishore, M R Ravi and Anjan Ray, Combustion and Flame, volume 158, issue 11, pages 2149-2164.

Work in progress

- Burning velocity for natural gas-air, biogas-air mixtures
- Attempt to understand how best to extend the range of AULBV values measurable by this method.

Thank you!