Flame Stabilization Aerodynamics and Emissions Performance at Stratified or Fully Premixed Inlet Mixture Conditions

by

G. Paterakis, K. Souflas, E. Dogkas and P. Koutmos*

Laboratory of Applied Thermodynamics,
Dept. of Mechanical Engineering and Aeronautics,
University of Patras, Greece

email: koutmos@mech.upatras.gr

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Introduction

- Lean premixed combustion is a popular concept for cleaner and controllable power generation over a range of applications.

- Partially premixed or stratified inlet mixture conditions expand the usefulness of the fully premixed ultra-lean concept.

- Studies of burner characteristics under ultra-lean and limiting flame operation in these conditions allow for a useful assessment of performance criteria in the critical evaluation of these configurations.

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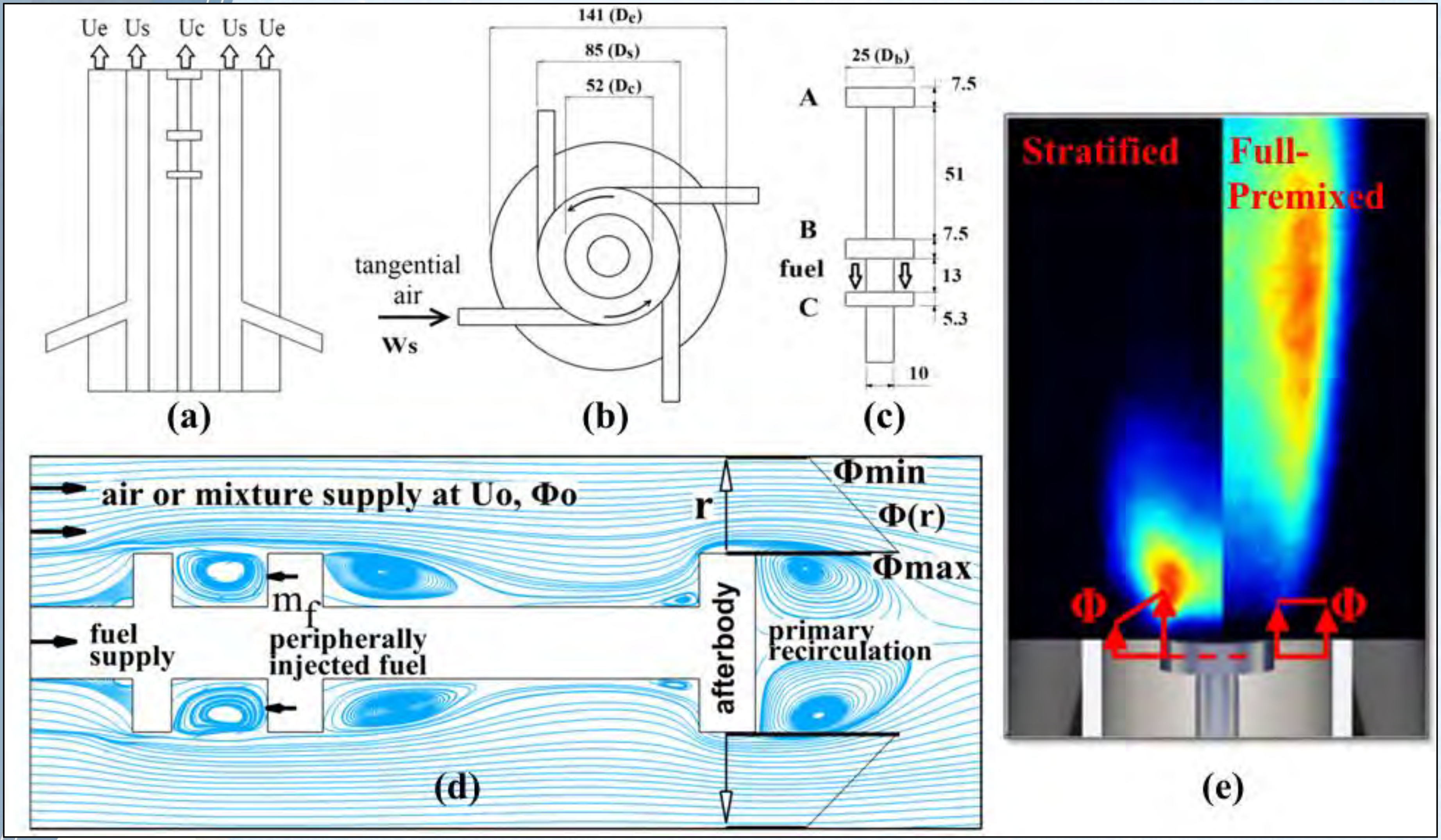
Aims of the Research

- This ongoing work investigates the differences and similarities between *fully-premixed* and *stratified* lean propane flames.
- Axisymmetric bluff-body stabilization is exploited for the *experimental and computational* evaluation of the impact of such variations in inlet mixture conditions.

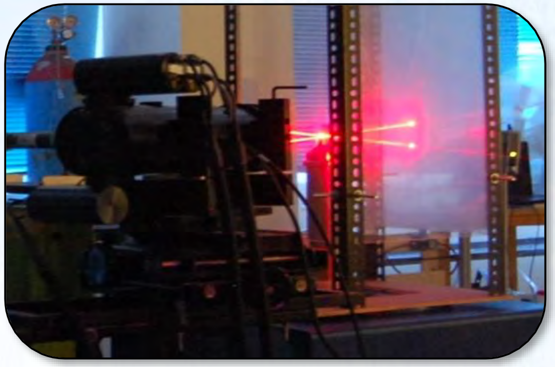
- ***Objectives:***
  - provide insight into the behavior of the two studied configurations at ultra-lean conditions.
  - identify individual characteristics of each limiting flame set up close to Lean Blow-Off (LBO).
  - determine suitable methodologies to extend operational stability, tailored for the particular flame topology.

Experimental Rig



Experimental Methodology

Chemiluminescence imaging system (LaVision®)

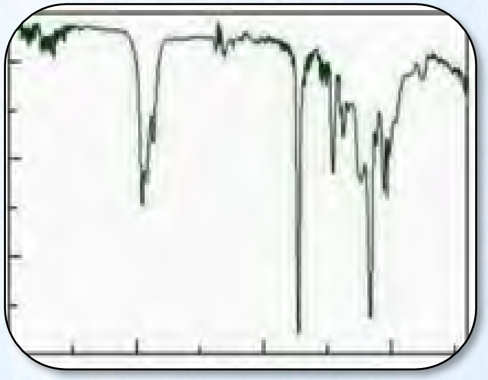


2-component TSI® Laser Doppler Velocimetry system.

3-D Particle Image Velocimetry (LaVision®)

Mass flow controllers, Bronkhorst MV-304/306 High-Tech

Gas analyzer Kane-MayKM9106 Quintox



FTIR and gas analysis instrumentation (Perkin Elmer®).

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Simulation Methodology

- The software (Ansys 16, ANSYS Inc.) was employed to benefit from its mesh adaption flexibility in the complex premixer/injector/stabilizer system.

- The Thickened Flame Model (TFM) was adopted to treat turbulence/chemistry interactions.

- A 10-species propane oxidation mechanism was employed to represent the local chemistry.

- The ISAT algorithm was used for the estimation of the reaction rate source terms.

Numerical Details

- Central differencing was used for all equations and the SIMPLE algorithm was utilized for pressure-velocity coupling.

- Subgrades scale fluctuations were modelled with the dynamic Smagorinsky turbulence model.

- Statistical moments of v, p, T and Y_i were sampled for six flow through-times. Quality Index, $QI=k_{resolved}/(k_{resolved}+k_{sgs})\approx 90\%$ for the finer mesh, 1.2Mcells.

- The simulations included the premixer cavity system and extended up to $15D_b$ downstream of the disk burner.

Flame Configurations Studied

Case	δ*(%)	L_R/D_b	Φ_{GLOBAL}	P (kW)
Swirl		0.00	0.00	0.00
IS	0	0.8	-	0
Stratified Conditions				
(S)LS	51	1.06	0.285	9.28
(S)US	24	1.32	0.234	7.62
(S)BS	7	1.56	0.200	6.57
Fully Premixed Conditions				
PLS	51	1.78	1.04	35.48
PUS	24	1.71	0.86	29.13
PBS	7	1.70	0.74	25.14

*δ is percent deviation from LBO (Lean Blow Off).

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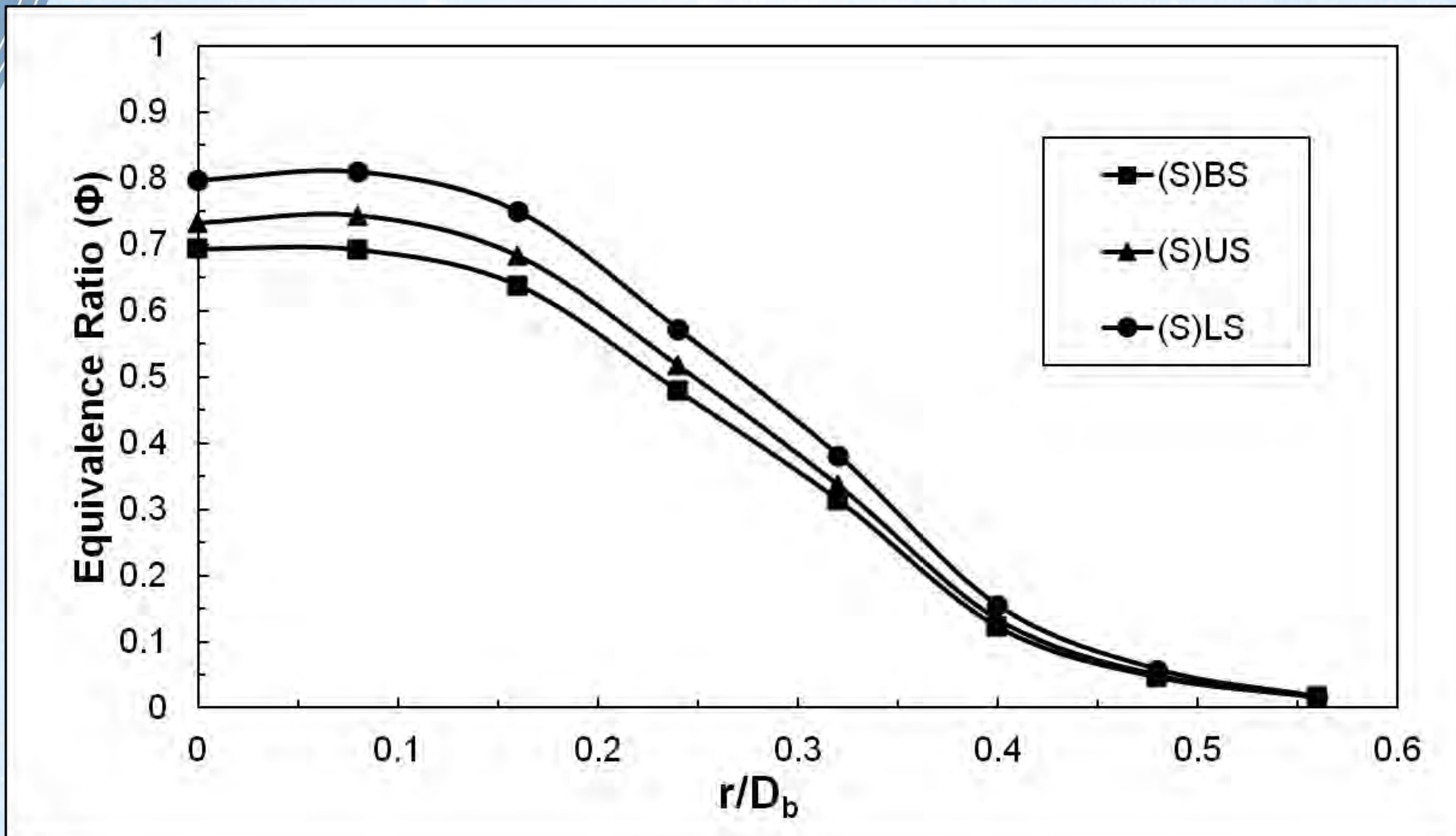
Flame Configurations Studied

Case	δ*(%)	L_R/D_b	Φ $_{GLOBAL}$	P (kW)
Swirl		0.00	0.00	0.00
IS	0	0.8	-	0
		Stratified Conditions		
(S)LS	51	1.06	0.285	9.28
(S				2
(S				7
P				8
PUS	24	1.71	0.86	29.13
PBS	7	1.70	0.74	25.14

$$\frac{\Phi_{\text{GLOBAL @ BLOW OFF, FULLY PREMIXED}}}{\Phi_{\text{GLOBAL @ BLOW OFF, STRATIFIED}}} \approx 3$$

*δ is percent deviation from Lean Blow Off.

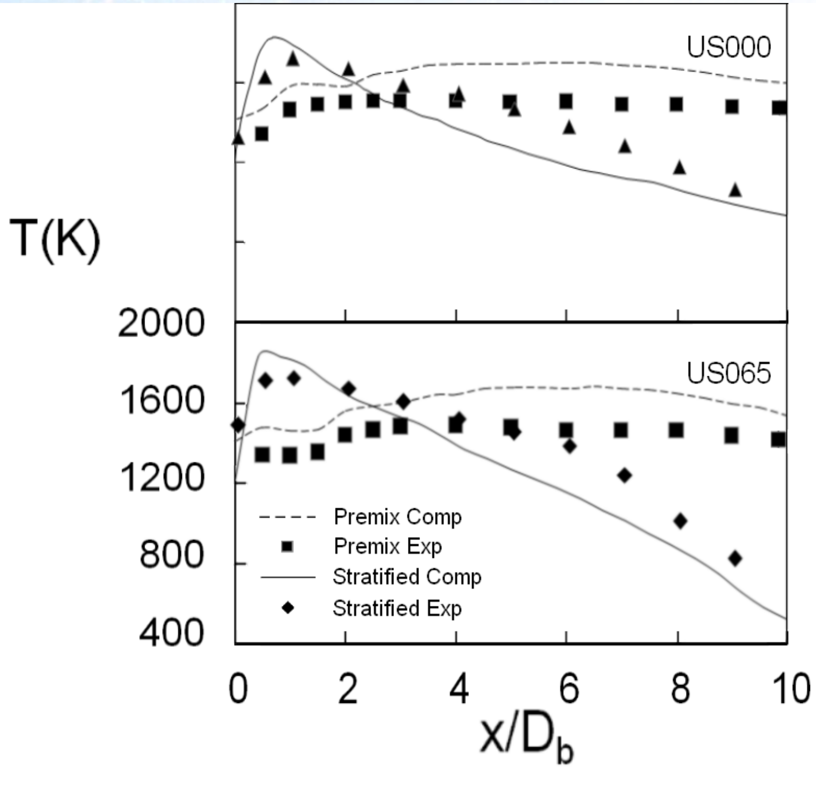
Inlet Mixture Stratification Profiles (S=0)

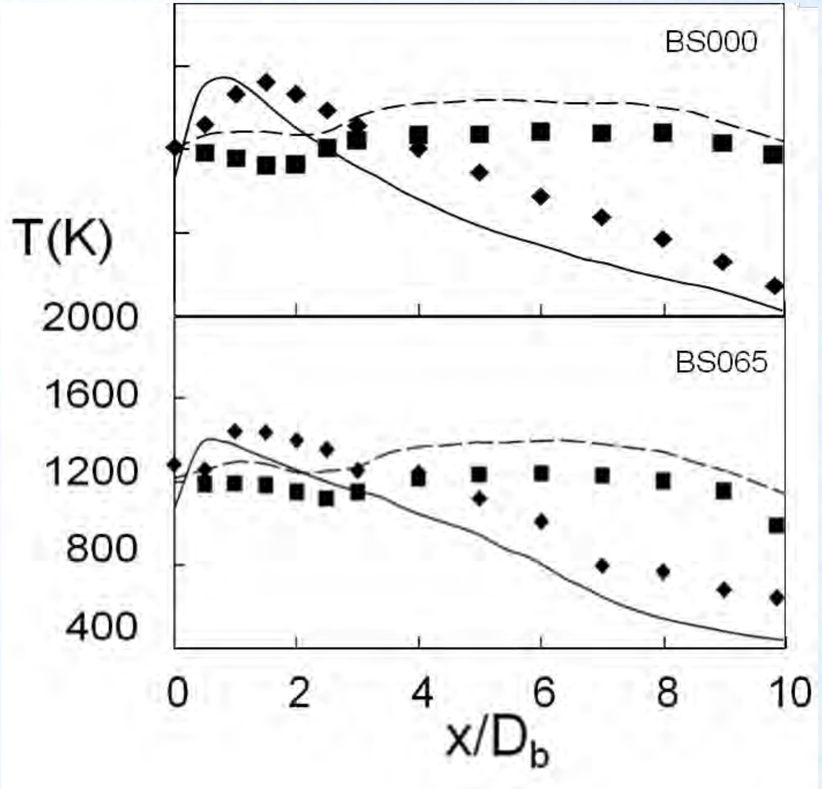


- Measured inlet mixture stratification profiles for various lean overall conditions

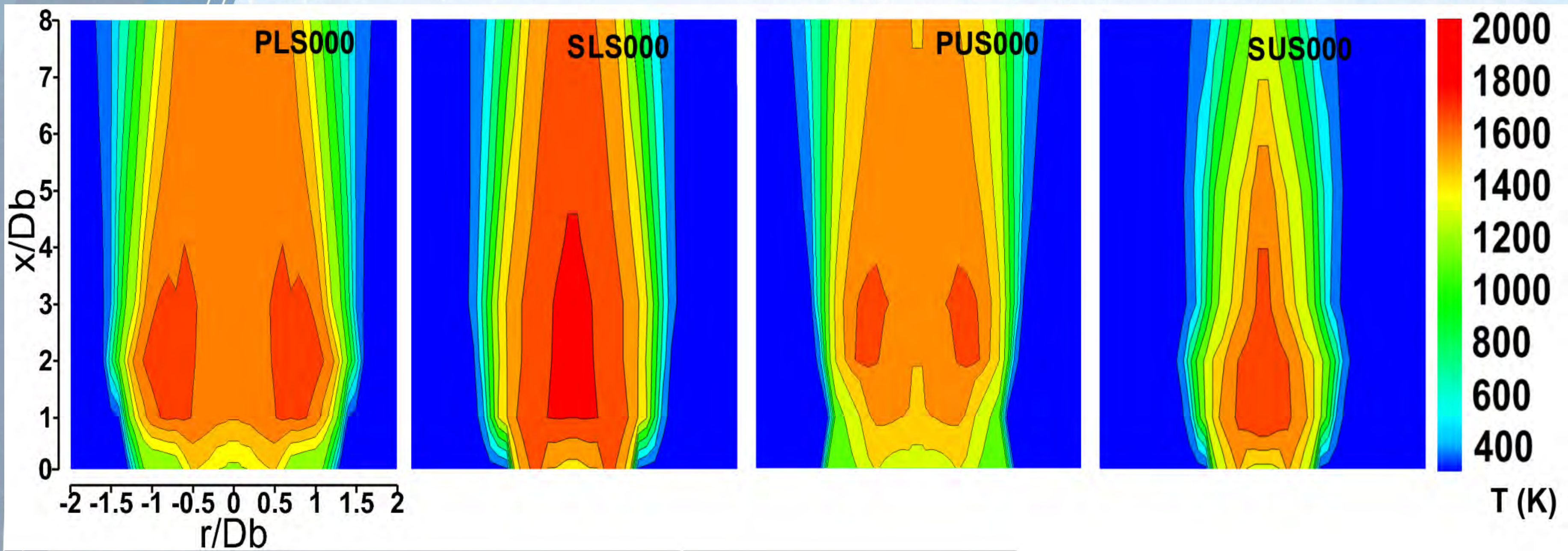
Center-line Temperatures

Comparisons between measurements and simulations of center-line temperature distributions for the premixed and stratified configurations at Swirl=0 and 0.65



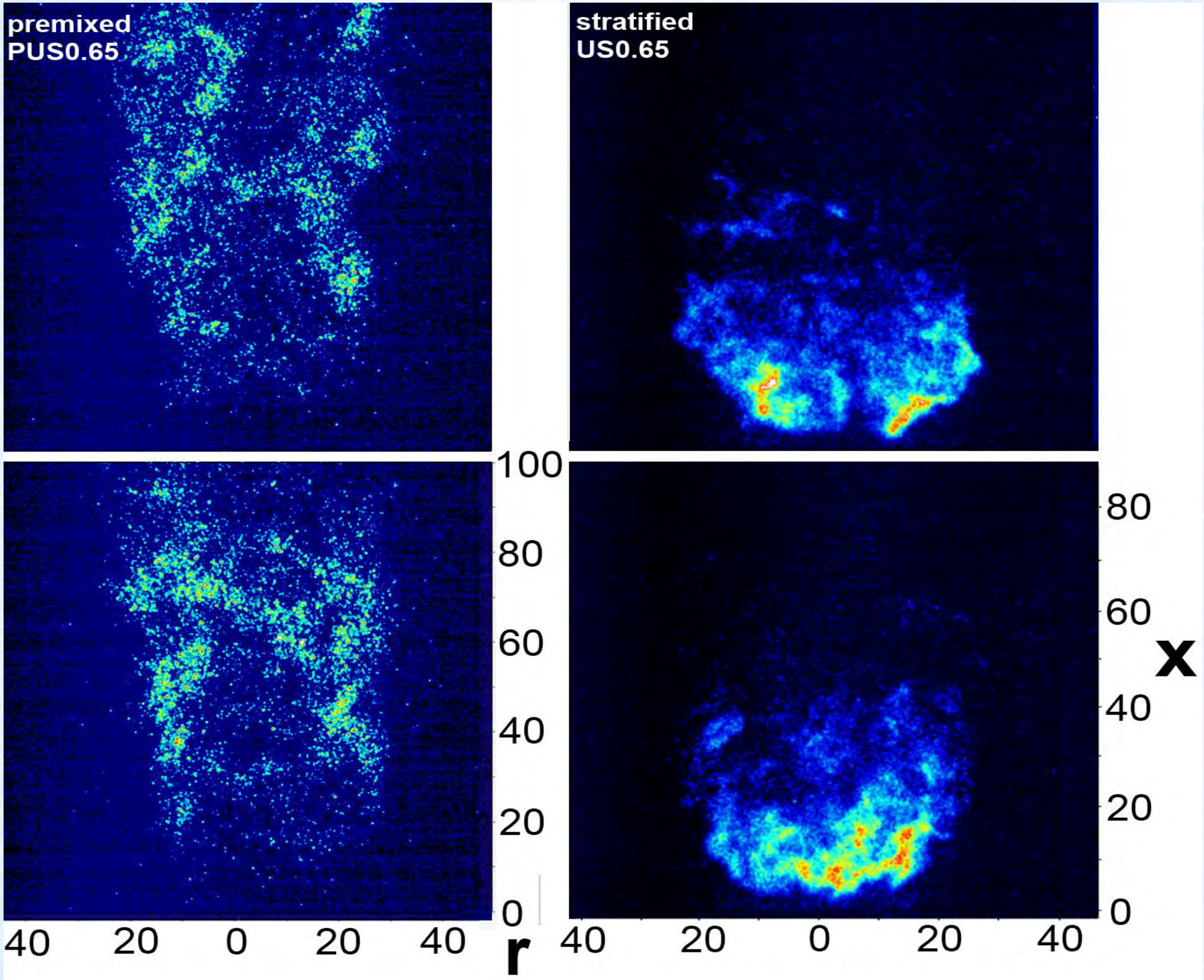


Temperature Distributions

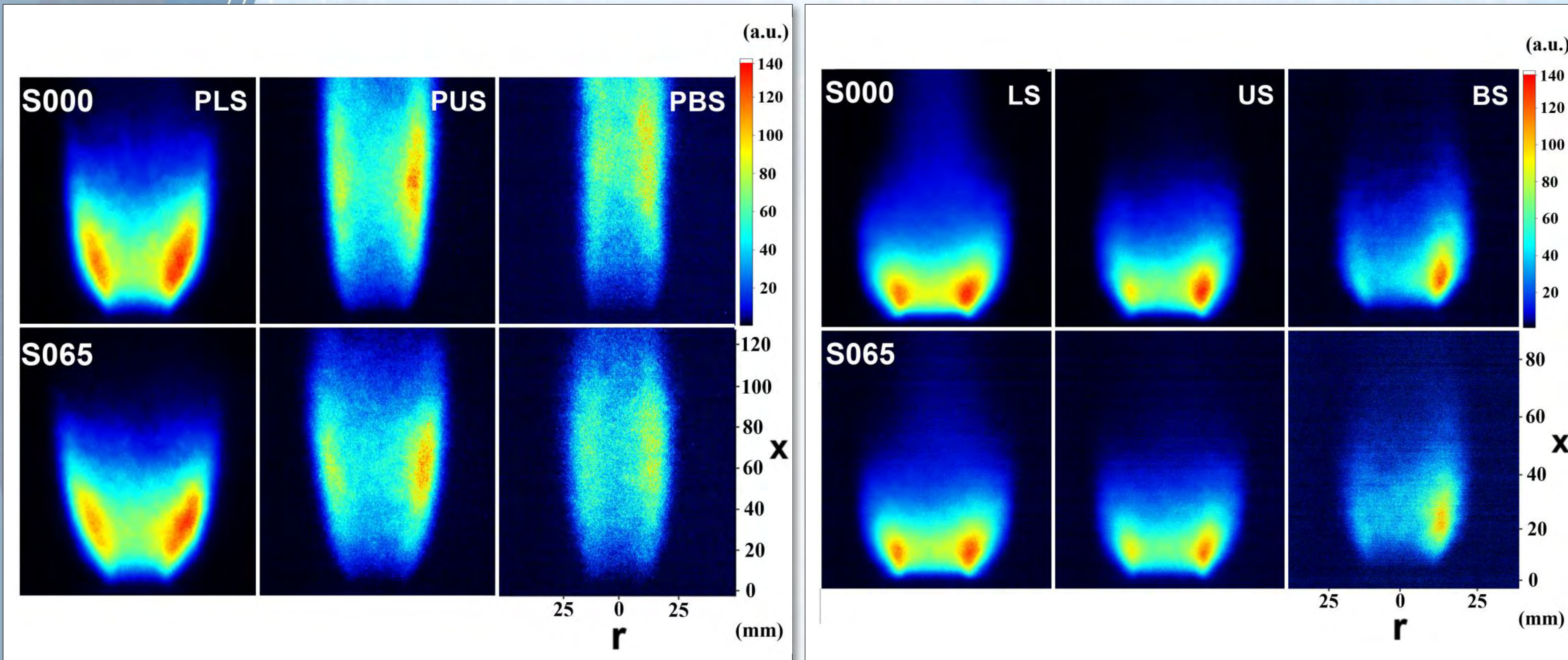


- Premixed plots exhibit localized regions of maximum temperatures extending from the burner face to the shear layers emanating from the afterbody disk rim.
- The stratified flames are shorter and narrower with similar temperature levels that are distributed more uniformly closer to the axis region

Instantaneous CH* Images,
PUS (Φ_{Global} =0.86) - (S)US065 (Φ_{Global} =0.234) Cases



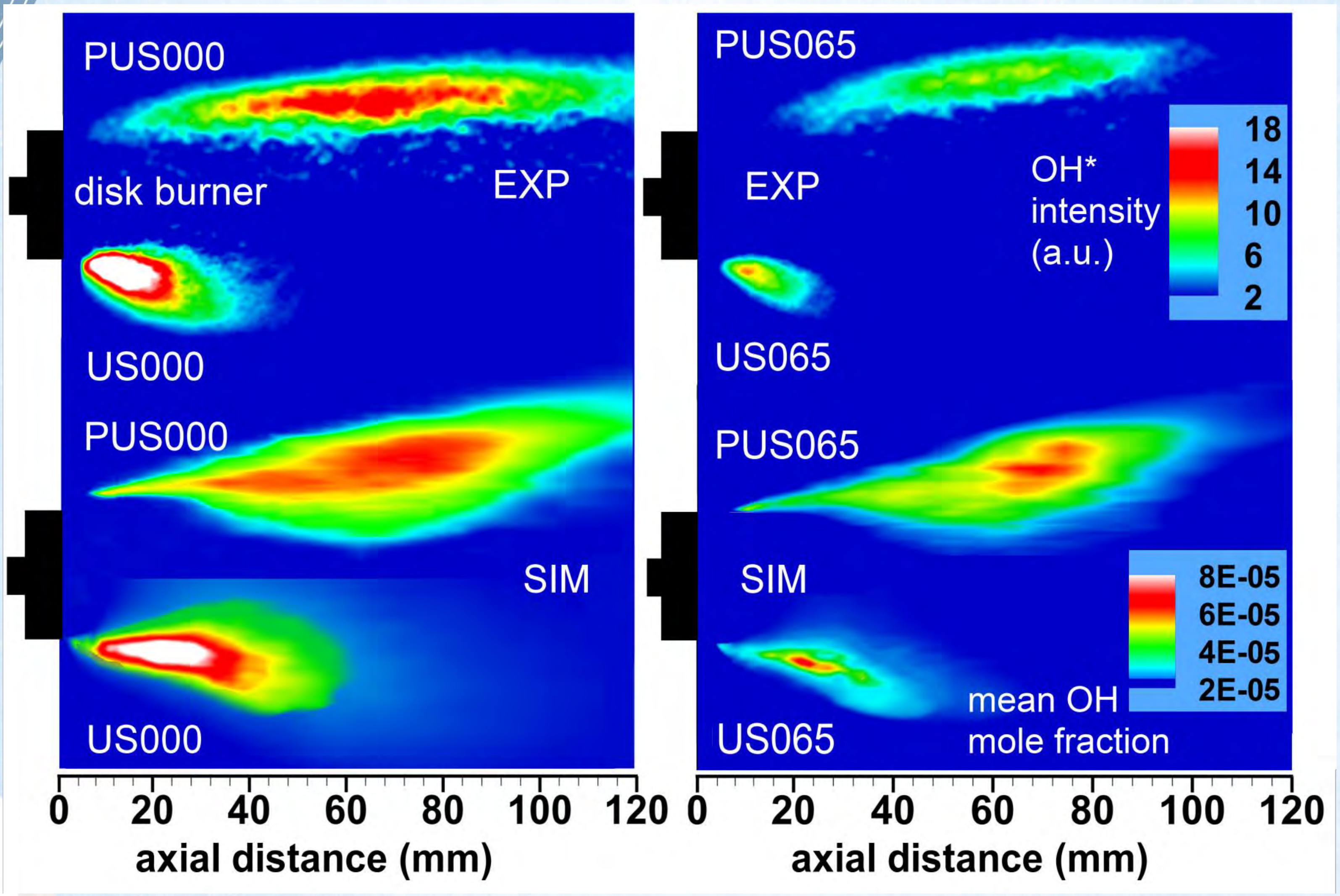
OH* Flame Chemiluminescence Images



(without Abel transform)

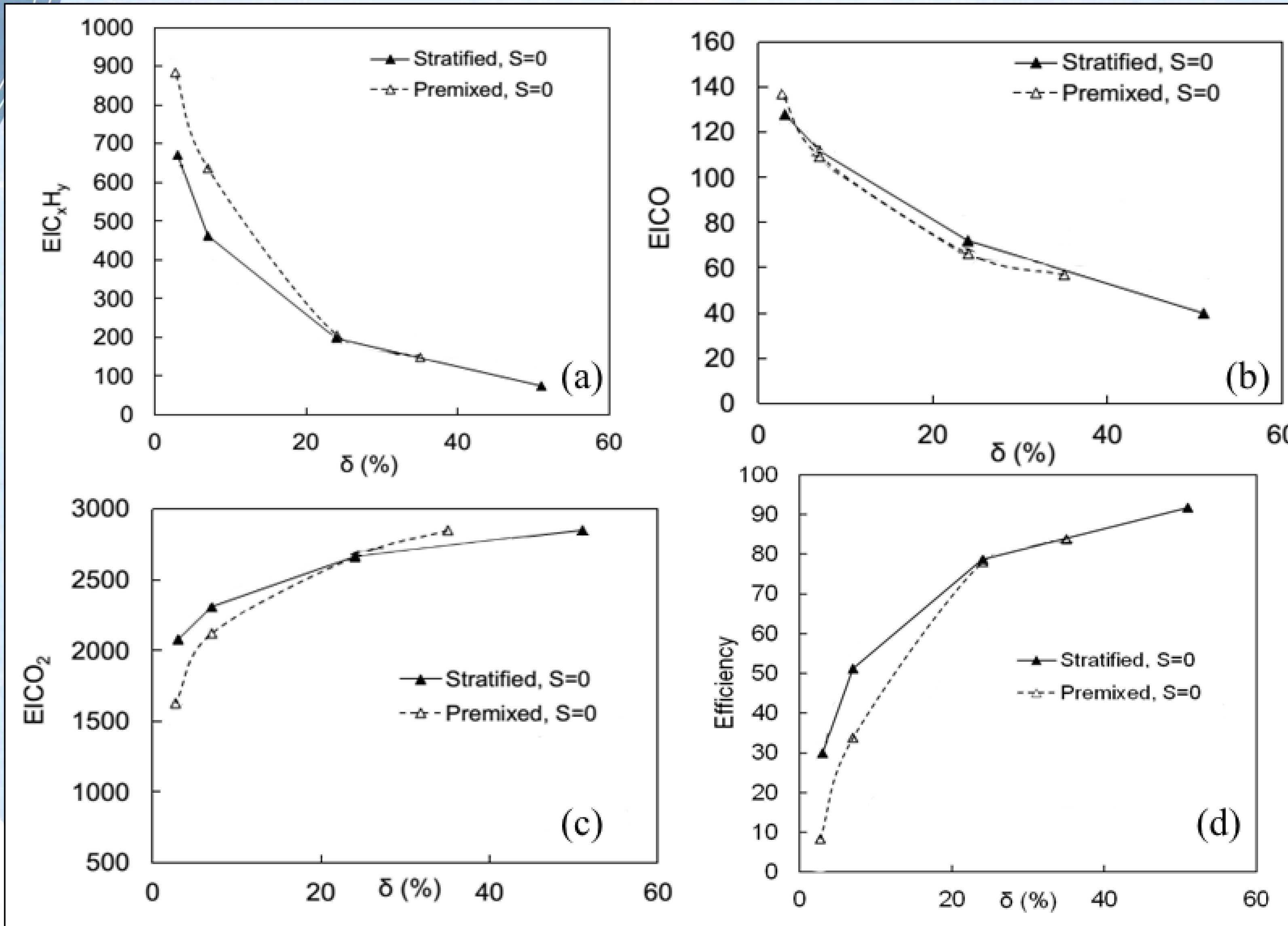
- The OH* emitting region can be considered as an indicator of the flame front placement in the flanks of the stabilizing near wake toroidal recirculation.

OH* Emissions Compared Against Simulated OH Mole Fraction Fields



(after Abel transform)

Distributions of the Emission Indices & Combustion Efficiencies



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Summary and Conclusions

- Inlet stratification promoted a somewhat wider LBO margin compared to the fully premixed configuration for the same *global* Φ.
- The chemiluminescence images suggested that stratification produced an overall more compact, frustrum shaped flame, well attached to the burner face and less sensitive to fuel variations.
- The stratified set up maintained higher efficiency levels over the lean operational range.
- Closing to LBO the present stratified set-ups, exhibited features similar to both non-premixed and fully premixed flames, i.e. flame front lift-off from the burner rim and merging of its aft end toward the axis respectively. These aspects have been considered important identifying trends when studying limiting LBO behavior.

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Thank you for your attention

Contact person :

Koutmos Panayiotis, Dipl. Eng., DIC, PhD

Associate Professor, Director, Laboratory of Applied Thermodynamics,
Department of Mechanical Engineering and Aeronautics,
Division of Energy, Environment and Aeronautics,
University of Patras, Patras, Greece 26 504
Tel: (+30) **2610 997244,** (+30) **6972894481**
koutmos@mech.upatras.gr **www.lat.upatras.gr**

10-step Global Scheme for C_3H_8-air

Rxn 1: $C_3H_8 + O + 2OH \rightarrow C_2H_2 + CO + 2H_2O + H_2 + 2H$

Rxn 2: $CO + OH \leftrightarrow CO_2 + H$

Rxn 3: $H_2 + OH \leftrightarrow H_2O + H$

Rxn 4: $2H + M_4 \rightarrow H_2$

Rxn 5: $C_2H_2 + O_2 \rightarrow 2CO + H_2$

Rxn 6: $2O + M_9 \leftrightarrow O_2$

Rxn 7: $O + H_2 \leftrightarrow OH + H$

Rxn 8: $H + O_2 \leftrightarrow OH + O$

(calibrated in laminar 1-D opposed jet, partially premixed and 2-D lifted jet flames and may include global thermal, N_2O and prompt contributions).