Experimental Investigation of cold mixing and flame stabilization Downstream of a Disk Stabilizer Under Variable fuel-air inlet mixture conditions

G. Paterakis, G. Z. Karamountzou, P. Koutmos

Laboratory of Applied Thermodynamics, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras, Rio-Patras, Greece.

Abstract

In the present work the characteristics of isothermal and reacting turbulent flow fields, downstream of a double-cavity premixer/disk burner configuration, are presented. Measurements of turbulent flow and scalar mixing fields were obtained to delineate the impact of management and optimization of the inlet fuel-air mixture profile on the stabilization and mixing performance of disk stabilized flames. The findings provide useful design information, regarding the suitable deployment of different inlet fuel-air mixing topologies aiming improvement stability and emissions.

Keywords: stratified flames, full-premixed flames, PIV, scalar mixing, bluff-body, isothermal flow field

Introduction

The evolution of advanced power generation and transportation systems is closely dependent on improved energy efficiency and reduced emission levels [1]. These targets can only be achieved through rigorous testing and evaluation of innovative combustor concepts under well controlled laboratory conditions [2]. As the projected future engine cycle is expected to lead to combustor operation closer to the lean stability limit, partially-premixed or stratified combustion concepts have been investigated as alternatives to the lean fully-premixed concept. These technologies are anticipated to improve flashback, instability, emissions, fuel flexibility and efficiency of the fully premixed combustion operation [3, 4]. A more effective control of the spatial mixture variation offers added flexibility to the design and operation of the combustion zone [7] through optimization flame anchoring, heat transfer, stability and emissions.

Therefore, the successful adaption and exploitation of partially premixed combustion technology into current industrial burners requires thorough understanding of the turbulent fuel air mixing within the primary zone. As a first step in the effort to delineate optimum conditions amongst the multiplicity of possible arrangements, isothermal mixing flow studies are conveniently undertaken to ensure cost-effective and safe design projections to reacting cases. Such an approach becomes more desirable when added complexities such as e.g. near LBO operation are introduced and then require a clearer exposition of the intricacies between fully premixed, partially premixed and stratified combustion.

Few works have addressed and compared the behavior of stratified flames to those of premixed flames close to extinction. This work aims to perform a comparative examination of the turbulent characteristics of stratified versus fully-premixed flame stabilization in axisymmetric bluff-body arrangement over a wide range of inlet mixture conditions. The impact of the characteristics of inlet equivalence ratio gradient conditions into the baffle stabilization zone, representing either fully-premixed (FPR) or stratified (STR) flame formation set-ups, has been measured and compared under reacting and non-reacting conditions.

<u>corresponding author</u>: *Georgios Paterakis, paterakis.gio@gmail.com*

Results and discussion

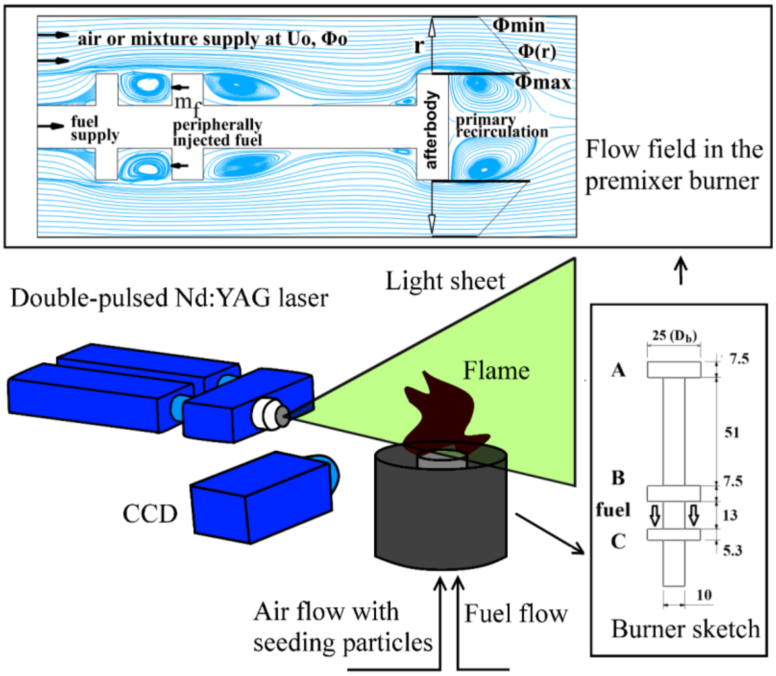

Figure 1: Experimental apparatus

In Figure 1 the combustion tunnel and the studied burner are showed, which are similar to those reported in [8]. The premixer/burner configuration consists of three axisymmetric baffles ("A", "B", "C") connected along their axis with a vertical hollow tube of 10mm diameter. In all examined cases the B and C baffles have disk shape of 25mm diameter and 7.5 and 5.3 mm width respectively. In the stratified cases, fuel was injected by disk "B" through an annular 1mm slot into the first fuel-air mixing cavity. The second cavity was designed to avoid flashback, to promote further fuel-air mixing and to produce a radially stratified equivalence ratio gradient appropriately regulated both via the central mixture supply and the primary cavity fuel injection at the exit plane. On the other hand, in the fully premixed cases, the central tube (Dc=0.052 m) could supply a uniform mixture of fuel and air. At the afterbody recirculation region either fully premixed or stratified flames could be stabilized. A sketch of the simulated flow streamlines within this cavity premixer burner system together with the possible placement of the fuel supplies and injection positions are illustrated in the Figure 1.

Figures 2 a and b provide a picture of the overall mixing patterns established under STR or FPR operation in the form of representative instantaneous photographic snapshots of Mie-scattering visualization for each inlet mixture condition respectively at two representative cases D-BR023-RIM2-D0%. These have been obtained through seeding the fuel supply in each case with olive oil droplets and passing the thin laser sheet via the window of interest. From the above snapshots the variations obtained for the different inlet mixture conditions is quite evident regarding the dispersion and the placement of the fuel along the near wake.

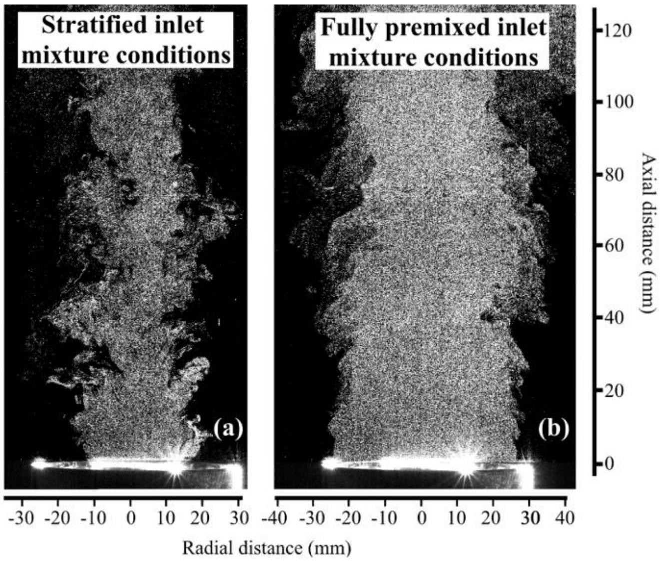

Figure 2: Mie-scattering visualization of the fuel-air mixing for STR and FPR inlet mixture conditions for case D-BR023-RIM2-D0%.

The entrainment features in each case are also different as evidenced by the deeper excursions of leaner mixture vortices into the richer fuel-air layer in the vicinity of the stabilization region along the afterbody rim in the case of the STR arrangement. On the other hand, intense mixing and vortex roll up appears at the edges of the uniform annular mixture body away distant from the stabilization region.

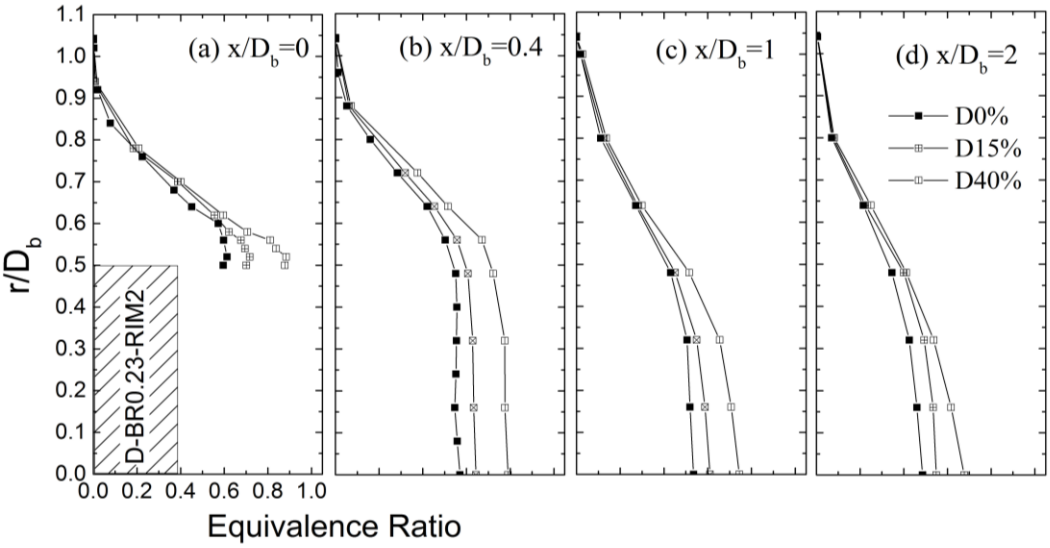

Figure 3: Transverse scalar mixing for various inlet fuel conditions under stratified mode for D-BR023-RIM2

Figure 3 presents fuel-air mixture radial distributions at various axial locations for case D-BR023-RIM2. At $x/D_b=0$ (exit plane), there is an almost linear relationship between Φ peak values and inlet fuel-air levels. Specifically, for d=0%, 15% and 40% the corresponding Φ peak values are 0.61, 0.71, 0.88. Similar behavior is observed for all measurement stations. At $x/D_b=0.4$, inside the recirculation zone, the level of Φ is close to Φ peak values at exit profile.

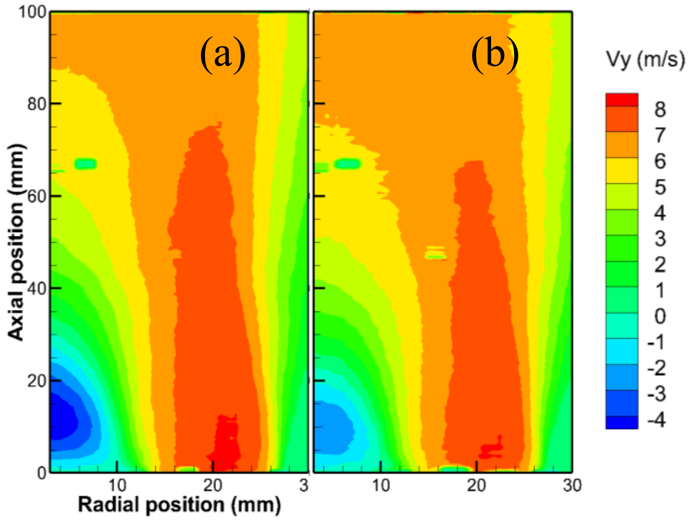

Figure 4: Axial velocities of a) FPR-D-BR0.23-RIM2-d5% and b) STR-D-BR0.23-RIM2-d5%

In Figure 4, axial velocities of cases FPR-D-BR0.23-RIM2-d5% and STR-D-BR0.23-RIM2-d5% are presented. These graphs clarify individual near wake flame disposition and flame anchoring topologies and may help determine possible strategies to extend operational margin though inlet mixture stratification.

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