Investigation of disk stabilized propane flames operated under stratified and vitiated inlet mixture conditions.

K. Souflas, G. Paterakis, P. Koutmos
Laboratory of Applied Thermodynamics,
Department of Mechanical Engineering and Aeronautics,
University of Patras, Patras, 26504, Greece

A significant increase in Global energy consumption has been forecasted for the next two decades [1] and as a result, the levels of carbon dioxide and nitrogen oxide released into the environment are expected to increase accordingly.

Lean premixed operation is one combustion technology that offers the potential for lower soot emissions as well as an improved trade-off in CO/NO_x production [2]. However, there are several drawbacks in the use of lean premixed flames, i.e., autoignition, flashback and flame instability (lean blowout-LBO and oscillations), particularly if a wide operational margin is required [3,4]. Recently combustion methodologies based on partially premixing and stratifying the reactive mixture have emerged as promising methodologies to alleviate these limitations in the effort to expand the usefulness of the lean fully premixed concept [e.g 5-8] .

The high temperature air combustion with vitiated air has been developed concurrently and has provided an environmentally friendly combustion technique to alleviate many issues regarding the challenge of promoting stable, efficient and clean combustion at limiting ultra-lean conditions. [9-10]. Vitiation is generally achieved through recirculating exhaust gases (EGR) into the oxidizing air raising its preheat and reducing its oxygen concentration. This has been shown to promote ultra-lean operation, significant energy savings, reduced pollution and equipment size, and uniform thermal characteristics within the combustion chamber .

The impact of a combination of these new combustion technologies, e.g. HiTAC under inlet mixture stratification, on critical flame characteristics such as flame front anchoring, stability margin, heat release topology and emissions performance has not been addressed extensively so far. Therefore, further investigations over a range of stabilization configurations, inlet mixture profiles and preheat conditions is warranted.

Within the above context the aim of the present work is to study the performance characteristics of stratified propane flames operated under preheated/vitiated oxidizing air. Mixture conditioning is established through staged premixing of propane with preheated/vitiated air in an axisymmetric double cavity arrangement . The adopted conditioning premixer configuration allows flames to stabilize on the afterbody disk under both stratified and vitiated conditions. This is a novel configuration promoting the exploitation of mixture stratification within the context of a HiTAC configuration. Managing inlet mixture distribution, and simultaneously regulating the preheat and vitiation profiles may offer additional flexibility in terms of better control of flame stability and emissions.

The impact of selected inlet equivalence ratio gradients and levels of preheat and vitiation on the stabilization performance and flame structure and topology has been studied for stoichiometric and lean flame conditions. Measurements of mean axial velocities, temperatures, chemiluminescence images of OH* and CH*, flame front visualization and gas sampling analysis (FTIR) provided information for the studied flames. The combined methodology provided some information regarding the variations in the toroidal flame front anchoring and stabilization and the impact of heat release disposition on the axisymmetric wake development under the variable inlet fuel-air mixture profiles.

K. Souflas, e-mail:souflaskonstantinos@gmail.com

The study illustrates some aspects regarding the influence of the preheated/vitiated conditions on the combustion of the inlet stratified fuel-air mixture profile, with respect to flame front stabilization, disposition and burner emissions. Some important differences in the vitiated flame structure and topology are discussed in comparison to the un-vitiated case characteristics, in an effort to establish the possible advantages or disadvantages of incorporating preheat and vitiation in stratified operation for the specific bluff-body configuration.

References

[1] International Energy Agency (IEA). “A 26-member-states policy-advice cooperative agency.” <www.iea.org>.
[2] Dunn-Rankin, D., Miyasato, M. M. and Pham, T. K. (2008) “Introduction and perspectives”, Lean Combustion: Technology and Control, *Academic Press, Elsevier*, BSN, 1-18.
[3] Lieuwen, T. C. and Yang, V. (2005). “Combustion Instabilities in Gas Turbine Engines: Operational Experience, Fundamental Mechanisms, and Modeling.” *Progress in Astronautics and Aeronautics, American Institute of Aeronautics and Astronautics*, Reston, VA.
[4] Stohr, M., Boxx, I., Carter, C. et al (2011). “Dynamics of lean blowout of a swirl-stabilized flame in a gas turbine model combustor.” *Proc. Combust. Inst*., 33, 2953-2960.
[5] Sweeney, M. S., Hochgreb, S., Dunn, M. J., Barlow, R. S. (2012). “The structure of turbulent stratified and premixed methane/air flames II: Swirling flows.” *Combust. Flame*, 159, 2912-2929.
[6] Tuttle, S. G., Chaudhuri, S., Kopp-Vaughan, K. M., Jensen, T. R., Cetegen, B. M., Renfro M. W., Cohen, J. M. (2013). “Lean blowoff behavior of asymmetrically-fueled bluff body-stabilized flames.” *Combust. Flame*, 160, 1677-1692.
[7] Xiouris, C. and Koutmos, P. (2012). “Fluid dynamics modelling of a stratified disk burner in swirl co-flow.” *Appl. Therm. Eng.*, 35, 60-70.
[8] Karagiannaki, C., Paterakis, G., Souflas, K., Dogkas, E., and Koutmos, P. (2014). “Performance Evaluation of a Model Swirl Burner under Premixed or Stratified Inlet Mixture Conditions." *J. Energy Eng.* , 10.1061/(ASCE)EY.1943-7897.0000242 , C4014010.
[9] Amato, A., Seitzman, J.M., Lieuwen, T.C. (2013). “Gas Turbine Emissions” *Cambridge University Press*, 209–234.
[10] Cavaliere, A., de Joannon, M. (2004). “Mild Combustion” *Progress in Energy and Combustion Science*, 30, 329-366.