Effect of Fuel-Evaporation Zone Length on Spray Combustion in a Gas Turbine Combustion Chamber

W. Ahmadi*, M. Chrigui, A. Sadiki and J. Janicka
* Department of Mechanical and Processing Engineering, Energy and Powerplant Technology, TU- Darmstadt, Petersenstr. 30, 64287, Darmstadt, Germany

Abstract

The combustion, especially in gas turbine engines, is strongly affected by the fuel preparation process. This includes the atomization of the liquid fuel, dispersion and evaporation of droplets in a fuel spray and the mixing of fuel vapor and air. As the control, design and optimization tasks are repetitive and costly and involve a large number of configuration variations, CFD may allow to carry out repetitive studies with clearly defined boundary conditions at moderate economical costs. For that purpose, accurate numerical models that need less computational costs have to be made available. This work focuses therefore on RANS-based models with the aim to use the spray module developed by Sadiki et al. [4] to study the effects of the pre-vaporization length on the entrainment, evaporation degree and combustion of kerosene sprays in a gas turbine combustion chamber.

Introduction

Engine applications can be improved by the investigation of the vaporization process as well as the mixing preparation. In this work we investigate numerically, the effect of evaporation zone length on the kerosene evaporation and combustion process. This investigation bases on a lean two phase combustion in a chamber where chemical reaction takes place far away from the injection nozzle. For the fuel kerosene a large amount of experimental research is being conducted to strive low NOx production by designing devices that permit rapid spray phase transition, mixing and combustion. Rokke [2] investigated venture LPP on mixing, atomization and evaporation behavior as well as emission. Nomura [3] studied experimentally a partially prevaporized spray burner with monodispersed ethanol droplets to investigate the interaction between fuel droplets and a flame. He investigated the effect of mean droplet diameter, and the entry length of droplets into a flame on the laminar burning velocity of partially prevaporized sprays.

Baessler et al. [1] studied the NOx emission of partially premixed vaporized kerosene spray flame at atmospheric conditions and found out that dealing with lean conditions a reduction of NOx requires a prevaporization of the kerosene spray and should pass over 50% upstream of the flame. He realized that increasing the prevaporization zone length reduce the emissions. In the present work the effect of evaporation zone length on the kerosene evaporation and its impact on the combustion process will be evaluated in comparison to experimental data of Baessler et al. [1].

Materials and Methods

The geometry of the configuration for the premixing and the partially pre-vaporization of kerosene droplets is shown in Figure 1. The burner consists of two parts: the pre-vaporization zone and the combustion tube. Within the first one, the kerosene is fed to an ultrasonic nozzle. The carrier phase (air) is heated by a set of sinter metal plates. It enters the pre-vaporization zone after being accelerated by the nozzle and it does entrain the dispersed phase.

The numerical simulation of kerosene spray combustion has been carried out on a three dimensional partially premixed prevaporized configuration. The simulations were performed using the Eulerian-Lagrangian procedure using a fully two way coupling. Prior to the NOx prediction planed in the next step the investigations were first focused on the flame temperature profile dependency with respect to the length variation of the pre-vaporization zone. The results have been analyzed and compared to the experimental data provided in [1]. To capture the temperature and flame flashback a parameter study has been performed with respect to the droplet diameter, the kerosene flammability limits, the combustion model parameters and the location of the combustion initialization. These investigations were achieved at atmospheric pressure conditions, with inlet air temperature of 90°C and a global equivalence ratio of 0.7. The droplets are being injected with a Sauter mean diameter of 50 μm. For the combustion, the conditioned progress variable approach (CPVA) based on Bray-Moss-Libby model (BML) has been adapted and used to account for the partially premixed combustion.

* Corresponding author: ahmadi@ekt.tu-darmstadt.de

Results and Discussion

In order to study the influence of the variation of the pre-vaporization zone length on the evaporation and combustion process, three simulations were performed, with the lengths L=0.6, 0.7 and 0.8[m], respectively. Experimentally the distance for the pre-vaporization was adjusted by adding tube elements that are interconnected by aluminum rings. Figure 2**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the results of the temperature profile for different pre-vaporization length "L". One observes a clear diminishing of the flame lift-off with decreasing value of "L". With a reduction of ΔL=25% the flame reduces its lift-off by Δh=0.05m. Due to the reduction of the pre-vaporization length "L", droplets have less time to survive, thus the evaporation duration is in turn reduced. In contrast the mass of kerosene droplets which arrive to the combustion tube and evaporate there increases. This phenomena influences the mixing process very strongly and a new field of mixture is obtained, namely the first part of the configuration exhibit less richer mixture whereas close to the ignition source the concentration of vapor increases and the mixture strides the flammability limit. Thus the combustion process starts earlier than the reference one (L=0.7m). It is also important to note that using shorter pre-vaporization zone the maximum temperature increases of ΔT=100K. This can be explained by the fact that the mixture in the combustion tube was slightly moved toward the stochiometric value since the amount of kerosene vapor at the second part of the configuration increased, too.

Acknowledgement

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References

[1] S. Baessler, K. Moesl and T. Sattelmayer: "NOx Emissions of a premixed partially vaporized kerosene spray flame" *J. of engeneering for gas turbine and power,* July 2007, Vol. 129 /695-702

[2] N. A. Rokke and A. J. W. Wilson Experimental and Theoretical Studies of a Novel Venturi Lean Premixed Prevaporized (LPP) Combustor *J. Eng. Gas Turbines Power* July 2001 Volume 123

[3] H. Nomura, M. Hayasaki and Y. Ujiie Effects of fine fuel droplets on a laminar flame stabilized in a partially prevaporized spray stream *Proceedings of the Combustion Institute* Volume 31, Issue 2, January 2007, Pages 2265-2272

[4] A. SADIKI, M. CHRIGUI, J. JANICKA and M.R. MANESHKARIMI *Modeling and Simulation of Effects of Turbulence on Vaporization, Mixing and Combustion of Liquid- Fuel Sprays*, *Flow*, Turbulence and Combustion 2005 **75:** 105–130

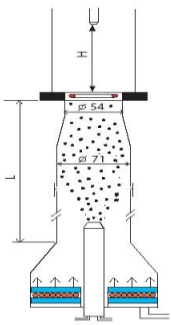

Figure 1. Geometry of the partially premixed prevaporized combustor

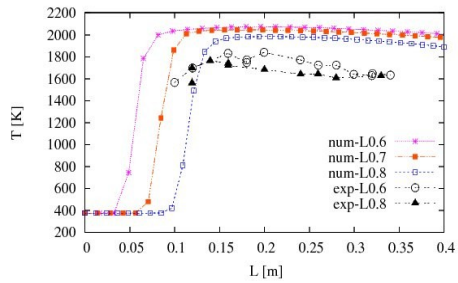

Figure 2. Temperature profiles for different lengths of the pre-vaporization zone: Comparison between experimental data and numerical results for different evaporation zone lengths