Experimental diagnostics of the flow downstream the gas turbine premixer using planar optical methods

L M Chikishev\textsuperscript{1,2}, V M Dulin\textsuperscript{1,2}, A S Lobasov\textsuperscript{1,2}, D K Sharaborin\textsuperscript{1,2},
A G Savitskii\textsuperscript{1,2}, V V Tsatsiashvili\textsuperscript{3} and V A Nazukin\textsuperscript{3}

\textsuperscript{1}Kutateladze Institute of Thermophysics, 1 Ac. Lavrentyev Avenue, Novosibirsk, 630090, Russia
\textsuperscript{2}Novosibirsk State University, 2 Pirogov Street, Novosibirsk, 630090, Russia
\textsuperscript{3}JSC “UEC-Aviadvigatel”, 93 Komsomolsky Prospect, GSP, Perm, 614990, Russia

E-mail: chlm@itp.nsc.ru

Abstract. This paper reports on experimental study of the flow in a model combustion chamber using planar optical methods. The flow was organized by model GT-premixer produced by JSC “EUC-Aviadvigatel”, Perm, Russia. The measurements were carried out in a cold flow without combustion at elevated pressure of 2 atm and air flow rate up to 0.5 kg/s. Acetone vapor was seeded to the flow as a tracer of model fuel. The distributions of local concentration were measured using planar laser-induced fluorescence approach. To measure velocity fields by particle image velocimetry technique, water-glycerol particles were introduced to the air flow. Two series of experiments were accomplished for design and off-design conditions. The pressure drop at the GT-premixer was the same for these two cases. The results for off-design conditions show that fuel concentration distribution drastically depends on the scheme of fuel supply.

1. Introduction

Fuel and air mixing is the most critical aspect for such characteristics of gas turbine combustion chamber as completeness of combustion and formation of pollutant emissions. Another important issue is thermoacoustic instabilities, caused by nonuniform fuel concentration distribution and different local equivalence ratio of the fuel-air mixture. In order to prevent such unfavorable conditions of operation of the gas turbine combustion chamber, numerical simulation of cold and hot fluid dynamics is used. For computational codes validation there is a need in reliable experimental data.

Several studies are dedicated to the numerical and experimental investigation of this issues, e.g., [1-3]. Authors from Loughborough University used water instead of air at Reynolds numbers up to 8\times10^4. Measurements of velocity field were carried out both with PIV (Particle Image Velocimetry) and LDA (Laser Doppler Anemometry). LDA was used to verify PIV data on velocity fluctuation measurements. Precessing vortex core and spiral vortices were detected. In the previous paper [4] the measurements were carried out for air flow at Reynolds numbers up to 1.4\times10^5.

The present paper is focused on the results of velocity and concentration measurements for two types of fuel supply conditions in the model combustion chamber.
2. Experimental setup
The measurements were carried out in the test rig, representing the model gas turbine combustion chamber [4]. The test rig consisted of the plenum chamber, test section with full optical access (fused silica cylinder) and outlet chamber with optical window. The test rig was oriented horizontally. The premixer produced by JSC “EUC-Aviadvigatel" (Perm, Russia) was examined (a schematic diagram is shown in Figure 1). Two series of experiments were carried out for design and off-design fuel supply conditions. The pressure inside the model combustion chamber was 2 atm. Pressure drop after the premixer was 4 %. Air mass flow rate was 437.5 g/s.

To evaluate the velocity field, water-glycerol particles were introduced to the flow. The premixer was painted black to reduce laser light reflections from the surface during PIV and PLIF (Planar Laser-Induced Fluorescence) measurements. The measurements were carried out in longitudinal axial cross-section (as shown in Figure 1). During the PIV measurements, the repetition rate of the double-pulsed Nd:YAG laser Quantel EverGreen 200 was 2 Hz with the time difference between pulses of 2 µs. The PIV signal was registered by the Bobcat ImperX 2020 camera mounted in the normal direction to the measurement plane. A thousand of double frames PIV-images was obtained. The spatial resolution of 0.056 mm/pix was achieved. The PIV recordings were processed by in-house software "Actual Flow" to obtain the mean velocity field. The interrogation area of the initial pass was set at 32×32 pixels with 50 % overlap.

The PLIF measurements were carried out using acetone vapor seeded to the flow of the model fuel. The concentration of the vapor was controlled by temperature stabilized bath at saturated pressure. PLIF measurements were done in axial and vertical cross-sections of the flow. Fourth harmonic of Nd:YAG laser Quantel Brilliant at 266 nm was used to excite fluorescence of acetone molecules. LaVision Imager Pro sCMOS camera with IRO (5 MPix) was used to measure the fluorescence signal. The laser repetition rate was set at 10 Hz. The exposure time of the camera was 200 ns. A thousand images was recorded with a spatial resolution of 0.056 mm/pix. Post processing technique algorithm included background subtraction, laser sheet correction and laser pulse energy correction.

3. Results and discussion
Figure 2 shows the distribution of the axial mean flow velocity in the axial cross-section of the model combustion chamber. It may be seen that concentration for the off-design conditions is significantly higher than for design conditions, especially for the initial region of the flow. To understand the flow structure, mean axial velocity profiles have been evaluated (see Figure 3). The velocity profiles are found to correspond to the presence of central recirculation zone and low-intensive corner recirculation zone, which are presented for both types of flow conditions. The black circles
demonstrate design conditions, while red square symbols demonstrate off-design conditions. Slight difference in the axial velocity profile could be seen for the inner mixing layer of the swirling flow. At the same time the flow velocity is slightly higher for the outer mixing layer for off-design conditions.

![Figure 2](image1.png)

**Figure 2.** Mean concentration and velocity distribution in the axial cross-section of the model combustion chamber for design (left) and off-design conditions (right).

![Figure 3](image2.png)

**Figure 3.** Mean axial velocity profiles for y/d=0.06 (a) and y/d=0.12 (b); black circles for design conditions, red squares for off-design conditions. The velocity profiles are normalized on average flow rate velocity, the coordinates are normalized on the premixer nozzle diameter.

In contrast to the velocity profile, the pronounced difference for the concentration profiles may be seen in Figure 4. The concentration is presented in arbitrary units. In the initial region of the flow near the premixer nozzle exit, the model fuel concentration is significantly higher for off-design conditions (about 1.7 times for the central region of the flow).
Conclusions
The velocity and concentration distributions at the initial region in a model combustion chamber after GT-premixer have been studied for two types of model fuel supply conditions. The flow structure has been analyzed using PIV measurements. Slight difference in the velocity profiles in the inner and outer shear layers was observed for design and off-design conditions. The model fuel concentration was measured using acetone vapor PLIF technique. The acetone PLIF approach is shown to be promising for the concentration measurements of the model fuel at realistic flow-rates and elevated pressure. The measurements have revealed strong difference in the concentration profiles for the central region of the flow. For the off-design conditions it may lead to higher fuel concentration and, consequently, higher temperature inside the recirculation zone which can cause more intense NOx formation. As it is shown, even with the same velocity profiles at the nozzle exit region, the model fuel concentration may be substantially different. The design conditions provide rapid mixing at the initial region of the flow in contrast to the off-design case.

References
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