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INVESTIGATION OF THE SPRAY GENERATED BY A Y-JET ATOMIZER

M. Mlkvik[*], M. Zaremba[**], J. Jedelský[***], G. Wigley[****]

Abstract: *The presented research is based on the application of optical diagnostics to determine the quality of a liquid fuel spray generated by a Y-type nozzle designed according to the works of Mullinger (1974) and Madsen (2006). Two non-intrusive optical measurement techniques were used to characterize the spray in terms of droplet velocity and size, PDA (Phase Doppler Anemometry), and flow structure, PIV (Particle Image Velocimetry). PDA measurements were made in the downstream region of the fully atomized spray, where uniform spherical droplets were expected. The velocity and drop size profiles were measured by PDA in a plane at a distance of 100 mm downstream from the nozzle. These velocity measurements were assumed as a reference for later comparison with the PIV flow measurements. The main application of the PIV technique was to determine the velocity field of the spray in the near nozzle region where the presence of the ligaments and large non-spherical droplets were expected. The simultaneous use of the two measurement techniques provides a more complete understanding of the fluid mechanic processes occurring in the spray. The spray quality produced by the nozzle design has been judged in terms of the Sauter mean droplet diameter and spray velocity profiles.*

Keywords: Y-jet atomizer, Spray characteristics, PDA, PIV, Sauter mean diameter.

1. Introduction

Y-jet atomizers are widely used for the atomization of the liquids in the combustion applications. The goal of the atomization is to increase the effective surface of the liquid. That means that the liquid stream must be disintegrated into small droplets. The spray quality is often evaluated using the criterion called the Sauter Mean diameter, SMD, which is the diameter of a sphere with the equivalent surface to volume ratio as a particle of interest, D_{32}. The quality of the spray from the Y-jet atomizer depends mainly on the flow in the internal mixing chamber. The relationship between the internal and external flows was studied by Song and Lee (1996). The SMD value is a dependent variable which is affected mainly by the hydraulic parameters, the geometrical parameters of the atomizer nozzle and the physical properties of the fluids. The flow in the mixing chamber can be described using the criterion, based on the hydraulic parameters, the Gas/Liquid Ratio, GLR.

2. Experimental Equipment and Methods

Experiments were conducted on a cold test bench equipped with Y-jet atomizer. The flow and spray quality were investigated by PDA and PIV.

2.1. Test bench

The Y-jet atomizers were operated on a test bench which was equipped with pressurised fuel and air supplies. The fuel supply system consisted of a pressurised fuel tank, a filter, a regulator valve and a Siemens Mass 2100 Coriolis flow meter fitted with Mass 6000 Ex Transmitter. Light heating oil (LHO) was used as the atomized liquid. Pressurised air was taken from the central compressed air supply system

[*] Ing. Marek Mlkvik, PhD.: Brno University of technology, Technická 2896/2, 616 69 Brno, CZ, mlkvik@fme.vutbr.cz
[**] Ing. Matous Zaremba: Brno University of technology, Technická 2896/2, 616 69 Brno; CZ, y116215@stud.fme.vutbr.cz
[***] Assoc. Prof. Jan Jedelský, PhD.: Brno University of technology, Technická 2896/2, 616 69 Brno; CZ, jedelsky@fme.vutbr.cz
[****] Dr. Graham Wigley: Loughborough University, LE11 3TU, United Kingdom, g.wigley@lboro.ac.uk

which provided a maximum pressure of 0.8 MPa. The air flowed through a dehumidifier and a filter into a regulator valve. Pressure sensors (BD sensors DMP 33li) and thermometers (resistance temperature sensor Omega SPRTX-S1) were mounted in both fuel and air loops.

2.2. Atomizer

The design of Y-jet atomizer was based on the findings of Mullinger (1974) and Madsen (2006). The schematic layout is shown in the following figure:

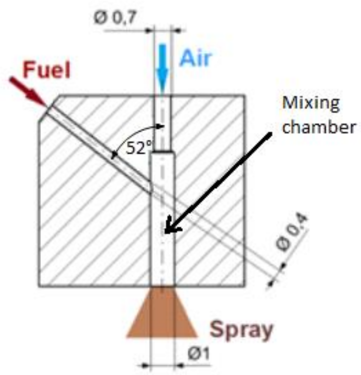

Fig. 1: Y-jet atomizer scheme.

Liquid is injected into the mixing chamber by a radial fuel port entry. Two phase flow is created inside mixing chamber and it is disintegrated when it reaches the exit orifice and expands into ambient air.

2.3. PDA system

A two component fiber based PDA system by Dantec Dynamics was used to measure velocity (in the axial and radial direction of the nozzle's main axis) and the droplet size distribution. The system consists of Spectra Physics Stabilite 2017 argon ion laser, 60X41 transmitter with Bragg cell, 60X81 2D 85 mm transmitting optics, 57X50 112 mm diameter fiber PDA receiver optics which is connected to the fiber PDA detector unit and signal is processed in BSA P80 flow and particle processor.

2.4. PIV system

A standard PIV system from TSI was used for the investigation of the flow. The illumination was provided by the New Wave Research PIV MiniLase, dual cavity Nd:YAG Laser System with attached sheet optics. The spray images were captured by the TSI PIVCAM 13-8 CCD camera. The image pairs were processed by the INSIGHT 3G software.

2.4.1. PIV measurements in spray

Atomization produced by twin fluid nozzles is driven by breakup of the initial structures i.e. ligaments and large droplets. It can be seen in the Fig. 2a, that these formations are created in regions close to the exit orifice of the nozzle and they disintegrate into smaller droplets further downstream.

From a light scattering point of view, the different liquid forms and varying droplet sizes cause problems for optical diagnostics since the amount of scattered light is related to the square of the droplet size. The differences in the scattered light intensities between the small and large droplets means that, for PIV, where the optimal droplets would be spherical with a small uniform size, the detectability of these droplets is going to be low. In the opposite situation, when the smaller droplets are made visible on the images, by increasing the camera gain, the large droplets and ligaments would be over exposed, especially in the central part of the spray which leads to complications in the image processing.

Another problem is caused by the heterogeneous distribution of the droplets. Most of the liquid mass is present in central regions of the spray, whereas, only a low amount of droplets is present in peripheral regions. The PIV system is tuned to obtain data from regions with defined range of the density of droplets. Visual data from regions where droplet density is out of this range cannot be processed by the PIV algorithm. Statistical analysis can be used to determine the distribution of the mass in spray over the long time period. The Root Mean Square (RMS) value of pixel intensity can be calculated over the set of captured images. Information about the mass distribution on the final RMS image is expressed by the intensity of each pixel. Further processing, for example, conversion of the grey-scale intensity into a colour spectrum, can help recognize regions in the spray.

If ligaments and large droplets are present in the spray, as in Fig. 2a, then small droplets cannot be captured due to the low intensity of the scattered light. Whereas, Fig. 2b demonstrates, that most of the captured droplets were in the central region of the spray. Different distribution of the mass influences the instrumental parameters of image acquisition. Hence the PIV system must be realigned for each regime.

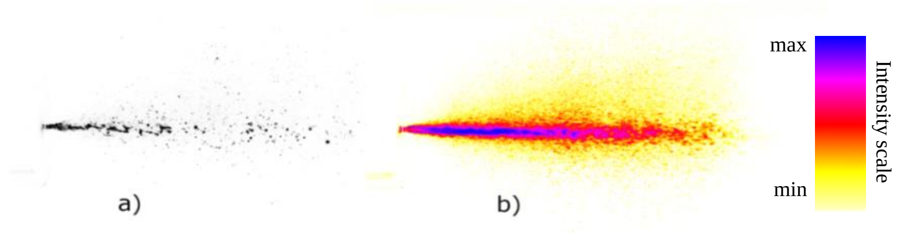

Fig. 2: Comparison of the inverted instantaneous PIV image and the RMS image created from 100 PIV double images (Δp = 0.035 MPa, GLR = 2.5%).

3. Results and Discussion

The PDA and PIV experiments were performed for eight different operating regimes. Two pressure values (0.035 and 0.07 MPa) and four values of GLR (2.5, 5, 10, 20%). The PDA results are reported, according to Jedelský (2009), with an integral value of the Sauter mean diameter (ID_{32}) which characterizes drop size distributions with one value.

As expected, higher fuel pressure leads to lower values of ID_{32} which is consistent with Madsen (2006). At low pressure regimes, fuel inside the mixing chamber has lower potential energy which leads to lower velocities and higher values of ID_{32}. As mentioned above, the nozzle performance is also dependent on GLR. An increase in GLR leads to lower values of ID_{32} which is consistent with the work of Zhou (2010).

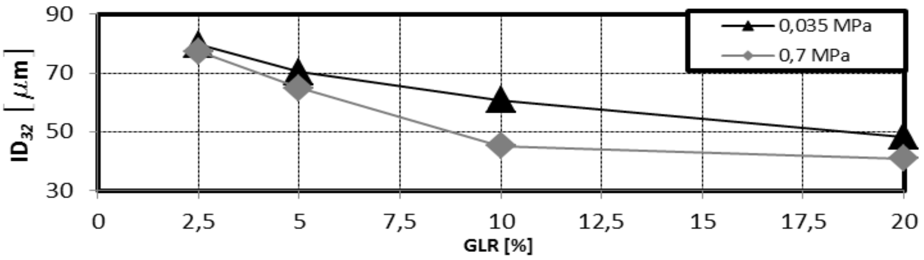

Fig. 3: Integral values of ID_{32} for different working regimes of the atomizer.

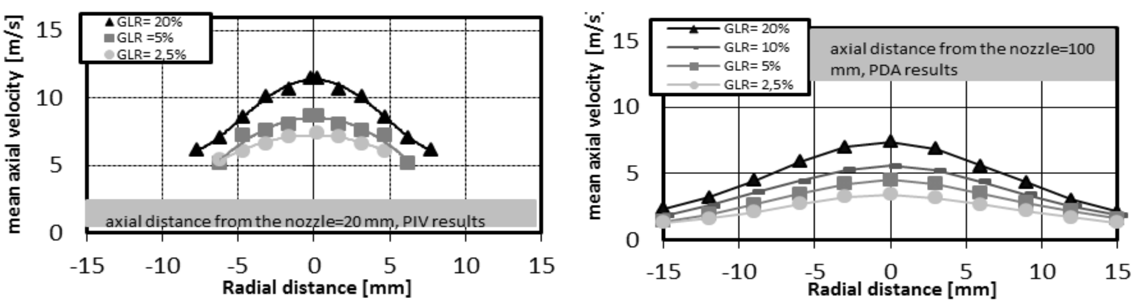

Fig. 4: Axial velocity profile at different distances from the nozzle (Δp = 0.035 MPa, measured using PIV and PDA).

The PIV measurements, presented on the left hand side in Fig. 4 and Fig. 5 show the velocity profile at a distance of 20 mm downstream from the exit orifice of the nozzle. It can be observed that information about the velocity field in outer regions of the spray is missing. These regions of the spray consist mostly of small droplets which cannot be captured along with the ligaments and large droplets. Thus, the velocity profiles from the PIV in Fig. 4 and Fig. 5 are valid only for large droplets which can be found in central region of the spray near the nozzle. It can be expected that the velocity of the droplets in the outer regions decreases, due to momentum transfer with the surrounding air, and that the velocity profiles would be similar to the distribution of the velocity profiles measured by the PDA technique and shown in the right side of Fig. 4 and Fig. 5.

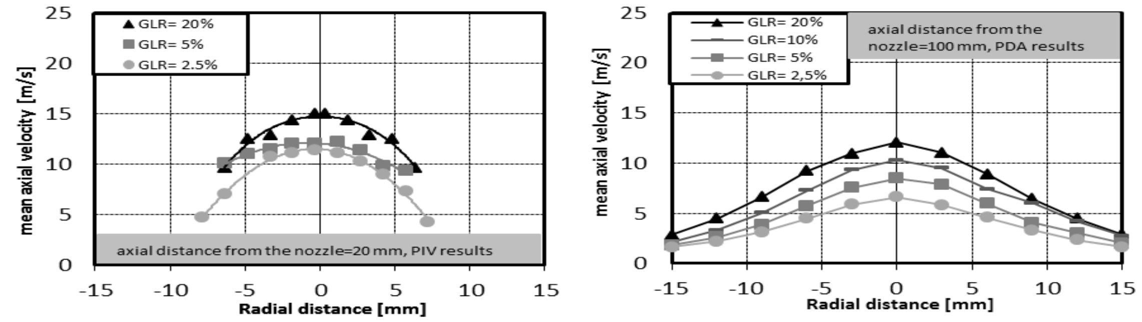

Fig. 5: Axial velocity profile at different distances from the nozzle ($\triangle p$ = 0.07 MPa, measured using PIV and PDA)

4. Conclusion

The PDA measurements were made at a distance of 100 mm from the nozzle where atomization was expected to be complete and all droplets spherical. In the region from the nozzle to an axial distance approximately 60 mm, the PIV measurements have been used to characterise the spray.

From presented results it can be stated that the flow field in the spray is symmetric in all measured regimes. The nozzle generates a stable spray with a narrow drop size distribution which is represented by the ID_{32} values. However, it can be seen that spray stability is related to the initial pressure of fluids. With higher pressure values, spray stability is increased from a visual point of view, due to the higher potential energy of the atomizing liquids.

Although, the PIV velocity measurements show the velocity profile in region near to the exit orifice of the nozzle. Further PIV experiments are indicated to be desirable especially with higher spatial resolution. This can be achieved, for example, by macro-imaging of the regions with different droplet size classes. It must be mentioned that this method is not only time-consuming in the experimental phase but also in the image processing phase. A second approach will be to reprocess the PDA data with the mean droplet velocity being calculated as a function of different drop size classes.

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