SPATIAL STRUCTURE OF A COMBUSTING SPRAY BY PIV

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ABSTRACT

PIV applications for non-combusting and combusting spray were investigated by an industrial oil burner of 0.1 MW. An optical parameter and signal-processing scheme are examined to have optimum set-up. Phase Doppler technique was used to evaluate the PIV data. Size classified technique was also implemented. The results show that non-combusting PIV can demonstrate well the 2 dimensional droplet vector map of 20-30 μm and combusting PIV could show whole field velocity vectors of medium size droplet of 5-30 μm. The spatial structure of combusting spray was measured by this PIV.

INTRODUCTION

Spray dynamics and its interaction to combusting turbulent air flow are the most important research subject to be investigated in spray combustion research (Chigier, N. A., 1988) (Williams, F. A., 1985) Spray combustion has been taking place in various industrial applications such as furnace, gas turbine, IC engines, heater and so on, however, it has been difficult to control local combustion characteristics and reduce undesirable combustion exhaust gas. Main physical characteristics in spray combustion can be understood by droplet break-up mechanism, strong shear flow, evaporation, turbulent interaction, mixing formation, flame propagation, combustion kinetics, flame holding and so on. These subjects have been fundamental research topics for several decades, (Lefebvre, A. H., 1989) (Kuo, K. K., 1996a) and numerous experimental and numerical investigations have been carried out (Kuo, K. K., 1996b) so far. Recent laser based diagnostics (Taylor, A.M. K. P., 1993) can push forward these researches to detail mechanism of turbulence, flame chemistry and reaction kinetics. But the spray dynamics and its combustion are essentially three dimensional and time varying. Although we have to demonstrate these physical parameter in this fashion, a planar measurement techniques (Adrian, R. J. et al., 1997) can only allow us to see spatial structure in two dimensional, having low temporal repetition, while a point measurement method (Durst, F. et. al., 1975) (Edwards, C. F., 1990) can provide detailed information of droplet diameter, velocity and evaporation characteristics but no spatial structure information. This is a trade-off relationship so far. PIV (Measurement Science and Technology, 1997) (Raffel, M., 1998) has been a most powerful tool to understand whole flow field and spatial turbulent flow structure. Since PIV uses Mie scattering from particles which travel in flow fields, it has been a problem and subject to be overcome, that is, particle diameter distribution, particle followability to turbulent flow, particle response, non-uniform particle dispersion, non-uniform particle number density. An application of PIV for combusting spray is a far away from its potential, very little trial has been demonstrated.

We have been examining a possibility of PIV in application for spray (Ikeda, Y. et. al., 1998) and have proved that an optimum set-up PIV could provide very useful information of spatial structure of industrial spray, and its error estimation was also examined. We think the PIV optimized can be a very useful tool to demonstrate combusting spray dynamics and its spatial structure when a certain condition was chosen. We have applied PIV to various industrial sprays and compared with those measured by PDA. Size classified method (Edwards, C. F., 1988) (Ikeda, Y. et al., 1997) (Kawahara, N. et. al., 1996) (Kawahara, N. et. al., 1997) was demonstrated. These measurements have been carried out in non-combusting spray and PIV applicability has been proven.

In this study, PIV was applied for combusting spray measurement, the droplet velocity measured by PIV is evaluated by size classified PDA data. An optimization process of PIV for combusting spray is examined here by changing optical conditions, signal processing scheme, data visualization and

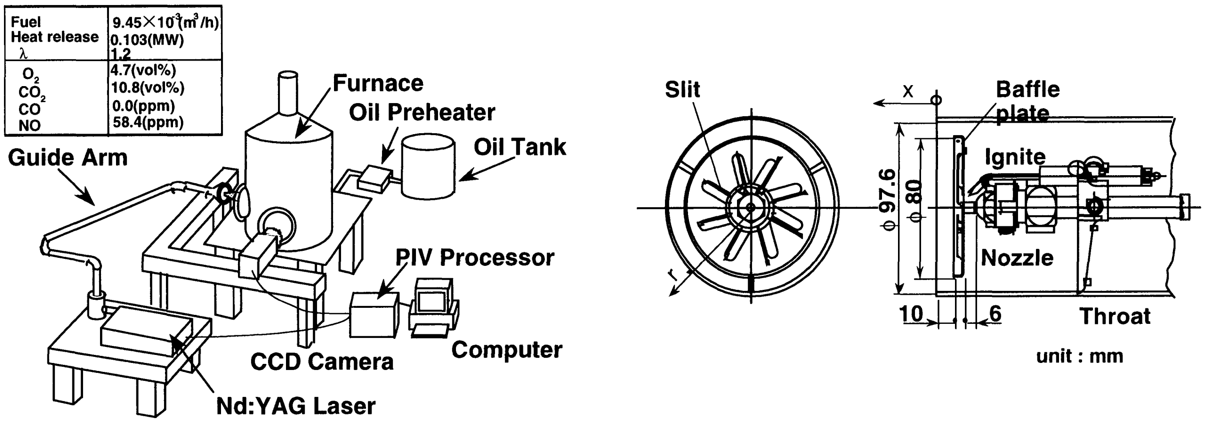

Fig. 1 Experimental aparatus and gun-type burner

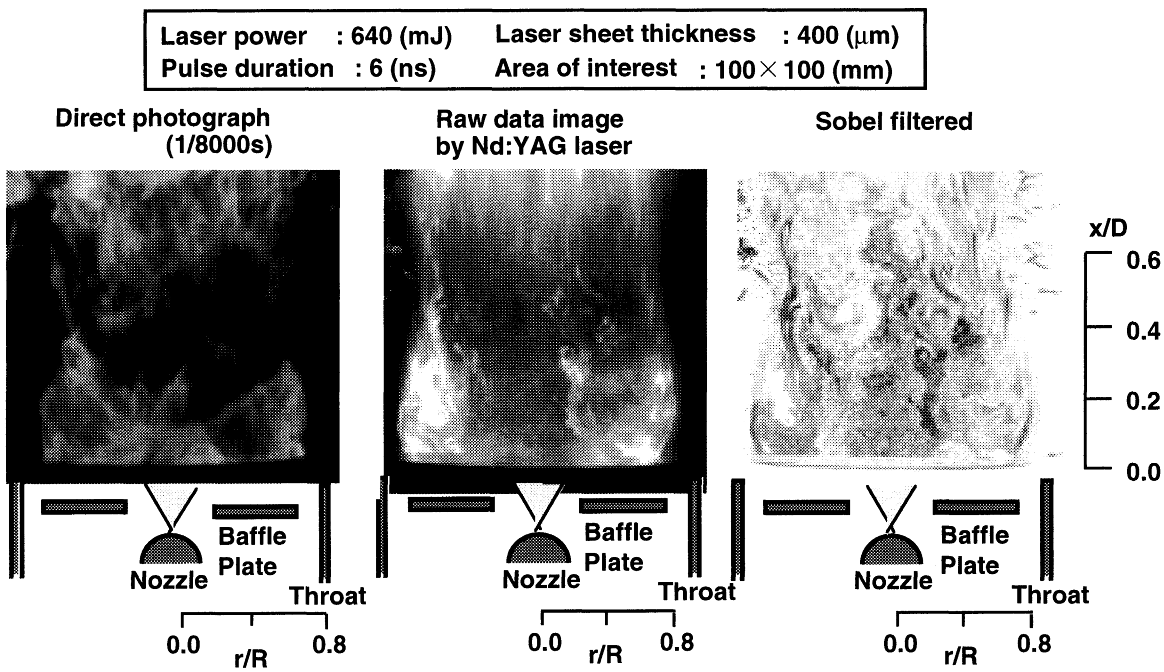

Fig. 2 Visualization of combusting spray

combustion condition. Measurements of spatial structure of non-combusting and combusting spray are examined by comparing droplet velocity profile of each droplet classes and vorticity in 2 dimensional plane. The applicability and its error estimation are examined here.

EXPERIMENTAL APPARATUS

Figure 1 shows an experimental apparatus and gun-type burner used in this measurement. The pictures of a direct observation and laser sheet visualization are shown in Fig. 2. The heavy-oil was pressurized at 0.7 MPa and a hollow cone spray was produced at 60 degree (Kawahara, N. et. al., 1996). In this study we have measured the detailed spray characteristics both under isothermal and combustion conditions by PDA (Kawahara, N. et. al., 1997). The light source was a Nd:YAG laser (double pulsed, 400 mJ per pulse), a cross-correlation camera (KODAK MEGAPLUS ES1.0) was used as the PIV components. The images were captured by CCD camera and then transferred to the processor and vector calculations was done in the processor and stored in the PC. The laser light duration at each pulse was 8 ns and the droplet movement on the CCD array while this 8 ns duration was ignoble small. The wavelength of the light source is 532 nm (green) and optical interference filter has been attached in the reacting flow measurement to achieve higher signal to noise ratio by removing the strong emission from the flame. The area of interest in this study is 100x100 mm so that physical dimension of each pixel is 100 μm in the flow.

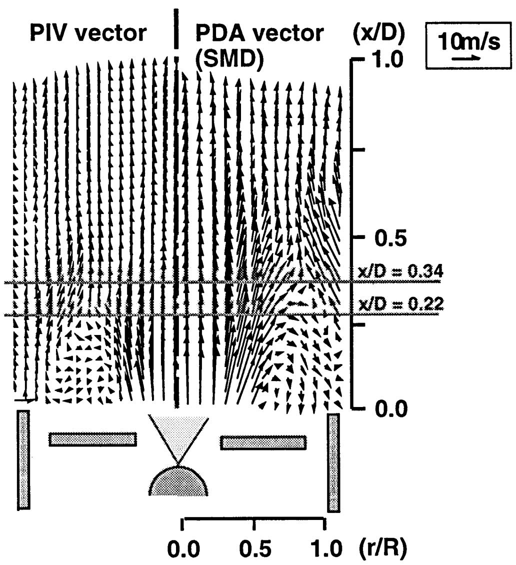

Fig. 3 Vector map comparison

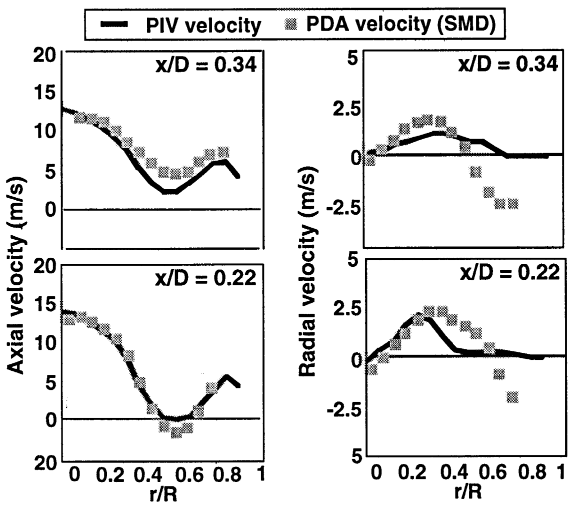

Fig. 4 PIV and PDA(SMD) comparison

RESULTS AND DISCUSSION

Applicability of PIV for non-combusting spray

Detailed droplet velocity and diameter were measured by PDA (Kawahara, N. et. al., 1995) and size-classified droplet velocity vectors were also discussed. An optimization of PIV optics and signal processing were examined and evaluated (Ikeda, Y. et. al., 1998). Figures 3 to 5 are comparison results of PIV and PDA data. Sauter mean diameter (Lefebvre, A. H., 1989) is the most popular description in spray research, then SMD velocity vectors are compared to those measured by PIV vectors in Fig. 3. It is found that a size and position of recirculating vortex was almost the same but its magnitude was different from each other. An entrainment air was measured by PDA but not by PIV. The strong flow velocities near the nozzle were observed both in PIV and PDA since SMD is one of a representative fashion of droplet characteristics. It is worth to compare PIV velocity to SMD velocity as shown in Fig. 4. Axial and radial velocities are compared, which show very nice agreement in both velocities. PIV velocity can also indicate negative velocity of the recirculation vortex. At r/R=0.5, the velocity discrepancies became large, which was due to smaller number density of droplet. Furthermore, an incredible agreement can be seen in Fig. 5, that is, the measured diameter was sorted into three droplet diameter classes (Ikeda, Y. et. al., 1998) so as to demonstrate more detailed droplet dynamics where the strong shear flow is existed. The grey solid circles (20 μm < Dp < 30 μm) fit very nicely to the PIV solid line at r/R=0.5. It is found that the applicability of PIV for non-combusting spray was very useful and acceptable to evaluate the droplet velocity vector in the industrial spray burner. The smaller droplet (Dp < 5 μm) can be regarded as a turbulent air flow (Libby, P. A., 1994) which can show stronger negative velocity to show strong recirculation flow. On the other hand, the larger droplet (60 μm < Dp) velocity was slightly larger than PIV velocity and could not show negative velocity. This is due to that the larger droplet penetrated the recirculating flow and hard to follow to the reverse flow. The PIV velocity can represent the medium droplet velocity of 20 to 30 μm in this experimental condition.

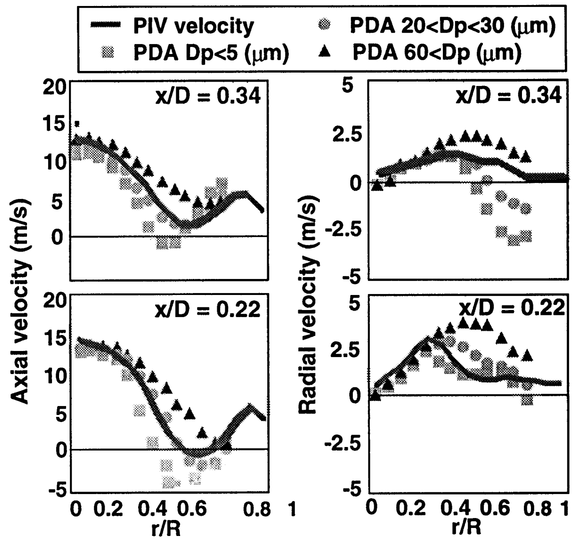

Fig. 5 PIV and PDA(Size classified) comparison

Applicability of PIV for combusting spray

It was found that the optimized PIV could measure droplet velocity of medium size (20 to 30 μm) in non-combusting spray. Since PIV measures Mie scattering from the droplet in flows, it is very hard to distinguish droplet velocity at a certain droplet diameter range, however, there is some possibility to be used in spray. Then, this optimization scheme was examined in combusting spray using the same furnace of 0.1MW.

The optimized PIV was implemented to measure droplet velocity in combusting conditions. The flame was the same as that in Fig. 2. First of all, numerous measurements were per-

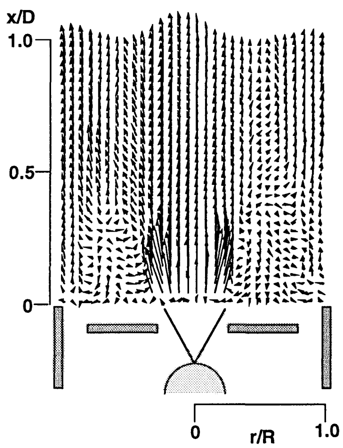

Fig. 6 PIV result of combusting spray

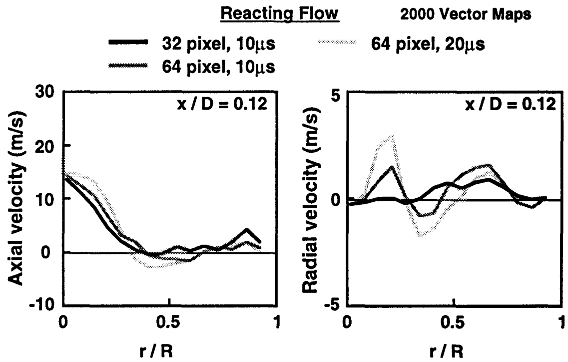

Fig. 7 Parameter optimization

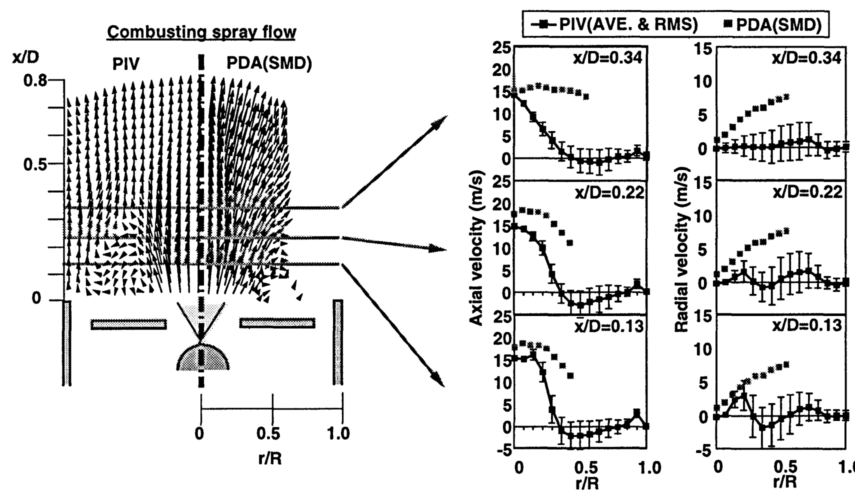

Fig. 8 Velocity component comparison

formed in order to obtain whole flow field velocity vector correctly as shown in Fig. 6. Several optical parameters were examined to obtain better PIV vector map, but it was also very difficult to determine the best condition because the measuring droplet has wide diameter distribution and droplet is evaporating and combusting. By changing interrogation area and laser pulse separation, axial and radial velocities are examined as shown in Fig. 7. Final set-up optimization was done empirically.

Figure 8 shows the comparison results of PIV velocity and SMD velocity measured by PDA (Edwards, C. F., 1990). Three axial locations were compared here. There are very large discrepancies both in axial and radial velocities. The difference was very small near center axis, while this difference became significant at large radius. The PIV data could show the recirculating flow and binary the negative velocity was measured, which could hardly be obtained by large droplet data. This means that the PIV might be able to measure combusting air or small droplet instead of large evaporating droplet. This figure also shows rms value of PIV data, here, 2000 velocity vectors were measured. The solid line is mean velocity and gray square is the rms.

For detail understanding of droplet dynamics, size-classified method (Ikeda, Y. et. al., 1997) was implemented here. As shown in Fig. 9, SMD velocity profile does not fit well to PIV data, but the droplet less than 30 μm shows almost the same tendency to PIV data. The large droplet over 50 μm penetrates the shear flow region due to large initial strong momentum. The medium droplet size droplet got strong influence of recirculating flows, rapid evaporation, and large thermal gas expansion. The SMD shows large velocity than the PIV, but the medium droplet can be agreed with the PIV value. The size classes used here are very fine, so that let's see more coarse classes as 5-30 μm in order to compare to that measured by PIV.

Figure 10 indicates the comparison of medium droplet sized velocity measured by PDA to those by PIV. The size and position of recirculating flow can be observed by both measured velocity vectors. It is clearly seen the very nice agreement at these three locations. The radial velocity of medium size was the edge of the rms of PIV data. It is very difficult to determine which kind of droplet diameter range suitable to PIV. By

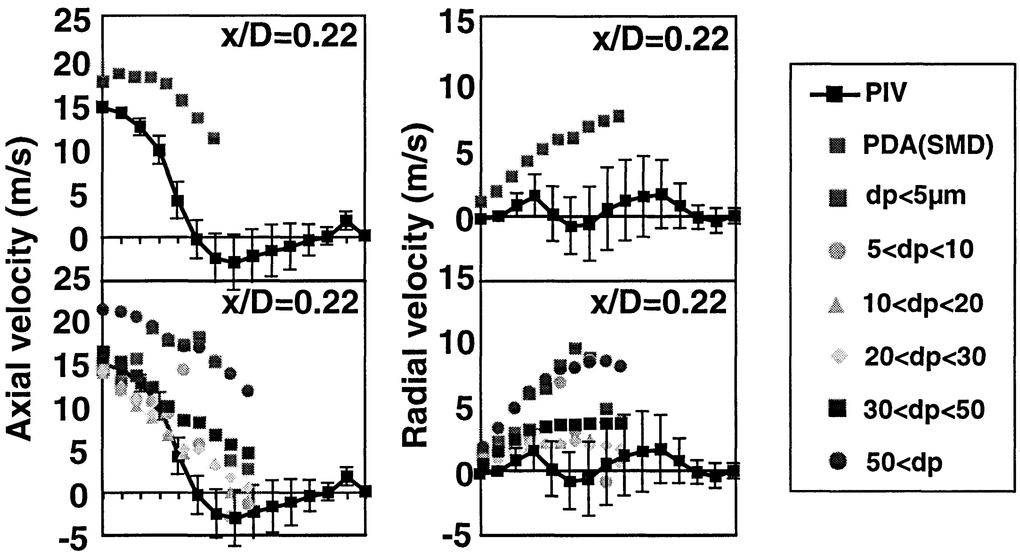

Fig. 9 PIV and PDA velocity component comparison

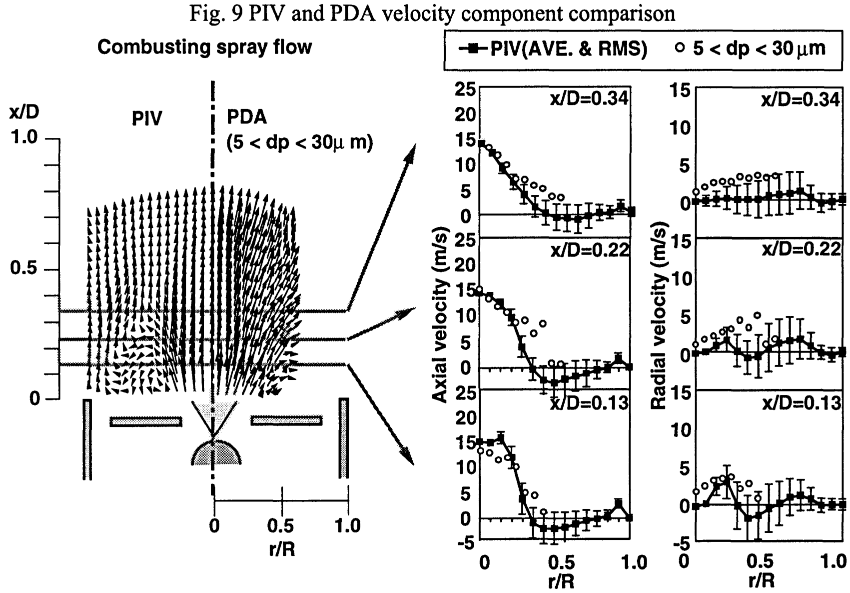

Fig. 10 Agreement of PIV and PDA

considering the droplet characteristics such as evaporation, strong shear, acceleration by thermal gas-expansion, radiation, combustion and so on, it is non-sense to say that the PIV can detect a droplet of certain diameter range, but it was found that the PIV measurement could measure the droplet velocity of medium size.

Spatial structure of combusting spray by PIV

It was found that the optimized PIV could measure medium size droplet (5-30 μm) and the measurement uncertainties were evaluated by PDA size classified data. Detailed discussion of local location was done in above section. In this section, spatial structure of combusting spray was investigated.

Figure 11 shows the comparison results of vorticity profile of combusting spray of PIV and that by size classified PDA. PDA can show positive and negative vortices but PIV can only demonstrate negative vorticity. The magnitude and shape of high vorticity region are almost the same in both data. Then, further application of PIV to understand spatial combusting spray was demonstrated as shown in Figs. 12 and 13.

Figure 12 is contour, that is, Reynolds stress. It is found that high region was due to spray penetration, evaporating, thermal expansion region at the tail of the recirculating vertex. The entrainment flow region near burner throat shows lager value. This PIV technique is very useful to see the spatial structure of combusting spray. Since these PIV data was 2000 average data, so that an instantaneous vorticity profile is shown in Fig. 13.

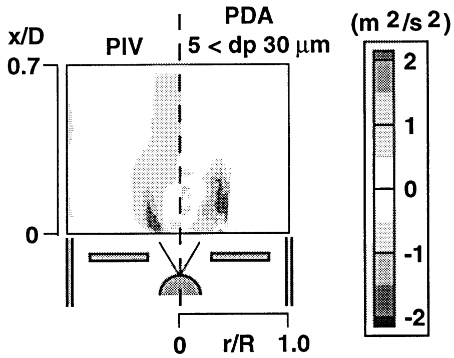

Fig. 11 Vorticity distribution

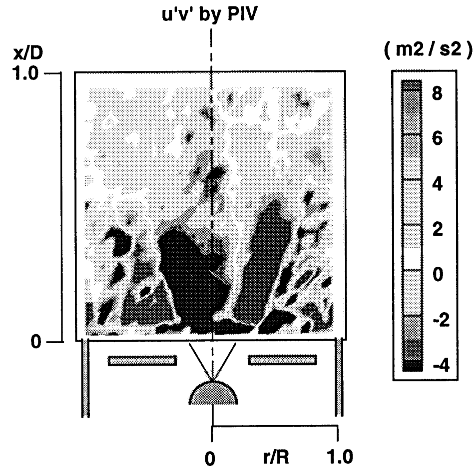

Fig. 12 Reynolds stress distribution

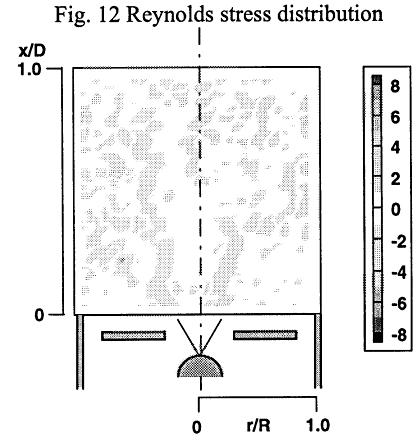

Fig. 13 Instantaneous vorticity distribution

CONCLUSIONS

In order to understand the spatial structure of combusting spray, conventional point measurement technique of PDA and an optimized PIV for a planar measurement were investigated and evaluated.

It was found that the optical parameter and signal processing of PIV technique could be optimized using size-classified PDA velocity data in order to measure spatial structure of certain size droplet velocity vectors. The PIV was examined for non-combusting spray and proved that the whole flow vector map of droplet (20-30 μm) can be obtained. Furthermore the application of the PIV for combusting spray was examined, which could demonstrate significant applicability of the PIV for combusting spray and the PIV set-up could measure spatial structure of combusting droplet.

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