Appendix-PIV measurement

The detailed information with the PIV experiments can be found in the following [13, 21].

The PIV experimental system consists of a CCD camera with a resolution of 1600 ×1200 pixels, a double-pulsed Nd:YAG laser of wavelength 532 nm with a delay of 10 μs, a timing controller, and a seeding generator. Fig. CA shows the apparatus for PIV measurements. An oil mist with 1-μm-sized particles was used as the particle tracing seed. Various scales of turbulent eddies exist in a turbulent field. Therefore, a Micro-Nikkor 105 mm f/2.8 G with tele-conversion lens MC7DGX and Nikkor 28 mm f/1.8 lenses were employed to image the turbulent flow for small and large measurement fields, respectively.

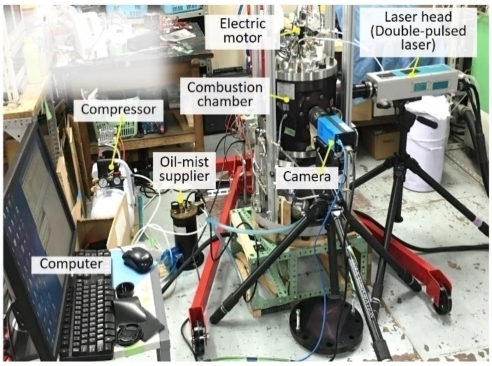
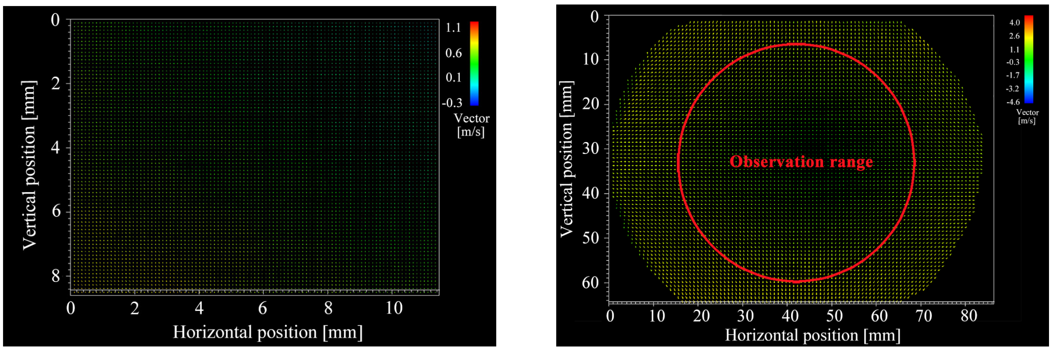


Fig. CA PIV measurement setup.

A small measurement field through an 8 mm window with a 7 μm pixel size in the flow for high resolution; and a larger field through a 60 mm window with a 54 μm pixel size in the flow. The analysis window was set to 32 × 32 pixels with a 50% overlap for both measurement fields. Four kinds of fan speed were used to carry out PIV experiments, including 500 rpm, 1000 rpm, 1500 rpm, and 2000 rpm.

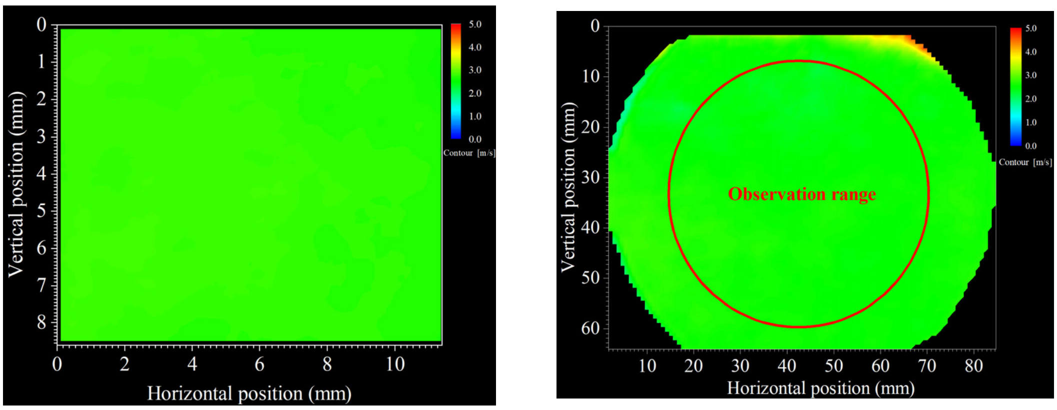
Fig. CB and Fig. CC show the results of the PIV measurement. Fig. CB (a) and (b) show the average flow velocity vector with 2000 rpm of the two fans rotation speed in small and large measurement scales.

The red circle in Fig. CB (b) indicates the observation area. Both cases show that the average flow velocity is almost 0 m/s at each measurement points. Fig. CC(a) and (b) show the distribution of the turbulence intensity in small and large measurement scales at the same condition. In the observation range, turbulence intensity has almost the same value in each measurement scale. In other cases of fan rotation speed, the same results were obtained. These results help to show the isotropic turbulence which is induced by the fans.



(a) Small measurement field, 2000rpm (b) Large measurement field, 2000rpm

Fig. CB Distribution of the average flow velocity vector



(a) Small measurement field, 2000rpm (b) Large measurement field, 2000rpm

Fig. CC Distribution of turbulence intensity

To confirm the turbulent uniformity furtherly, the energy spectrum function of turbulence, $E(k)$ was calculated by Eq. (CA) [13, 21]:

$$\mathrm{E}(k) = \frac{k^2}{\pi}\int_0^{\infty} r^2 u'^2 R_{11}(r)\cdot\left(\frac{\sin kr}{kr} - \cos kr\right)dr, \tag{CA}$$

where k is wavenumber, and r is separation distance, and u' is turbulence intensity, and $R_{11}(r)$ is the longitudinal correlation coefficients [13, 21]. Fig. CD shows the energy spectrum function of turbulence divided by total kinetic energy of turbulence, $\mathrm{E}(k)/[(3/2)u'^2]$. In the local isotropic turbulence field, Kolmogorov's -5/3 law is common for the inertial sub-region, and actually the gradient is almost -5/3. It also helps to show the turbulence uniformity.

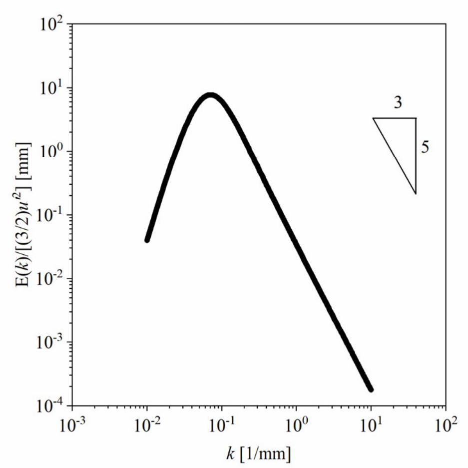


Fig. CD Variation of energy spectrum function of turbulence with wavenumber

As a result, the isotropic turbulence was verified by the PIV measurements.

On basis of the confirmation of the homogeneous turbulence, we obtained the relationship of the turbulence intensity with the fan speed by the PIV experimental result which can be seen in Fig. CE.

Turbulence intensity, u', which was proportional to the fan speed, found to be represented by Eq. (CB):

$$u' = 0.00129 f_s, \tag{CB}$$

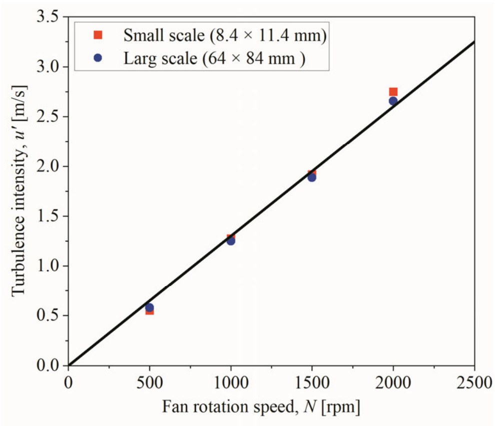


Fig. CE Turbulence intensity as fan speed

References

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