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PARTICLE MODULATION TO LOCAL TURBULENCE IN A TWO-PHASE ROUND JET

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ABSTRACT

Turbulence modulations by particles in two-phase round jets were experimentally studied by means of Phase Doppler Anemometer (PDA). The measured turbulence intensities were presented to show the modulations induced by changing particle size, particle material density and particle mass loading ratios. Turbulence intensities are enhanced by the laden-particles in the near-fields, but it is significantly attenuated in the far-fields. The smaller, or heavier, particles have a more profound effect on the attenuation of turbulence intensities. As the particle mass loading ratio increases, the turbulence intensities are decreased. The turbulence modulations by particles depend on the energy production, transport and dissipation mechanisms between the turbulence and the laden-particles.

INTRUDUCTION

The particle modulation to turbulence in two-phase jets is one of the most issues for the practical applications of two-phase flows. Some key parameters- such as the particle size, the particle material density and the particle mass loading ratios, influence the particle modulation to turbulence significantly. The modulation of turbulence by inertia-particles in a two-phase round jets have been investigated over the years.

Shuen et al. (1985), Barlow and Morrison (1990), Jou et al.(1993), and Prevost et al. (1994), Gillandt et al.(2001) measured the decreased turbulence intensities in the two-phase jet compared to the single-phase jet. Tsuji et al (1988) presented the measurements of both increased and decreased turbulence intensities in two-phase jets. Sheen, Jou and Lee (1994) adopted the polystyrene particles of 210, 460 and 780μm with the particle mass loading ratios ranged from 0 to 3.6 in their experiments and found that the axial gas-phase turbulence intensities of two-phase flow are decreased in the far-fields. Modarress, Tan and Elghobashi (1984) presented that the presence of 50μm glass beads reduces both the gas-phase fluctuating velocity and the reduction is proportional to the particle mass loading ratio. Cui et al. (2006) studied the turbulence modulations by adding six groups of glass beads in diameters from 50μm to 300μm into jets and found that the gas-phase turbulence intensities are increased by the particles over 250μm, otherwise decreased.

However, the particle modulations to turbulence, whether enhancing or attenuating turbulence and their corresponding conditions , have been still very ambiguous. The more comparisons for the velocity fields of particle-free jets and particle-laden jets are necessary to be done when the particle size, particle material density, and particle mass loading ratios are changed respectively while all other experimental conditions are fixed. In addition, the physical interpretations of turbulence modulations under different particle conditions are also needed to be completed further.

Therefore, in this paper, turbulence modulations in round jets by changing particle size, particle material density and particles mass loading ratios are experimentally investigated by means of PDA measurement technology. The physics based on the energy exchange mechanisms is then analyzed and discussed.

EXPERIMENTAL SETUPS AND CONDITIONS

The schematic diagram of the two-phase experimental system in the present study is shown in Fig.1. The environmental air is pumped into the fluid-tracer container and is extracted by the other pump placed at the end of the device. The air flows pass the commutating section, the stabilization section, the contraction section and finally jet out. The experimental test section is surrounded by four glass baffles preventing from the interference and contamination. The inertia particles are added into the flow from a hopper on top of the commutating section and an air flow is used to stabilize particles dropping. Particles are separated from the gas-phase in a cyclone separator. The fluid-tracers are 0~20μm hollow light glass beads.

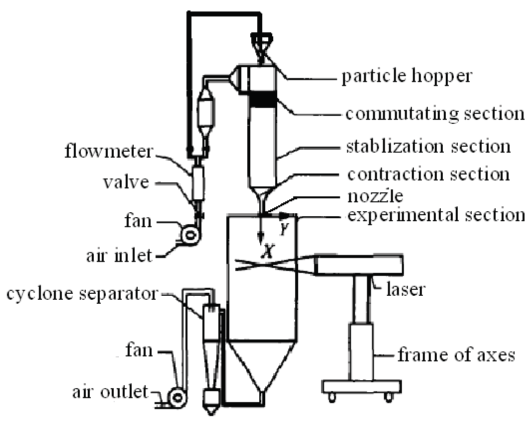


Fig.1 Schematic diagram of the experimental system

The DANTEC 58N50 Phase Doppler Anemometer (PDA) system is employed in the present experimental measurements. The PDA setups can measure the velocity ranged from 0-500 m/s with 1% accuracy, and can distinguish the particles with a range of 0.5μm to 1000μm in diameters with 4% accuracy.

Table 1 shows the flow and particle parameters adopted in the experiments. The Reynolds number, $Re_{jc}=\rho U_{jc}D/\mu$, based on the nozzle diameter D and the mean outlet velocity U_{jc} is 8240.

Three experiment cases are performed. In Case1, the effects of particle size on turbulence modulations are studied, in which particles are specified glass beads in diameter of 190 and 360μm with the same mass loading ratio γ=3.92. In Case2, the effects of particle material density on turbulence modulations are especially studied, where the particles are made of glass with density 2500kg/m^3 and polystyrene with 20-40kg/m^3. The particles mass loading ratios are the same. In Case3, particles mass loading ratios are specified as 3.92 and 5.79 to study the effects of particle mass loading ratios on turbulence modulations.

In the experiments, the particle mass loading ratios are kept in a low level so that the interactions among particles are neglected.

Table 1 Flow and particle parameters

Case	Particle Size [μm]	Particle material density [kg/m^3]	Particle volume concent ration	Particle mass loading ratio γ
1	~190	2500	0.16%	-
	~360	2500	0.16%	-
2	~355	20-40(poly.)	0.16%	-
	~360	2500(glass)	0.16%	-
3	~360	2500	-	3.92
	~360	2500	-	5.79

RESULTS AND DISCUSSIONS

In the experiments, the two-phase velocities are measured along the central axial line of the jet and in different sections away from the jet nozzle exit. The variation of turbulence intensity, mainly representing turbulence modulations, are then calculated by,

$$u' = \sqrt{\overline{u'^2}}/u_{m0} \text{ (the axial component)} \quad (1)$$

$$v' = \sqrt{\overline{v'^2}}/u_{m0} \text{ (the radial component)} \quad (2)$$

based on the measured data, where u_{m0} is the mean velocity of gas-phase at the central axial line.

Effects of Particle Size on Turbulence Modulation

The gas-phase turbulence intensities along the central axial line are shown in Fig.2 when the flow is loaded with particles in different sizes.

In the figures, herein after, both the axial distance away from the nozzle exit and the radii are non-dimensionlized by the nozzle diameter D.

For the two-phase particle-laden jets, in the near-fields x/D<5, turbulence intensities both in the axial and radial directions are enhanced by particles. For the axial component of the turbulence intensities, it is increased about 10% maximally. Conflictingly, Gillandt et al. (2001) measured a 0.5% decreased turbulence intensity in a Re=5,700 particle-laden jet. In the far-fields, turbulence intensities are strictly suppressed by particles. For the radial component of turbulence intensities, it is depressed and kept constant at the level of 5% by 190μm particles in the jet. For the particle sizes effects on the turbulence intensities, the smaller particles have a profound effect on turbulence modulations of attenuation.

The distributions of the turbulence intensities in the radial direction in different sections are shown in Fig.3. It is shown that the turbulence intensities are lower in the central of the flow, lower than 10% in the near-fields. In the shear layer production of turbulence kinetic energy is high and due to the energy transfer in the radial direction from the outer shear layer and therefore the turbulence intensities is higher, up to 25%. It is shown that both the axial component and the radial component of turbulence intensities are enhanced by particles in the jet cone in the near-fields, where they are depressed outside the jet cone. Downwardly, the turbulence intensities are depressed by particles. At the sections of x/D=10, x/D=20 in the far-fields, the turbulence intensities are attenuated by particles. As a whole, the smaller particles have a more profound effect on the turbulence attenuation, especially for the radial component of turbulence intensity.

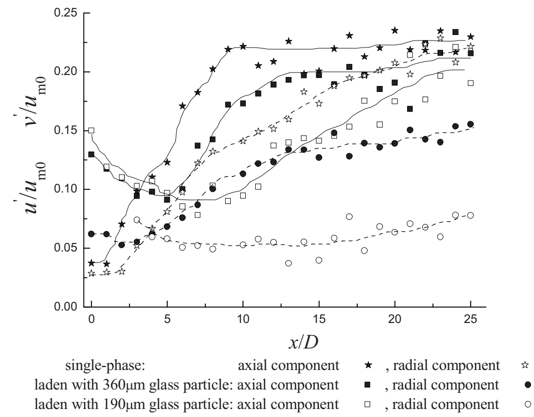
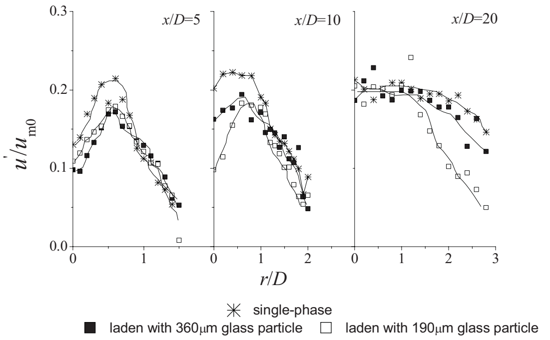
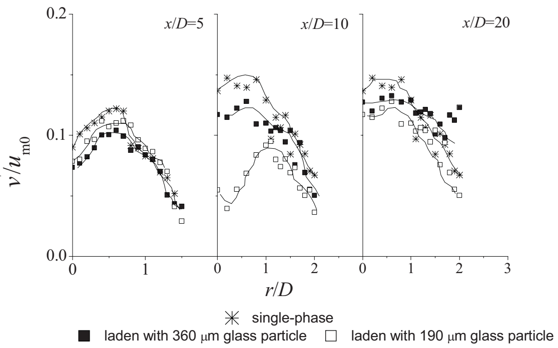


Fig.2 Gas-phase turbulence intensity variation along the central axial line laden with particles in different sizes



(a)



(b)

Fig. 3 Profiles of turbulence intensities in different sections laden with particles in different sizes. (a) the axial component , (b) the radial component.

Effects of Particle Density on Turbulence Modulation

The gas-phase turbulence intensities along the central axial line are shown in Fig.4 when the flow laden with particles with different material density. In the far-fields, the turbulence intensities are strictly suppressed by particles. The heavier glass particles have a profound effect on the attenuation of turbulence intensities than the lighter polystyrene particles.

The same as shown in Fig. 2, in the near-fields x/D<5, the turbulence intensities in the axial and radial directions are enhanced by particles due to the flow instability inspired by the laden particles.

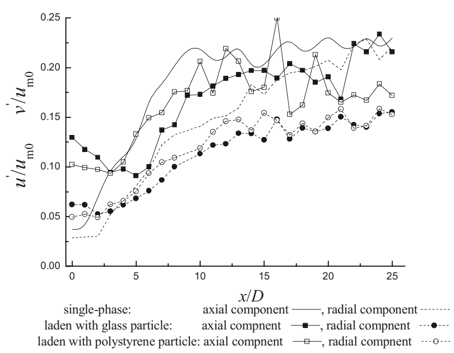


Fig.4 Gas-phase turbulence intensity variation along the central axial line laden with particles with different material density

The radial component of turbulence intensity in different cross sections is shown in Fig.5. It is shown that the turbulence intensity is attenuated by the particles in the jet cone; however, the turbulence intensity is enhanced a little bit by the particles outside the jet cone in the section of *x/D*=5. It is because the existence of the particles induces the flow instability in the shear of the jet fluid and the ambient fluid. Downwardly, particles depress the turbulence intensity. The same turbulence modulations in the radial direction have been found in the experiments. The glass particles have overall stronger modulations to the local turbulence than the lighter polystyrene particles. It can be concluded again that that the heavier particles have a more profound effect on the turbulence augment or attenuation.

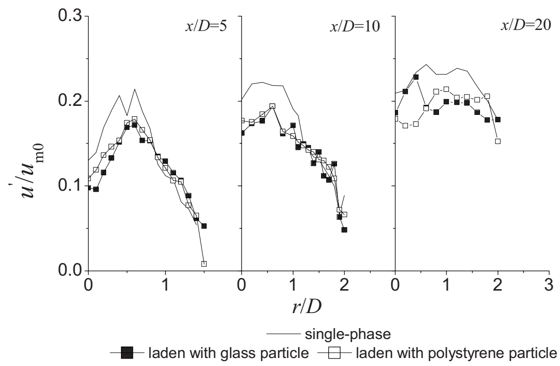


Fig. 5 Profiles of turbulence intensity of axial component in different sections laden with particles with different material density

Effects of Particle Mass Loading Ratio on Turbulence Modulation

Figure 6 shows the gas-phase turbulence intensities variation along the central axial line laden with 360μm particles for different particle mass loading ratios. As shown in the figure, with increasing of particle mass loading ratio, particles have a stronger modulation to the local turbulence. Upstream, particles can enhance turbulence intensities, and this enhancement is strengthened more as the jet is loaded more particles. Downstream, particles can dissipate turbulence energy and hence attenuate the turbulence intensities. This attenuation is also stronger when the flows are laden with more particles.

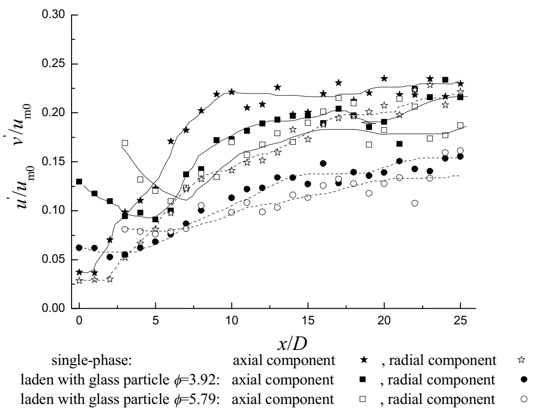
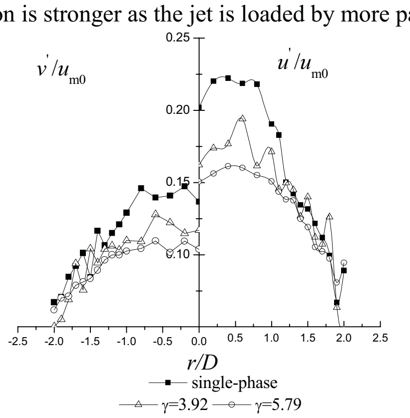
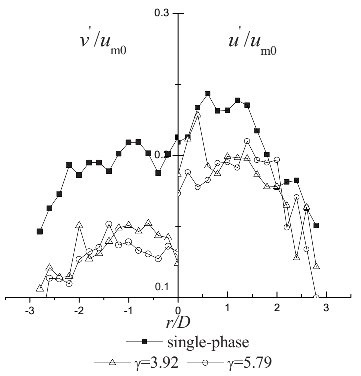


Fig.6 Gas-phase turbulence intensity variation along the central axial line laden with 360μm glass particles for different particle mass loading ratios

Figure 7 shows the turbulence intensities in different sections when the particle mass loading ratios are different. The axial turbulence intensity is higher than the radial one. In the far fields of jet, for *x/D*=10 and *x/D*=20, the turbulence is depressed by the laden particles. The degree of attenuation is stronger as the jet is loaded by more particles.



(a)



(b)

Fig. 7 Profiles of turbulence intensity in different sections for different particle loading ratios. (a) *x/D*=10, (b) *x/D*=20

In the present experiments, the particles released in each case are so small that the particle Reynolds numbers are smaller than 400. Therefore, there exit no wakes behind particles.

Without particle wakes, there are two key mechanisms to dominate the energy of the two-phase jet flows. Firstly, the energy production or strengthening mechanism comes from the flow shear, which can lead to very high velocity gradients. It is the mechanism for the high turbulence production and hence higher turbulence intensities in the near-fields. Secondly, the energy dissipation or weakening mechanism comes from the consumption of the laden particles. The particle inertia filtering to the turbulence fluctuations is the main mechanism to cause the dissipation of turbulence in the far-fields.

The higher turbulence intensity indicates the higher production and lower dissipation. It depends on the energy transferring modes between the two phases, further depending on the flow status, or the local position in the jet. In the initial stage of the jet, the flow instability is excited in advance by particles, which function as a kind of disturbance source, and therefore the energy is transferred from particles to the gas-phase fluid in the near-fields and more turbulence energy is produced, correspondingly to the higher turbulence intensity. With the flow developing, the particle's filtering effects on the gas-phase fluctuations dominate the energy transfer from the gas-phase turbulence to the particles and more turbulence energy is dissipated. The particles can only response the turbulent eddies with the same or longer characteristics time scale as the particle relaxation time scale. For the particles made of same material, the smaller the particle is, the shorter the particle relaxation time is. Therefore, the smaller particles can response to a various range of turbulence fluctuations. The more response to turbulence fluctuation is, the more dissipation of turbulence energy by particles is and hence, the stronger the attenuation of turbulence intensities is performed by particles. This is the reason that more attenuation of turbulence intensities by smaller particles observed in the far-fields of the jets. However, for the same particle size, when their density is larger, the particles can attenuate more turbulence intensities in the jet far-fields.

While the jets are loaded by more particles, the more energy is excited or consumed by particles. Therefore, the turbulence intensities are decreased significantly with the number of particles increasing in the far fields.

CONCLUSIONS

Under the present experimental conditions of small particle Reynolds numbers without particle wake effects, the conclusions are be summarized as below.

The gas-phase turbulence intensities are reduced with a decrease in particle size in the far-fields, while the jets are loaded with the same material density particles. For laden with the same size particles, the heavier particles decrease the turbulence intensities more strongly than the lighter ones in the far-fields. When the jets are loaded with more particles, i.e. the particle mass loading ratio is higher, the turbulence intensities are attenuated more. In the particle-laden jets, the particles act as a dissipation source for attenuation turbulent energy in fully developed status. The particle inertia plays a fundamental role in turbulence modulation, especially in the turbulence intensity attenuation. In near-fields, particles however act as a source of disturbance and induce the flow instability in advance, which causes an increase of turbulence intensity.

The particles modulation to local turbulence , whatever enhancement or attenuation, is stronger by increasing the particle mass loading.

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