CHARACTERISTIC DISTRIBUTION OF SUBMICRON AND NANO-PARTICLES LADEN FLOW AROUND CIRCULAR CYLINDER

by

Cheng-Xu TU[a,b*] ***and Jian ZHANG***[b]

[a] Department of Mechanics, Zhejiang University, Hangzhou, China
[b] Institute of Fluid Mechanics, China Jiliang University, Hangzhou, China

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Multiphase flow, including submicron and nano-particles simultaneously, around circular cylinder is studied experimentally in this paper, with Reynolds number in the range of 5200 to 35000. The results show that as Re increasing, flow characteristics hardly influence particles larger than 60.4 nm. For Re = 9000 and 16000, despite of the particles deposition, the concentration of bigger particles ranged from 220.7 nm to 523.3 nm in the wake is obviously higher than that at the free stream, whereas both is close to each other for smaller particles.

Key words: *particle characteristic distribution, particles laden gas flow*

Introduction

Flow around circular cylinders is a classic fluid mechanics problem owe to its regular unsteady characteristics and widely applications [1-8]. Moreover, as one of the current hot research issues, multiphase flow attracts more and more attentions, and there are rich achievements [9-13]. However, the issue that characteristic distribution of submicron and nano-particles in the flow around cylinder is so far of little concern, in spite of its extensive existence in nature phenomenon and industry. But previous research results relative to submicron and nano-particles laden gas flows indicate some efficient methods. One of them is the phase-Doppler anemometer [14], which simultaneously measures the drop size and velocity distribution. Van Den Moortel *et al.* used a phase Doppler particle analyzer to measure the particle flow in a circulating fluidized bed, and design the post-processing method to adjust the high count rate which result from Doppler disturbed pulse [15]. Now a widely applied photographic technology is particle imaging velocimetry (PIV), which allows the simultaneous measurement of the velocity of both phases over an imaged area [16]. Kiger *et al.* used a 2-D median filter to generate separate images of the two phase, so eliminating the errors induced by the distinct motion of the dispersed phase [17]. In 1923, Rohmann proposed the electromigration theory which is proved practically later. There are two advanced technology, namely, scanning mobility particle sizer (SMPS) and fast mobility particle sizer (FMPS), based on this theory. Both mea-

* Corresponding author; e-mail: xklx-5@163.com

surement methods are used extensively in aerosol science, because which can directly measure the number concentration of dispersed phase. Isella *et al*. used SMPS to study experimentally the dynamics of non-volatile particles emitted from a diesel vehicle along the transfer tube [18]. Biskos *et al*. introduced the characteristics of FMPS and its principle carefully, and concluded that the time resolution of FMPS should be improved before replacing the SMPS [19].

Experimental details

The experiment is performed in a low speed circulating wind tunnel which testing section dimension is 600 mm × 600 mm and 2 m in length. The circular cylinder was adopted with diameter of 50 mm. The particles are gained through lighting permethrim based mosquito coil. The FMPS 3091 produced by TSI Inc. with 32 sampling channels and the time resolution of 1 s is utilized to measure the number concentration of particles. The sampling time at each testing point is 1 minute with sampling frequency of 1 Hz. PIV made form Lavision Inc. is used to detect the instant velocity fields from which the time-averaged velocity field can be acquired. Refer to fig.1 and fig. 2 for more details.

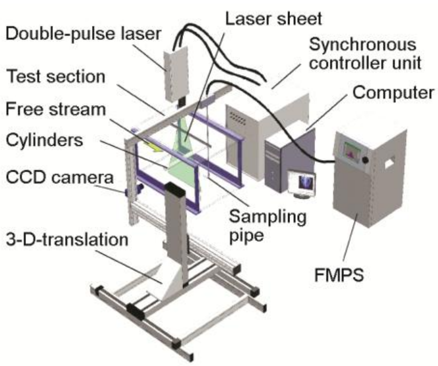

Figure 1. Experimental details

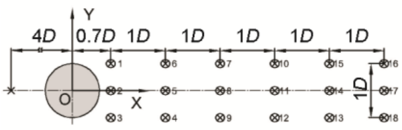

Figure 2. Testing grid and sequence for FMPS

Characteristic distribution of particles for different Re

The given diameter of sub-micron and nano-particles mainly distributes from 16.5 nm to 523.3 nm, and with the highest concentration around Dp = 191.1 nm, seen in fig. 3. Where N is the initial particles quantity, Dp and D denote the diameter of the particle and the circular cylinder, respectively, dN/dlogDp the dimensionless particles number concentration normalized by logarithmic Dp, δ_p the root-mean-square of instantaneous dN/dlogDp, and ρ_p the time-averaged particles number concentration. The experiments are performed as Re ranged from 5200 to 35000. The co-ordinate positions of the free stream and downstream testing points are (–4 D, 0) and (1.5 D, 0), respectively, and either is designated as the prior detecting position in turn for convenience. The concentration of dispersed phase may reduce because of the particles deposition.

As shown in fig. 3, the difference of the time-averaged particles number concentration between free stream and downstream is slight for varied Re, and the largest distinction, below 10%, distributes around Dp = 191.1 nm. With Re = 2000, own to the testing sequence, dN/dlogDp in the wake should be lower than it at free stream, the number concentration of Dp = 29.4 in the wake is obviously higher than it at free stream, and for Re = 23000 both approach each other.

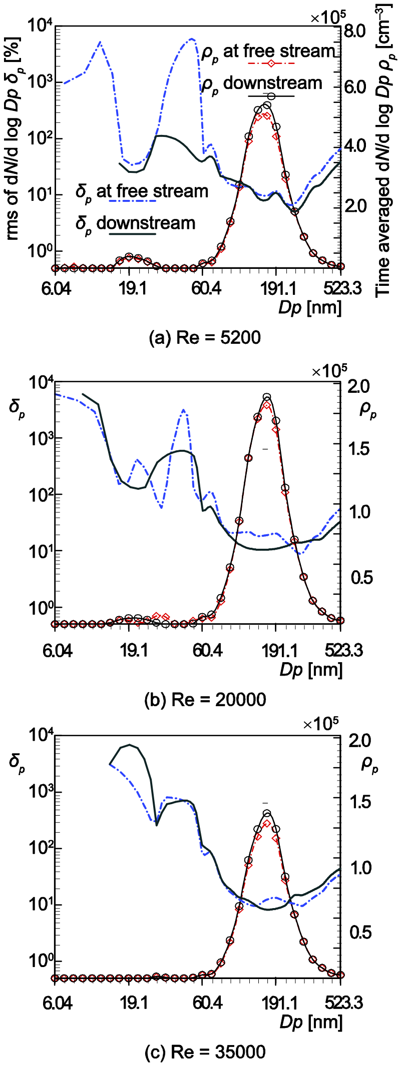

Figure 3. Time-averaged particle number concentration and its root mean square for different Re

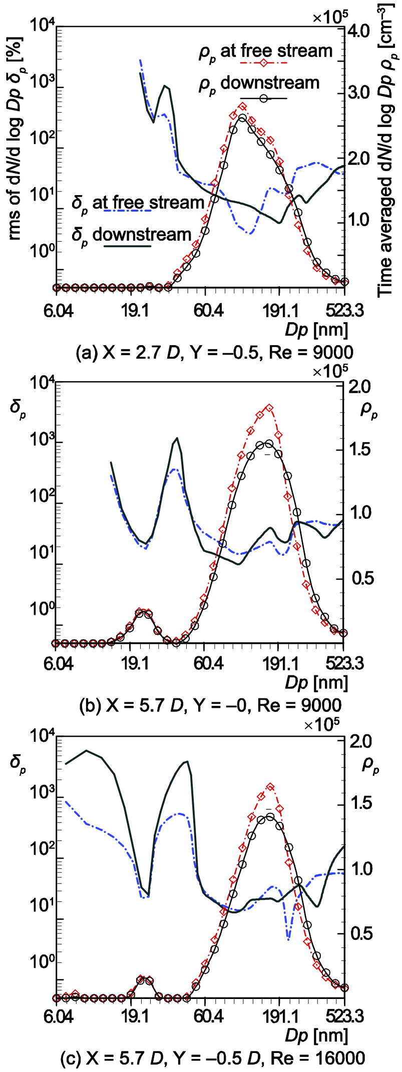

Figure 4. Time-averaged number concentration and its root mean square in the wake

Characteristic distribution of particles in the wake

The sampling at the free stream and the downstream testing points was alternately carried out to reduce the effect of particle deposition. As Re = 9000, the detection at free stream is always prior performed, the distribution of d*N*/dlog*Dp* shows only a peak around *Dp* = 107.5 nm. For 34 nm ≤ *Dp* ≤ 191.1 nm, the number concentration at free stream is higher than it in the wake. Despite of the particle deposition, for 220.7 nm ≤ *Dp* ≤ 339.8 nm, ρ_p in the wake that is higher than ρ_p at free stream, the largest increment up to about 15%, seen in fig. 4. As the time averaged streamline chart shows, the particles of 220.7 nm ≤ *Dp* ≤ 339.8 nm may follow the carrier phase better.

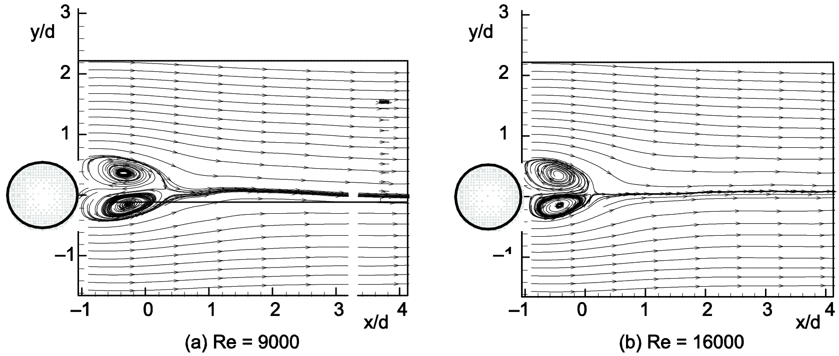

Figure 5. Time-averaged streamlines

It is remarkable that the testing sequence of Re = 16000 is in reverse order, contrary to that at Re = 9000. There is mostly bi-modal concentration distribution both at free stream and downstream. For all testing points, of 220.7 nm ≤ *Dp* ≤ 523.3 nm in the wake is almost obviously higher than that at the free stream, and the deviation between them reaches its maximum, *e. g.* $1.0 \cdot 10^4$ [cm^{-3}] on (0, –1.7 *D*), at *Dp* = 254.8 nm, like that for Re = 9000. Without supplying particles, the particles deposition would result in the dilution, so the higher ρ_p of 220.7 nm ≤ *Dp* ≤ 523.3 nm can be definitively attributed to the interaction between gas and particles. For the particles of 254.8 nm ≤ *Dp* ≤ 523.3 nm, δ_p in the wake are almost lower than that at free stream. It seems that the flow around cylinder forces the particles of diameter range to disperse more efficiently.

Conclusions

The results indicates that Re plays little role in the characteristic distribution of larger particles ranged from *Dp* = 80.6 nm to 523.3 nm, but has significant influence on the distribution of smaller particles. Despite of the particles deposition, the particles number concentration of 220.7 nm ≤ *Dp* ≤ 523.3 nm in the wake is still obviously higher than that at free stream for Re equals to 9000 and 16000. It can be deduced that the particles with 220.7 nm ≤ *Dp* ≤ ≤ 523.3 nm may follow the gas better and be more apt to be absorbed into the adjacent wake. A circumstantial evidence is that δ_p of 254.8 nm ≤ *Dp* ≤ 523.3 nm in the wake are almost lower than that at free stream with few exception.

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