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The Drag Force on An Oscillating Sphere Travelling in Power-law Shear-thinning Fluid

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Extended Abstract

Shear-thinning fluid occurs in many industry processes, such as wastewater treatment, oil recovery processes, and biological processes. Compared to the dispersion in the Newtonian fluid, more complex physical changes are found during the dispersion of bubbles[1], drops[2] and particles[3] in the shear-thinning fluid. Applying mechanical treatments, such as pulsation, oscillation and ultrasound irradiation, can significantly manipulate the behaviors of the flows induced by the dispersion of bubbles[4], particles and particles in shear-thinning fluid. To shed light on how to control the motion of the dispersion, it is important to investigate the drag force. We consider the flow dynamics induced by an oscillating sphere travelling in power-law shear-thinning fluid with the velocity of $U = 1 + A\cos\omega t$ (here, $U, A,$ and ω are the velocity, the oscillation amplitude and oscillation angular frequency of the sphere) and focus on the drag force on the sphere, as shown in Figure 1.

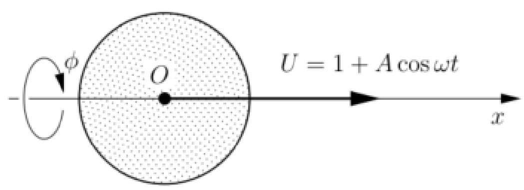

Figure 1 The schematic system of the oscillating sphere with the velocity of $U = 1 + A\cos\omega t$[5]

To explore how the drag force control the sphere in the shear-thinning power-law fluid, we focus on the time-averaged variation of the drag force D. Evidently, the drag force D shows almost independence of angular frequency ω, whereas, D is significantly reduced with increasing amplitude A. We are curious with the almost independence of drag force D on ω irrespective of amplitude A. Considering that the drag force for each amplitude is consistent with that at low angular frequency ω, so we employ the assumption of quasi-steady state in our study.

When a fluid flow is in quasi-steady state, the temporal variation of the fluid velocity can be neglected, i.e. $\frac{\partial \boldsymbol{u}}{\partial t} = \nabla \cdot \boldsymbol{\sigma} = 0$, and we assume that the shear rate scales the sphere velocity $\dot{\gamma} \sim U = 1 + A\cos\omega t$. It is easy to find that $\boldsymbol{S} = \frac{1}{2}(\boldsymbol{\nabla u} + (\boldsymbol{\nabla u})^T)$ and $\mu = \dot{\gamma}^{n-1} \sim |U|^{n-1}$. Therefore, the stress tensor $\boldsymbol{\sigma} \propto 2\mu\boldsymbol{S} \sim |U|^{n-1}\boldsymbol{U}$. So the instantaneous drag force F can be approximately expressed as $F \approx D_0(n)|U|^{n-1}U$. Finally, after assuming $\chi = \omega t$, the scaled drag force for the quasi-steady state can be represented by $\frac{D(n,A)}{D_0(n)} = \langle |1 + A\cos\omega t|^{n-1}(1 + A\cos\omega t)\rangle$.To check the application of the quasi-steady theoretical solution, we compare the numerical result with it in Figure 2. Obviously, the quasi-steady theoretical solution can exactly predict the numerical results over wide oscillation amplitude range.

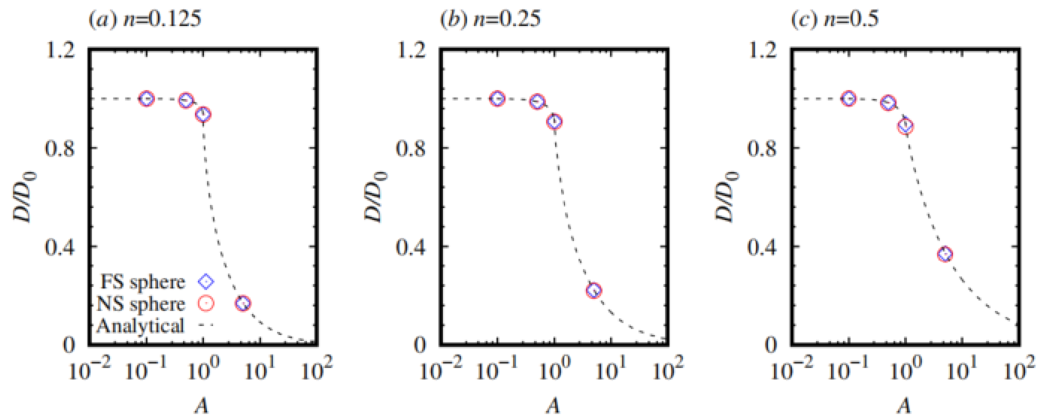

Figure 2 The relation between time-averaged scaled drag force D/D_0 and oscillation amplitude A at angular frequency $\omega = 1$ for various power-law indices n. Symbols indicate the numerical results and the dashed curves indicates results predicted by the quasi-steady analytical solution. (a) $n = 0.125$, (b) $n = 0.25$, (c) $n = 0.5$.

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