THE MAGNUS FORCE ON SPINNING MICROPARTICLES

Miguel Solsona[1] , Hans Keizer[1], Hans L. de Boer[1], Yannick P. Klein[3], Wouter Olthuis[1], Leon Abelmann[2] and Albert van den Berg[1]

[1]BIOS-Lab on a chip group, MESA+ Institute for Nanotechnology, Max Planck-University of Twente Center for Complex Fluid Dynamics University of Twente, Drienerlolaan 5, Enschede, The Netherlands

[2] KIST Europe, Saarland University, Saarbrücken, Germany

[3] Mesoscale chemical systems group, MESA+ Institute for Nanotechnology, University of Twente, Drienerlolaan 5, Enschede, The Netherlands

ABSTRACT

Here we report the first study of the trajectory deflection of Janus particles rotated with a rotating magnetic field inside a liquid. Also, we developed a model able to predict the deflection of these particles. We believe that the Magnus force can be used to sort cells and microparticles based on shape, size or even magnetic material shape anisotropy.

KEYWORDS: Magnus force, Microparticles, rotating magnetic field

INTRODUCTION

A rotating object moving relative to and inside a fluid experiences the Magnus force. Many studies have shown the existence of this phenomenon, [1-3] however not with microparticles and at low Reynolds numbers. This work aims at studying the deflection of microparticles 80 µm in diameter caused by the Magnus force. The Magnus force can be used for sorting microparticles based on their radius and magnetic properties. Rubinov and Keller[4] derived the magnitude of the Magnus force for low Reynolds number as,

$$\boldsymbol{F}_{\text{magnus}} = \pi \rho_{\text{f}} r^3 \boldsymbol{\Omega} \times \boldsymbol{u}, \quad (1)$$

where ρ_f [kg m^{-3}] is the fluid density, r [m] the radius of the particle, Ω [rad s^{-1}] the angular velocity and u[m s^{-1}] the relative velocity between the particle and the fluid. The Magnus force will tilt the trajectory of the particles. Balancing the drag forces in perpendicular and translational directions, see Figure 1, and considering that the magnetic torque is applied perpendicular to the gravity we obtain that the tilt is:

$$\phi = \tan^{-1}\left(\frac{r^2}{6\upsilon_{\text{f}}}\Omega\right) \quad (2)$$

where υ_f [m^2 s^{-1}] is the kinematic viscosity of the fluid in which the particle is moving.

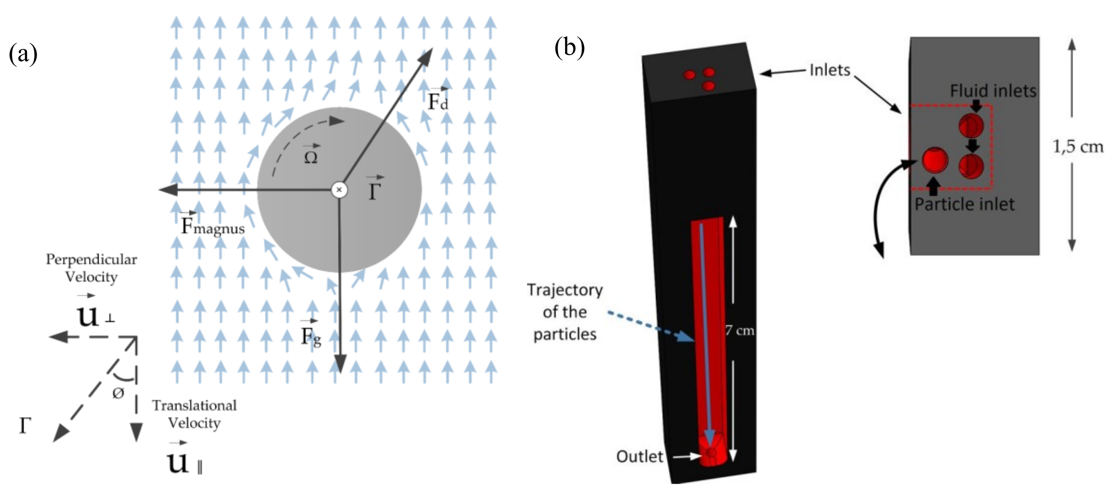

Figure 1: (a) Schematic drawing of the principle causing the Magnus force. The fluid on the left part of the particle is dragged along to the back-right side, thus, due to Newton's 3rd law, pushing the particle to the left. Also, difference in velocity on both sides of the particle cause a difference in pressure and (b) drawing of the fluidic system used.

EXPERIMENTAL

For testing, we used commercially available silica particles half coated with a 2 µm thick superparamagnetic material. A rotating magnetic field was used so that a torque can be applied over a large spatial region. Two magnets were used, one on each side of the fluidic system, in order to provide a high magnetic field and low magnetic field gradient in order to avoid magnetic forces acting on the particles. The fluidic system, Figure 1b, consisted of three inlets, two to introduce the liquid and one to introduce the particles. The particles were introduced by gravity and no-flow was applied to the system in order to enhance the time and therefore, the angle tilt of the particles' trajectories. Particles were rotated in both directions.

RESULTS AND DISCUSSION

Three experiments were performed using two solutions, DI water and a mix of glycerol and water in a 1:3 volume ratio, and 2 rotational speeds, 5 and 2 rps. When using water and 5 rps, see Figure 2a, a clear difference can be observed in the angle tilt of particles rotation clockwise and anti-clockwise being the total angle difference (1.2±0.2 °). Figure 2b shows a decrease in angle tilt when using a lower rotational speed, 2 rps. (0.42 ± 0.2 °). Both results are very similar to the calculated angle using Equation 2, (1.2 °and 0.49 ° respectively). Figure 2c presents an experiment with low rotational speed (2 rps) and higher viscosity (2.310^{-6} m^2 s^{-1}), showing no difference between angles.

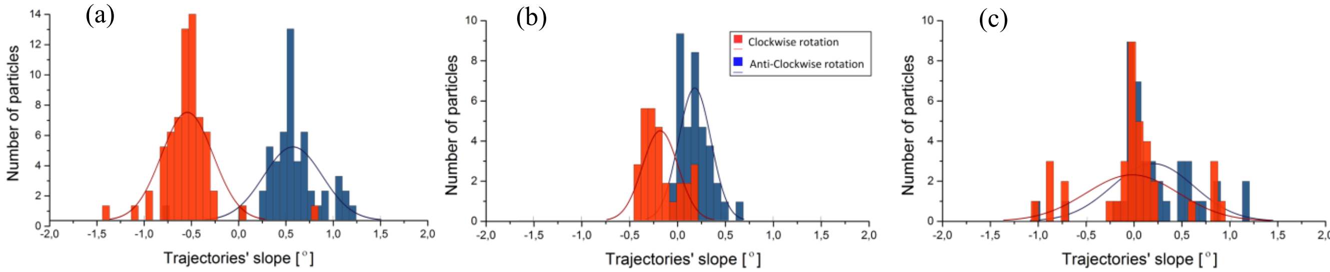

Figure 2: Histograms and their cumulative distribution function (CDF) of the trajectory slope angles of particles rotating clockwise (red) and anticlockwise (blue) (a) with low viscosity (water) and 5 rps, (b) low viscosity (water) and 2rps and (c) high viscosity (mix of water and glycerol 3/1 v/v) and 2 rps.

CONCLUSION

In conclusion, the particles rotated with the field and are therefore subject to a Magnus force that caused a measurable tilt difference of up to 1.2 degrees in their trajectories. The direction of the tilt agrees with rotation direction and its magnitude agrees within measurement error with the theoretical prediction. The tilt angle increased with increasing rotation velocity and decreasing viscosity.

ACKNOWLEDGEMENTS

This work was supported by the Netherlands Centre for Multiscale Catalytic Energy Conversion (MCEC), an NWO Gravitation programme funded by the Ministry of Education, Culture and Science of the government of the Netherlands.

REFERENCES

[1] H. M. Barkla, L. J. Auchterlonie, *J. Fluid Mech. 47*, 437–447, 1971.
[2] P. C. Rem, N. Fraunholcz, E. A. Schokker, *Sep. Sci. Technol. 37*, 3647–3660, 2002.
[3] P. G. Saffman, *22, 1965*.
[4] S. I. Rubinow, J. B. Keller, *J. Fluid Mech.*, *11*, 447–459, 1961.

CONTACT

* M. Solsona; phone: +34-669944673; Miguel.solsona8@gmail.com