Electronic Supplementary Material (ESI) for Lab on a Chip.

Trapping and Patterning of Large Particles and Cells in a 1D Ultrasound Standing wave†

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I. Supplementary Information (SI)

I.1. Damping and bulk viscosity effects

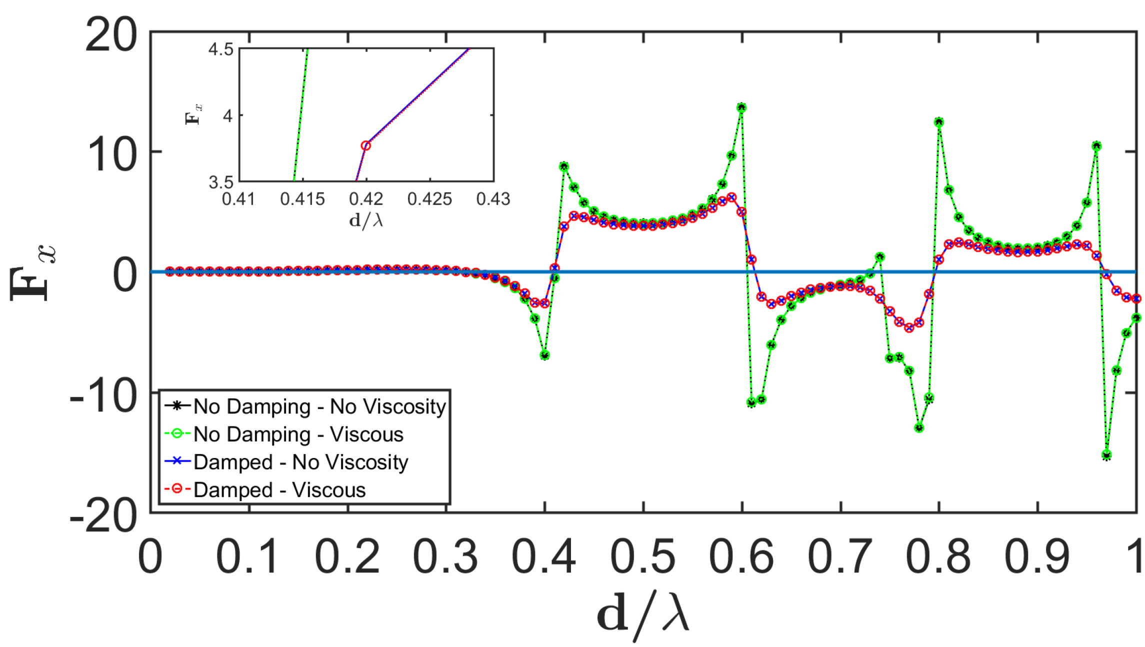

Fig. S1: *Force (in nN) versus size plot for PMMA with the consideration of the damping in the solid particle and the viscosity in the fluid bulk. Viscosity has little influence on acoustic radiation force while the damping of solid (modelled with isotropic loss factor=0.05) reduces the force magnitude at resonating sizes (frequencies). Though, damping does not have considerable effect on AFR at other sizes.*

To consider the effect of the solid damping and fluid viscosity, the axisymmetric model of the single particle under a 1D acoustic wave was simulated considering the viscosity in the fluid bulk

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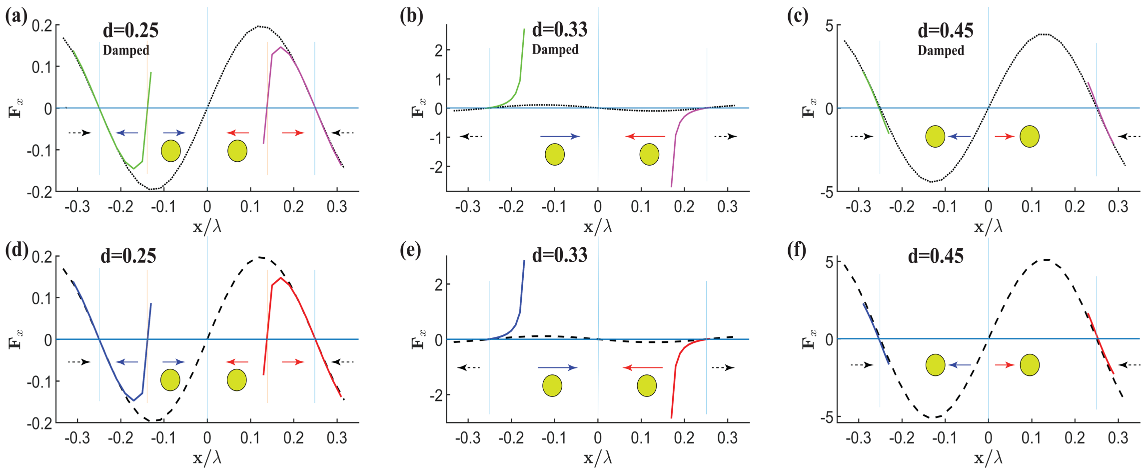

Fig. S2: *Force (in nN) vs Position for different sizes: black dashed/dotted line shows Primary forces on single particles along their positions sweeping from a node to other opposite node for previously investigated representative sizes while solid damping and fluid viscosity were included (a) $d = 0.25\lambda$ (b) $d = 0.35\lambda$ (c)$d = 0.45\lambda$. Magenta and green solid lines show Total force on particles A (top/right side) and B (down/left side) respectively as their gap increases. Figures (d), (e) and (f) reproduced from the main article's Fig. 2(d)-(f) for the same sizes without damping. Damping decreased the primary and total forces slightly but does not change the interparticle attraction / repulsion behaviour*

and loss factor for the solid. To investigate the effect of these two parameters, acoustic radiation force (ARF) on a PMMA spherical particle in a fluid (water) domain were computed while other parameters of Table 2 of the main article remained unchanged.

Fig. S1 which is comparable with Fig. 2a in the main article shows that viscosity has almost no distinguishable effect on the AFR. It should be noted that, as only large size particles are considered ($d > 0.10\lambda$), we do not consider streaming effects and the viscosity is only applied to the bulk of the fluid and the viscosity were only applied on the fluid bulk properties.

On the other hand, it is observed that damping decreases the force magnitude considerably at resonating sizes. However, its effect becomes negligible at the non-resonating size, i.e. the majority of sizes. Although, the solid damping absorbs a portion of energy from the incoming wave, thus flattens the peaks and troughs in the ARF curve, it does not change the force shifting pattern or its turning points.

Inter-particle behaviour will not change significantly and the patterning regime is still valid. Nevertheless, it is expected that the secondary force which is under influence of resonance, will reduce as well. The reduction of secondary force and consequently the total force is negligible at non-resonating sizes. This said the regions and the general trend of inter-particle secondary force at different sizes remain unchanged as it can be observed in Fig. S2.

I.2. Implementation of damping and viscosity in the COMSOL model

In the Pressure Acoustics module of COMSOL Multiphysics ver. 5.1, the fluid is modelled as viscous by considering its dynamic viscosity μ, and bulk viscosity μ_B. This will incorporate the attenuation due to bulk viscous losses and the speed of sound is altered accordingly as denoted here in Eqn. 1:[1]

$$c_{vis} = c_0 \left(1 + i\omega \frac{\left(\frac{4\mu}{3} + \mu_B \right)}{\rho c_0^2} \right)^{0.5} \tag{1}$$

where c_{vis} indicates the altered speed of sound, c_0 fluid's speed of sound, $i = \sqrt{-1}$, ω angular frequency and ρ_0 as the density of the fluid. The damping also can be added to the solid particle's properties by implementing isotropic loss factor into its elastic moduli matrix:[1]

$$\boldsymbol{C_D} \equiv (1 + i\eta_s)\, \boldsymbol{C} \tag{2}$$

that $\boldsymbol{C_D}$ denotes 'damped' moduli matrix, η_s isotropic loss factor and $\boldsymbol{C}$ elastic moduli matrix. The isotropic loss factor, η_s of PMMA considered 0.05 which is valid for temperatures (here 25 °C) below its glass transition temperature.[2]

References

[1] C. Multiphysics, *COMSOL, Burlington, MA*.

[2] M. Dixit, S. Gupta, V. Mathur, K. S. Rathore, K. Sharma and N. Saxena, *Chalcogenide Letters*, 2009, **6**, year.