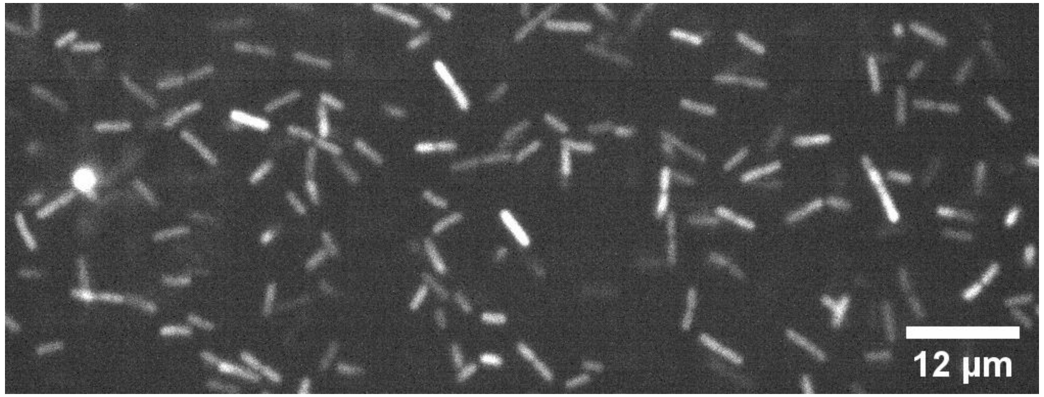
Rheology of bacterial suspensions under confinement



Zhengyang Liu

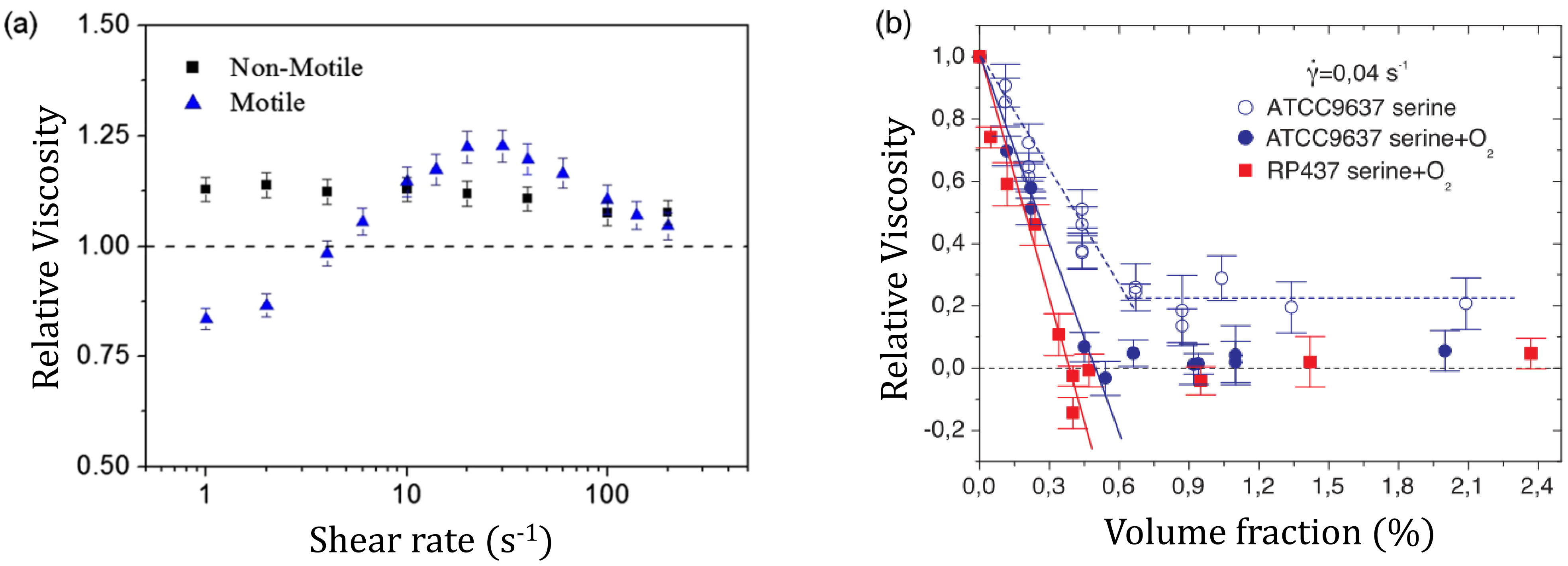
Co-authors: Kechun Zhang and Xiang Cheng

APS March Meeting, Boston, 2019

University of Minnesota

CEMS | Chemical Engineering & Materials Science

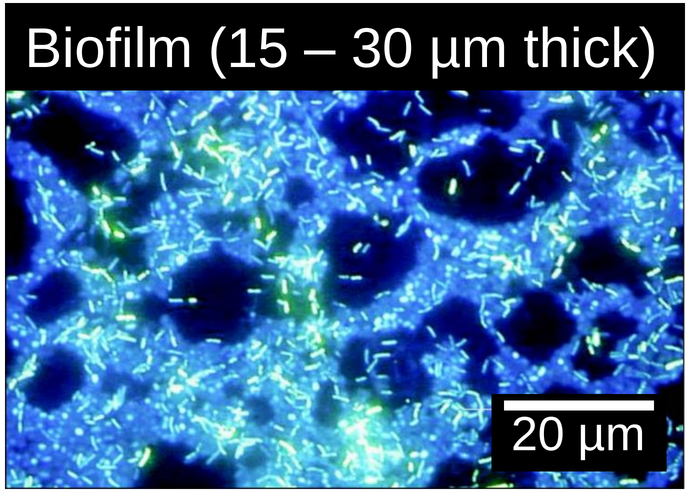
Bacterial suspension rheology



- In contrast to passive particle suspensions, bacteria can **reduce** the viscosity of their suspending fluids
- Zero apparent viscosity "bacterial superfluid" can be achieved

Bacterial suspensions under confinement

Natural processes

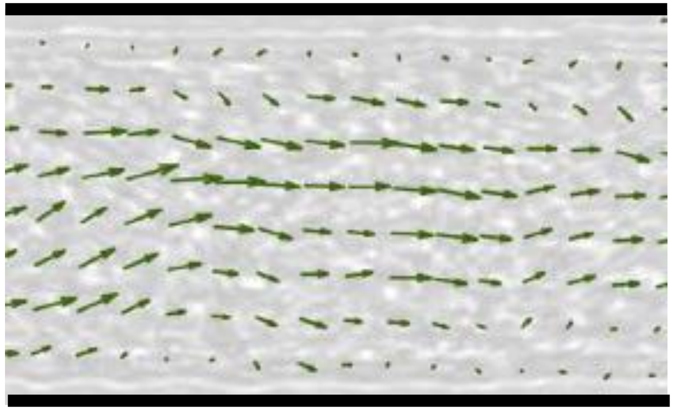


Donlan, *Emerg. Infect. Dis.*, 2002

https://sustainablepulse.com

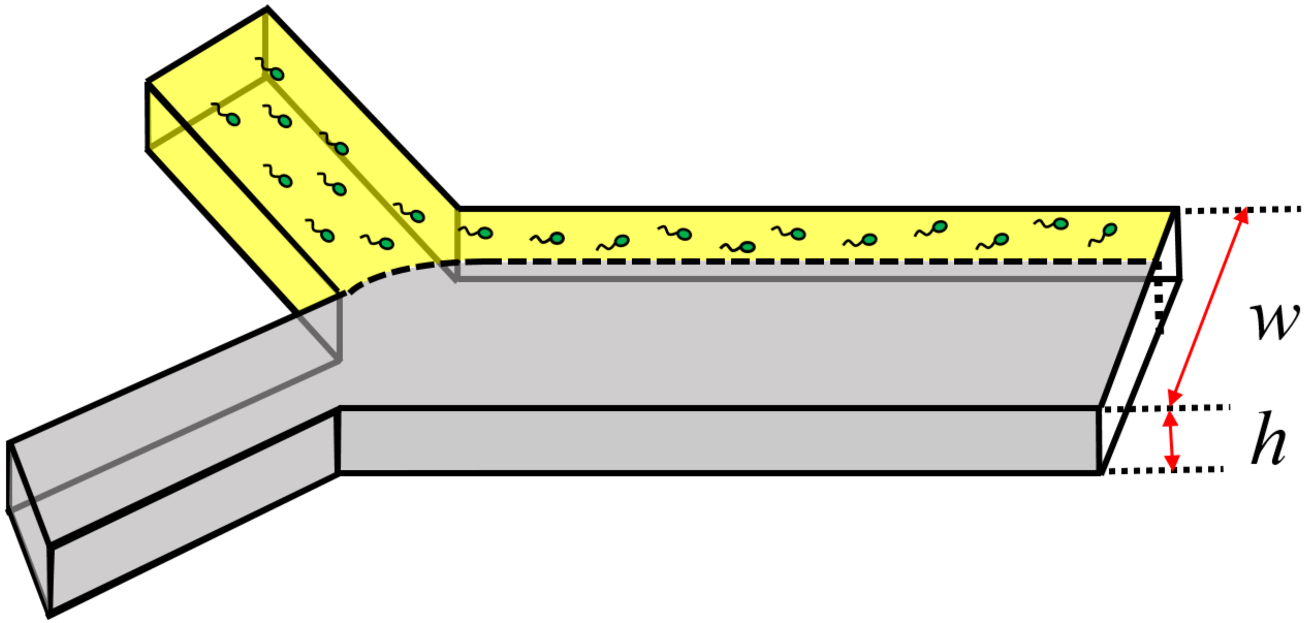
Fundamental interest

Lushi et al., *PNAS*, 2014



Wioland, *New J. Phys.*, 2016

Microfluidic channel viscometer



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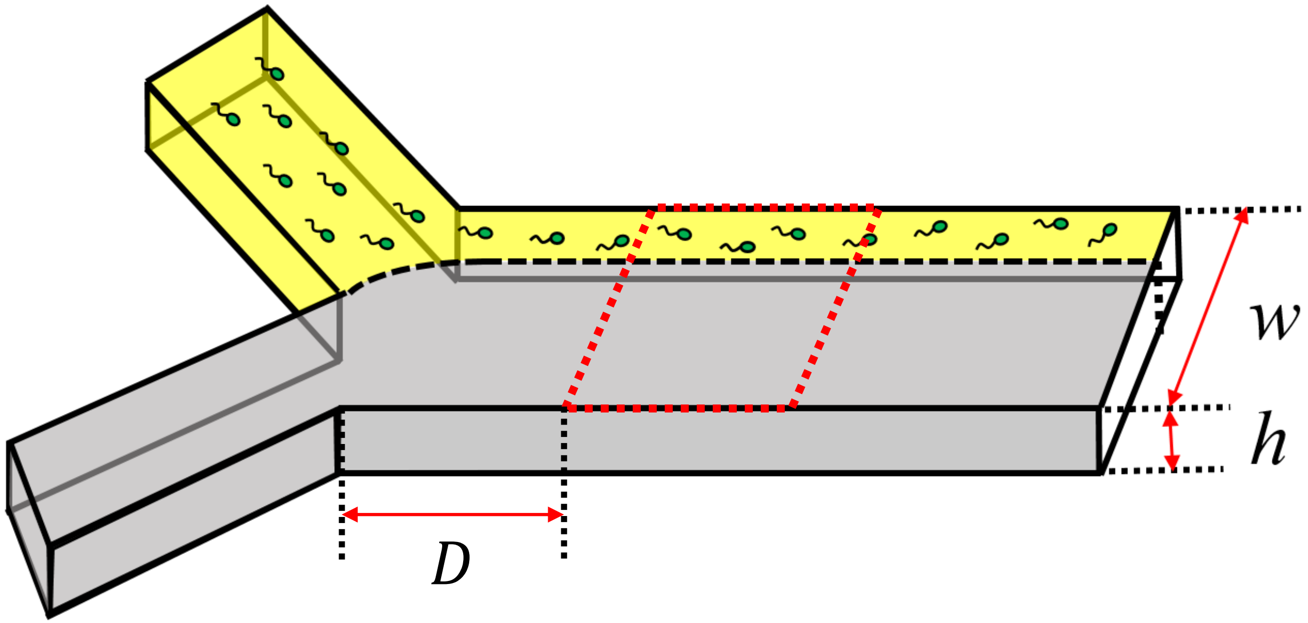

$$w = 600\ \mu\text{m}$$
$$h = 25\sim128\ \mu\text{m}$$
$$D = 500\sim1000\ \mu\text{m}$$
$$n = 1.6\times10^{10}\ \text{ml}^{-1}$$

Guillot et al., *Langmuir*, 2006; Gachelin et al., *PRL*, 2013

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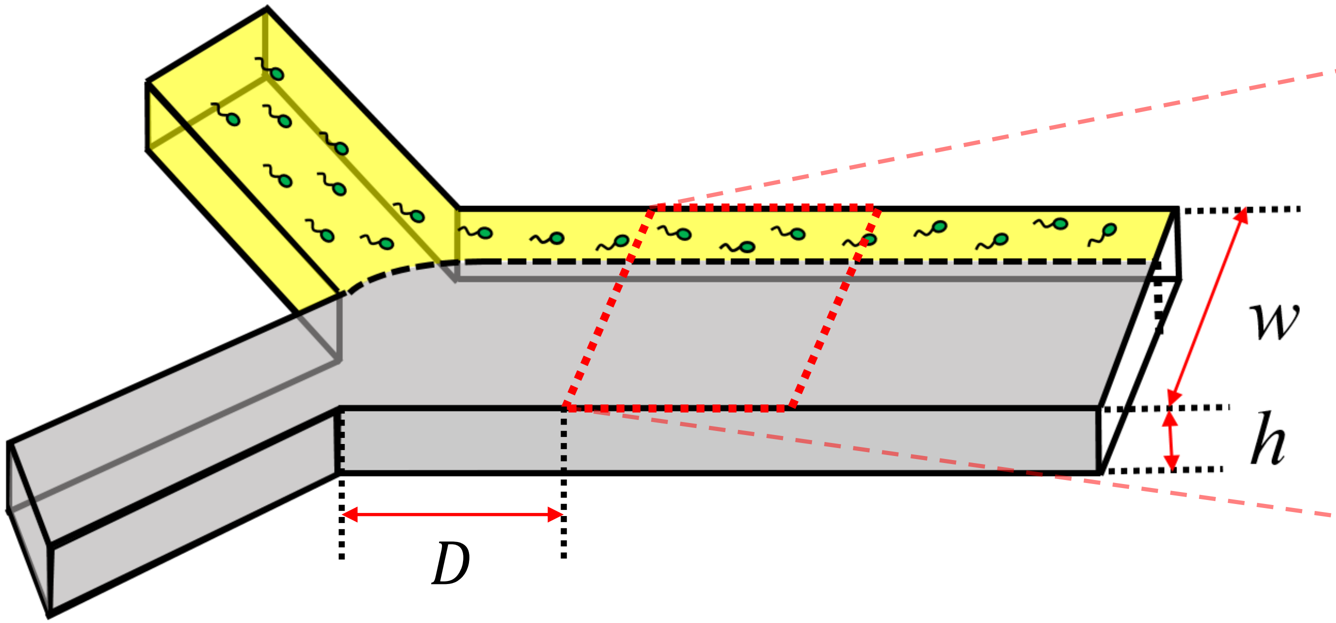

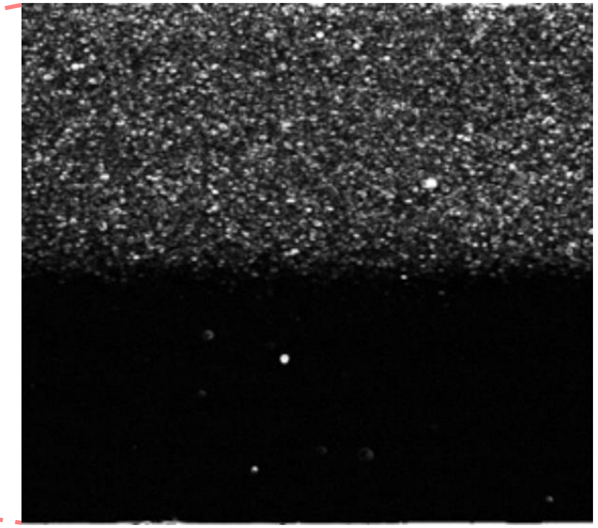

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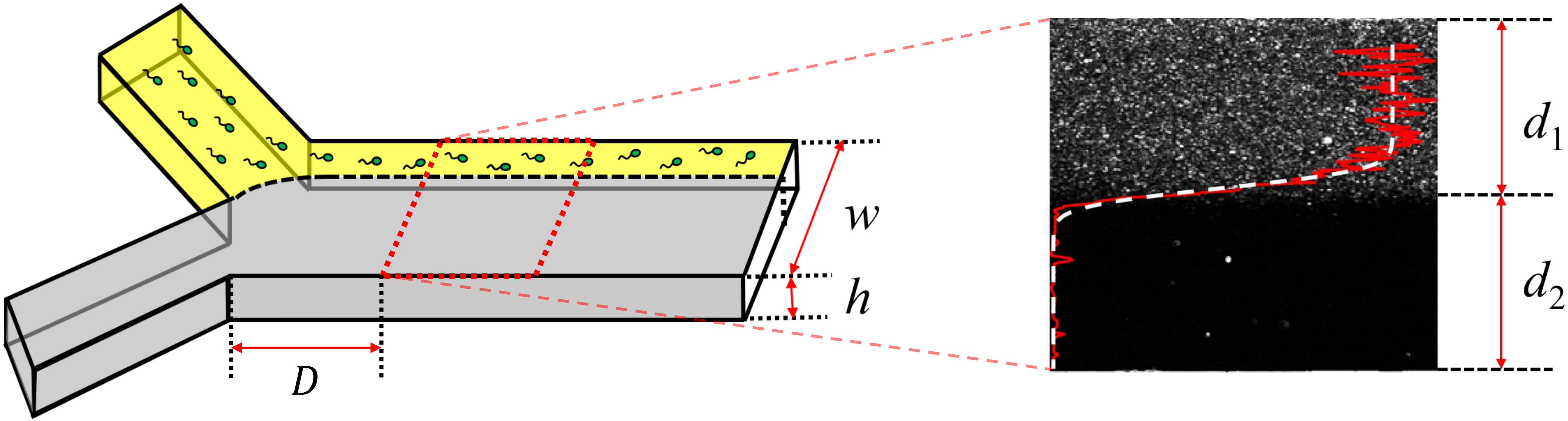

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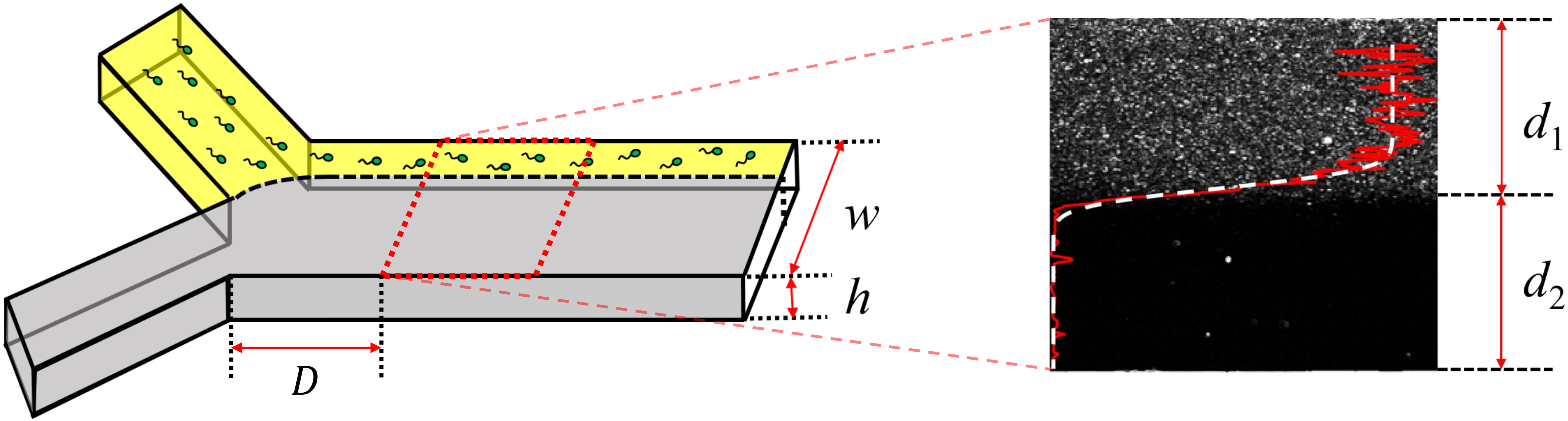

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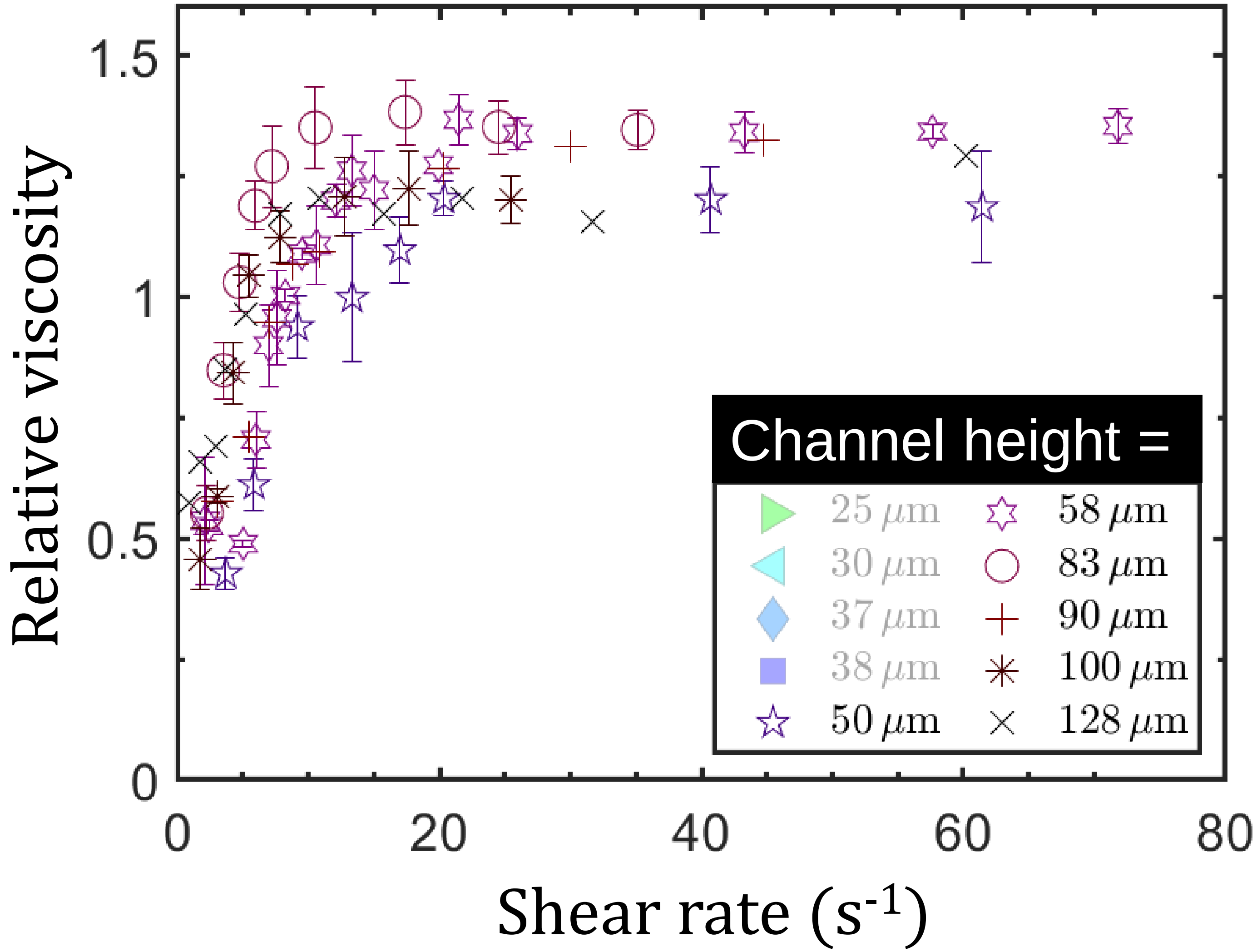
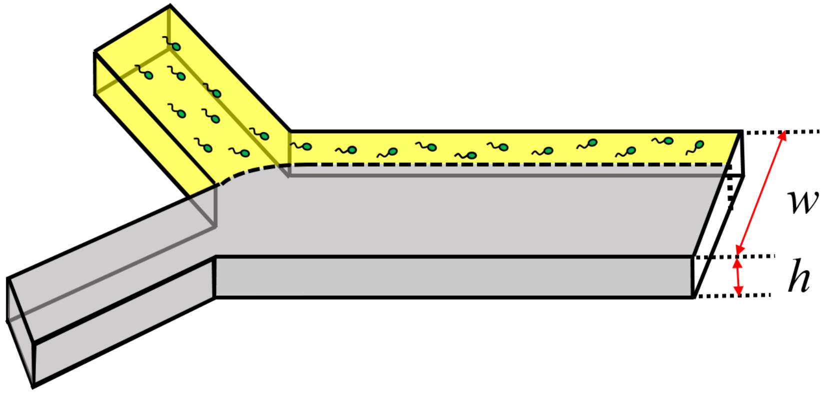
Relative viscosity $= \dfrac{\eta_1}{\eta_2} = \dfrac{d_1}{d_2}$

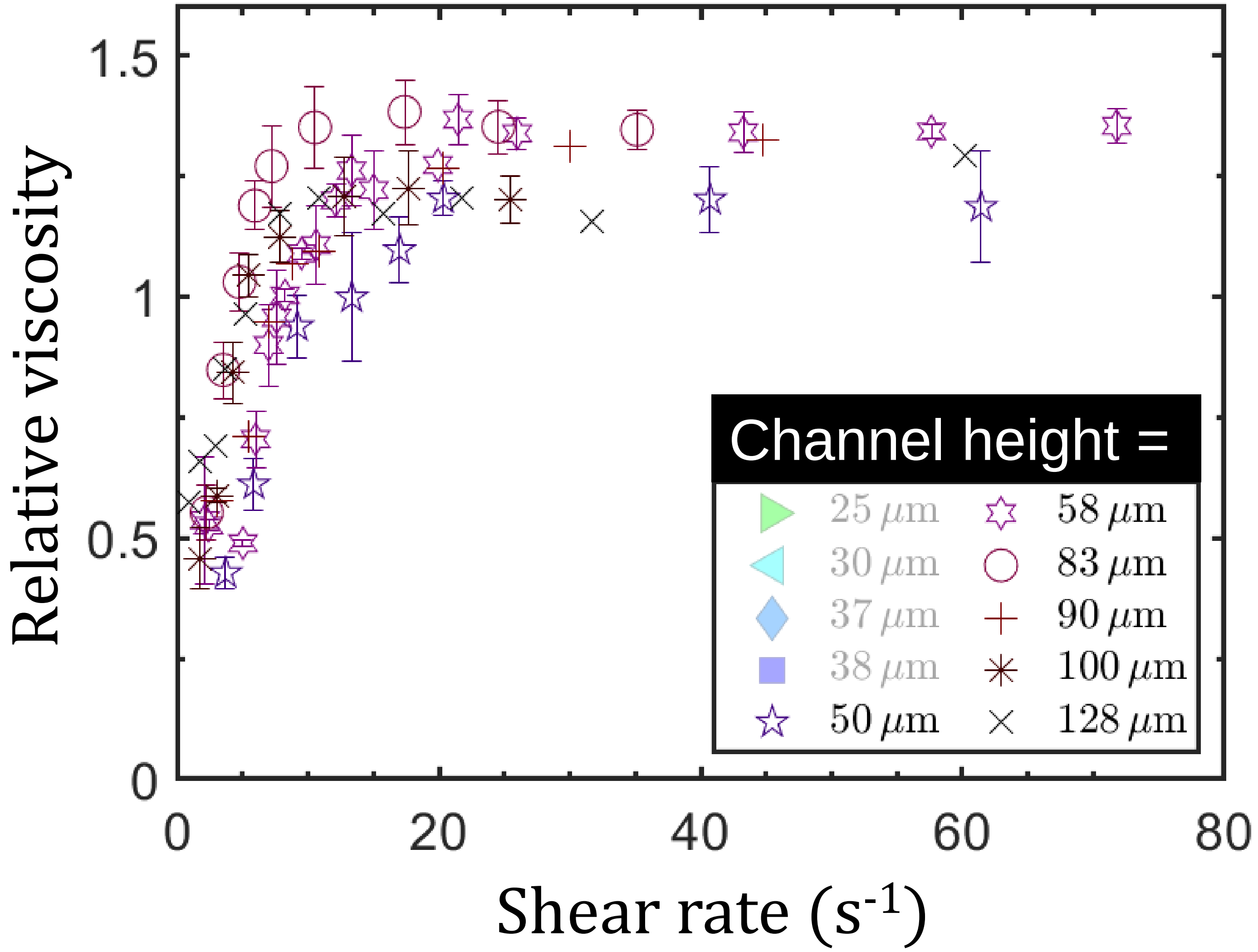
Viscosity under confinement

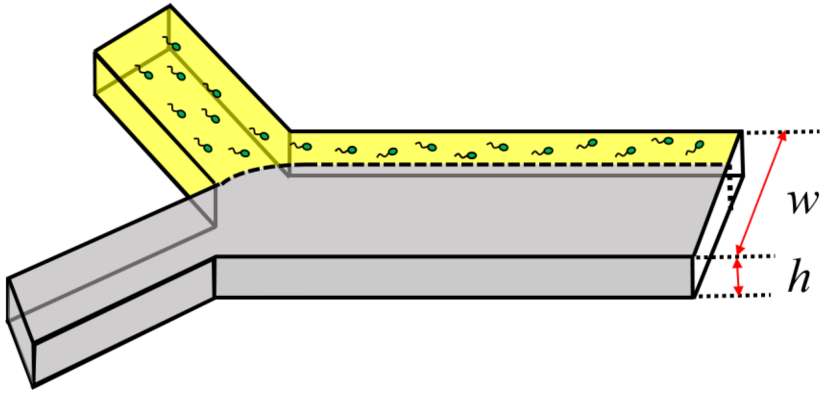




$h \geq 50\ \mu\text{m}$

Viscosity under confinement

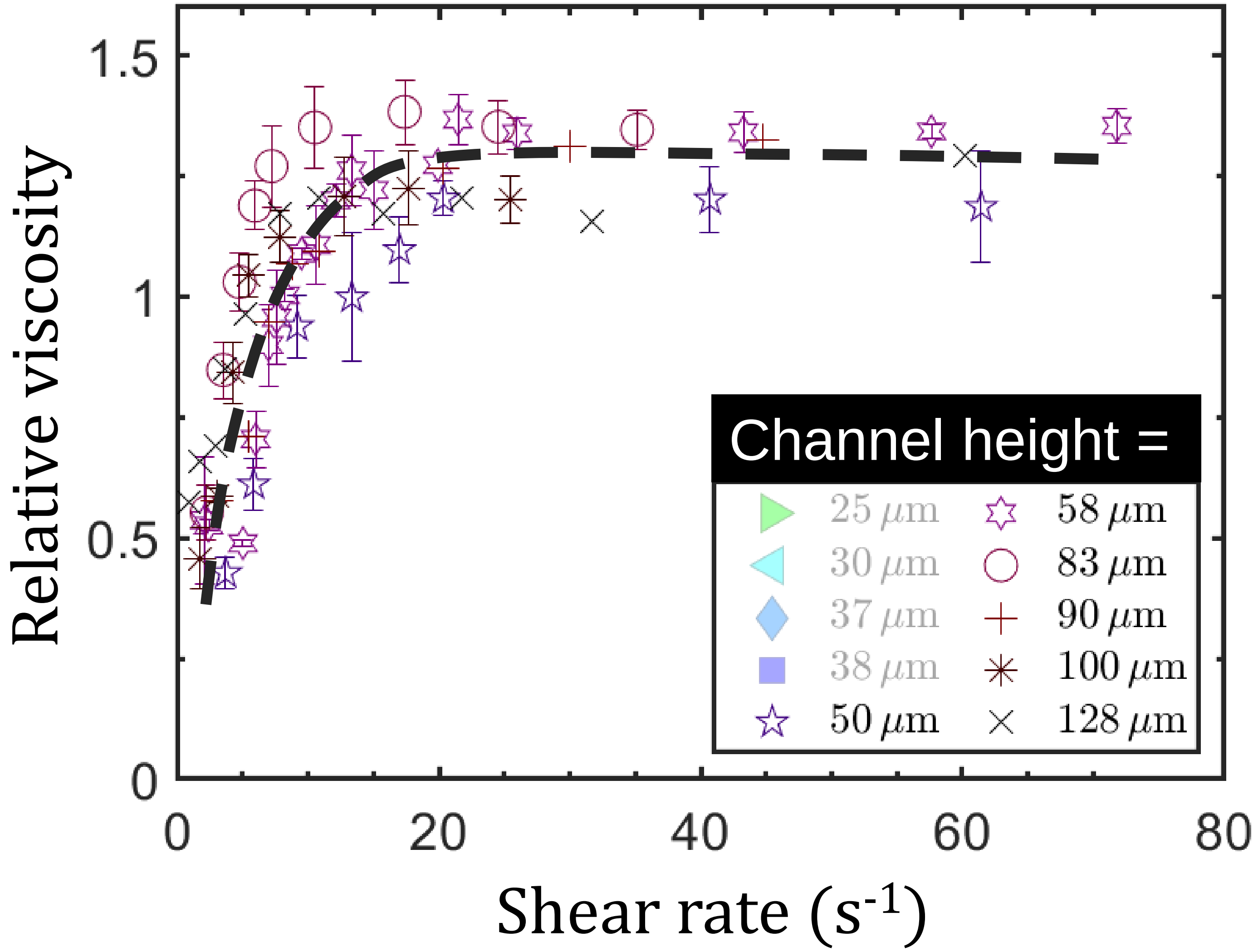


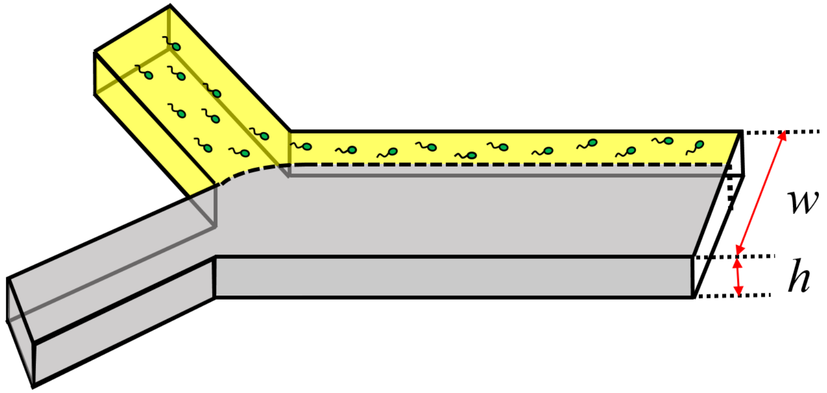


$h \geq 50\ \mu m$

- Shear thickening at low shear rate

Viscosity under confinement

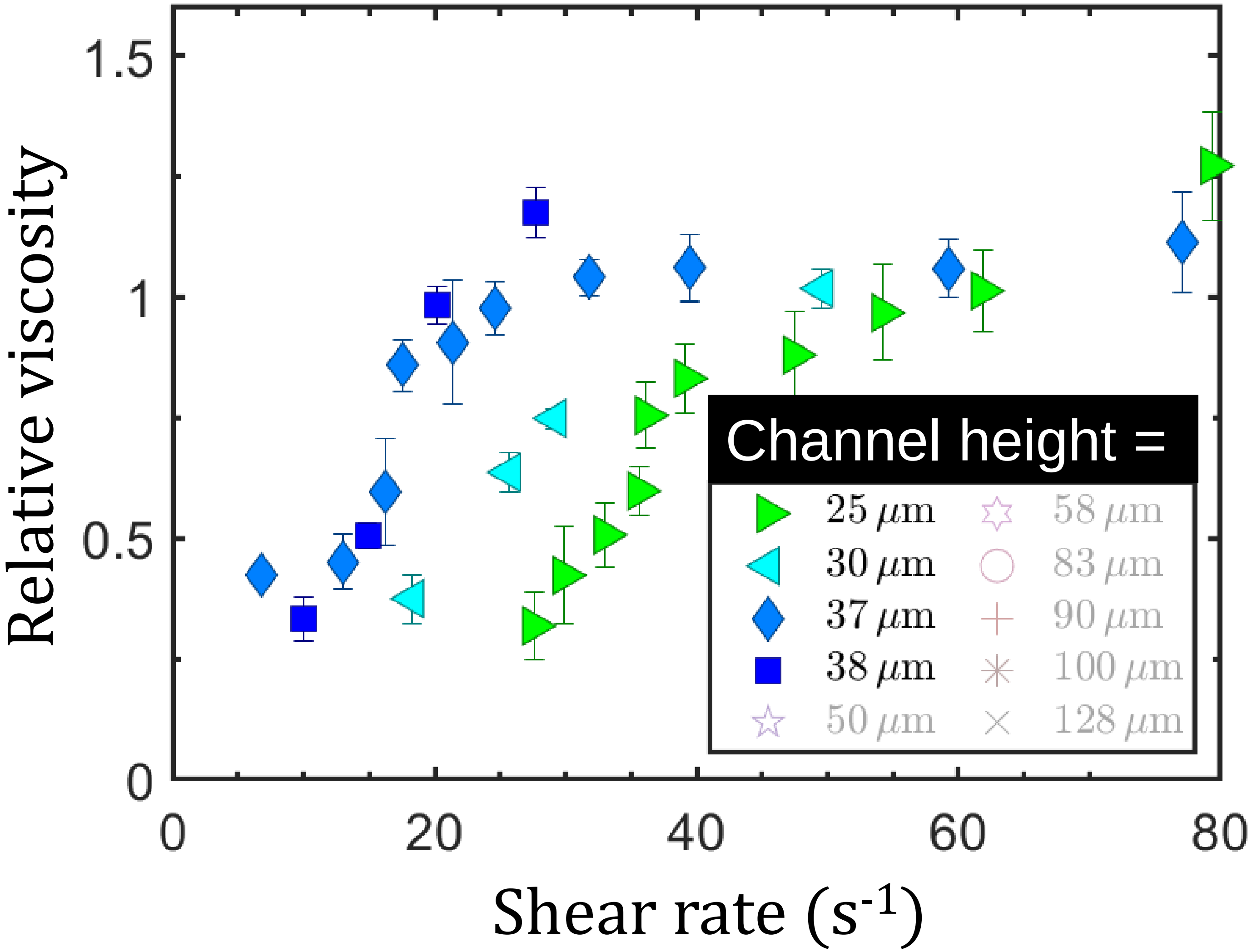


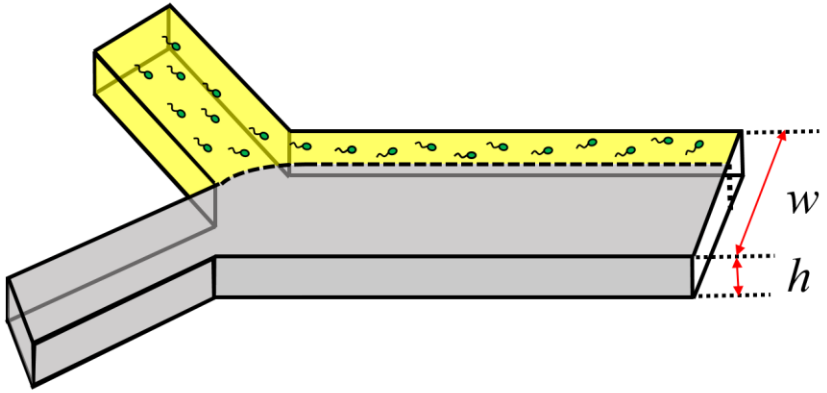


$h \geq 50\ \mu m$

- Shear thickening at low shear rate
- Fall on a same master curve: no confinement effect

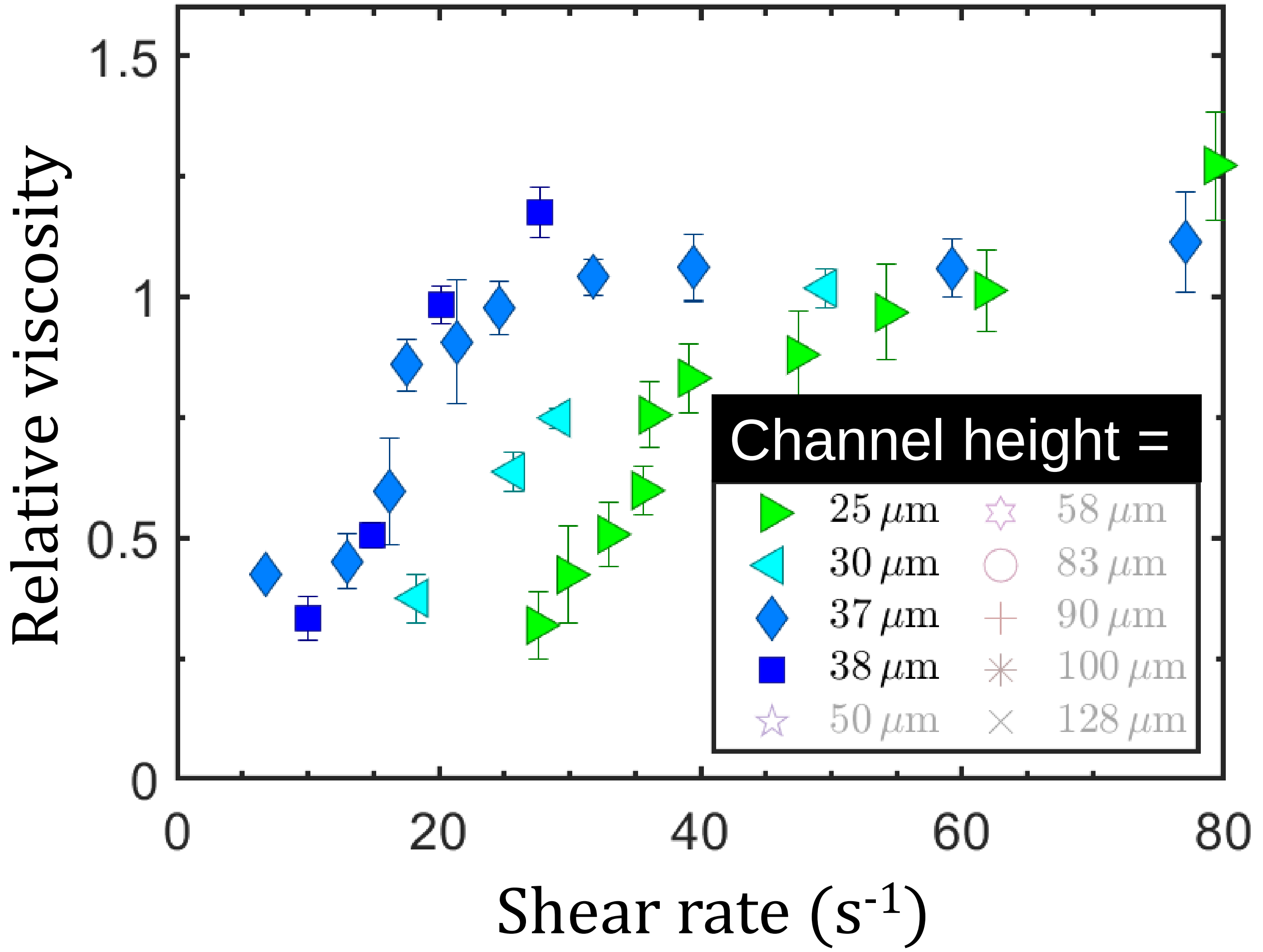
Viscosity under confinement

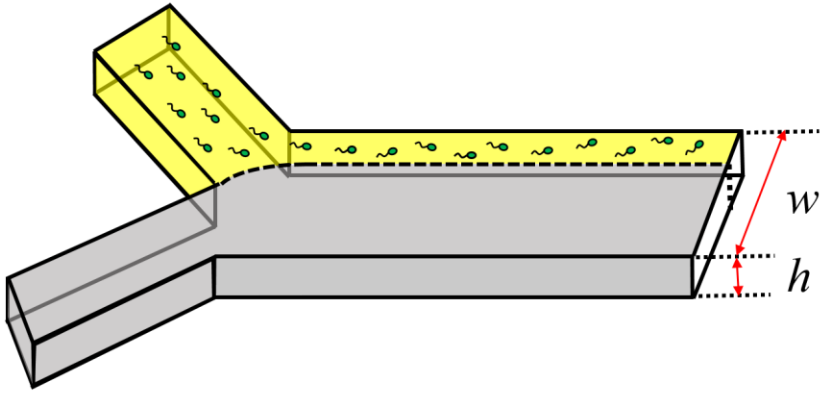




$h < 50\ \mu m$

Viscosity under confinement

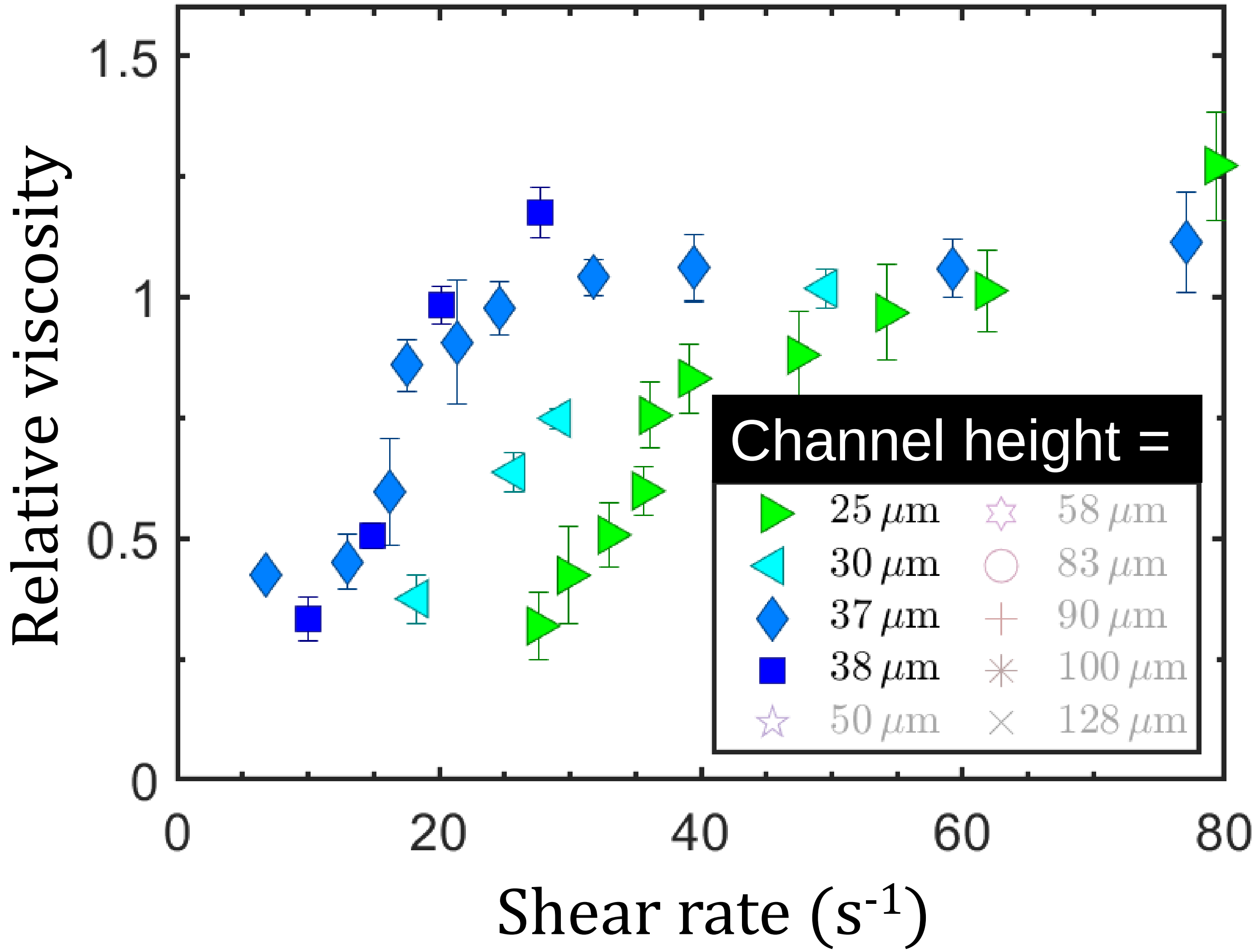


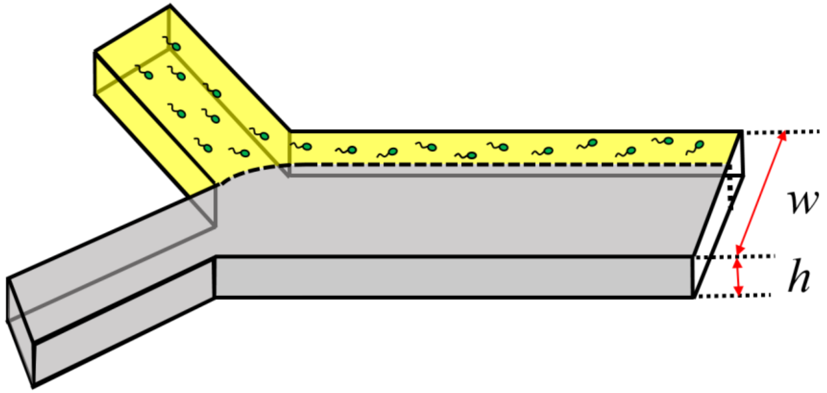


$h < 50\ \mu\text{m}$

- Shear thickening at low shear rate

Viscosity under confinement

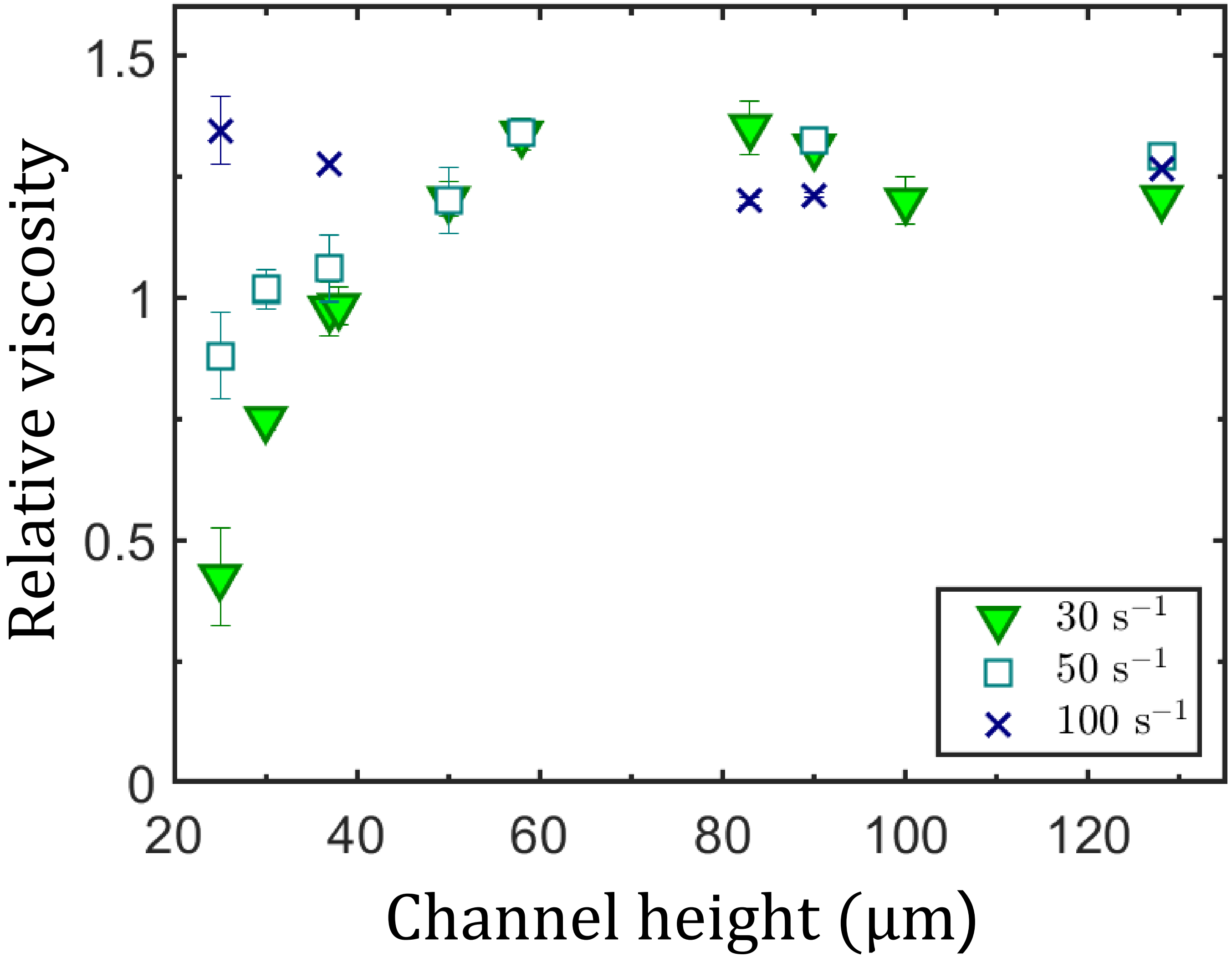




$h < 50\ \mu m$

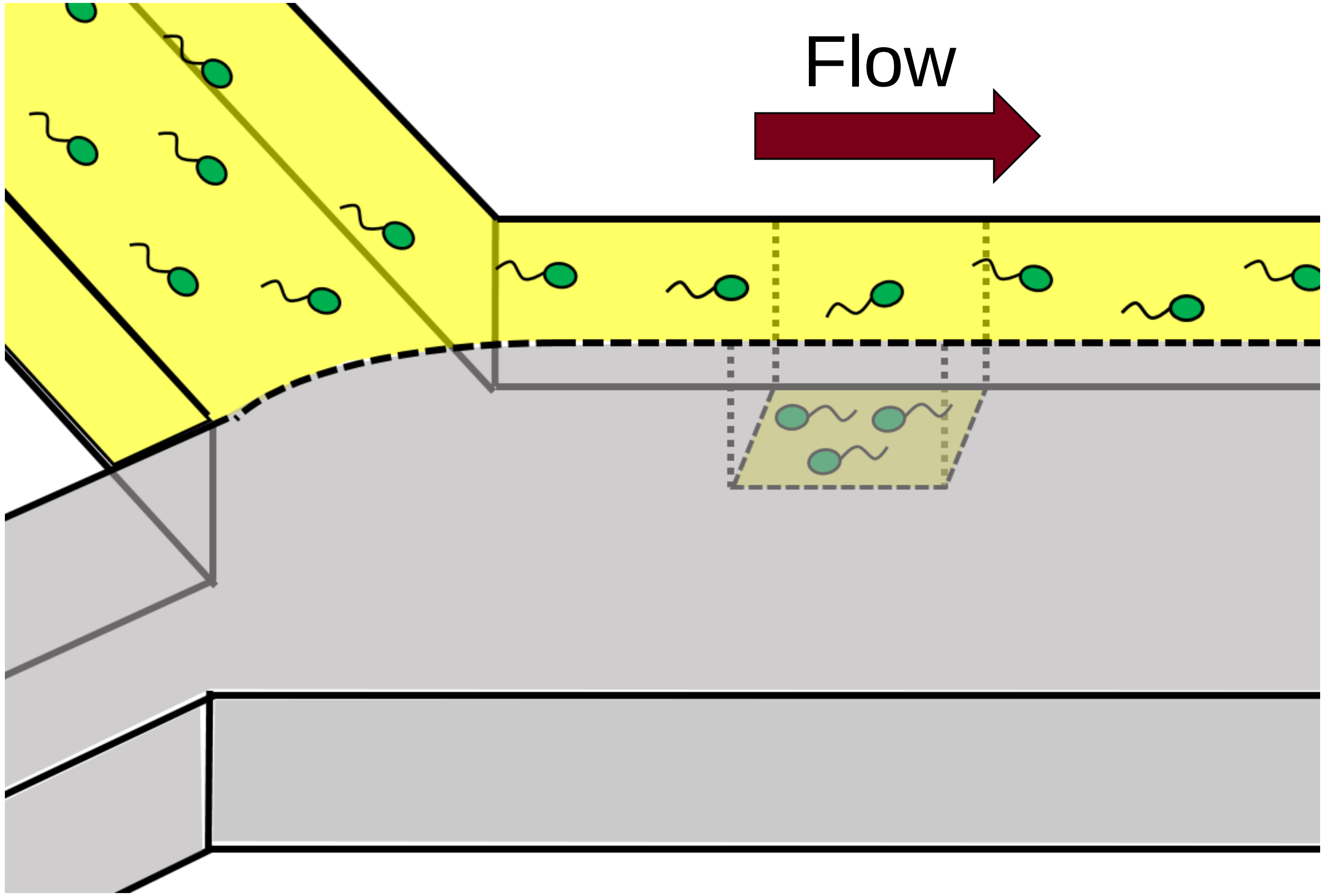
- Shear thickening at low shear rate
- Separated: a sign of confinement effect

Viscosity under confinement

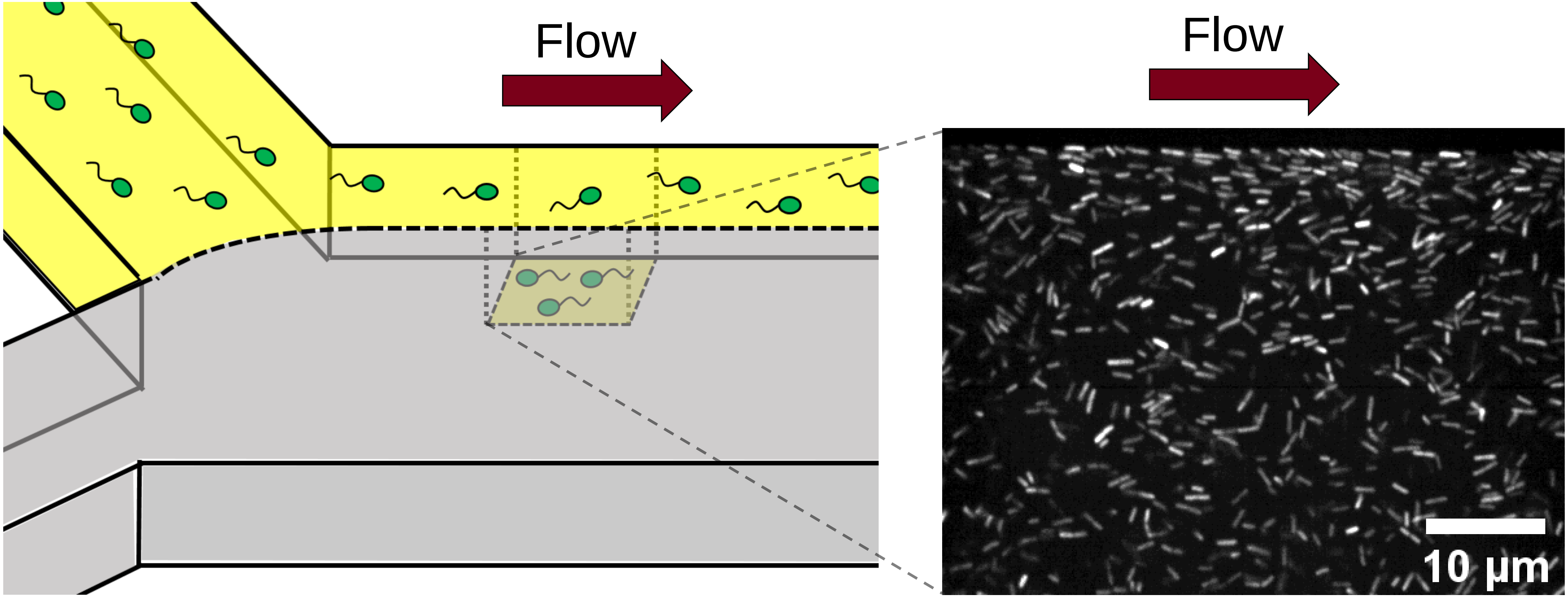


- At low shear rate, confinement **reduces** viscosity
- At high shear rate, viscosity is **independent** of confinement

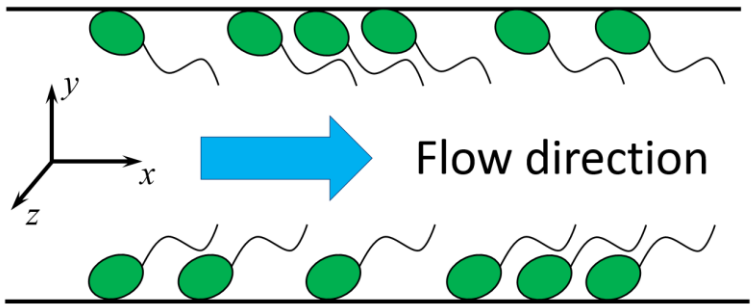
Upstream swimming near boundary



Upstream swimming near boundary



Boundary bacteria push fluid forward



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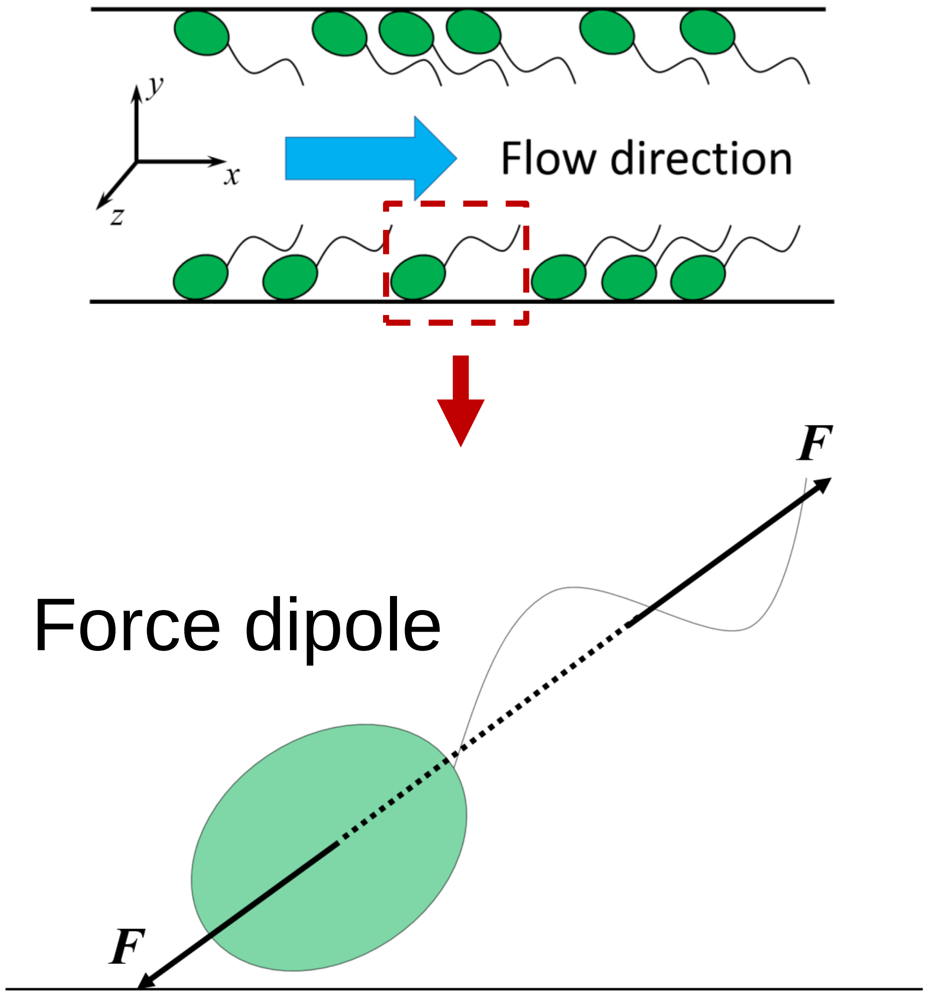
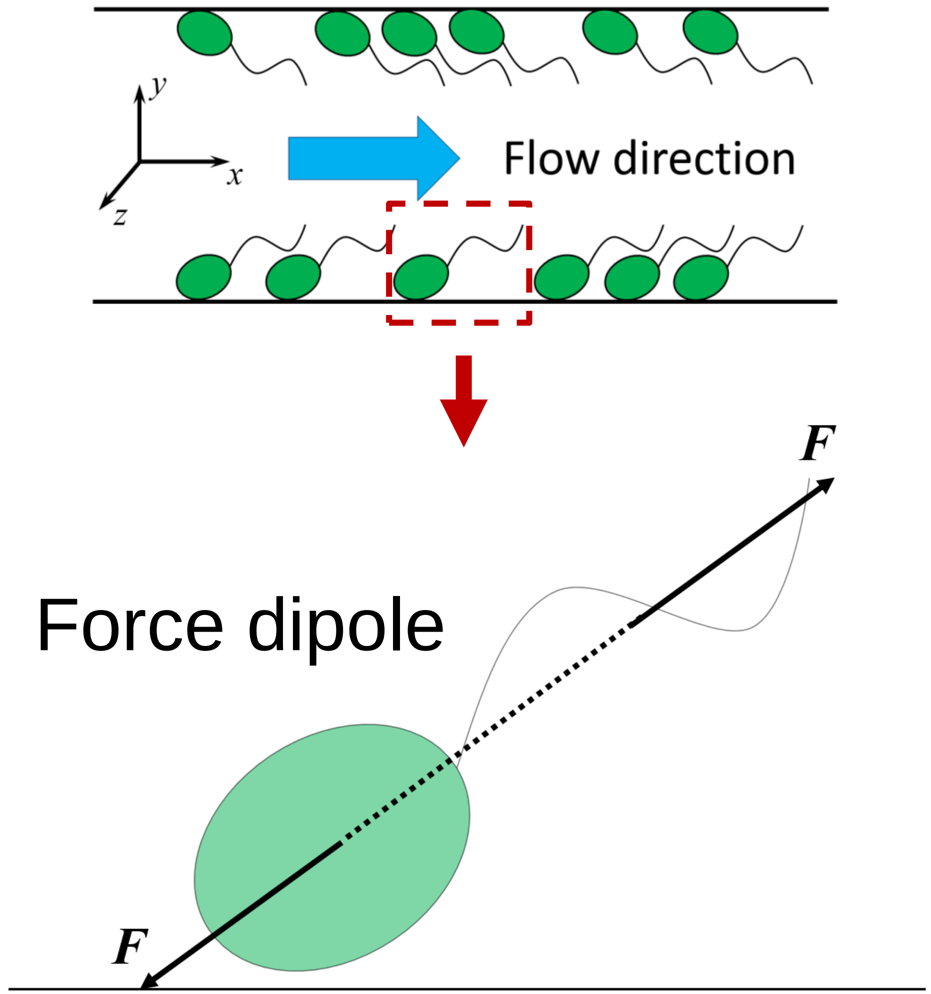
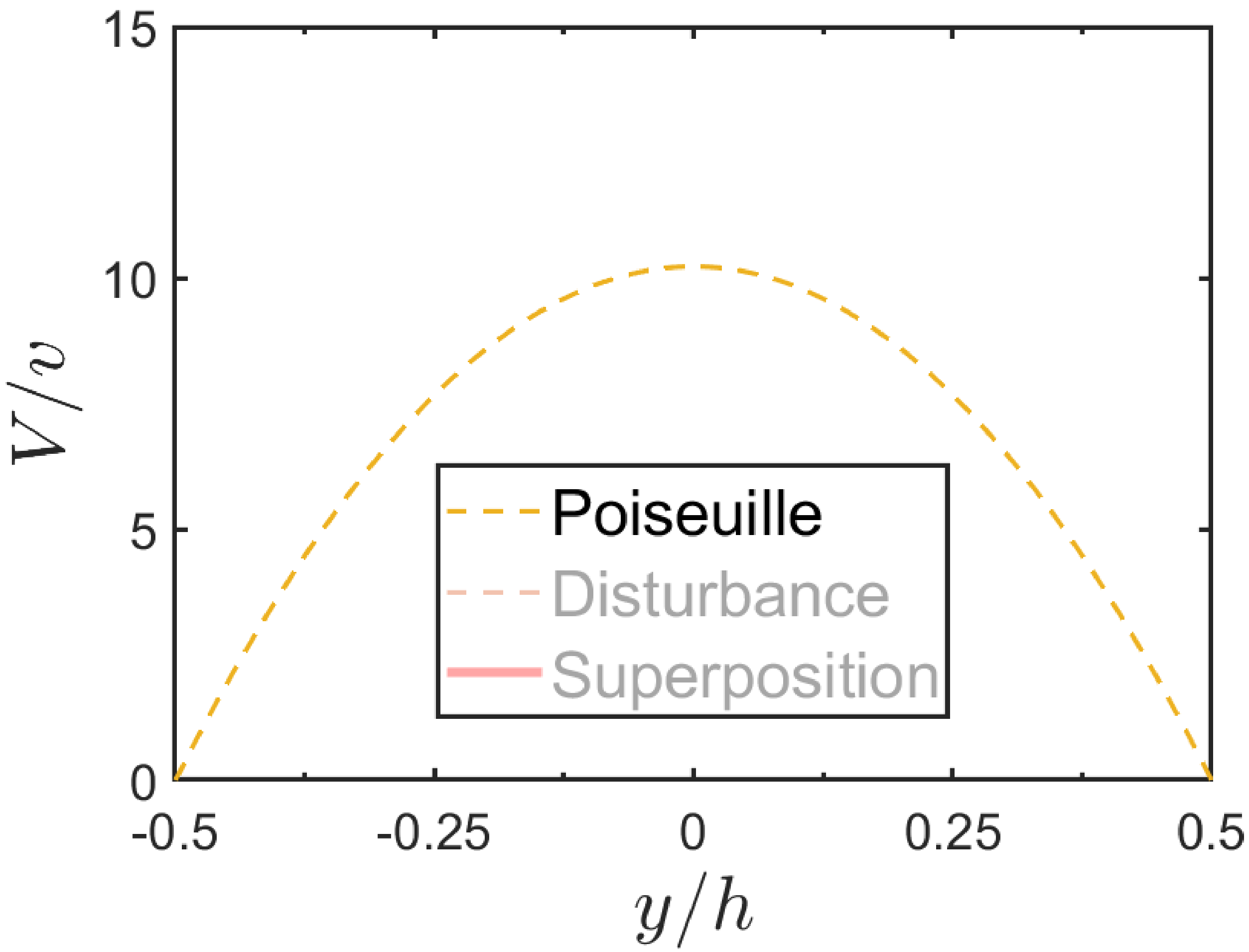


Force dipole

Boundary bacteria push fluid forward





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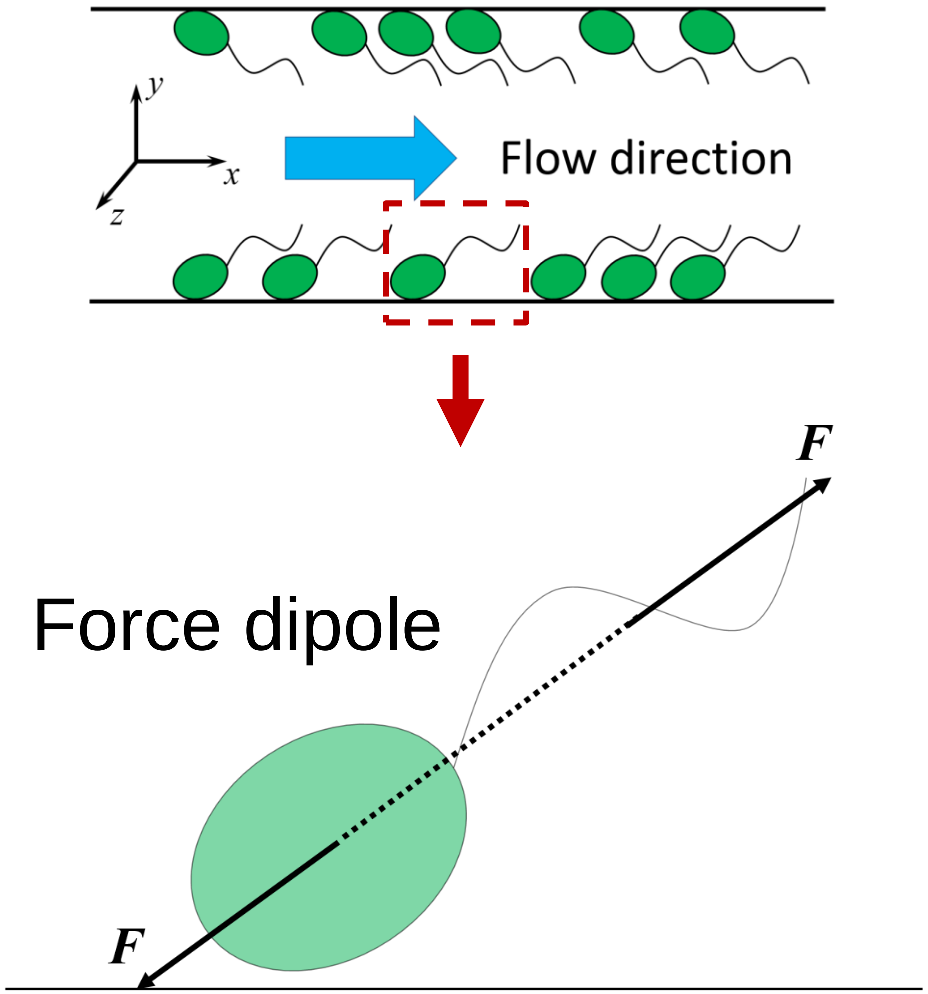

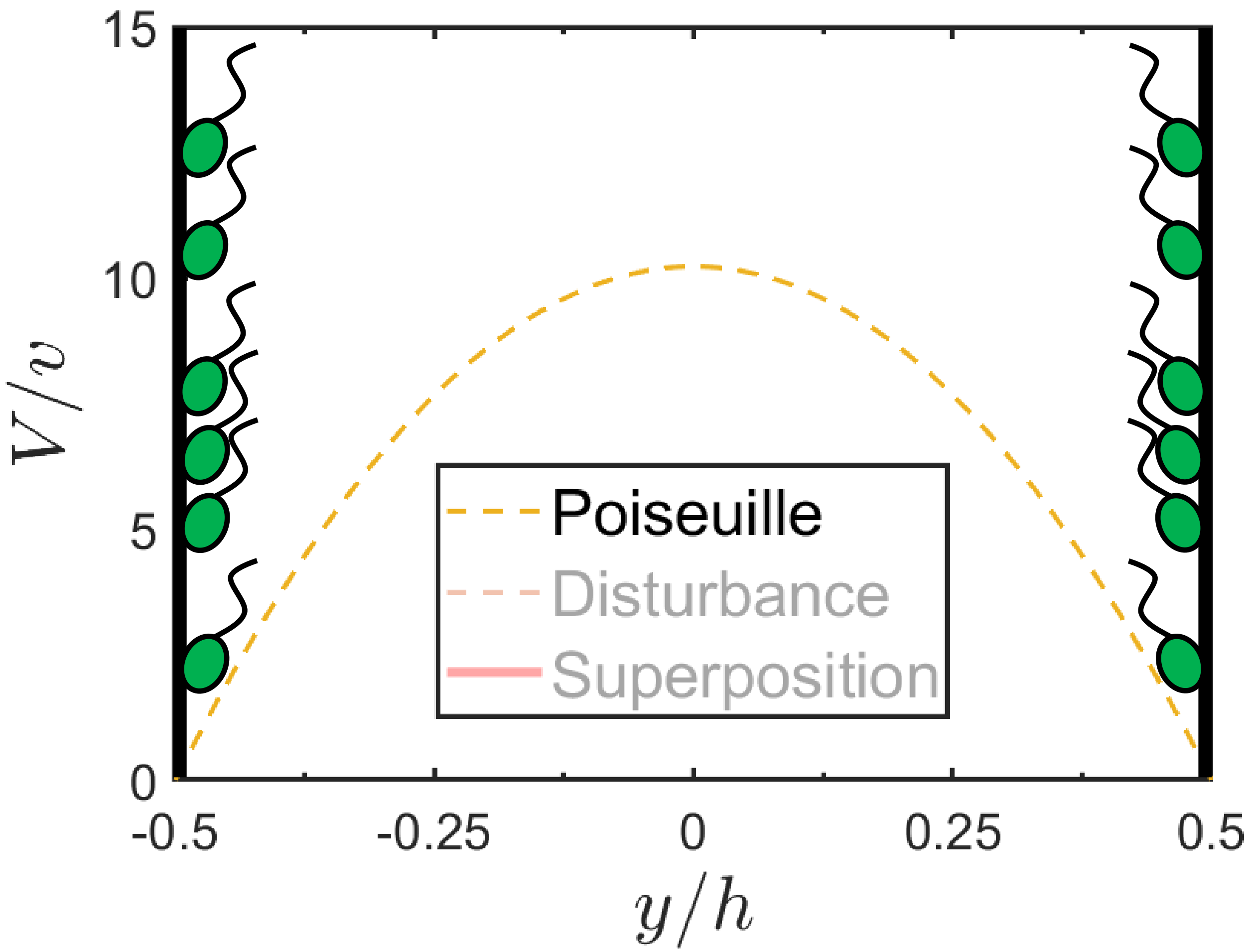

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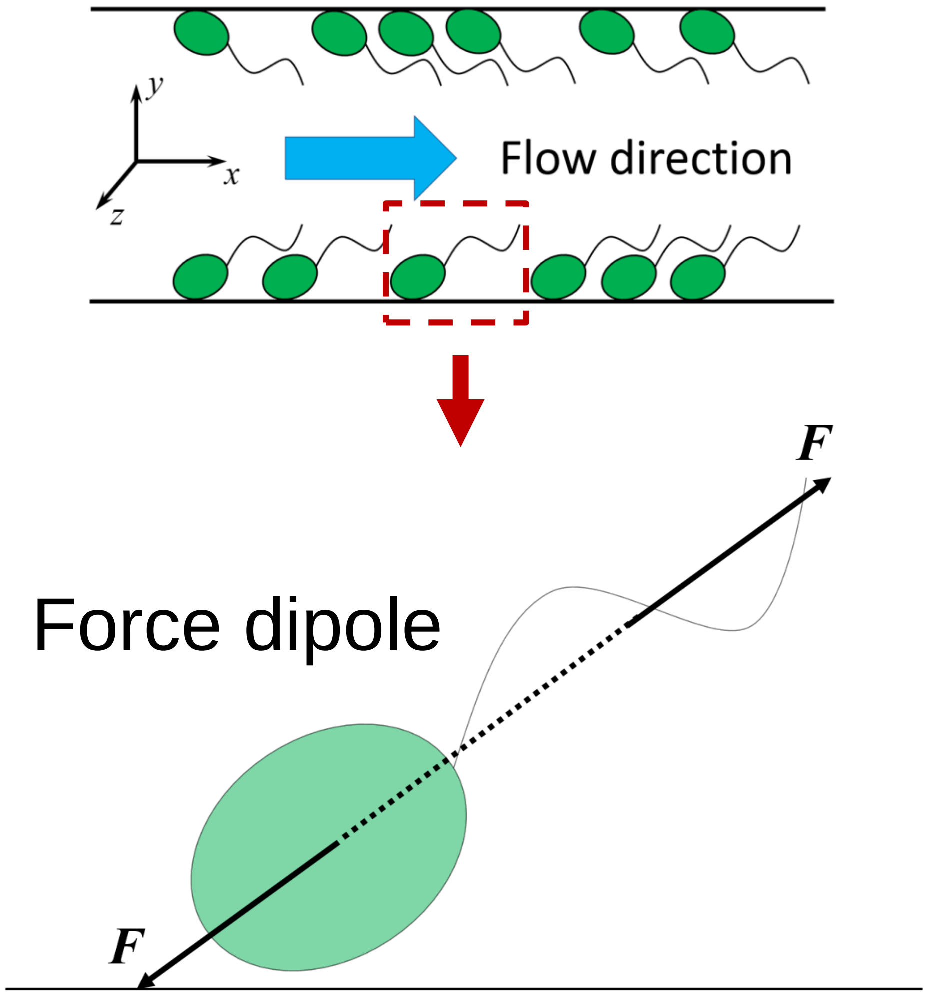

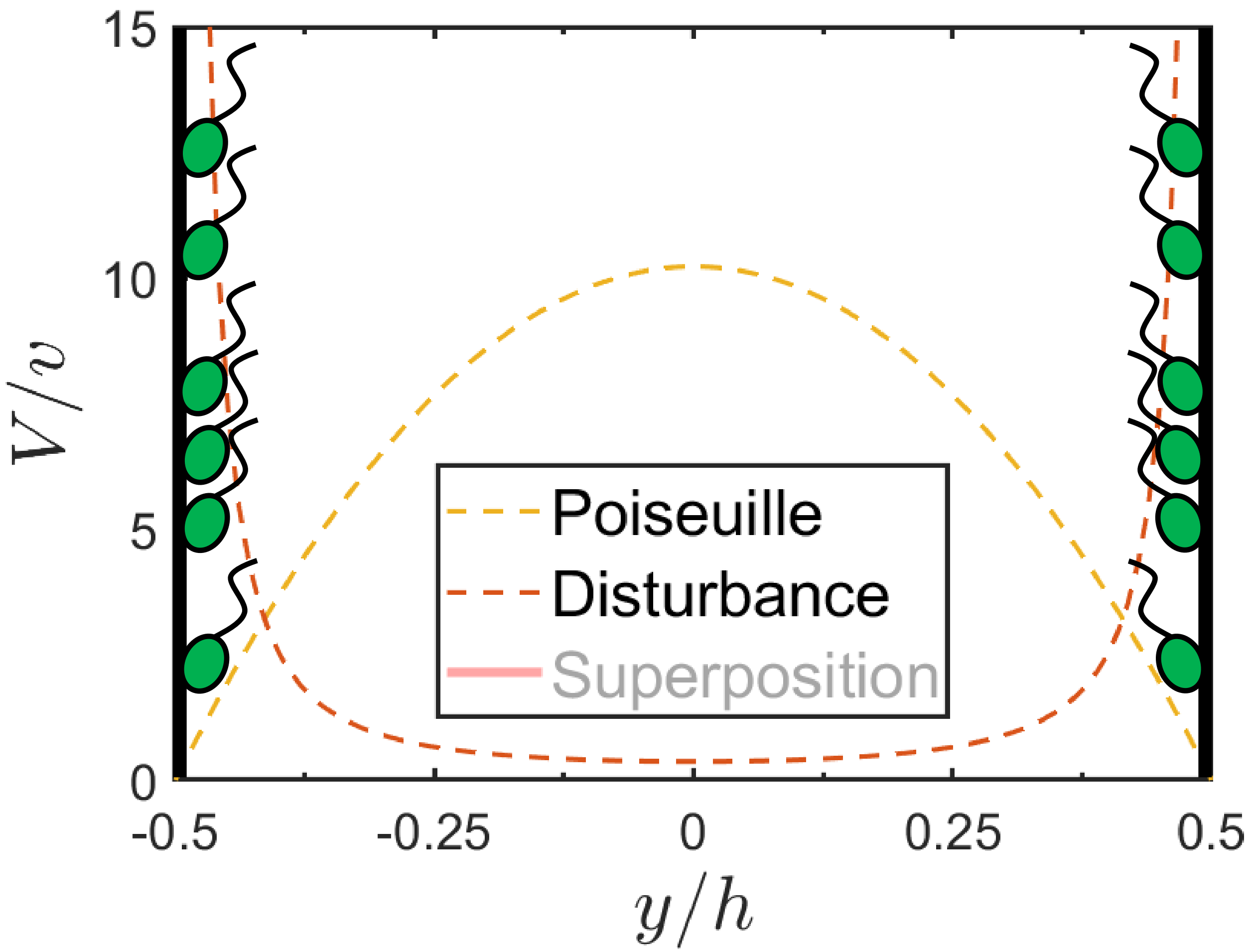

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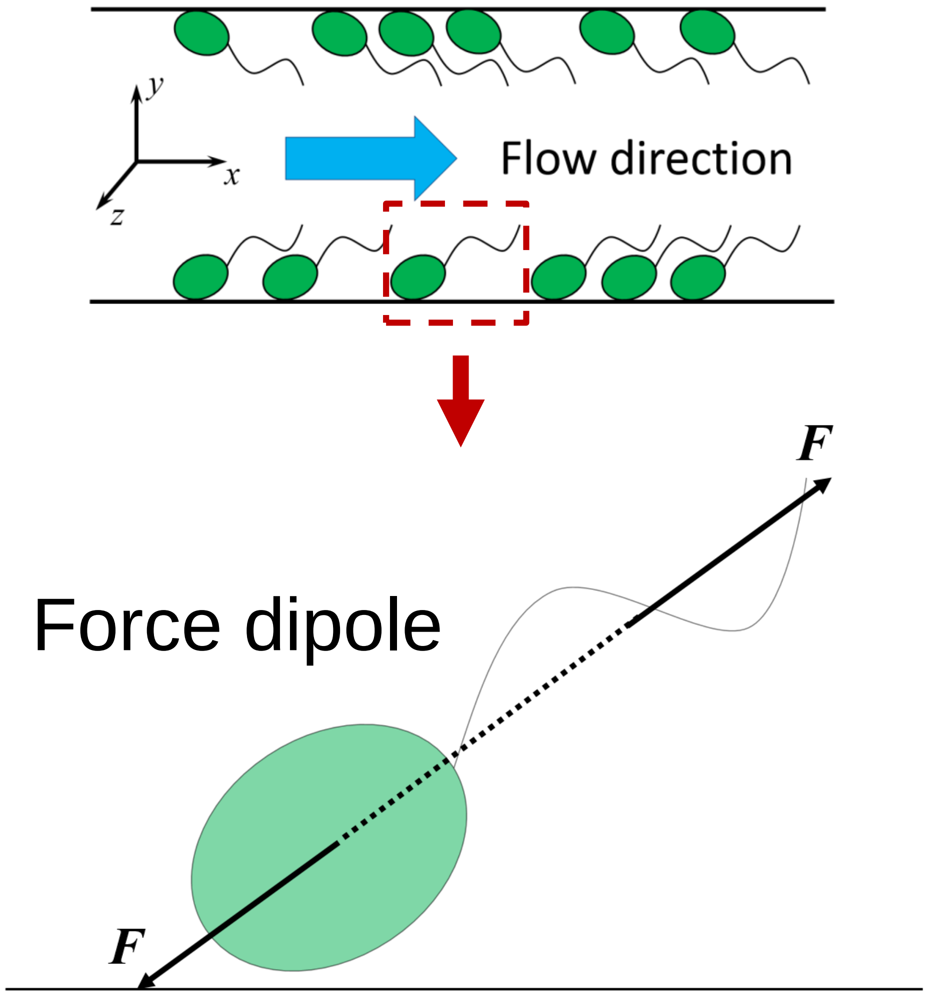

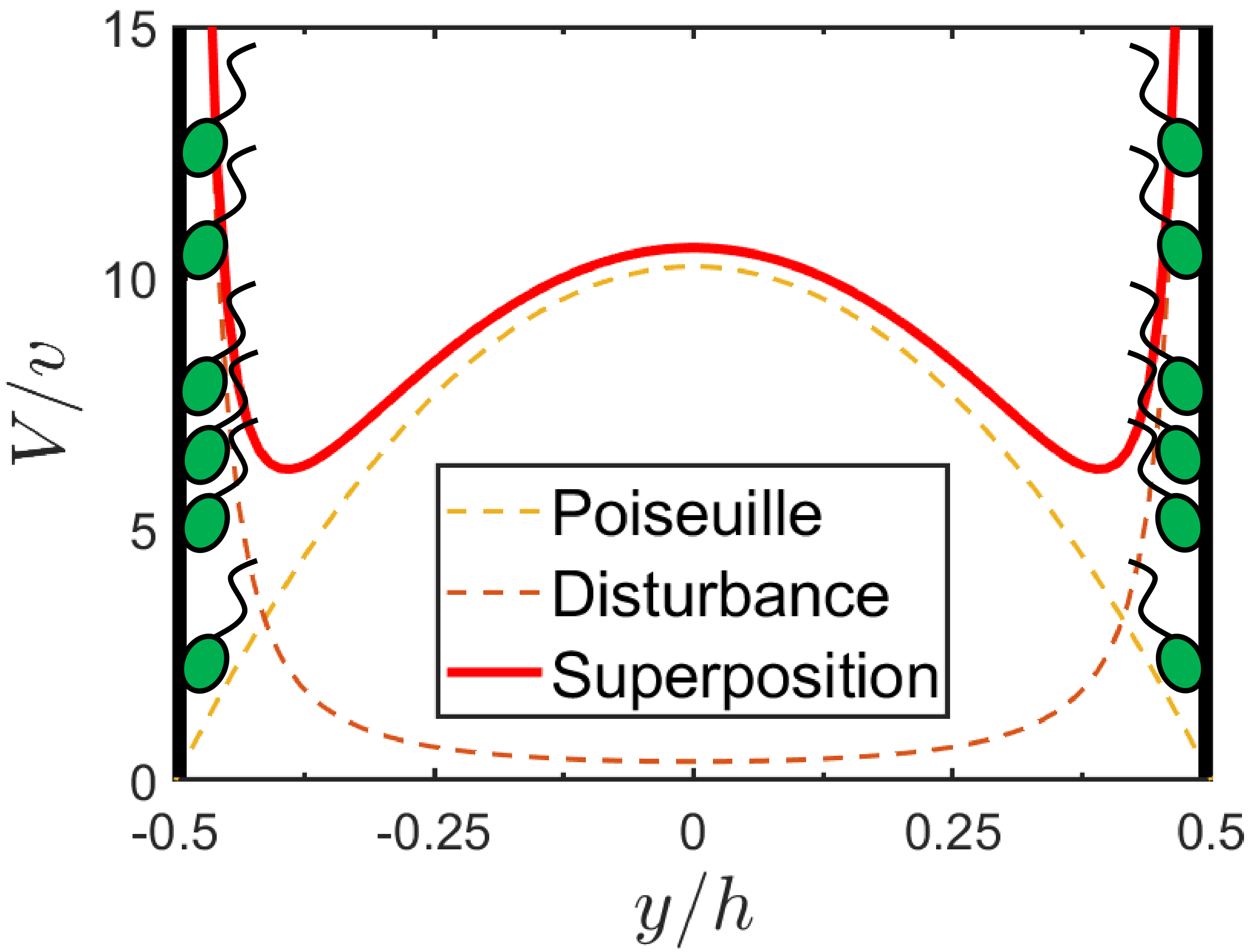

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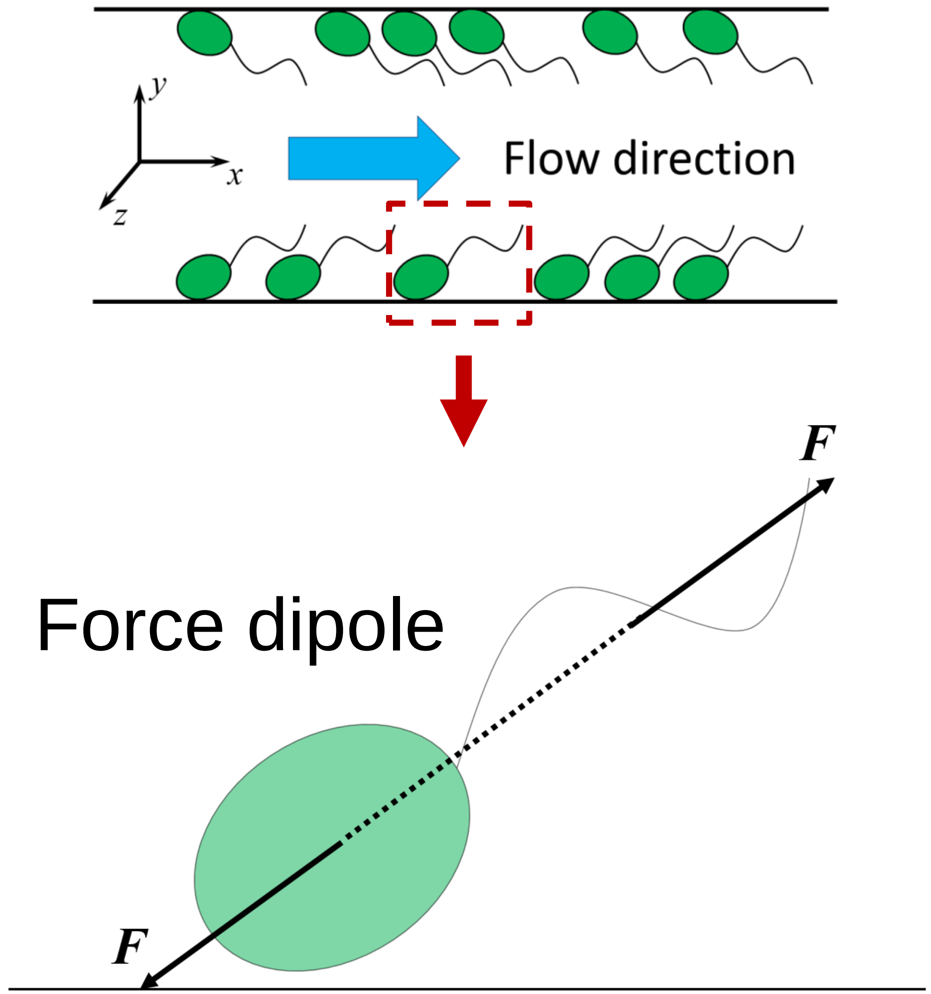

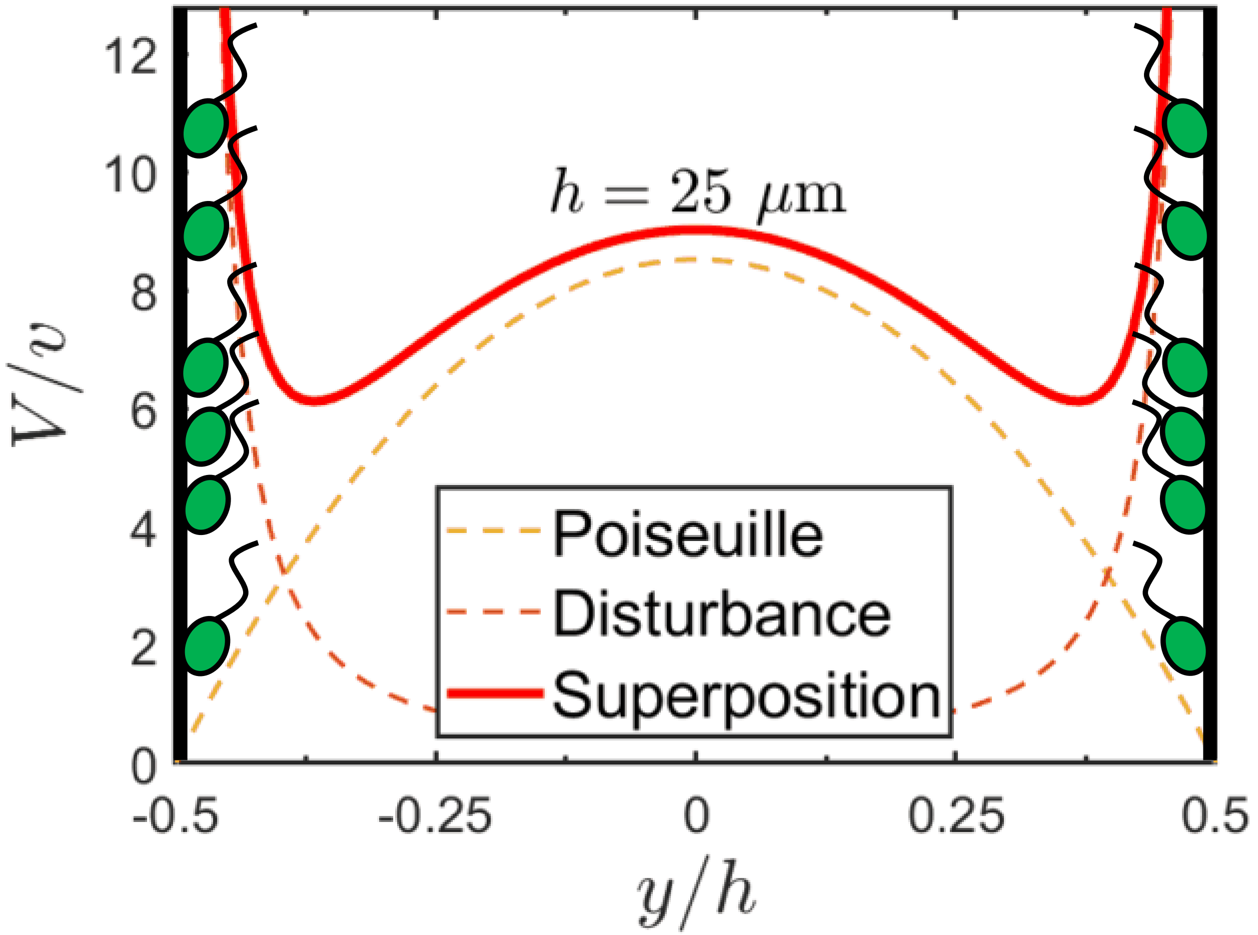

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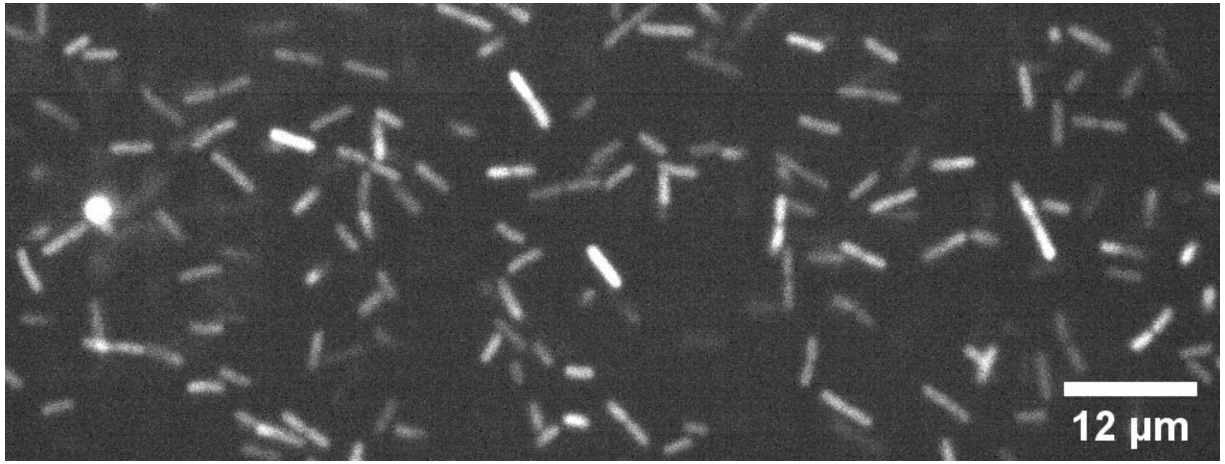
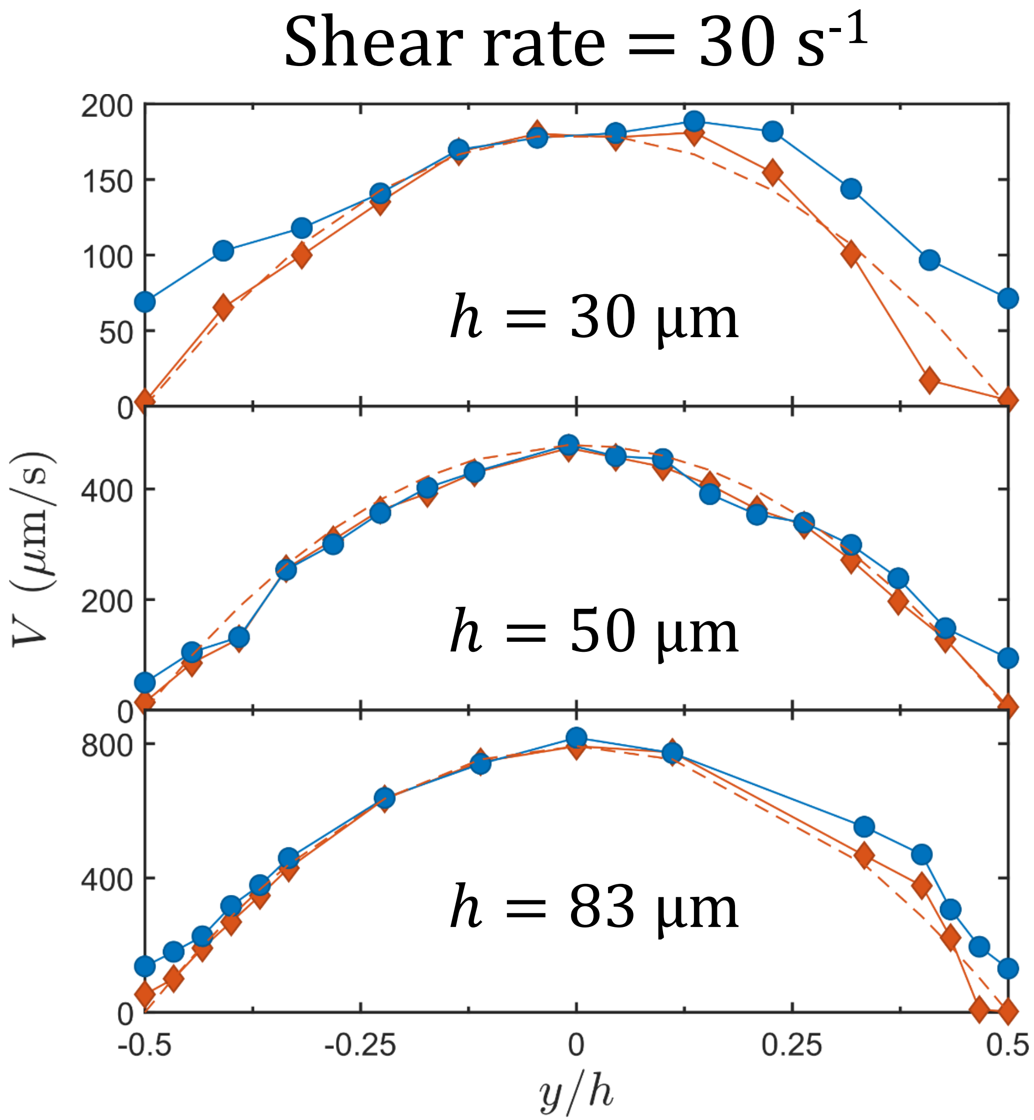
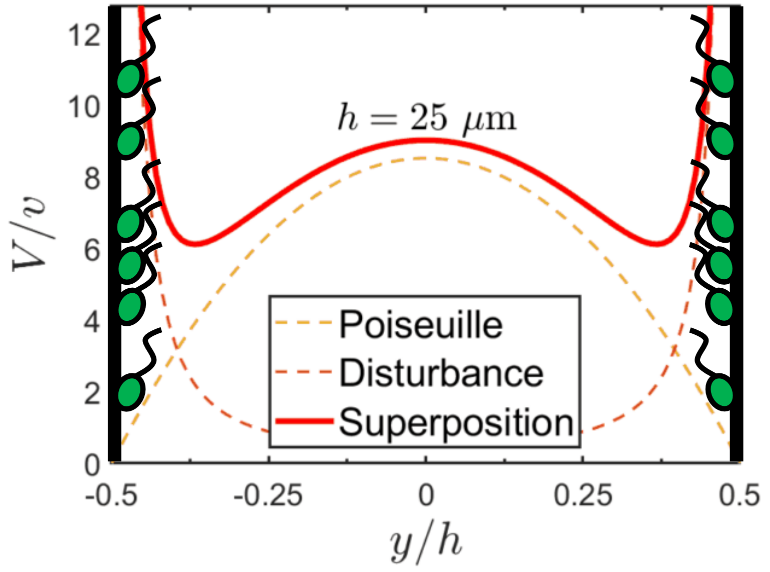
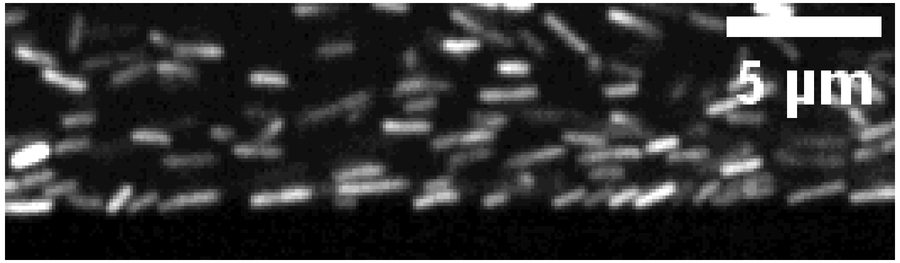


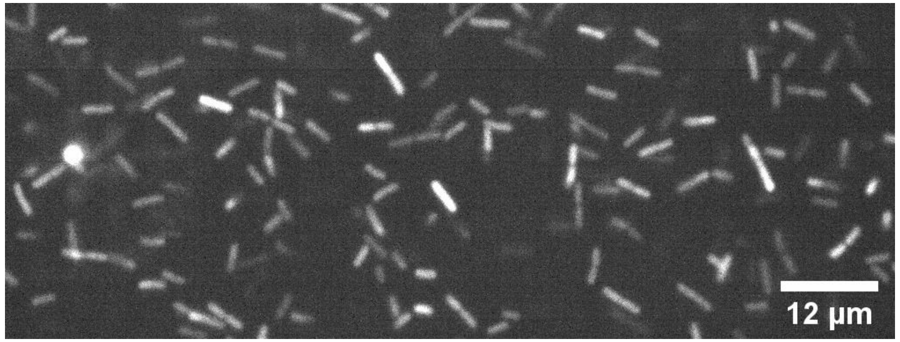


Conclusion

- Confinement **reduces** the viscosity of *E. coli* suspensions.
- The origin of confinement effect is an **upstream swimming boundary layer** of *E. coli* pushing fluid forward.
- Due to the divergent nature of force dipole flow, the flow immediately next to boundary cannot be resolved. in order to obtain more **quantitative** characterization of this confinement effect, more detailed near field bacterial flow field is needed.







Acknowledgment

Group members

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