MULTI-SCALE MODELING OF HYDRAULIC FRACTURING OPERATIONS

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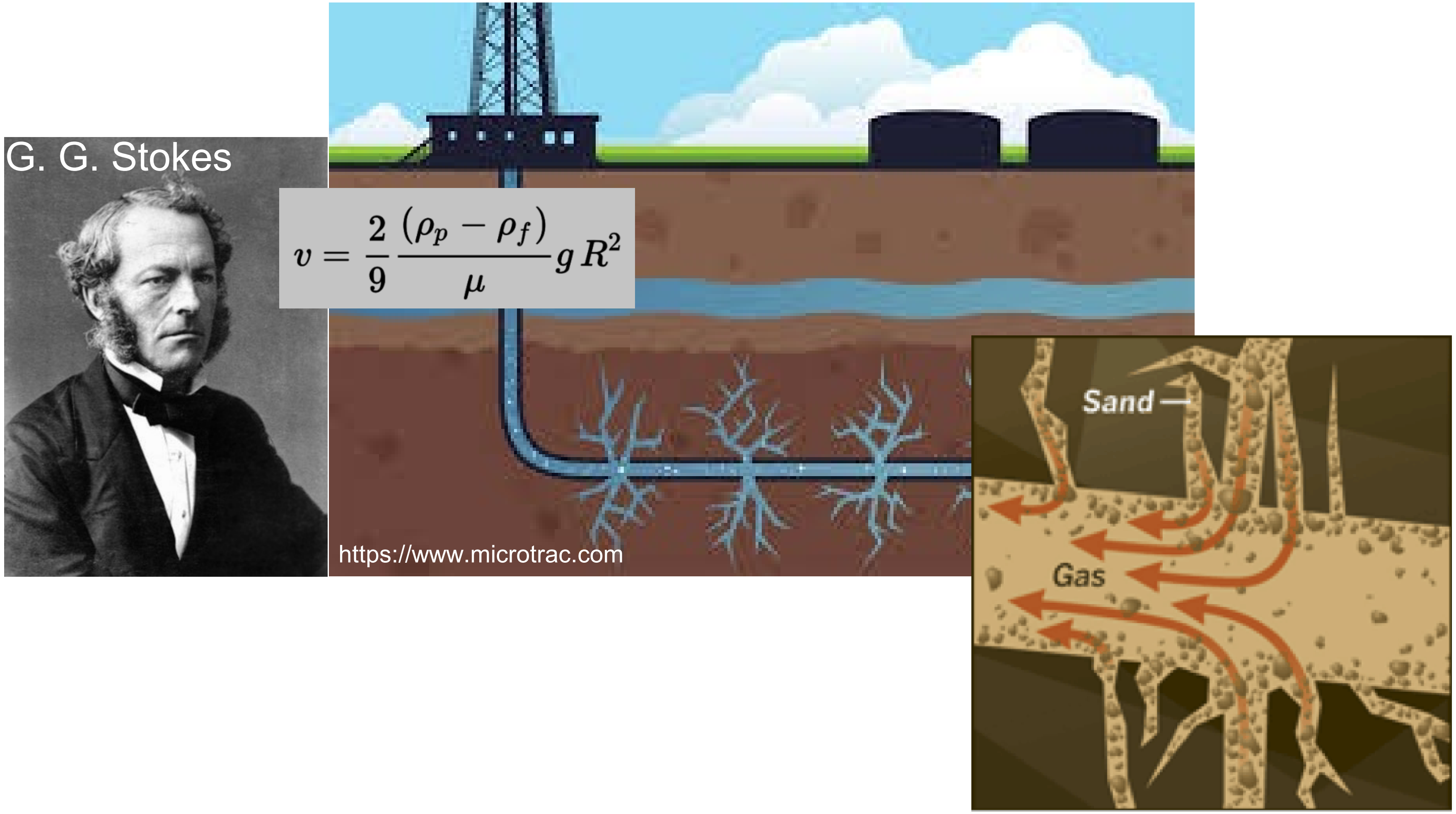
Outline

1. Introduction & Motivation
2. Numerical Approach
3. Direct Numerical Simulations
4. Case Study 1 | *Annular Flow*
5. Case Study 2 | *Rectangular Channel Flow*
6. Conclusions

1. Introduction & Motivation



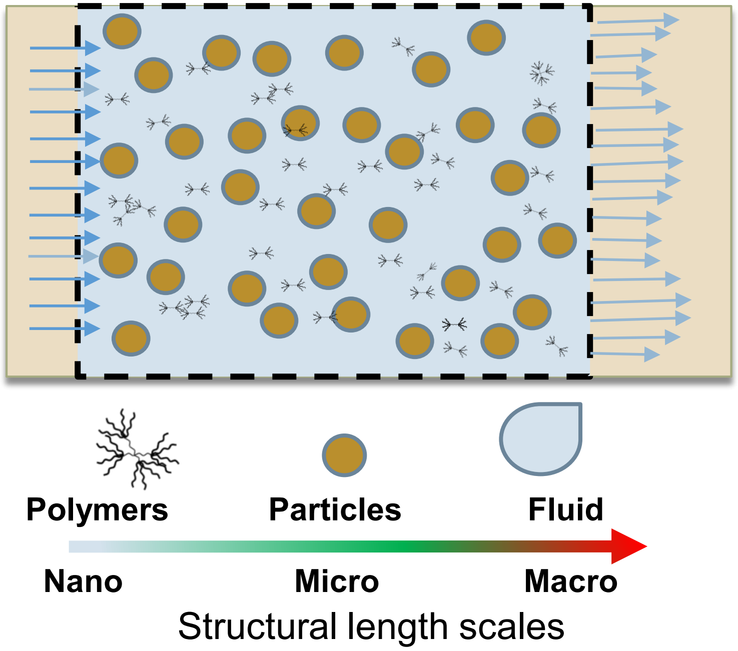
G. G. Stokes

$$v = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} g R^2$$

https://www.microtrac.com

*A.C. Barbati, et al., "Complex fluids and hydraulic fracturing“, *Annual review of chemical and biomolecular engineering,* 7, 415, 2016.

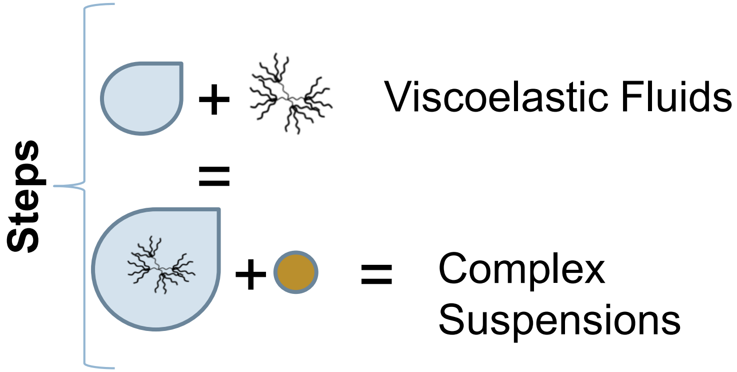
2. Numerical Approach



Polymers **Particles** **Fluid**

Nano **Micro** **Macro**

Structural length scales



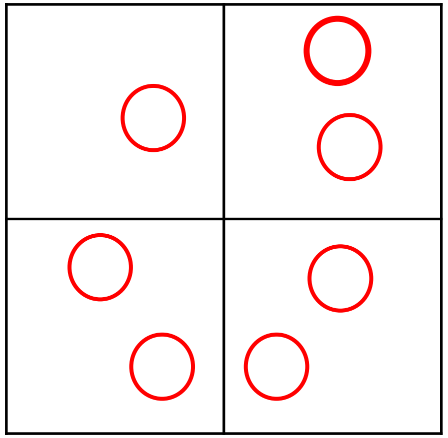
Viscoelastic Fluids

Complex Suspensions

$$\rho \frac{D\boldsymbol{u}}{Dt} = \boldsymbol{\nabla}.\boldsymbol{\Pi} + \rho\boldsymbol{g} \;\; \rightarrow \boldsymbol{\Pi} = -p\boldsymbol{I} + \boldsymbol{\sigma_s} + \boldsymbol{\sigma_p}$$

Oldroyd-B model $\sigma_p + \lambda_1 \overset{\nabla}{\sigma}_p = \eta_P(\nabla \mathrm{u} + (\nabla \mathrm{u})^{\mathrm{T}})$

$$\boldsymbol{\delta x > d_p}$$

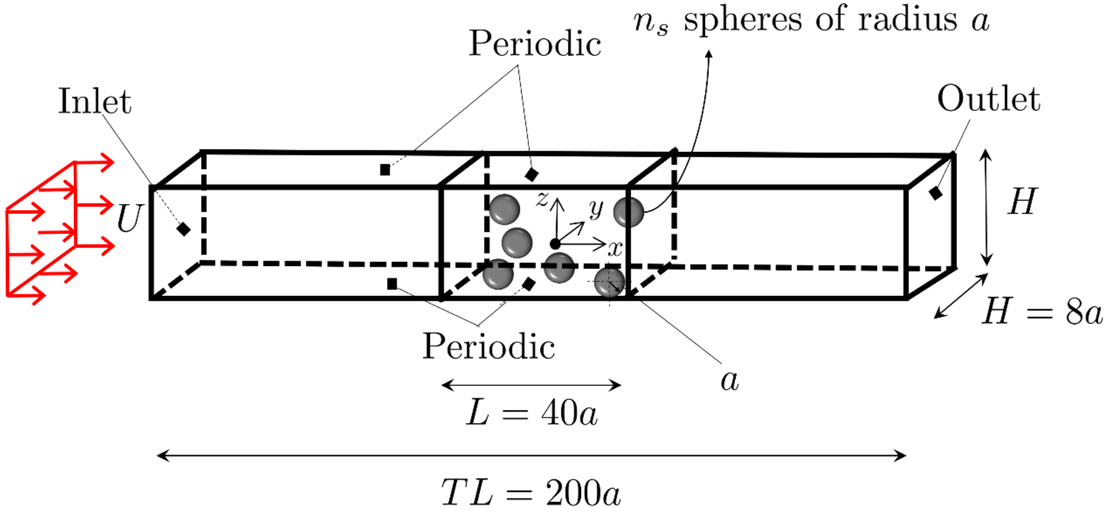


But need to know expressions for

1- Drag force

2- Hindrance effect (due to presence of other particles)

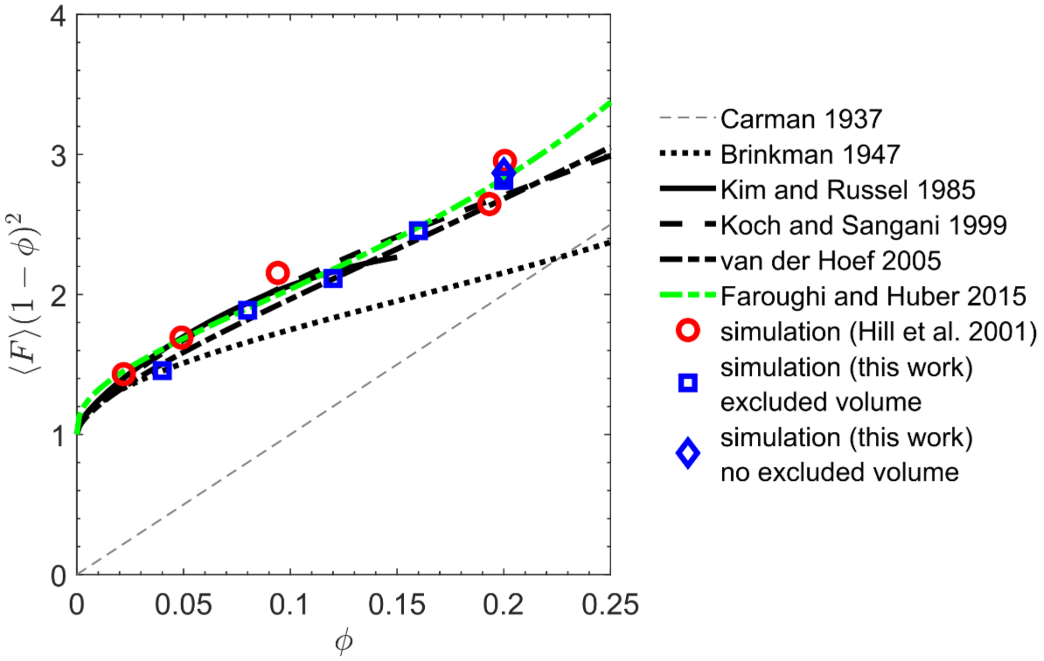
3. Direct Numerical Simulations



$$Re_D = 2Re_a = \frac{2a\rho U_{in}}{\eta_0} = 0.05$$

$$0 \le \phi \le 0.2$$

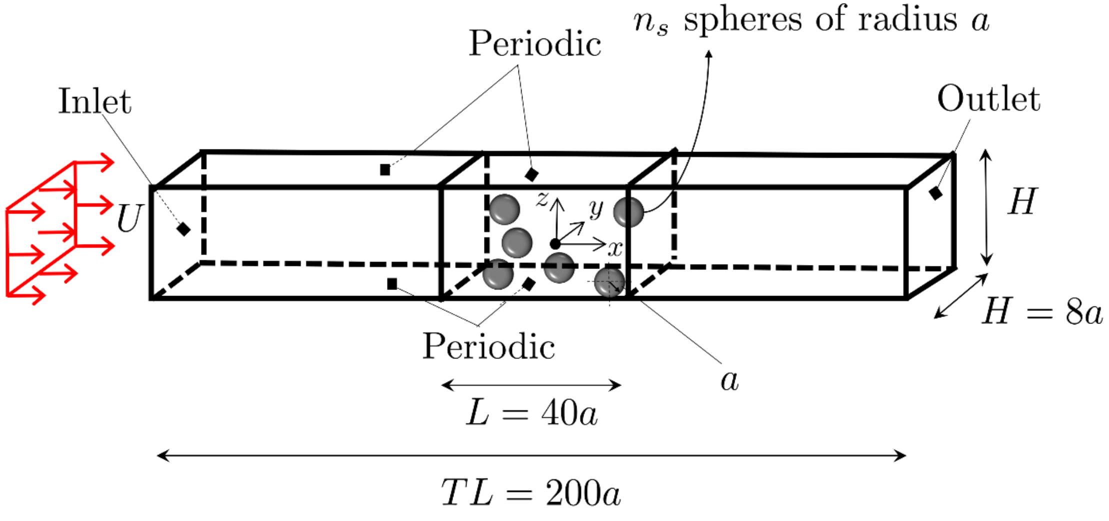
Newtonian Fluid



van der Hoef Drag Force Model

$$< F >= (1-\phi)^2(1+1.5\sqrt{\phi})$$

3. Direct Numerical Simulations



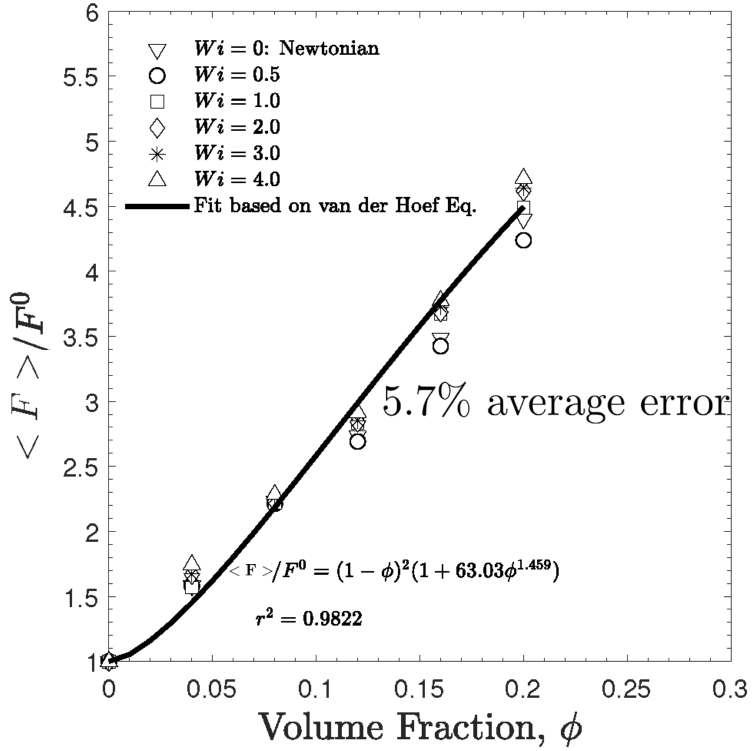
$$\beta = \frac{\eta_S}{\eta_S+\eta_P} = \frac{\eta_S}{\eta_0} = 0.5$$

$$Re_D = 2Re_a = \frac{2a\rho U_{in}}{\eta_0} = 0.05$$

$$0 \leq Wi = \frac{\lambda_1 U_{in}}{a} \leq 4$$

$$0 \leq \phi \leq 0.2$$

Viscoelastic Fluid (Oldroyd-B)



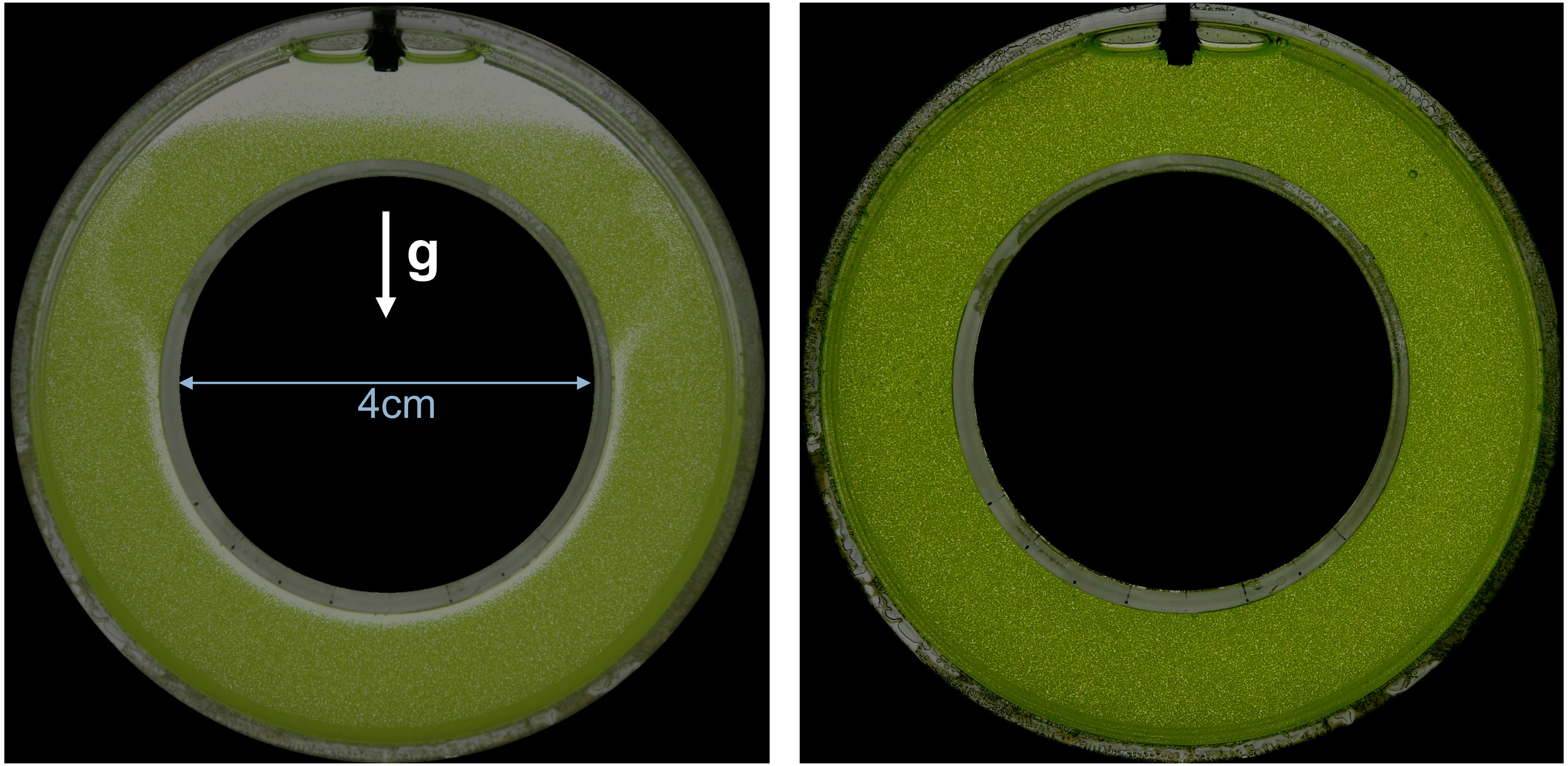
F^0 is the drag force of a single sphere translating in a viscoelastic fluid (Oldroyd-B)*

*S.A. Faroughi, et al., “A closure model for the drag coefficient of a sphere translating in a viscoelastic fluid”, *Journal of Non-Newtonian Fluid Mechanics*, 277, 104218, 2020.

4. Case Study 1 | Annular flow

in a donut shape geometry (as a proxy for horizontal well) filled with Newtonian oil, 10 times more viscous than water.

1% volume spherical particles (D = 200 μm) in Newtonian oil, with density ratio 2.6.



Performed by Agathe Robisson, SLB

4. Case Study 1 | Annular flow

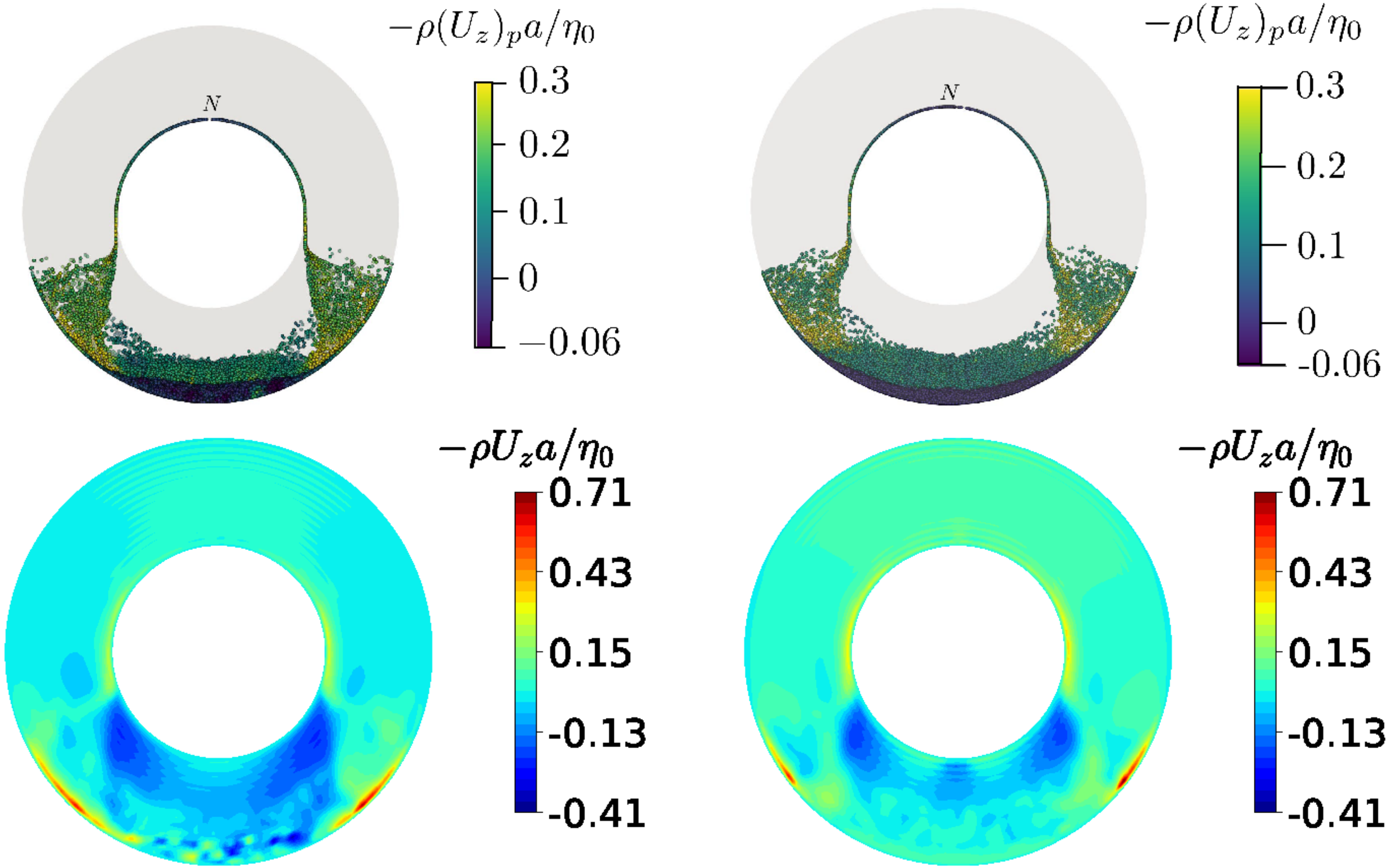
*C. Fernandes, et al., “Validation of the CFD-DPM solver DPMFoam in OpenFOAM through analytical, numerical and experimental comparisons”, *Granular Matter*, 20, 64, 2018.

4. Case Study 1 | Annular flow

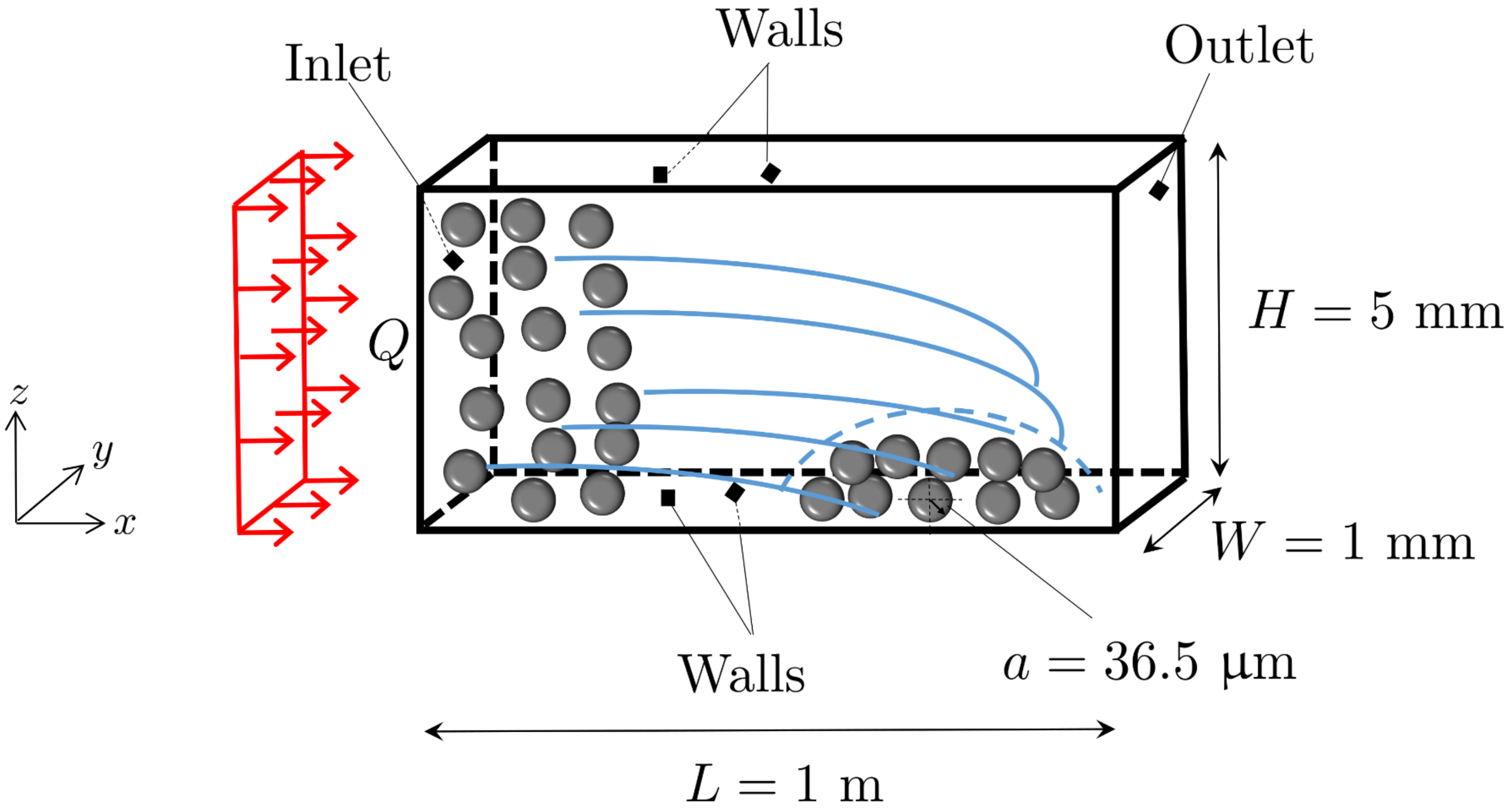
$$El = \frac{Wi}{Re} = \frac{\lambda_1 \eta_0}{2a^2 \rho}$$

$El = 0.1$

$El = 5$



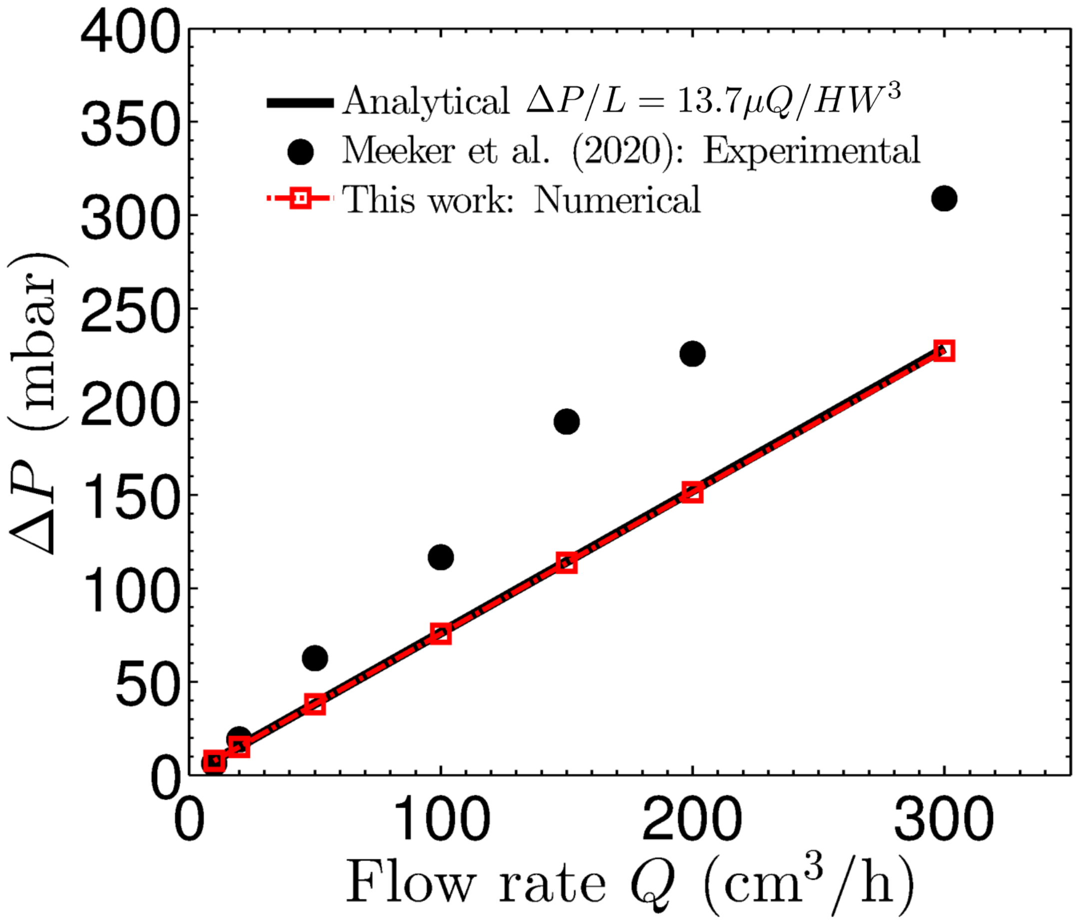
5. Case Study 2 | Rectangular channel flow



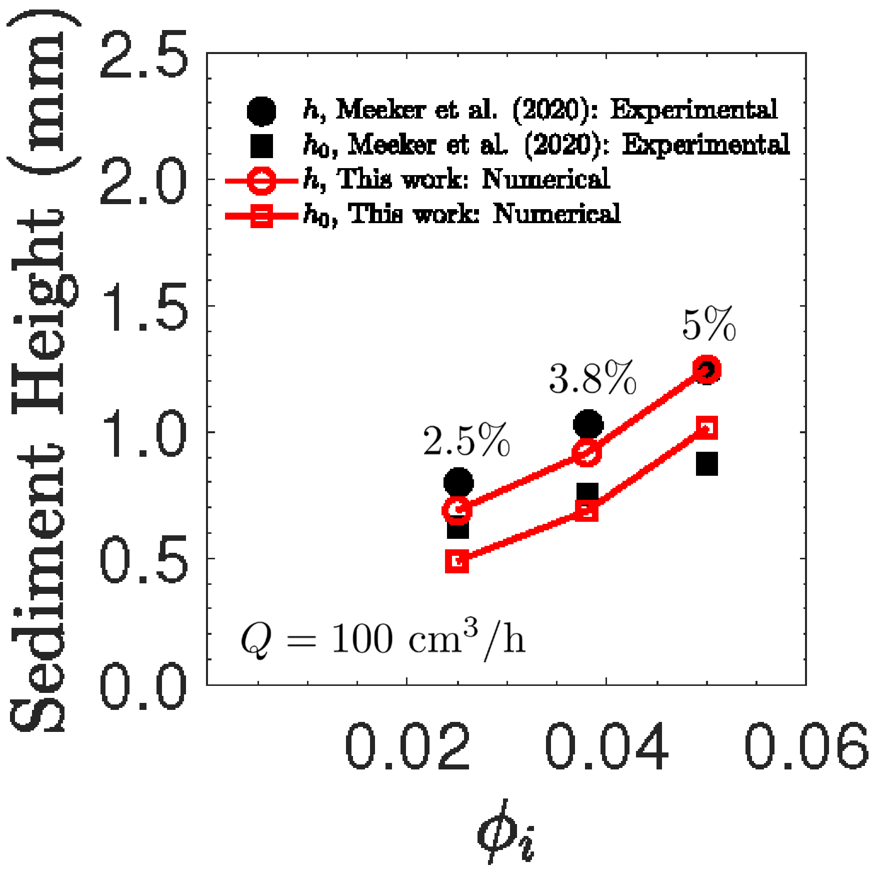
*S. Meeker, et al., "Proppant transport in a Newtonian fluid under laminar flow", Society of Petroleum Engineers, 25, 2020.

5. Case Study 2 | Rectangular channel flow

Newtonian Fluid



Newtonian Fluid + Proppant Particles



h steady-state sediments under flow

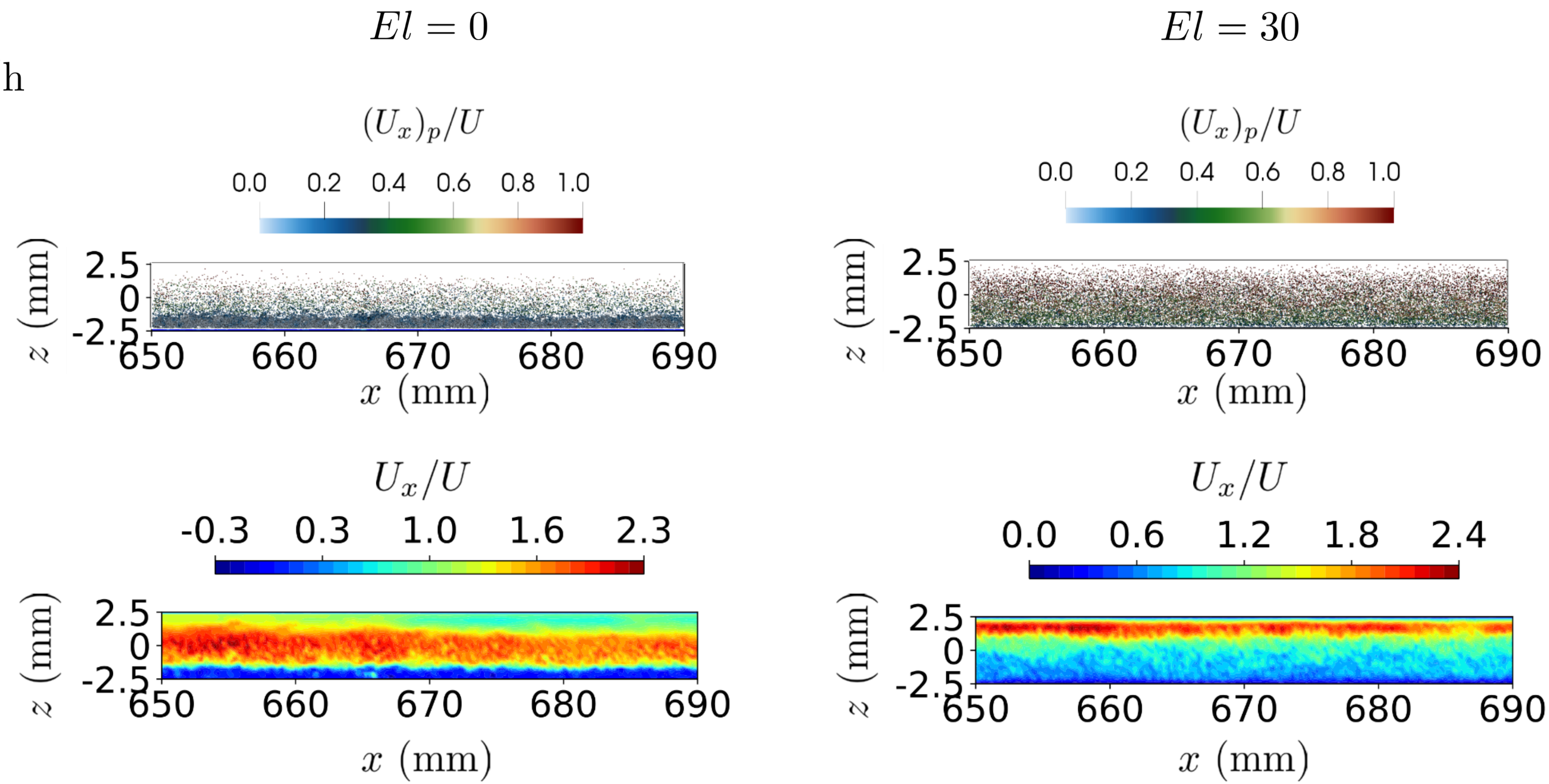
h_0 static sediment heights once the suspension flow has ceased

5. Case Study 2 | Rectangular channel flow

$\phi_i = 0.05$

$Q = 100\ \mathrm{cm}^3/\mathrm{h}$

$2L/3$



$El = 0$

$El = 30$

6. Conclusions

- Direct numerical simulations (DNS) of **random arrays of spherical particles** immersed in Newtonian and **viscoelastic** liquids were performed using a finite-volume method.

- An approximate closed form model was developed for the **drag force** obtained from numerical simulations of the unbounded flow of an **Oldroyd-B fluid past random arrays of spheres**

  $Re \ll 1,\ \beta = 0.5, 0 \leq Wi \leq 4 \text{ and } 0 < \phi \leq 0.2.$

- An **Eulerian-Lagrangian solver for particle-laden viscoelastic flows** was developed in the open-source computational library OpenFOAM.

- As a proof-of-concept, the newly-developed solver was assessed in terms of accuracy in two case studies. First, the segregation phenomena which occurs when creating casing for **horizontal wells in an annular** domain. Second, the **proppant transport sedimentation** was also studied in a long **channel of rectangular cross section**.

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  - ➢ **Texas Advanced Computing Center** (TACC) at The University of Texas at Austin (URL: http://www.tacc .utexas.edu);
  - ➢ **Gompute HPC** Cloud Platform (URL: https://www.gompute.com);
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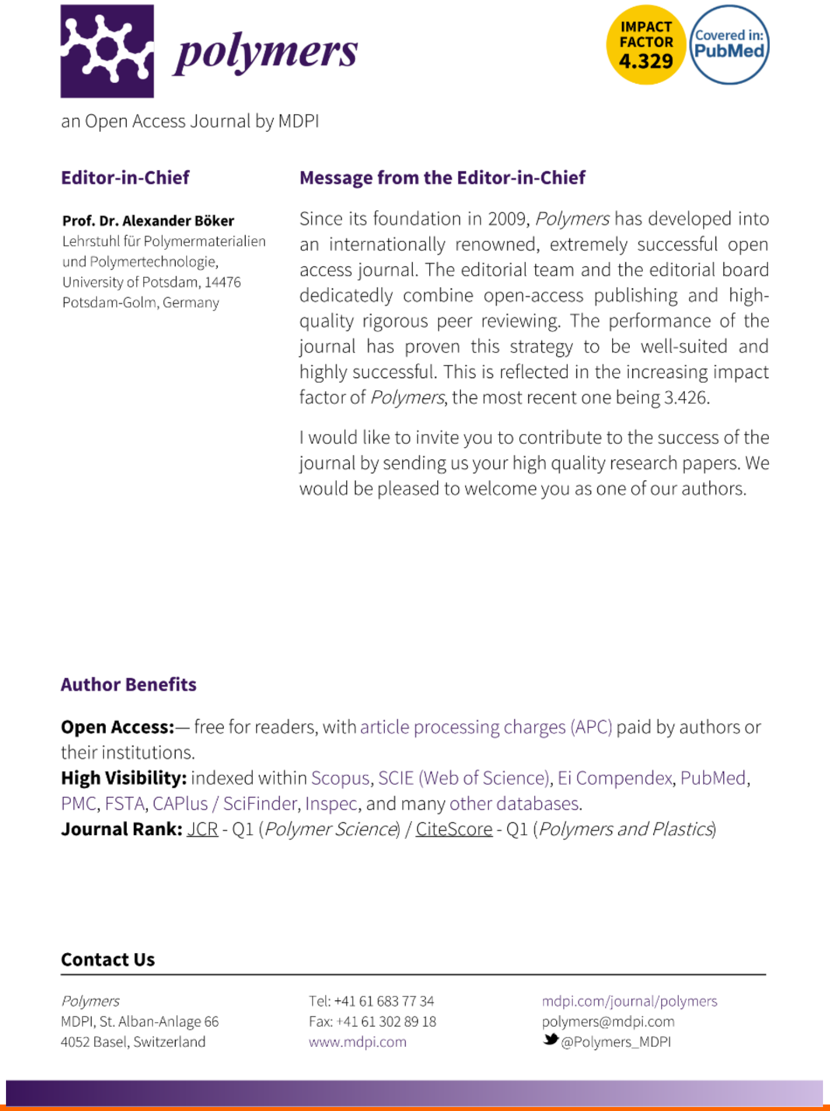

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