RHEOLOGICAL PROPERTIES OF GAS-FLUIDIZED GRANULAR MATTER

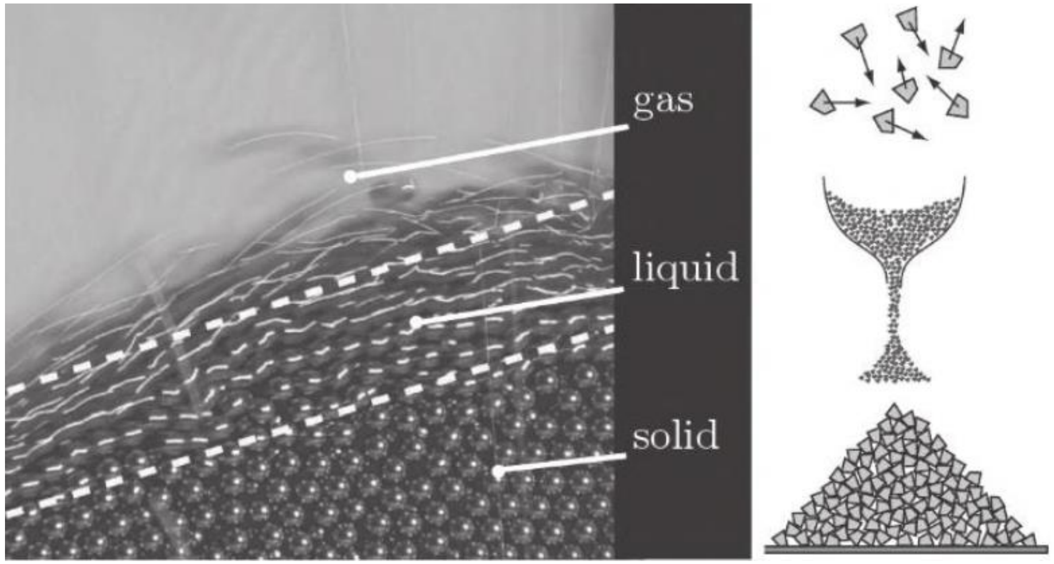
MARLO KUNZNER[1], MATTHIAS SPERL[1,2] and Jan P. Gabriel[1]

[1]Institut für Materialphysik im Weltraum, DLR Köln, Deutschland — [2]Institut für Theoretische Physik, Universität zu Köln, Deutschland

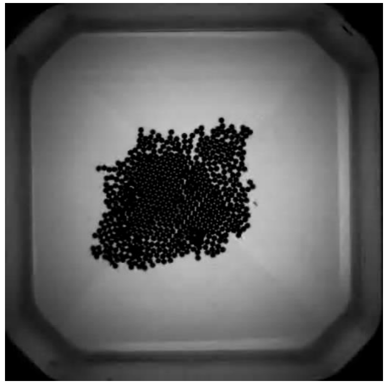
Motivation

- Granular materials are abundant

- Moon
  - Regolith layer on the moon
    - First meters are fluidized
  - Support of structures
  - Infrastructure
  - Dust-Plume-Interactions

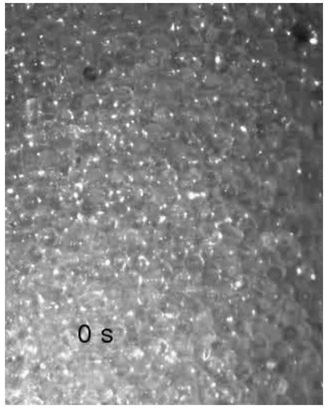


Different behaviours of granular media depending on the supplied energy and environment. (Andreotti, Granular media: between fluid and solid.)



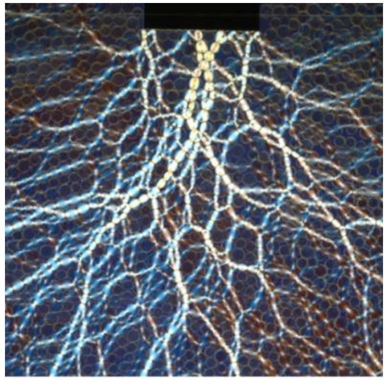
Gas

Sperl,



Liquid

Schröter,

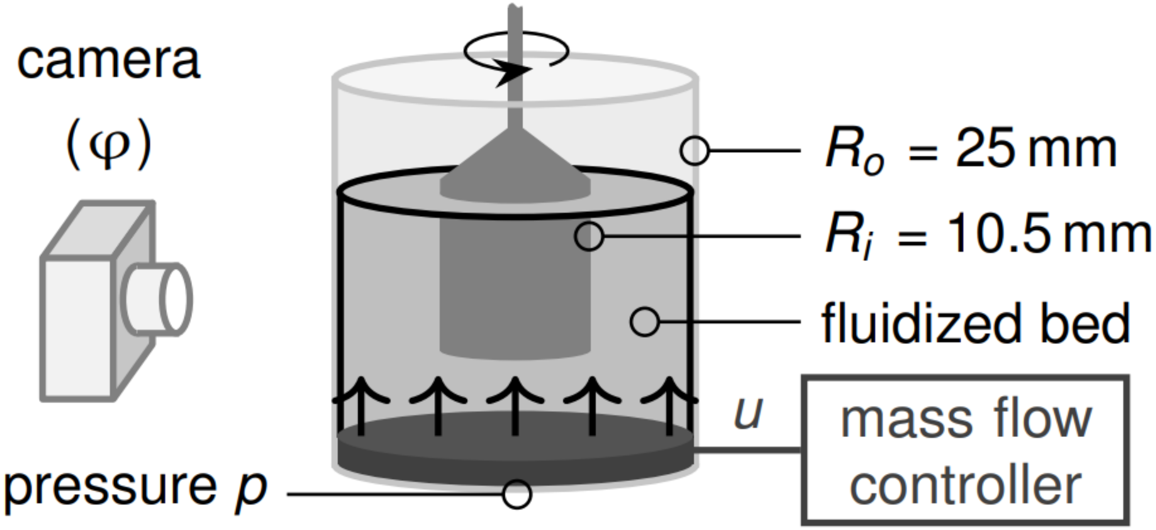


Solid

Yu and Sperl

Granular Material and Fluidized Beds

- Rheometer
  - Anton Paar MCR 102
    - Powder Flow Cell
  - Searle Geometry
    - Cylinder rotates and measures torque
- Many effects:
  - Charging/Electrostatic
  - Dissipation of energy by collision
  - Gravitational effects
  - Support weight
  - Can flow

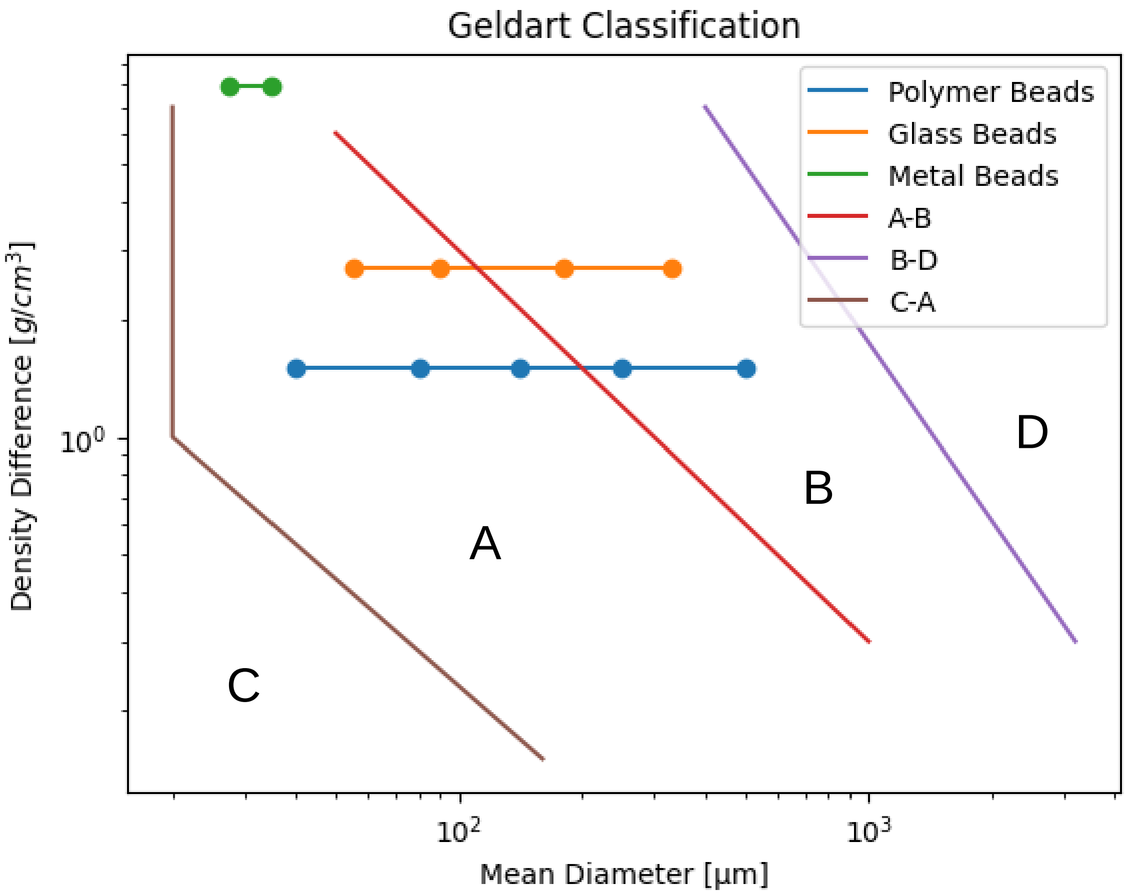


Measurement set-up used in our experiments.

D'Angelo, Kranz, Sperl, „The manifold rheology of fluidized granular media“, PRL

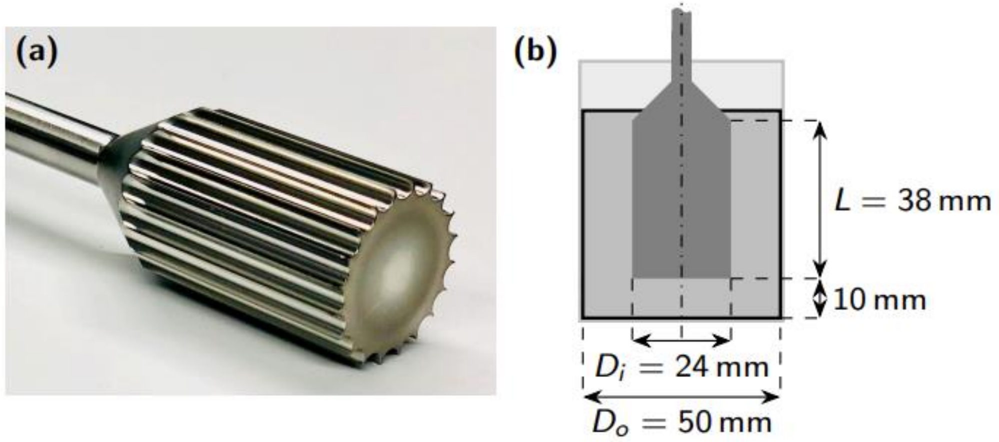
Granular Material and Fluidized Beds

- Fluidized Beds
  - Increasing the granular Temperature
    - Non zero kinetic energy
  - Exciting the system by agitation (from the bottom)
    - Can either be a liquid, gas or shaking
  - Using Geldart classification for gas agitated systems
    - Classified by densities and diameter
  - A: Aerated
  - B: Bubbling
  - C: Cohesive
  - D: Dramatic



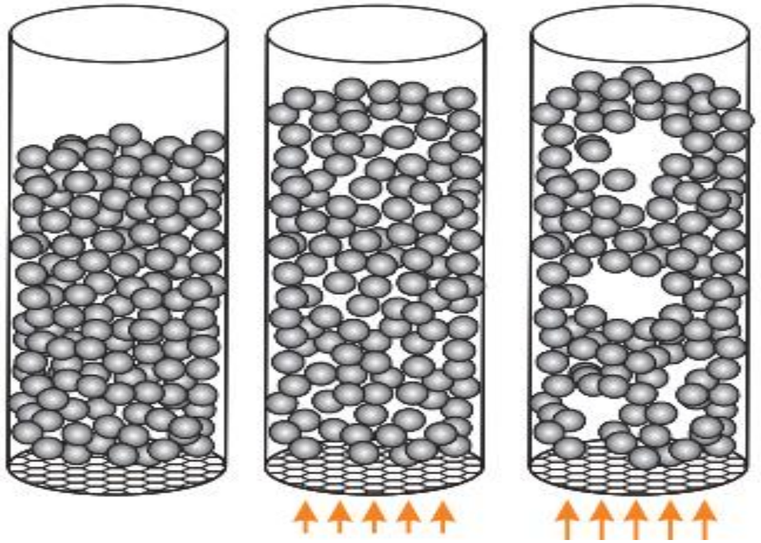
An overview of the particles used and where they fall in the Geldhart Classification

Granular Material



Measurement system/Geometry used to stir the sample (b) D‘Angelo (2023).

Pictures of the fluidized bed at different excitation rates D’Angelo.

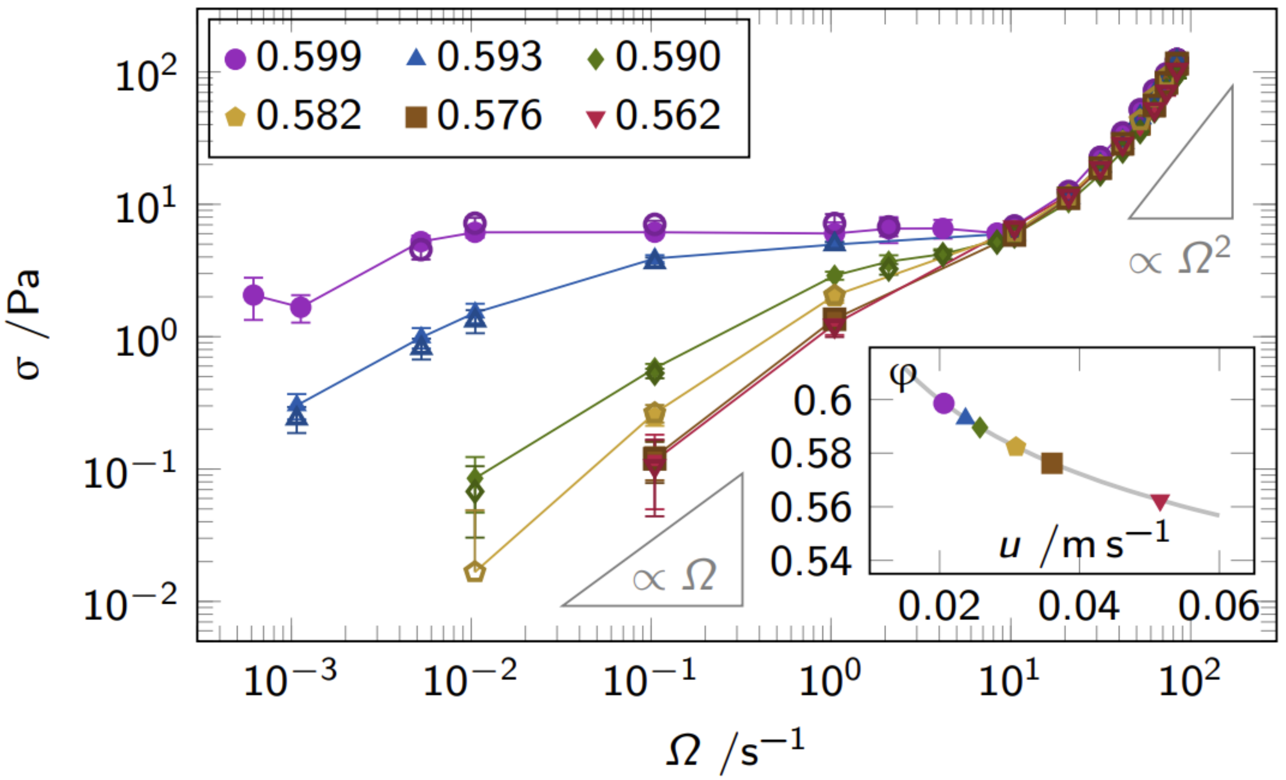


Sketch of an air-fluidized granular layer in three phases Stennarius (2017).

D‘Angelo, „The manifold rheology of fluidized granular media“
D‘Angelo, Kranz, Sperl, „Rheological regimes in agitated granular media under shear“, PRL

Literature

- Glass particles
  - 150-200 µm
  - Geldart Group B
  - 170 g total sample mass
- Theoretical Description Granular-ITT (Integration Through Transients)
  - Constitutive relation for relating shear stress σ and shear rate $\dot{\gamma}$
  - Uses monodisperse inelastic hard spheres
  - Coefficient of Restitution (ε), 0.8
  - Vicinity to granular glass transition (Mode Coupling Theory)
  - $\Delta\varphi_{th} = \varphi_g^{MCT}(\varepsilon) - \varphi$



Flow curves with a Bagnoldian regime, viscous regime and yield behavior depending on packing fraction.

D'Angelo, Kranz, Sperl, „Rheological regimes in agitated granular media under shear", PRL
Zippelius, Kranz, Sperl (2010)

Non-linear Maxwell-Model for Granular Media

- 4 Parameters
  - Critical Strain, γ_c
    - Constant
    - $\frac{Yield\ Stress}{G_\infty}$
  - Elastic modulus, G_∞
  - Structural Relaxation Time Scale, τ
  - Bagnold Coefficient, *C*

$$\sigma = \frac{G_\infty \gamma_c}{\frac{\gamma_c}{\tau} + |\dot{\gamma}|}\dot{\gamma} + \eta\dot{\gamma}$$

$$\rightarrow \sigma = G_\infty \gamma_c + \eta\dot{\gamma}$$

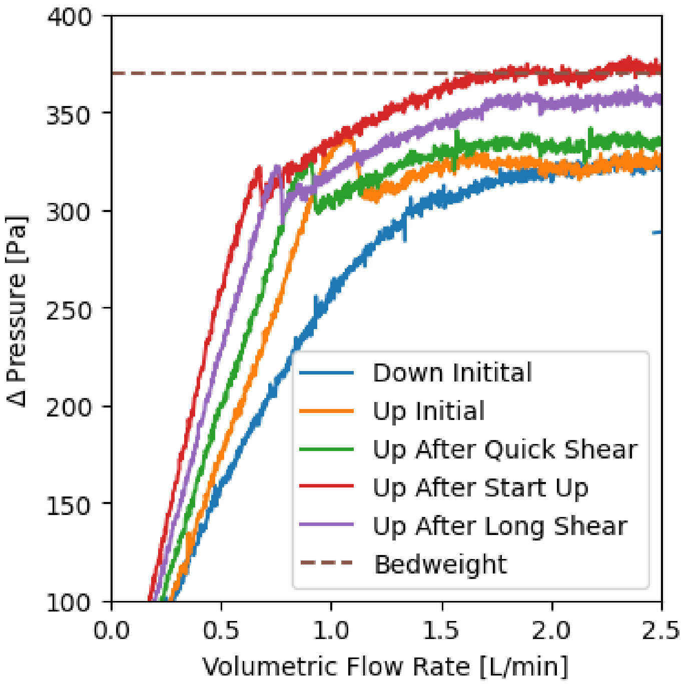
Bagnold: $\sigma = \frac{G_\infty \gamma_c}{\frac{\gamma_c}{\tau} + |\dot{\gamma}|}\dot{\gamma} + C\dot{\gamma}^2$

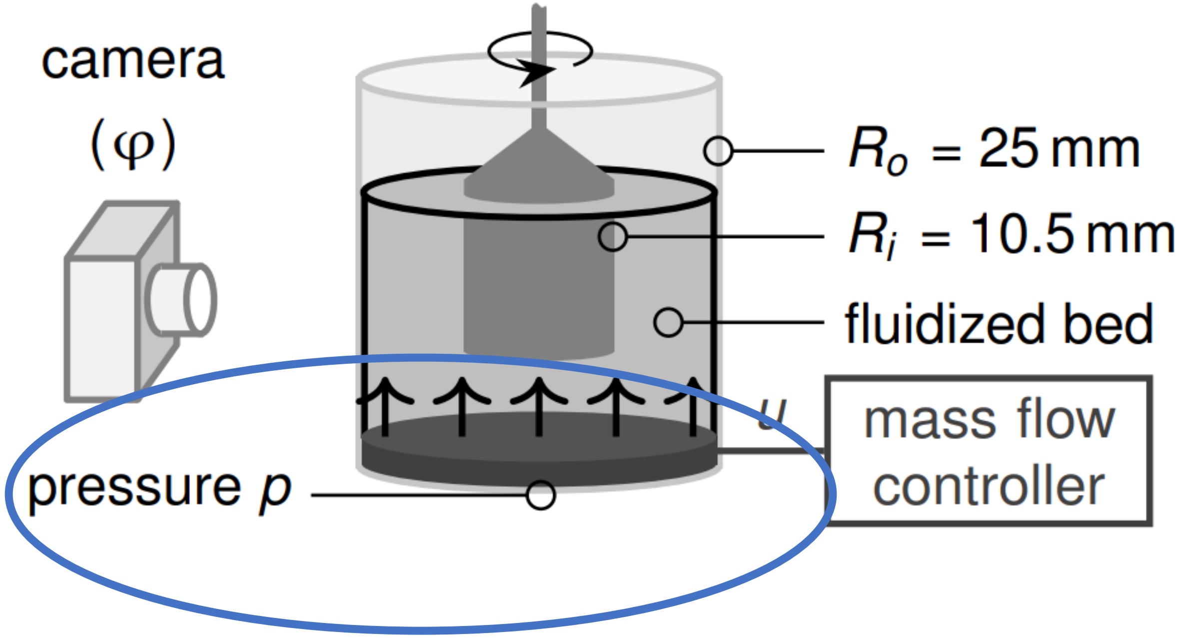
Motivation

- *New Measurements of Polydisperse Particle Distributions*
  - *Friction should be more dominant in lighter Particles*
  - *Changing the material*

- *Glass*
  - *Density: 2.5e3* kg/m^3
  - *40-70 µm, Borosilicate*
  - *70-110 µm, Soda-Lime*
  - *150-210 µm, Borosilicate*
  - *250-420 µm, Soda-Lime*
  - *125 g Total Sample Mass*
- Polystyrene
  - *Density: 1.057e3* kg/m^3
  - *140 µm*
  - *61 g Total Sample Mass*

140µm Polystyrene Pressure Drop

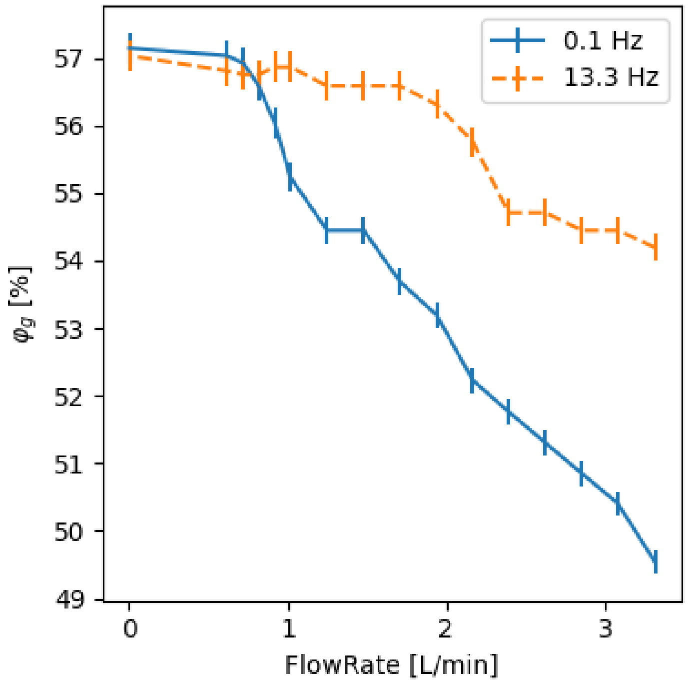


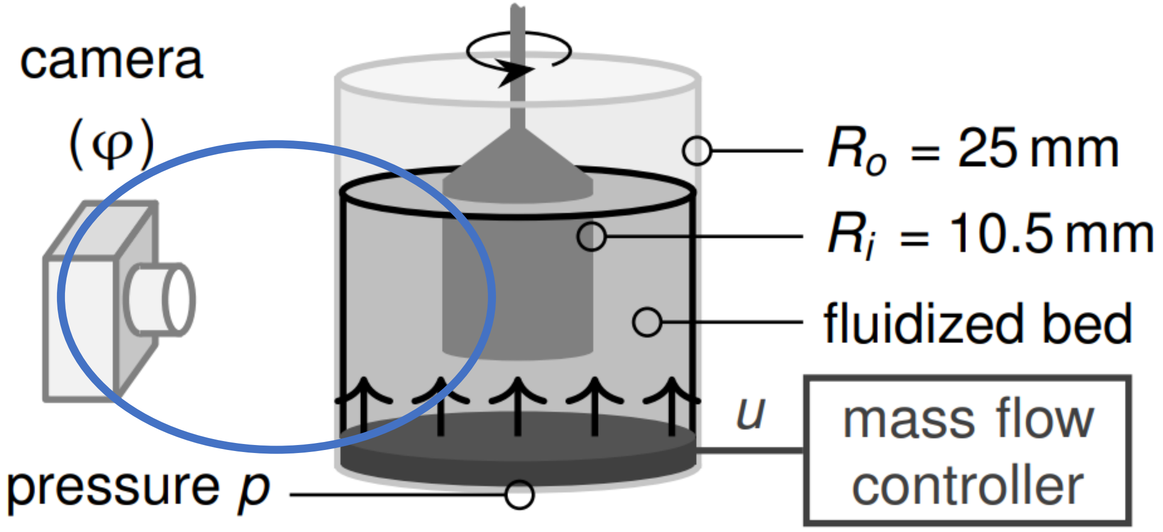


Change flow rate
Keep rotational rate constant (0)

Deduct pressure of empty cell from pressure in filled cell.
Flow rate necessary for overshoot determines the lower flow rates used for the flow curves.

140µm Polystyrene Packing Fraction

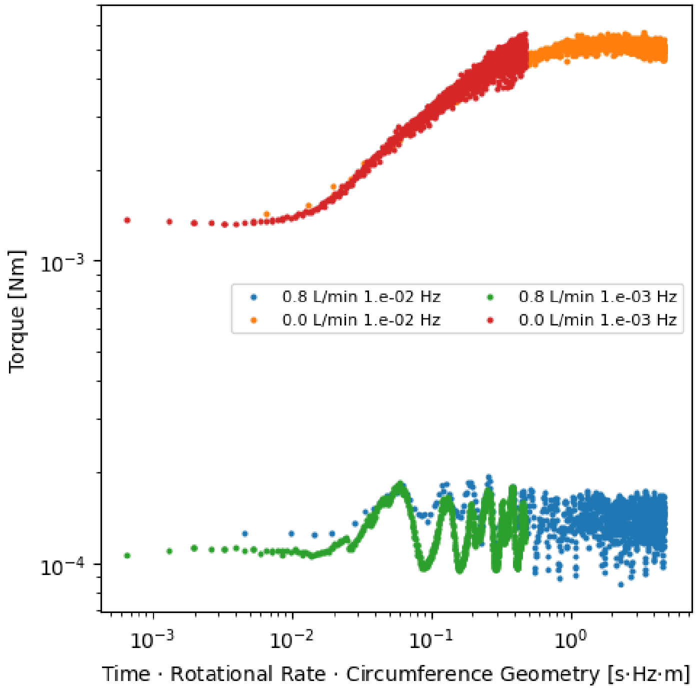


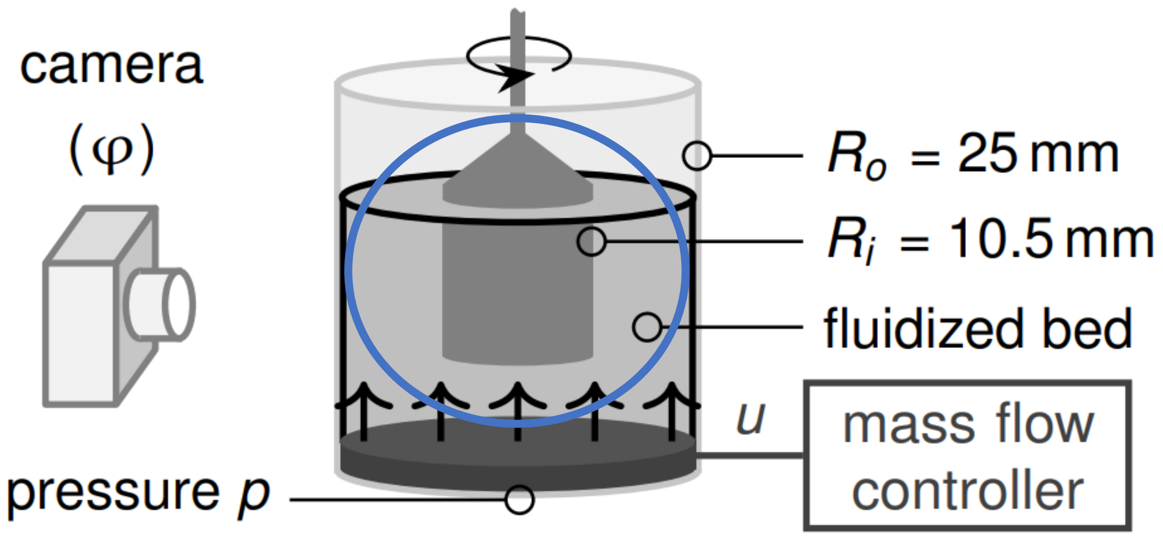


Change flow rate
Change rotational rate

The global packing fraction φ_g changes depending on flow rate and rotational speed. High rotational rates lead to higher packing fractions.

140µm Polystyrene Steady-State Determination

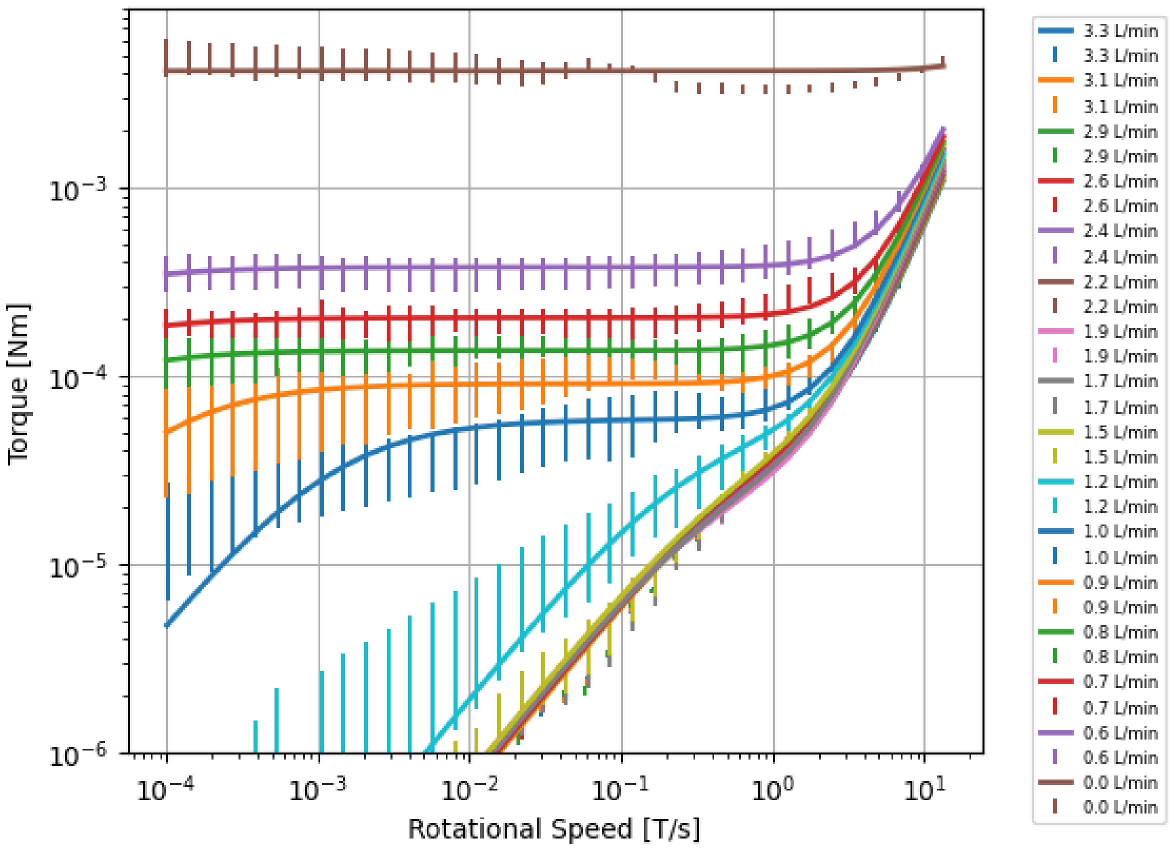




Keep flow rate constant
Keep rotational rate constant

Start-Up curve for determining the vicinity to steady-state. The Curves are normalized to rotational distance.

140µm Polystyrene Flow Curve

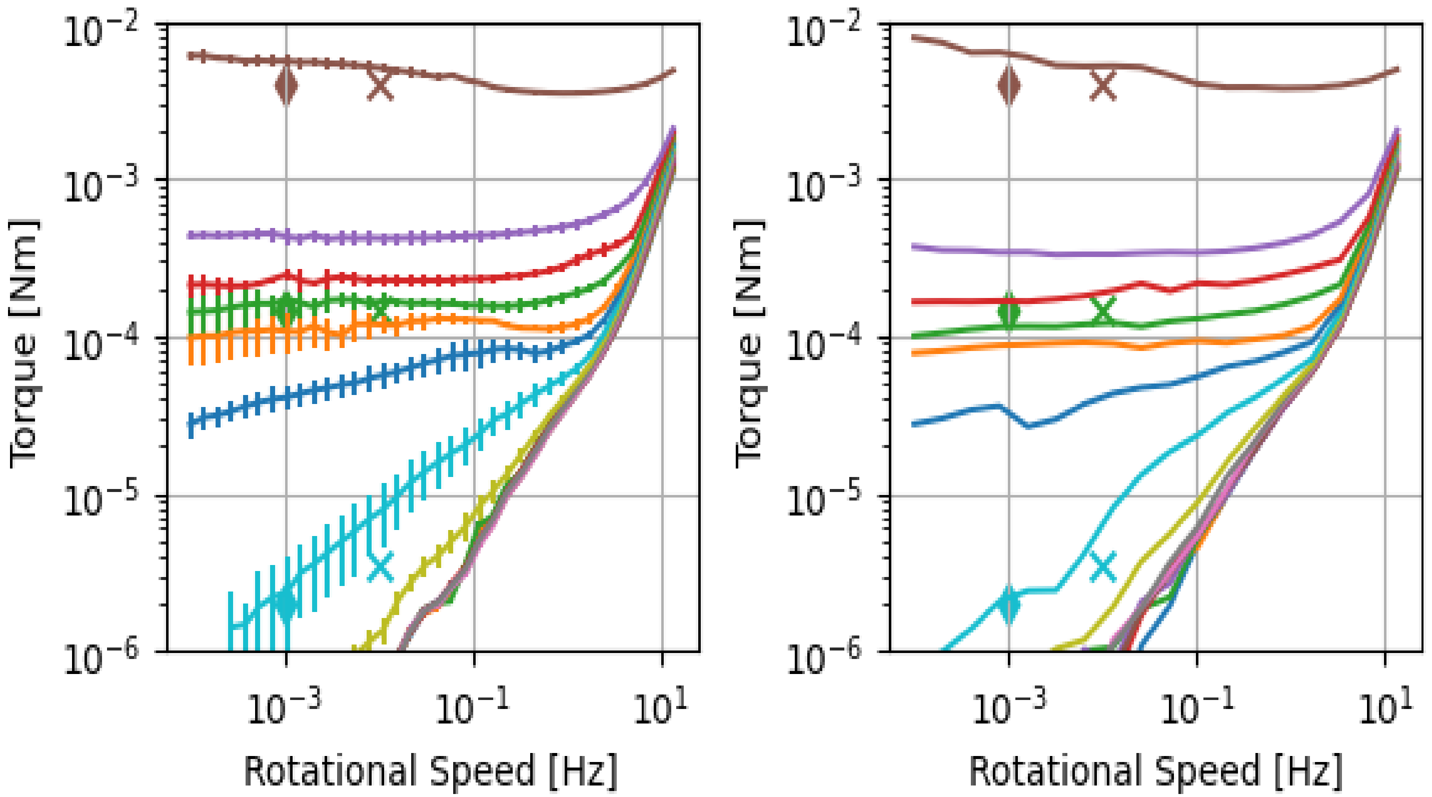


Change flow rate
Change rotational rate

Bagnold: $\sigma = \frac{G_\infty \gamma_c}{\frac{\gamma_c}{\tau} + |\dot{\gamma}|}\dot{\gamma} + C\dot{\gamma}^2$

Flow curve for different flow rates with the non-linear Maxwell model (solid line) and datapoint standard deviation over 7 measurements as error bars.

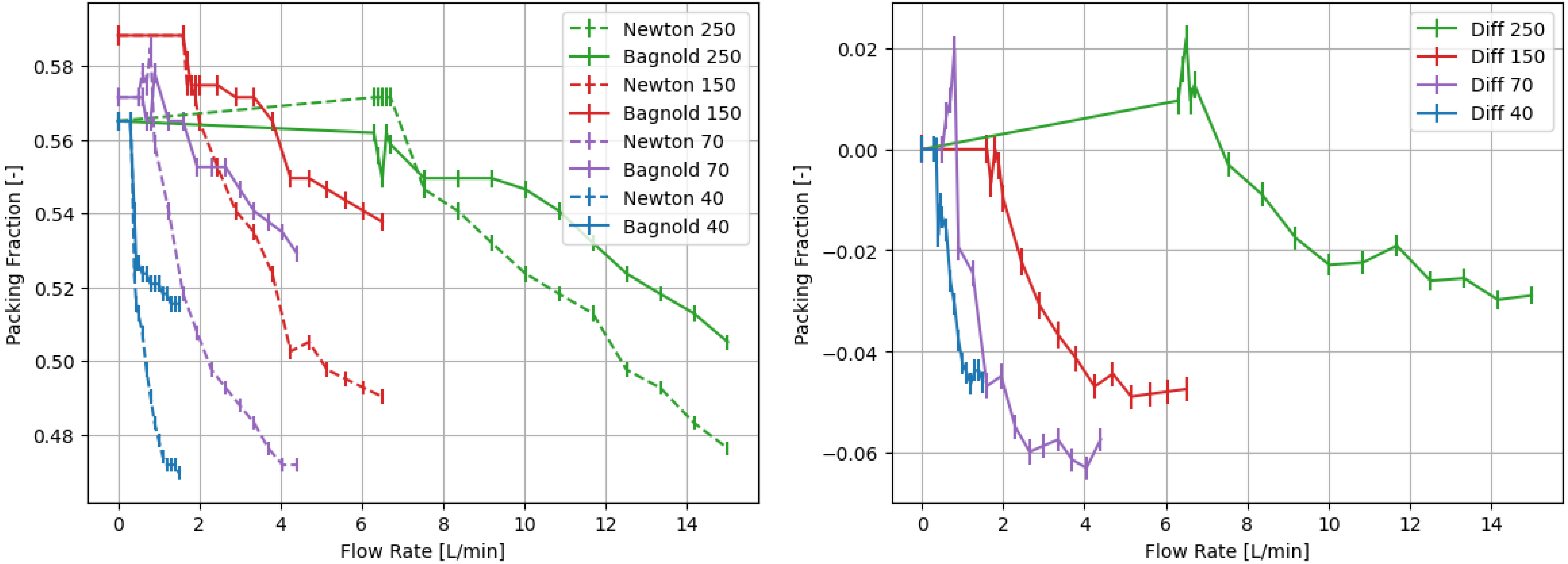
140µm Polystyrene Flow Curves
Not in Steady-State



Change flow rate
Change rotational rate

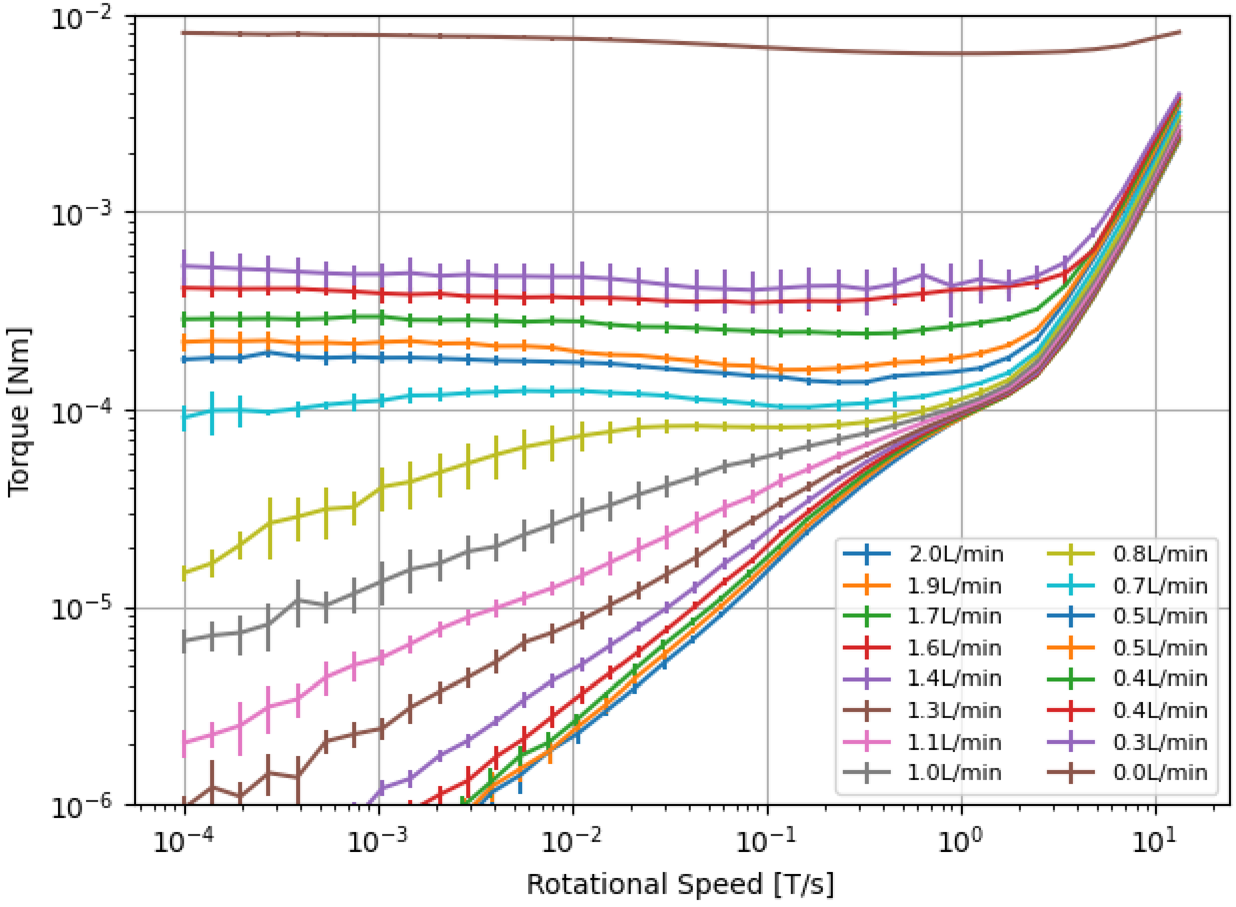
Flow curve for different flow rates averaged over the last 3 measurements with standard deviation on the left. A quickly taken flow curve on the right. Steady-state values shown as diamonds and x-es.

Glass Packing Fraction



The global packing fraction φ_g changes depending on flow rate and rotational speed. High rotational rates called Bagnold here and lower rates Newton. The right plot shows the difference between the regimes.

40 - 70µm Glass Shear Sweep

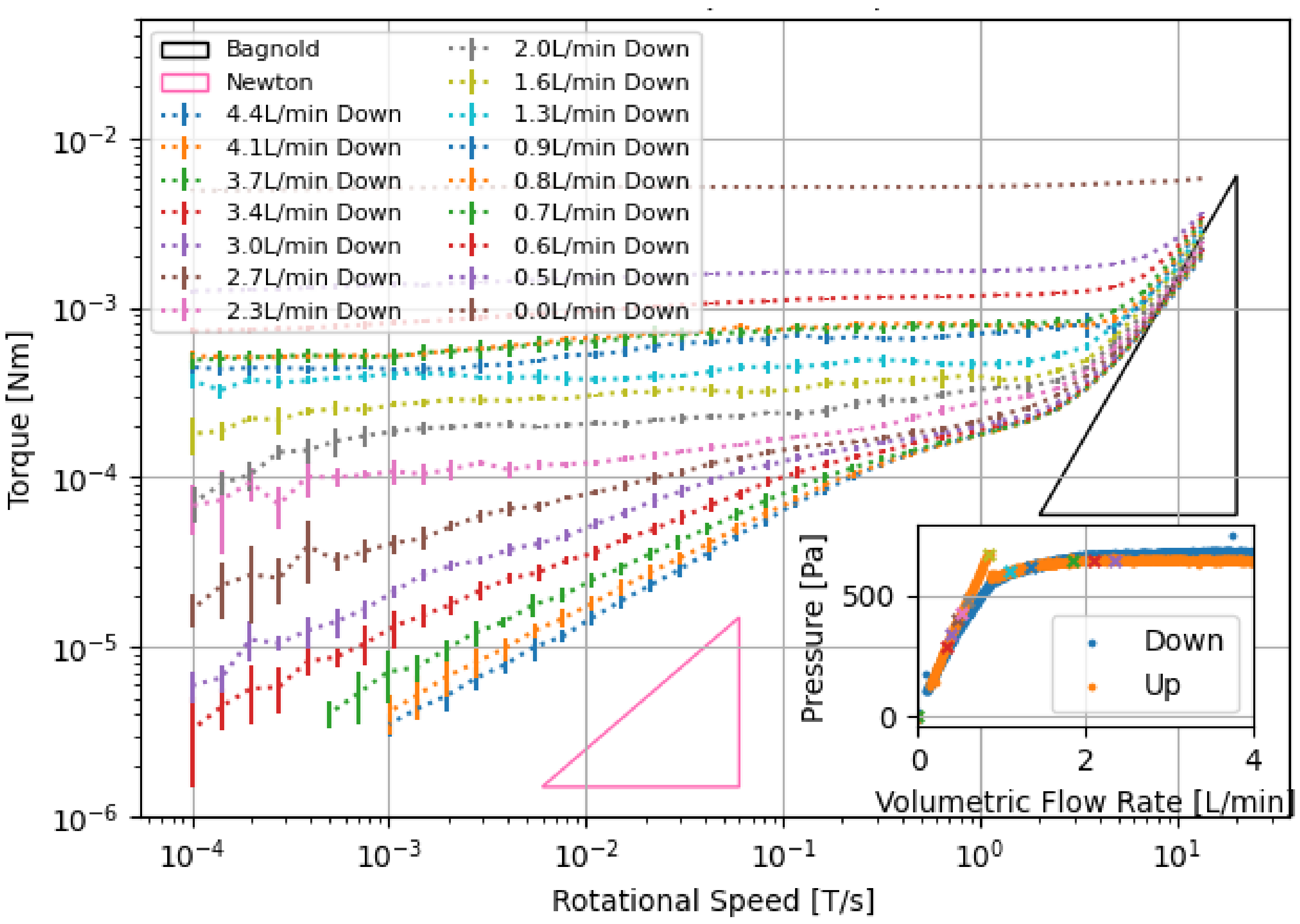


Pressure overshoot at ~ 0.5 L/min

Viscous slope ~1
Slight plateau visible
Bagnold regime visible

Marlo Kunzner, DLR, Institute of Materials Physics in Space

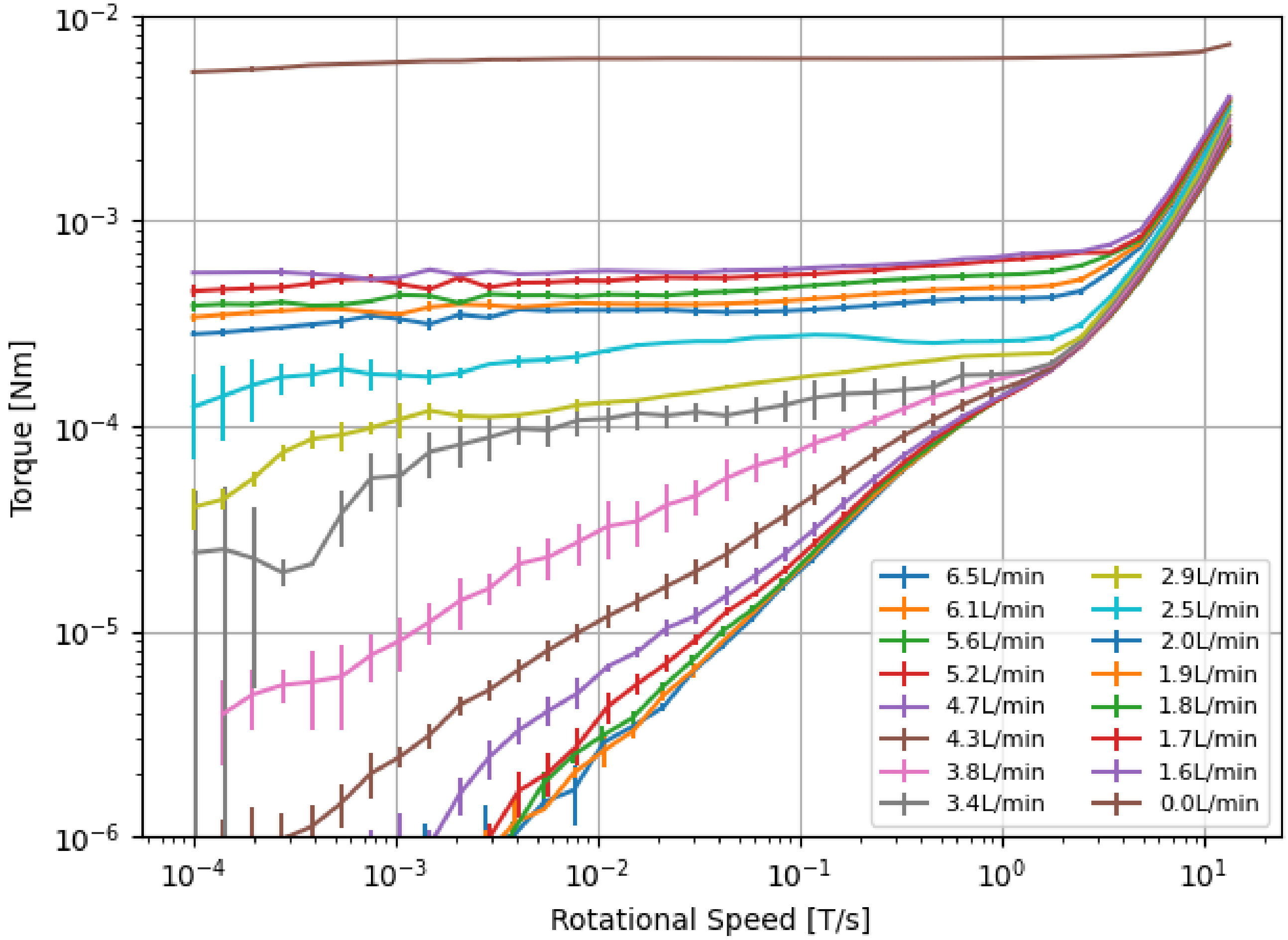
70 - 110µm Glass Shear Sweep



Pressure overshoot at ~ 0.65 L/min

Viscous slope ~0.6
Elongated plateau visible
Bagnold regime visible

150 - 210µm Glass Shear Sweep

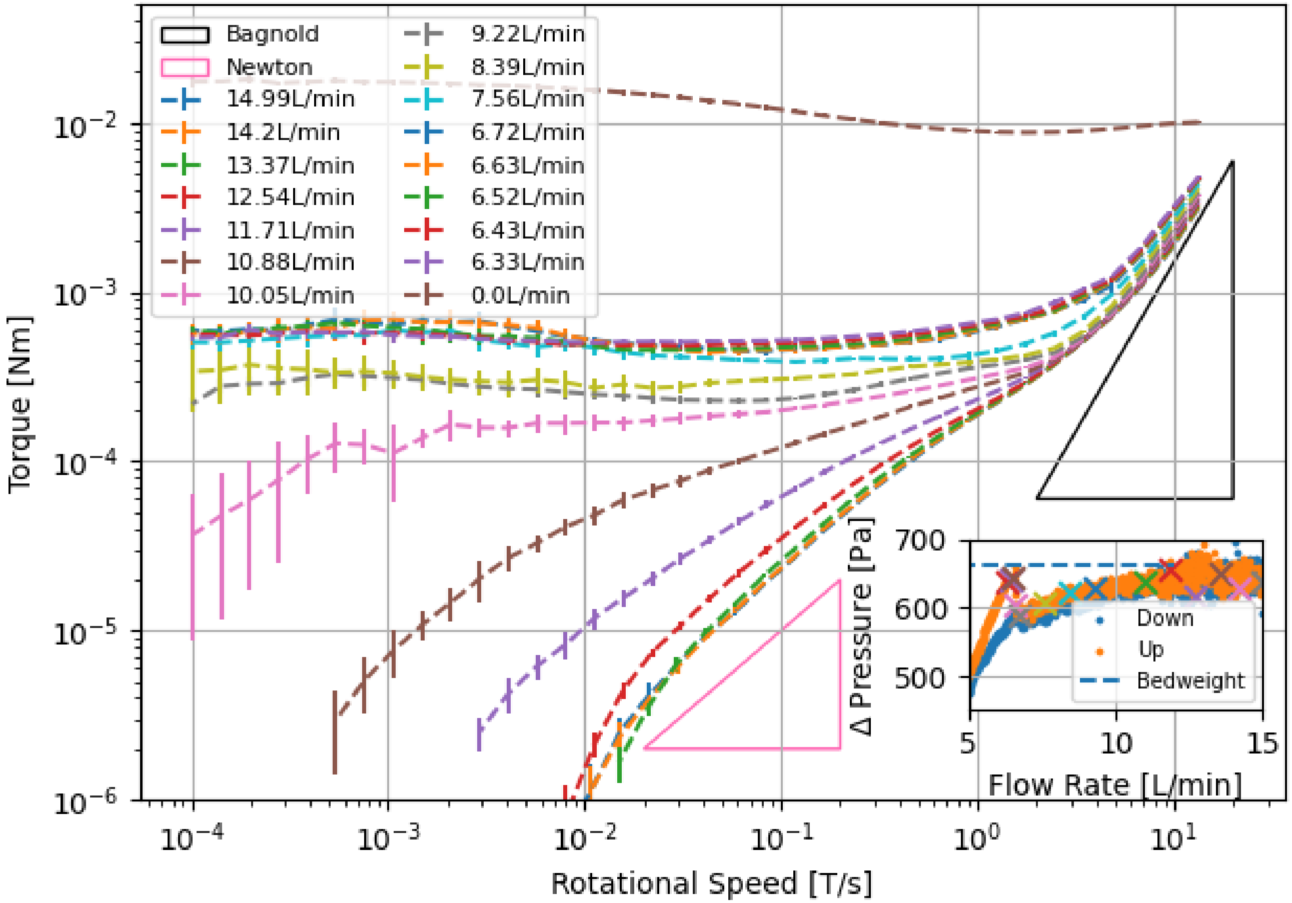


Pressure overshoot at ~ 1.9 L/min

Viscous slope ~1
Elongated plateau visible
Bagnold regime visible

Marlo Kunzner, DLR, Institute of Materials Physics in Space

250 – 420µm Glass Shear Sweep



Pressure overshoot at ~ 6.6 L/min

Viscous slope ~1

Elongated plateau visible

Bagnold regime visible

Summary and Outlook

- More polydisperse systems
- Using Light Scattering
- Cohesive forces
  - Using pressure overshoot curves
  - Influence of charges
    - Controlling the humidity
  - Influence of surfaces
    - Aerogel
- Special spherical particles
  - Hollow
  - Core-shell
- Non-spherical particles
  - Regolith