RHEOLOGICAL PROPERTIES OF FLUIDIZED GRANULAR MATTER

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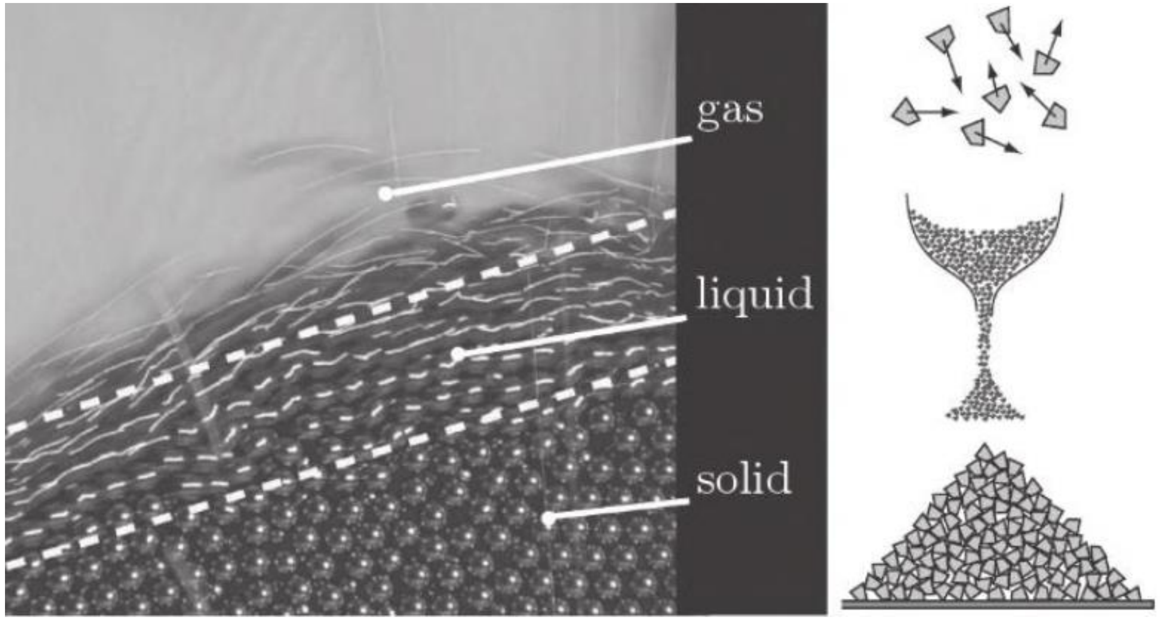
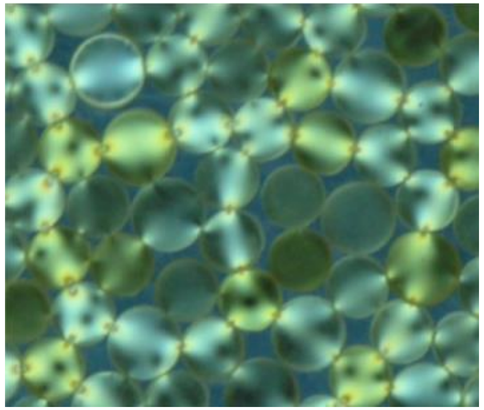
DLR

Motivation

- Granular material is abundent
- Building of obelisks
- Moon
  - Regolith layer on the moon
    - Support of structures
      - Infra structure
      - Space ships
- Industrial applications
  - Chemistry
    - Catalysists
    - Polymer extrusion
  - Silos and faults



Different behaviours of granular media depending on the situattion [1].

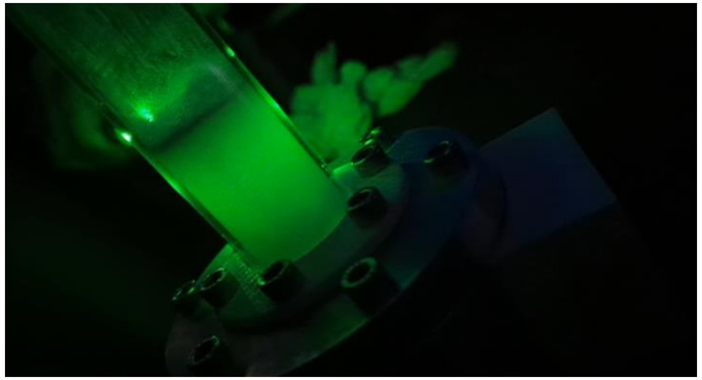


An example of force chains in a solid region.

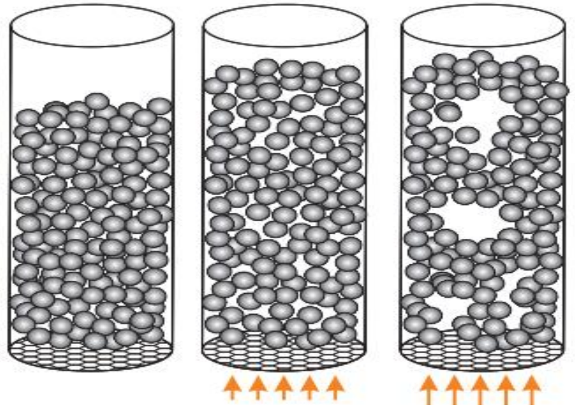
[1] B. Andreotti, Y. Forterre, and O. Pouliquen, “Granular media: between fluid and solid.”

Theoretical Background
Granular Material and Fluidized Beds

- Many effects:
  - Charging/Electrostatic
  - Dissipation of energy by collision
  - Force-chains
  - Gravitational effects dominate
  - Behaviour between fluids and solids
    - Support weight
    - Can flow
- Fluidized Beds
  - Exciting the system by agitation from the bottom
    - Can either be a liquid of gas
  - Using Geldart classification for gas agitated systems
    - Classified by densities and diameter



Example of a bubbling fluidized bed, illuminated with a green laser to see the bubbles more clearly.

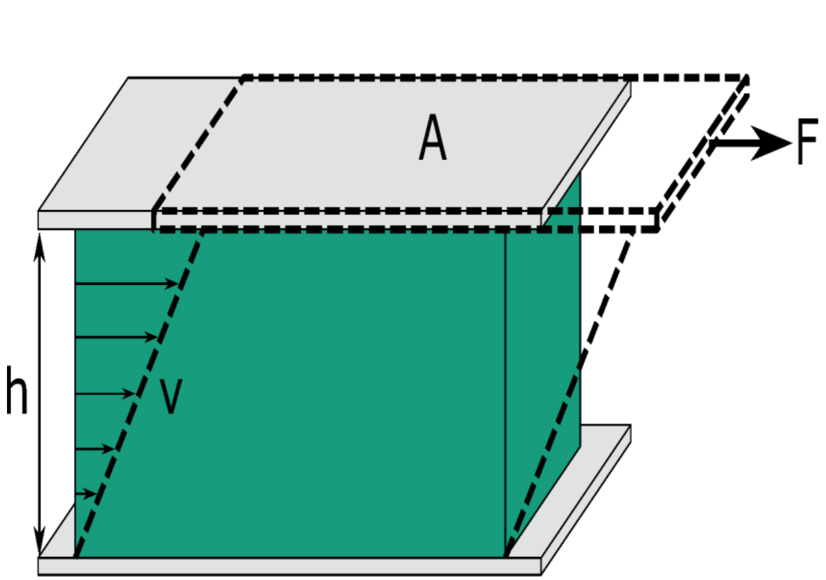


Sketch of an air-fluidized granular layer in three phases [2].

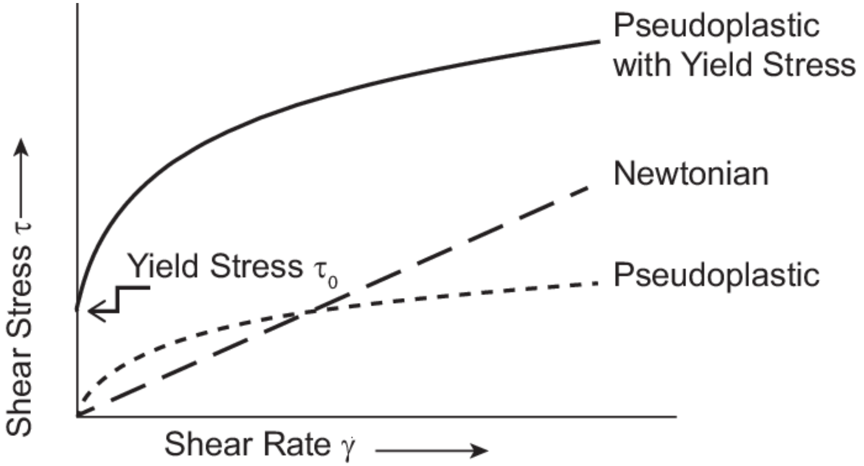
[2] Ralf Stannarius, Magnetic Resonance Imaging of Granular Materials

Theoretical Background
Bulkrheology

- Rheology: Study of flow behaviour
- Bulkrheology, uses two-plate-model and continuum assumptions
  - Shear stress $= \frac{\text{Force}}{\text{Area}},\ \tau = \frac{F}{A}$
  - Shear rate $= \frac{\text{Velocity}}{\text{Distance}},\ \dot{\gamma} = \frac{v}{h}$
  - Viscosity $= \frac{\text{Shear stress}}{\text{Shear rate}},\ \eta = \frac{\tau}{\dot{\gamma}}$
  - Shear modulus, $G = i\omega\eta$
- Bulkrheometer:
  - Sample volume > 1 ml
  - Frequencies usually between 10^{-3} and 10^{2} Hz



Two-plate-model [3]
$h \triangleq$ Distance; F $\triangleq$ Force; $v \triangleq$ Velocity; A $\triangleq$ Area

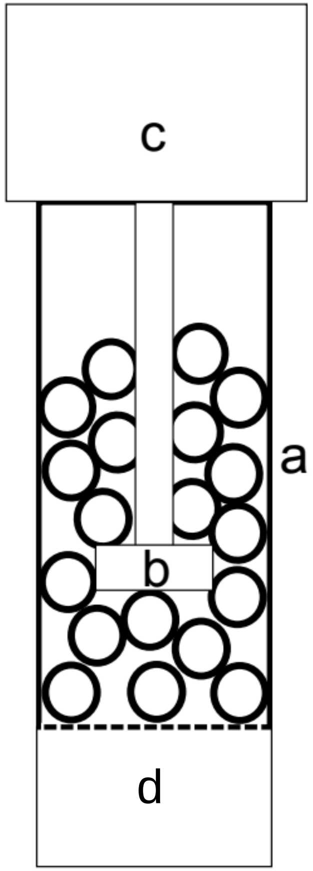


Typical shear stress versus shear rate curves for Newtonian and shear thinning fluids [4]

[3] Mezger, "Angewandte rheologie - mit joe flow auf der rheologie-straße", [4] Gandolfi, Lisa, and Ramiro Galleguillos. "Rheology modifiers and consumer perception."

Experimental Set-up
Rheometer

- Creates precise turning or oscillatory motions of different geometries in a sample cell
- Measures (in this case)
  - Torque
  - Turns per Interval
- Uses Navier-Stokes equation and Continuum Mechanics to extract
  - Shear stress
  - Viscosity
  - Shear rate

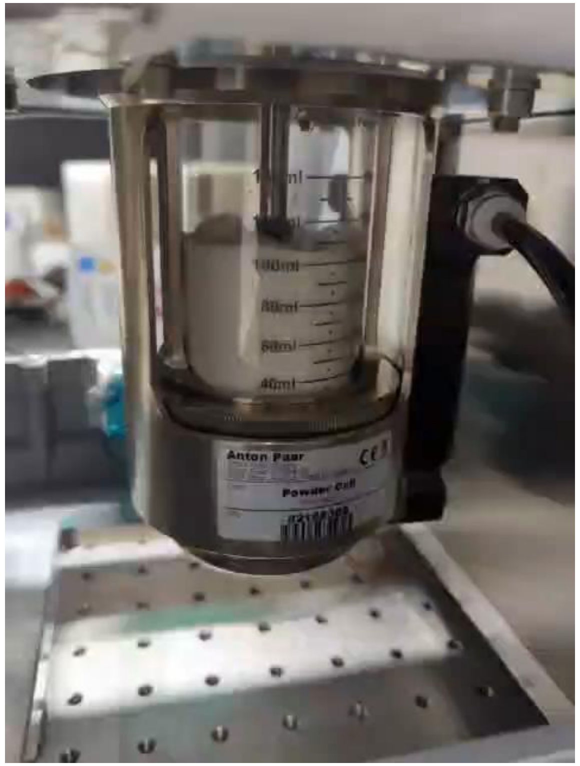


Sketch of the rheometer sample cell and important components. (a) container, (b) measurement system, (c) motor used to turn the geometry, (d) gas inlet [5].

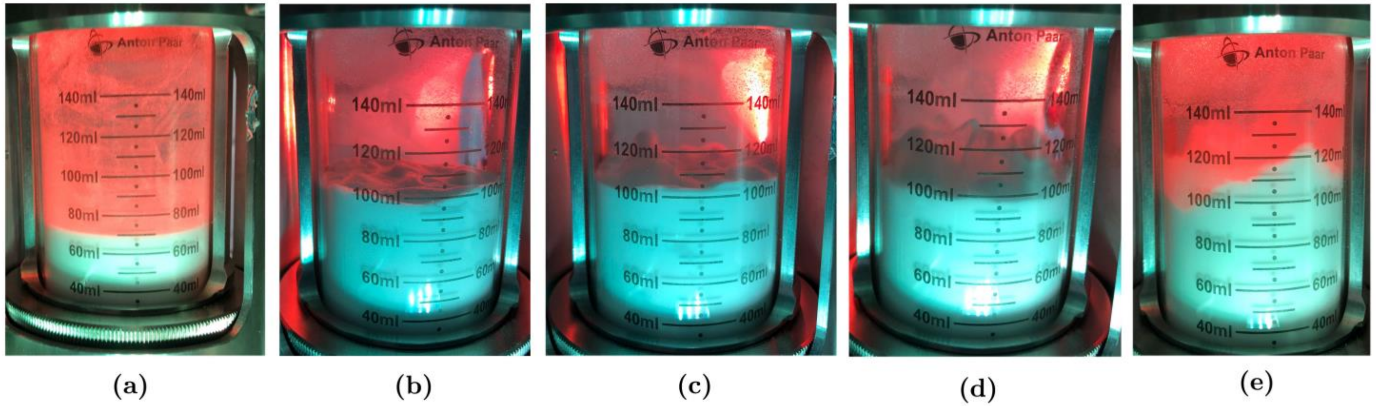
Measurement system/Geometry used to stir the sample (b).

[5] J. Haeberle, “Properties of tailored granular media,”Ph.D. dissertation, Universität zu Köln,2018

Experimental Set-up
Fluidized Bed



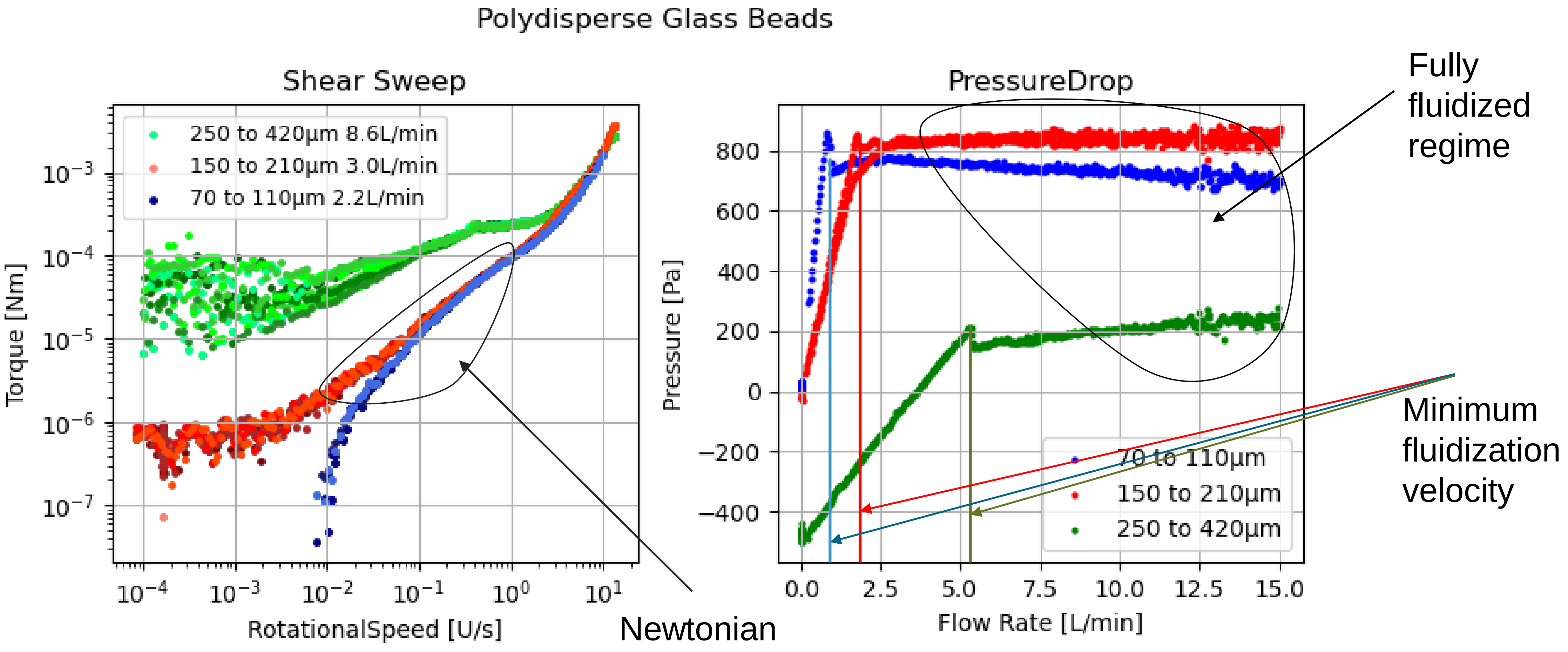
An example or our fluidized bed in the rheometer, during high flow rates.



The type of fluidisation observed in the granular bed shifts as the gas velocity is increased, from (a) no fluidisation to (e) turbulent fluidisation, for the same powder sample [6].

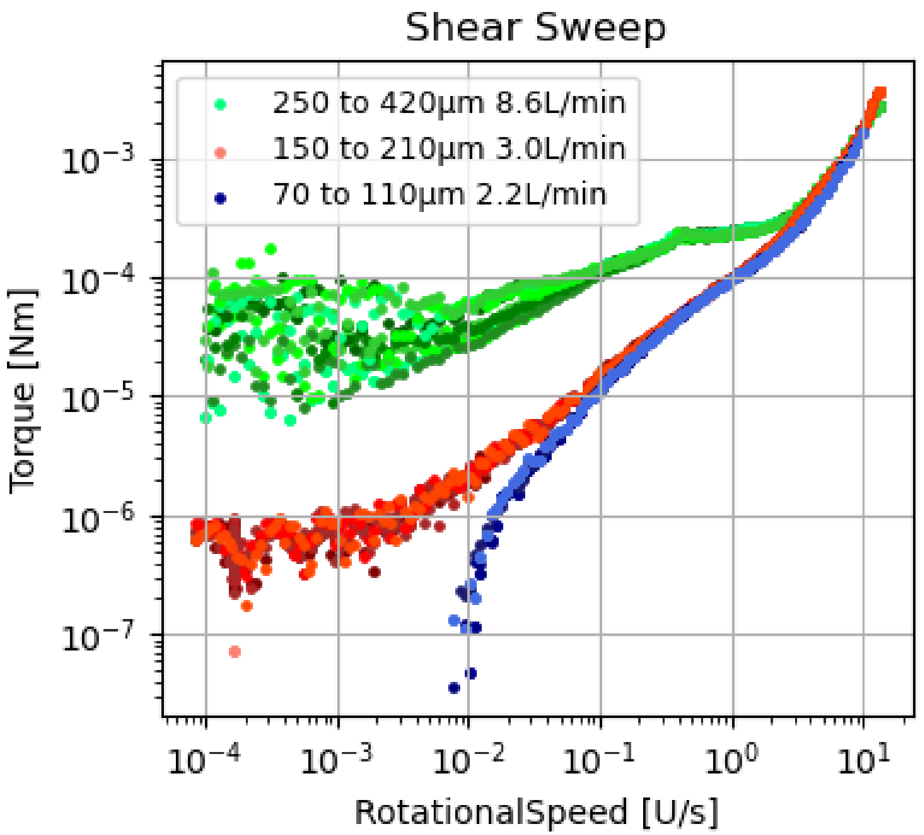
[6] O. Lopez D’Angelo, “Powder-based additive manufacturing for space ”Ph.D. dissertation, RWTH Aachen University,2021

Results
Shear Sweep And Pressure Drop

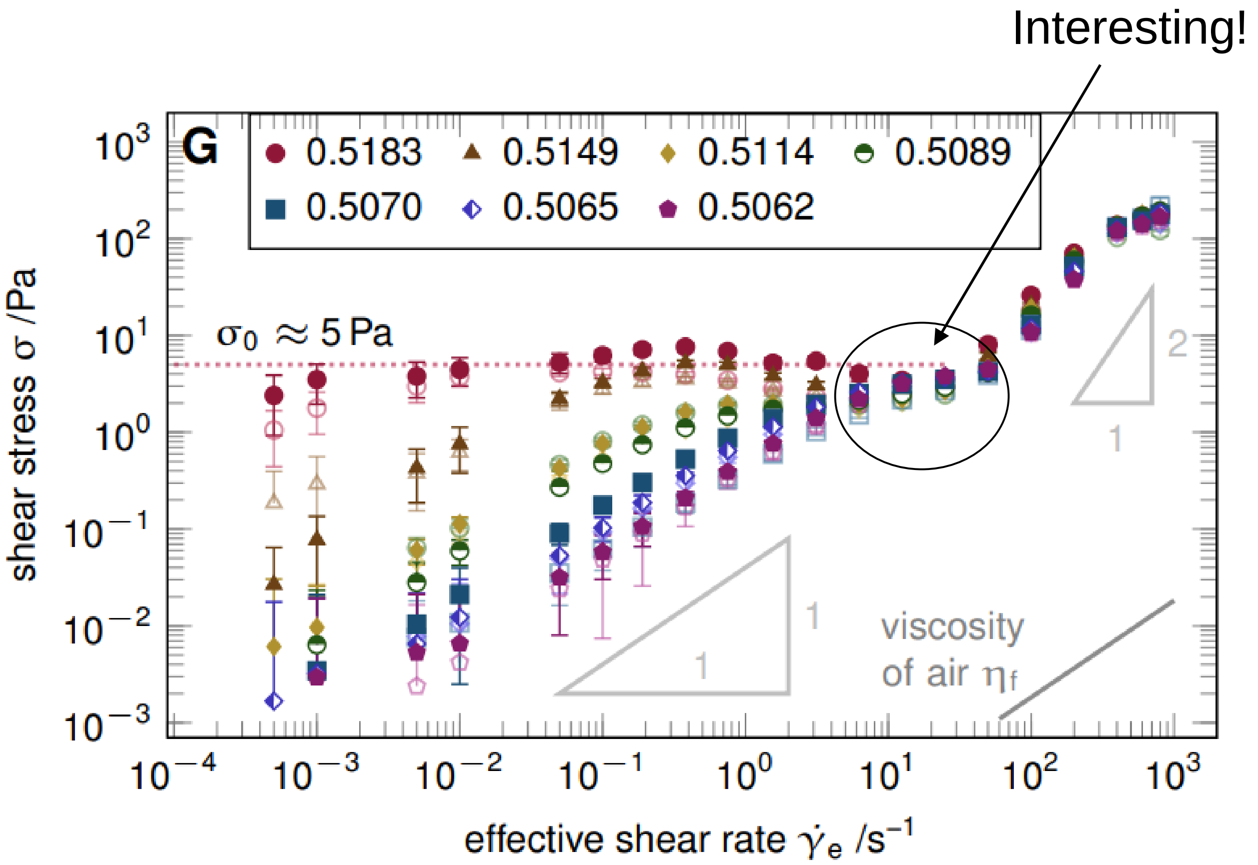


Shear sweeps and pressure drops for different spherical polydisperse particle ranges.

Results
Shear Sweep In Comparison To Literature



Own results for different particles.



Comparison of results taken from D'Angelo at different fluidization velocities, with symbols indicating packing fractions [6].

[6] O. Lopez D'Angelo, "Powder-based additive manufacturing for space "Ph.D. dissertation, RWTH Aachen University,2021

Outlook

- To find out more about assumed shear bands
  - Measurments on
    - Monodisperse particles
    - Polydisperse particles
  - Changing
    - Distance of geometry from the glass frit
    - Diameter of geometry