Binghampluggens utseende vid två-dimensionell radiell strömning

The Bingham-plug in radial flow of a yield stress fluid between smooth parallel disks

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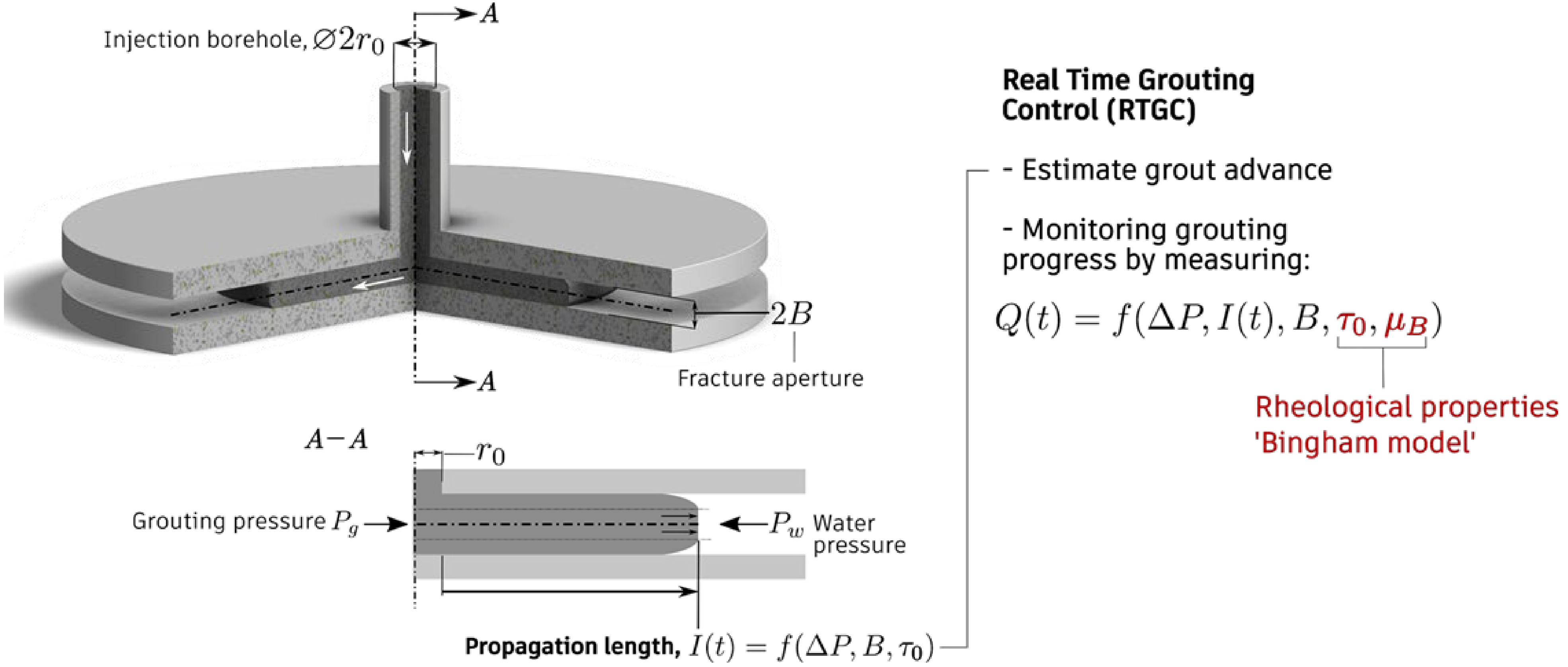
1. Background information

The two-dimensional (2D) radial flow geometry is an idealized flow configuration that is widely used to estimate cement grout flow in rock fractures. However, the ***'true'*** shape of the plug-flow region, that forms the central region of cement grout flow has not been fully resolved analytically. Below is a schematic illustrating idealized 2D radial flow.



1. Main objectives

- To complement the analytical work an experimental radial flow model was designed, built and used to visualize for the first time, radial flow velocity profiles of a ‘Bingham-type’ model fluid, namely Carbopol 980.

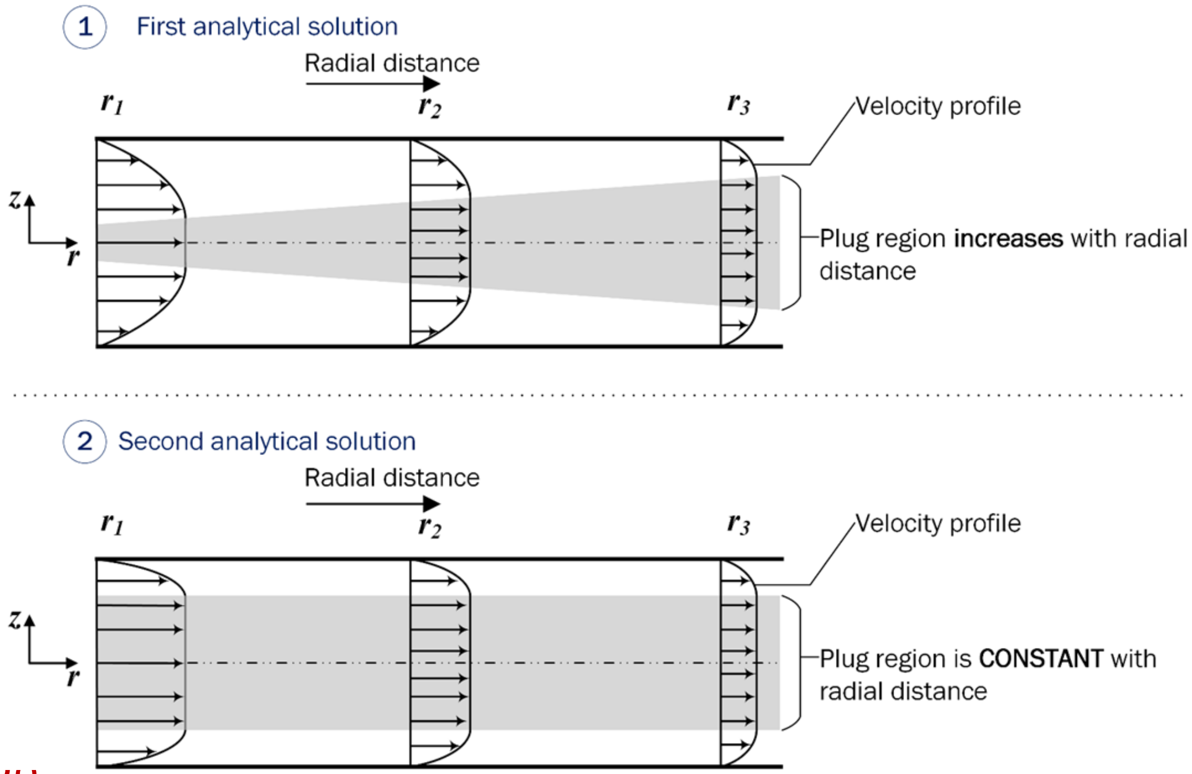
- The aim of the radial experiments is to determine the analytical solution that best describes radial flow of yield-stress fluids. This is carried out by quantifying the plug-flow region from measured velocity profiles and comparing with the analytical predictions.

2. Theory: Analytical solutions

The major difference in analytical solutions for 2-D radial flow is seen in the **shape of the plug flow region**. The velocity profile which includes the plug-flow region is obtained by assuming a steady-state condition at a time instant along the radial direction, using lubrication approximation, constant aperture & pressure (see Zou et al., 2020).

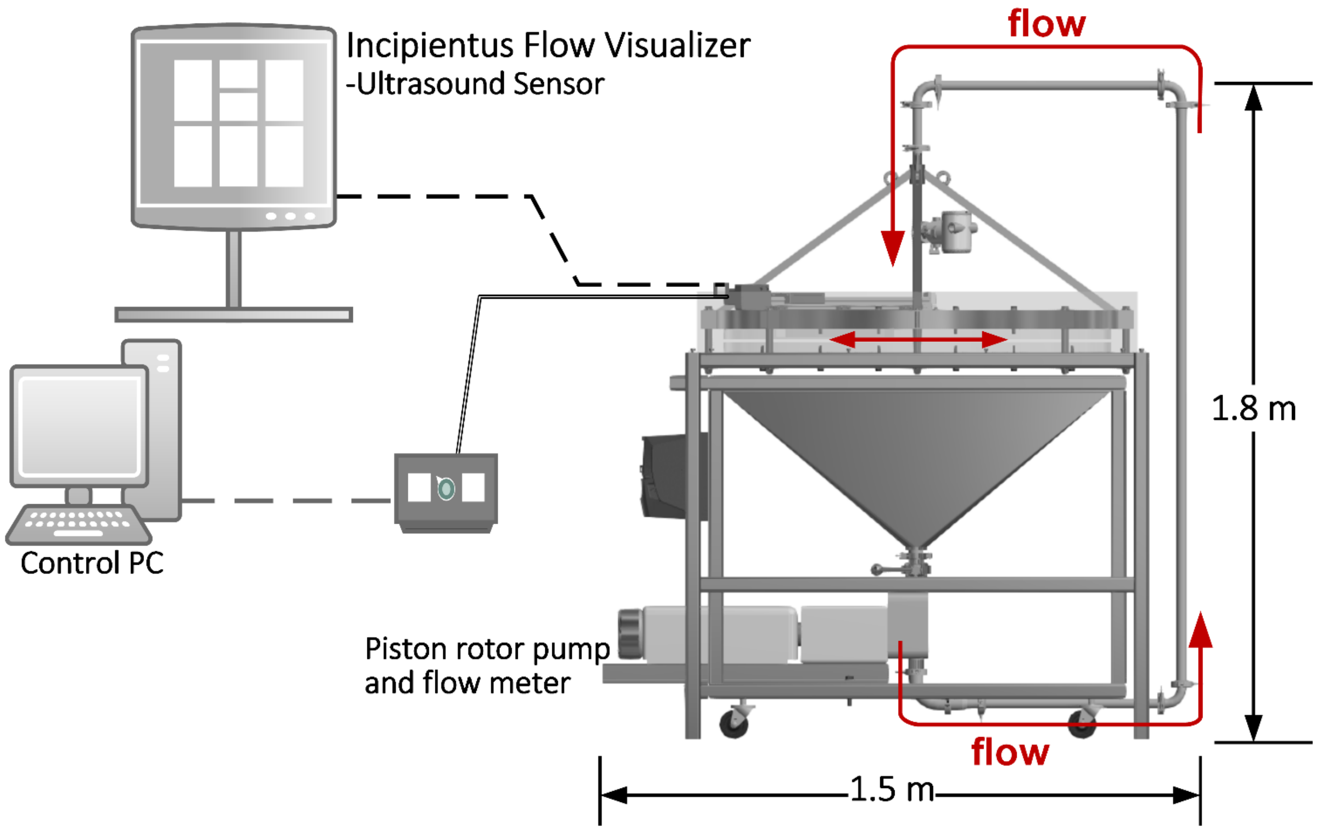
(1) Describes an *increasing* plug flow region (Gustafson et al., 2013).

(2) Describes a *constant* plug-flow region (Zou et al., 2020).



3. Completed radial flow experimental setup

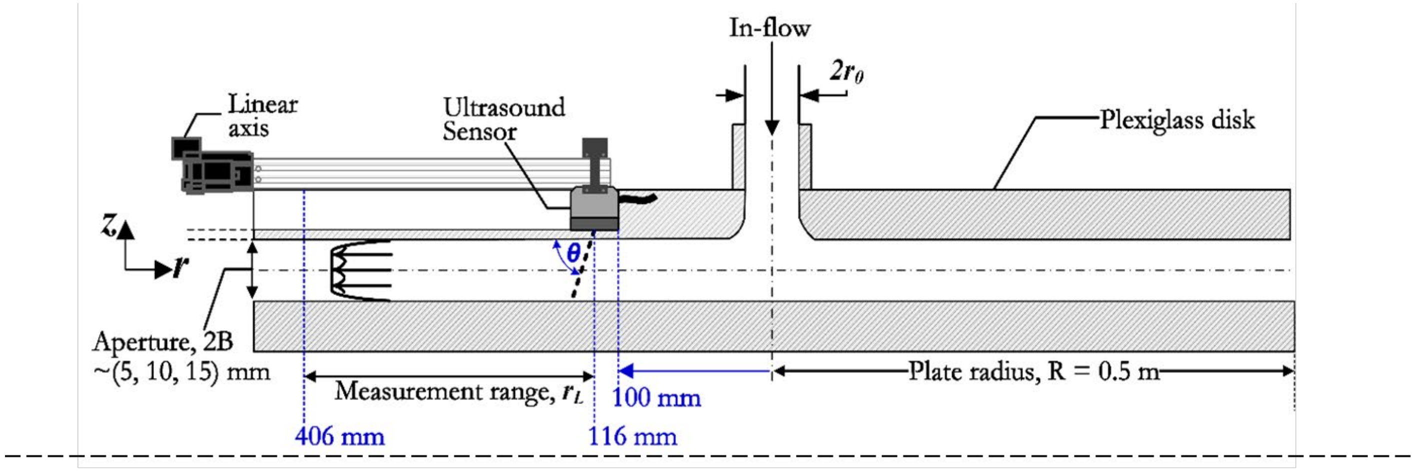
Schematic illustration of radial model that was designed and assembled for velocity profile measurements using an Ultrasound method, **Ultrasound Velocity Profiling (UVP)**

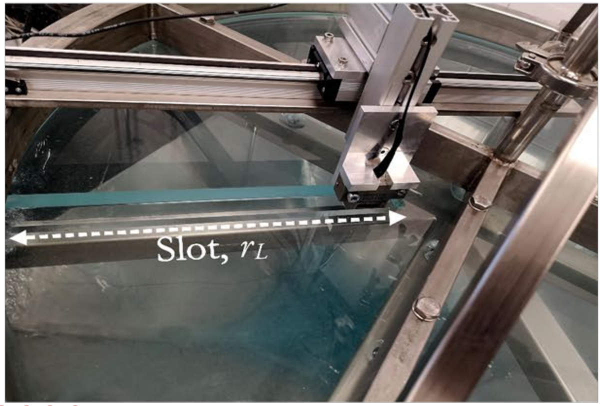


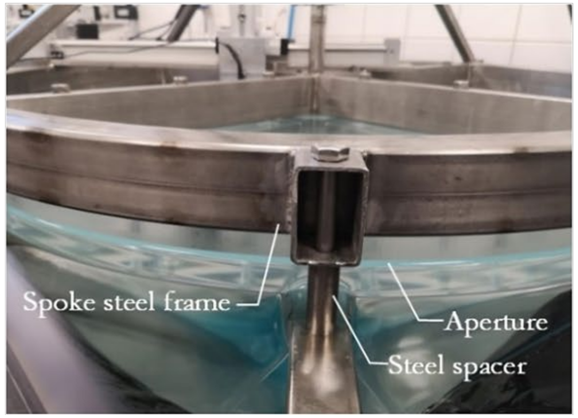
- A special UVP based flow visualizer supplied by *Incipientus AB*, was used for the Velocity profile measurements.
- Carbopol was circulated from the tank around the flow loop into the central injection area, where it then spread out radially.

4. Radial flow area and experiments performed

- The radial flow area was designed with an external spacer system, such that the radial flow area is clear of obstructions, e.g., bolts (Shamu et al., 2020).
- The measurement of velocity profiles, was done at **3 apertures**: 5 mm, 10 mm and 15 mm
- For each gap, the model fluid (Carbopol) was pumped at **3 different constant flow rates**, and velocity profiles along the radial direction were then measured at **20 mm intervals**.







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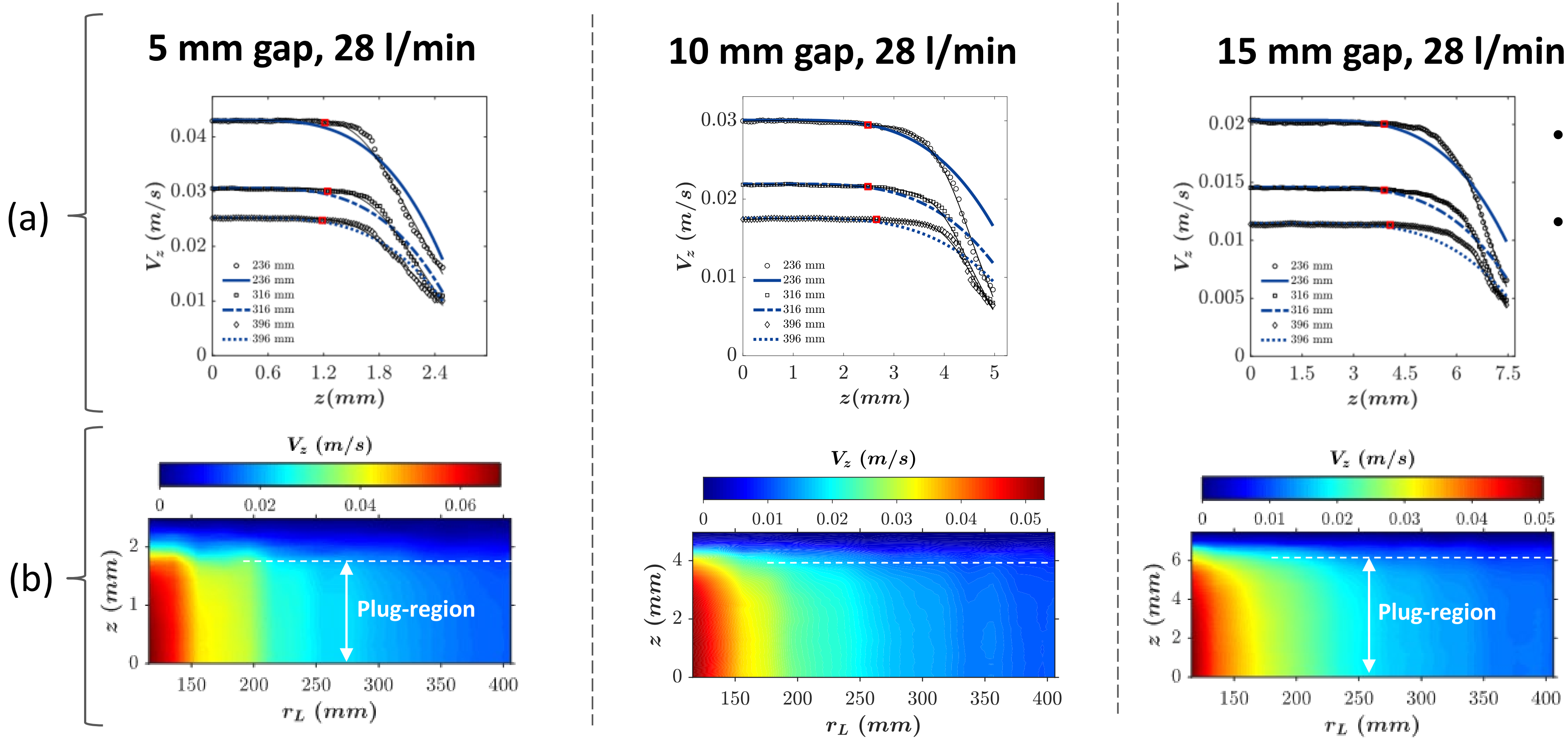
5. Results: Measured velocity profiles



- Analytical velocity profiles shown as blue lines.
- Red points are the calculated Plug-region points (Shamu et al., 2020)

(a) Example measured velocity profiles, showing pronounced wall slip within the smooth-walled geometry; 3 gaps at the same flow rate and radial locations. Wall slip increases the extent of the unsheared plug-region.
(b) Corresponding color maps of the velocity field from 17 interpolated velocity profiles along the radial length.

6. Conclusions and future work

- A 2D-radial flow experimental model was successfully designed, assembled and tested
- Carbopol 980 a model fluid, was prepared according to the recent studies in the literature and used to simulate grout flow behaviour in the absence of time-dependency and thixotropy.
- For the first time, UVP (ultrasound) was used to measure and visualize the velocity profile of a Bingham-type fluid (Yield Stress Fluid) in radial flow
- Analytical velocity profiles were compared to measured velocity profiles; despite the pronounced wall-slip effect a good agreement was observed.

Future work aims to:

- Use roughened plexiglass walls and eliminate wall slip effects.
- Use different concentrations of Carbopol
- Improve plug-flow region detection calculation from the measured velocity profiles.
- Compare measured and analytical profiles with minimal wall slip.

7. References

1. Zou, L., Håkansson, U., Cvetkovic, V., 2020. **Critical analysis of Bingham fluid radial flow in smooth fractures with application to rock grouting**. J. Rock Mech. Geotech. Eng. 12.

2. Gustafson, G., Claesson, J., Fransson, Å., 2013. **Steering Parameters for Rock Grouting**. J. Appl. Math. 2013.

3. Shamu, T.J., Zou, L., Kotzé, R., Wiklund, J., Håkansson, U., 2020. **Radial flow velocity profiles of a yield stress fluid between smooth parallel disks**. Rheol. Acta 59, 239–254. https://doi.org/10.1007/s00397-020-01203-x