In Situ Mechanical Analysis of Sludge in Hazardous Environments

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Introduction and Aims

- Sellafield site is a nuclear decommissioning and reprocessing facility in the United Kingdom (Figure 1)
- Challenges include legacy storage tanks and silos
  - Uncertain mechanical properties of remnant materials, sludge is radioactive material, often in chemically aggressive solution
  - Limited entry points, large distances to cover further complicate sampling

Fig. 1: Sellafield, nuclear decommissioning and reprocessing facility in Cumbria, United Kingdom [1]

- Aim is to design and develop a robust device capable of *in situ* analysis of shear behaviour, with following characteristics:
  - Compact design, must fit through 50 mm opening
  - Non-sampling measurement capability
  - Gamma radiation and chemically resistant design
  - Low cost with consideration for disposal
- Aims support current industry challenges and needs
  - Robust, versatile design intended for use in wide variety of sites
  - Eliminating need for sampling reduces risk, costs
  - Data will support ascertaining appropriate procedures for clean-up and decommissioning, can be used for optimising downstream solutions as well
  - Possible cross-industry applications for research output

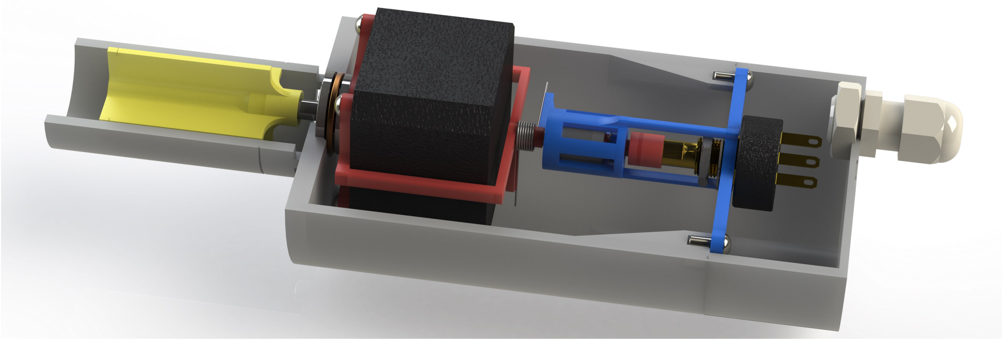

Fig. 2: Laboratory scale prototype for *in situ* shear behaviour analysis

In Situ Viscometer Prototype

- Commercial off the shelf components, 3D printed parts (fused deposition modelling—Figure 2)
- Only 2 electronic components deployed *in situ* (Figure 3)
  - Stepper motor, inside protective case, driving analysis geometry
  - Single sensor based measurement without sensitive electronics
- Modular, easily serviceable design, scalable to application

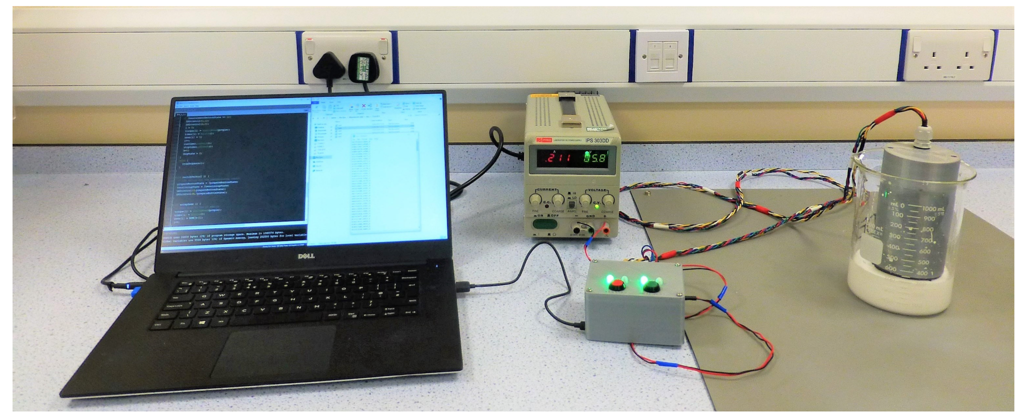

Fig. 3: Experimental setup with the prototype. Left to right: Data acquisition laptop, power supply, external control unit, viscometer device

- Vane type shear viscometry with easily changeable measurement geometries (4 blade vanes and cylinders—Figure 4)
- Validated with ISO/DIN standard geometry
- Non-standard geometries (L/r > 3) tested as well
- State of the art, chemically resistant 3D printed polymers (glass fibre reinforced polypropylene)
- Final prototype may be made from 3D printed metal

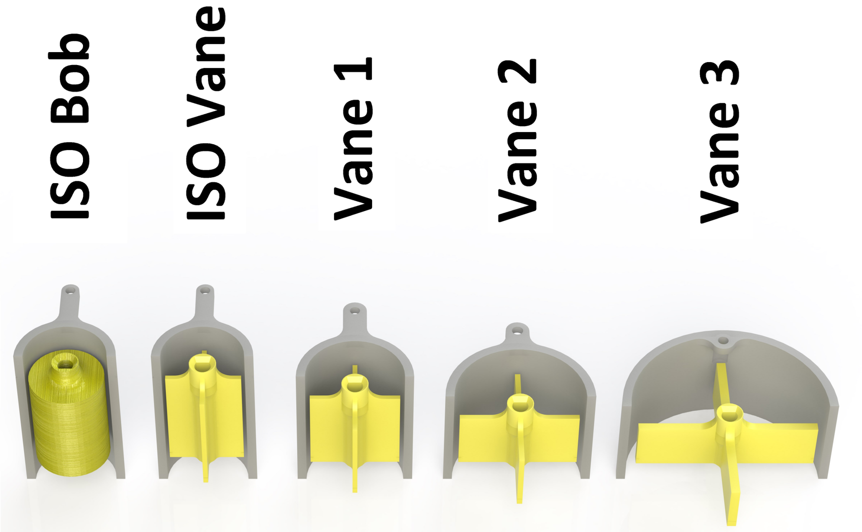

Fig. 4: Bob and vane geometries used with the prototype

- ISO standard geometry
  - Best comparison with scientific, conventional instruments
- Non-standard geometry
  - Improved mechanism function, proportionally lower losses
  - Deployment advantages—less material required for analysis
  - Less sensitive to manufacturing and assembly imperfections

Control and Data Acquisition

- Mains or AA battery powered and portable (<300 mA current draw)
- Arduino based micro-controller, commercial components, Arduino IDE based control and data acquisition code, and USB connectivity
- Sensitive components detached from hazardous environments, device physically tethered
- Non-active side electronics reusable

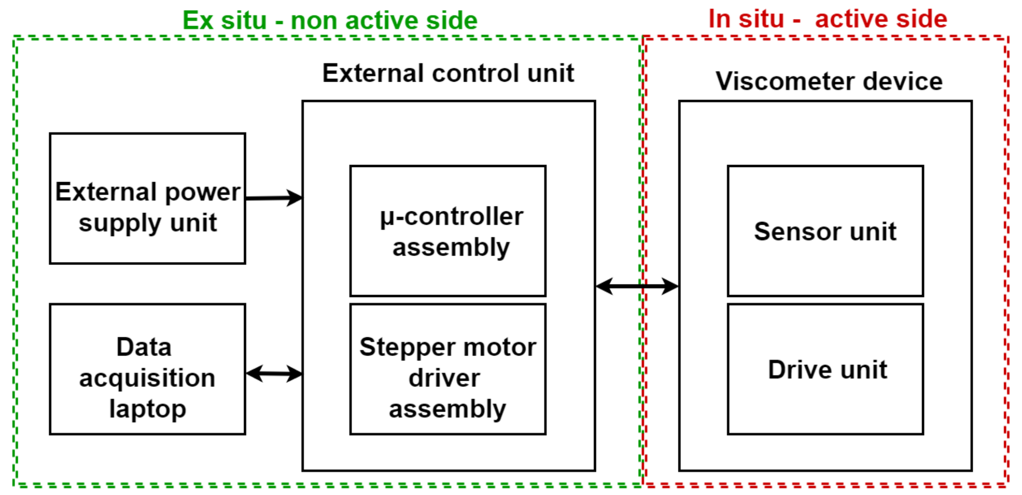

Fig. 5: Schematic of the electronic control system

Calibration

- Prototype calibrated using silicone viscosity standard oil (Figure 6)
- Effect of possible secondary flows not observed with non-standard geometry, expected only with Vane 3
- Calibration doesn't indicate differences in performance using non-standard against ISO standard geometries
- ISO geometries best for higher shear stress consistency
- Non-standard geometry suitable for low shear stress detection

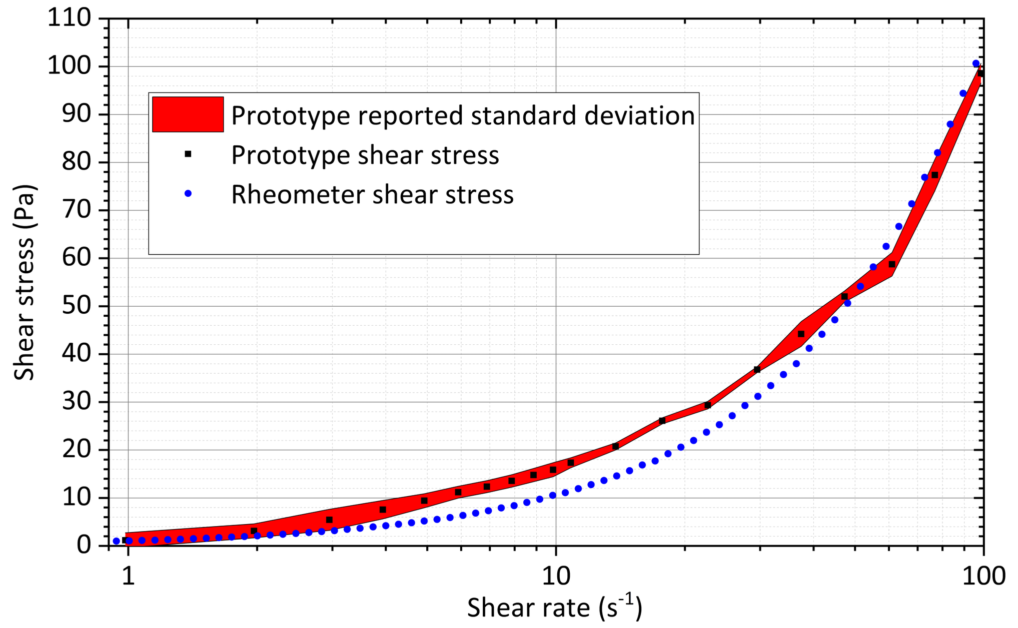

Fig. 6: Calibration of the prototype with a 1 000 mPa·s oil and Vane 3

Laboratory Tests

- Titanium dioxide powder (anatase) suspended in de-ionised water has been used as initial test material
- Average particle size roughly 350 μm, volume fraction of suspension ϕ=0.40—0.45
- Quick settling, shear thinning behaviour

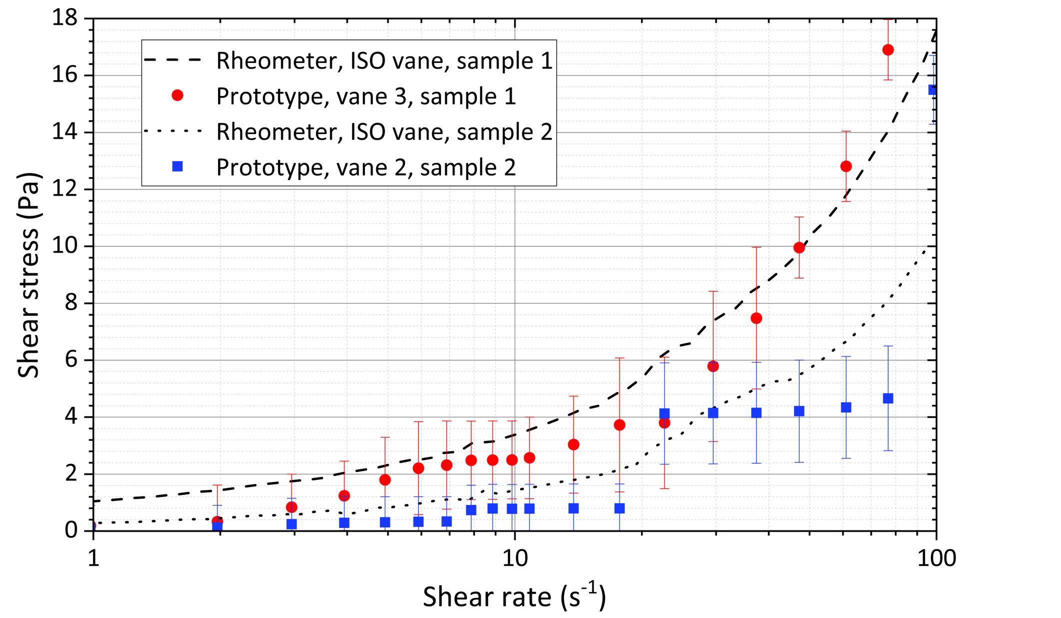

Fig. 7: Performance comparison between two different geometries using similar samples of TiO_2 suspensions

- Performance of prototype compared with conventional, benchtop rheometer (Bohlin CVO100)
- Highest precision, lowest deviation between measurements with the largest geometry—Vane 3
- Smaller geometries not suitable for low viscosity samples
- Possibility of Taylor vortices effects at higher shear rates (>50 s^{-1}), prototype reports increase in viscosity
- Prototype consistently reports shear thinning behaviour

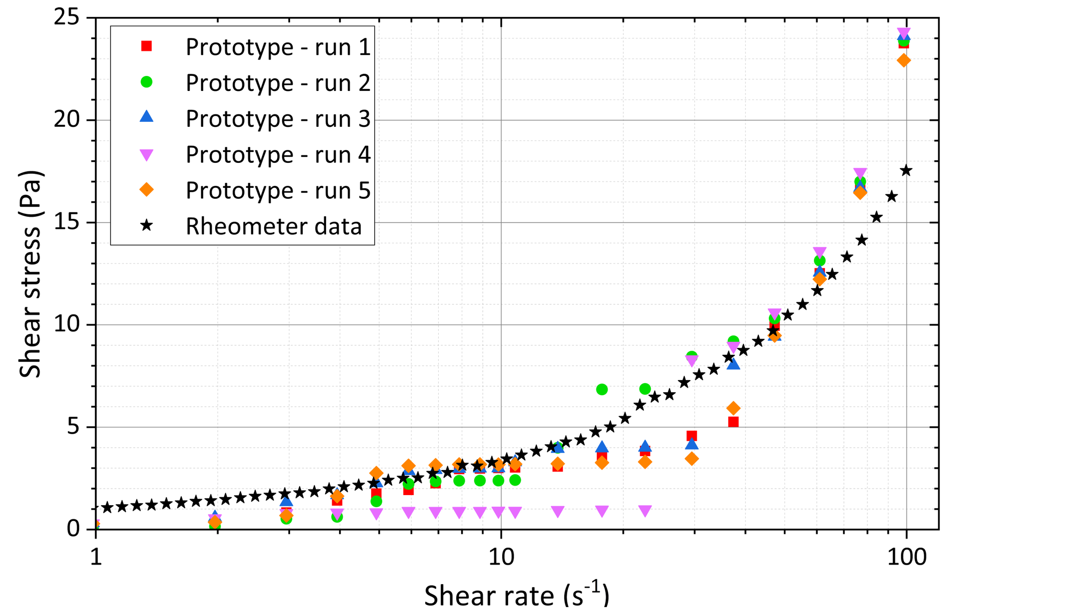

Fig. 8: Shear stress output comparison between the prototype with Vane 3 and the Bohlin CVO100 rheometer with TiO_2 suspension

Conclusions and Future Work

- Prototype exhibits predictable, repeatable behaviour with Newtonian substances
- Non-standard measurement geometry requires lower material height, improving the low shear-stress response
  - Risk of secondary flows at higher shear rates
  - Measurement appropriate for yield stress analysis
- Deployment *in situ* decreases disturbing sample structure, offers more realistic view of material properties
- Device eliminates need for sampling, reduces risk, low cost ($300), compact design maximises deployment potential

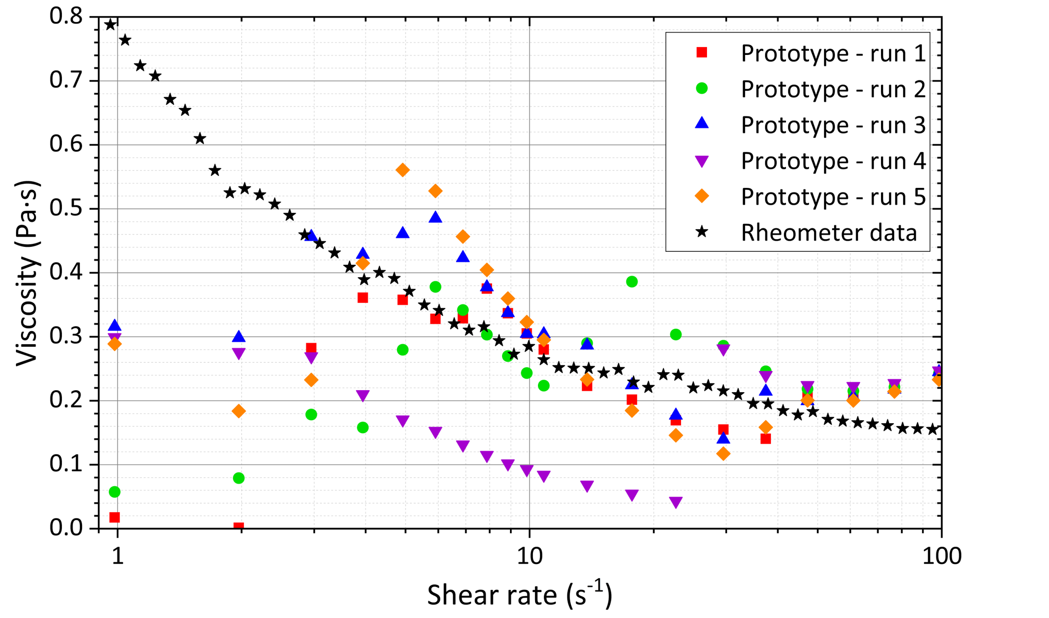

Fig. 9: Viscosity measurement comparison between the prototype with Vane 3 and the Bohlin CVO100 rheometer with TiO_2 suspension

- Further development steps
  - Irradiation testing
  - Validation with high viscosity test materials
  - Built-in density measurement and material level detection
  - Improved low shear stress performance
  - Bespoke mechanism drive design
  - User interface development with real time data analysis

Acknowledgements

This work has been supported by the Centre for Innovative Nuclear Decommissioning (CINDe), which is led by the National Nuclear Laboratory, in partnership with Sellafield Ltd and a network of Universities that includes the University of Manchester, Lancaster University, the University of Liverpool and the University of Cumbria.

References

[1] CHAMBER INSIGHT. Nuclear: Where next for Sellafield? | Cumbria Chamber of Commerce . [online]. 26th April 2017. Available from: http://www.cumbriachamberofcommerce.co.uk/nuclear-where-next-for-sellafield/