In Situ Mechanical Analysis of Sludge in Hazardous Environments

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Abstract

In situ mechanical analysis of sludge in hazardous environments is critical for the management of nuclear decommissioning sites. This work presents a novel viscometer prototype capable of in situ measurement of sludge properties, enabling continuous monitoring and improved decision-making during decommissioning activities.

Introduction and Aims

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

In Situ Viscometer Prototype

- Commercial off the shelf components, 3D printed parts (Figure 2).
- Devoid 2 electronic components deployed in situ (Figure 3).
- Stepper motor, inside raw recovery process, for taking analysis geometry.
- Single sensor based measurement without sensitive electronics.
- Modular, easily serviceable design, scalable to application.

Control and Data Acquisition

- Mains or AA battery powered and portable (430 mAh current draw).
- Arduino based microcontroller, commercial components, Arduino IDE based control and data acquisition code, and USB connectivity.
- Sensor, components detached from hazardous environments, device physically tethered.
- Non-active side electronics re usable.

Deployment advantages

- Improved mechanism function, proportionally lower losses.
- Best comparison with scientific, conventional instruments.
- Single sensor based measurement without sensitive electronics.
- Great settling, shear thinning behaviour.

Fig. 1: Sellafield, nuclear decommissioning and reprocessing facility in Cumbria, United Kingdom (1).

ISO Std
ISO Vane
Vane 1
Vane 2
Vane 3

Fig. 2: Non-invasive geometries used with the prototype.

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. 3: Schematic of the electronic control system.

Viscosity measurement comparison between the prototype with Vane 3 and the Bohlin CVO200 rheometer with T05, suspensions

Fig. 4: Performance comparison between two different geometries using similar samples of T05, suspensions.

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 regimes.
- 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.

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.

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Fig. 5: Experimental setup with the prototype. Left to right: Data acquisition board, power supply, sensor control unit, sensor unit device.

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

Fig. 7: Shear stress output comparison between the prototypes with Vane 3 and the Bohlin CVO200 rheometer with T05, suspensions.

Fig. 8: Viscosity measurement comparison between the prototype with Vane 3 and the Bohlin CVO200 rheometer with T05, suspensions.

Fig. 9: Performance comparison between two different geometries using similar samples of T05, suspensions.