Classification of texture-modified drinks: an experimental and computational fluid dynamics investigation.

Ben Hanson[1], Rashid Jamshidi[1], Andrew Redfearn[1], Ryan Begley[1], Catriona Steele[2]
[1] University College London, United Kingdom [2] Toronto Rehabilitation Institute, University Health Network, Toronto, Canada

1. Introduction

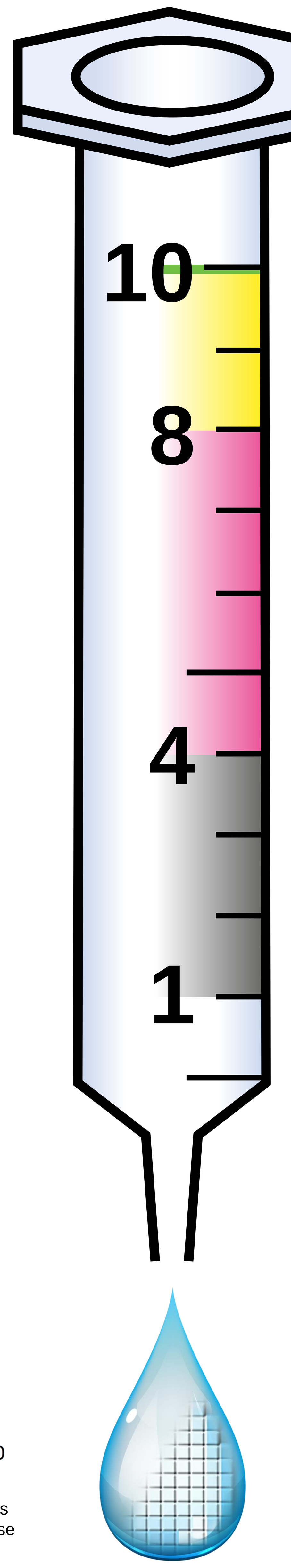
Texture-modified thick drinks are widely used and have potential to be more clearly-defined to standardise practice and enable international research. The previous American Dietetic Association's NDD standards mentioned **viscosity** measurement (in appendix A, as "a basis for discussion"), but this is now superseded by **IDDSI[1]** which includes a **gravity-driven test of flow** in preference to viscosity measures. As part of a detailed investigation of the IDDSI flow test, the following **two questions** were addressed here:

Q: How does the IDDSI flow test relate to lab. rheometry?

Approach: Measure fluids' rheology and quantify outflow rate throughout the IDDSI flow test.

Q: What are the flow rates *inside* the syringe?

Approach: Use computer simulation based on experimental rheology to investigate internal flow.



2A. Experimental Methods

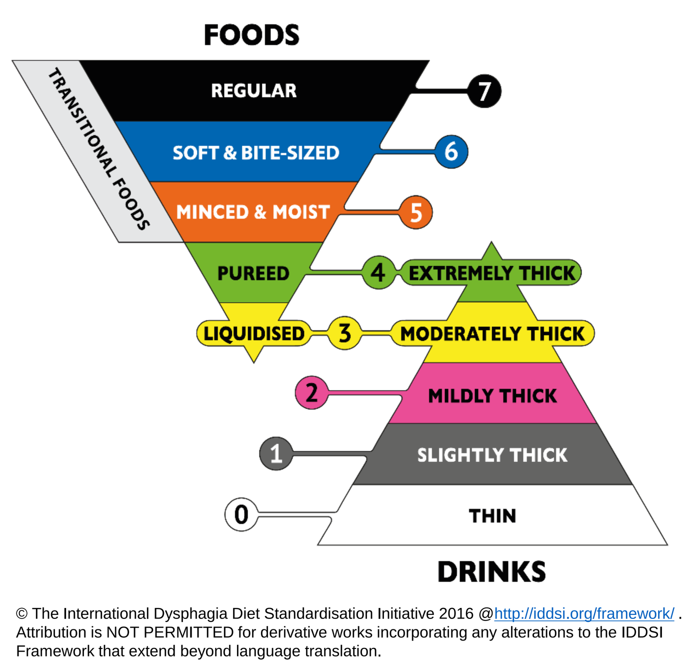


Figure 1: The IDDSI Framework

Starch- and Gum-based thick liquids were created.

Powder : liquid dosages were designed to achieve the mid-points of IDDSI levels 1, 2, 3 (Fig 1). With the addition of water, these liquids cover the full range of dysphagia management drinks.

A lab rheometer characterised these at shear rates from 0.1-1,000 /s plus yield stress measurement. Results shown in fig 4.

A motion-tracking system was created to monitor the IDDSI flow test (Fig 3).

This tracked the decrease in liquid level, from 10ml initially, for the 10 seconds' flow. The liquid level remaining at t = 10s is the final value which comprises the IDDSI flow test result (shown in fig 6). BD model 302188 syringes were used which had a Luer tip and scale length 61.5mm, required by IDDSI.

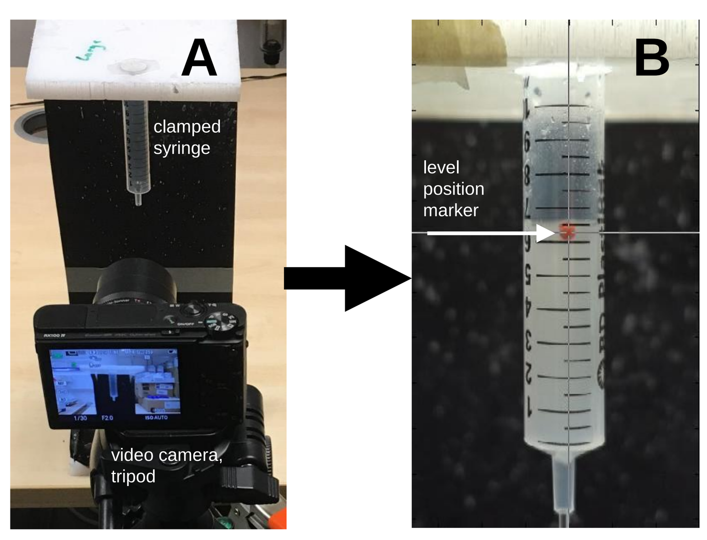


Figure 3: (A) Rig for video analysis of the IDDSI flow test (B) Contrasting red particle was used to identify the liquid surface level, automated in software.

2B. Computational Methods

A computerised fluid dynamics (CFD) model of the gravity-driven syringe flow was created (Fig 2).

Axial symmetry was assumed and the fluids' rheological data was modelled using a Herschel-Bulkley equation[2] including yield stress: $\tau = \tau_0 + K\dot{\gamma}^n$. For thicker liquids (Levels 2-3) where the outflow regime is dripping instead of streaming, **surface tension was included[3]**.

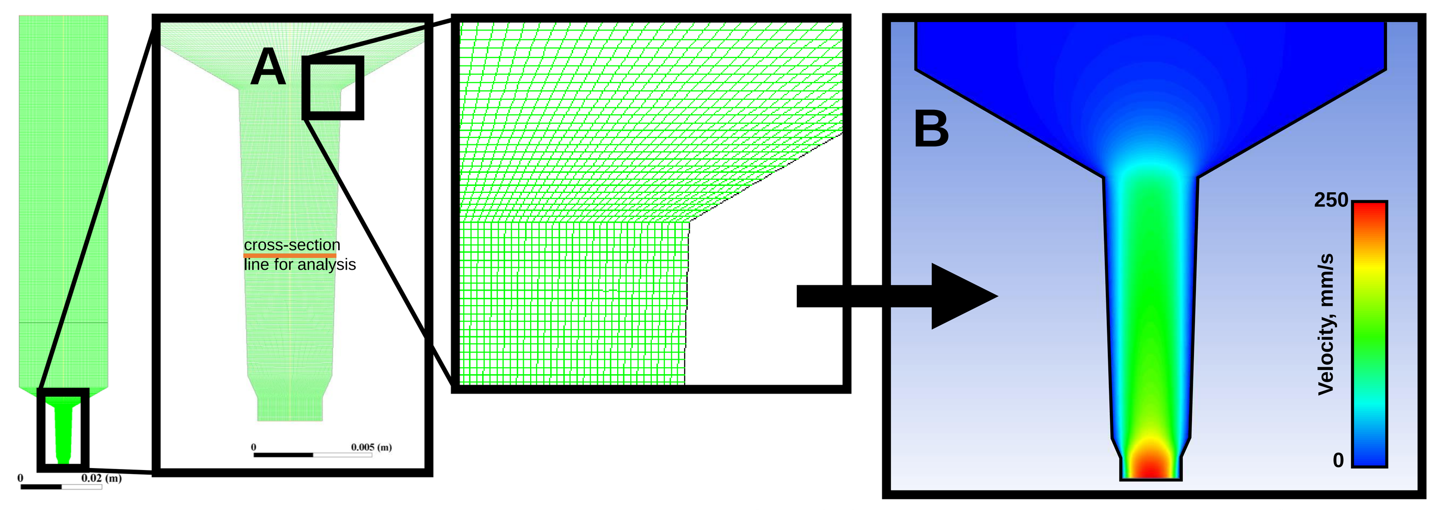


Figure 2: (A) The syringe geometry was discretised into quadrilateral elements. (B) Discrete computation of non-Newtonian fluid models produced maps of fluid velocity, pressure and shear rates

3A. Experimental Results

Shear rheology: Gum liquids had consistently steeper shear-thinning profile than starch (lower power index "n"), Fig 4.

These lines of apparent viscosity overlap and intersect; the plots for nutritional supplements and other brands of thickeners have different gradients and intersections (results not shown here)

Thus, apparent viscosity at any one shear rate cannot classify the flow of different liquid types.

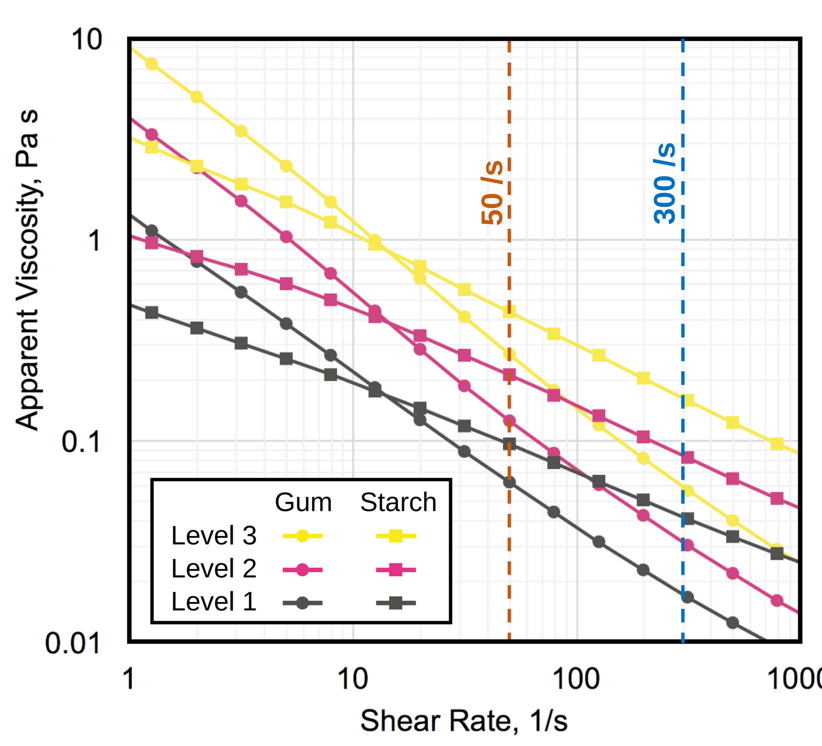


Figure 4: Shear rheology of Gum- and Starch-thickened water. Rates of 50 and 300/s are highlighted, referring to prior work, however these are not applicable to classify the liquids investigated here.

3B. Computational Results

Velocity and shear rate varied due to the difference in cross-sectional area.

Velocity and shear rates were typically 30x higher in the nozzle than the barrel

Examining shear rate through a cross-section of the nozzle, Fig 5, shear rate is maximal at the walls and **zero in the centre**:

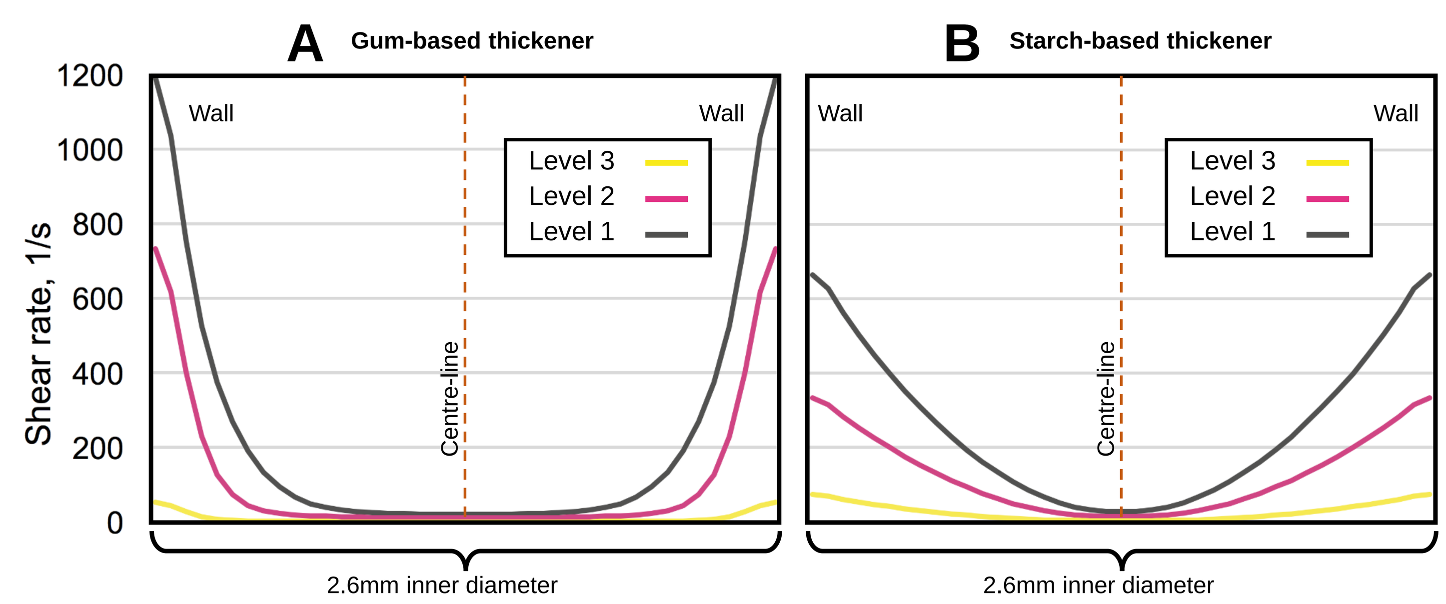


Figure 5: Shear rates in a cross-section through the syringe nozzle (shown by orange line in Fig 2A).

Gum liquids showed higher shear rates than Starch

Fig 5A shows that within a 1mm fluid layer from the internal walls, Gum-thickened liquids exhibited shear rates varying from 1200 /s to near-zero. The central 50-75% fluid volume exhibited very little shear flow: a "plug"-like distribution[4] consistent with the highly shear-thinning shear rheology measurements (Fig 4).

4. Comparing Experimental and Computational Investigations

Figure 6 shows the liquid level vs time as measured by motion tracking experiments, compared to CFD computer simulations.

To achieve the results in Fig 6, the computational fluid models required experimental measurements of shear rheology *plus* yield stress and, for Level 2-3 liquids, surface tension.

The more-detailed fluid models could simulate experimental flow results in all cases (Fig 6), thus the calculated internal shear rate profiles (Fig 5) were taken to have construct validity.

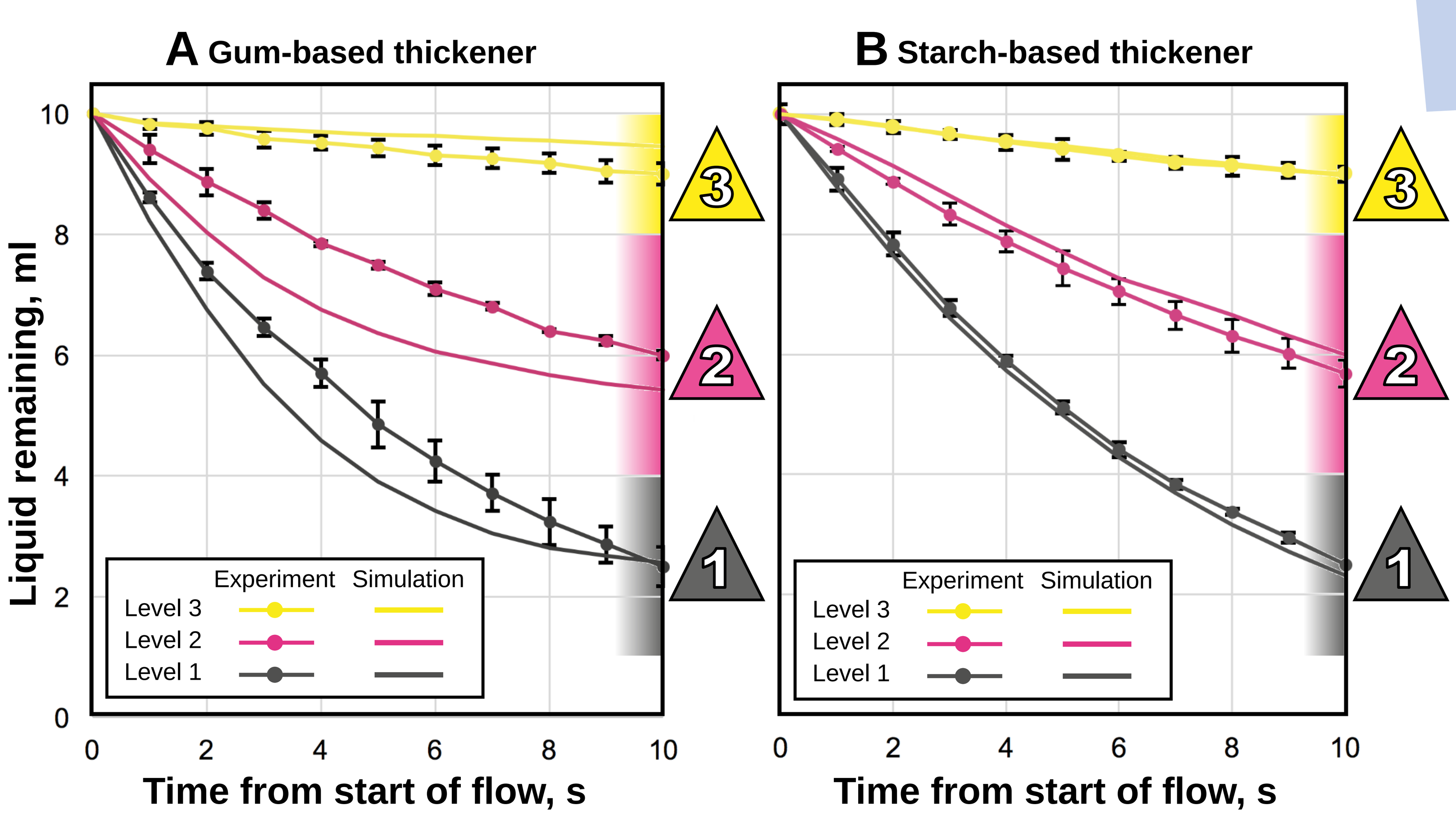


Figure 6: Comparison between measured (motion tracked) and simulated (CFD) liquid level during the 10 seconds duration of an IDDSI flow test. Final values at 10 seconds reach the centres of IDDSI Levels 1-3.

Fig 6B: Starch-thickened liquids could be very closely simulated in CFD by using experimental data from shear rheometry (yield stress, apparent viscosity and surface tension). However, the simulated flow rate for Gum-thickened liquids showed differences to experimental observations (Fig 6A).

Thus there must be further properties of the gum-thickened liquid which affect flow significantly; these could include tribology[5], extensional viscosity or elasticity.

5. Conclusions

In dysphagia management, many aspects of fluid behavior are important to clinical efficacy.

Shear rheology (i.e. measuring apparent viscosity) was *not sufficient* to classify liquids' flow.

The IDDSI flow test is a composite assessment of a liquid's shear rheology (0 to >1000/s), yield stress and surface tension. Ongoing research in this NIH project is mapping clinical outcomes to IDDSI-classified drinks.

National Institutes of Health

This study was funded by the National Institutes of Health on Deafness and other Communication Disorders (NIH) for Grant Number R01DC011020

References

(1) Cichero, J.A.Y., Lam, P., Steele, C.M. et al. *Dysphagia* (2017) 32: 293.
(2) Vickers Z, Damodhar H, Grummer C, et al. *Dysphagia*. 2015;30(6):702-13.
(3) Zhang, X. and Basaran, O.A., *Physics of Fluids* 7, 1184 (1995) (4) Waqas MQ, Wiklund J, Altskar A, Ekberg O, Stading M. *J. Texture Stud*. 2017:1-11.
(5) Pradal C, Stokes JR. *Current Opinion in Food Science*. 2016;9:34-41.

ESSD2018 2--8E
Session 08. Poster session 8E: Treatment 2
Ben Hanson
DOI: 10.3252/pso.eu.ESSD2018.2018
Poster presented at: