High Throughput Measurement of Particle Jamming:
A proposal quick guide

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ECFP

Formulate for the Future

THE UNIVERSITY of EDINBURGH

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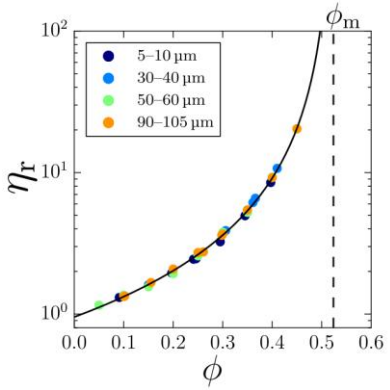
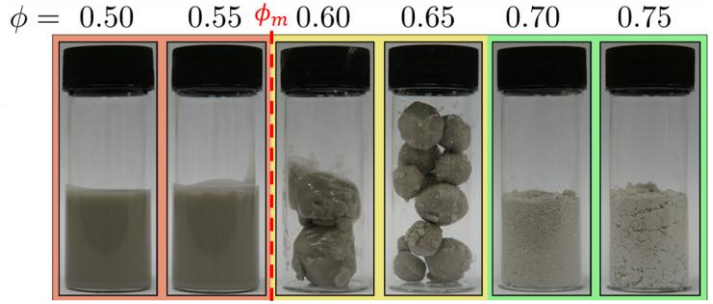
IFPRI

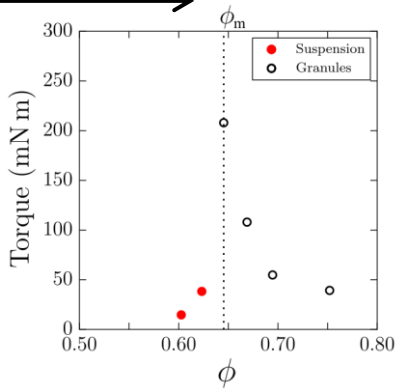
International Fine Particle Research Institute

Why is ϕ_m an important quantity in industrial processing of dense suspensions?

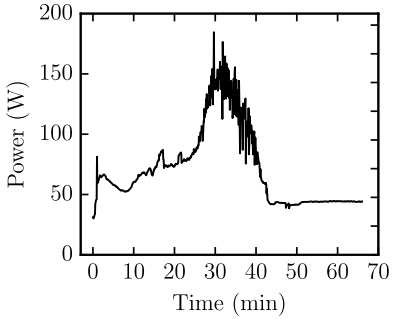
Increasing volume fraction, ϕ







Suspensions ϕ_m Granulation



D. J. M. Hodgson, M. Hermes, E. Blanco and W. C. K. Poon, "Granulation and suspension rheology: A unified treatment," Journal of Rheology, vol. 66, p. 853–858, August 2022.

E. Blanco, D. J. M. Hodgson, M. Hermes, R. Besseling, G. L. Hunter, P. M. Chaikin, M. E. Cates, I. Van Damme and W. C. K. Poon, "Conching chocolate is a prototypical transition from frictionally jammed solid to flowable suspension with maximal solid content," Proceedings of the National Academy of Sciences, vol. 116, p. 10303–10308, May 2019.

Key Points

- The jamming point, ϕ_m, controls the transition from suspensions to granules
- Usually, these states are researched by separate communities
- ϕ_m a key parameter in suspension rheology and granule properties
- Many applications operate close to ϕ_m so being able to predict it for new formulations or with feed stock variability is essential for industry
- Some products, e.g., chocolate traverse the jamming transition during production and directly influences processing energy

Current methods for measuring ϕ_m and their limitations

Technique	High throughput	Widely available	Accurate	Precise	Complex systems
Shear rheometry	×	×	✓	✓	✓
Atterberg plastic & liquid limits	✓	✓	×	×	✓
Sedimentation/centrifugation	✓	✓	✓	✓	×
Immobilisation cell rheometry	✓	×	✓	✓	×
Capillary-stress controlled rheometry	✓	×	✓	✓	×
Tap density	✓	✓	✓	×	×
Single particle μ	×	×	✓	×	×
Angle of repose	✓	✓	✓	×	×
Simulation	✓	✓	✓	×	×

Most other techniques are not well suited to industrial settings or cannot handle complex samples

Multi-sample rheology is tried and tested for complex systems, **BUT** it is...

- Relatively **slow** to collect data
- **Expensive**, delicate equipment not well suited to production environments
- **Requires expertise** in sample loading and data interpretation

Key Point

Rheology is the best way to accurately measure ϕ_m in the lab, but it is time consuming and requires operator expertise. **We need a new, high throughput method for measuring ϕ_m in industrial settings.**

Investigating mixer-torque rheometry as a high throughput method for determining ϕ_m

Kitchen mixer

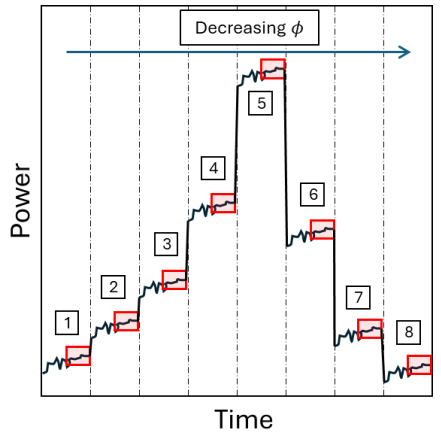
Bespoke equipment

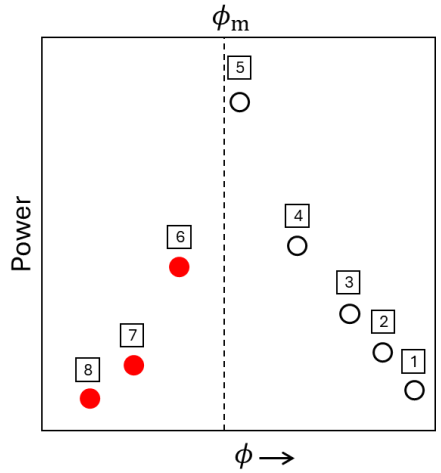
Twin-screw extruder

Brabender torque viscometer

Many different types of equipment available

Measure power or torque vs ϕ





Measure power vs ϕ: peak in power indicates ϕ_m

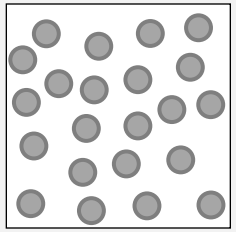
Key Point

Mixer-torque rheometry is a promising technique to determine ϕ_m rapidly in industrial settings for a range of system complexity and does not require expensive equipment or expert operators

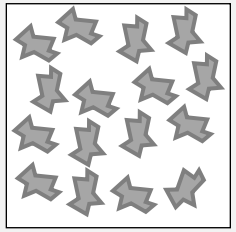
- We will investigate mixer torque rheometry to measure ϕ_m for complex industrial systems
- Volume fraction ϕ calculated by converting mass fraction via material density
- We will explore both liquid-to-solid and solid-to-liquid addition
- Jamming point determined using mixer-torque rheometry will be compared to standard multi-sample shear rheometry to assess accuracy across complex systems

Proposed research overview & work packages

WP1

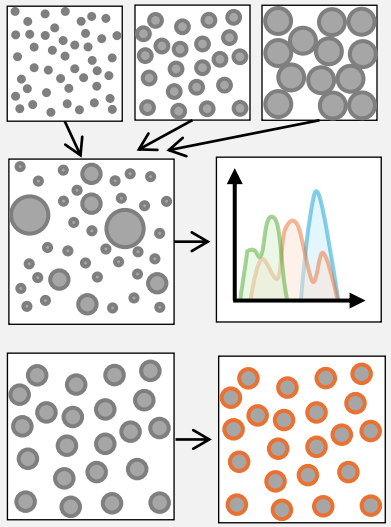


- Baseline mixer-torque rheometry for simple systems



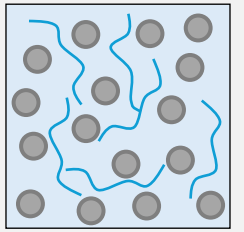
- Increase complexity by exploring non-spherical particles (simple chemistry)

WP2

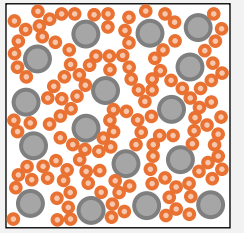


- Increase complexity further by exploring size and poly-dispersity
- Modify surface chemistry to change particle-particle interactions

WP3

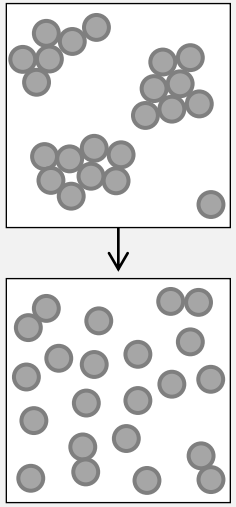


- Focus on complex non-Newtonian binders
- These will encompass polymeric solutions with increasing concentration



- We will also explore complex yield-stress particulate gel binders

WP4



- The most complex systems will also show dynamic behaviour
- Here we focus on aggregate or friable particle breakage
- The challenge will be experimental design and data interpretation for a system which changes in response to applied mixing stress

WP5

- Round robin activity to test company systems and determine ϕ_m

- This WP runs in parallel to WP1-4, and ideally builds in complexity in tandem

	2025	2026				2027				2028		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
WP1												
WP2												
WP3												
WP4												
WP5												

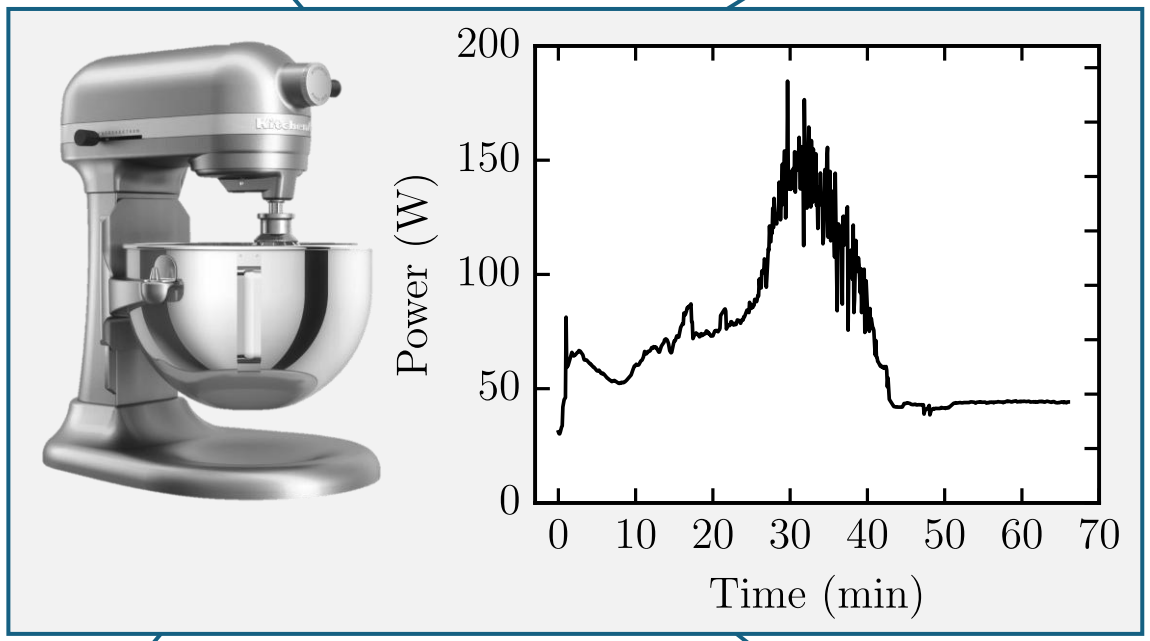
Key Point

We will explore mixer-torque rheometry in **increasingly complex industrial formulations**, including company-supplied systems as part of a round robin activity

High Throughput Measurement of Particle Jamming: Project Summary

Flexible, robust, cheap measurement equipment

Capable of handling complex industrial systems

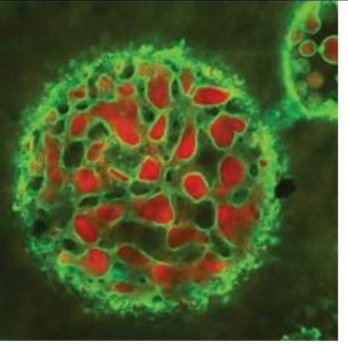
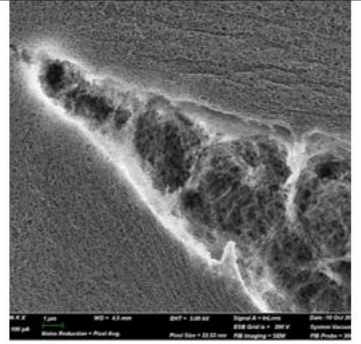
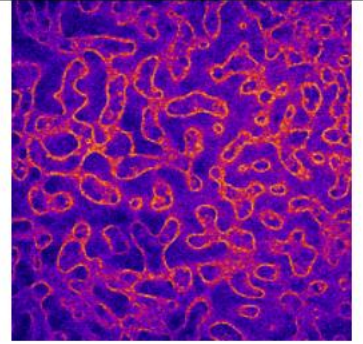
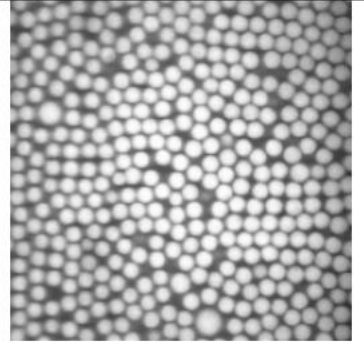
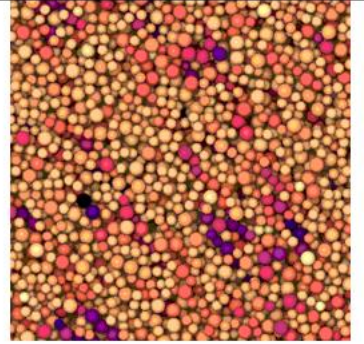
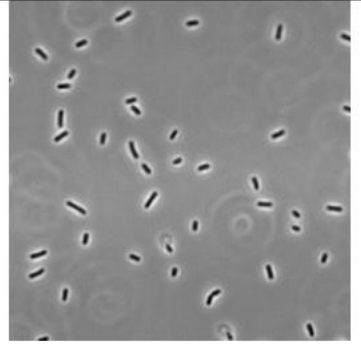
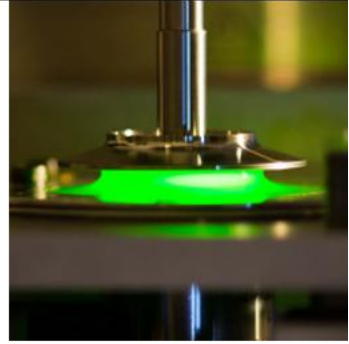
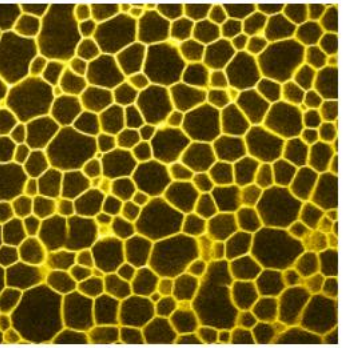
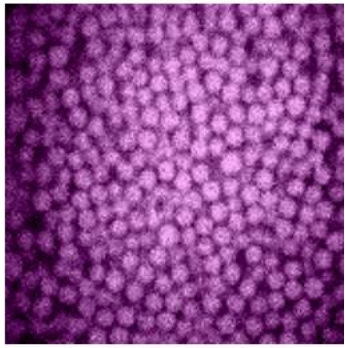
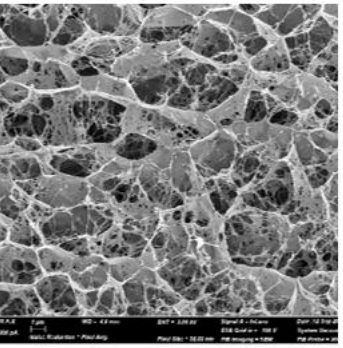


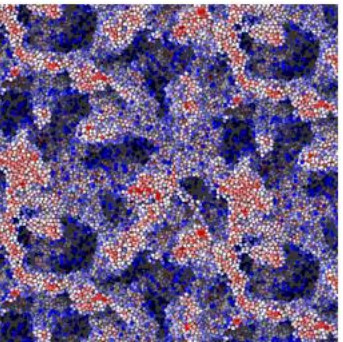
Edinburgh team has significant suspension expertise and industry collaboration experience

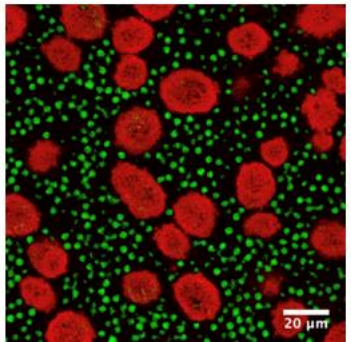
Project is designed with industrial adoption at its core. Round robin activity facilitates direct industry input and rapid feedback

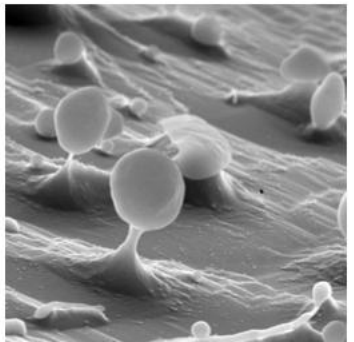
Deliverables:

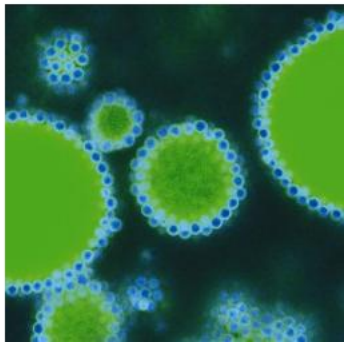
1. A high-throughput methodology with which to identify jamming in particulate suspensions
2. Technique explored and validated in a range of complex systems
3. Company-specific systems tested using new technique and validated using best-in-class research methods
4. Regular reporting and dissemination of understanding to accelerate industry adoption of new methodologies.







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