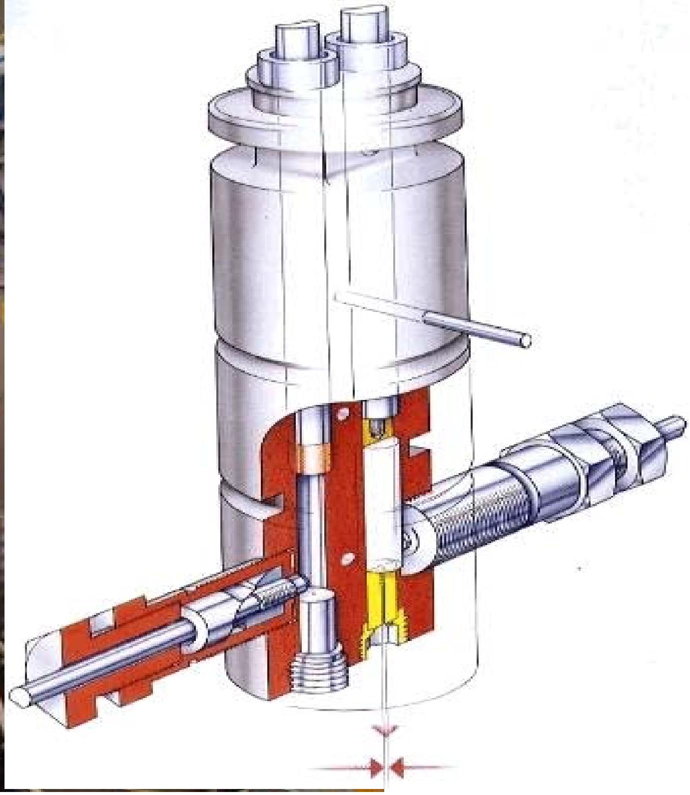

Rheological Aspects of Process Engineering in Food Manufacturing

Jay Sellahewa

Research Group Leader, Process Engineering Science

25 November 2009

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Overview

- Consumer trends and the food manufacturing industry
- Process engineering in the food industry
- The role of rheology in food manufacturing

FOOD MEGA-TRENDS

Health
('well-being')

Safety and security
(no compromise!)

Pleasure
(sensory experience)

Individualism
('tailored food')

Convenience
('time factor')

Environment
('clean-green')

Price
(good value)

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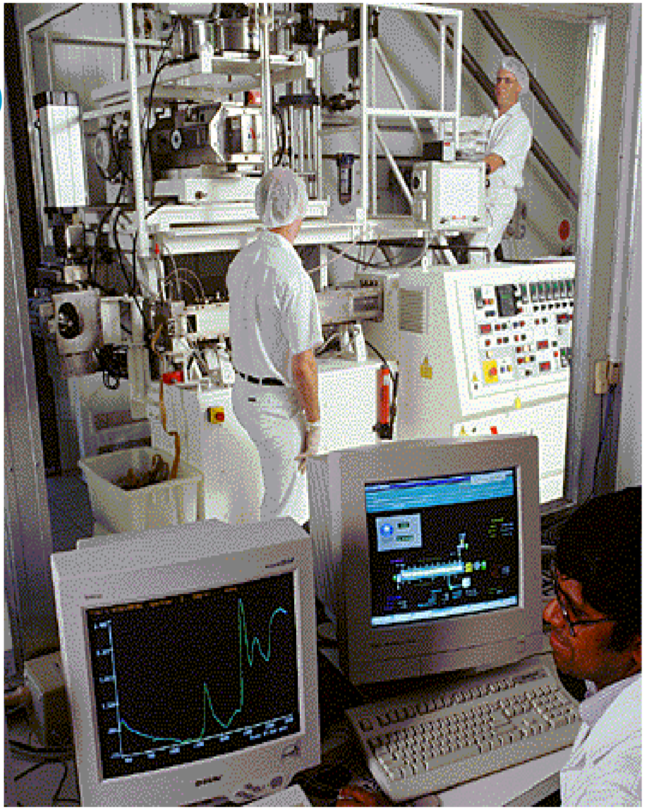
Snapshot of the food processing industry in Australia

- Total value - $34.8b (2005/06)
- Share of total manufacturing sector 20% (2005/06)
- Australia accounts for 2.6% of world food exports (world's 13th largest food exporter)
- Australia's main processed food exports
  - Beef (raw, frozen and chilled)
  - Wine
  - Dairy products
  - Sugar



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Drivers to profitability in manufactured foods
low margin, high volume

- Consumer acceptance
- New product opportunities
- Cost-savings
- Process and energy efficiencies
- Standards that can be cost-effectively met
- Inventory and logistics management
- Sustainable competitive advantages
- Confidentiality
- Brand loyalty
- Strong influence by the retailers

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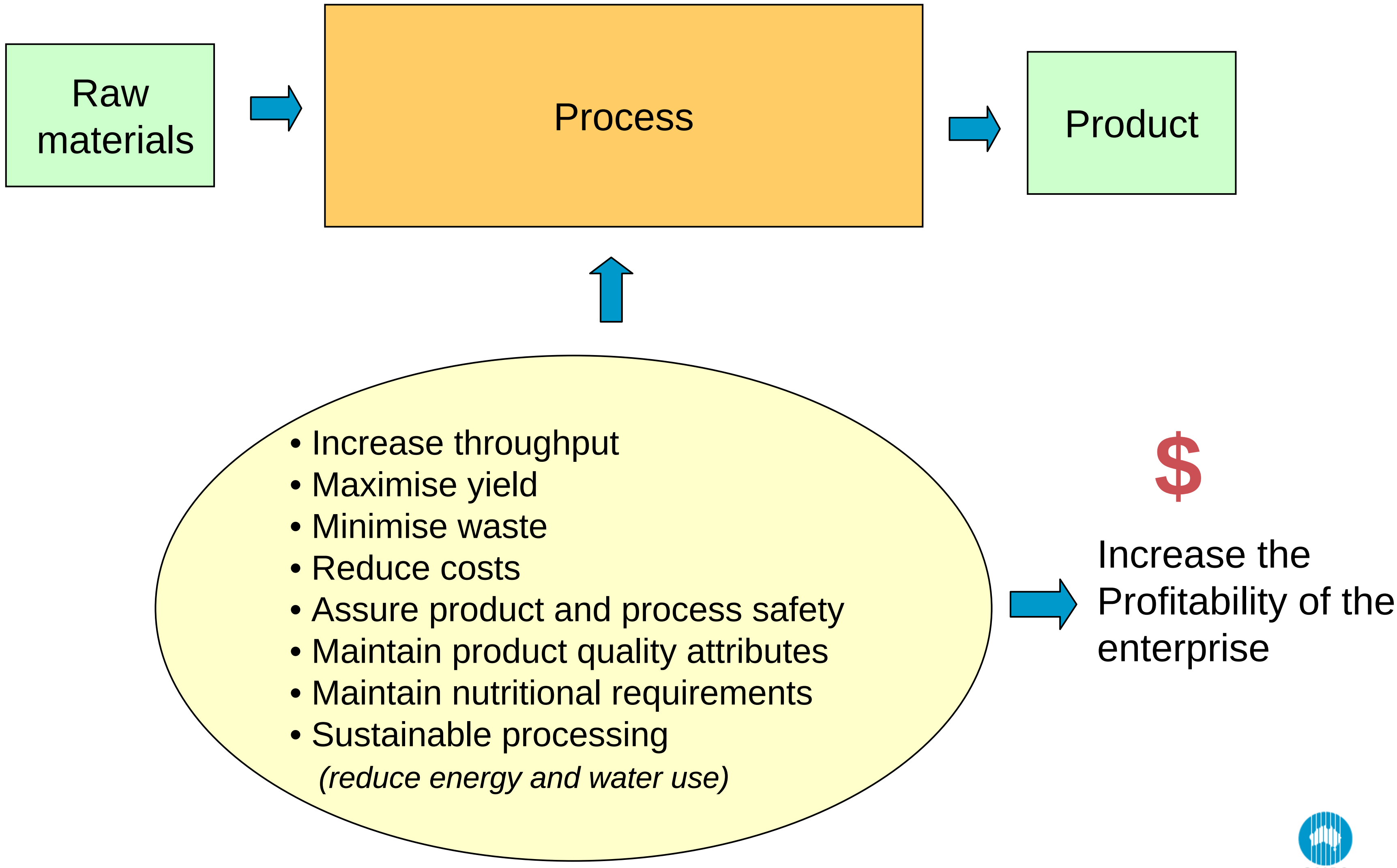
A typical food processing system



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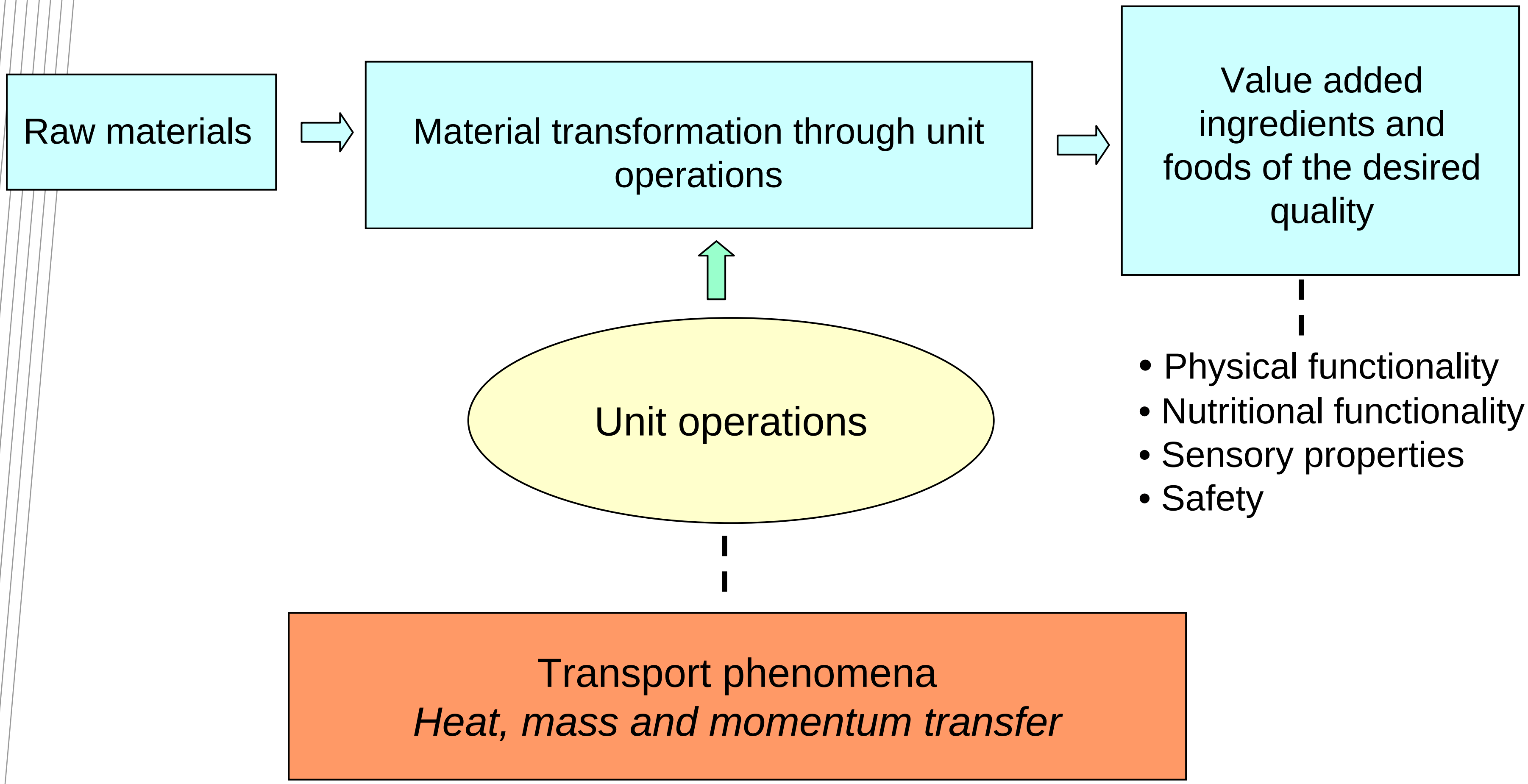
Material transformation



Process / Product interactions

Process | Product quality

Understanding the process / product interaction is critical for the development of innovative products and processes

Understanding the fundamental principles of Process Physics, Engineering & Science

Scientific approach instead of an empirical approach

Enables industry to:

- Develop innovative products and processes
- Improve the performance of existing processes

Process Engineering Science capability

Social, economic and environmental benefits

The role of food rheology in food manufacturing

- Why is rheology important in food manufacturing?

- Food rheology in process design, modelling, optimisation, control, product formulation, sensory science

- Measurement of rheological parameters in food
  - off line measurement
  - on line measurement

- Future trends

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Types of foods

- Fluids
- Solids
- Pastes
- Slurries
- Emulsions





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Rheology and food

- Pouring ketchup from a bottle

- Spreading butter and other spreads on toast

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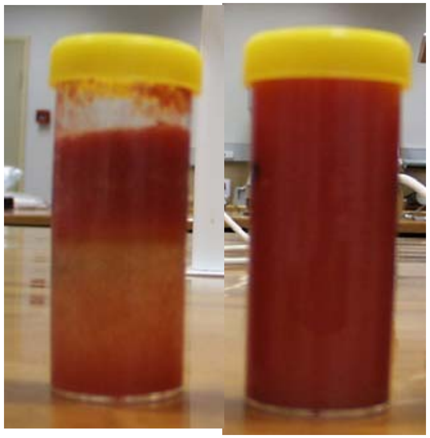
Rheology and food

- Depositing dough and creams from a nozzle to a container

- Stability of emulsions
- Clarity of juices



Rheology and food

- Enrobing chocolates

Rheology and food

- Pouring honey

- Eating food

Importance of food rheology

- Process design
  - Sizing pumps, heat exchangers, mixing vessels
- Process optimisation
  - Minimising waste
  - Maximising throughput
- Process control
  - E.g. – impact of the viscosity of milk concentrate on spray drying
  - Traditionally, process control in the food industry is an ‘art’ because of the difficulty of quantitatively measuring product quality
  - The food industry relies on experienced operators to make decisions (e.g. master bakers and cheese makers), *end point detection*
- Quality control
  - Quality control is difficult because of lack of instruments to measure product quality on-line me

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Importance of food rheology

- Product formulation
  - Understanding of food rheology is important in formulating products
- Understanding product structure / texture and other sensory properties
  - Rheology in the mouth
  - Tribology
  - Designing foods to the elderly who find it difficult to chew and swallow
  - Dough rheology
- Stability of foods
  - Stability of emulsions

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Typical Shear Rates for Food Operations

Source: Chemical Engineering for the Food Industry; Fryer et al

Operation	Shear Rate (s^{-1})	Examples
Settling of suspensions	10^{-6} - 10^{-4}	Salad Dressings
Draining under gravity	10^{-1} - 10	Vegetable oils
Extrusion	10 - 100	Snack Foods, Cereals
Pipe Flow	10 - 1000	Chocolate, Sauces
Chewing and Swallowing	10 - 100	Most Foodstuffs
Mixing or stirring	10 -1000	Fruit squashes
Spreading	10 - 10^{4}	Margarine, butter

Measurement of rheological properties of foods

- Food rheology is complex. Most foods are:
  - Non uniform
  - Heterogeneous
  - Non Newtonian *(mostly pseudoplastic – shear thinning)*
  - Viscoelastic
  - Difficult to characterise
  - Difficult to measure rheological properties

Instruments used for the measurement of rheological properties of foods

Rapid Visco Analyser (RVA)

An example - extrusion

Raw material properties

- Moisture content
- Particle size distribution
- Protein content
- Water absorption

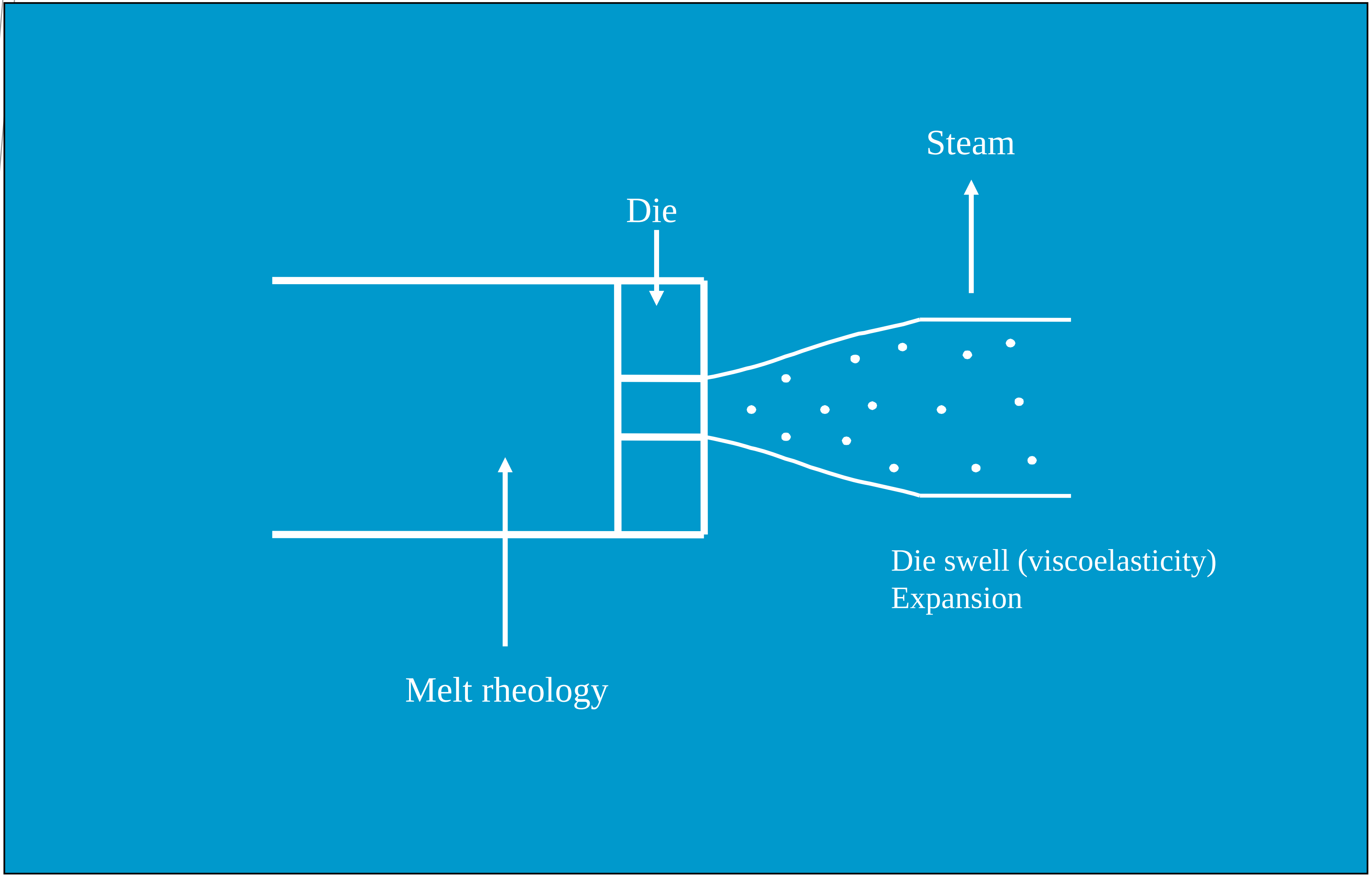
Process variables

- Screw speed
- Water feed rate
- Powder feed rate
- Melt temperature
- Barrel temp profile

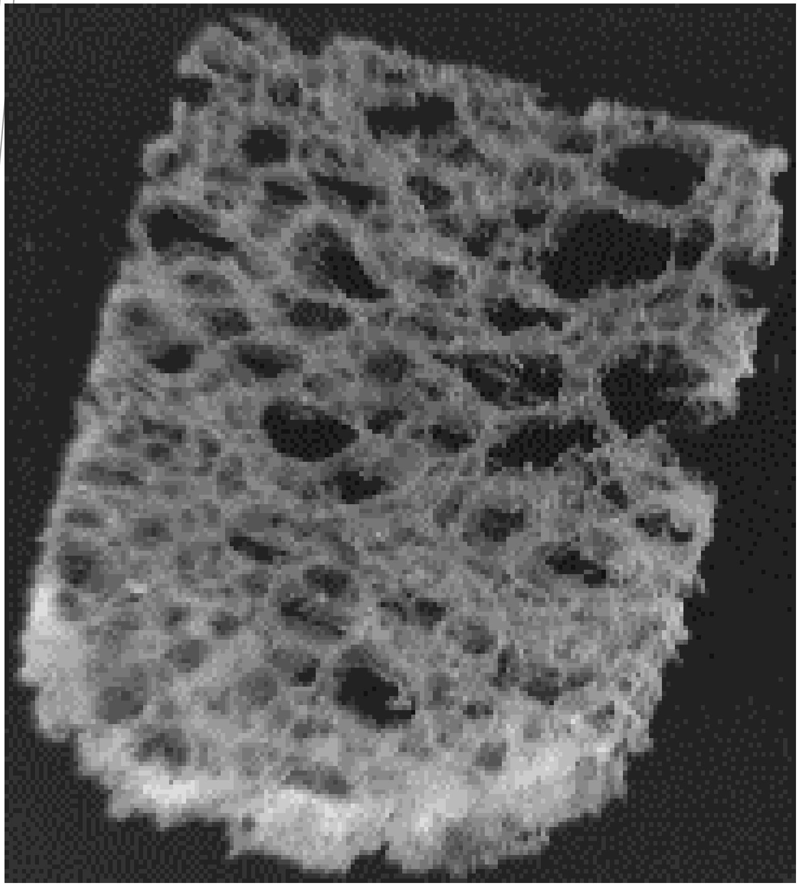
Product quality attributes

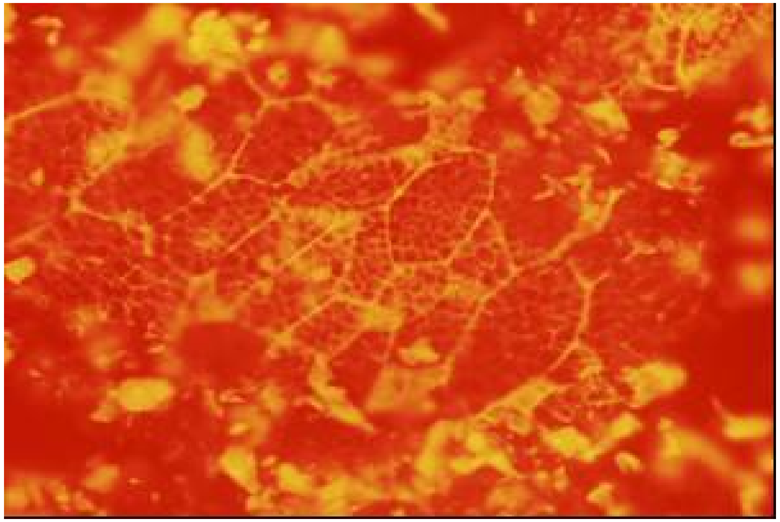
- Colour
- Texture
- Bulk density
- Rehydration properties
- Flavour
- Nutritional properties

Melt rheology and product expansion



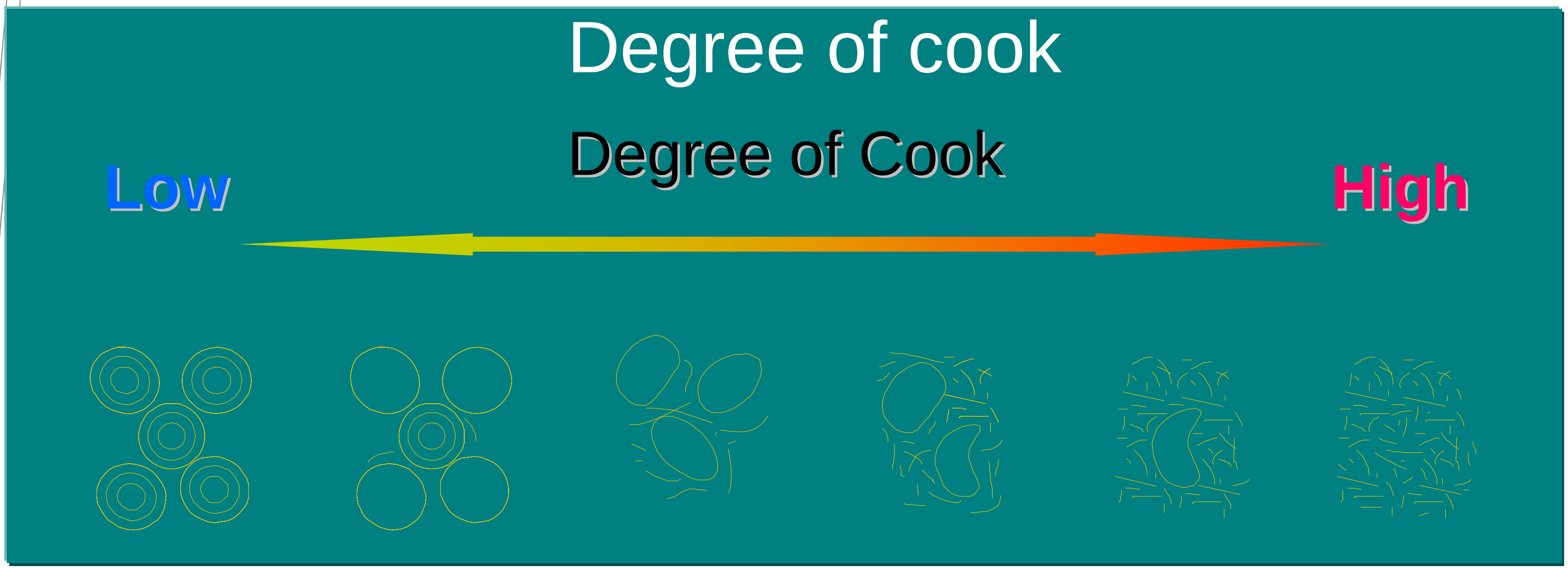
Product Structure affects texture



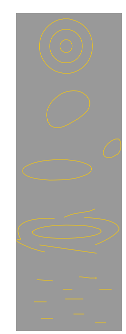


Degree of Cook

(From Guy and Horne 1988)



Native crystalline granules
Gelatinised granules
Damaged granules
Starch dispersed
Starch degraded



Measurement of Degree of cook - Starch

- Gelatinisation
  - Polarised light microscopy
  - X ray crystallography
  - DSC
  - Enzymic methods

- Molecular breakdown
  - **Viscometric methods**
  - MS chromatography

Degree of Cook (DOC) Measurement
(Guy and Horne (1988))

$$\eta_{app} = K\gamma^{(n-1)}$$

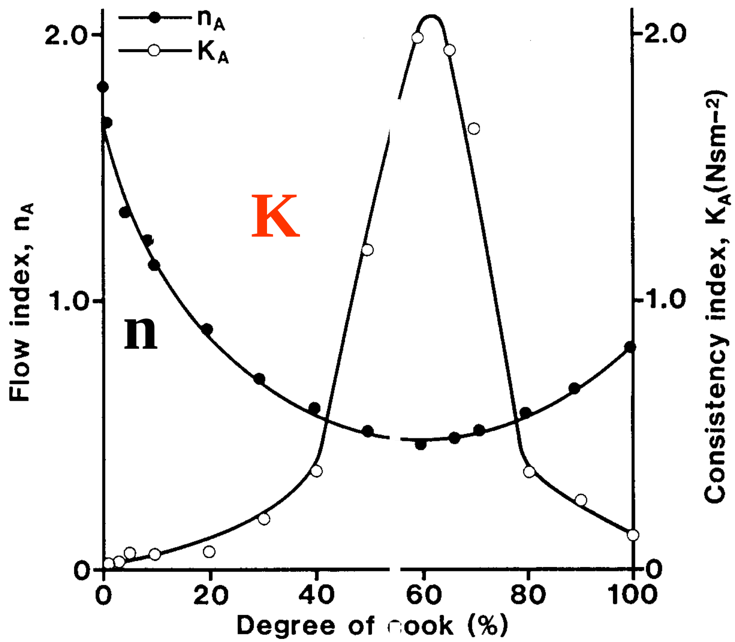


Fig. 3. Graphs of viscosity parameters K_A and n_A versus DC values

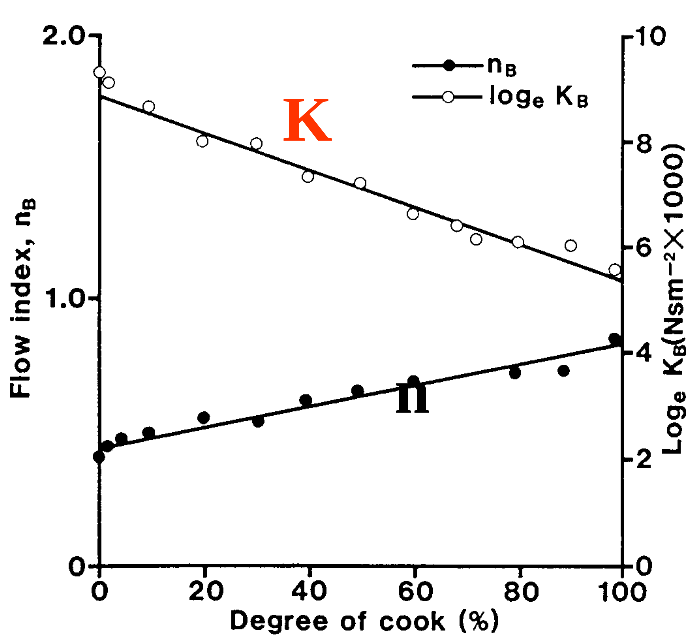
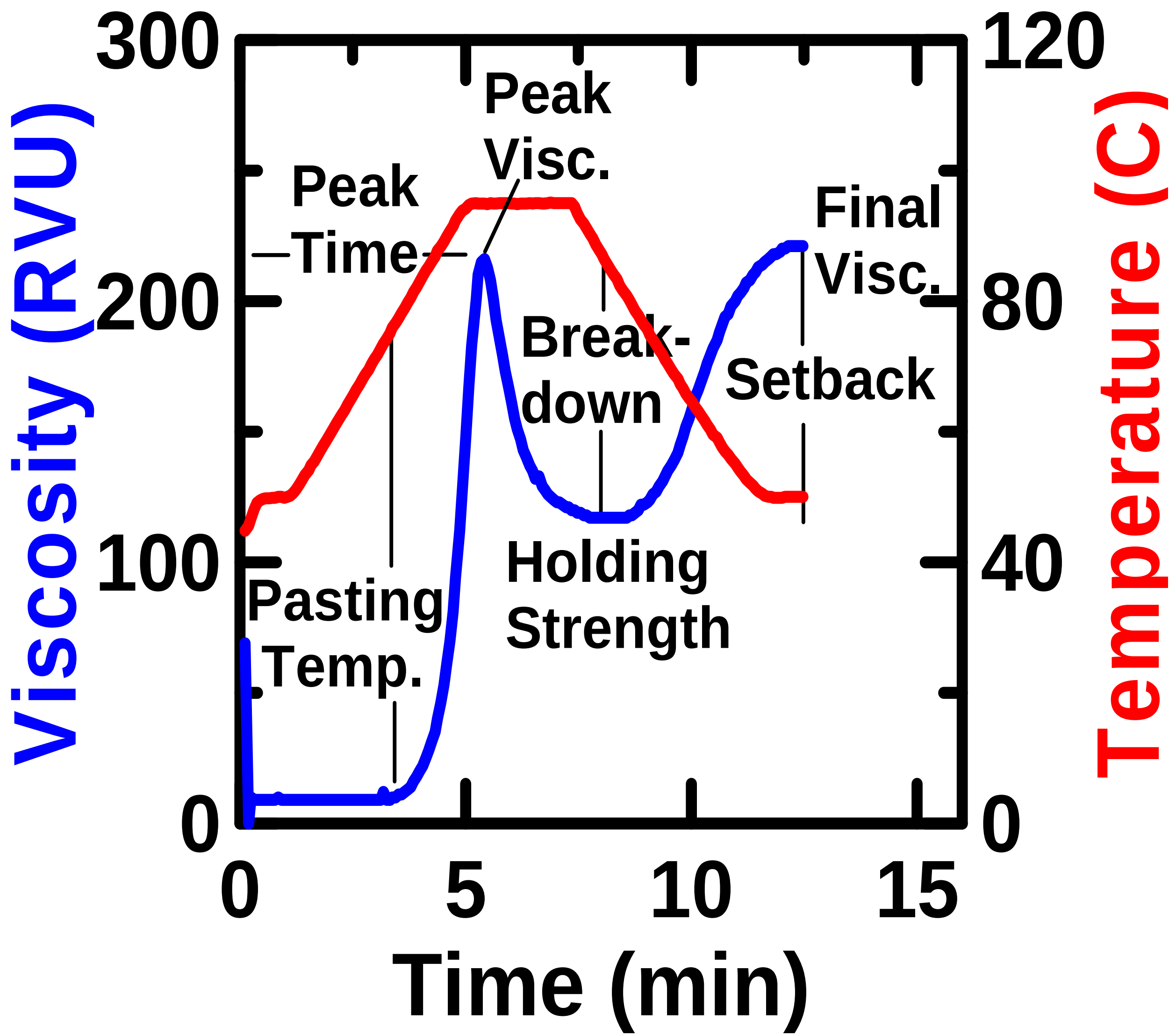
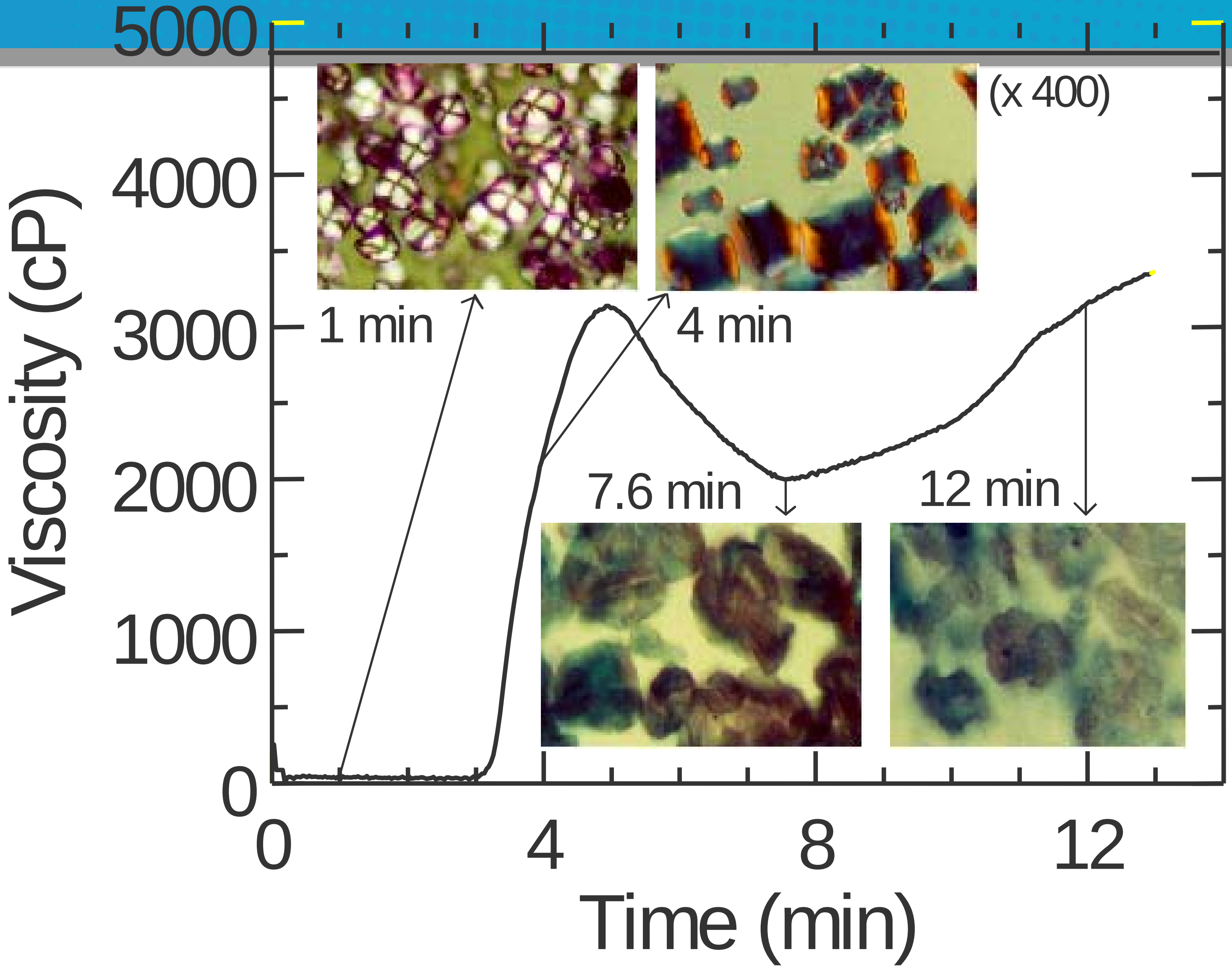


Fig. 4. Graphs of viscosity parameters K_B and n_B versus DC values

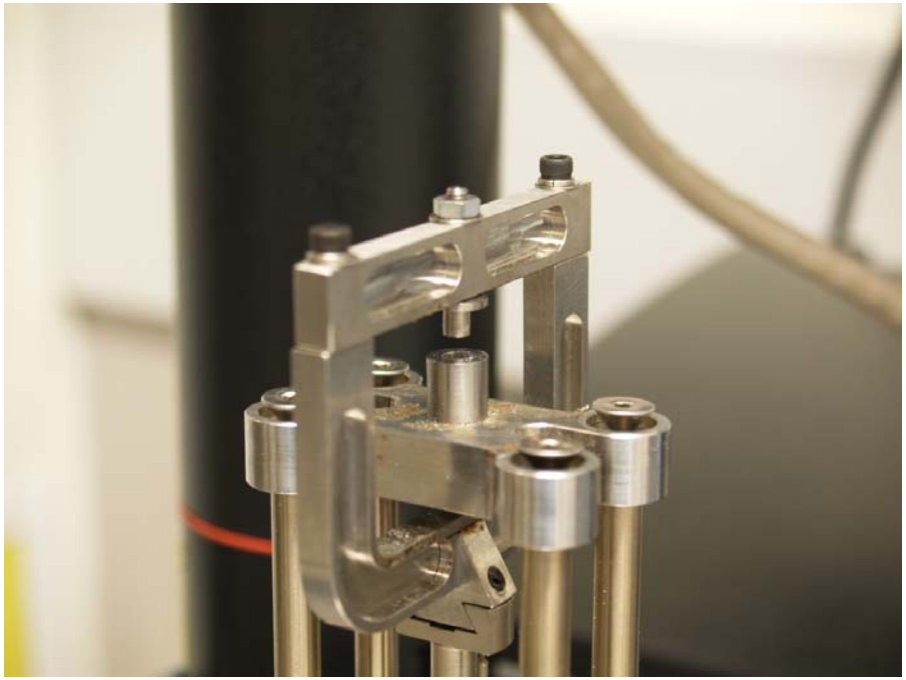
RVA Viscosity curve



RVA Pasting Curve *(Guy and Horne (1988))*

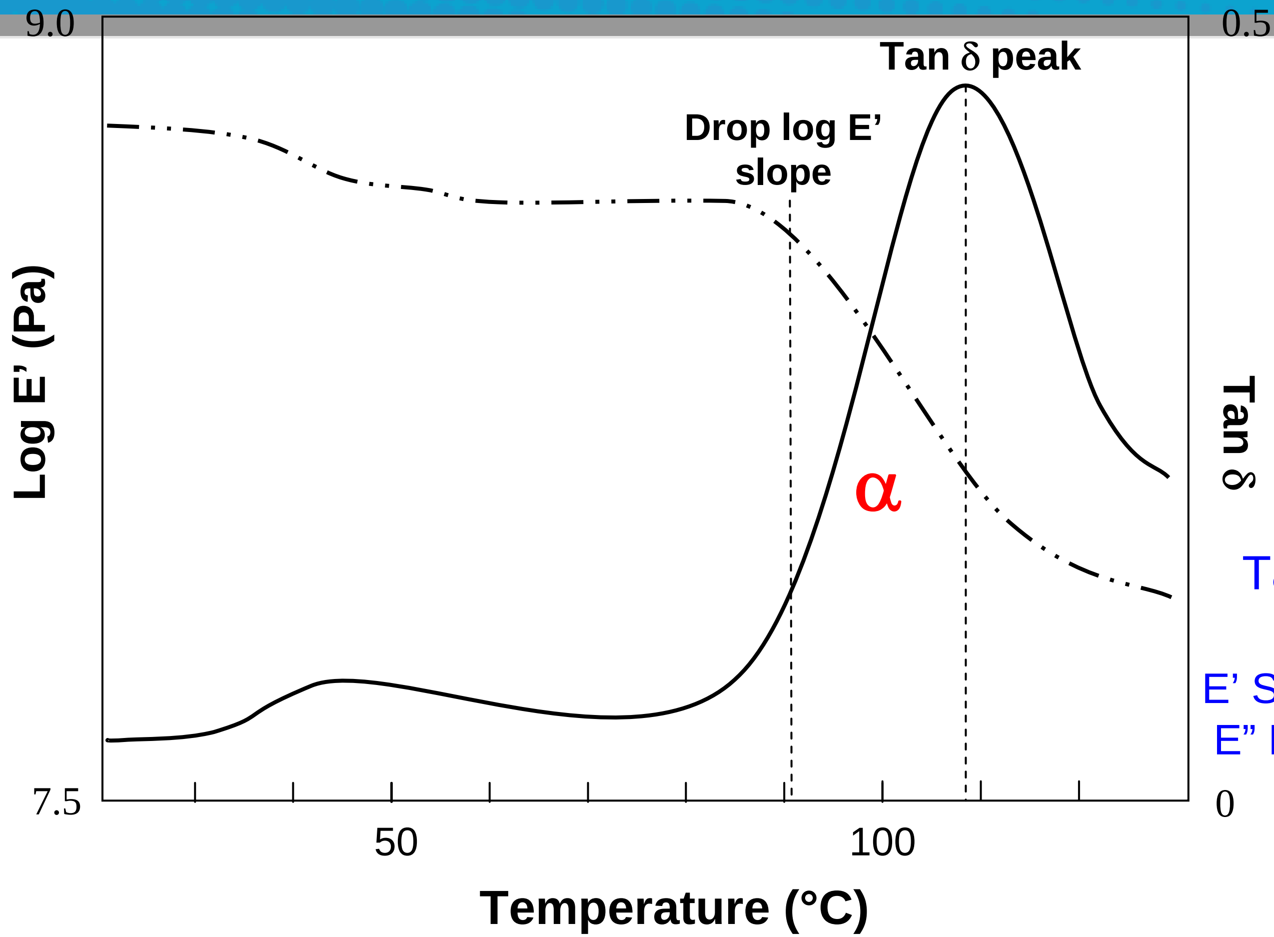


Dynamic Mechanical Analyser (DMA)



Enables the measurement of glass transition temperature, loss modulus and storage modulus of food stuffs

DMA of pregelatinised waxy maize starch (wms)



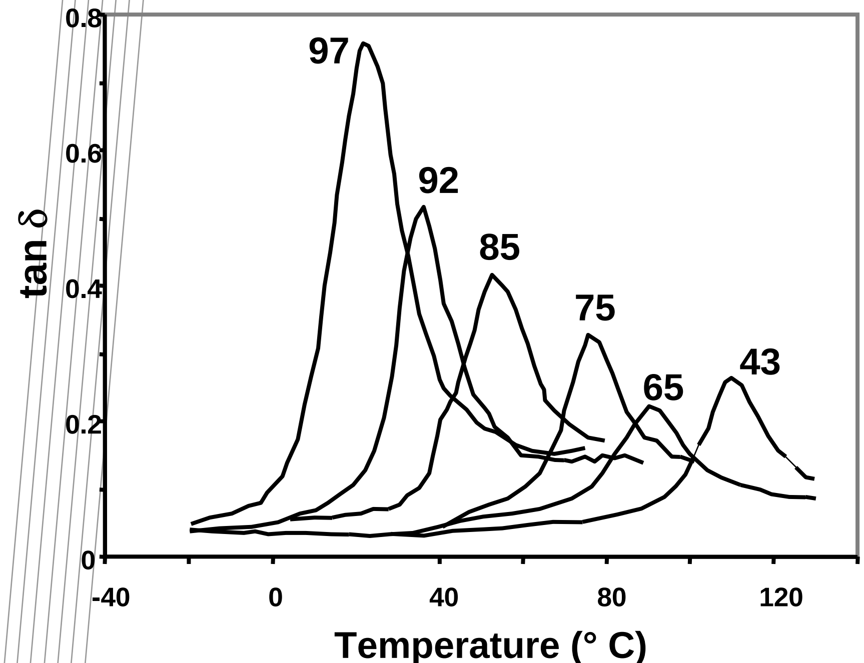
Tan δ = E" / E

E' Storage Modulus
E" Loss Modulus

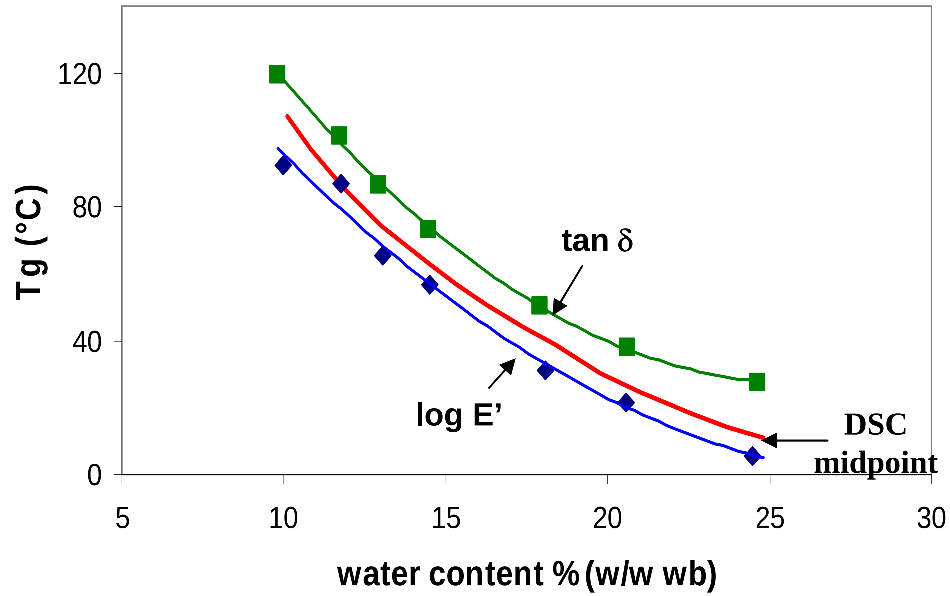
Pregelatinised wms powder, hydrated 20-25% (w/w), pressed (20 tons, 90-100°C, 5-10 min), re-equilibrated in at room temperature different RH enviroments. RH=43% for sample shown. (Kalichevsky *et al*.,1992).

Effect of water content on the Tg of waxy maize starch

(Aung Htoon, CSIRO)

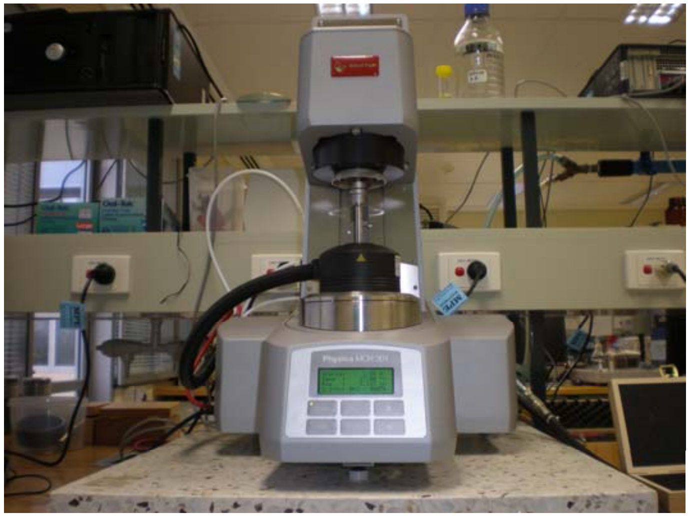


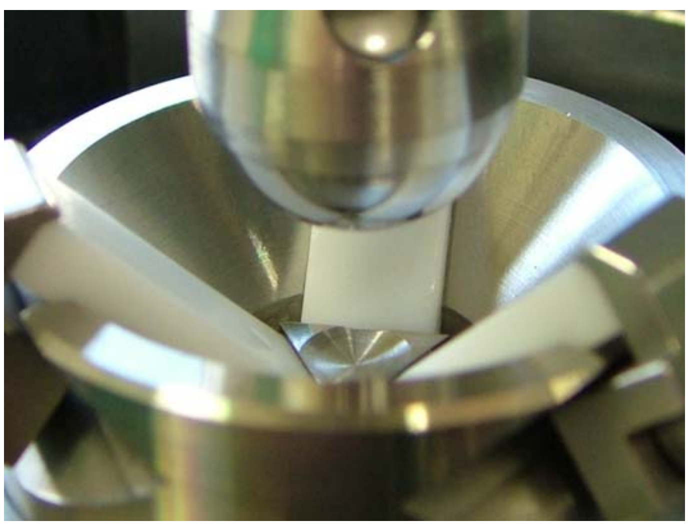
DMA thermograms (tan δ) of pregelatinised wms at different RH (%)

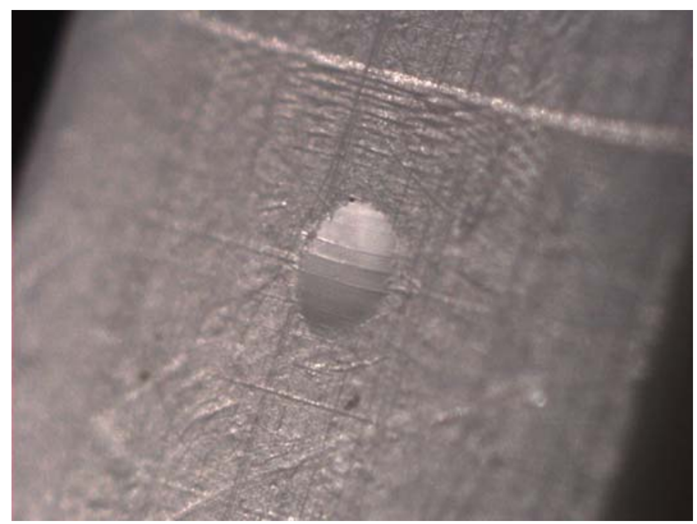


Effect of water content on the T_g of pregelatinised wms

Paar Physica MCR301

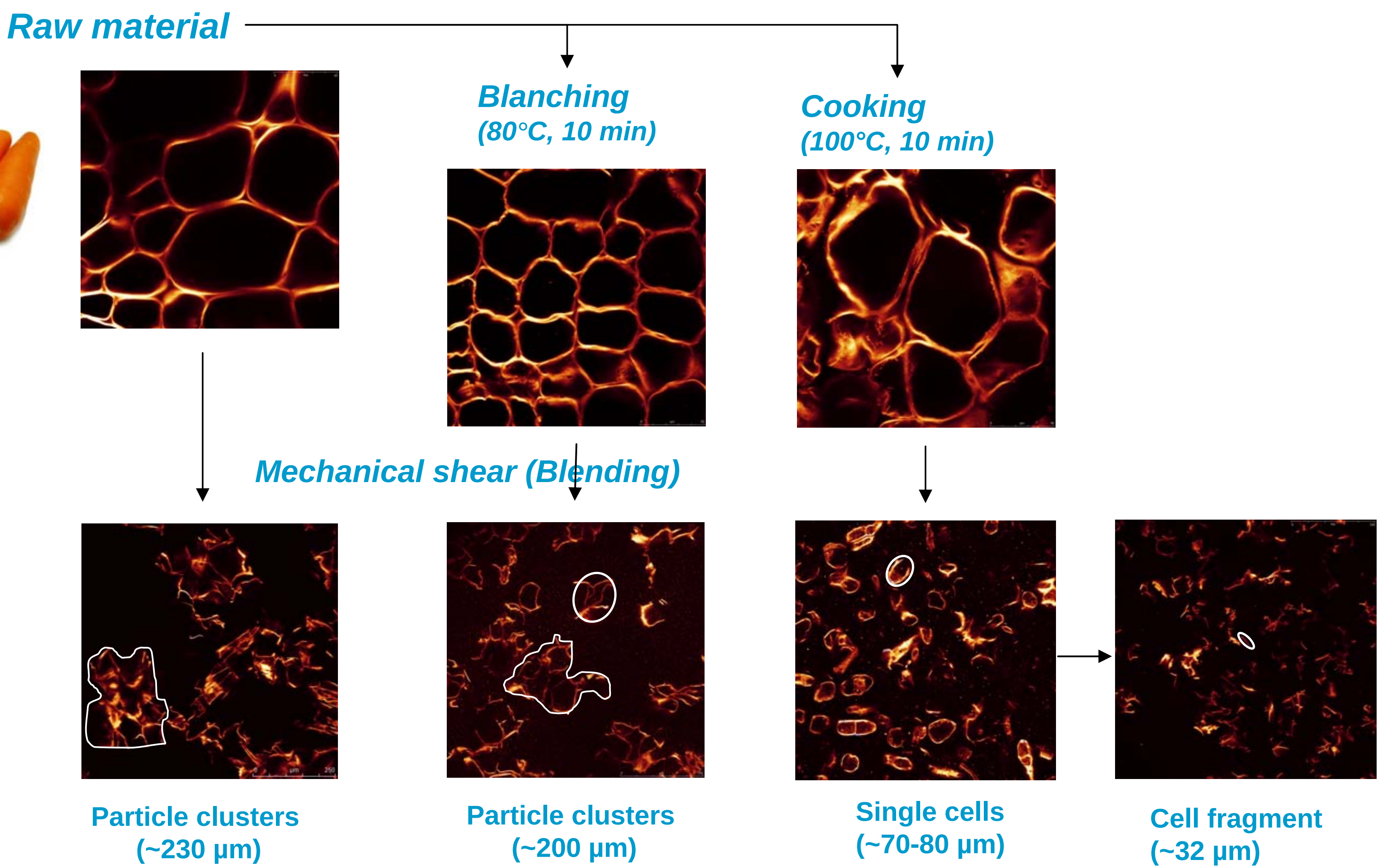






Plant cell wall microstructure

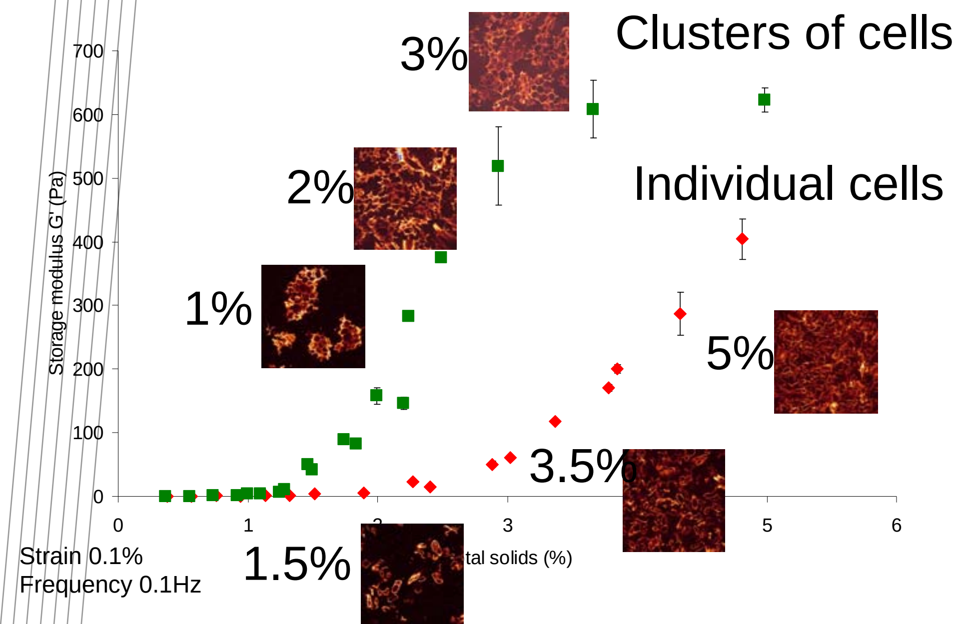
(Leif Lundin, CSIRO)

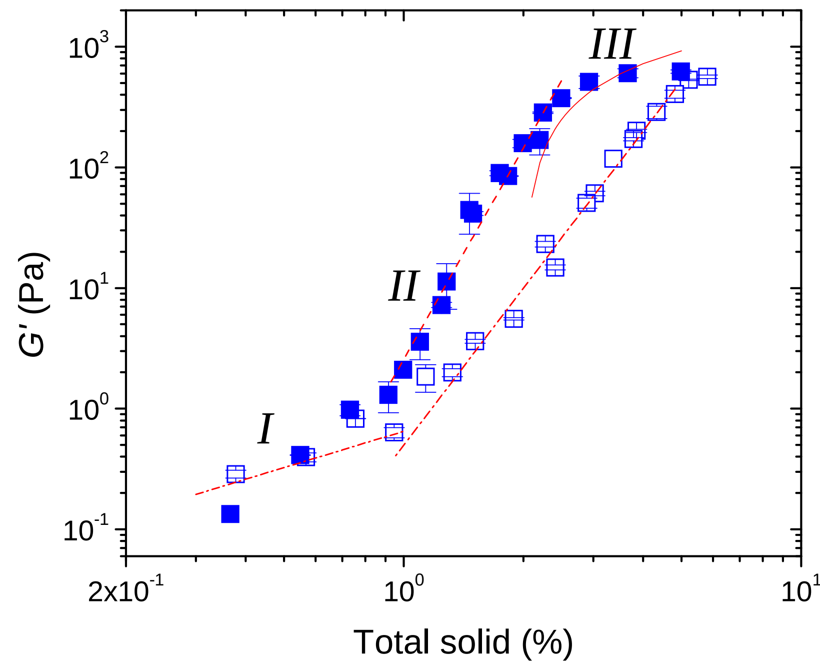


Scale = 775 µm × 775 µm

Rheology of soft elastic particles

(Leif Lundin, CSIRO)



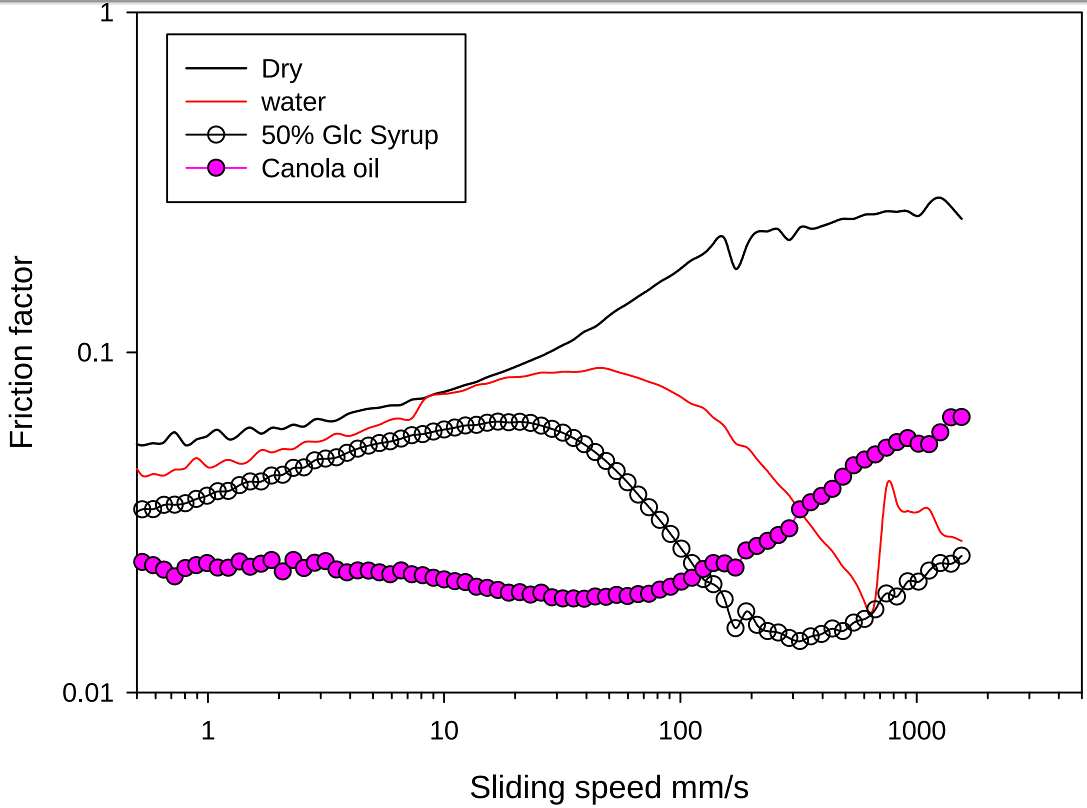


$$G = \phi_{\mathrm{CP}}\, nG_p/[5\pi(1-\sigma)] \times [\phi_{\mathrm{RED}}^{1/3}(1-\phi_{\mathrm{RED}}^{-1/3})^{1/2} - (8/3)\phi_{\mathrm{RED}}^{2/3}(1-\phi_{\mathrm{RED}}^{-1/3})^{3/2}]$$

$$G' = A\left[1-\left(\frac{\phi_c}{\phi}\right)^{1/3}\right]$$

Effects of altering solvent properties

(Leif Lundin, CSIRO)



- Stribeck curve delineates three main regions: Boundary, mixed, and hydrodynamic
- Start of lubrication by water (entry to mixed) indicated by divergence from dry contact
- Water begins to lubricate from ~ 10mm/s but probably does not enter hydrodynamic regime
- Oil lubricates from < 0.05 mm/s enters hydrodynamic regime from ~ 100mm/s
- Increasing viscosity of aqueous system enhances low speed lubrication
- Effects due to surface (hydrophobic / hydrophillic) properties

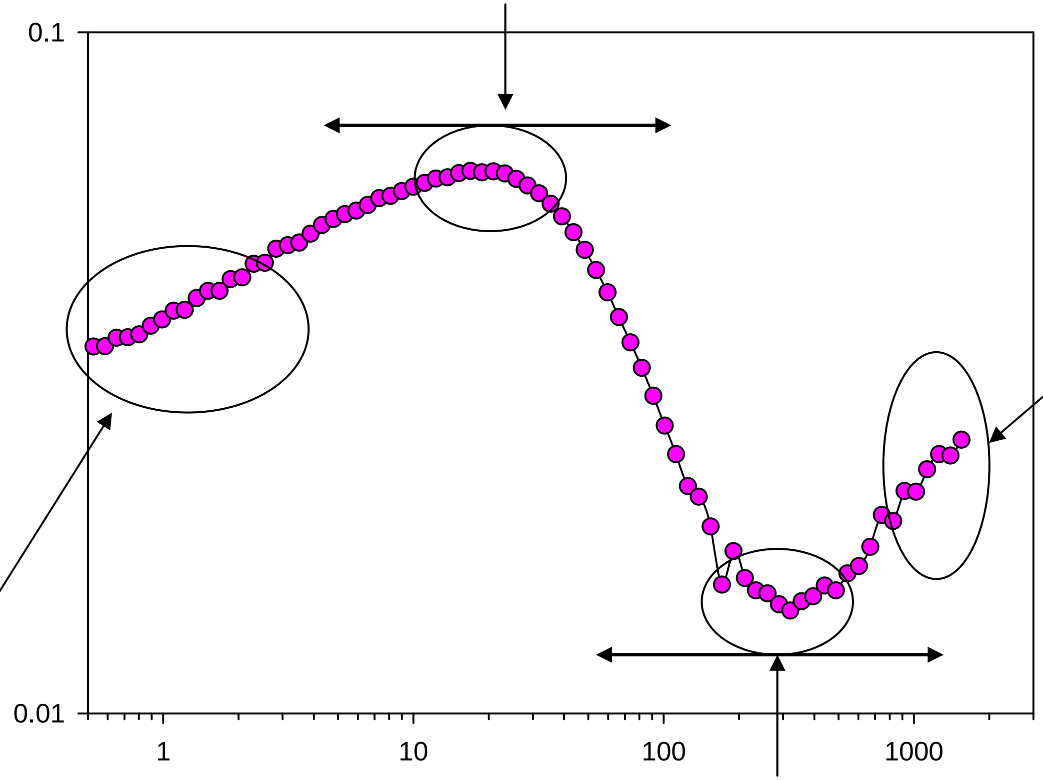
Generic 'master curve' for aqueous based samples

(Leif Lundin, CSIRO)

Onset of mixed lubrication modified up or down speed and friction axes depending on particles and viscosity

Information from speeds below ~0.5 mm/s unreliable, but contributes to 'shear history'

Critical viscosity is high shear



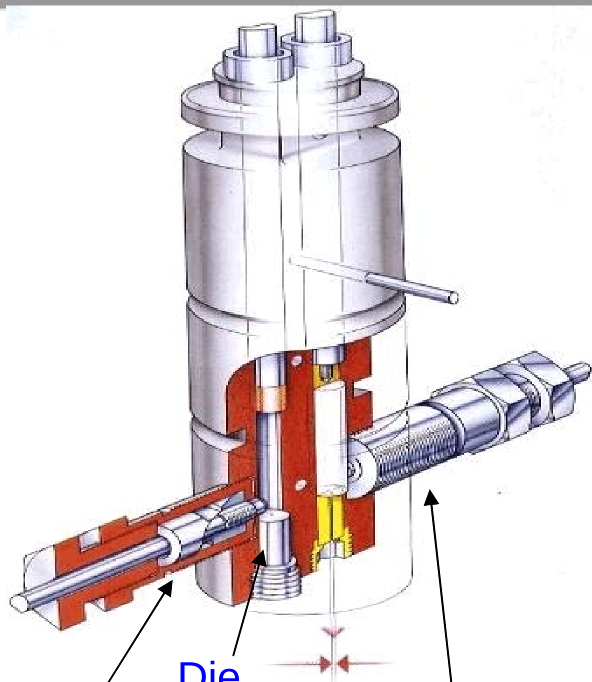
High speed friction modified by particles and viscosity

Plasticity?
Rigidity?
Strength?

Low speed, hard contact region
Modified ↑↓ by solvent properties – fat, surface tension etc

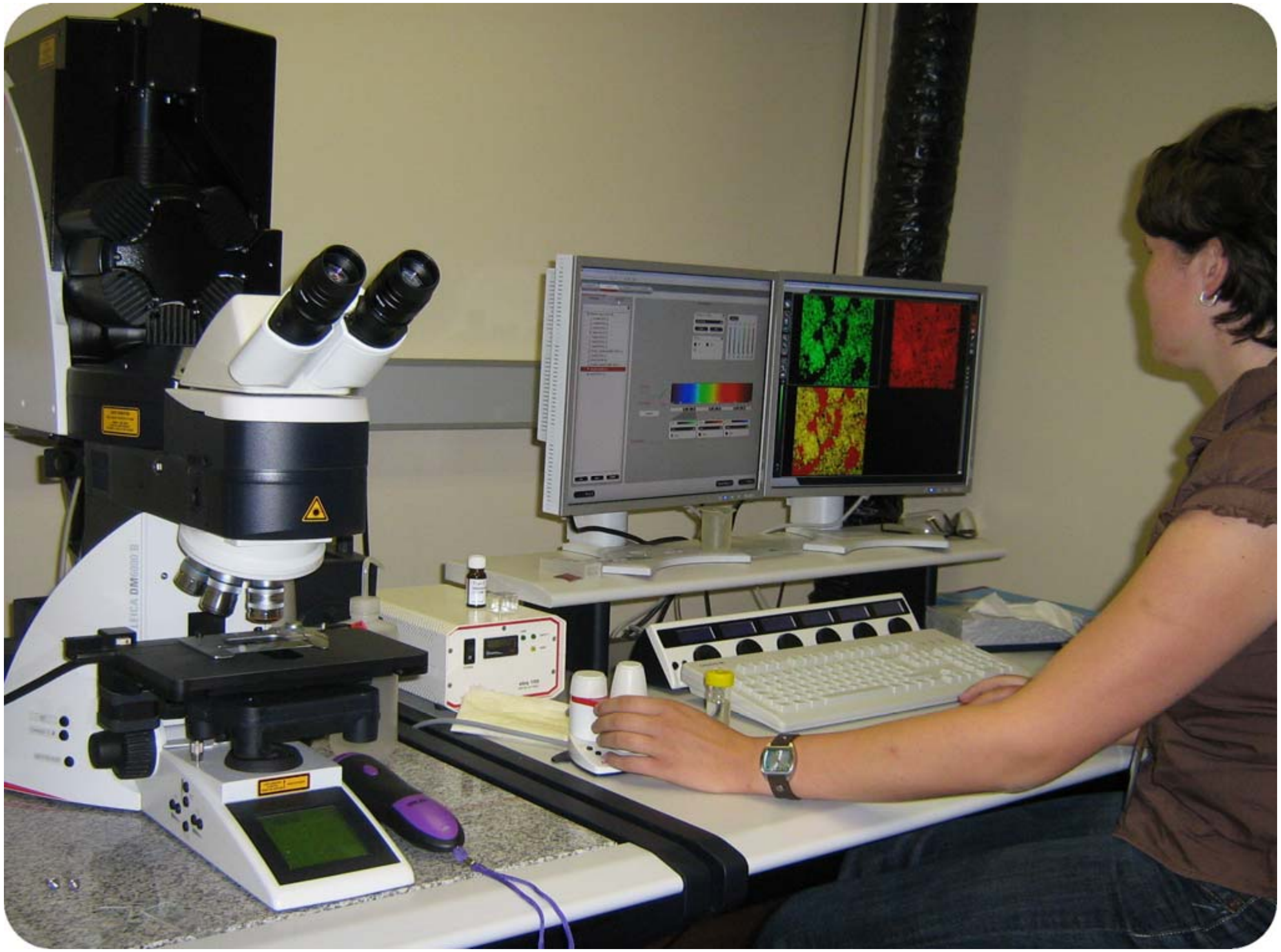
Onset of Hydrodynamic lubrication modified up or down speed and friction axes depending on particles and viscosity

Capillary Rheometer (twin bore)



- Small scale prediction of the correct appearance, texture and processibility of cereals
- Experimental design to understand the effect of processing on temperature, pressure, shear, moisture, etc on product quality

Confocal Microscopy



On-line measurement of rheology

- No accurate instruments for on-line measurement of food rheology
  - Oscillating blade
- Difficult to correlate instrument readings with product quality and traditional measurement of product quality (e.g. Bostwick instrument for tomato paste)

Future trends

- Better characterisation of foodstuffs through a deeper understanding of rheology
- Development of food rheology databases
- Using rheological data in process modelling (*lack of data is a major limitation at the moment)*
- Correlation of rheological data with product quality attributes (including sensory attributes)
- Optimal design of processing conditions and formulations
- Process control and quality control through the development of on-line rheometers

Groups active in food rheology

- Australia
  - CSIRO *(Sumana Bell, Leif Lundin, Jay Sellahewa)*
  - University of Queensland *(Jason Stokes)*
  - University of Melbourne *(David Boger)*
  - University of NSW *(Janet Paterson)*

- Overseas
  - Michigan State University *(James Steffe)*
  - Purdue University *(Osvaldo Campanella)*

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