The role of rheology in everyday fluid flow

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Introduction

A **Newtonian fluid** is a fluid with a linear relation between shear stress and shear strain.

Figure: Water flow in a river

Non-Newtonian

A **Non-Newtonian fluid** is a fluid that doesn't obey this relation.

- Shear Thickening: viscosity increases with shear
- Shear Thinning: viscosity decreases with shear
- Bingham: flow after reaching a yield shear stress

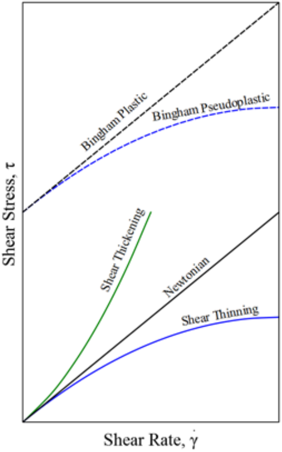
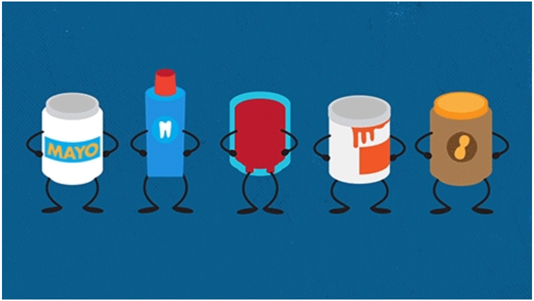


Figure 1. Shear stress as a function of shear rate for several kinds of fluids

Aim of the workshop



Objective 1

Characterise non-Newtonian fluid behaviour

Objective 2

Investigate existing models of non-Newtonian fluids and apply them to everyday fluids

Power Law

The **power law model** is a simple model used for fluids that exhibit shear thickening and thinning behaviour.

$$\tau = k \left(\frac{\partial u}{\partial y} \right)^n \tag{1}$$

where k is the *Consistency*, $n > 1$ for thickening and $n < 1$ for thinning.

Shear Thickening – Stirring

- A spoon stirring a cornflour–water mixture gets stuck
- Modelled using flow past a sphere [2]

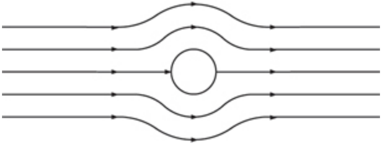


Figure: Stokes Flow past a sphere

Figure: Stirring Cornflour–water mixture

Shear Thickening – Stirring

Higher Concentration ⇔ More Thickening ⇔ Larger Force

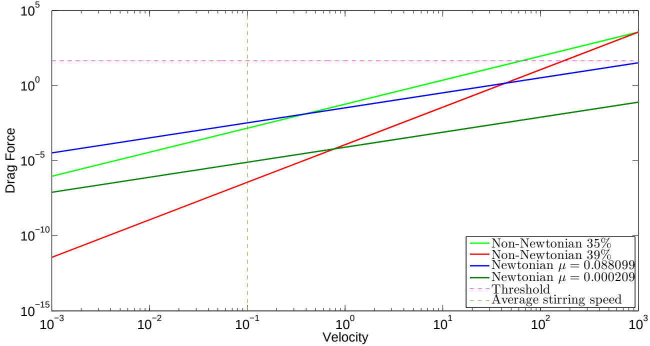


Figure: Drag Force vs Velocity for different rheologies

Shear Thickening – Falling

- A spherical object falling in the non-Newtonian fluid
- Modelled using flow past a sphere [2]

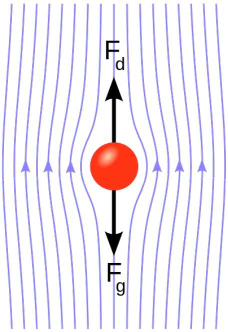


Figure: Stokes Flow past a sphere

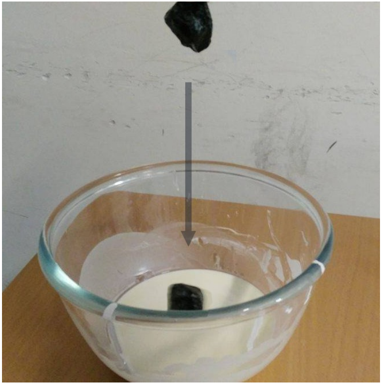
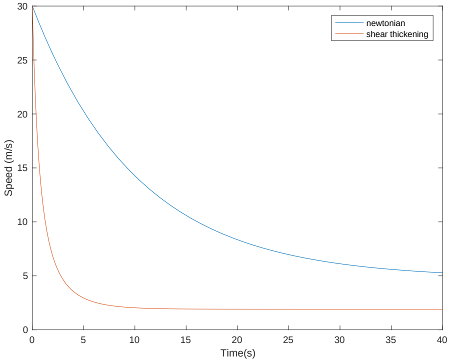


Figure: A stone falling in cornflour

Shear Thickening – Falling

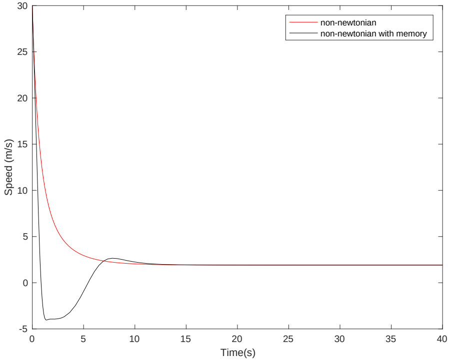
$$\dot{u} = \frac{1}{m} F_{buoyancy} - \frac{1}{m} F_{drag} \tag{2}$$



Non-Newtonian ⇔ Faster Deceleration

Shear Thickening – Falling with Memory

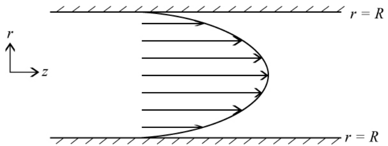
$$\dot{u} = \frac{1}{m} F_{buoyancy} - \frac{1}{m} F_{drag}(t - \tau) \quad (3)$$



Introduce Delay ⇔ Bouncing

Shear Thinning

Many everyday fluids exhibit shear thinning behaviour.



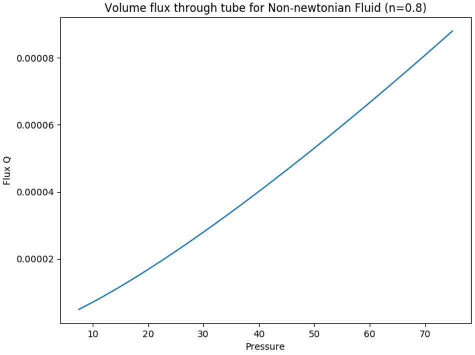
To model the flow of toothpaste we decided to look at channel flow.

Shear Thinning

We calculated the flux of a power law fluid in a pipe.

$$Q = \frac{n}{2n+1}\left(-\frac{dp}{dx}\frac{1}{k}\right)^{\frac{1}{n}}\left(\frac{h}{2}\right)^{\frac{2n+1}{n}}$$

We can see here that the flux has a power law relation with the pressure.

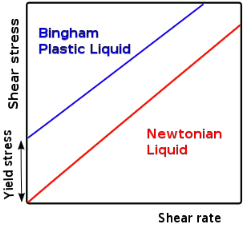


Bingham Fluid

Shake

What is better?

Squeeze



Conclusions

- The power law fluid model is itself an approximation–curve fitting to experimental data.
- It is a useful model for probing complex rheologies, however it cannot predict all observed behaviours.
- Non-Newtonian fluids are very common in everyday life, however their rheology is extremely complicated and difficult to model accurately.

Questions?

NON-NEWTONIAN FLUIDS
Shear Thickening Phase Transition
Thinning
Thickening
lower Newtonian Plateau
upper Newtonian Plateau
ETHYLENE-GLYCOL

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