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- The word *Rheology* was coined by Bingham in 1922 at Lafayette, with the assistance of a classics colleague.
- Two books
  - D.V. Boger & K. Walters, *Rheological Phenomena in Focus* (1993 Elsevier). NB: a picture book.
  - R.B. Bird, R.C. Armstrong & O. Hassager, *Dynamics of Polymeric Liquids, Vol. 1 Fluid Dynamics* (2nd edition, 1987, Wiley). NB 2nd edition much better than 1st. Vol 2 is dangerous. *NB: uses the pressure tensor* $= -\sigma$

Complex fluids

- What & where? tooth paste, soup, ketchup, synthetic fibres, plastic bags, anti-splat ink-jet printing, oil well drilling muds, DIY paints

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- Why & when? micron microstructure: nano reacts in 10^{-9}s, time $\propto$ volume, so micron in 1s

More than: Viscous + Elastic

- Viscous:
  Bernoulli, lift, added mass, waves, boundary layers, stability, turbulence

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- Elastic:

  structures, FE, waves, crack, composites
- Visco-elastic is more

  Not halfway between Viscous & Elastic – strange flows to explain

Lecture 1

Phenomena

- Nonlinear flow
- Inhibition of stretching
- Elastic effects
- Normal stress

Nonlinear flow

Nonlinear flow

Flow down a pipe: flux Q, pressure drop Δp

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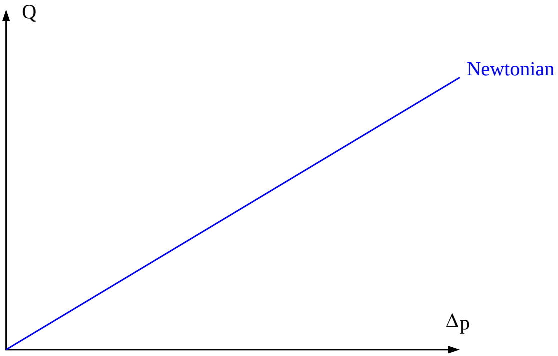

Nonlinear flow

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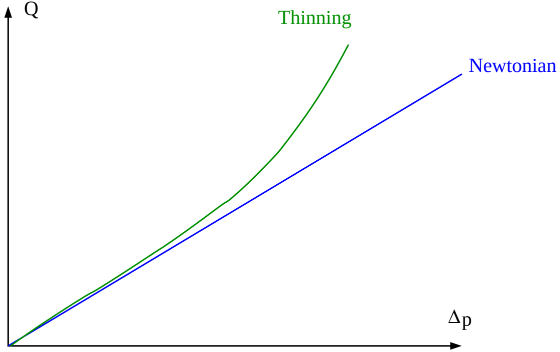
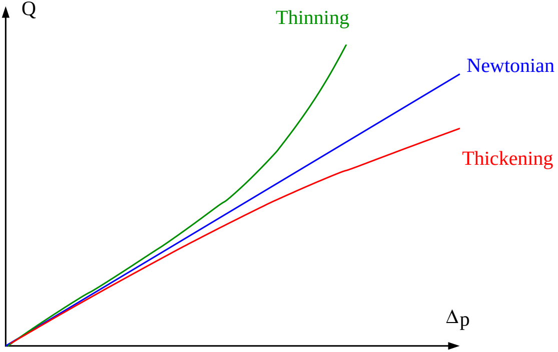


Thinning – more flow/less effort.
Breakdown of structure

Nonlinear flow

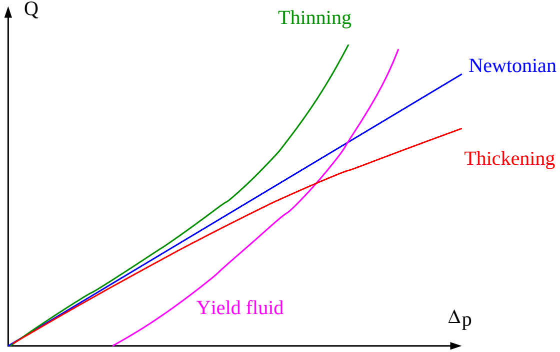
Flow down a pipe: flux Q, pressure drop Δp – just $\mu(\dot{\gamma})$



Thickenning – less flow/more effort.
Chaos & jamming

Nonlinear flow

Flow down a pipe: flux Q, pressure drop Δp – just $\mu(\dot{\gamma})$



Yield fluid – toothpaste, ketchup, non-drip paints, particle transport

Nonlinear flow

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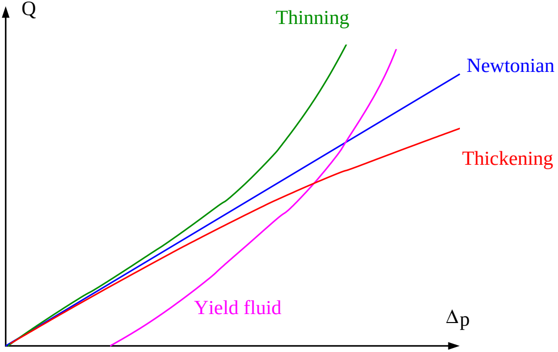

Also 2D channel flow, as in injection molding, coatings

Nonlinear flow – summary

- Newtonian – linear flow.
- Thinning – more flow/less effort. Breakdown of structure
- Thickenning – less flow/more effort. Chaos & jamming
- Yield fluid – toothpaste, ketchup, non-drip paints, particle transport

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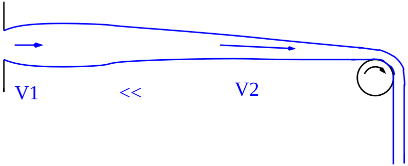
Also possible effects $\mu(p)$, and $\mu(T)$ with internal heating.

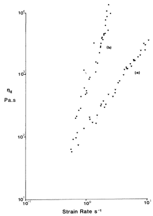
Inhibition of stretching

Inhibition of stretching

Spinline



Extensional viscosity



Inhibition of stretching

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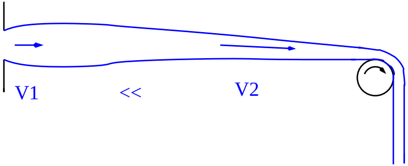
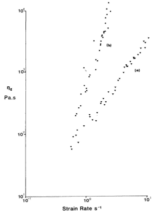


Extensional viscosity



Large values compared to shear viscosity

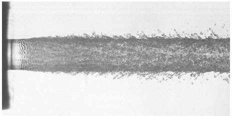
Inhibition of stretching

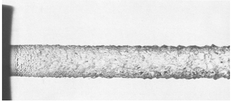
Pointed bubbles

Inhibition of stretching

Pointed bubbles

Smooth jets



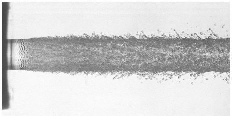


Inhibition of stretching

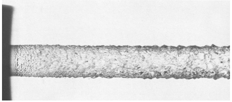
Pointed bubbles

Smooth jets

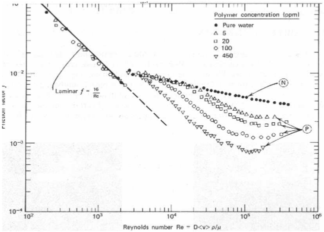


Applications



Inhibition of stretching 2

Reduction of turbulent drag



Inhibition of stretching 2

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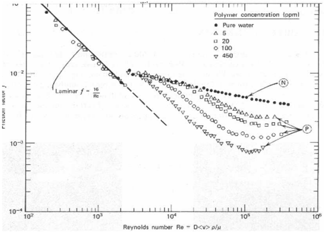

Application: 48km pipeline, flow 1.8m/s, 50% drag reduction by 9ppm of polymer

Inhibition of stretching 2

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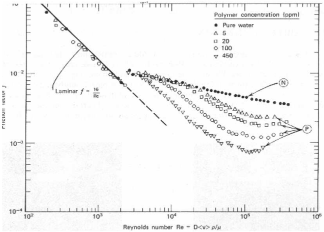
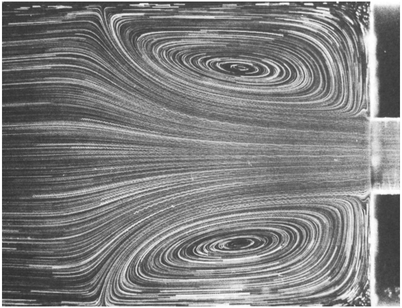


Application: 48km pipeline, flow 1.8m/s, 50% drag reduction by 9ppm of polymer
Application: Bristol Sewers, aircraft fuel

Inhibition of stretching 3

Long upstream vortices



Inhibition of stretching 3

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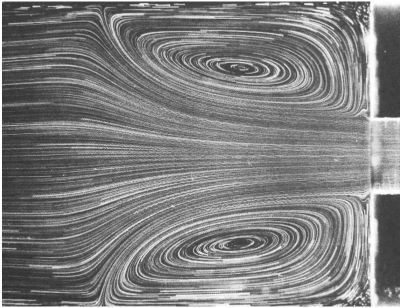


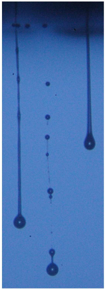
Uncontrolled output

Inhibition of stretching 4

Capillary squeezing of a liquid filament
very slow to break

Inhibition of stretching 5

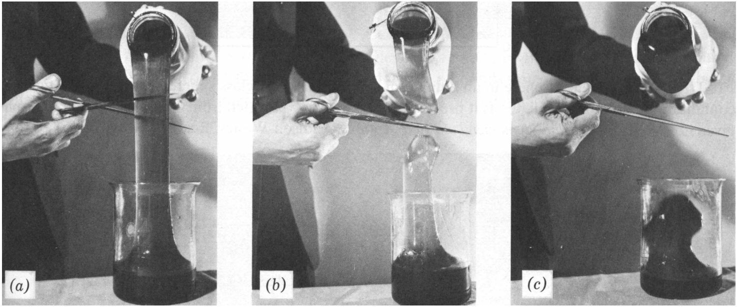
Drop-on-Demand Inkjet printing with too much polymer in ink



Elastic effects

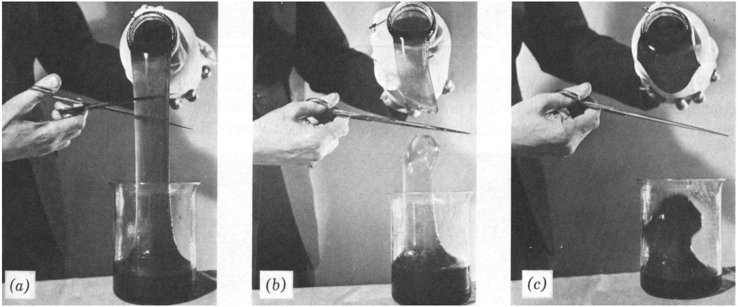
Elastic effects

Recoil



Elastic effects

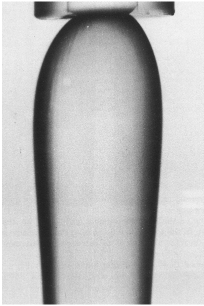
Recoil


(a) (b) (c)

- also thick soup

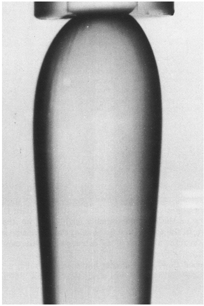
Elastic effects 2

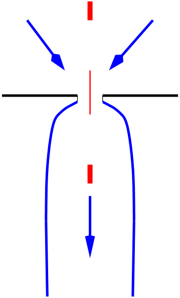
Die swell



Elastic effects 2

Die swell

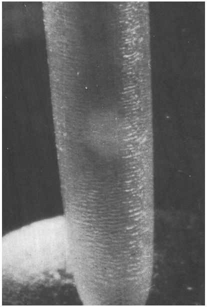




– recoil of fluid stretched in converging into hole

Elastic effects 3

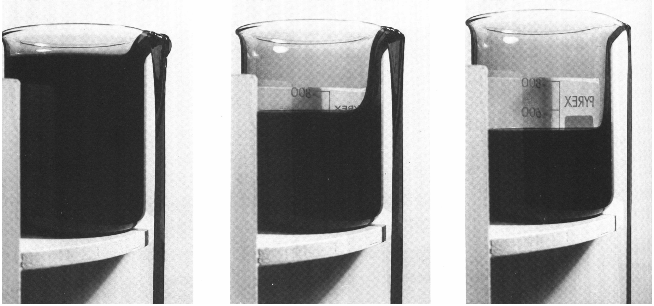
Die swell with ‘sharkskin’



May be a stick-slip effect?

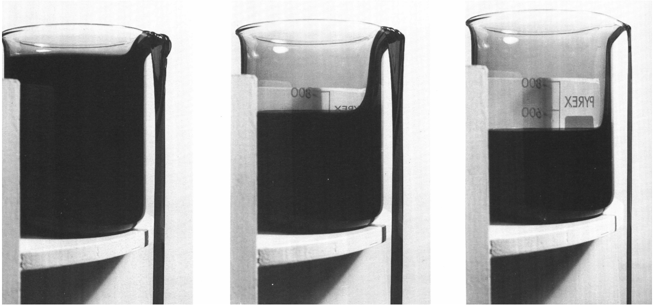
Elastic effects 3

Open syphon



Elastic effects 3

Open syphon



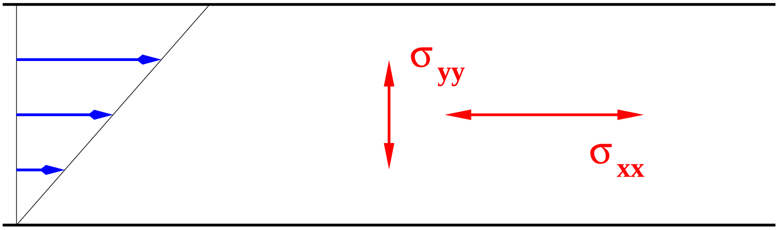
Find videos on web.

Normal stress

Normal stress

Simple shear flow

Normal stresses



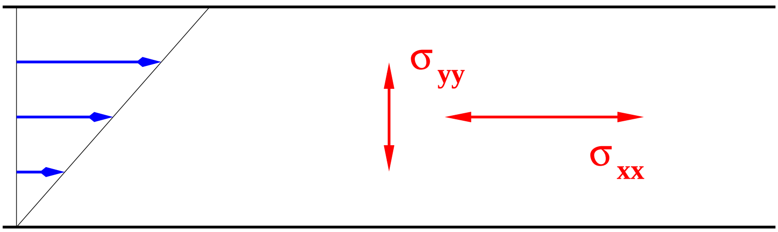
$\mathbf{u} = (\dot{\gamma} y, 0, 0)$

tension in streamlines

Normal stress

Simple shear flow

Normal stresses



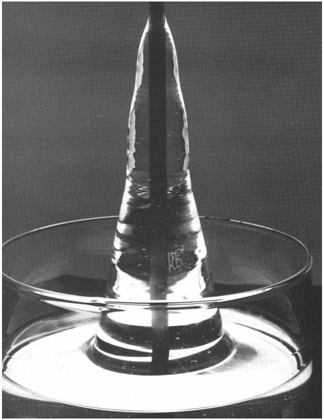
$\mathbf{u} = (\dot{\gamma} y, 0, 0)$

tension in streamlines

Sort of elastic stresses in shear flow

Normal stress 2

Rod climbing – Newtonian centrifuged out!



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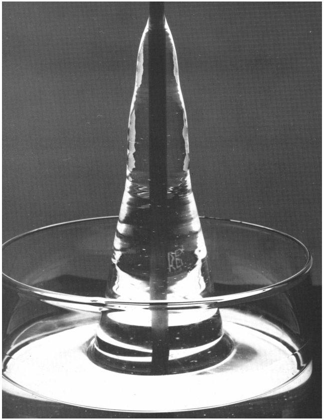
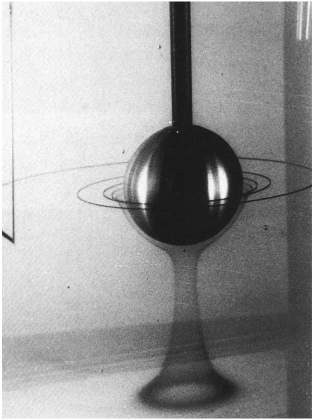


Fluid squeezed in by hoop stresses.

Normal stress 3

Secondary circulation for rotating sphere.



Same hoop stress effect.

Normal stress 3

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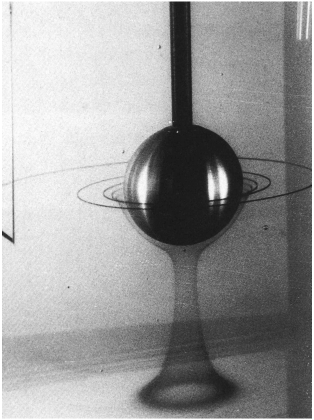
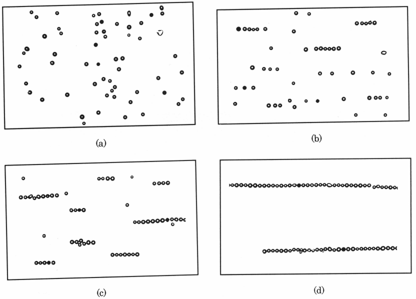


Same hoop stress effect.

Elastic effects always in opposite direction to inertial effects.

Normal stress 4

Agregation in time in (oscillating) shear.



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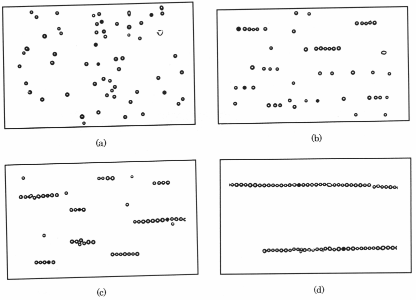
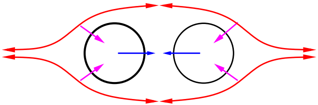




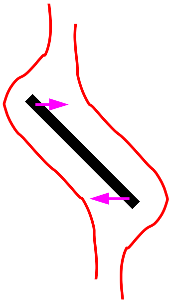
tension in streamlines

hoopstress effect

migration

Normal stress 5

Sedimenting rods become vertical in an elastic liquid



Normal stress 5

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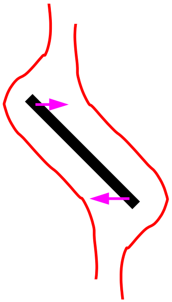
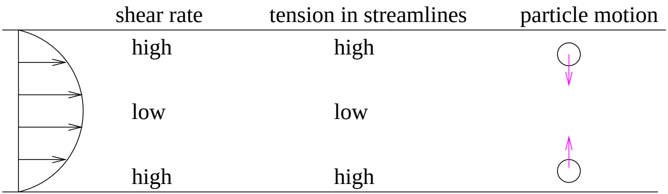
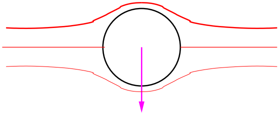


But become horizontal due to inertial effects

Normal stress 6

Migrate of particles to the centre line of pipe





Gradient in tension in streamline. Hoop stress force

Summary

Phenomena

- Nonlinear flow
- Inhibition of stretching
- Elastic effects
- Normal stress

No lecture Tuesday 25 January.

Next lecture Thursday 29 January.

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Student Exercises: Find

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