Heinrich Hencky (1885-1952)

- Natural logarithmic strain measure;

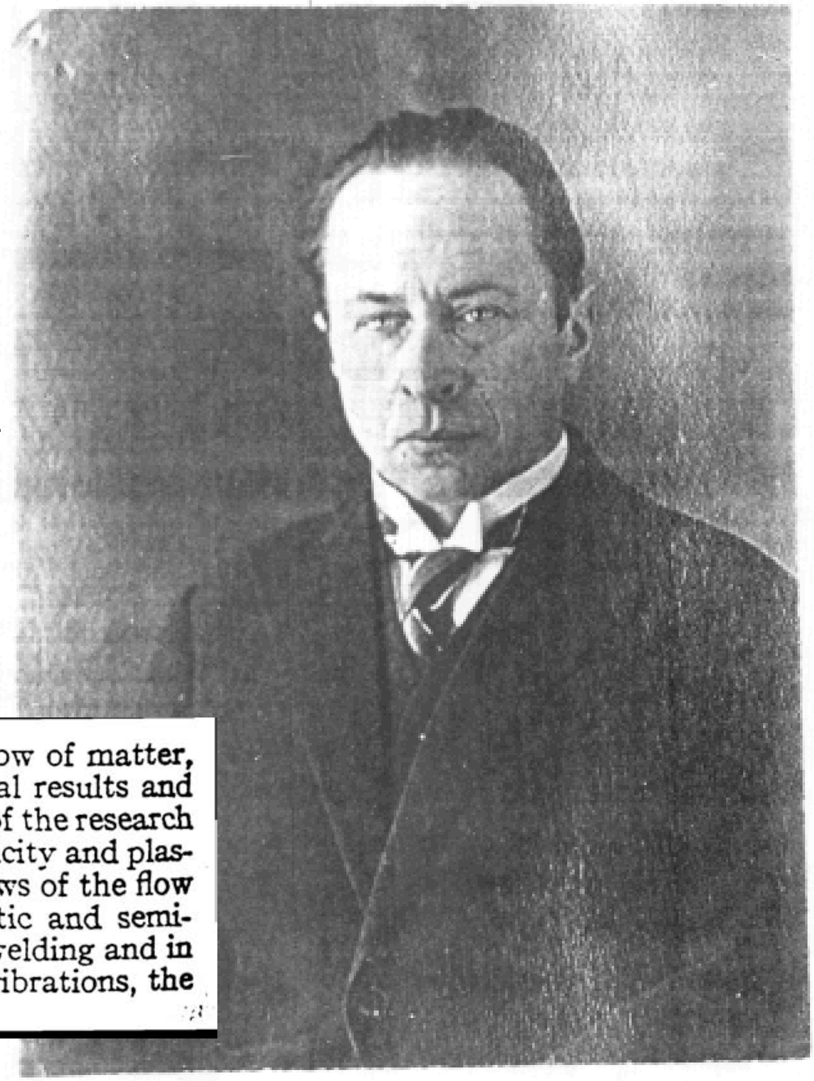
$$\boxed{\varepsilon(t) = \ln\left(L(t)/L_0\right)}$$

- Biography:
  - High School (Humanistic Gymnasium), Speyer am Rhein, Germany
  - Technical University, Munich; Dipl. Eng. 1908
  - Technical University, Darmstadt; D. Eng. 1913
- Professor of Mechanical Engineering, M.I.T. 1930-1933.
  - Office 1-321

From the 1930-31 M.I.T. Course Catalog:

2·341, 2·342. Rheology (A). A study of the science of the flow of matter, especial attention being given to the relations between experimental results and theory. The theory is developed as far as possible to meet the needs of the research engineer. Examples taken from the theories of hydrodynamics, elasticity and plasticity are given to illustrate the general principles underlying the laws of the flow of matter. A special study is made of the behavior of semi-elastic and semi-plastic fluids of metals at high temperatures used in forging and in welding and in the rolling mill, as well as the behavior of materials under forced vibrations, the fatigue of metals and frictional resistances in such bodies.

Courtesy of MIT. Used with permission.



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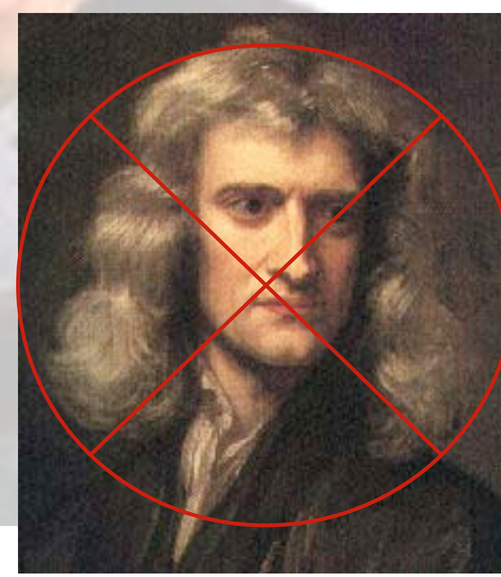
So What is a Complex Fluid?

- Complex fluids possess an underlying microstructure that can be affected by (and in turn then affect) a flow field
- Examples include:
  - Polymer solutions, polymer melts, liquid crystals
  - Foams, gels, bubbly-liquids,
  - Suspensions, emulsions, slurries, mud..
  - Food stuffs, paints, adhesives and other consumer products
- Basically everything except air, oil, water!
- These fluids violate Newton's viscosity law:

$$\tau_{yx} = \mu \frac{\partial v_x}{\partial y} \qquad \boldsymbol{\tau} = \mu \left\{ \nabla \boldsymbol{v} + \nabla \boldsymbol{v}^t \right\}$$

•**Rheology**: study of the material properties of complex fluids in specified/known flow fields

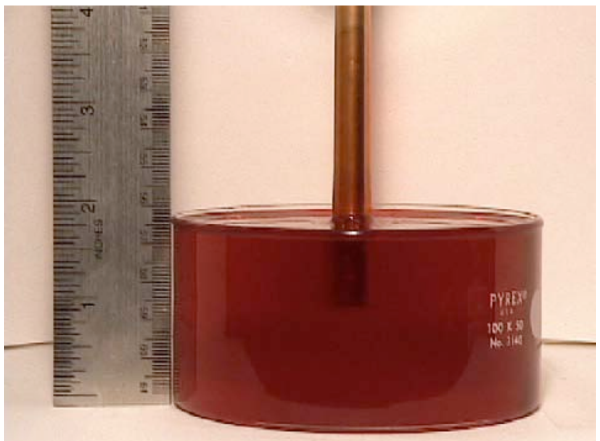
•**Non-Newtonian Fluid Dynamics**: self-consistent solutions of cons. of mass, momentum PLUS a constitutive model (rheological equation of state)



Important Non-Newtonian Fluid Effects

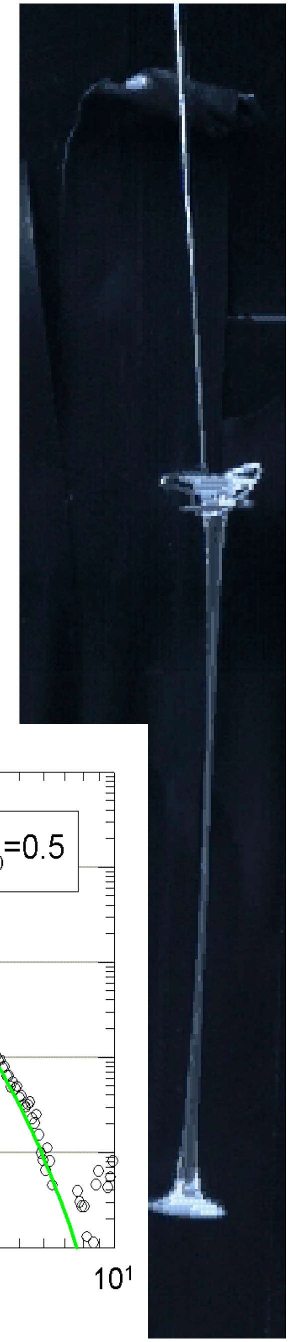
- Shear thinning (rate-dependence of viscosity)
  - "inelastic", "generalized Newtonian fluids"

$$\eta(\dot{\gamma}) \equiv \frac{\tau_{yx}}{\dot{\gamma}}$$

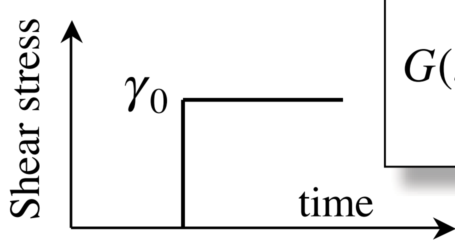


- Elasticity (normal stress differences)
  - "Second order fluids" (SOF)
  - Boger fluids

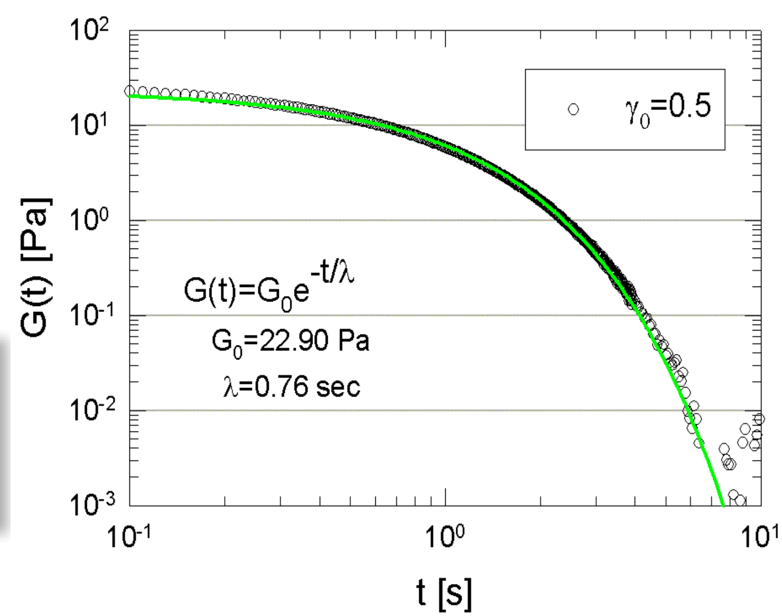
$$\Psi_1(\dot{\gamma}) \equiv \frac{\tau_{11} - \tau_{22}}{\dot{\gamma}^2}$$



- Fluid Memory (stress relaxation)
  - Relaxation time λ



$$G(t) = \frac{\tau_{12}(t)}{\gamma_0} \sim G_0 e^{-t/\lambda}$$



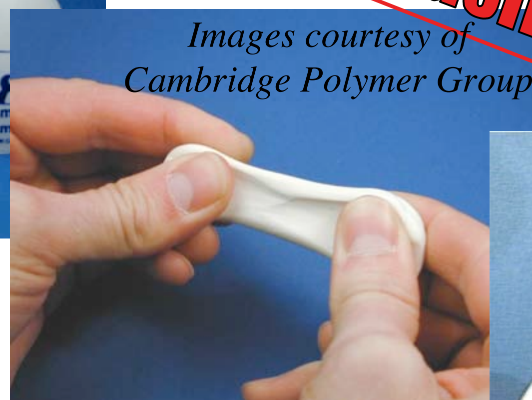
Natural Time Scale of Complex Fluids

- Natural time scale $\lambda_{material} \approx 100$ sec.
- The **Deborah number** is a dimensionless measure compared with the time scale of the deformation...

http://www.sillyputty.com

Increasing Deborah Number

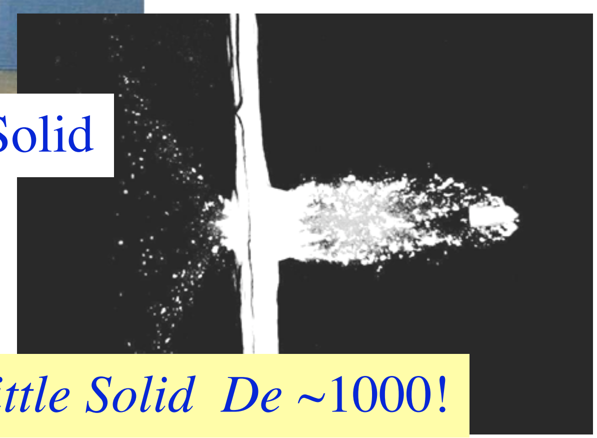
De < 1
Viscous Liquid



Images courtesy of Cambridge Polymer Group

De ~ 1
Viscoplastic Solid

De ~ 10 Elastic Solid



Brittle Solid De ~1000!

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$$\text{De} \sim \frac{\text{(Relaxation time of the material)}}{\text{(The timescale of the process)}} = \frac{\lambda_{material}}{\mathcal{T}_{process}}$$

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2.341J / 10.531J Macromolecular Hydrodynamic
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