

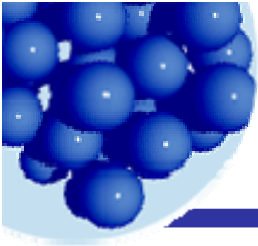
# Particle charge and Rheology

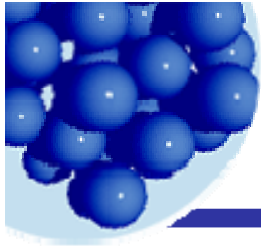
Dispersions in liquids: suspensions,  
emulsions, and foams

*ACS National Meeting*

*March 21 – 22, 2009*

*Salt Lake City*



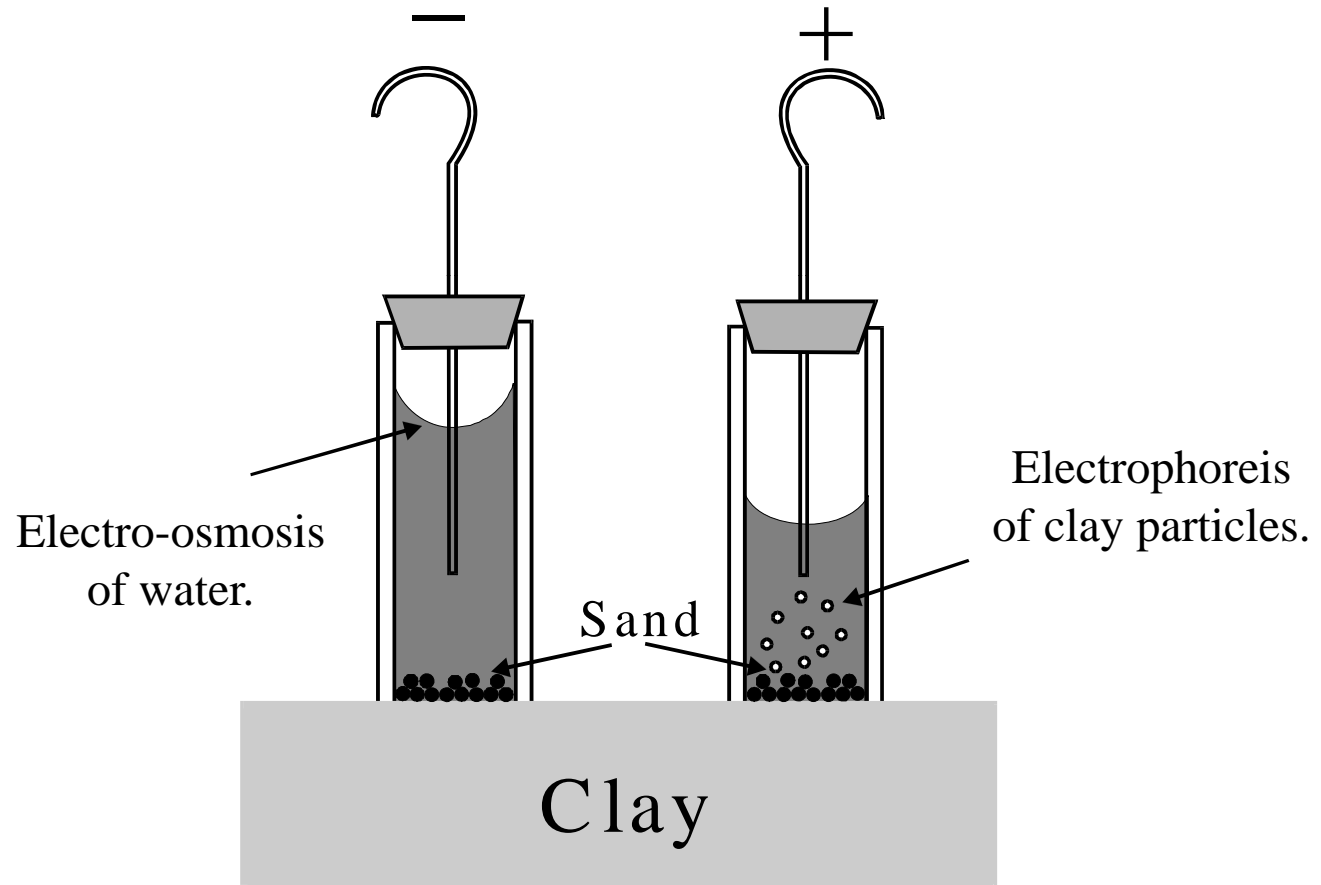


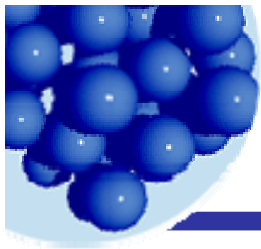
# Electro-osmosis and electrophoresis

Voltaic reports the “pile” in 1800. Steady power.

Napoleon rewards Volta 1801.

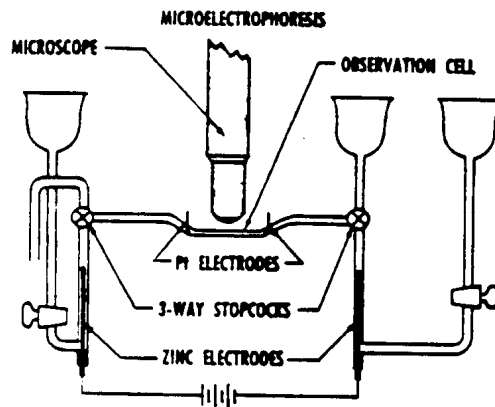
Reuss reports this experiment in 1809.



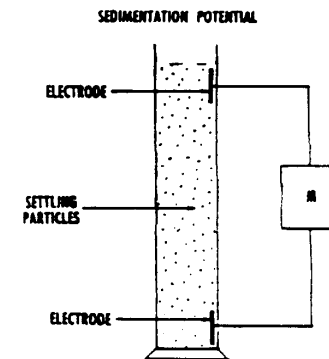


# Electrokinetic phenomena

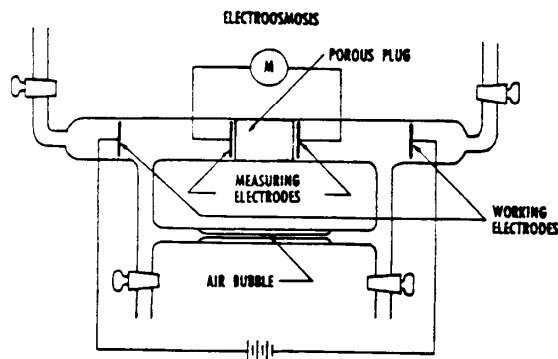
## Microelectrophoresis



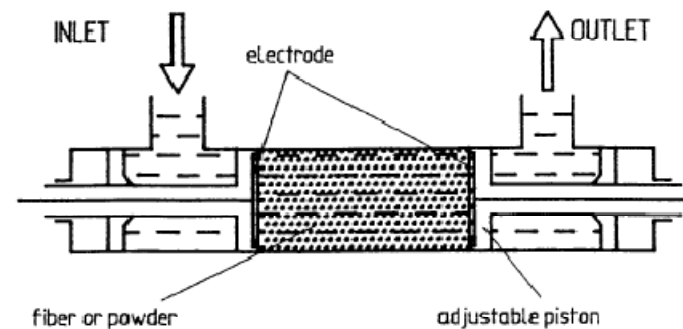
## Sedimentation potential

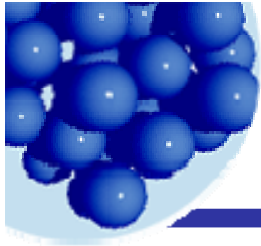


## Electro-osmosis

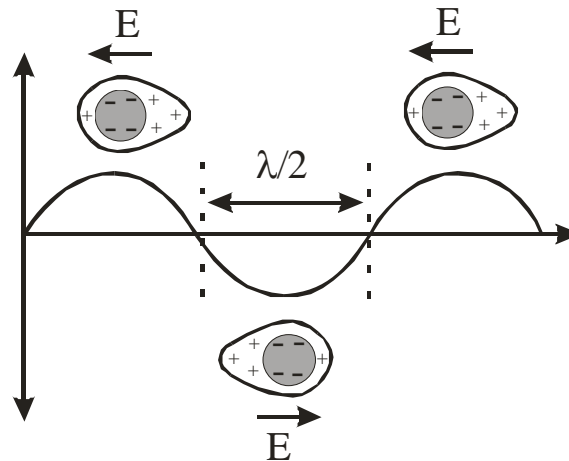


## Streaming potential (BIC)





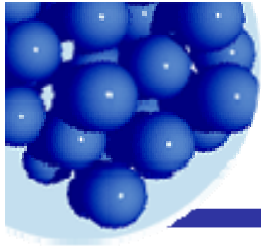
## Particle charge – Electroacoustic measurements



The technique uses an ultrasonic pressure wave to perturb the equilibrium double layer. This polarization generates an alternating electric field called the Colloid Vibration Potential:

$$CVP = \frac{2p\phi}{\lambda_0} \left[ \frac{\rho_2 - \rho_1}{\rho_1} \right] \frac{\varepsilon_0 D\zeta}{\eta}$$

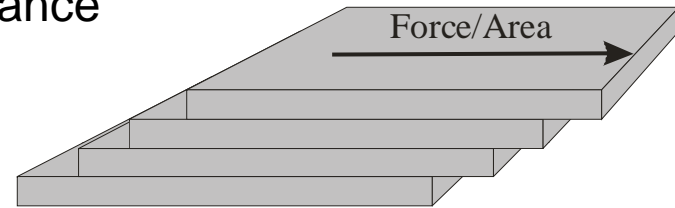
The great advantage is its use at high particle concentrations



# Rheology – The science of flow

**Shearing stress** = Force/Area =  $F/A$  = Newton/m<sup>2</sup>

**Rate of shear** = Change of velocity with distance  
=  $dv/dx$  = sec<sup>-1</sup>

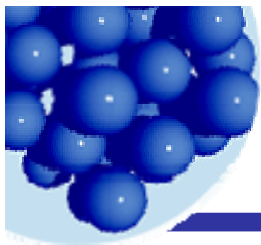


Newton's equation for viscous flow:

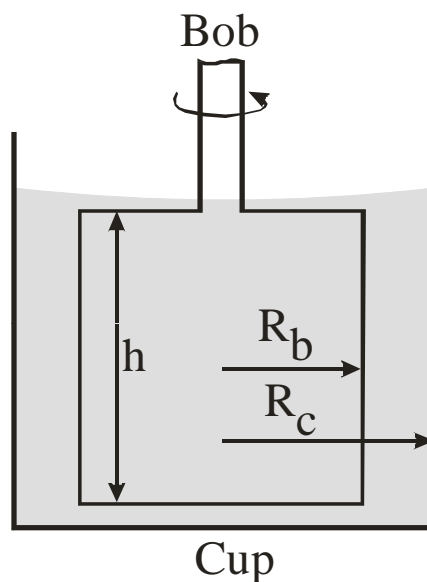
$$\frac{F}{A} = \eta \frac{dv}{dx}$$

$$\eta = \frac{\text{shear stress}}{\text{shear rate}} = \frac{\text{Newton} \times \text{sec}}{\text{m}^2} = \text{Pascal-sec}$$

Kinematic viscosity = Newtonian viscosity/density = Stoke

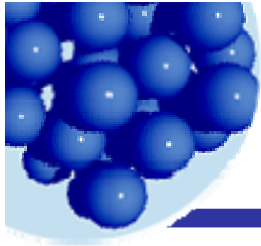


# Couette viscometer

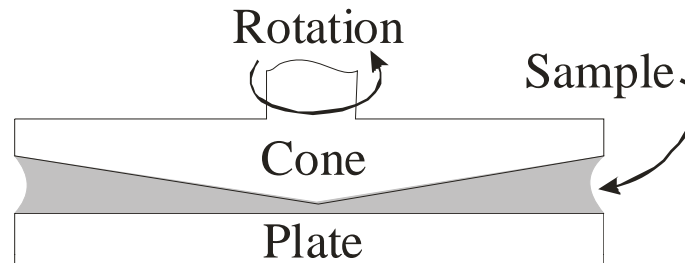


In modern Couette viscometers the bob is either driven with a known stress and the resulting angular velocity measured or it is driven at a known angular velocity and the required stress measured. The first provides viscosity as a function of shear stress, the latter provides viscosity as a function of shear rate.

CW Macosko "Rheology: Principles, Measurements, and Applications" VCH:New York, **1994**.



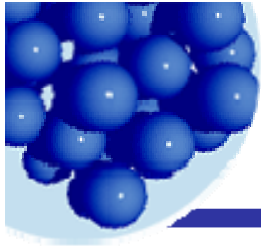
## Cone and plate rheometer



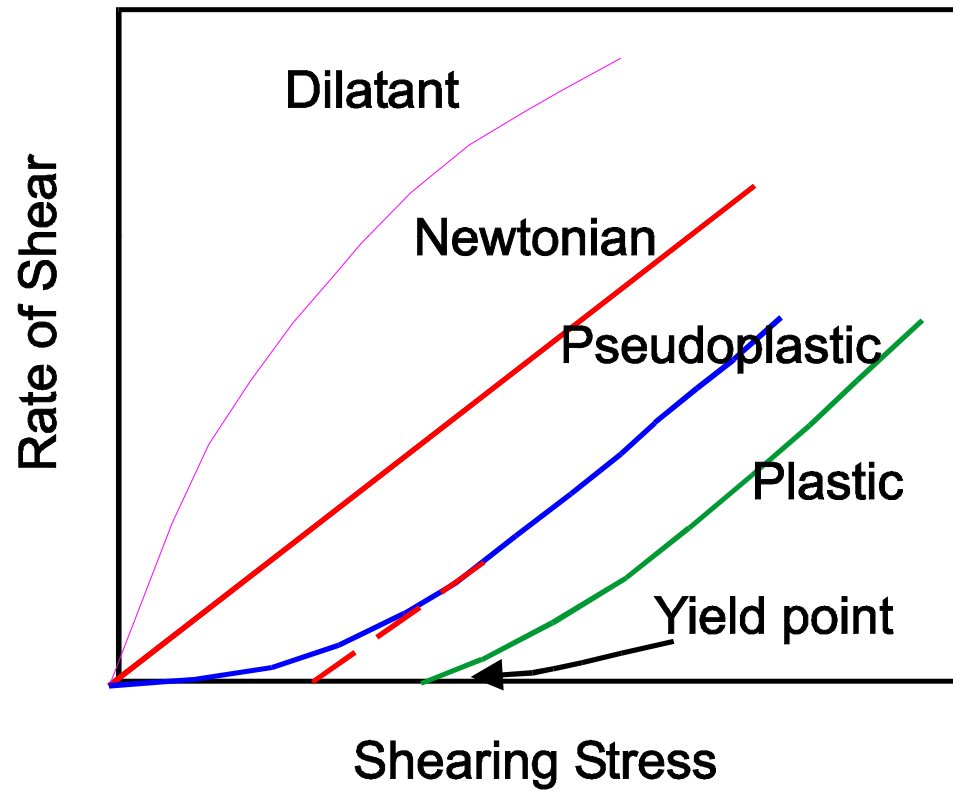
Consists of a flat plate and a cone with an apex angle of nearly  $180^\circ$

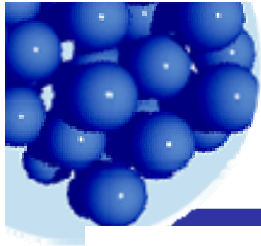
For such a geometry, the rate of shear is very nearly constant over the entire sample so that a well defined viscosity is measured.

The rate of shear is changed by changing the rotational velocity of the cone.

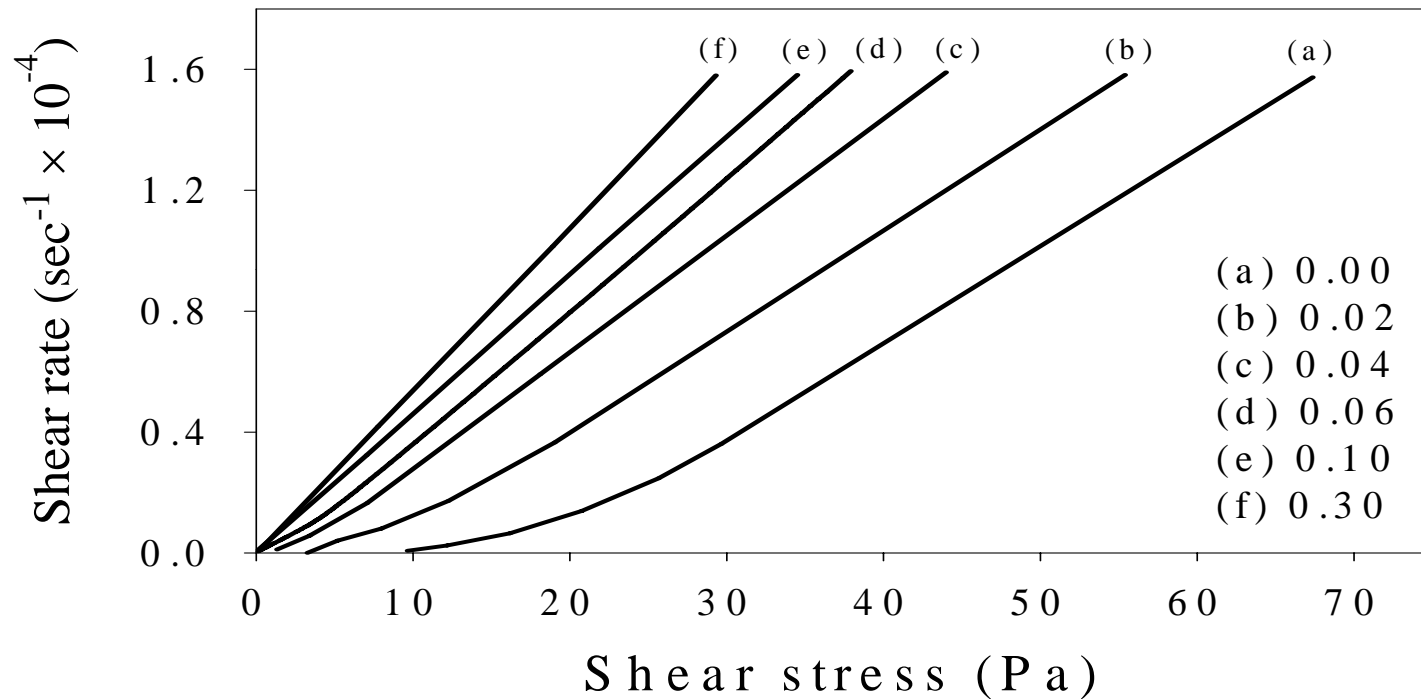


# Rheological behavior



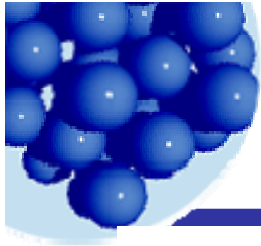


# Pseudoplastic flow

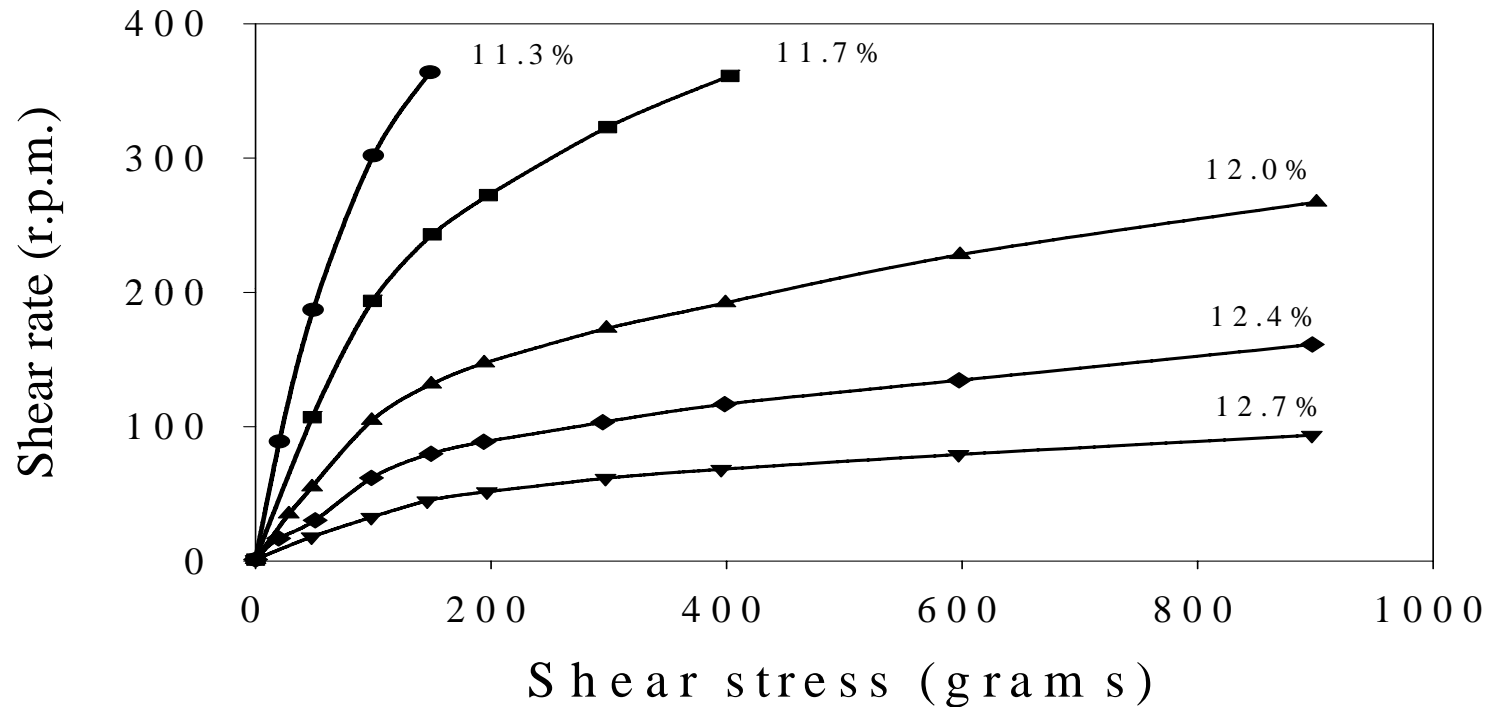


Rheograms of 20 w% deionized kaolin slurries at several levels of tetrasodium pyrophosphate\* addition. The figures on the curves indicate percent TSPP per weight of clay. An extrapolation of the linear region determines an apparent yield point.

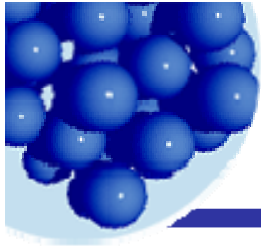




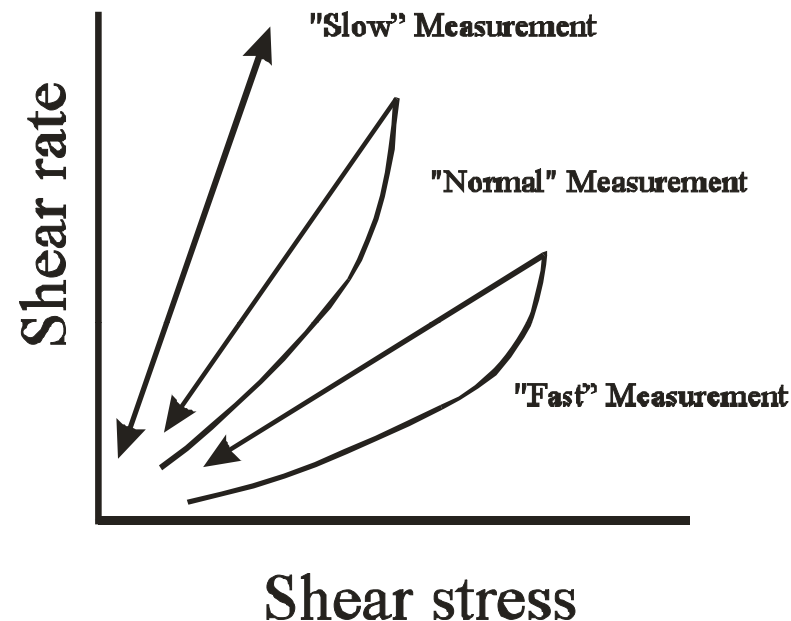
# Dilatancy



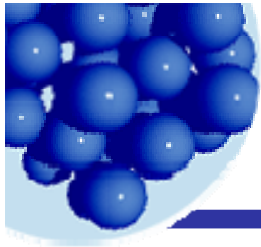
Dilatant flow of a series of suspensions of red iron oxide in an aqueous solution of sodium lignin sulfonate at 10% concentration at 30° C. The volume concentrations of solids are noted on the curves.



# Thixotropy

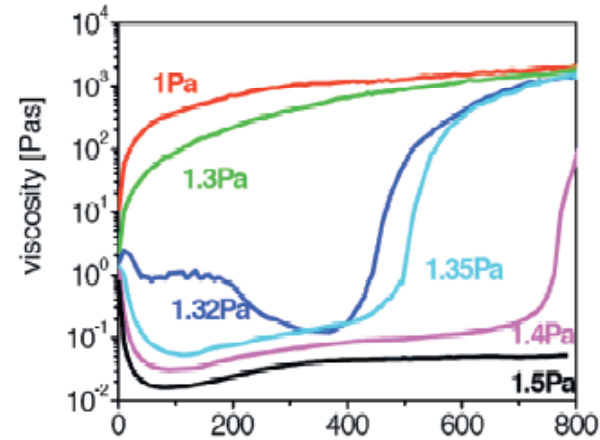
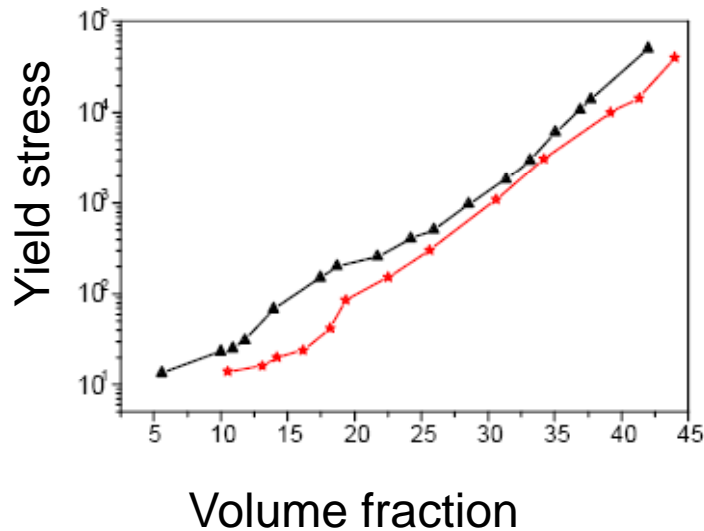


Thixotropic behavior is a temporary destruction of structure by stirring or shaking, and may be measured as the time required to “heal.” The diagram depicts rheological behavior of a thixotropic system as measured with a rotational viscosimeter. The area and nature of the thixotropic loop depends upon the type of instrument and the circumstances of measurement.



# Rheology of quicksand

At high stress (explorer falling into the quicksand), the viscosity drops, and the explorer sinks. When the thrashing is finished. The viscosity climbs, and hope fades.



▲ Fig. 1: Liquefaction of quicksand under stress: viscosity measurements show that there can be almost a factor of 1 million difference between quicksand in its normal 'solid' state, and quicksand that has been liquefied because it was disturbed too much (a too large stress was applied to the system).

The yield stress increases with concentration.  
The solution is dilution!

Khaldoun et al., *Nature*, 437, 635, 2005.

