Velocity and concentration profiles measurements in concentrated particle suspensions

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Geophysical flows
Geophysical flows

Complex fluids

- Particles
  - Material
  - Shape
  - Size distribution
  - Roughness
- Interstitial fluids
  - Viscosity

How do we measure the rheological properties?

- Yield stress
- Shear-thinning, Shear-thickening
- Thixotropy, rheopexy
Geophysical flows

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How do we measure the rheological properties?
- Yield stress
- Shear-thinning, Shear-thickening
- Thixotropy, rheopexy
Consequences for the rheologist

1. \( (T, \Omega) \implies (\tau, \dot{\gamma}) \)

2. **Wide gap** (because of the size distribution)

Solve the Couette inverse problem

\[
\tau(r) = \frac{T}{2\pi r^2 h}
\]

\[
\Omega = \int_{R_{in}}^{R_{out}} \frac{\dot{\gamma}(r)}{r} dr
\]

- \( T \): Total Torque
- \( \Omega \): Angular velocity
- \( \tau \): shear stress
- \( \dot{\gamma} \): shear rate
- \( r \): Radius
- \( h \): Height of fluid
- \( R_{in/out} \): Radius of the inner/outer cylinder
Associated Couette inverse problem

Solving methods:

- **Infinite series approach**
  \[
  \dot{\gamma}(\tau) = \frac{\omega}{\ln s} \left[ 1 + \ln s \frac{d\ln \omega}{d\ln \tau} + \frac{(\ln s)^2}{3\omega} \frac{d^2\omega}{d(\ln\tau)^2} + ... \right]
  \]

- **Least square approach**
  \[
  \min ||\omega - K\dot{\gamma}||
  \]

- **Projection approach**
  \[
  < K\dot{\gamma}, u_i > = < \omega, u_i >
  \]

- **Adjoint operator approach**
  \[
  \dot{\gamma} = \sum_{i \in J} < K\dot{\gamma}, u_i > \psi_i
  \]
  \[
  K^* u_i = \psi_i
  \]
Consequences for the rheologist

Solving methods:
- Mooney (1931)
- Krieger & Maron (1952)
- Krieger & Elrod (1953)
- Krieger (1968)
- Yang & Krieger (1978)
- Nguyen (1992)
- Yeow (2000)
- Ancey (2005)
- De Hoog & Anderssen (2005)(2006)
Consequences for the rheologist

Example: an artificial Herschel-Bulkley fluid $\tau = \tau_y + K\dot{\gamma}^n$

$$s = \frac{R_{in}}{R_{out}} = 0.9$$
Consequences for the rheologist

The same fluid with a wide-gap geometry

\[ s = \frac{R_{in}}{R_{out}} = 0.2 \]
Example : a polymeric gel

Ancey, J.Rheology 49 (2005) 441-460
Example: a particle suspension

\[ S : \text{adimensionalized shear stress} \]
\[ \Gamma : \text{adimensionalized angular velocity} \]

Example: a particle suspensions

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Ancey, J. Rheol. 45 (2001) 1421-1439

Ancey, J. Rheology 49 (2005) 441-460
Flows  Rheology and Rheophysics  Concentrated particle suspensions  Measurement method  Results

- Shear localization?
- Particle segregation?
- Particle migration?
- Ordering?

- Particle roughness?
- Particle Shape?
- Slipping?

Do we measure material’s physical properties...

... or disturbing effects?
Classical and optical rheometry

Classical rheometry

T and Ω

Solve the Couette inverse problem

τ and ˙γ

Rheophysical approach

Clear suspensions

Particle motion (FPIV / FPTV)

Differentiate the velocity profile

τ and ˙γ
Where do the properties come from?

Studied flows

Optical methods

concentrated particle suspensions
(25mm thickness)
Properties of the suspensions

The simplest complex fluid

- Iso-index $\Rightarrow$ transparency
- Iso-density $\Rightarrow$ No gravity effects
- Molecular tagging of the particles $\Rightarrow$ the laser excites fluorescence

Particles

- Shape: spherical
- Granulometry

Fluid

- Three fluids mixture
- Newtonian
- Viscosity: variable
Non colloidal and highly concentrated particle suspensions

- Spherical PMMA particles with a diameter of 50 to 350 $\mu m$
- Mixture of three newtonian fluids (Lyon & Leal 1997)
Properties of the suspensions

Wet sieving

![Graph showing particle diameter distribution for raw and sieved PMMA samples.](image)

- **raw PMMA**
  - \( \mu = 168 \, \mu m, \sigma = 54 \, \mu m \)
- **sieved PMMA**
  - \( \mu = 198 \, \mu m, \sigma = 4.8 \, \mu m \)
Temperature and wavelength effects

- Temperature effects
- Wavelength effects
Temperature effects

Density

Temperature [ °C]

Density of dibromohexane [g/cc]

Density of Triton X100 [g/cc]

\( \frac{\Delta \rho}{\Delta T} = 1 \text{ [kg/m}^3 \text{ ° C]} \)
Temperature effects

Density

Refractive index

Dibromohexane \(-3.667 \times 10^{-4} \, 1/°C\)
UCON oil \(-3.425 \times 10^{-4} \, 1/°C\)
Triton X100 \(-3.208 \times 10^{-4} \, 1/°C\)
Fit lineaire
Temperature effects on light transmission

Laser 532nm → Particle suspension (more than 500 interfaces) → Pinhole → Photodetector → Measurement
Temperature effects on light transmission

![Graph showing temperature effects on light transmission]

The graph illustrates the relationship between temperature and light transmission for concentrated particle suspensions. The y-axis represents the ratio of light transmission through the suspension to that through the fluid, while the x-axis shows temperature in °C.
Wavelength effects

Effects of mismatch in the Refractive index on transmission

![Graph showing the effect of mismatch in refractive index on transmission]

- The graph plots the ratio of suspension intensity to fluid intensity ($I_{\text{suspension}} / I_{\text{fluid}}$) against the refractive index ($n$).
- The data points indicate a trend where the ratio increases as the refractive index increases.
- This suggests that mismatches in refractive index significantly affect transmission in concentrated particle suspensions.
Wavelength effects

![Graph showing wavelength effects](image-url)

- **Monochrome with Microlens**
- **Red**
- **Green**
- **Blue**
Wavelength effects

RGB picture with a color CCD camera:

Blue component

Red component
FPIV / FPTV techniques

Measurement methods
Measurement methods
Measurement methods

- LASER SHEET
- FILTER
- CAMERA
Measurement methods
The setup
FPIV Images

Area of interest 23mm x 20mm
Laser sheet
Laser sheet 532 nm and optics

Filter to reject 532 nm

0.00 to 60.00 if the transparency of the dense suspension is high enough

Camera view from the bottom
Validation

Validation measurements

\[ V_{\theta}(r) = \frac{A}{r} + Br \quad \text{with} \quad A = \frac{R_{in}^2 R_{out}^2 \Omega}{R_{out}^2 - R_{in}^2}, \quad B = \frac{R_{in}^2 \Omega}{R_{in}^2 - R_{out}^2} \]
Velocity profile of concentrated suspensions

Time evolution of the suspension

![Graph showing the velocity profile of concentrated suspensions over time. The graph plots radial position against normalized velocity, with different colors and markers indicating data points after 1, 2, 3, and 5 hours.]
Velocity profile of concentrated suspensions

Bottom end effects

\[ \frac{V_{\theta,r}}{V_{\theta,in}} \]
Flow curve derivation

Flow curve comparison

\[ \dot{\gamma} \quad \text{[s}^{-1}] \]

\[ \tau \quad \text{[Pa]} \]

- velocity profile
- macsporran86
- yeow00
- ancy05
- dehoog06
- other methods
We want to use the same techniques to carry out experiments on the dam-break problem (sudden release of a finite volume of fluid down a plane) and measure the cross-stream velocity profile inside the bulk within the head.
Acknowledgment

- Christophe Ancey
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- Iso-index ⇒ transparency
- Iso-density ⇒ No gravitation effects
- not toxic

**Particles**
- Sphericity
- Good optical properties
- Granulometry
- Fluorescent molecular tagging

**Fluide**
- No evaporation
- Wet the PMMA
- Should not dissolve PMMA
- Low absorption
- No excitation
- Variable viscosity
Fluide

- Lyon (1997)
- Dibromohexane
- Triton X 100
- Huile UCON 75H
Transparent concentrated noncolloidal suspensions

- Spherical particles: 200 to 600 $\mu$m
- Iso-index and iso-density fluid mixture
Why Rhodamine 6G?
How much rhodamine 6G?

- High concentration
  - More fluorescence
  - COMPROMIS
    - Lower effect on the refractive index
      - Low concentration
Produit brut PMMA BS 520

$\mu = 168.0 \mu m$

$\sigma = 54.33 \mu m$
Produit tamisage par voie humide dans de l’alcool
Choix de la Rhodamine 6G

- Excellent efficacité ?
- Suffisamment faible "Stokes shift"
Suspension properties

- Iso-index $\Rightarrow$ transparency
- Iso-density $\Rightarrow$ No gravitation effects
- Non toxic

**Particules**
- Sphericity
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