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

$\Rightarrow$

How do we measure the rheological properties ?

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

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- Thixotropy, rheopexy

Consequences for the rheologist

1. $\begin{pmatrix} T \\ \Omega \end{pmatrix} \dashrightarrow \begin{pmatrix} \tau \\ \dot{\gamma} \end{pmatrix}$

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

$\Rightarrow$

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
Ω : Angular velocity
τ : 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
  $\dot{\gamma}(\tau) = \frac{\omega}{ln\, s}\left[1 + ln\, s\frac{d\, ln\, \omega}{d\, ln\, \tau} + \frac{(ln\, s)^2}{3\omega}\frac{d^2\omega}{d(ln\, \tau)^2} + \ldots\right]$
- Least square approach $\min ||\omega - K\dot{\gamma}||$
- Projection approach $< K\dot{\gamma}, u_i > = < \omega, u_i >$
- Adjoint operator approach $\dot{\gamma} = \sum_{i \in J} < K\dot{\gamma}, u_i > \Psi_i$

$$K^\star u_i = \Psi_i$$

Consequences for the rheologist

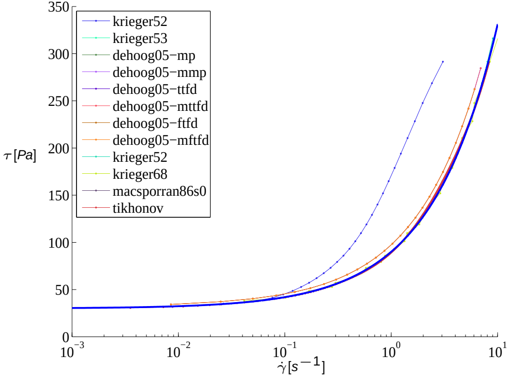
Solving methods :

- Mooney (1931)
- Krieger & Maron (1952)
- Krieger & Elrod (1953)
- Krieger (1968)
- Yang & Krieger (1978)
- Mac Sporran (1986)(1989)
- Nguyen (1992)
- Yeow (2000)
- Ancey (2005)
- De Hoog & Anderssen (2005)(2006)

Consequences for the rheologist

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

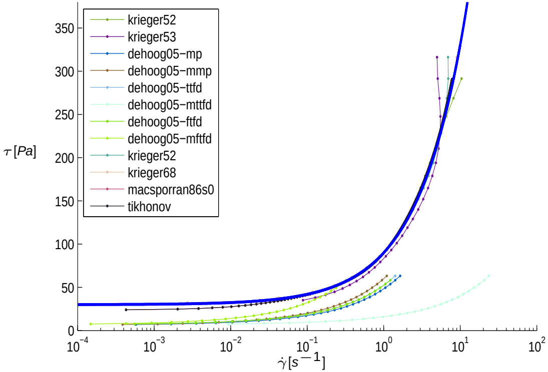
$$s = \frac{R_{in}}{R_{out}} = 0.9$$



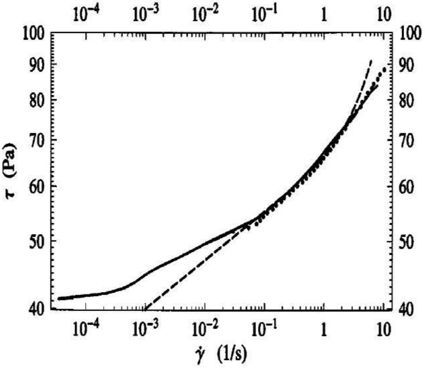
Consequences for the rheologist

The same fluid with a wide-gap geometry

$$s = \frac{R_{in}}{R_{out}} = 0.2$$

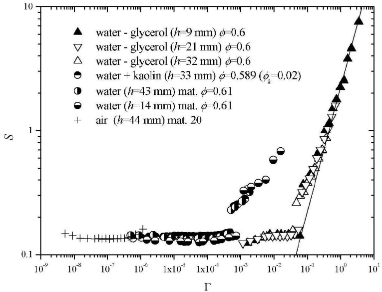


Example : a polymeric gel



Ancey, *J.Rheology* **49** (2005) 441-460

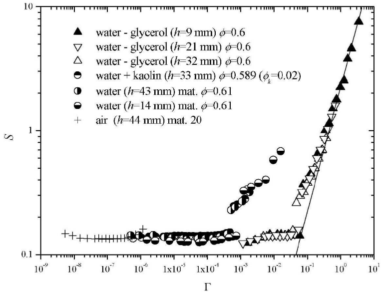
Example : a particle suspensions



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

S : adimensionalized shear stress
Γ : adimensionalized angular velocity

Example : a particle suspensions



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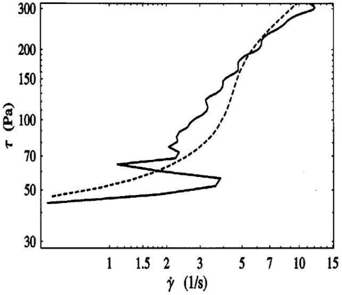

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S : adimensionalized shear stress
Γ : adimensionalized angular velocity

- 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

Continuum mechanics approach

$\Downarrow$

Classical rheometry

$\Downarrow$

T and Ω

$\Downarrow$

Solve the Couette inverse problem

$\Downarrow$

τ and $\dot{\gamma}$

Rheophysical approach

$\Downarrow$

Clear suspensions

$\Downarrow$

Particle motion (FPIV / FPTV)

$\Downarrow$

Differentiate the velocity profile

$\Downarrow$

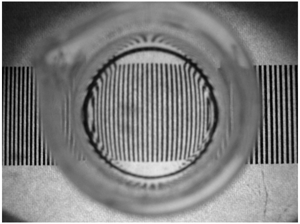
τ and $\dot{\gamma}$

Where do the properties come from ?

Studied flows

Optical methods

$\Longrightarrow$



concentrated particle suspensions (25mm thickness)

The simplest complex fluid

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

<u>Particles</u>

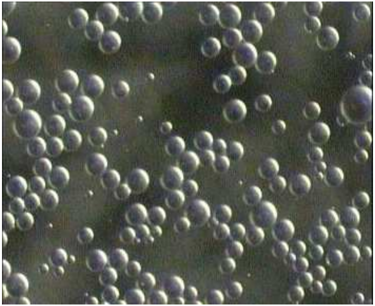
- Shape : spherical
- Granulometry

<u>Fluid</u>

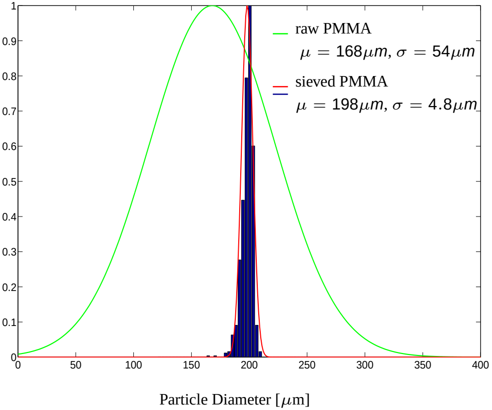
- Three fluids mixture
- Newtonian
- Viscosity : variable

Non colloidal and highly concentrated particle suspensions

- Spherical PMMA particles with a diameter of 50 to 350 μm
- Mixture of three newtonian fluids (Lyon & Leal 1997)



Wet sieving

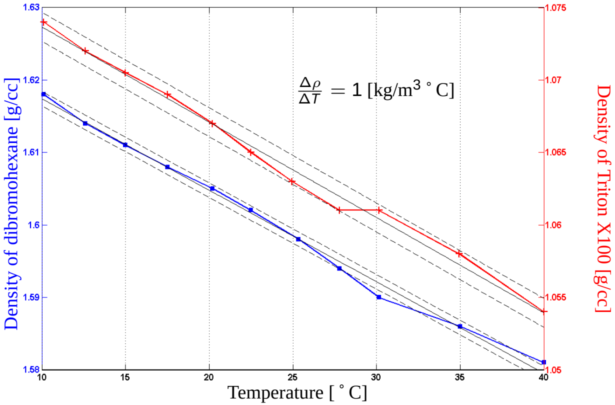

raw PMMA
$\mu = 168\mu m$, $\sigma = 54\mu m$
sieved PMMA
$\mu = 198\mu m$, $\sigma = 4.8\mu m$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
Particle Diameter [μm]

Temperature and wavelength effects

- Temperature effects
- Wavelength effects

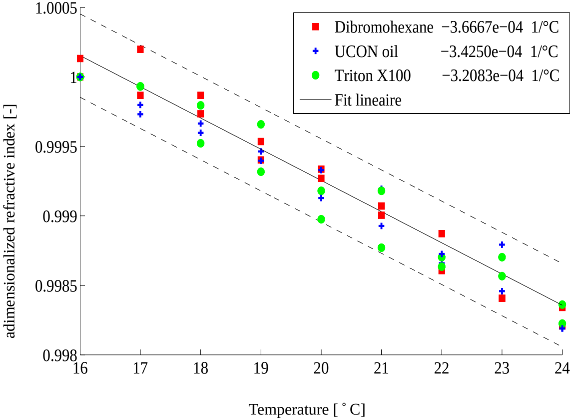
Temperature effects

- Density
- Refractive index

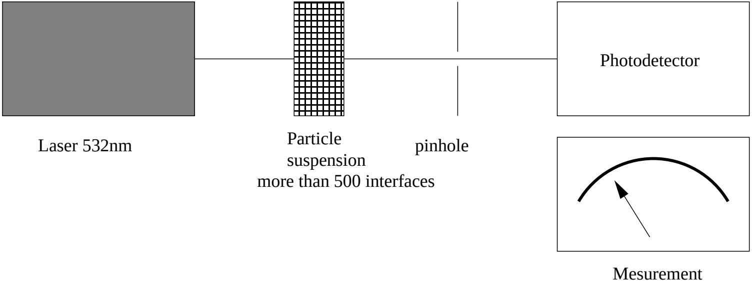


Temperature effects

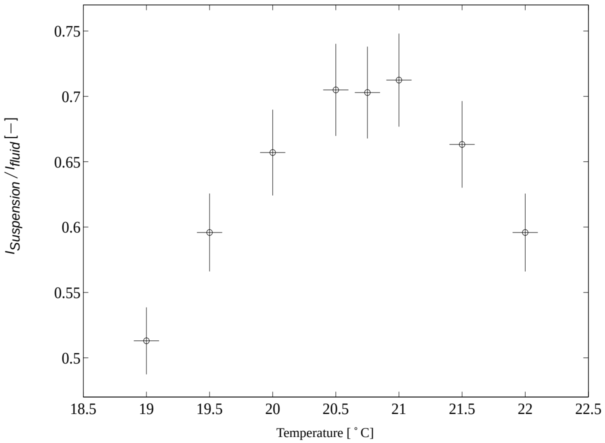
- Density
- Refractive index



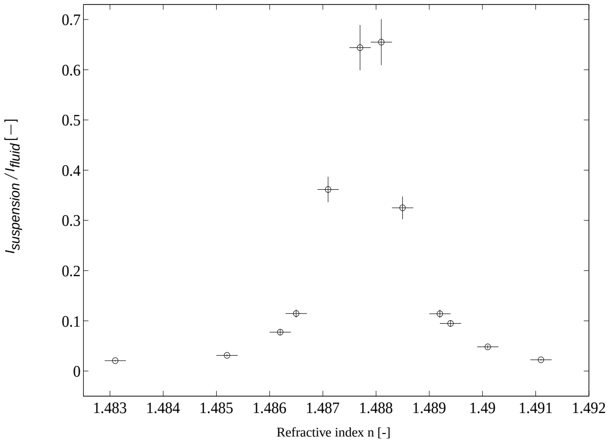
Temperature effects on light transmission



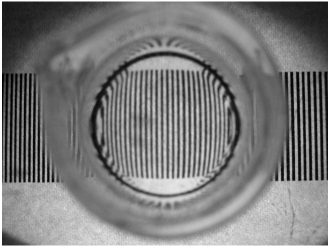
Temperature effects on light transmission

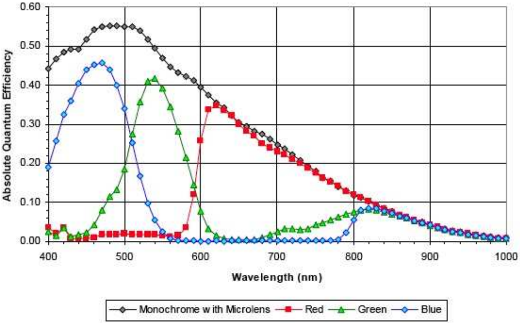


Effects of mismatch in the Refractive index on transmission



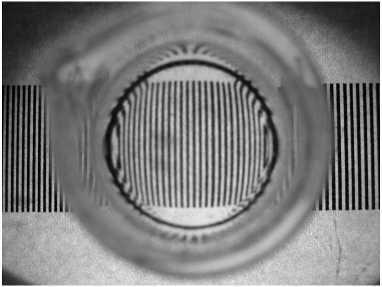
Wavelength effects



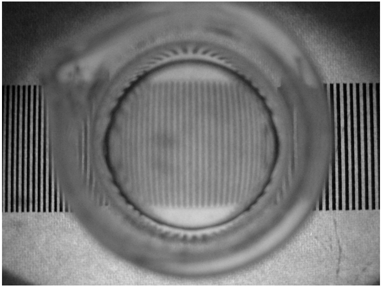


Wavelength effects

RGB picture with a color CCD camera :

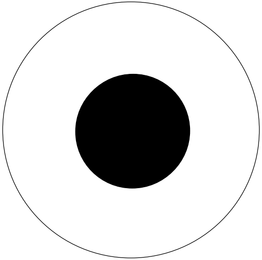


Blue component

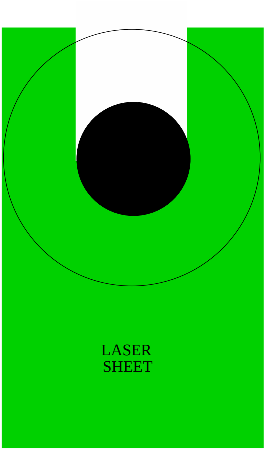


Red component

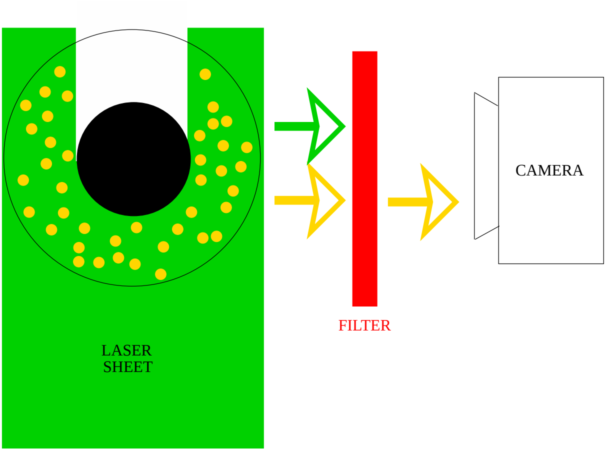
Measurement methods



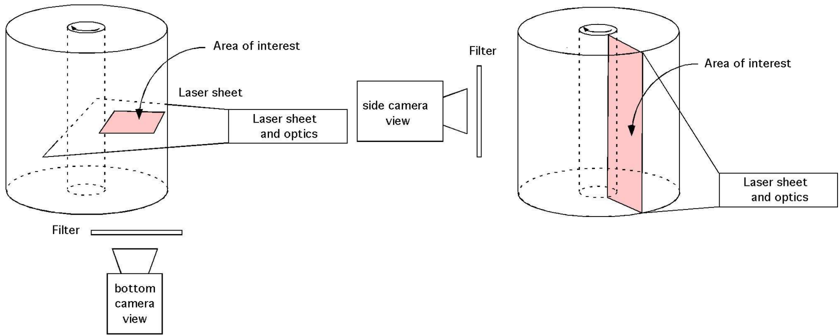
Measurement methods



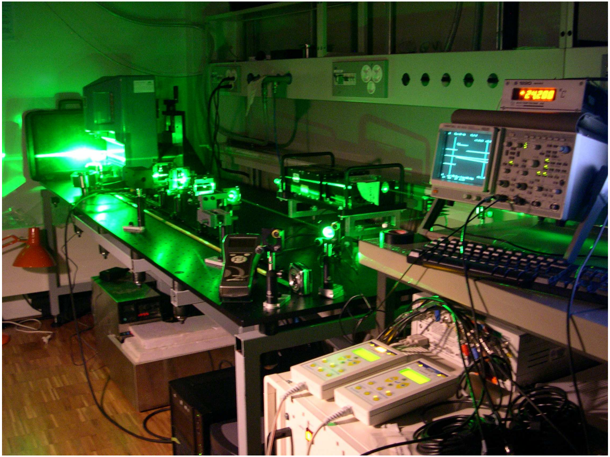
Measurement methods



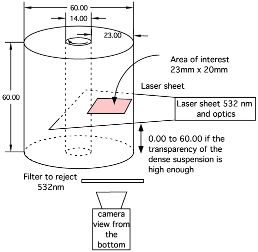
Measurement methods



The setup

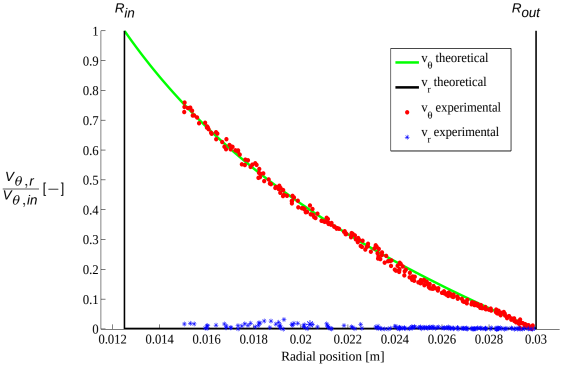


FPIV Images

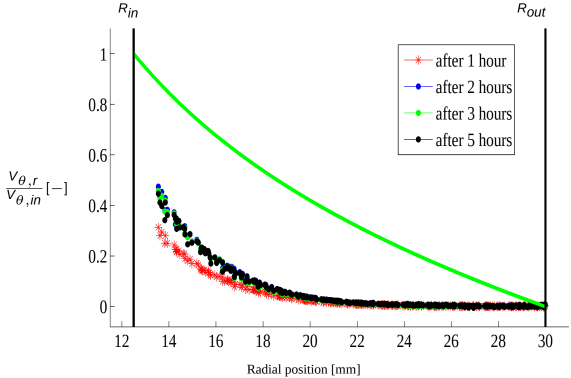

60.00
14.00
23.00
60.00
Area of interest
23mm x 20mm
Laser sheet
Laser sheet 532 nm
and optics
0.00 to 60.00 if the
transparency of the
dense suspension is
high enough
Filter to reject
532nm
camera
view from
the
bottom

Validation measurements

$$V_\theta(r) = \frac{A}{r} + Br \text{ with } A = \frac{R_{in}^2 R_{out}^2 \Omega}{R_{out}^2 - R_{in}^2}, \quad B = \frac{R_{in}^2 \Omega}{R_{in}^2 - R_{out}^2}$$

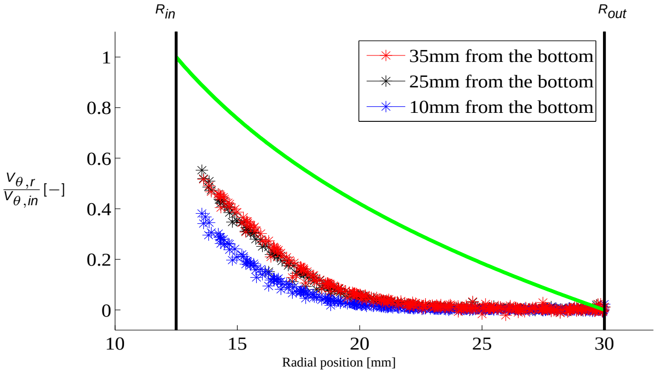


Time evolution of the suspension

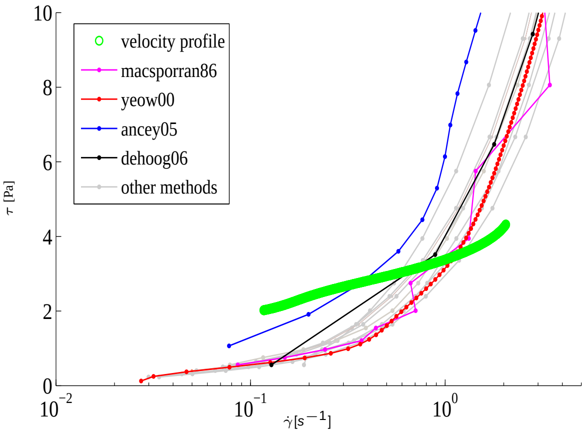


Velocity profile of concentrated suspensions

Bottom end effects



Flow curve comparison



Future work

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
- Nicolas Andreini, Martin Rentschler
- The Swiss National Science Foundation

- Iso-index $\Rightarrow$ transparency
- Iso-density $\Rightarrow$ No gravitation effects
- not toxic

<u>Particles</u>

- Sphericity
- Good optical properties
- Granulometry
- Fluorecent molecular tagging

<u>Fluide</u>

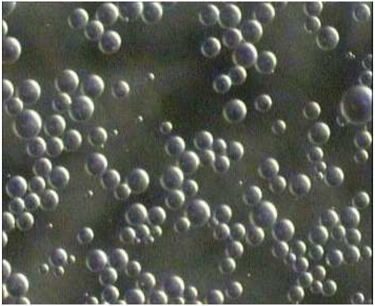
- No evaporation
- Wet the PMMA
- Should not disolve PMMA
- Low absorption
- No excitation
- Variable viscosity

Fluides

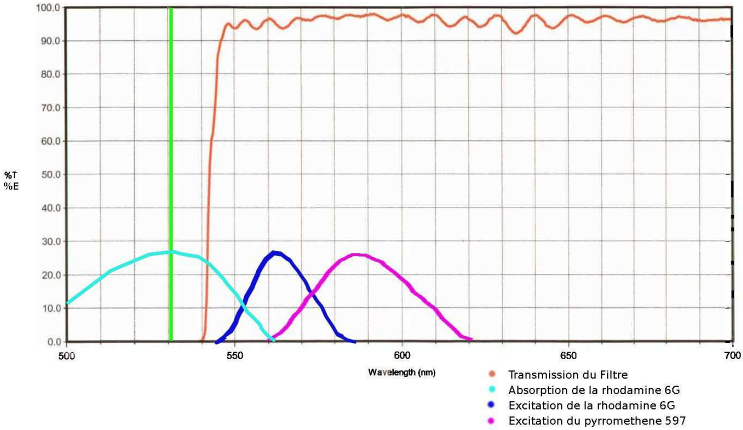
- **Lyon (1997)**
- Dibromohexane
- Triton X 100
- Huile UCON 75H

Transparent concentrated noncolloidal suspensions

- Spherical particles : 200 to 600 μm
- Iso-index and iso-density fluid mixture



Why Rhodamine 6G ?



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How much rhodamine 6G ?

High concentration

$\Downarrow$

More fluorescence

$\Downarrow$

COMPROMIS

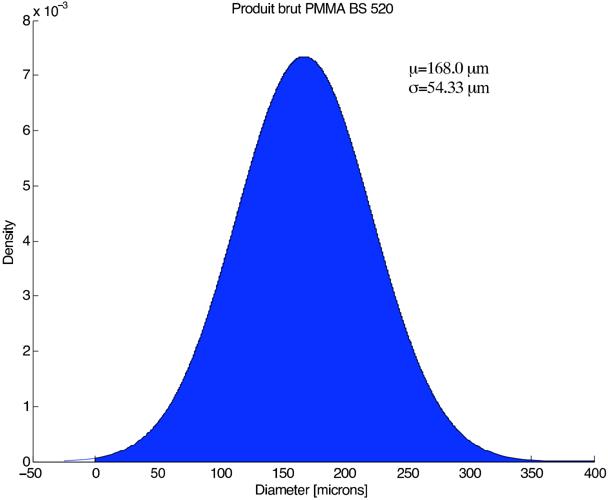
$\Uparrow$

Lower effect on the refractive index

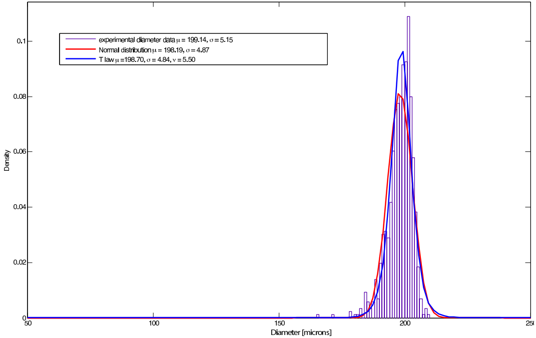
$\Uparrow$

Low concentration

Produit brut



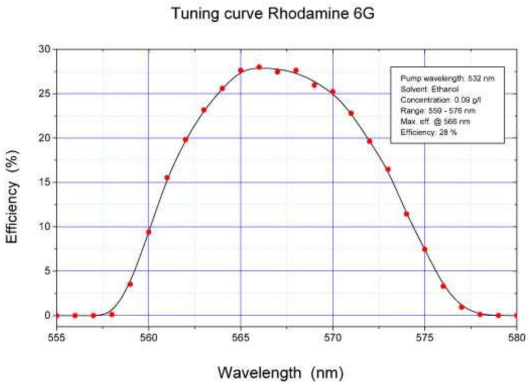
Produit tamisage par voie humide dans de l’ ?thanol



REPRODUCTIBILITE

Choix de la Rhodamine 6G

- Excellent efficacit ?
- suffisamment faible ”Stokes shift”



Suspension properties

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

Particules

- Sphericity
- Good optical properties
- Granulometry
- Fluorecent molecular tagging

Fluide

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- Wet the PMMA
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