Flow of NFC suspensions in Couette device-MRI invetigations

S. Skali Lami, S. Leclerc, D. Stemmlen
Lorraine University (LEMTA – Nancy)

C. Quezennec, D. Guerrin
(CTP Grenoble)

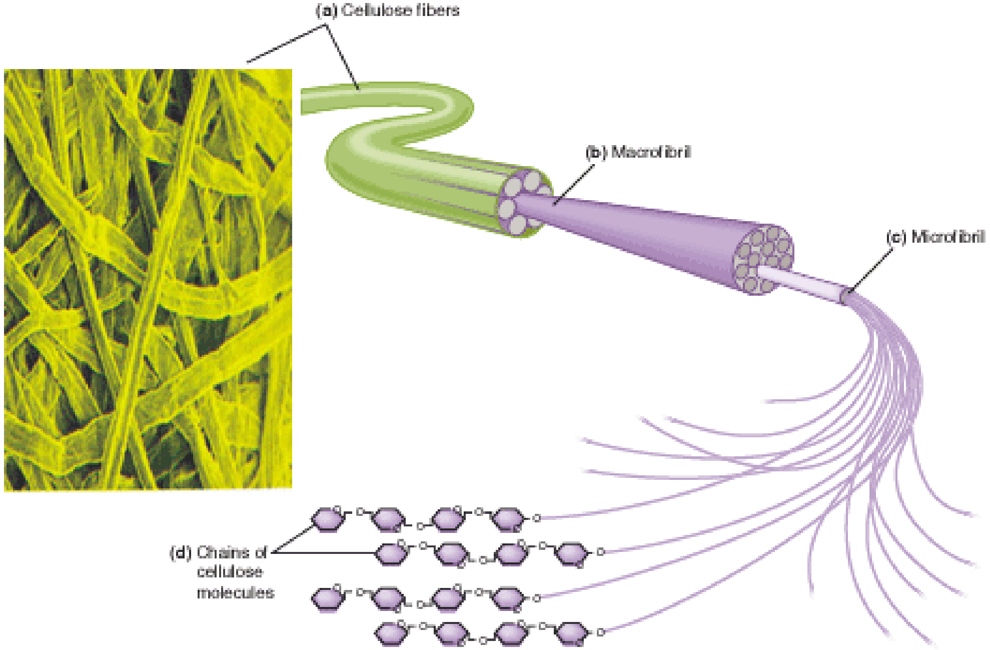
COST FP1005 "Fibre Suspension Flow Modelling"- ERCOFTAC SIG43 "Fibre suspension flows".
Coimbra – March 2013

Introduction

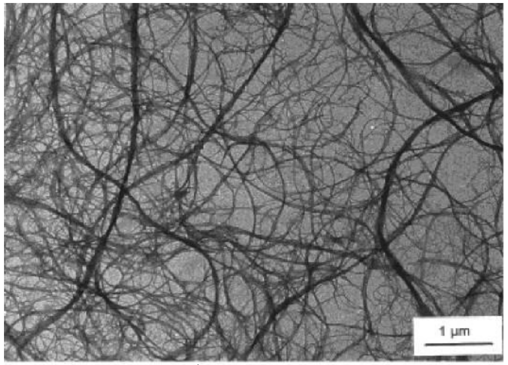
- M/NFC generality
- Rheology of NFC
- IRM and experimental device
- Preliminary results
- Theoretical approach
- Conclusions and perspectives

Generality

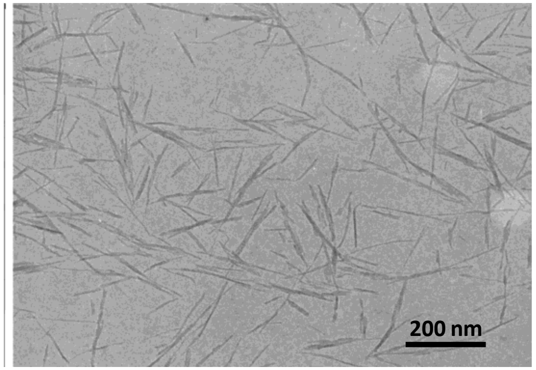
What are nanocelluloses?



Nutrition Resources: Carbohydrates, http://nutrition.jbpub.com/resources/chemistryreview9.cfm, Jones and Bartlett Publishers (june 2012).

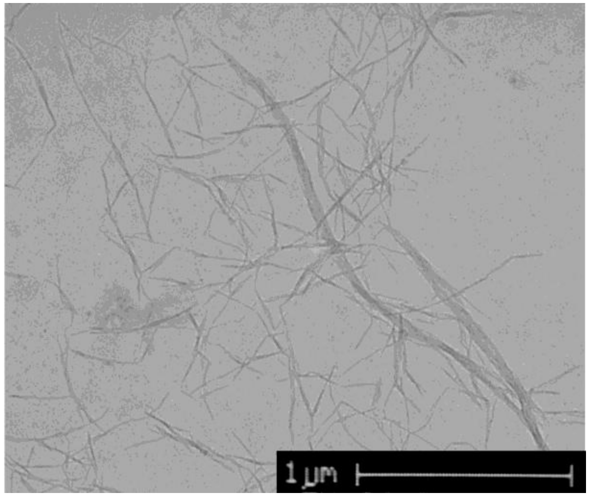


Dufresne A., Cavaillé J.Y., Vignon M.R., "Mechanical Behavior of sheets prepared from sugar beet cellulose microfibrils," *Journal of Applied Polymer Science* 64, no. 6 (1997): 1185-1194.



Da Silva Perez D., Tapin-Lingua S., Janodet A., Petit-Conil M., Dufresne A., "Nanofibres: Production of cellulose micro and nano-fibres: state of the art and first results", *5th Intechfibres Research Forum: Centre technique du Papier*, Grenoble (2009).

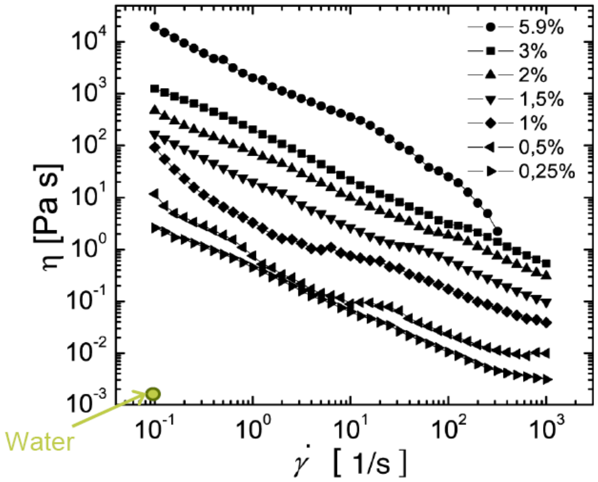
Generality



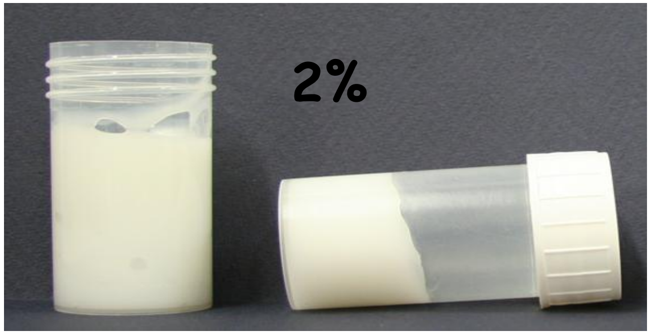
TEM picture of highly diluted dispersion of NFC/MFC Source CTP

Picture of NFC gel

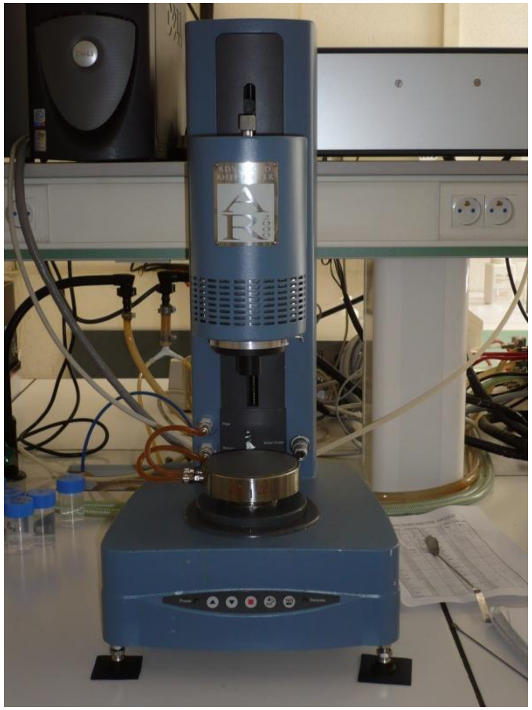
Source Innventia



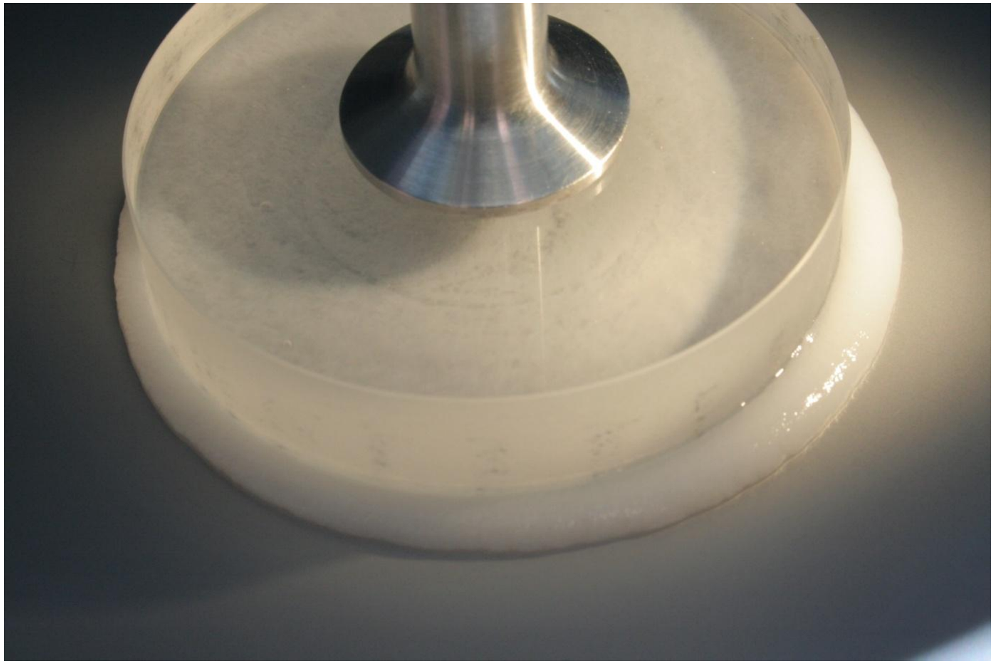
Rheology of NFC, M.Pääkkö *et al.*, Biomacromolecules 8(6), 1934-1941, 2007



Rheology

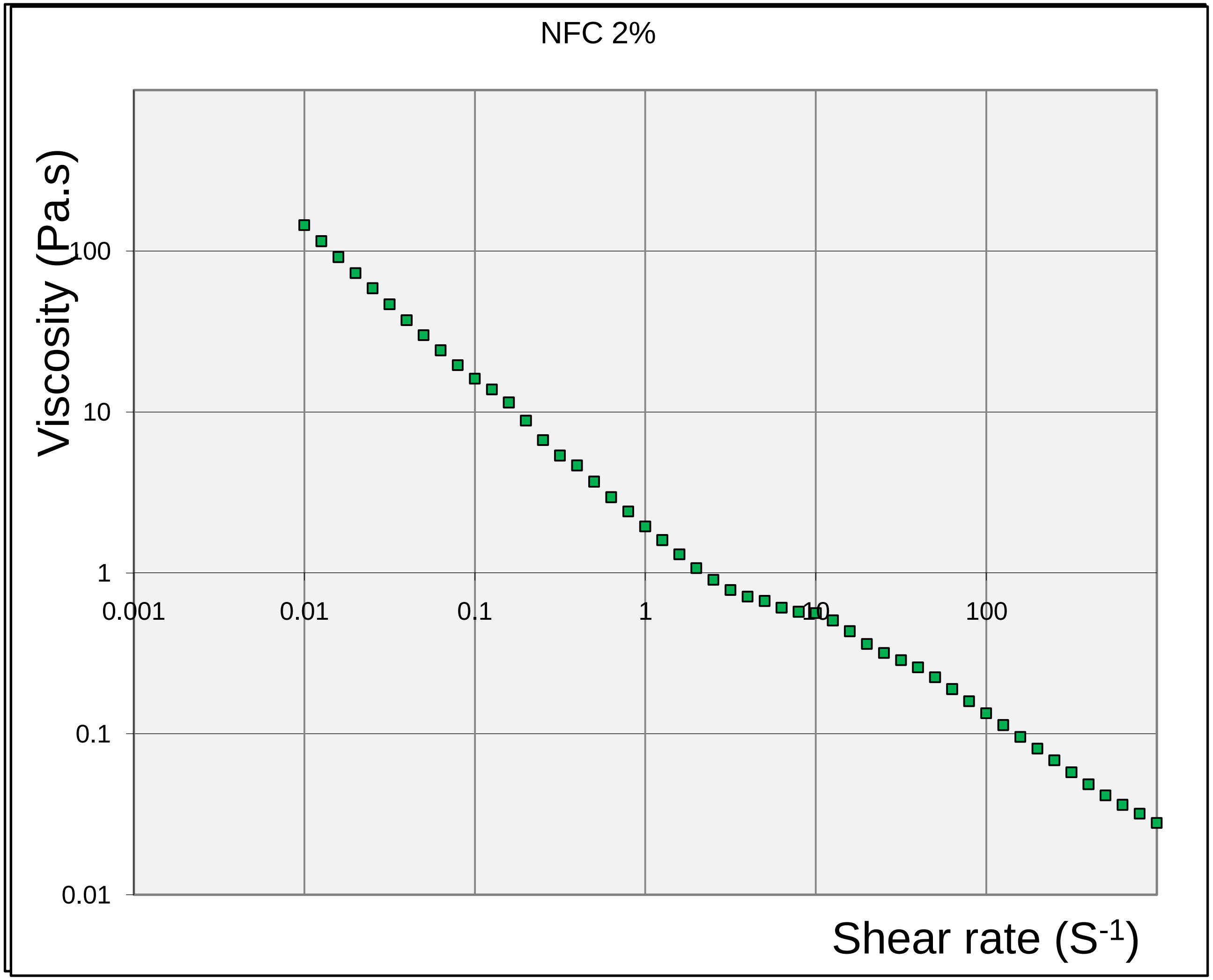


Rheometer AR 2000



Rheology

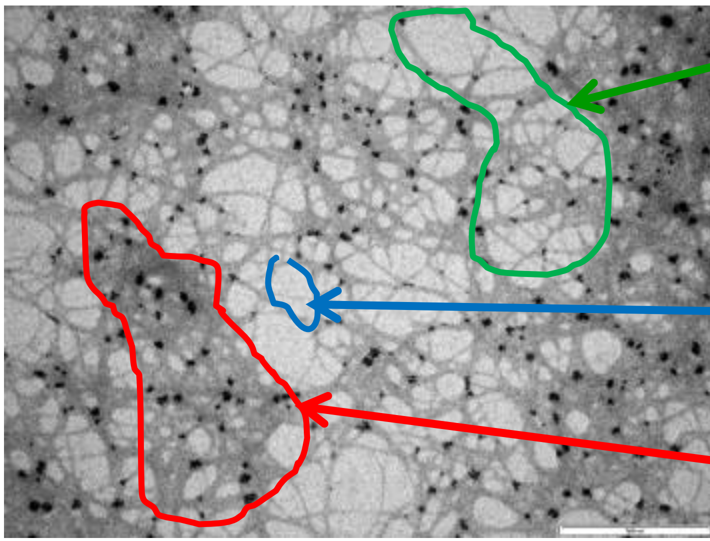
Rheology


NFC 2%
Viscosity (Pa.s)
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Shear rate (S-1)

Theoretical approach

This Study concern the Case of viscometric flow

NFC suspension



Elasticity G_1 -> coherence Length ε_1

Exclude volume -> δ/h

Free water

Flow

Elasticity G_2 -> coherence Length ε_2

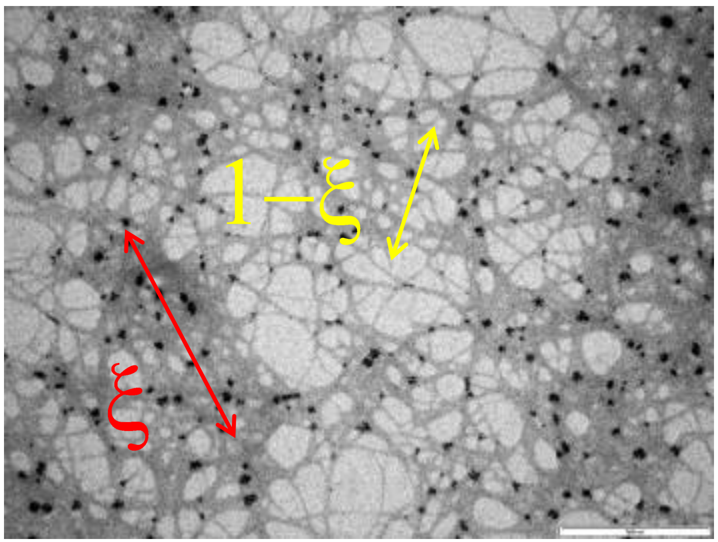
R. Masoodi, and all (2012), *Mechanical characterization of cellulose nanofiber and bio-based epoxy composite*, Materials & Design, Volume 36, April 2012, Pages 570-576

Hypothesis the gel is formed by two scale of elasticity

Theoretical approach by mean shear stress

$$\boldsymbol{\sigma}_{ij} = -\left(\frac{\delta_{ij}}{V} \int_{V-\Sigma V_0} p \; dV \right) + \mu \left(\mathbf{U}_{i,j} + \mathbf{U}_{j,i} \right) + \boldsymbol{\sigma}^{f}_{ij}$$

Exclude volume characterized by δ/h



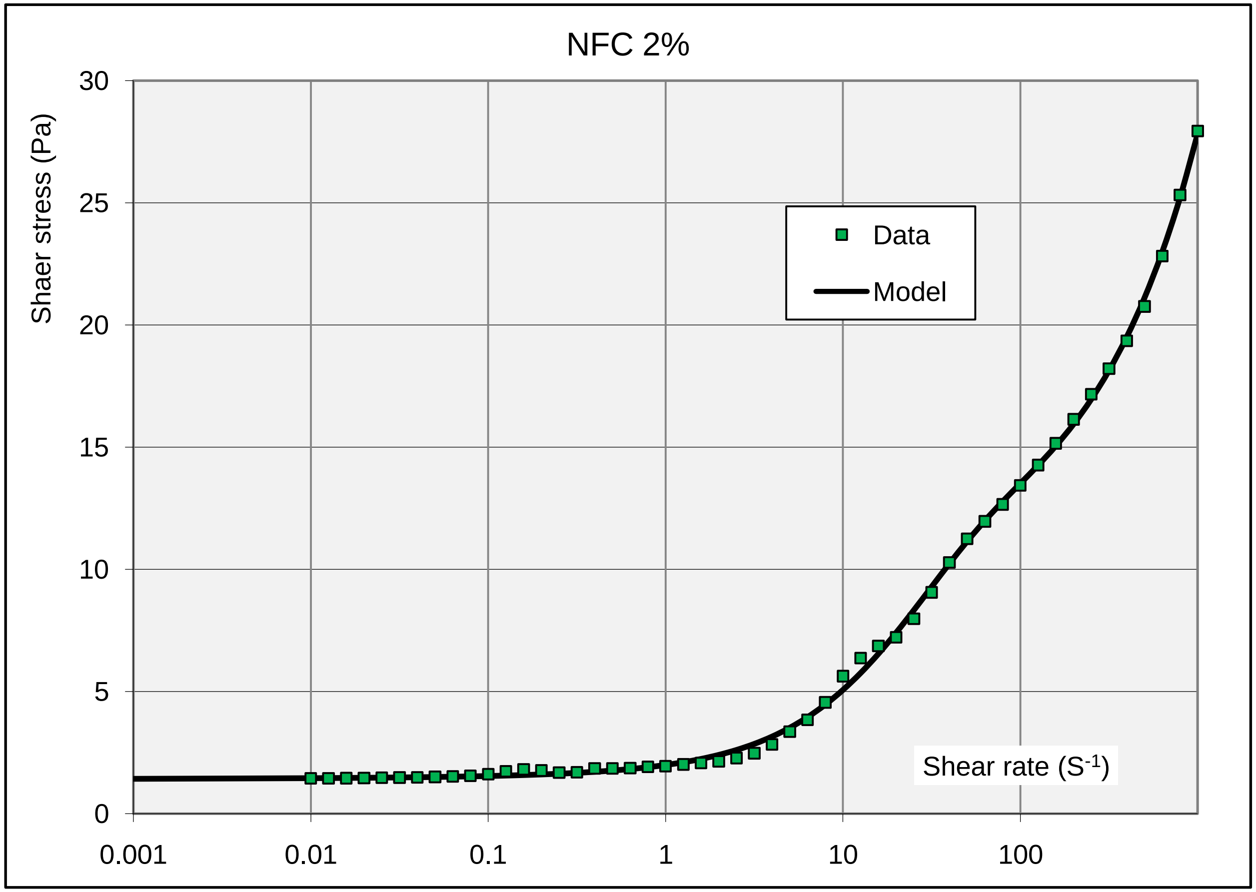
$$\boldsymbol{\sigma}^{f}_{ij} = \frac{1}{V} \sum_{1}^{n} \left(\int_{A_0-A1} \boldsymbol{\sigma}_{ik} x_j n_k \; dA + \int_{A_1} \boldsymbol{\sigma}'_{ik} x_j n_k \; dA \right)$$

$$\sigma^{f}_{ij} = \left[\sigma^{f\,1}_{ij} \left(1-\xi \right) + \sigma^{f\,2}_{ij} \xi \right]$$

G1 G2

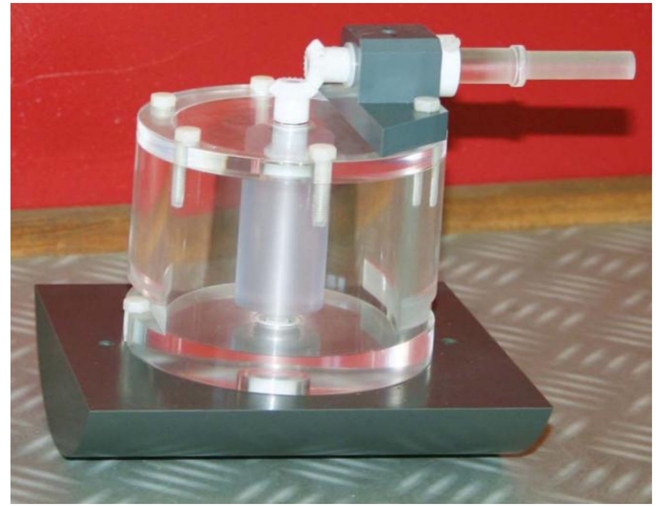
Double elasticity of network

Results



G_1(Pa)	1,412
μ (Pa.s)	0,010
G_2(Pa)	8,091
γ_C (S^{-1})	22,506

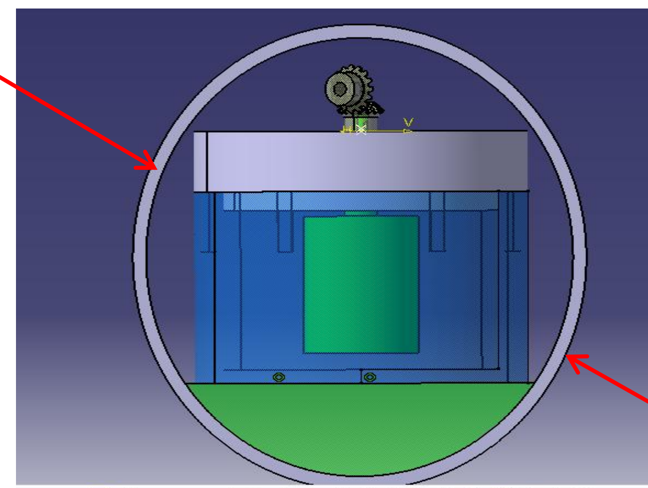
Test section



R_{int}=2cm

R_{ext}=5cm

Φ=20cm



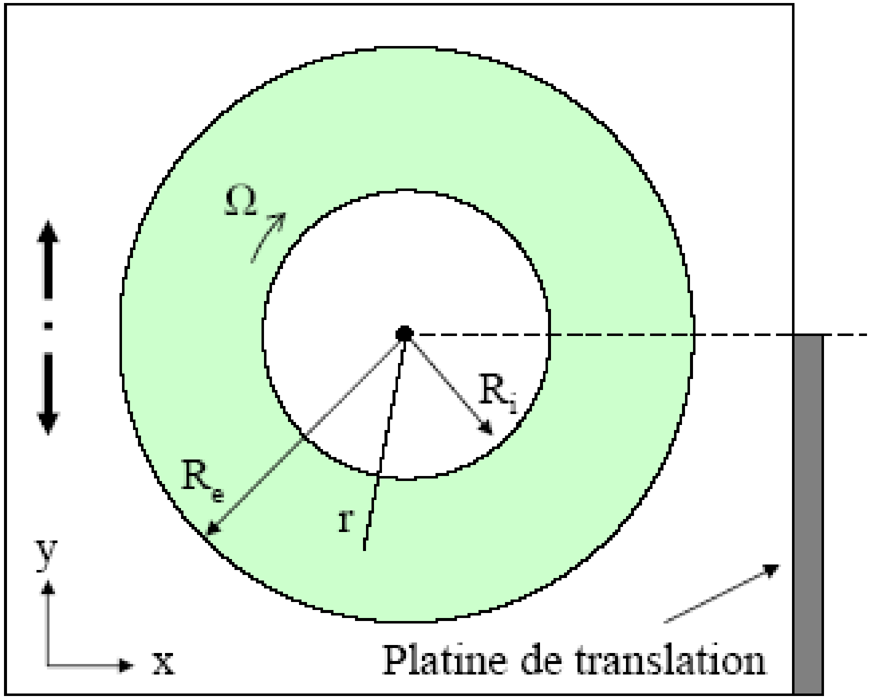
Biospec 24/40 Bruker
100MHz

Test section

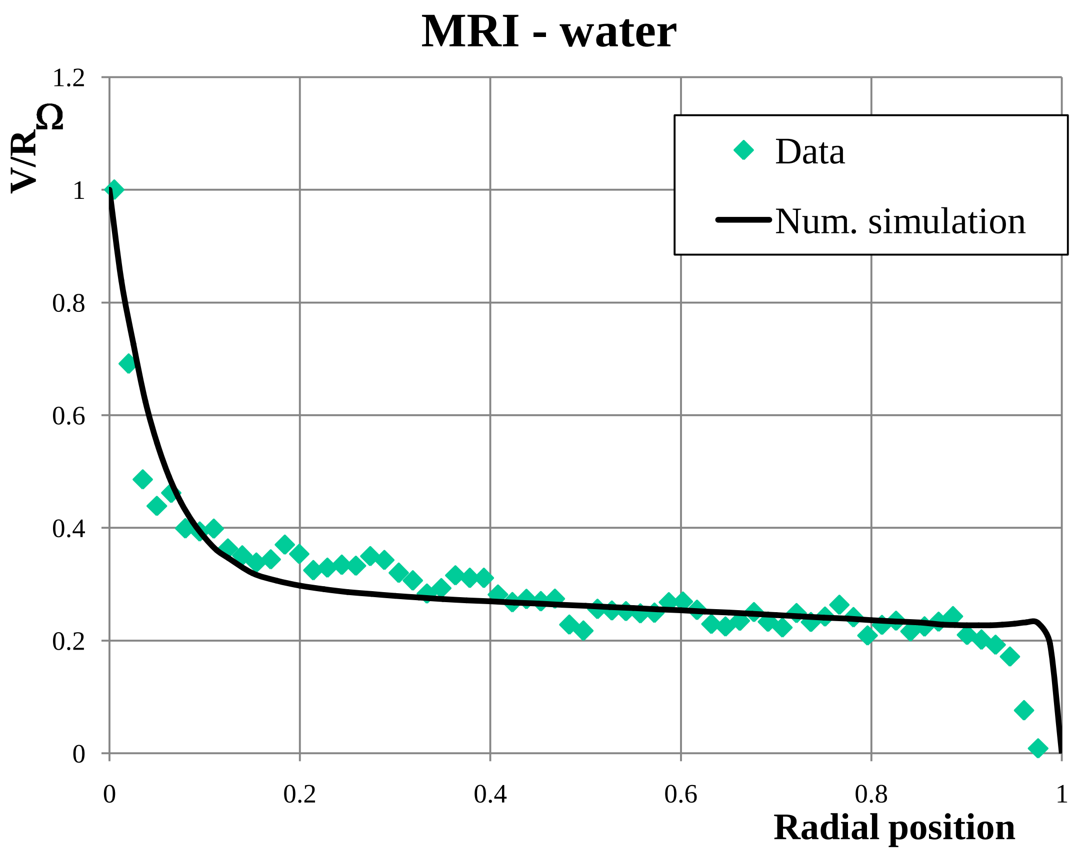
- Couette flow at large gap)
- IRM investigation (Velocity profile measurement)

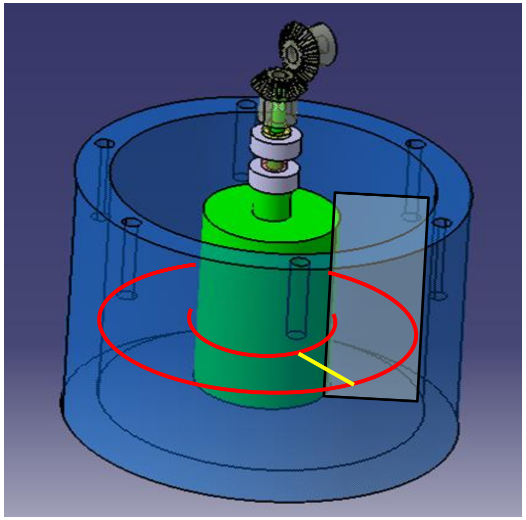
Advantage of Couette device

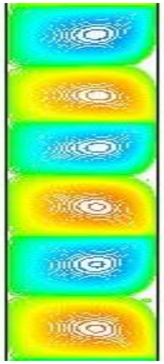
$$\sigma = \frac{C^{te}}{r^2}$$



Preliminary results – water test



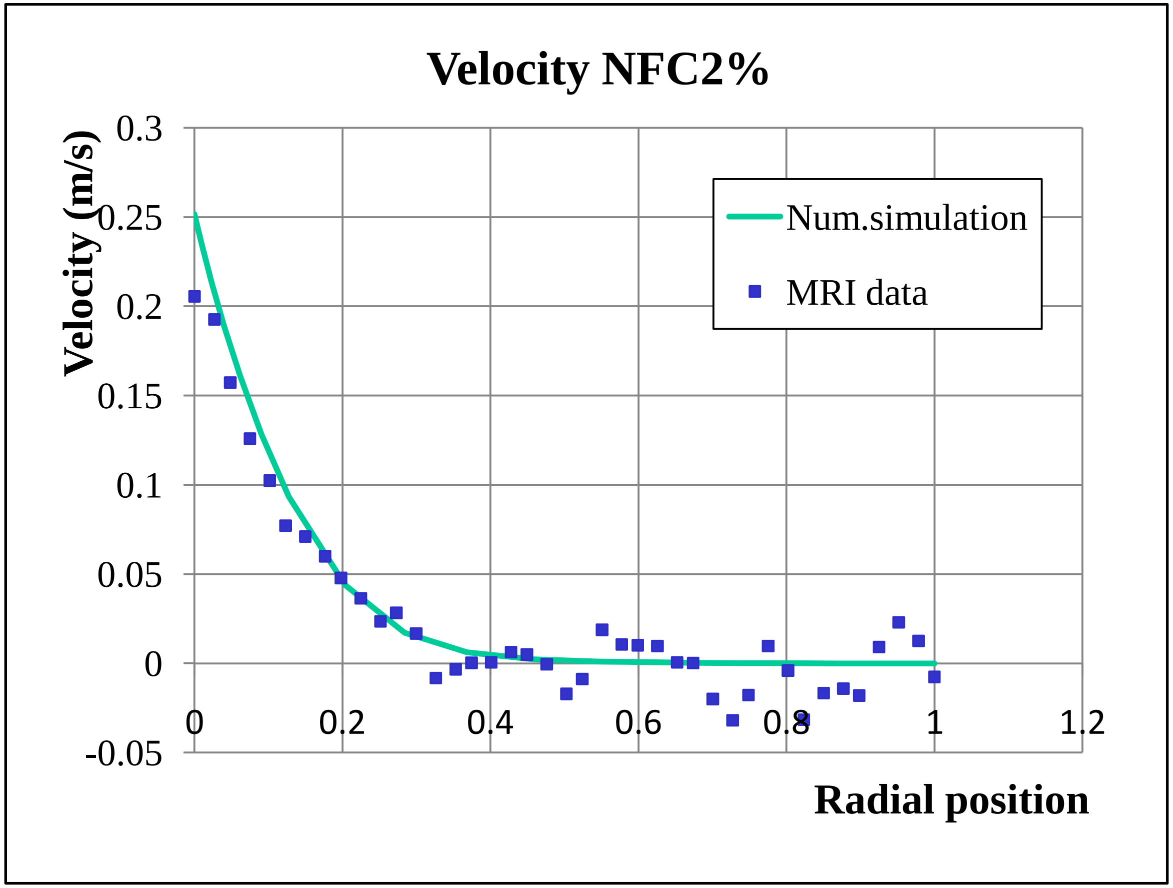




Ω (rpm)	126
μ (Pa.s)	0,001
Ta_c	42
Ta	9700

Taylor Vortices

Preliminary results



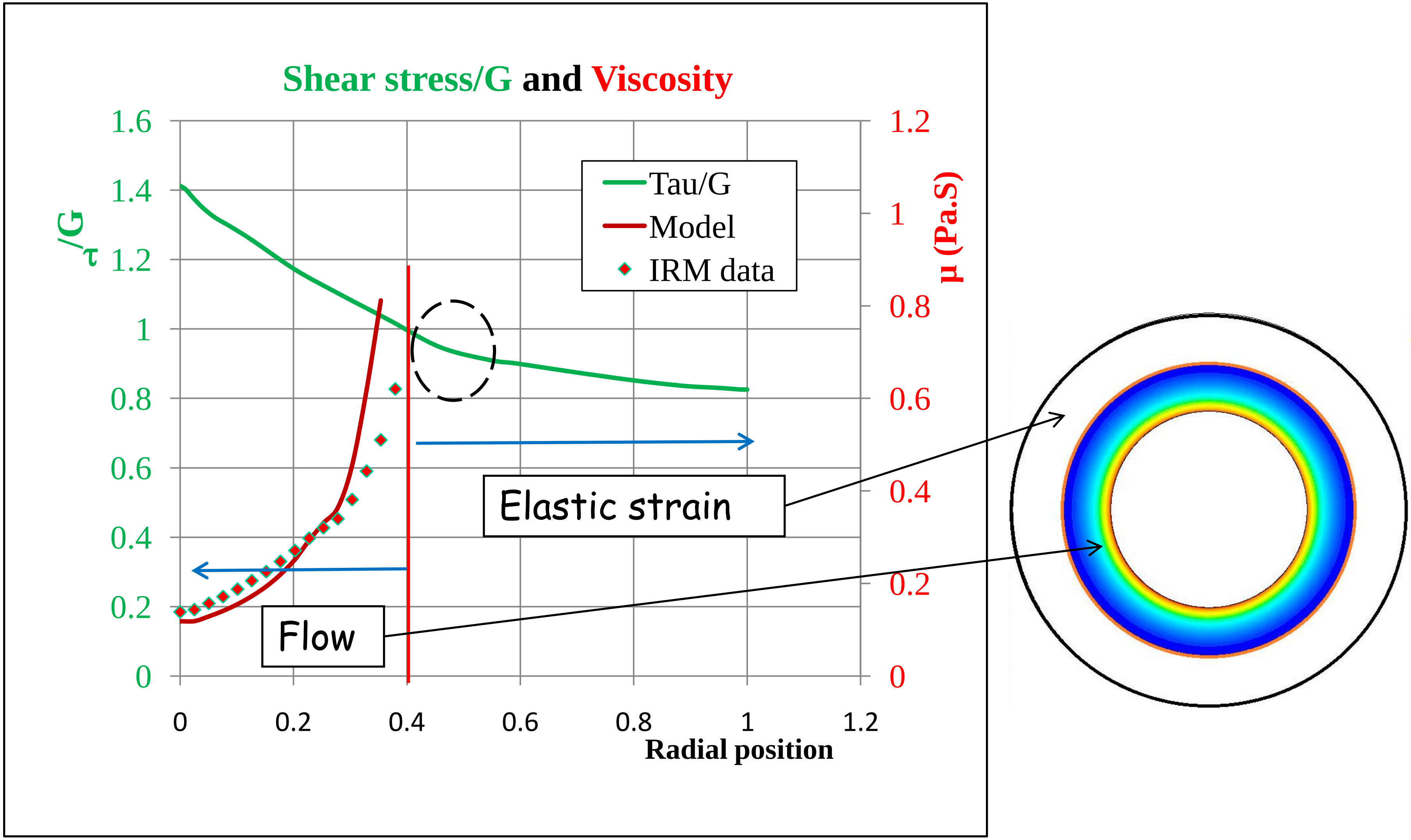
$$\sigma = \frac{C^{te}}{r^2}$$

$$r^2\tau(r) = C^{te} = R_1^2\tau_w$$

$$\mu\gamma(r) = \frac{R_1^2\tau_w}{r^2}$$

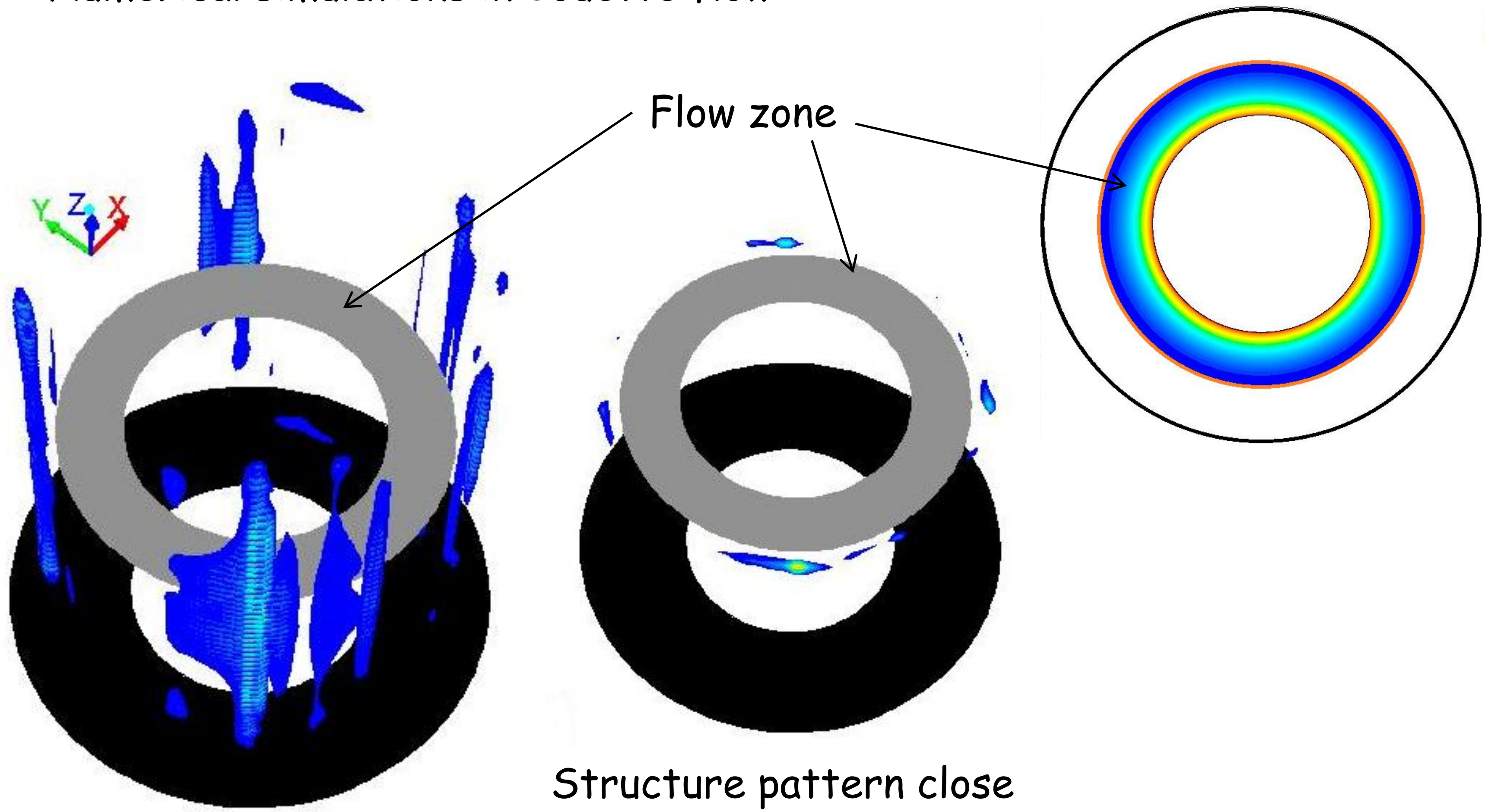
Ω (rpm)	126
τ_w(Pa)	9.31
μ_w (Pa.s)	0,12
μ_{fw} (Pa.s)	0.037
Ta_c	42
Ta	20

Preliminary results



Preliminary results

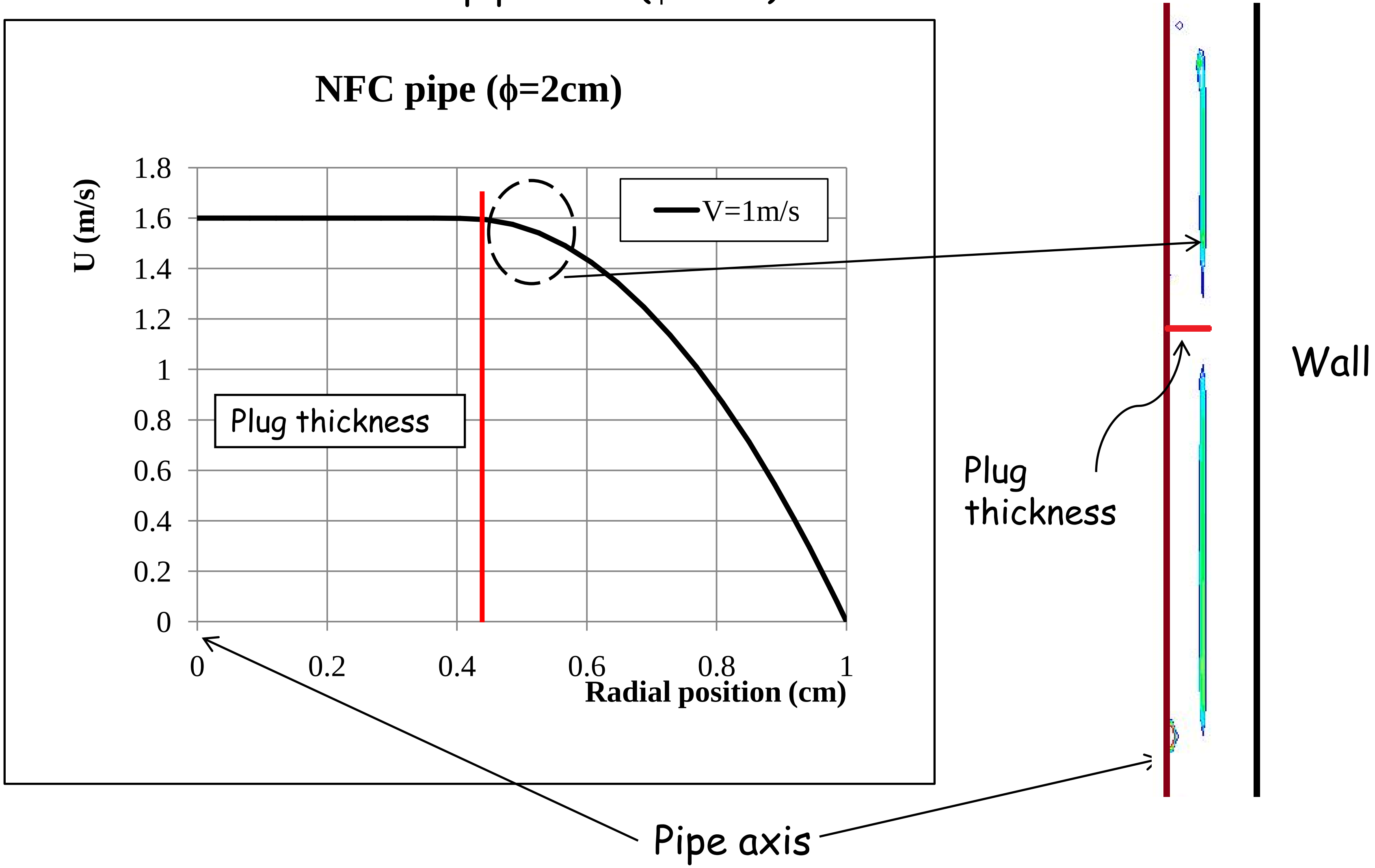
Numerical simulations in Couette flow



Structure pattern close
null velocity zone

Preliminary results

Numerical simulations in pipe flow (ϕ=2cm)



Principal conclusions and future

- Rheology of NFC -> heterogeneity
  Consider the confinement
  Rheology measurement under vibrations

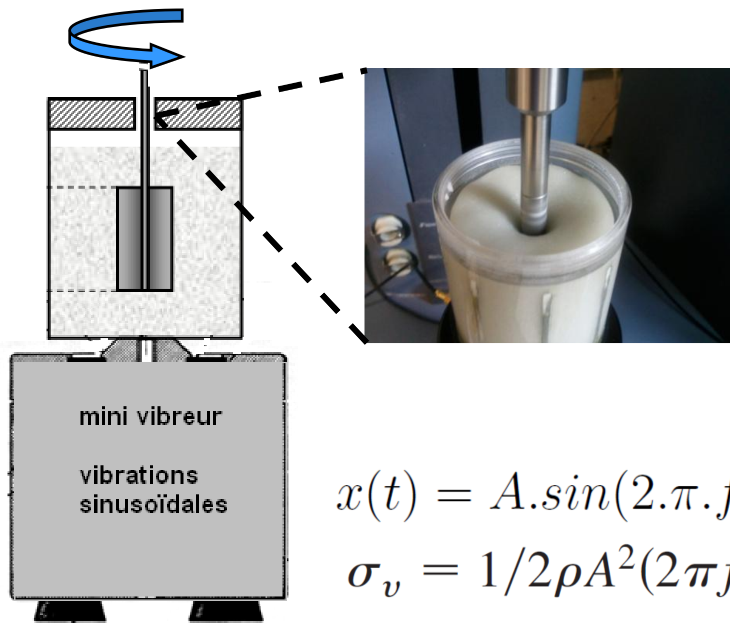
- IRM preliminary investigations -> promising results
  Investigation of different concentrations
  To check $G \approx C^{9/4}$

- Theoretical approach -> good predictions
  Time dependant

Future

Suspensions of vibrated fibers (S. Kiesgen, S. Skali Lami, P. Marchal)

<u>Rheological measurements with a vibration device</u>



$$x(t) = A.sin(2.\pi.f.t)$$

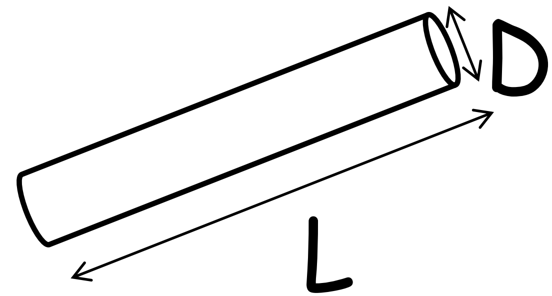
$$\sigma_v = 1/2\rho A^2(2\pi f)^2$$

m: masse dof the sample

A: Amplitude of vibrations (A~[10µm 1mm])

f: frequency of vibrations (f~[10Hz 500Hz]

Energy injected By vibrations per unit of volume



R= L/D (Large Aspect ratio)

$L \approx 1mm$
$D \approx 10\ \mu m$

$$\Delta\rho g D^2 L \gg \frac{kT}{L}$$

→ Non-Brownian particles

$$\underbrace{\sigma_v L^2}_{\approx 10^{-5}} \geq \underbrace{\Delta\rho g D^2 L}_{\approx 10^{-9}}$$

Effect of mechanical vibrations on the rheology ????

THANK YOU FOR YOUR ATTENTION