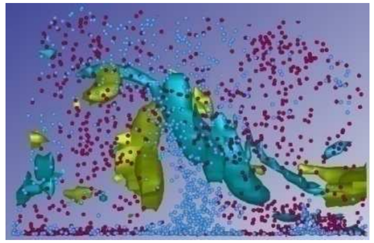
Università degli Studi di Udine

C.I.F.I.- Centro Interdipartimentale di Fluidodinamica e Idraulica



Drag reduction by bio-polymer additives in industrial size turbulent pipe flow

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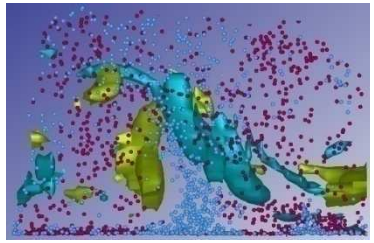
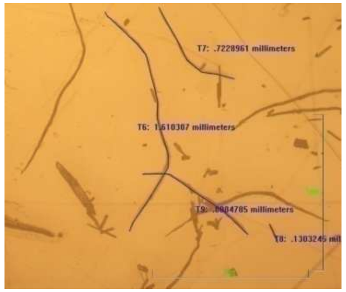
6th Joint MC/WG Meeting - Udine, October 23th 2013

Introduction



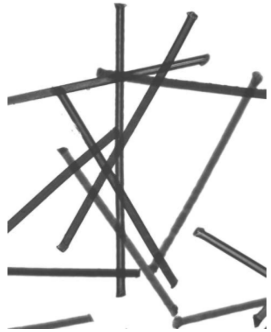


Wood fibres

FIBRES IN INDUSTRIAL FLOWS

Fibres from the process

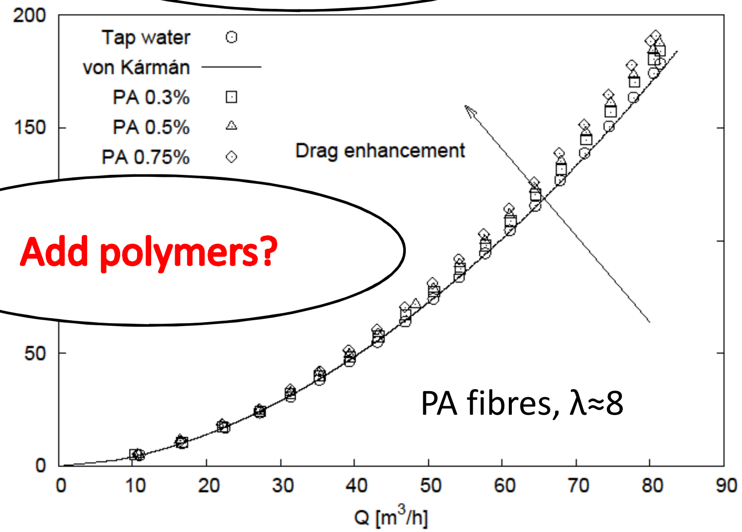
Fibres added to obtain DR



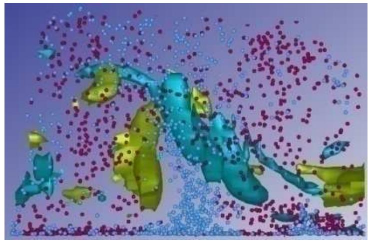
Nylon fibres, $\lambda \approx 30$

If drag enhancement is encountered, how can we reduce the effect or better obtain DR?

Add polymers?



PA fibres, $\lambda \approx 8$



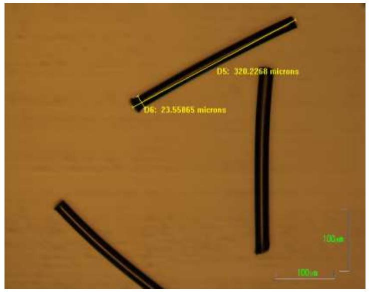
Experimental protocol

Perform experiments with polymer and fibres in pipe flows to evaluate the pressure drop.

We started with Xanthan gum bio-polymer solutions (water as solvent, 5 concentrations) and polyamide fibres suspensions (water as solvent, 3 concentrations) individually, measuring pressure drop and flow rate.

$$PA \begin{cases} 0.3\% \\ 0.5\% \\ 0.75\% \end{cases}$$

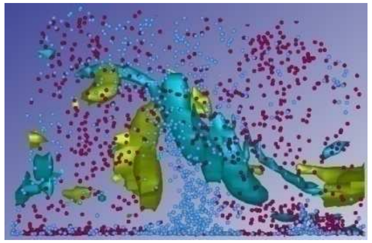
$l_{mean} \approx 250\ \mu m$
$d_{mean} \approx 30\ \mu m$
$\lambda \approx 8$

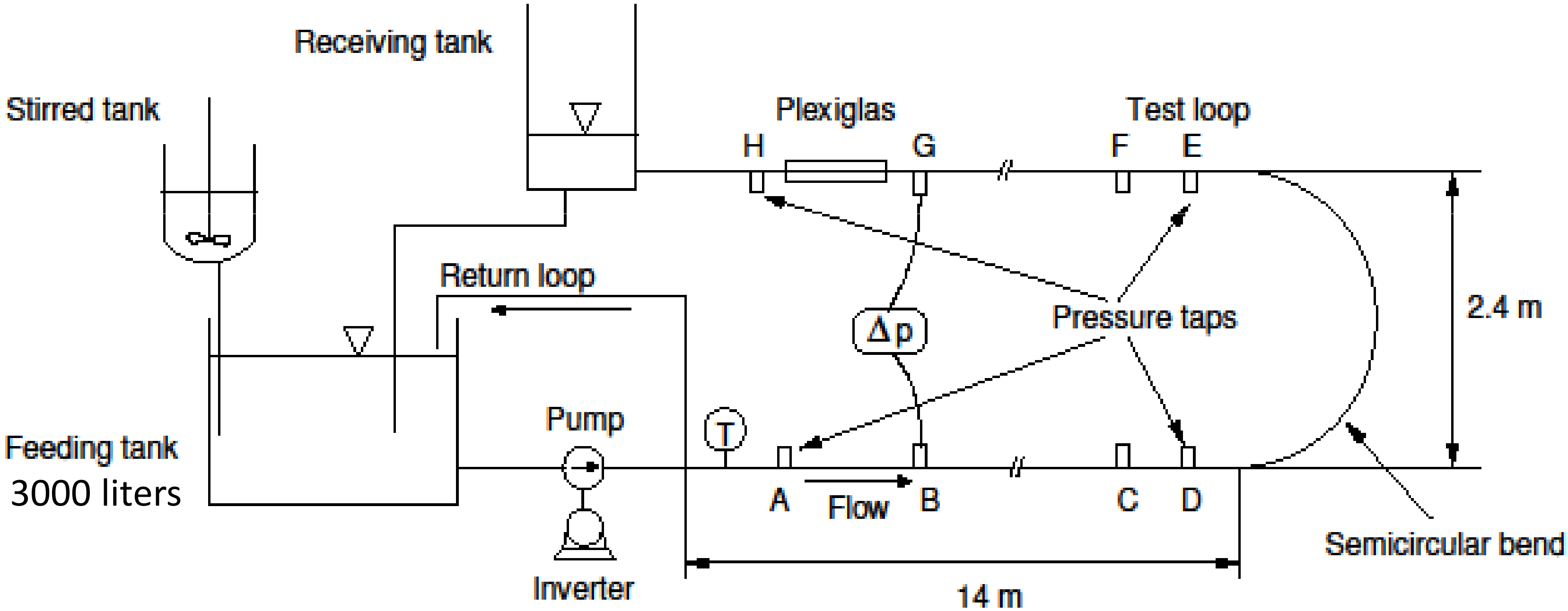


$M_w \approx 10^6$

$$XG \begin{cases} 0.2\% \\ 0.1\% \\ 0.075\% \\ 0.05\% \\ 0.01\% \end{cases}$$

Polymer DR: experimental rig

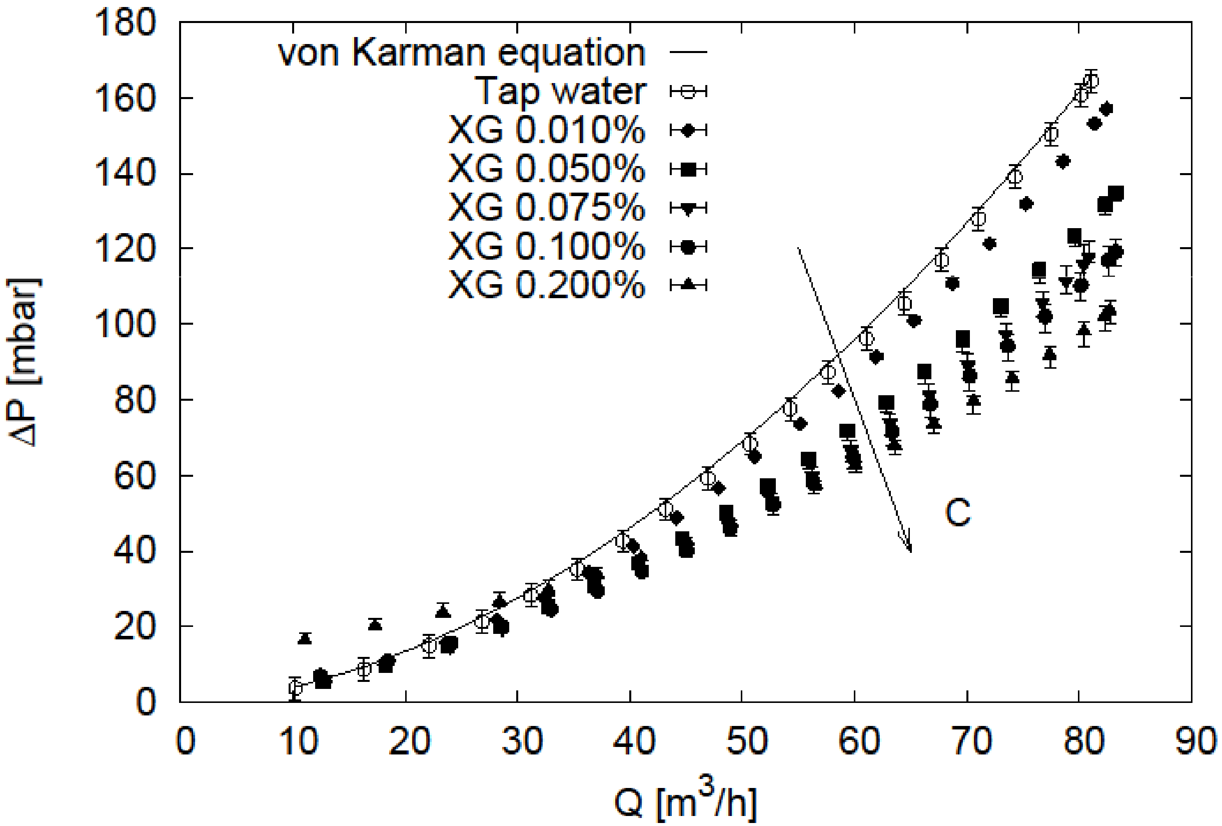


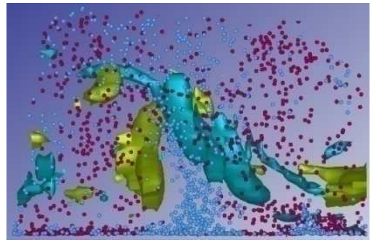


Q≈10÷81 m^3/h
(3÷23 l/s)

Re≈4.8e4 ÷ 3.6e5
(pure solvent)

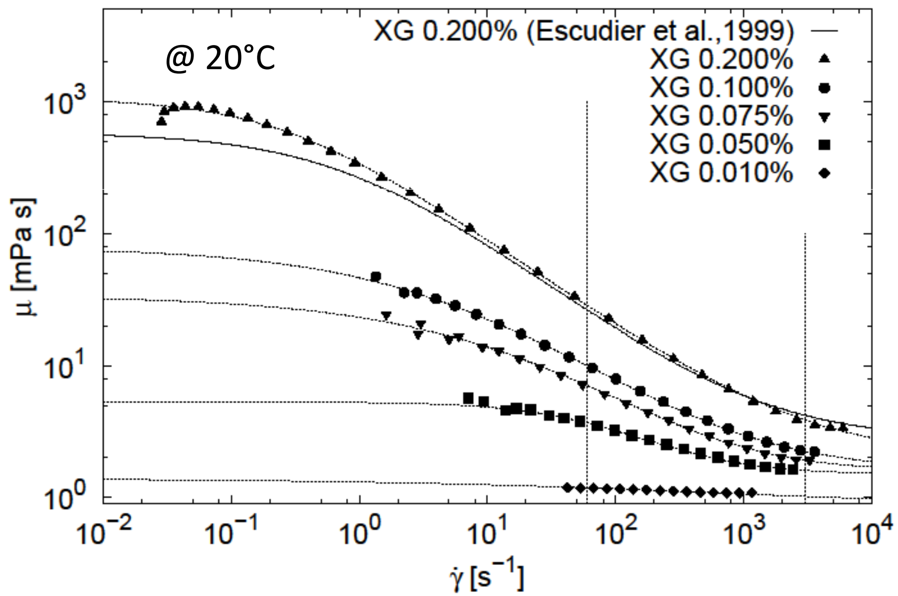
Drag reduction results: Δp-Q





Fluid characterization

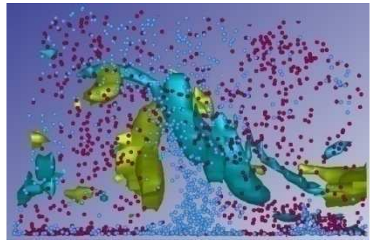
Polymer solution behaves as non-Newtonian; to calculate the Reynolds number, the viscosity of the solution has to be evaluated

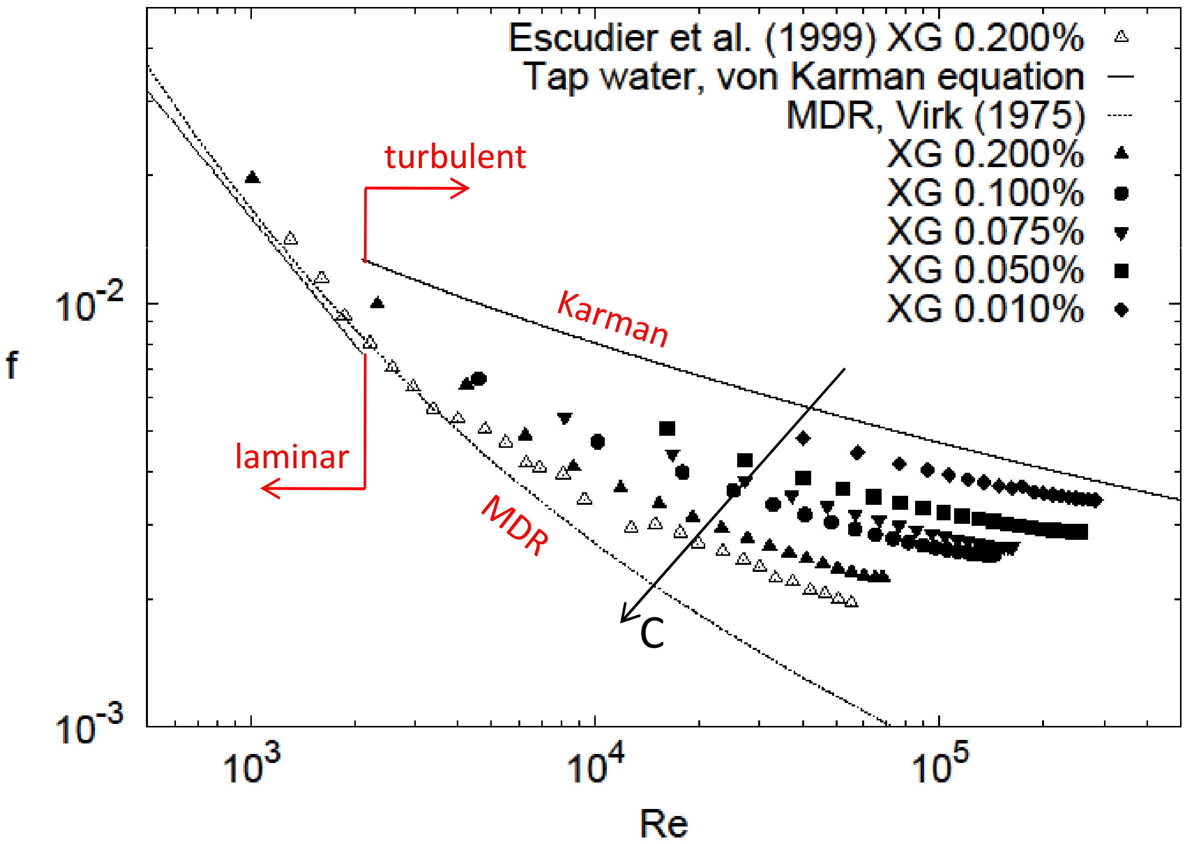


$$5\ concentrations \begin{cases} 0.2\% \\ 0.1\% \\ 0.075\% \\ 0.05\% \\ 0.01\% \end{cases}$$

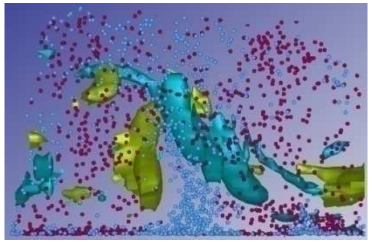
Rheological characterization performed @15, 20 and 25°C (Haake stress-controlled rheometer)

Drag reduction results: friction factor

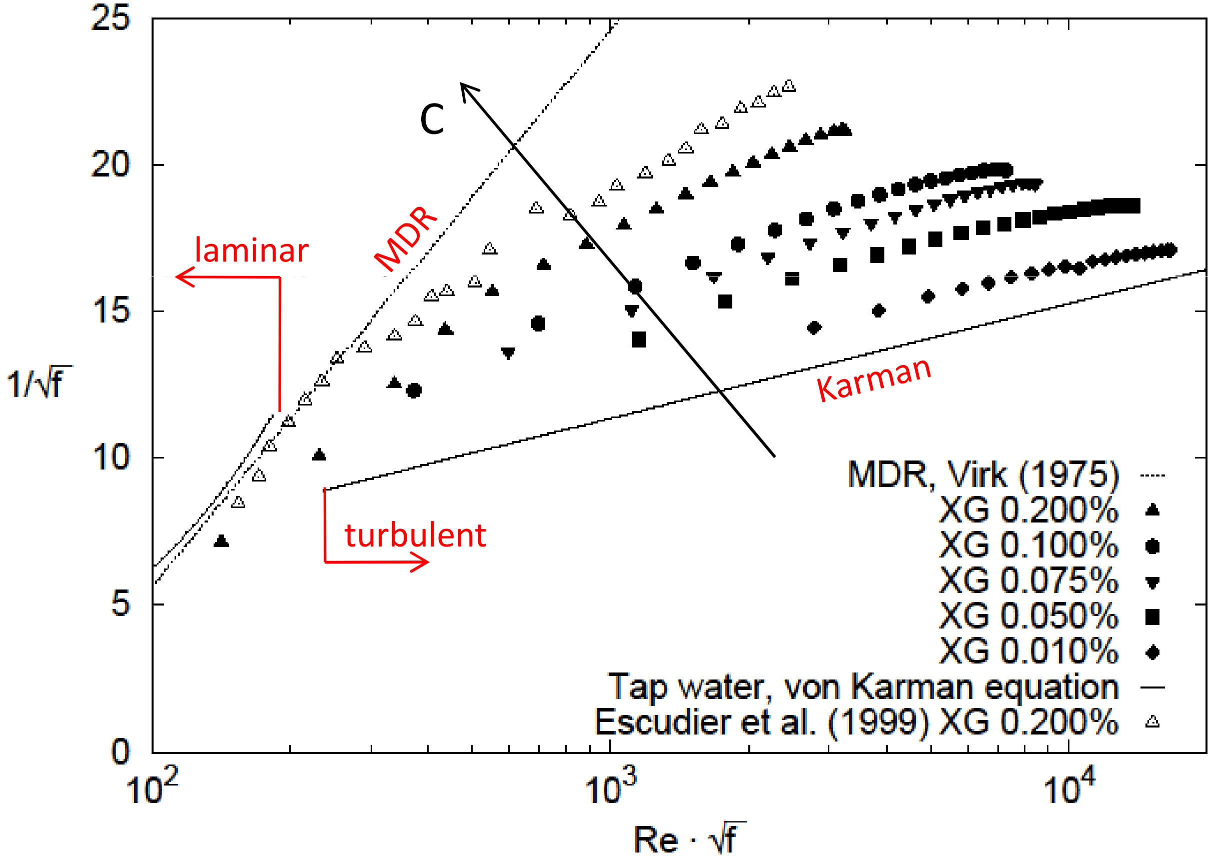




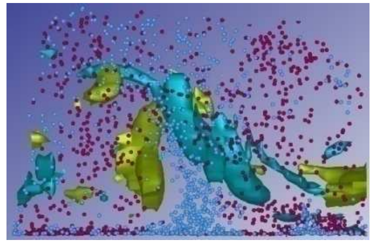
Drag reduction results: friction factor

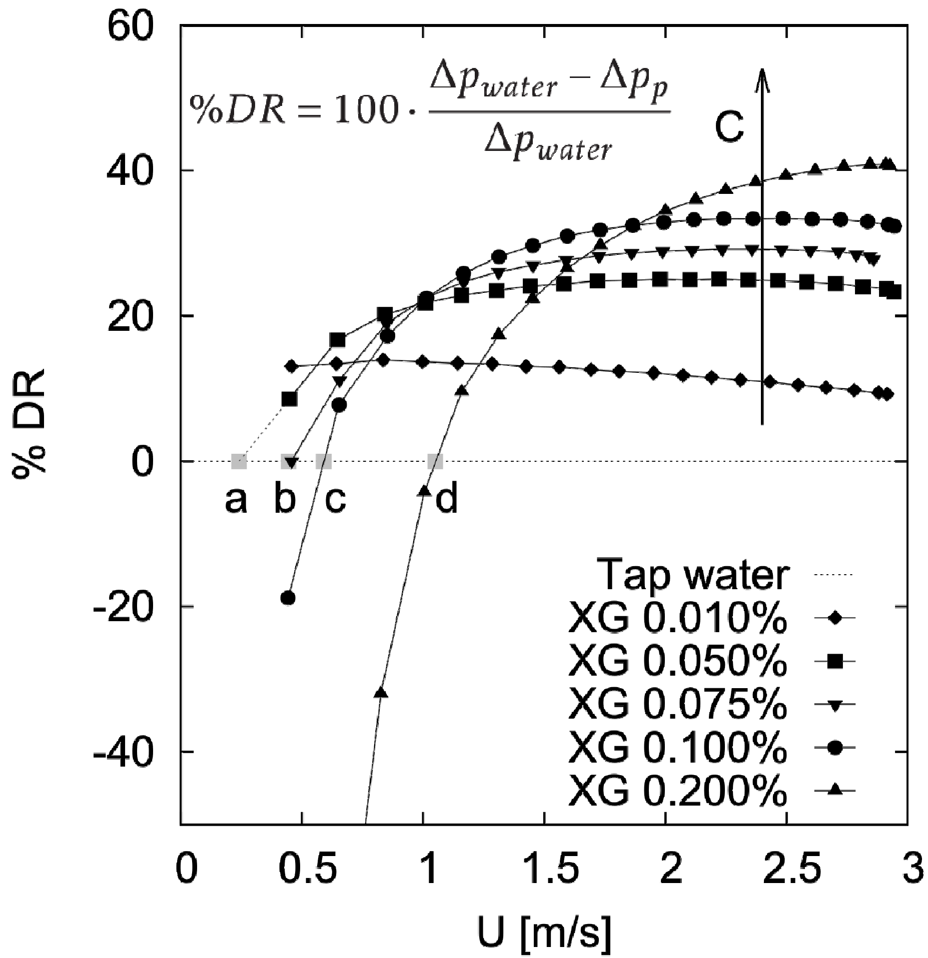


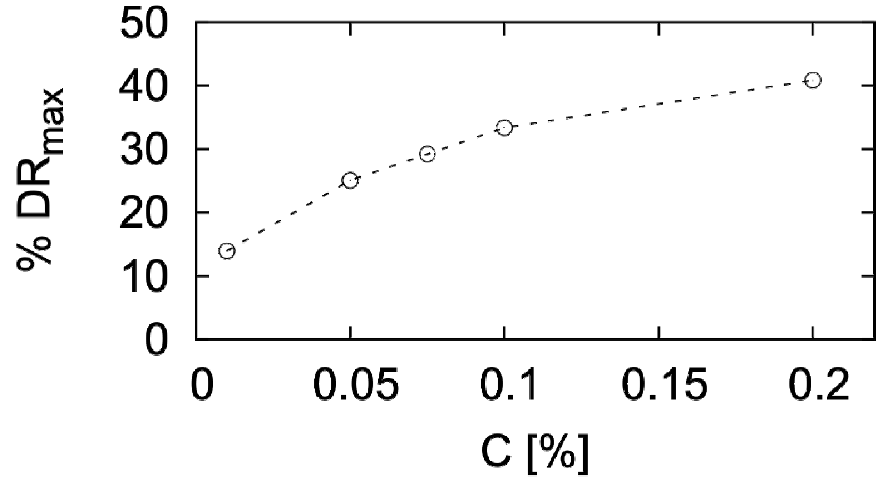
Max deviation of f 26% @ same Re_τ

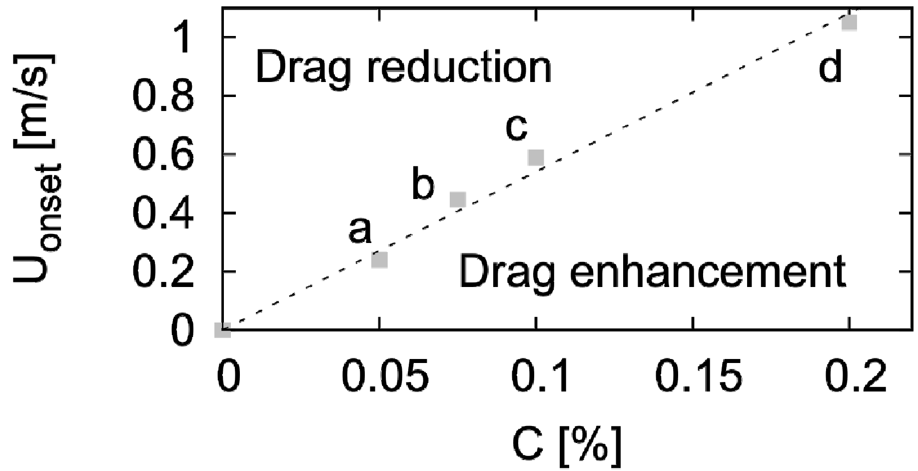


Drag reduction results: %DR

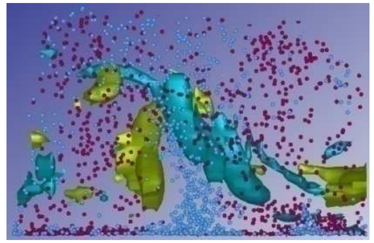


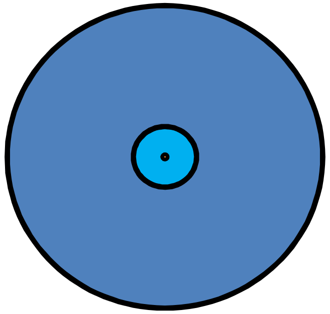






Scale & shape effects

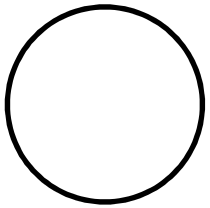




Laboratory scale $D \approx O(10^{1})$mm $\neq$ Industrial scale $D \approx O(10^{2 \div 3})$mm

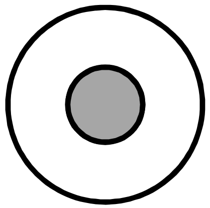
Are laboratory scale results reliable for DR prediction in industrial scale pipelines?

Does the shape influence the DR effect?

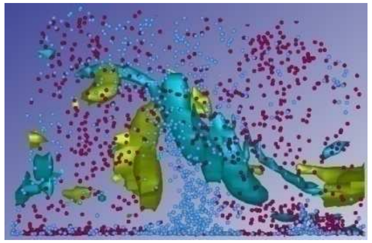


Pipe flow

Channel flow



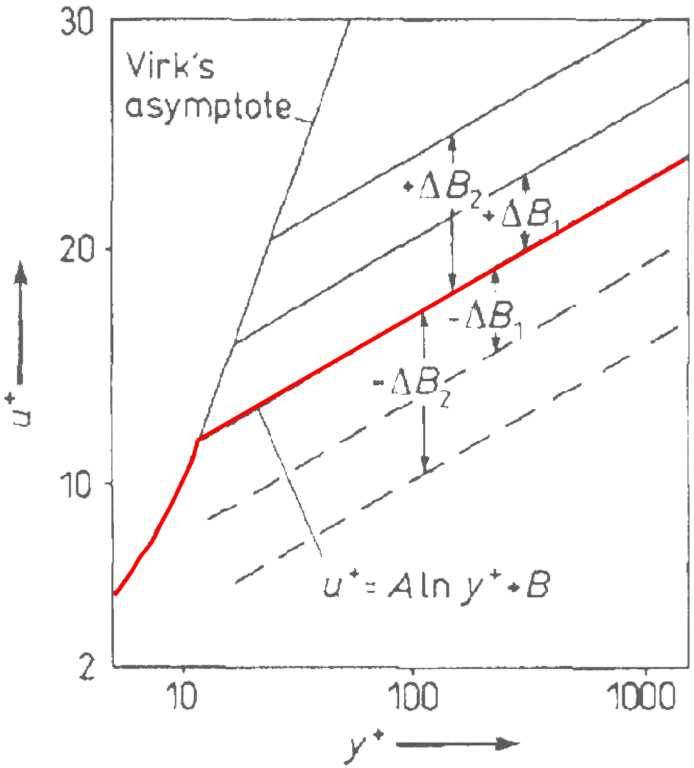
Annular flow



Scaling-up: introduction

From small scale to large scale

1. Similarity of the velocity profiles
2. Negative roughness concept

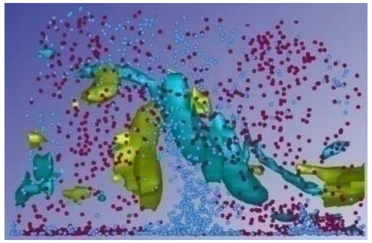


Hoyt, Exp. in Fluids, 1991

$$\Delta B = f\left(u_\tau, l, \nu\right)$$

Sellin & Ollis, Ind. Eng. Chem. Prod., 1983

Scaling-up: practical procedure



Polymer “stretching” or deformation close to the wall must be the same in large and small scales. Scaling procedure is based on two equations:

$$\left(Re\sqrt{f}\right)_2 = \left(Re\sqrt{f}\right)_1 \left(\frac{D_2}{D_1}\right) \longleftrightarrow u_\tau = const$$

x coordinate

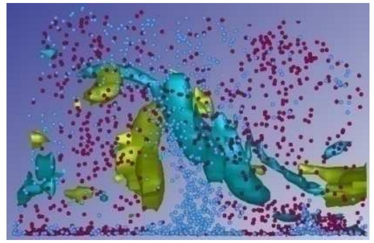
$$\left(\frac{1}{\sqrt{f}}\right)_1 = 1.7 \ln\left[\frac{\left(Re\sqrt{f}\right)_1}{4.67} + N\right] + 2.88$$

y coordinate

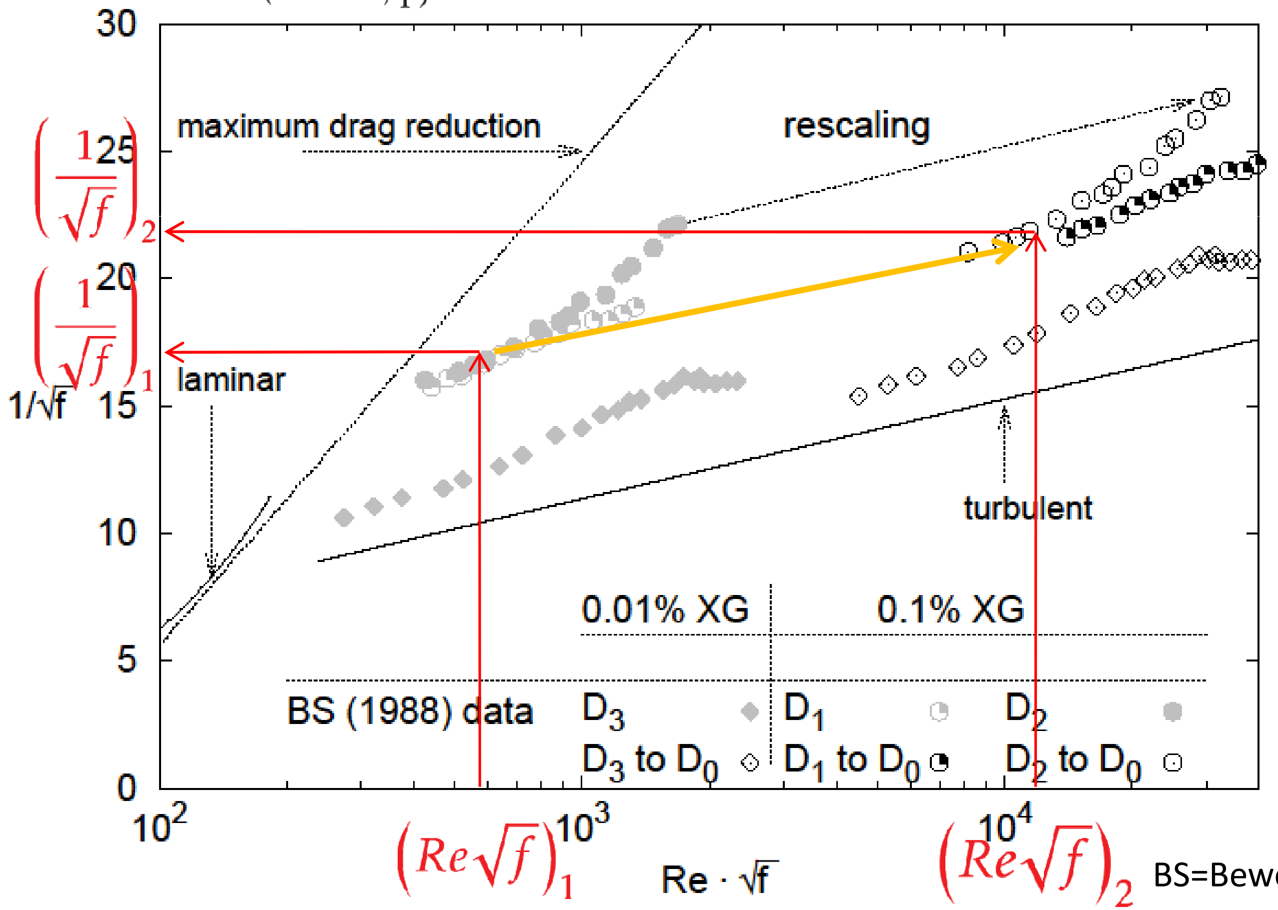
$$N = \frac{D}{k} \quad \text{negative roughness parameter}$$

Hoyt & Sellin, Exp. In Fluids, 1993

Scaling-up: practical procedure

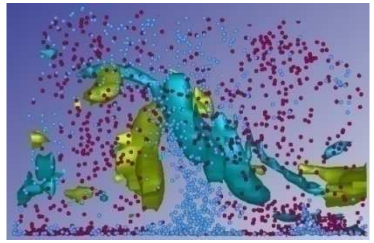


Knowing: $\left.\begin{matrix}\left(\frac{1}{\sqrt{f}}\right)_1 \\ \left(Re\sqrt{f}\right)_1\end{matrix}\right\} \Rightarrow N \Rightarrow \left(\frac{1}{\sqrt{f}}\right)_2$ given D_2



$$D_0 = 100\,mm$$
$$D_1 = 3.146\,mm$$
$$D_2 = 5.186\,mm$$
$$D_3 = 6.067\,mm$$

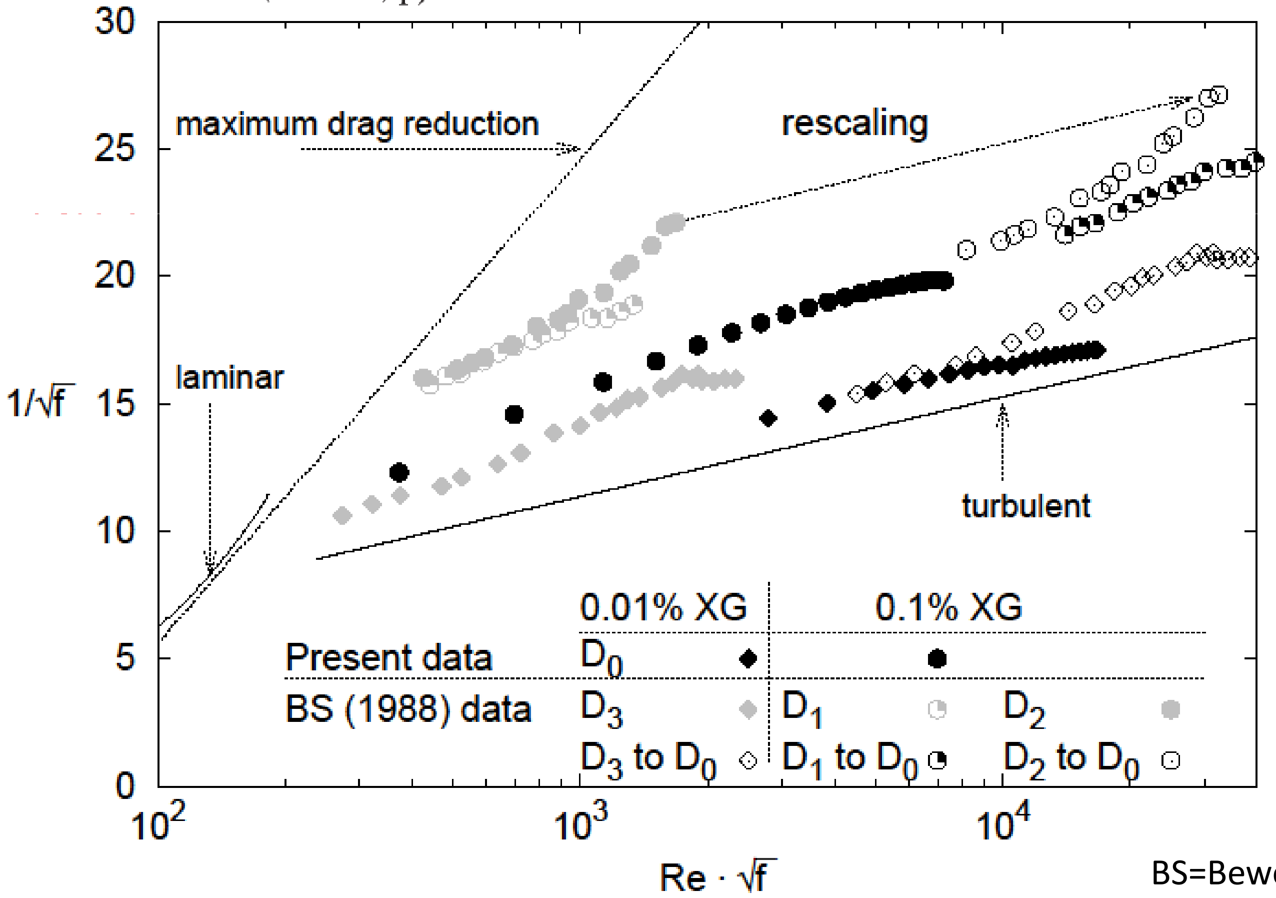
BS=Bewersdorff & Singh, Rheol. Acta, 1988



Scaling-up: practical procedure

Knowing: $\left.\begin{matrix}\left(\dfrac{1}{\sqrt{f}}\right)_1 \\ \left(Re\sqrt{f}\right)_1\end{matrix}\right\} \Rightarrow N \Rightarrow \left(\dfrac{1}{\sqrt{f}}\right)_2$ given D_2

Max deviation of f between 7÷20%



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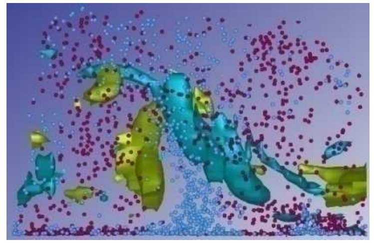
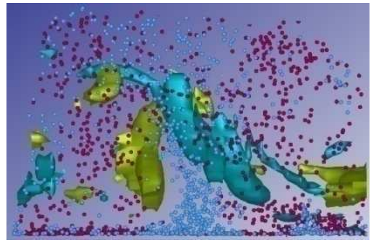
Pipe shape effect

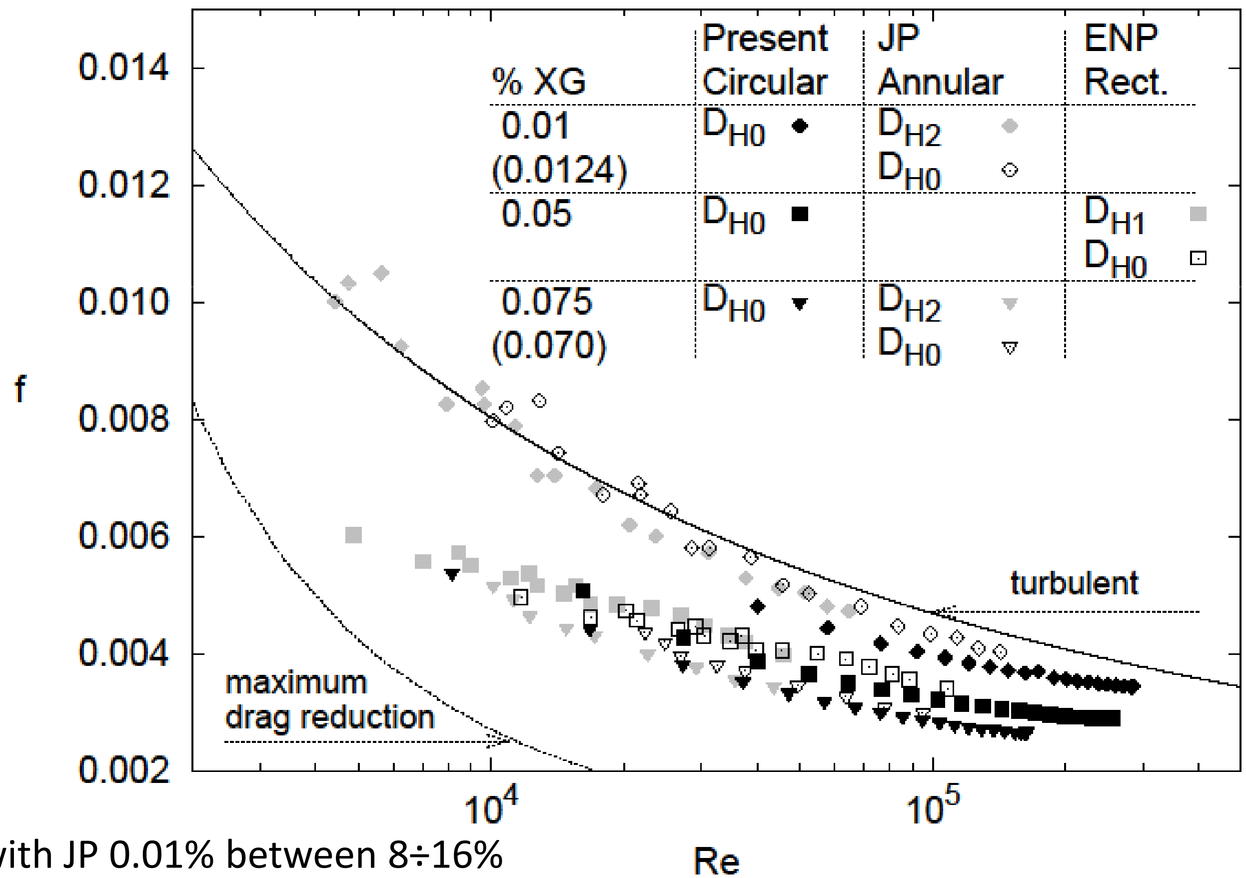


In many industrial applications, circular pipes are not the typical choice (e.g. heat exchangers); yet drag reduction may still be of interest. Pipe shape effect was therefore investigated to assess DR prediction over different pipe shapes:

- rectangular channel: D_{H1}=46 mm (Escudier et al., 2009)
- annular pipe: D_{H2}=49.2 mm (Japper-Jaafar et al., 2010)

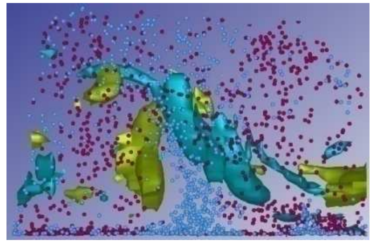


Pipe shape effect



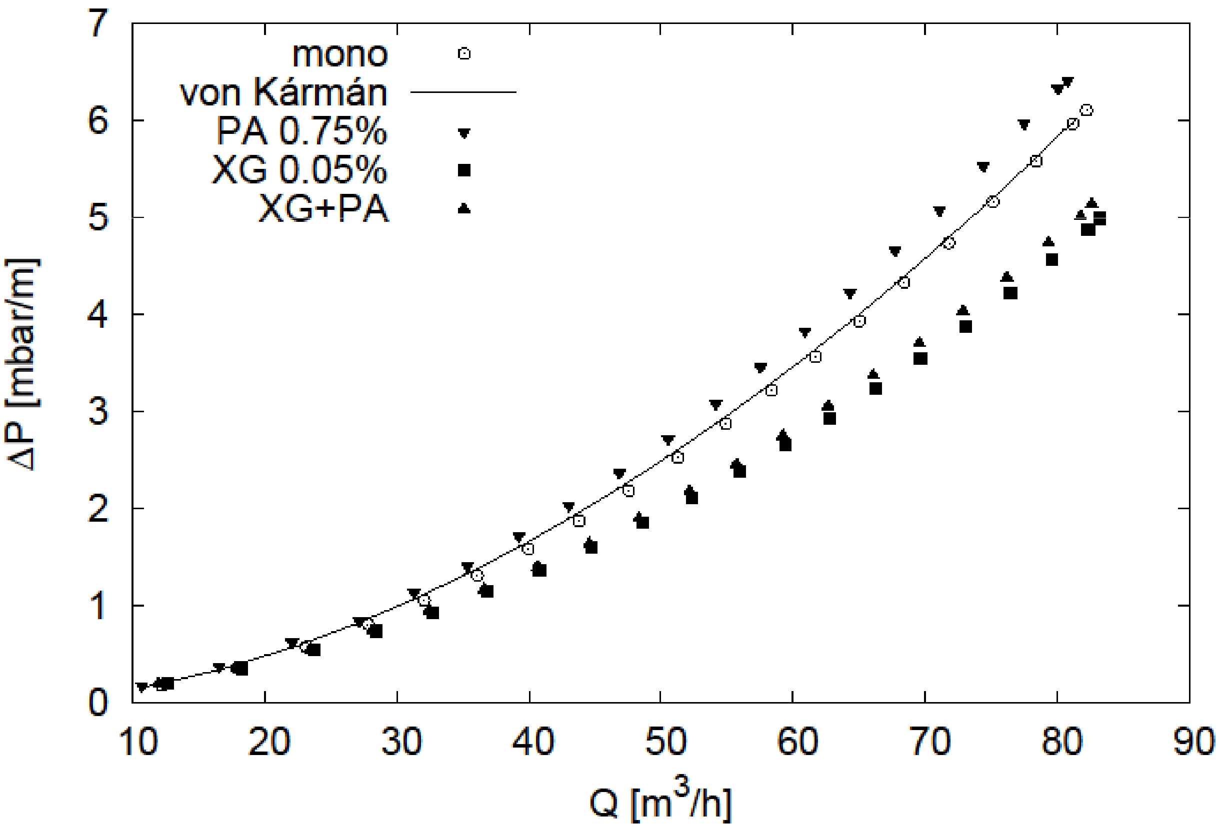
Difference with JP 0.01% between 8÷16%
Almost perfect agreement with JP 0.075%
Max difference with ENP 10%

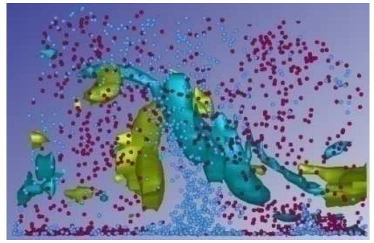
ENP=Escudier et al., JNNFM, 2009
JP=Japper-Jaafar et al., JNNFM, 2010



Work in progress

Experiments with polymer and fibres flow:





Thanks for your attention