Laboratory-Scale Pipe Rheometry: A Study of Microfibrillated Cellulose Suspension

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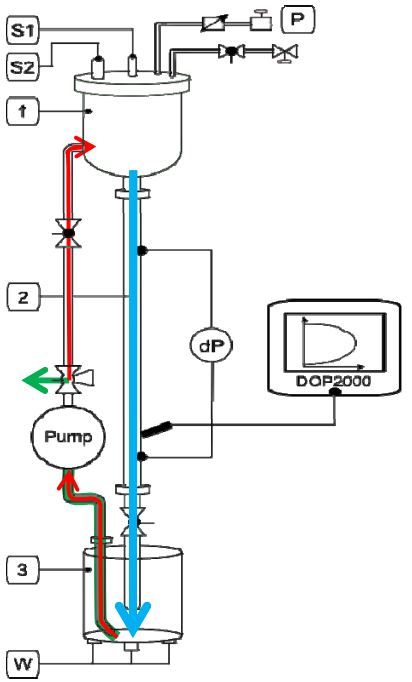
Laboratory-Scale Pipe Rheometry: A Study of Microfibrillated Cellulose Suspension

- Motivation
- Background
- Methods
- Results
- Summary

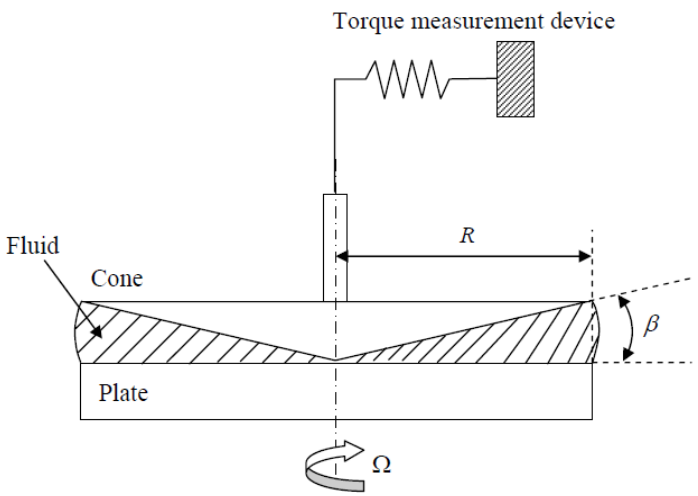
Motivation / Goal

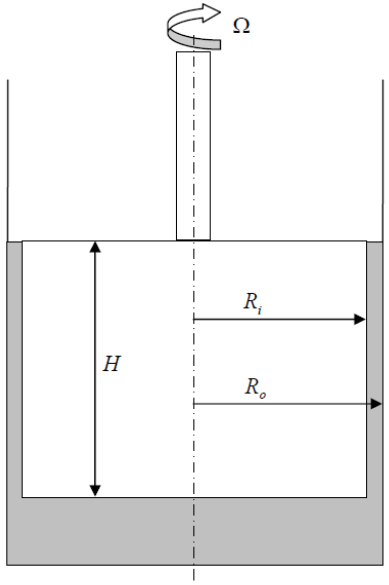
- Characterize rheological behavior of Microfibrillated cellulose suspensions
  - Rheology and composition of Microfibrillated Cellulose (MFC) is very complex
- Develop a well controlled flow environment
  - Reliable
  - Repeatable
  - Scalable
  - Low volumes
  - High dynamic and viscosity range
  - Allows flocculation

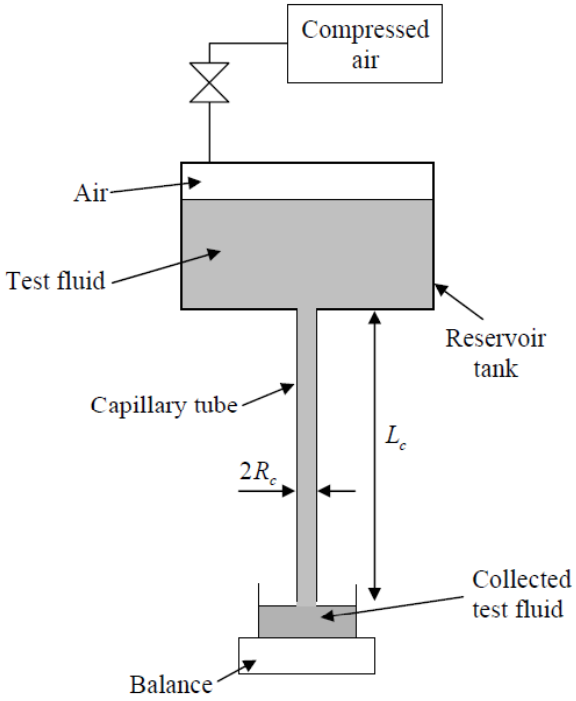


Background

- Rheology – a science of flow and deformation of matter
- Most of traditional rheometers don't work for flocculating or granular suspensions
- In traditional rheology true velocity profile of the flow is not used
  - This is compensated by using assumptions



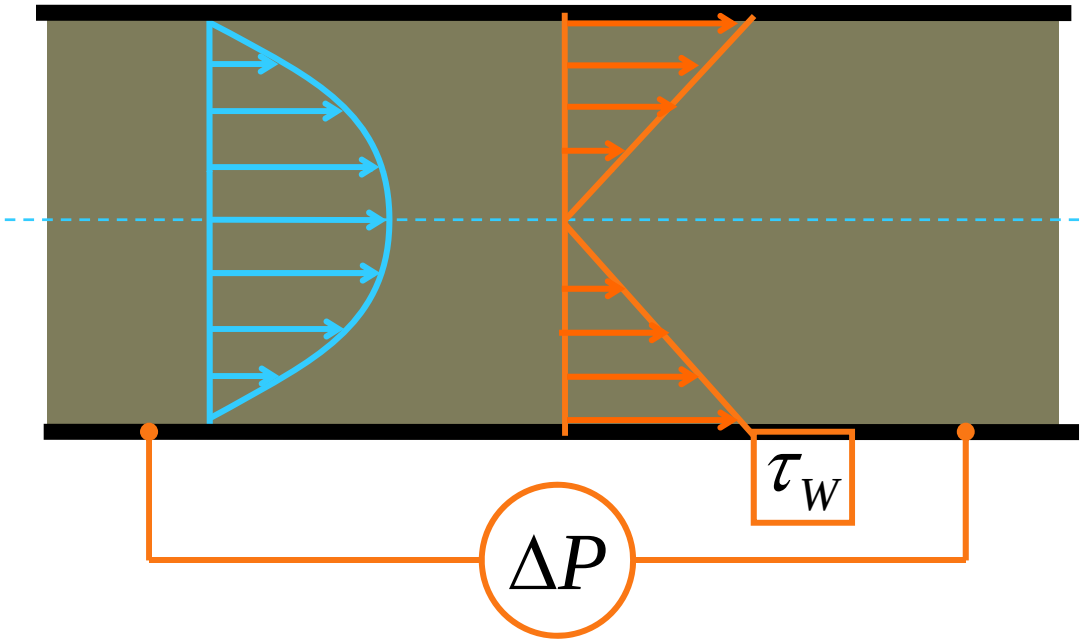


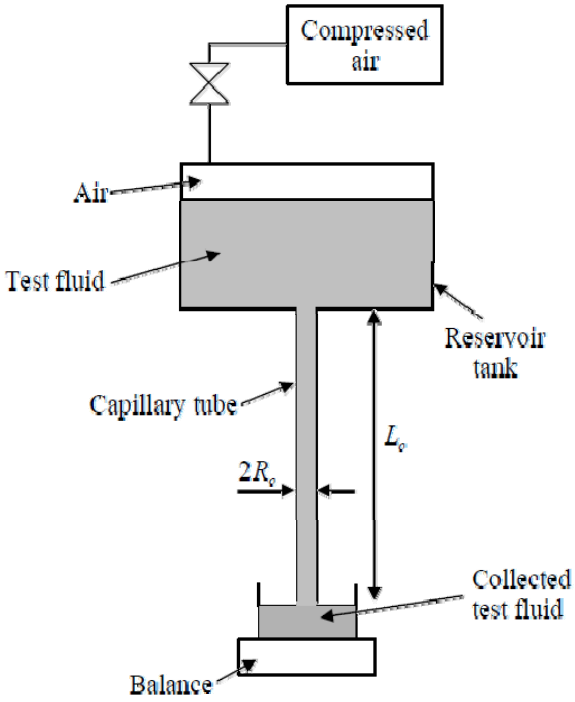


Rheology in Pipe Flow:
METHODS

Apparent viscosity

- Capillary rheometer (Pipe Flow)
  - Assuming laminar Newtonian flow





Shear rate

$$\dot{\gamma}_a = \frac{4Q}{\pi R^3}$$

Shear stress

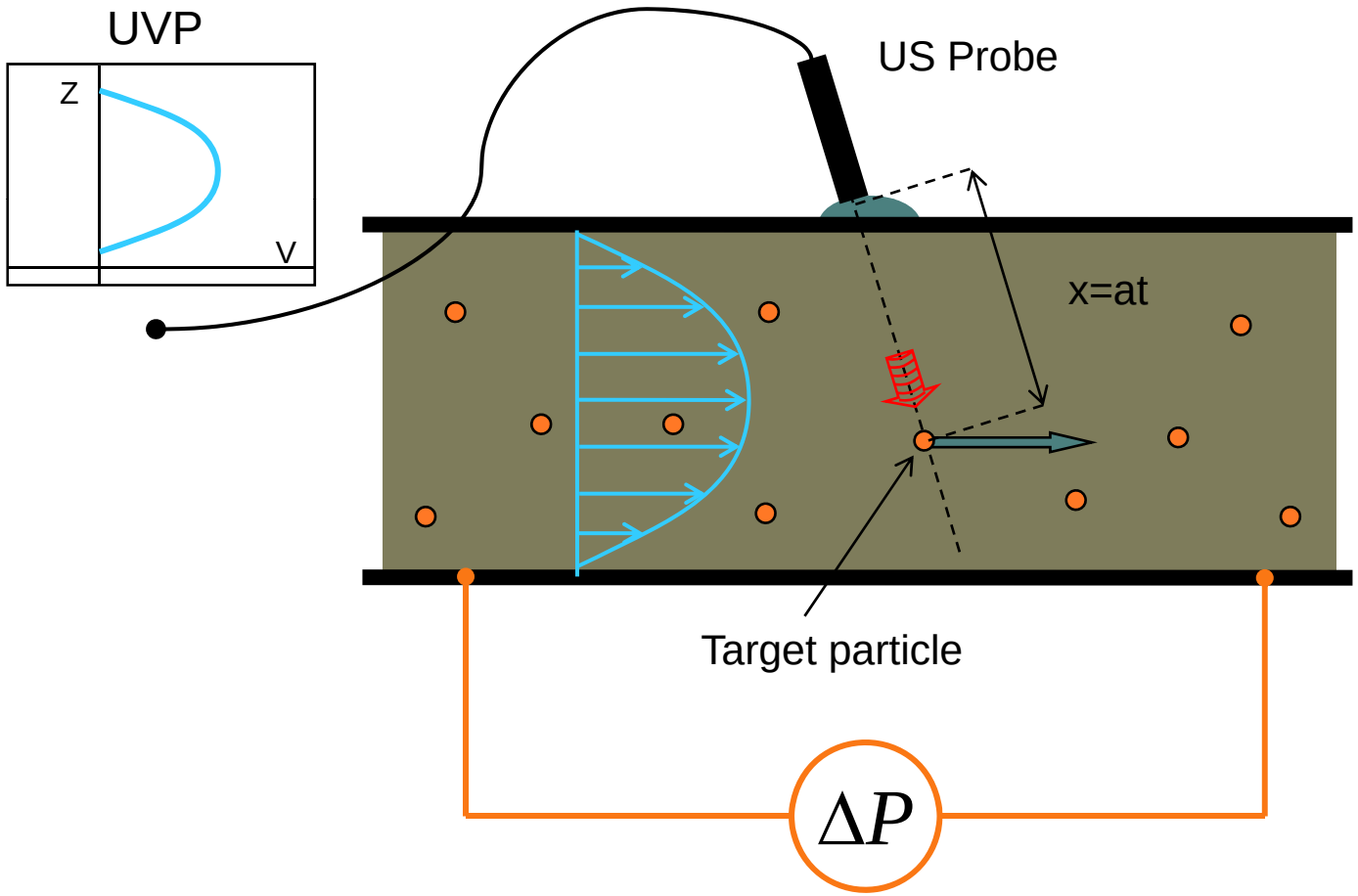
$$\tau_W = \frac{\Delta P R}{2L}$$

Apparent viscosity

$$\mu_a = \tau_W / \dot{\gamma}_a$$

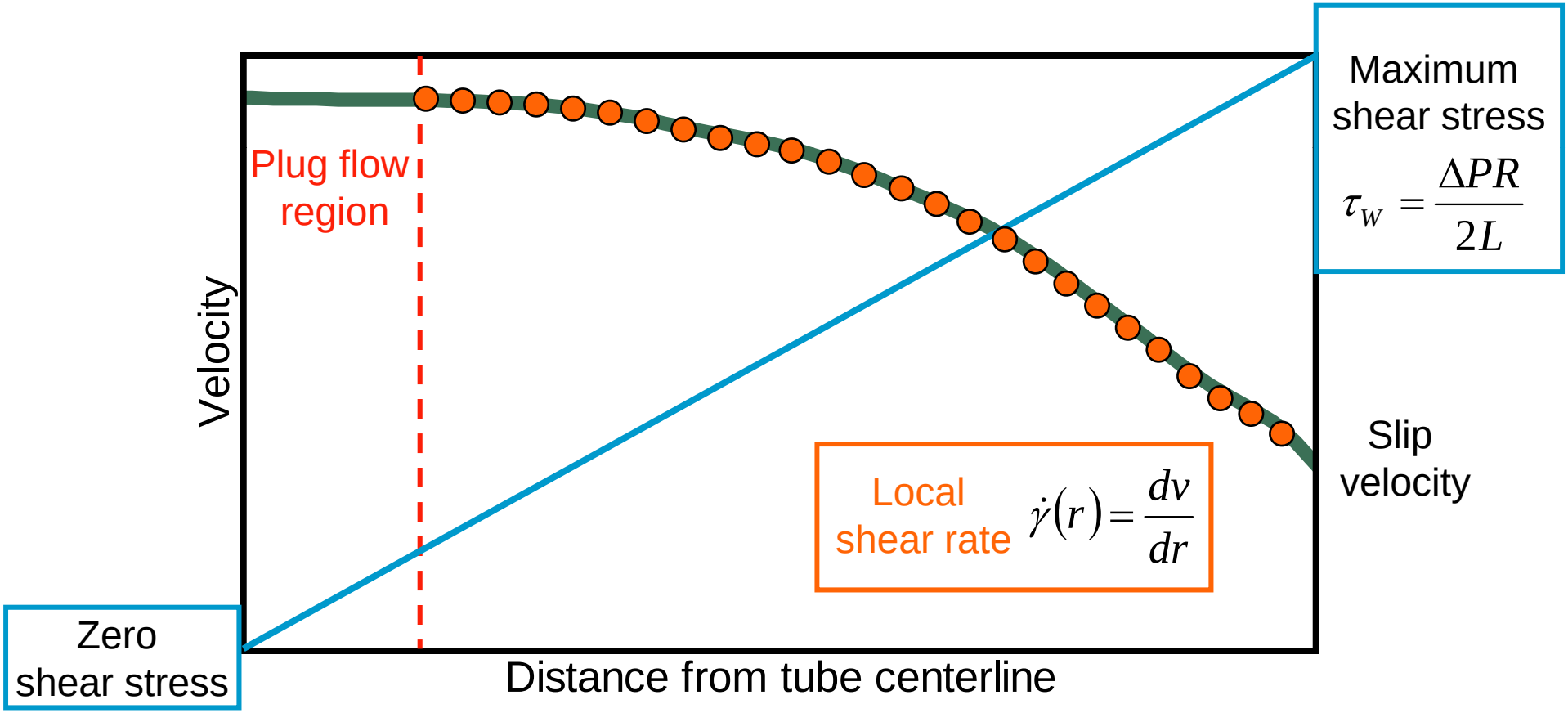
Local viscosity
UVP-PD Technique

- Ultrasound Velocity Profiling and Pressure Difference



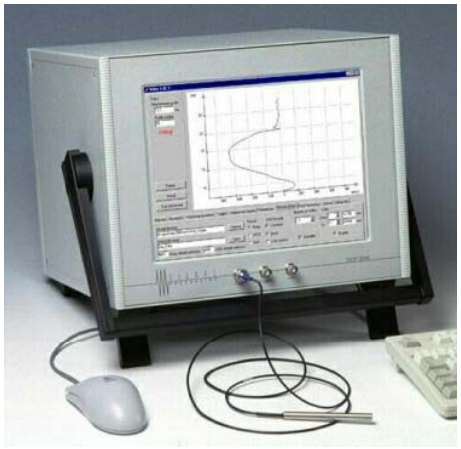
Local viscosity
Data analysis

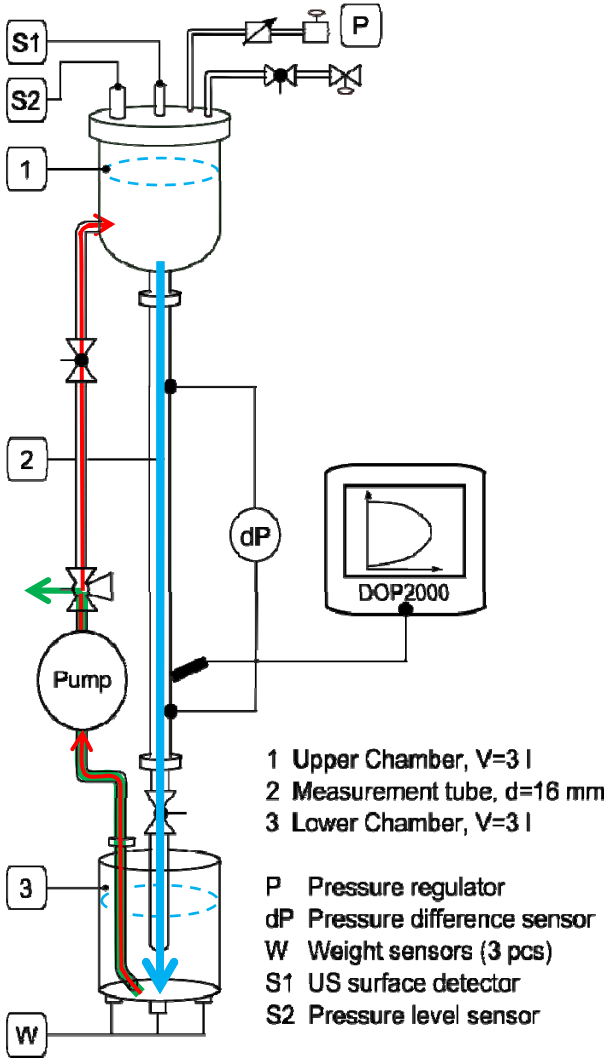
- Calculation of local viscosity



Laboratory-Scale Pipe Rheometer and UDV-PD

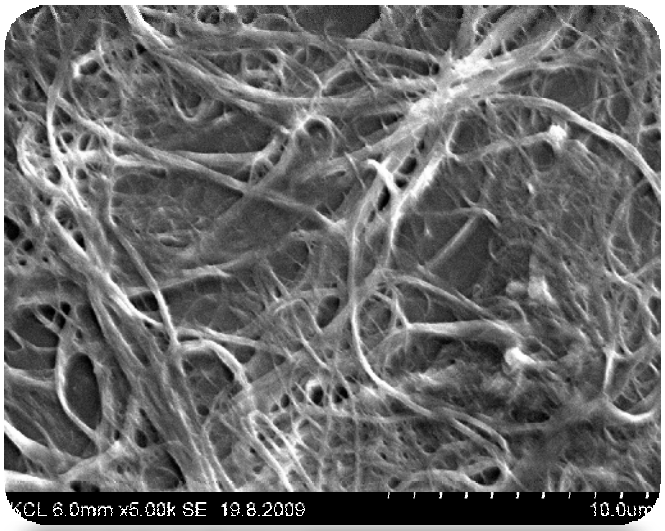
- Results based on direct measurements
  - Local viscosity
- Effortless modification and scalability
- Small sample size
  - 3 litres
- Minimal disturbances
  - Fully computer controlled
  - Flow is driven by:
    - Gravity
    - Overpressure



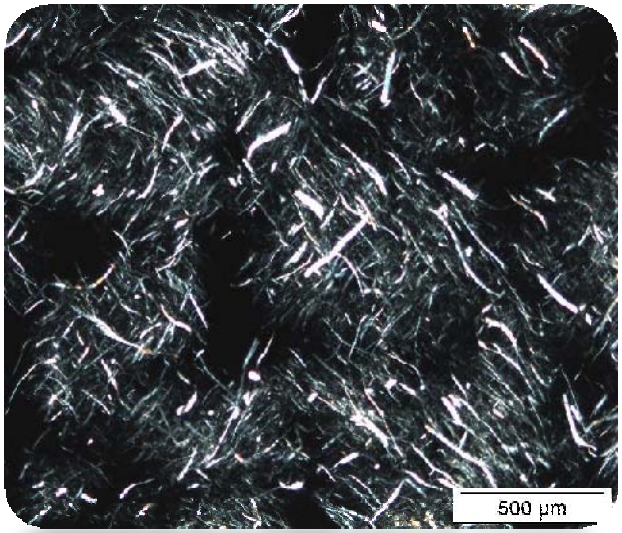


Microfibrillated Cellulose

- SEM and Polarized light microscope images

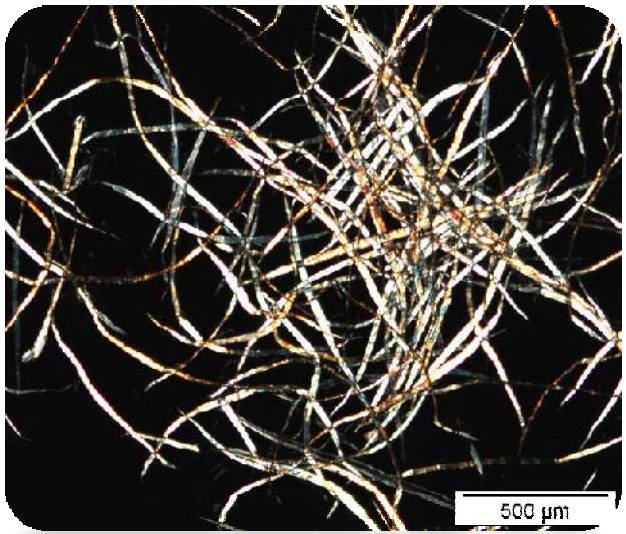


SEM image of MFC



MFC

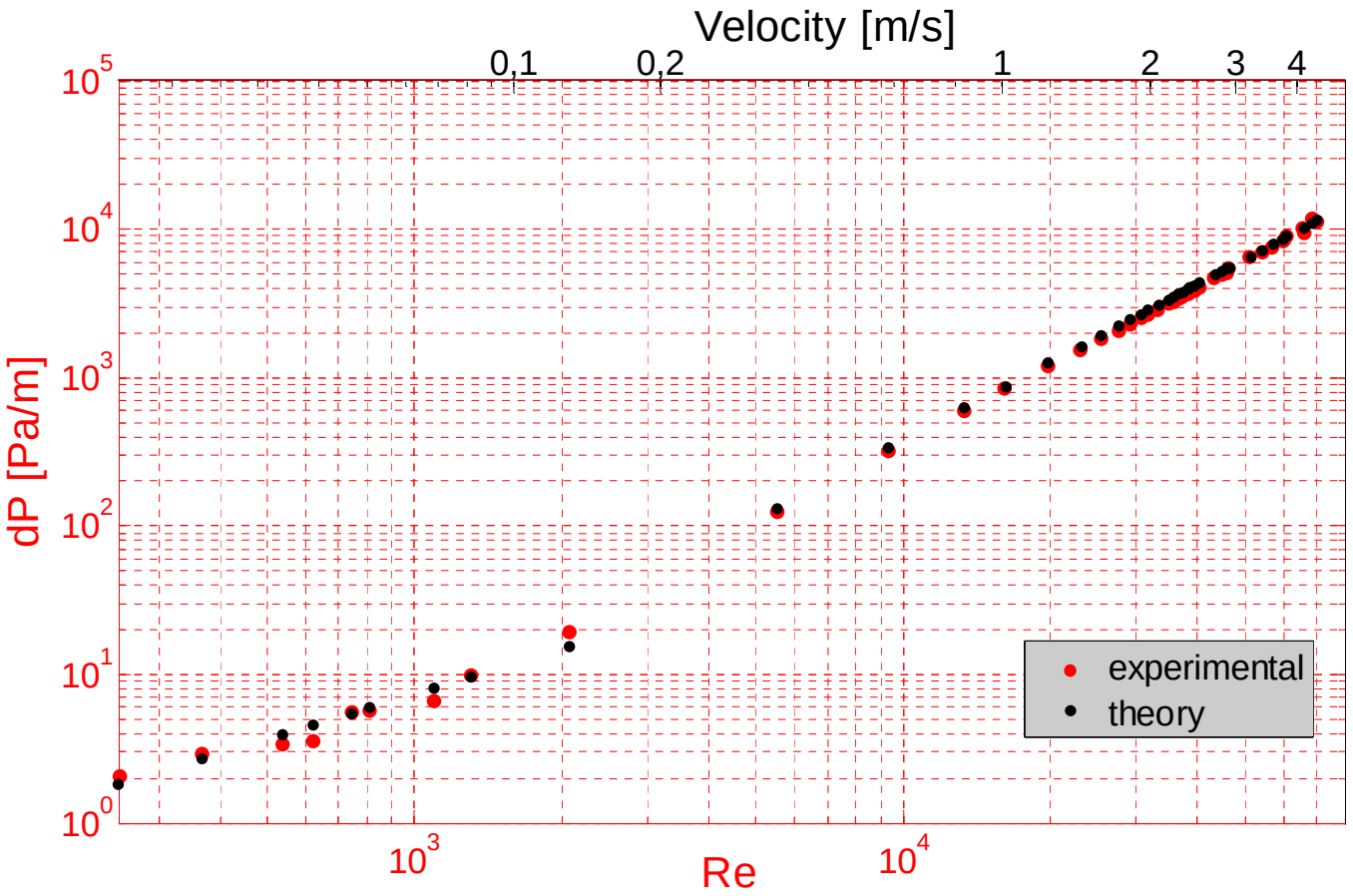
Celish KY100-G by Daicel Industries, Japan



Birch Cellulose

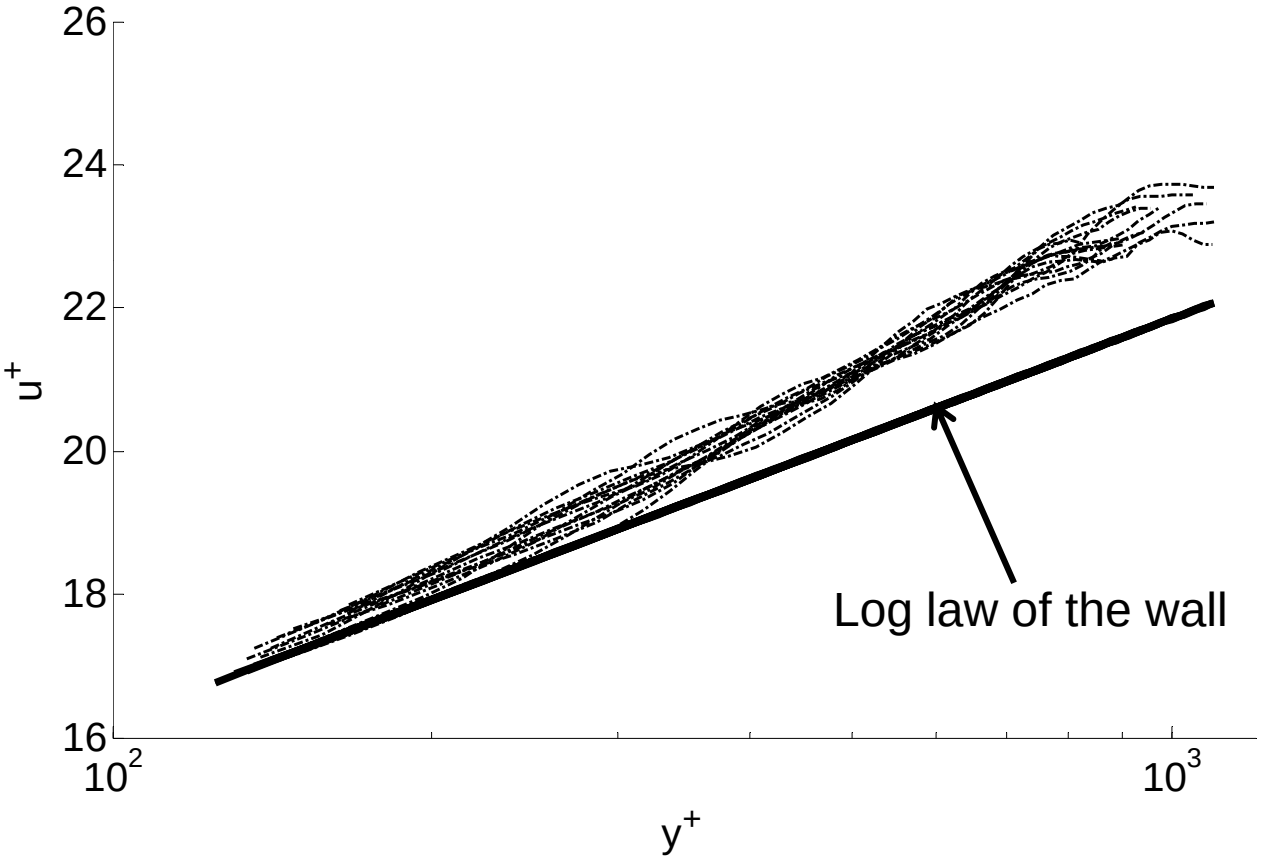
RESULTS
VERIFICATION MEASUREMENTS

Verification measurements



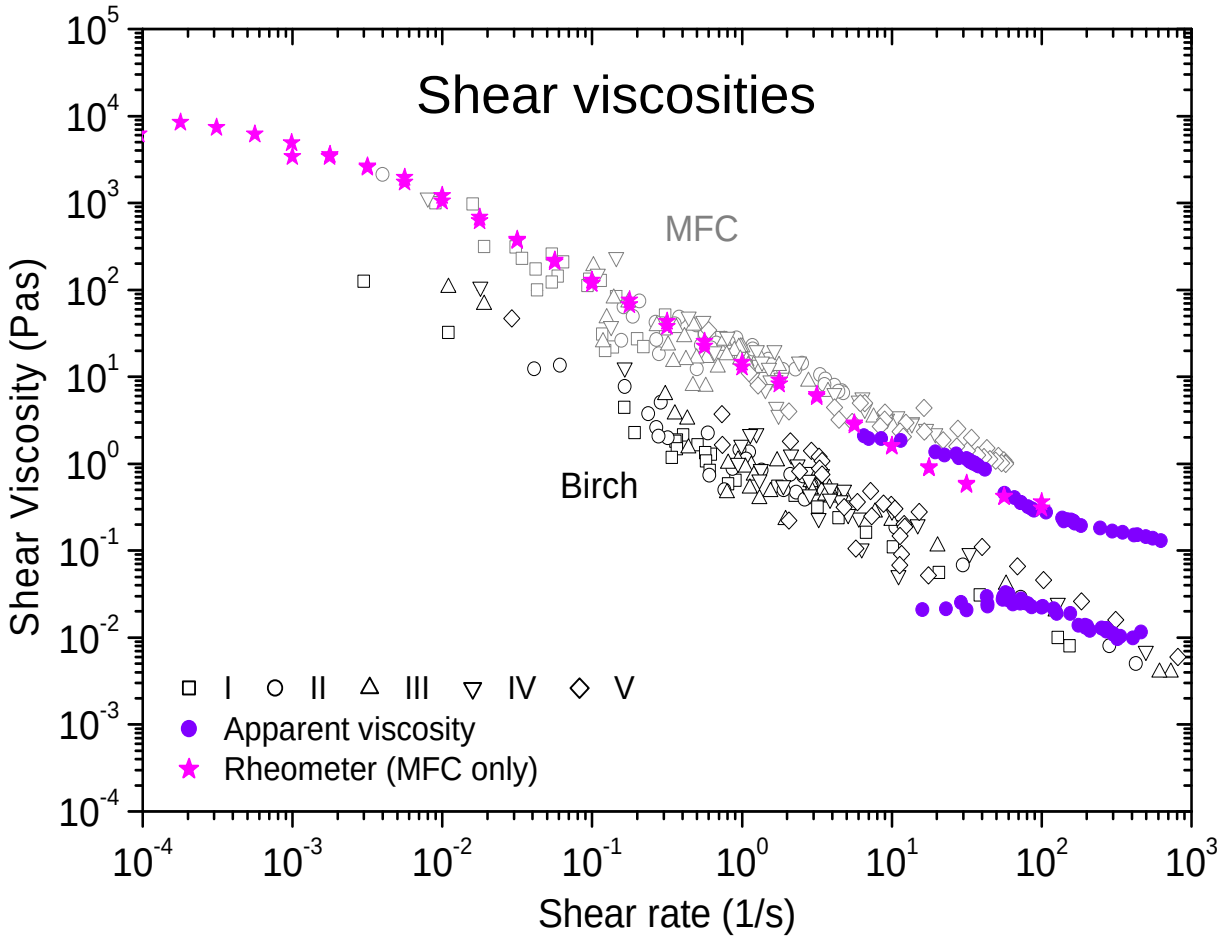
- Pressure drop of a pure water agrees well with the theory
  - Both in laminar and in turbulent region

Verification measurements



- The measured velocity profile of a pure water matches closely with the theoretical log law of wall curve

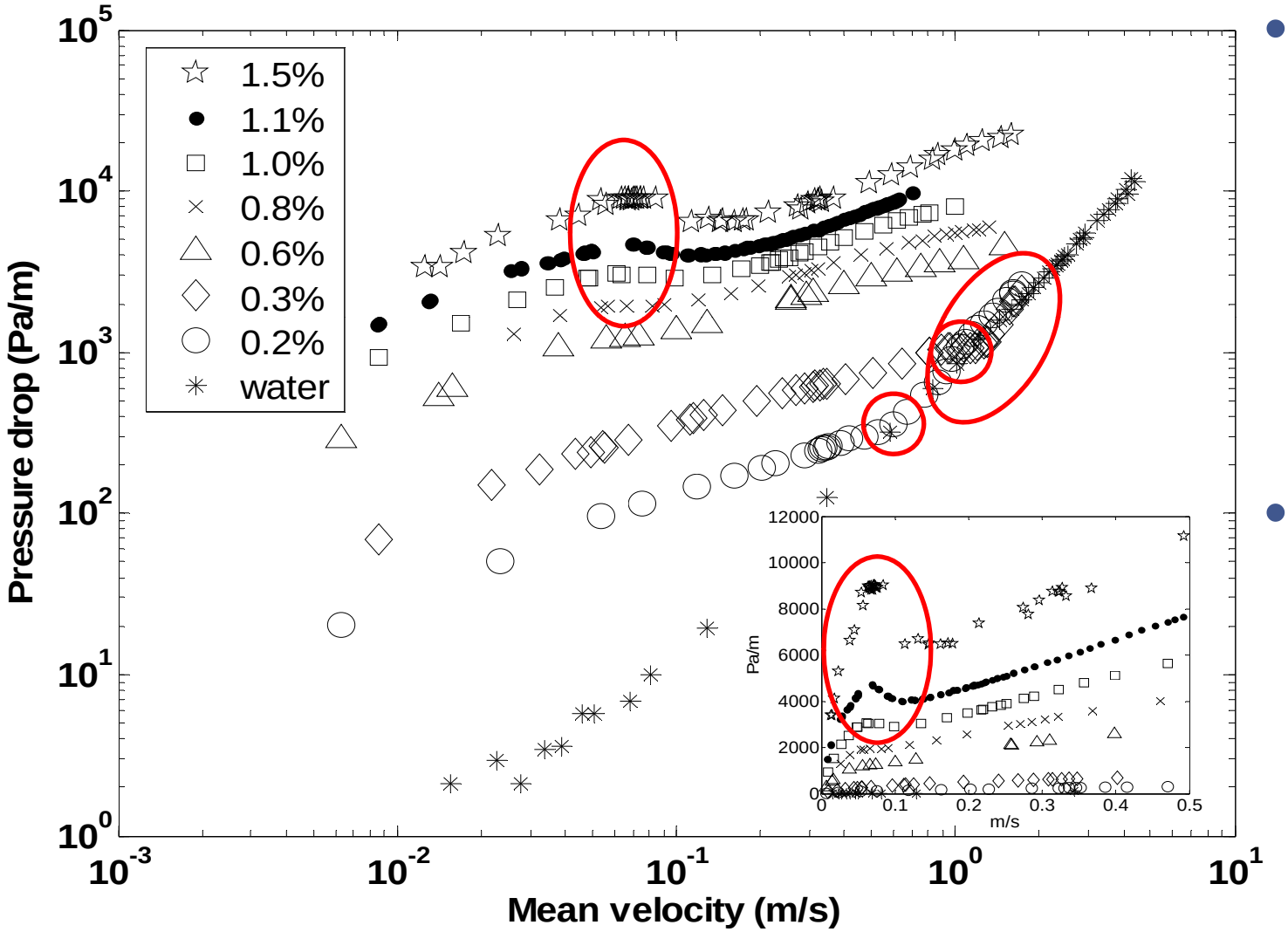
Verification measurements



- Results were compared with results obtained from rheometer
- Good agreement

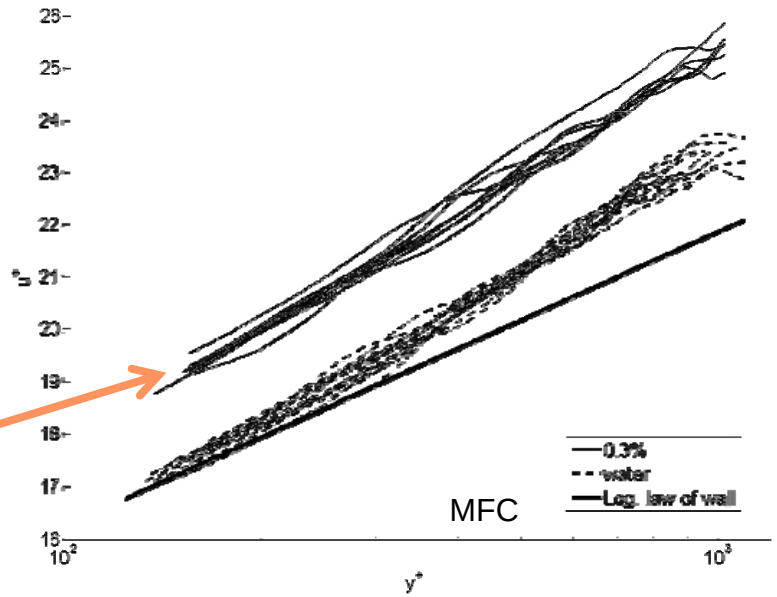
RESULTS
PRESSURE LOSS BEHAVIOR

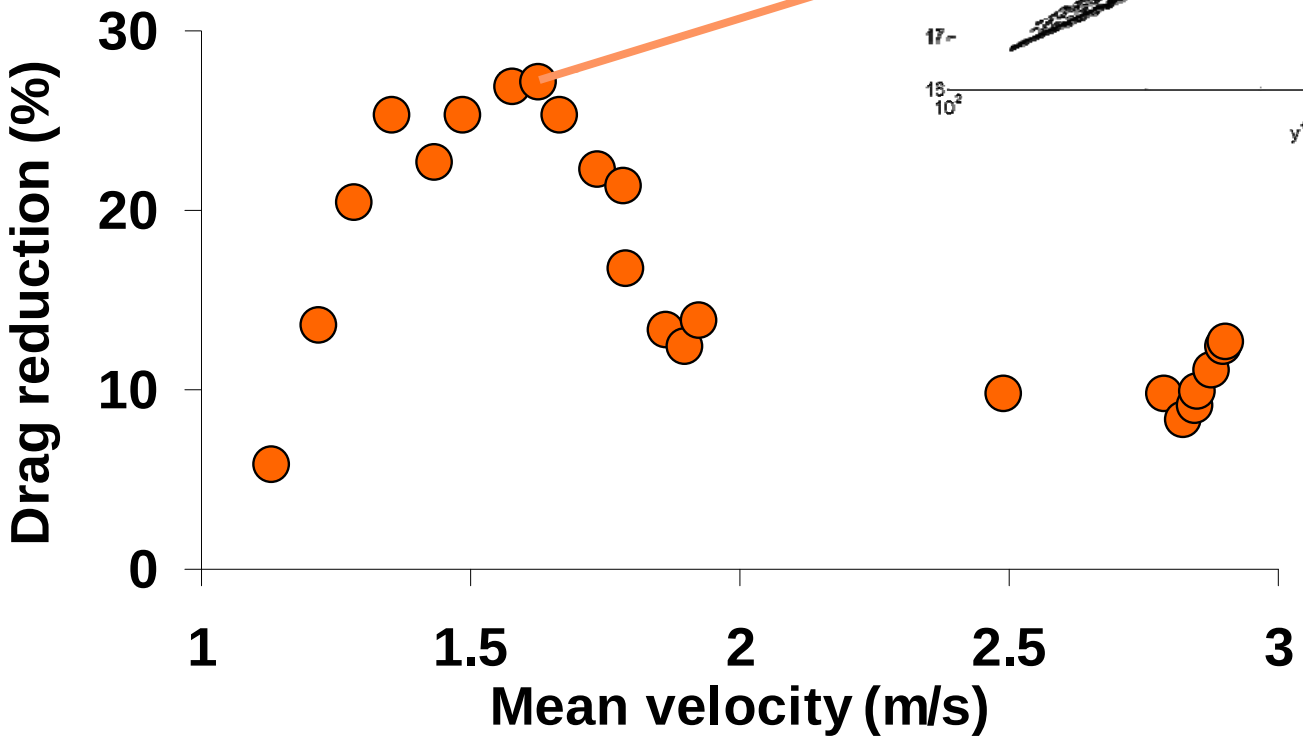
Pressure loss



- For low consistencies a clear transition from laminar to turbulence can be observed
- For high consistencies a big drop in pressure loss

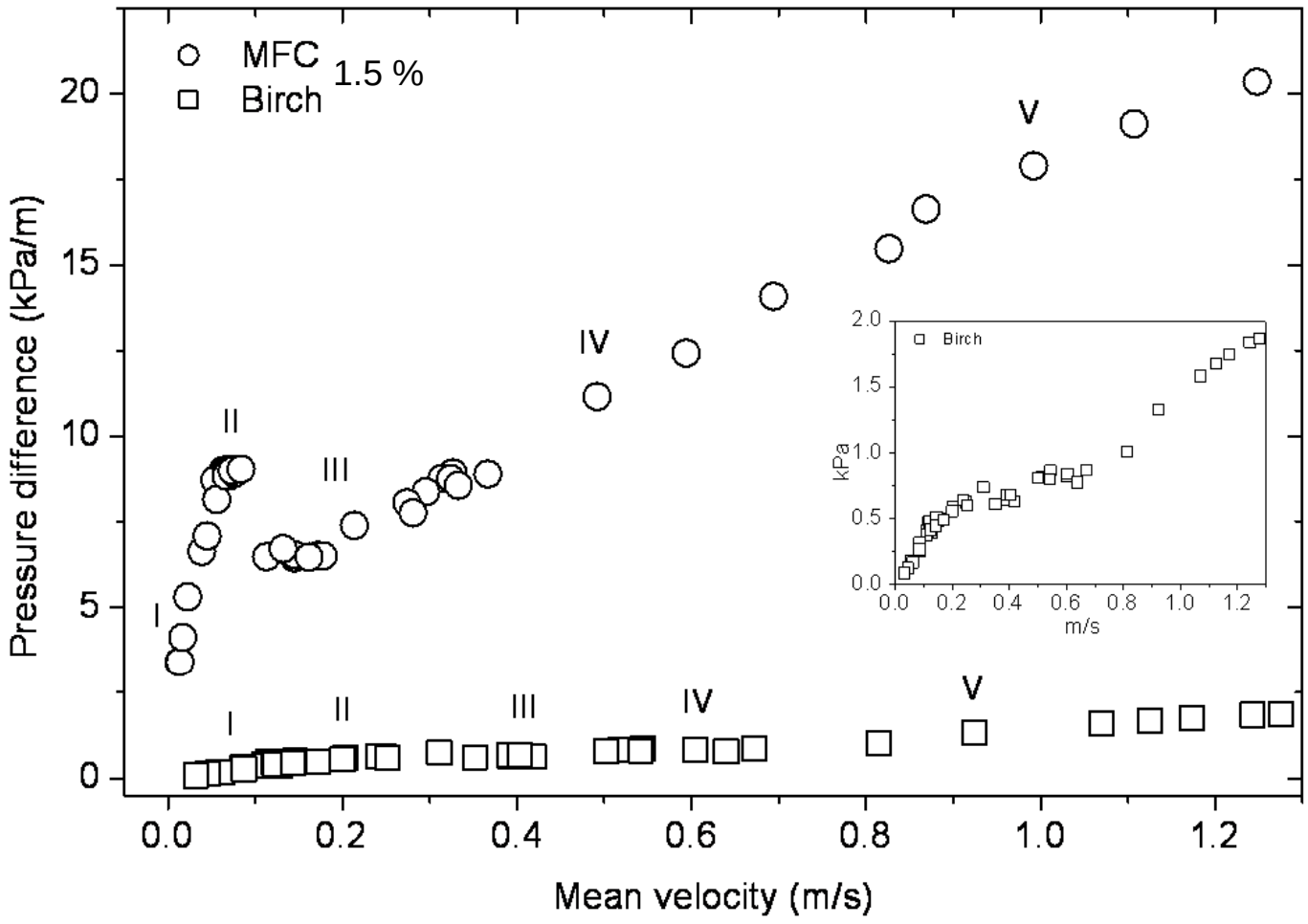
Drag Reduction (DR)





- At 0.3 % consistency up to 30 % Drag reduction

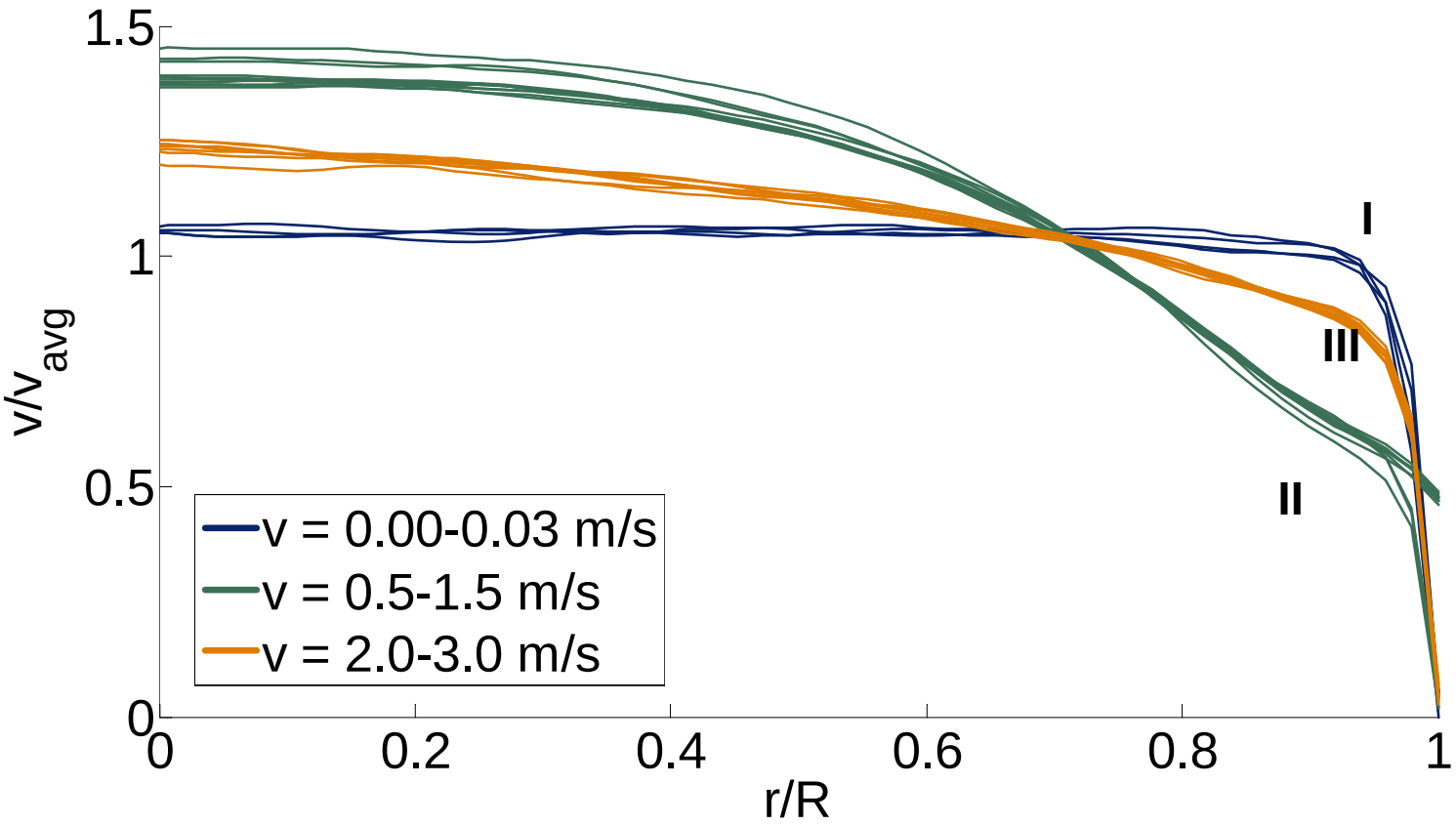
Pressure loss behavior



- Similar flow regions than for normal fibre suspension flow was found for MFC

MFC Velocity Profiles

- Mass consistency of 0.3%



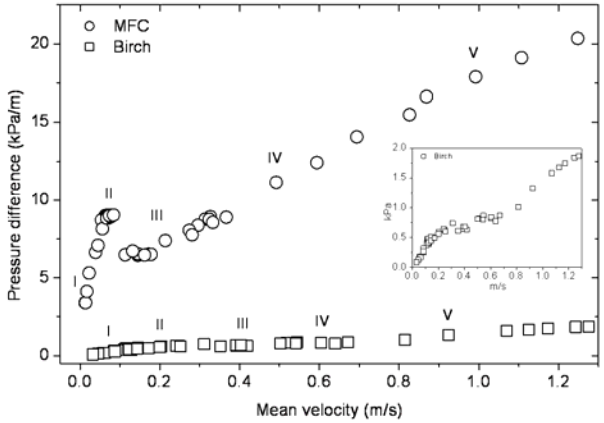
I Plug flow

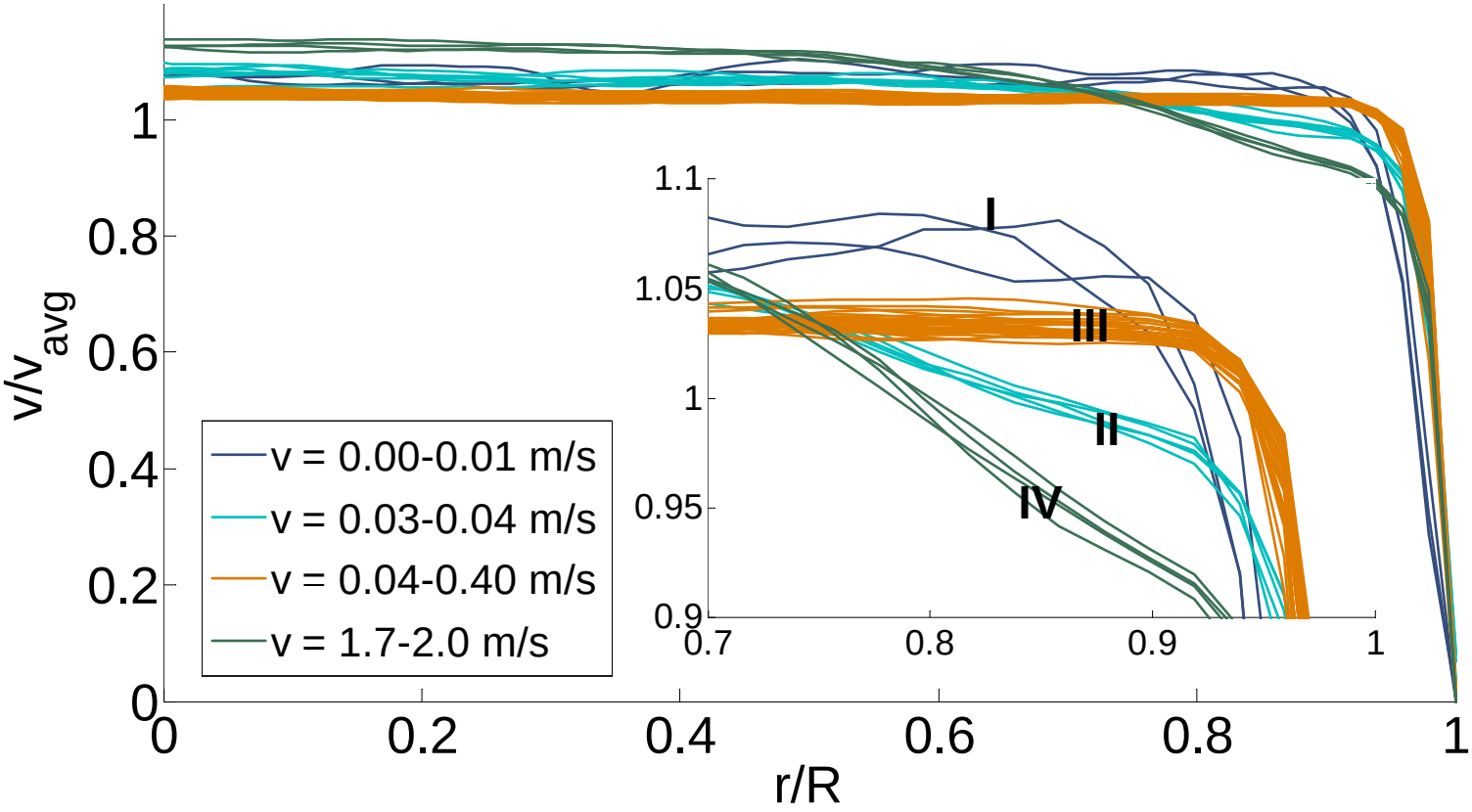
II Yielded viscous flow

III Turbulent flow

MFC Velocity Profiles

- Mass consistency of 1.0%





I Plug flow

II Yielded viscous flow

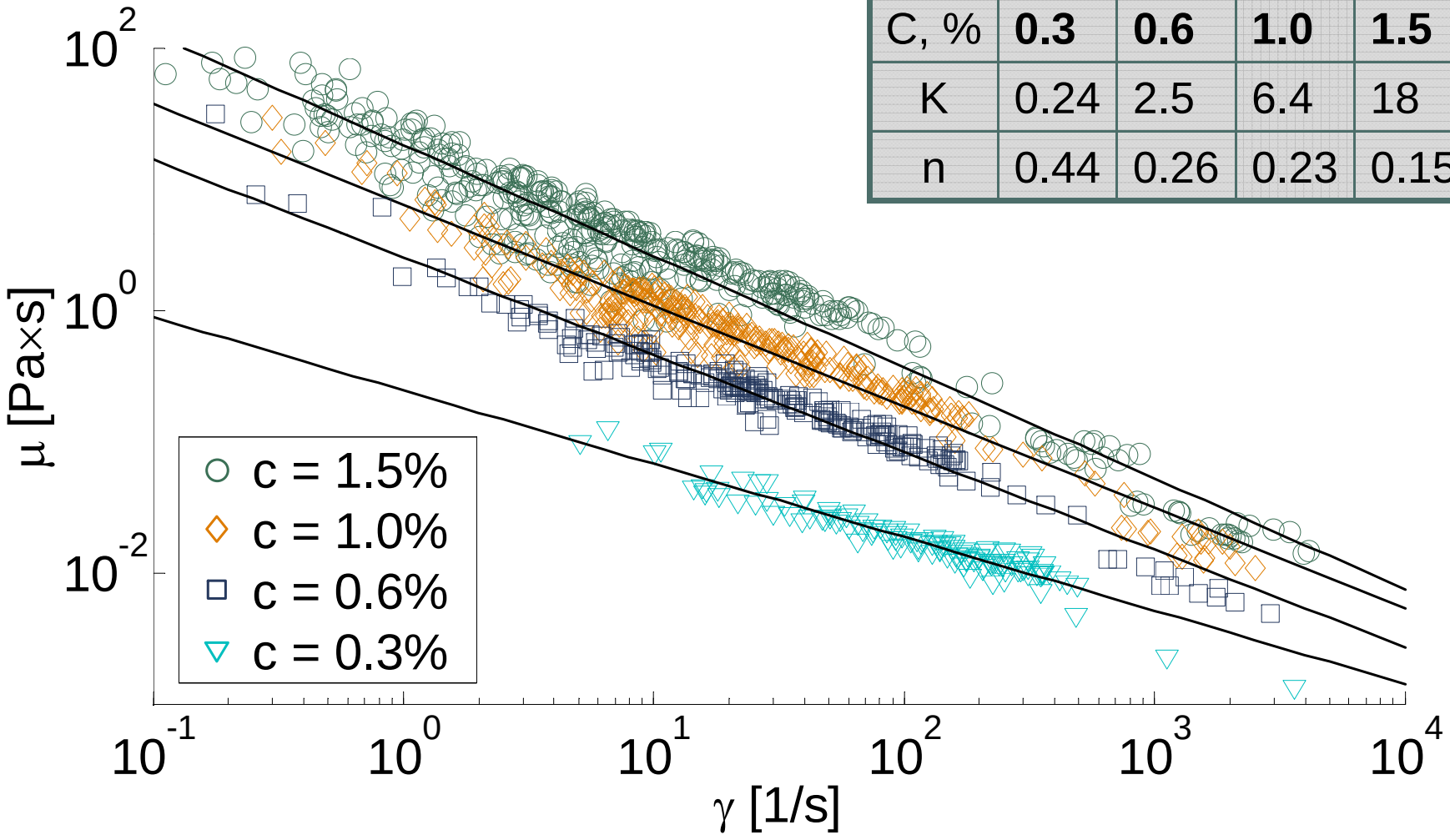
III Flow with lubrication layer

IV 'Fully' developed Turbulent flow

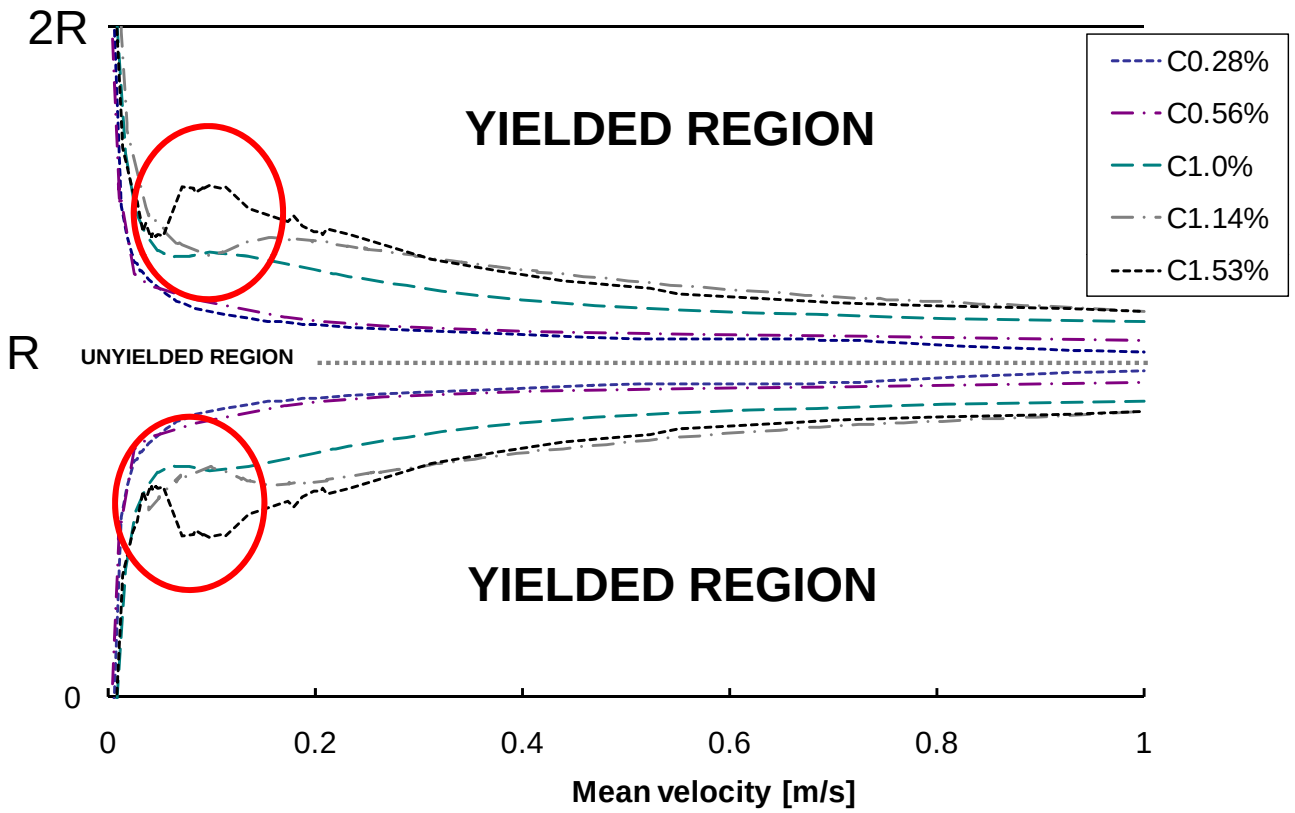
RESULTS
VISCOSITY, PLUG SIZE AND YIELD STRESS

Shear Viscosity

Power-law fit	$\mu = K\dot{\gamma}^{n-1}$			
C, %	**0.3**	**0.6**	**1.0**	**1.5**
K	0.24	2.5	6.4	18
n	0.44	0.26	0.23	0.15



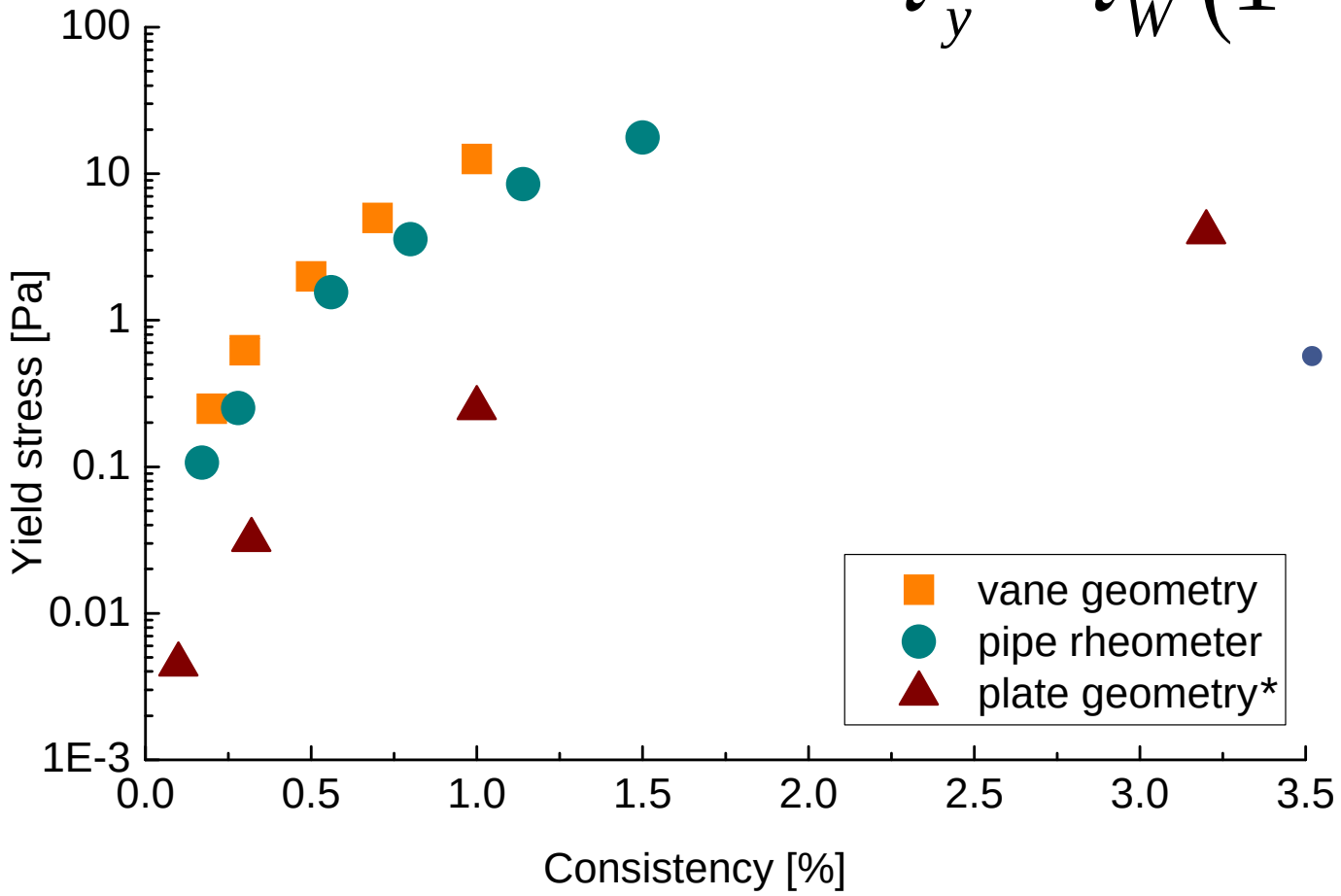
Plug size



- Plug size defined from velocity profile
- Bumps in pressure drop can also be seen in plug size

Yield Stress

$$\tau_y = \tau_w \left(1 - R_0/R\right)$$



- Yield stress can be obtained using plug size information

(*) Tatsumi D et.al: *Effect of fiber concentration and axial ratio on the rheological properties of cellulose fiber suspensions, Journal of Society of Rheology 32 (2002) 27-32.*

Conclusions

- A novel laboratory scale pipe rheometer combined with ultra sound Doppler velocimetry and pressure drop measurement was developed
- Device was succesfully used for studying rheology of **micro fibrillated cellulose (MFC)** suspension
  - Pressure drop
  - Velocity profile
  - Size of plug flow region
  - Viscosity
  - Yield stress

Conclusions

- Tested MFC grade is:
  - Highly shear thinning
  - High yield stress already at low concentrations
  - Drag reducing potential
  - Pressure drop and velocity profiles are very complex in nature