# Flocculation in accelerating flow

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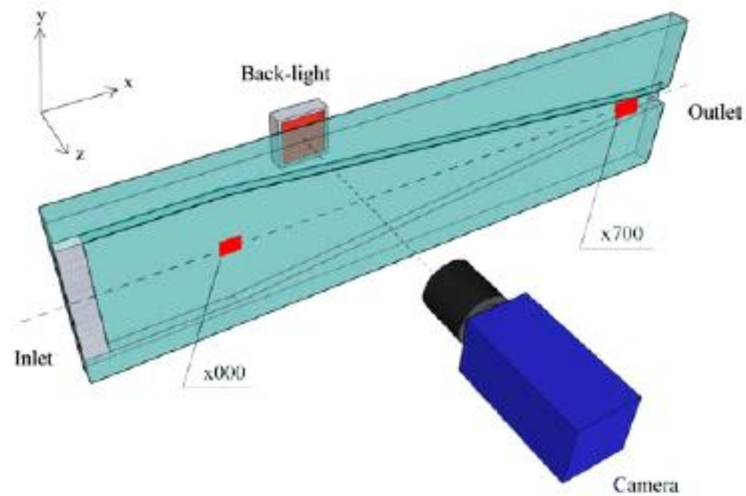
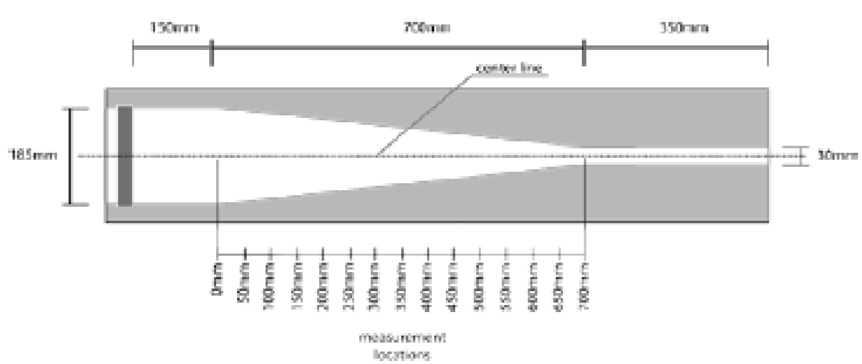
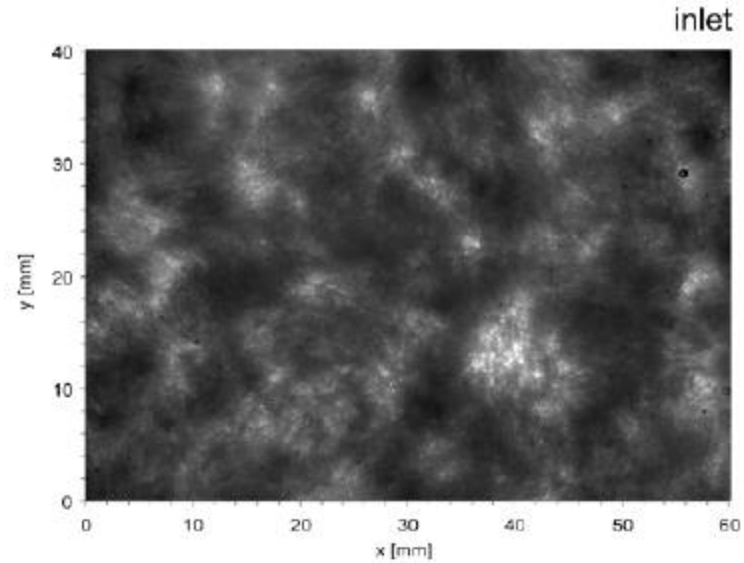
# Experimental setup

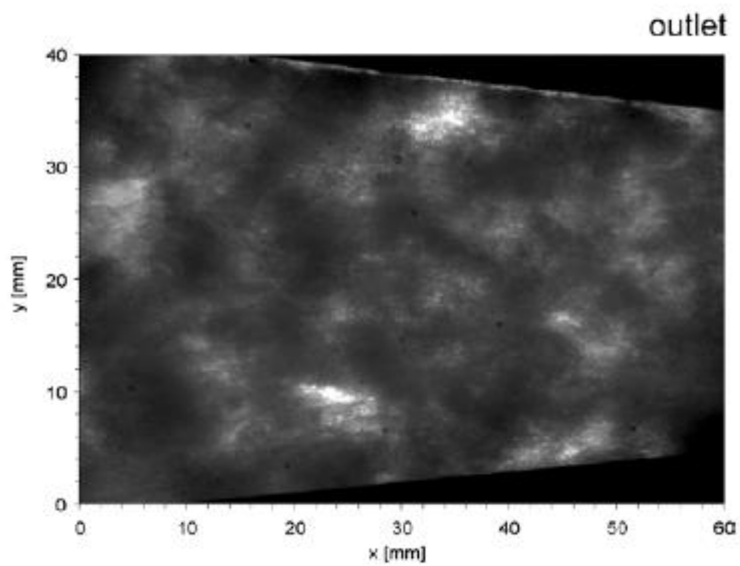



- Contraction from 185 to 30 mm, lenght (150 +700) mm, channel width 15 mm
- Contraction ratio 6:1
- Inlet turbulence generator 9 pcs Ø12 mm holes
- Two flow rates 2,25 l/s and 4,0 l/s
- Imaging PCO Sensicam, image size 40x50 $mm^2$ (0,040 mm/px) $f_{\#}$= 8 (sufficient depth of field)
- 1000 double frame images at each location.
- Illuminatio Cavilux Diode laser (680 nm)

# Suspension

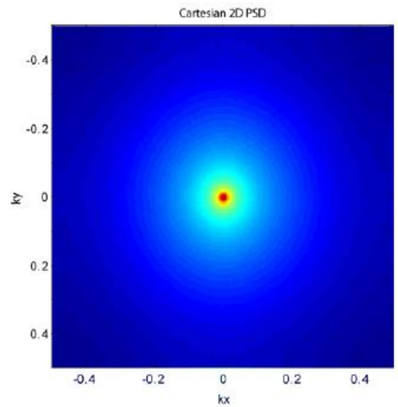


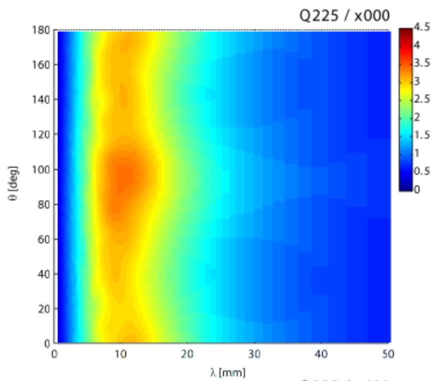



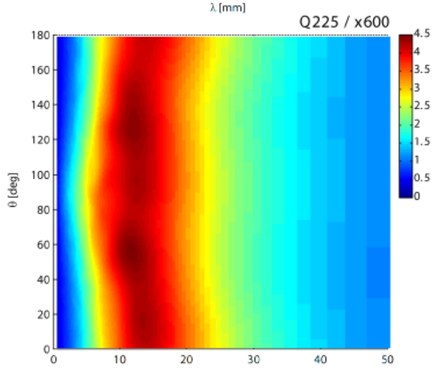

- Pine fibers
  - concentration 0,5 % mass
  - length weighted average length 2.13 mm
  - coarseness 0.18 mg/m (kajaaniFS300 analysis)
  - crowding number of the suspension 60 (slightly over the limit of continuous contact of fibers)

$$N = \frac{2}{3} C_V \left( \frac{L}{d} \right)^2 \approx \frac{5 C_m L^2}{\omega}$$

# Floc scale and shape

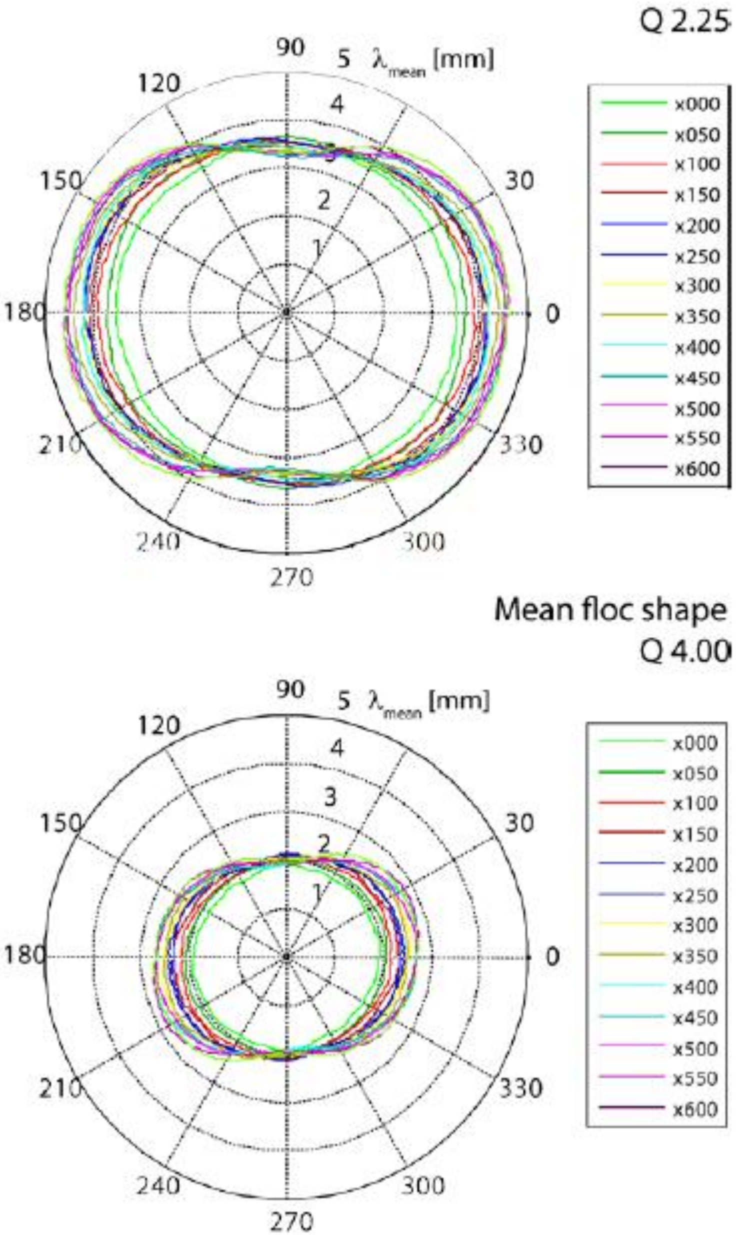


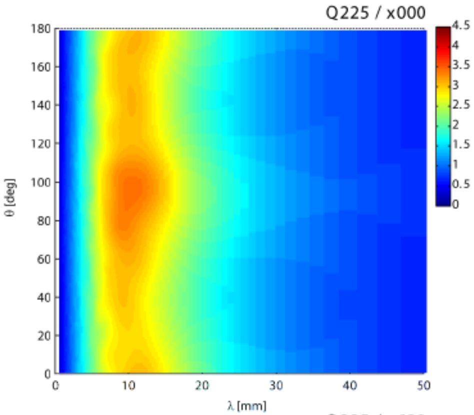



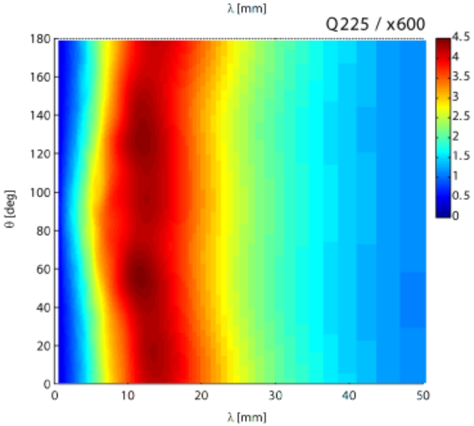

1. Compressed and background compensated images to 2D-PSD, for each position 500 maps averaged
2. 2D-PSD estimate at x 0 mm, kx and ky wave numbers
3. Transformation to polar coordinates (angle to x-coordinate, wavelength)
4. $\Rightarrow$ <u>Distribution of variance over spatial scales as function orientation</u>
5. Intensity variations are directly related to the fiber consistency variations
6. Intensity - consistency relationship is nonlinear, thrue concistency is not determined
7. Dominating length scale of the flocs is estimated by averaging the 2D-PSD map over $\theta$-axis, this <u>gives the PSD-profile</u>
8. The spectrum peak is in the range 5-20 mm

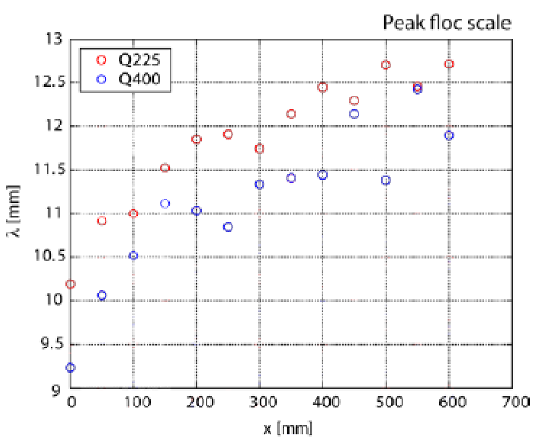
# Estimation of floc properties




- Another way to estimate the <u>flocculation length scale</u> is to consider the PSD as a probability function.
  - The mean length scale can be obtained by multiplying the normalized spectral density with the wave number vector.
  - This operation can be performed in any direction, the mean floc shape can be estimated by computing the mean length scale as a function of orientation angle in the x–y –plane.
- The <u>floc aspect ratio</u> is computed as the ratio between the length scales in x and y direction.
- The PSD is also utilized to assess the <u>flocculation intensity.</u>
  - This is done by computing the local variance from the PSD map.
  - High variance in the image data corresponds to large consistency variations, which indicates intense flocculation.
- <u>Fiber phase velocity</u> is obtained with a conventional PIV analysis of 500 double-frame images of flocculated flow at each measurement location.
  - Vector fields are calculated with multi-pass interrogation area refinement from 128x128 to 64x64 with 50% overlap.



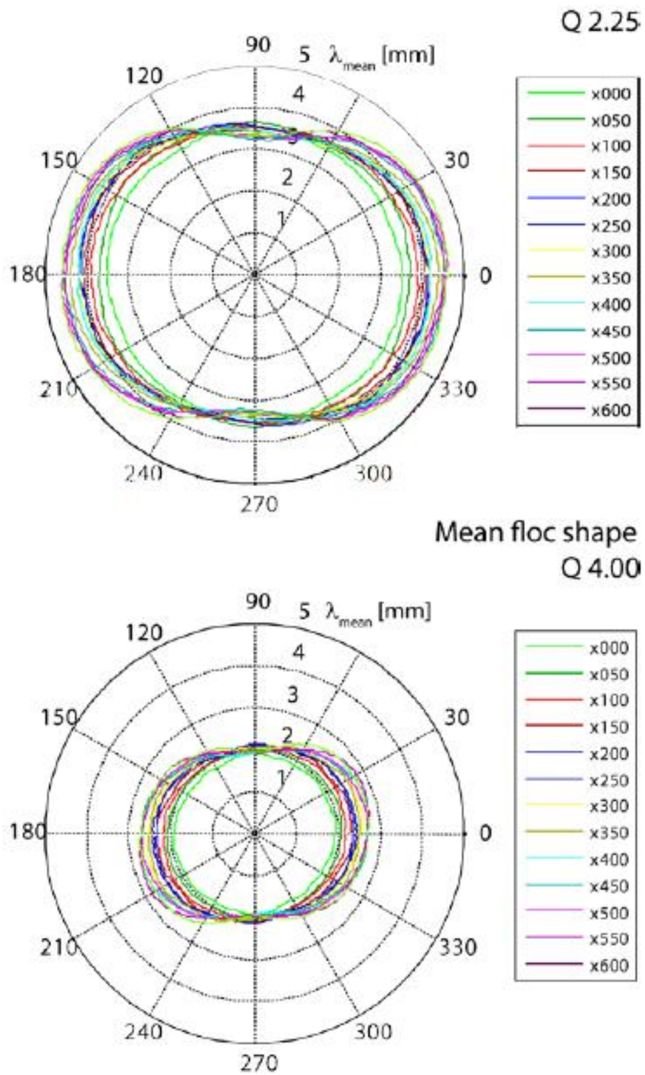




# Results: Floc scale

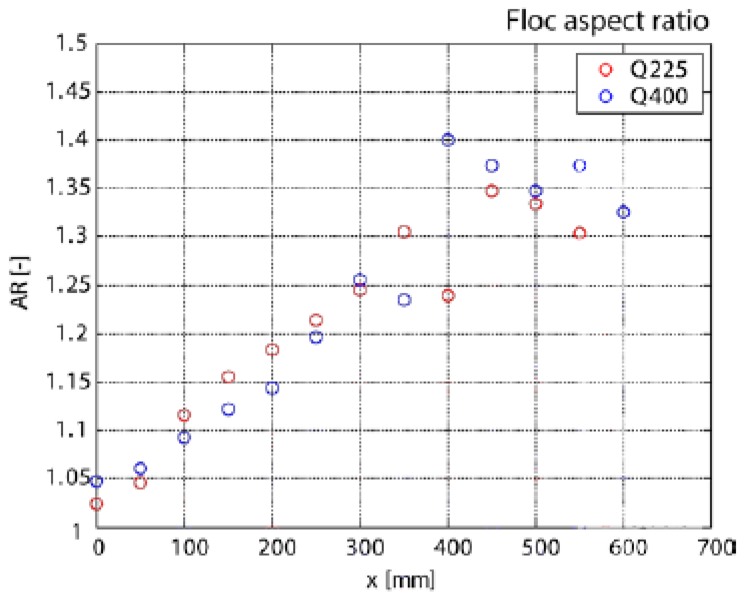
- The variance is higher near the channel outlet particularly in the scales between 5 and 15 mm compared to the inlet
- The streamwise development of the dominating length scale.
  - At both flow rates the floc scale increases towards the outlet.
  - The dominating floc scale is 3-4.5 times fiber length
  - (The dominating floc scale is larger than 1-2 fiber lengths )

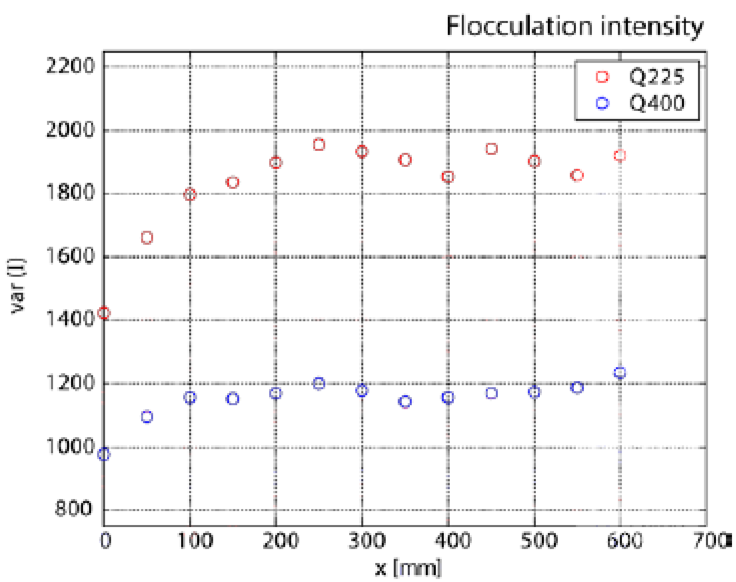
# Results: Floc shape




- Mean floc shape in measurement locations from x 0 mm to x 600 mm
- At the inlet, the floc shape is rather spherical.
- As the flow proceeds towards the outlet, the flocs are elongated in the flow direction, i.e. flocs become ellipsoidal.
- At the higher flow rate the mean floc scale is clearly smaller than in the lower flow rate.

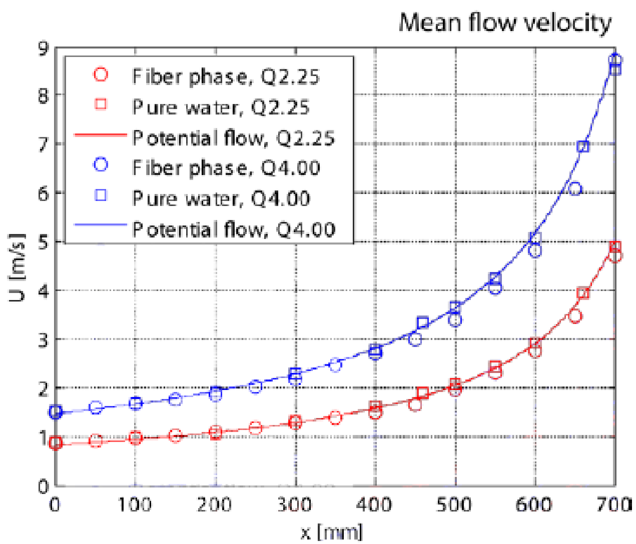
# Results: Floc aspect ratio and flocculation intensity

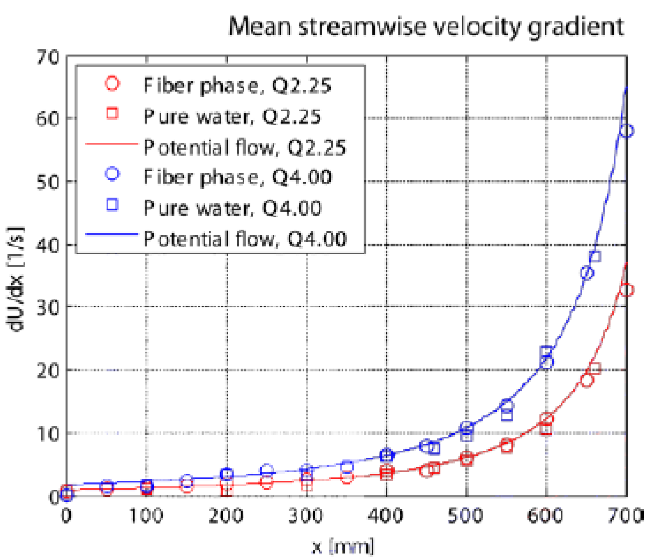



- The evolution of <u>floc aspect ratio</u>
- The floc aspect ratio (AR) clearly increases towards the outlet.
- The change in aspect ratio is rather small compared to elongation of fluid
- <u>The flocculation intensity</u> indicate that the flocculation is stronger at the lower flow rate.
- The flocculation increases quickly in the beginning of the channel.
- After x 200mm the flocculation intensity remains at a rather constant level.

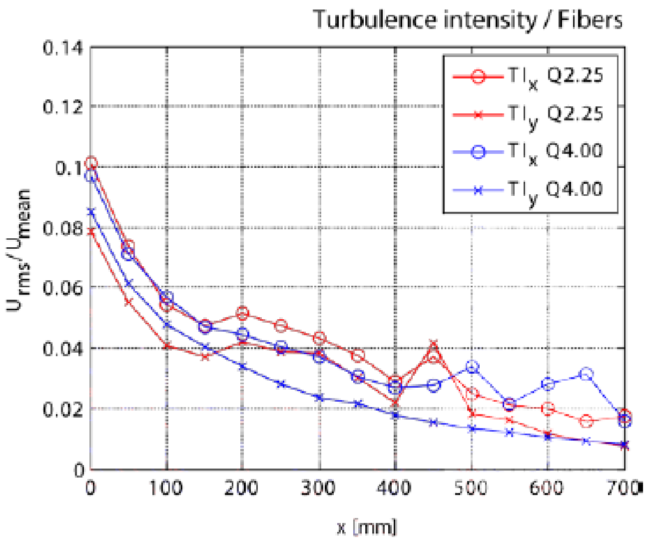
# Fiber phase streamwise mean velocity

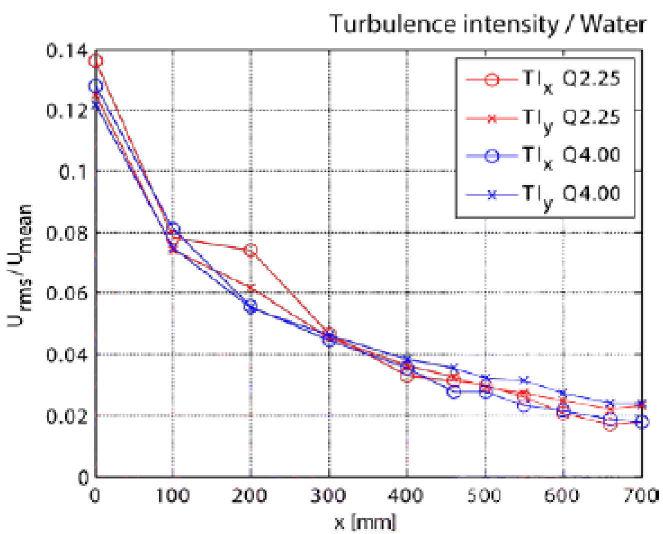



- Reynolds number is $1.6 \times 10^5$ and $2.7 \times 10^5$ at flow rates 2.25 l/s and 4.0 l/s for pure water based on local mean streamwise velocity and channel height
- As can be seen velocity of fiber phase agrees well with the potential flow curve and the PIV results.
- The flow velocity is increasing significantly at the end of the channel.
- The mean streamwise velocity gradient, *dU/dx* as a function of x location in the channel.
- Fiber phase mean streamwise velocity gradient is also agreeing well with the potential flow and the measured *dU/dx* for pure water.

# Turbulence intensity of the fiber phase




- Turbulence intensity of the fiber phase can be compared with the turbulence intensity measured with pure water,
- Note that the resolution of fiber phase and pure water is different, since the imaged area in pure water PIV measurements was only 10 × 8 mm2.
- Trends and orders of magnitude are clearly similar: turbulence intensity is decreasing fast in the beginning of the contraction and it is in both cases well below 4 % at the end.
- It seems that in fiber phase the TIx is higher than TIy at both flow rates, whereas TIy is higher in pure water.
- The significant decay of turbulence intensity and growth of flocs seem to happen in same locations from *x 0 mm to x 200 mm.*
- The mutual role of turbulence and streamwise velocity gradient on controlling floc growth and deformation is interesting.
- The channel can be divided into two sections: upstream and downstream halves.
- In the upstream half, the dominant flow characteristic is turbulence.
- As *dU/dx* becomes dominant in the downstream half, turbulence has already decayed.
- One can note that the foremost increase of floc scale and aspect ratio has already happened in the downstream half.

# Conclusions

- The mechanical flocculation of softwood pulp fibers is studied in a consistency and geometry relevant to papermaking.
- The flocculated suspension is subjected to accelerating flow, which deforms the flocs more ellipsoidal towards the channel outlet.
- In this study the flow <u>is not able to breakup flocs</u> into smaller units.
- The two-dimensional Power Spectral Density (2D PSD) estimate is applied in analyzing the images of flocculated suspension, which enables the study of floc scale and shape.
- PIV is applied to measure fiber phase velocity and turbulence to complement flocculation measurements.