CHALLENGES IN PULP PROCESSING

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Noss AB

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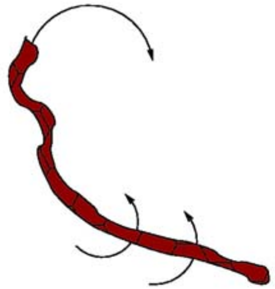
NOSS AB

Noss AB is a Swedish company serving customers in the pulp and paper industry. We supply advanced Fiber Development Systems comprising equipment for,

- hydrocycloning,
- screening,
- thickening,
- fiber fractionation,
- deaeration,
- refining and bleaching.

The total number of employees in the Noss group is 160.
The main offices, process laboratory and manufacturing plant are located in Norrköping.

FIBERS IN TURBULENT FLOW

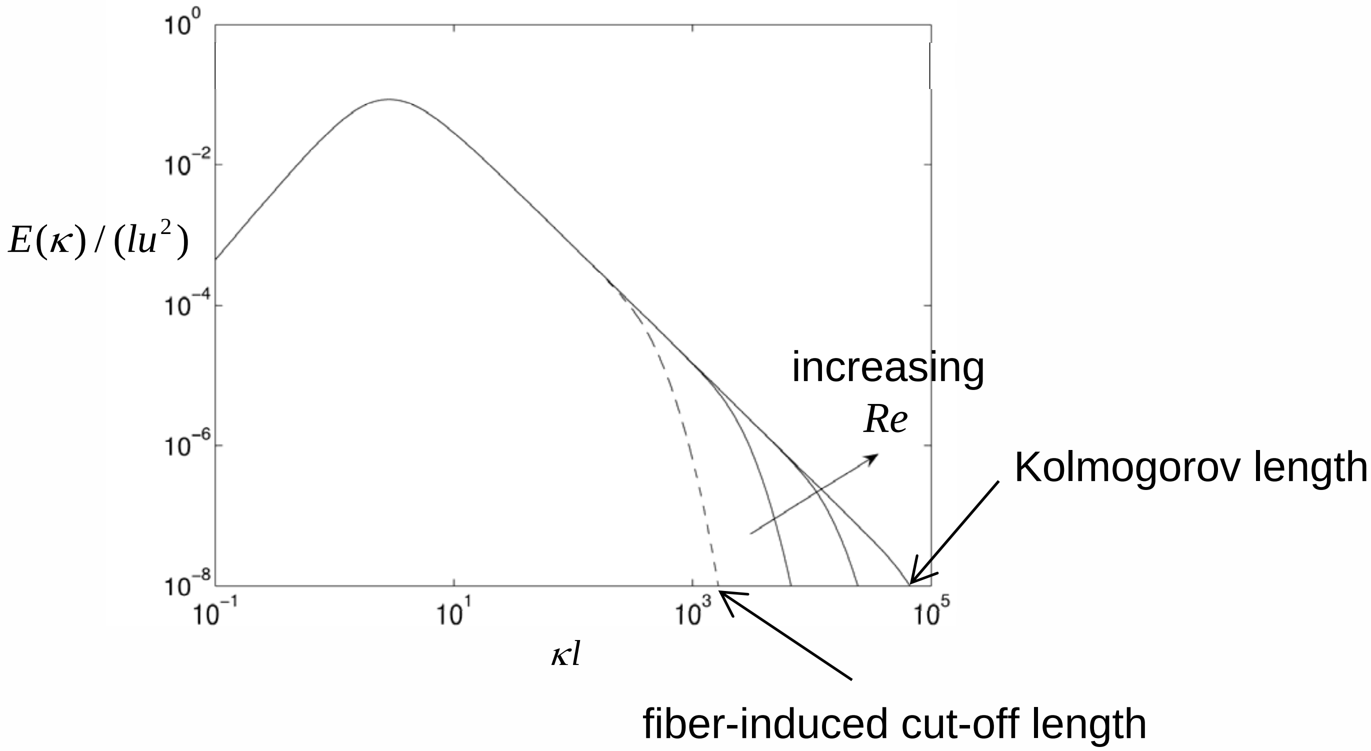


A fiber moves with the large whirls essentially as a solid body with negligible loss of turbulence kinetic energy to friction and deformation work.

Bending stiffness prevents the fiber from aligning with the small whirls resulting in loss of turbulence kinetic energy to both friction and deformation work.

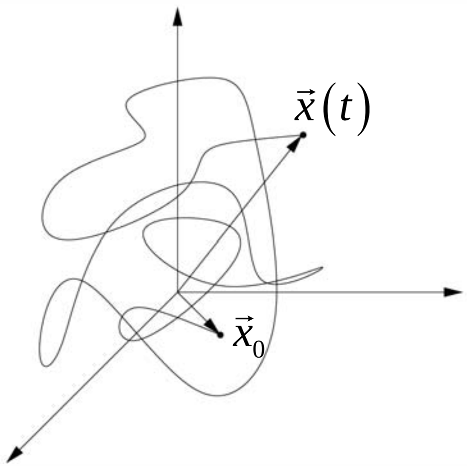
The presence of fibers enhances the decay-rates of turbulent eddies with length-scales on the order of the fiber length.

TURBULENCE ENERGY SPECTRUM



A need for new friction laws

STATIONARY HOMOGENEOUS TURBULENCE



A fluid particle performs a random walk with,

$$\left|\left\langle \vec{x}(t) - \vec{x}_0 \right\rangle\right| \sim \sqrt{t}$$

where $\langle \ldots \rangle$ denotes a spatial average.

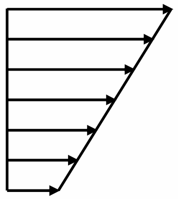
The length of the path traced out by the particle is $\sim t$

High probability of entanglement (flocculation) in S.H.T.

TURBULENCE WITH MEAN STRAIN

shear flow

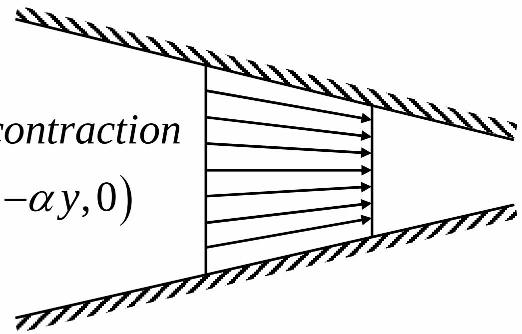
$(\beta y, 0, 0)$



$$\left|\langle x(t) - \bar{x}(t) \rangle\right| \sim t^{3/2}$$

$2D-contraction$

$(\alpha x, -\alpha y, 0)$



$$\left|\langle x(t) - \bar{x}(t) \rangle\right| \sim e^{\alpha t}$$

- Mean strain reduces the rate of entanglement
- Flocs and networks may break up if the strain is strong enough

→ *yield stress*

CROWDING NUMBER

The flow of non-dilute fiber suspensions is largely characterized by the aspect ratio of the fibers. The effect is conveniently incorporated through a modeling approach based on the crowding number.

Definition: $N = \frac{2}{3}\alpha_f\left(\frac{l_f}{d_f}\right)^2$, where α_f is the volume fraction, l_f is the fiber length and d_f is the diameter of the fiber.

Interpretation: the number of fibers contained in a sphere with a diameter equal to the fiber length (l_f).

Observations:

$N \leq 16$	dilute
$16 \leq N \leq 60$	flocculation occurs
$60 \leq N$	networked

TRANSPORT EQUATIONS

$$\frac{\partial N}{\partial t}+\vec{\nabla}\cdot\left(N\left(\underset{\text{mixture}}{\vec{V}_m}+\underset{\text{Relative}}{\vec{V}_R}\right)\right)=0,$$

$$N=\overline{N}+n,\qquad \vec{V}_m=\overline{\vec{V}}_m+\vec{v}_m,\qquad \Rightarrow$$

$$\frac{\partial \overline{N}}{\partial t}+\vec{\nabla}\cdot\left(\overline{N}\left(\overline{\vec{V}}_m+\vec{V}_R\right)\right)=-\vec{\nabla}\cdot\left(\overline{n\vec{v}_m}\right),$$

variance - flocculation

$$\frac{\partial \overline{n^2}}{\partial t}+\left(\overline{\vec{V}}_m+\vec{V}_R\right)\cdot\vec{\nabla}\overline{n^2}+2\overline{n^2}\vec{\nabla}\cdot\vec{V}_R=\underbrace{-2\overline{n\vec{v}_m}\cdot\vec{\nabla}\overline{N}}_{\boxed{1}}\underbrace{-\vec{\nabla}\cdot\left(\overline{n^2\vec{v}_m}\right)}_{\boxed{2}}.$$

1. *Production due to mean gradient*
2. *Should include anticipated effects from S.H.T. and turbulence with mean strain*

ALGEBRAIC SLIP MODEL

The mixture model in FLUENT makes use of an algebraic slip formulation where the relative velocity between phases *p* and *q* is given by,

$$\vec{V}_R = \vec{V}_p - \vec{V}_q = \frac{\left(\rho_p - \rho_m\right) d_p^2}{18\mu_q f_{drag}} \vec{a},$$

where d_p is the diameter of the particles, ρ_m is the mixture density and the acceleration is defined in terms of mixture quantities,

$$\vec{a} = \vec{F} - \frac{\partial \vec{V}_m}{\partial t} - \left(\vec{V}_m \cdot \vec{\nabla}\right) \vec{V}_m,$$

The effective viscosity is easily modified to include a yield stress,

$$\mu_{eff} = \mu_q + \frac{\tau_{yield}}{S}.$$

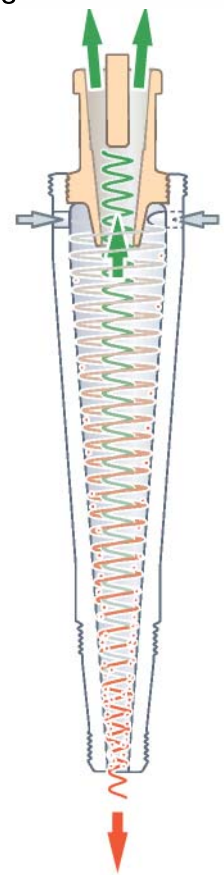
LOW Re_p DRAG FOR FIBERS

$$f_{drag} = -1.5\frac{\left(1+\frac{\tau_{yield}}{\mu_q S}\right)}{\log\left(\underbrace{\alpha_p}_{\text{fiber-distance cut-off}} + \underbrace{\left(\frac{d_p}{l_p}\right)^2}_{\text{single cylinder limit}}\right)} = -1.5\frac{\left(1+\frac{\tau_{yield}}{\mu_q S}\right)}{\log\left(\frac{3}{2}N+1\right)+2\log\left(\frac{d_p}{l_p}\right)},$$

where α_P is the fiber volume fraction, $S=\sqrt{2S_{ij}S_{ij}}$ and,

$$\tau_{yield} = \begin{cases} 3.2\times10^{-5}\left(N-N_{sed}\right)^{2.7} & N \geq N_{sed} \\ 0 & N \leq N_{sed} \end{cases}$$

RADICLONE - CYCLONING



Function:

Particles are separated according to specific weight through the action of the centrifugal force

HYDROCYCLONE SIMULATIONS

B. Cyclone 2

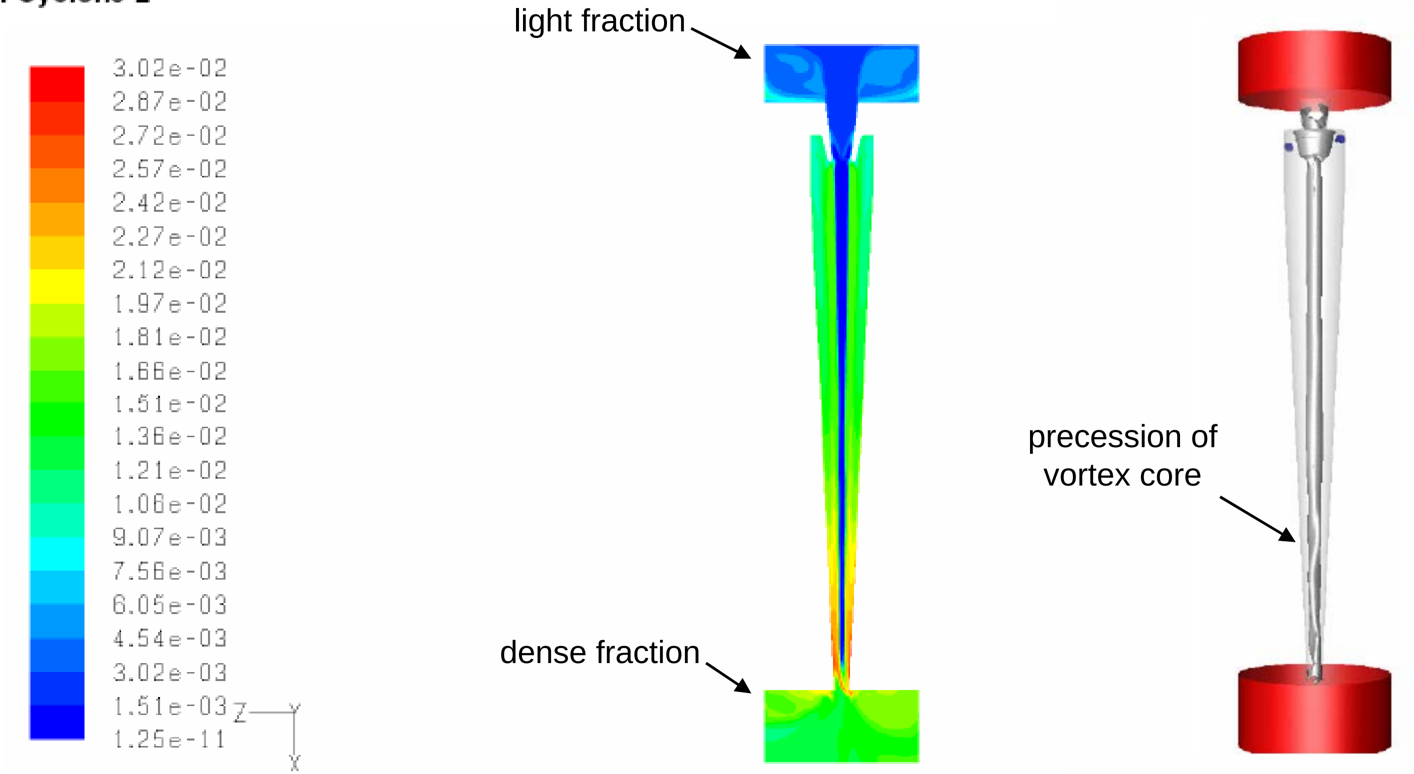
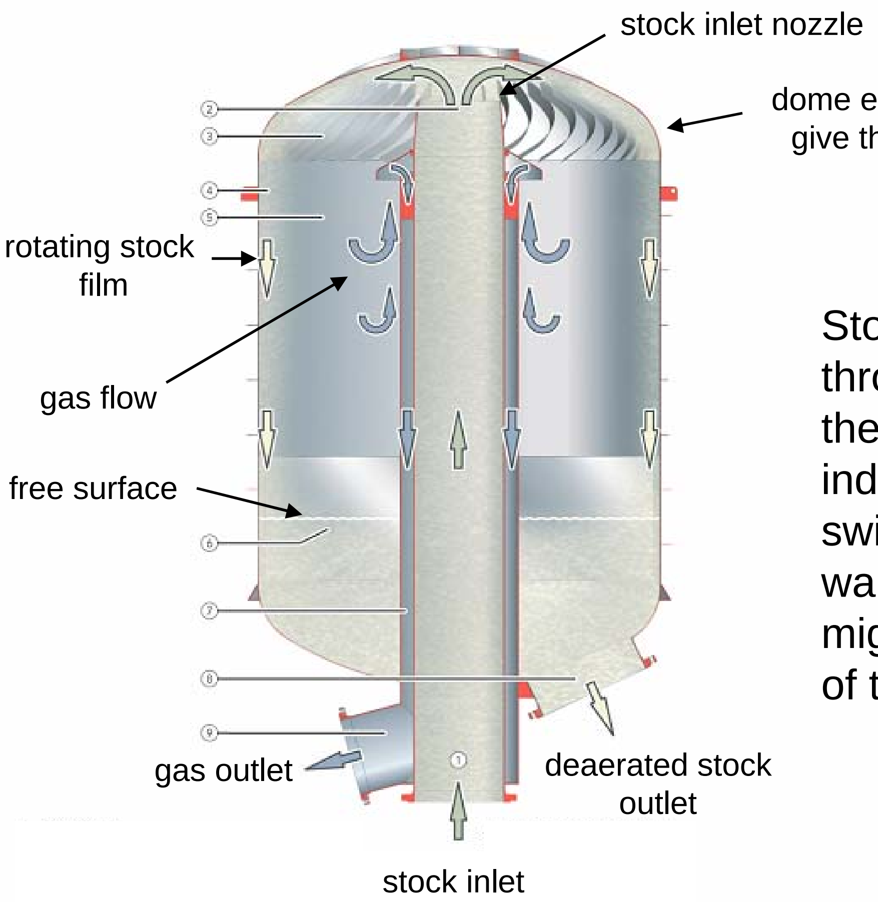


Figure B.1: Fibre volume fraction at plane 1.

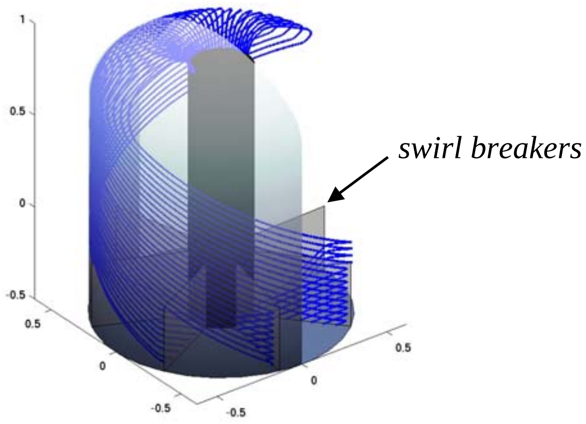
PERIVAC – DEAERATION



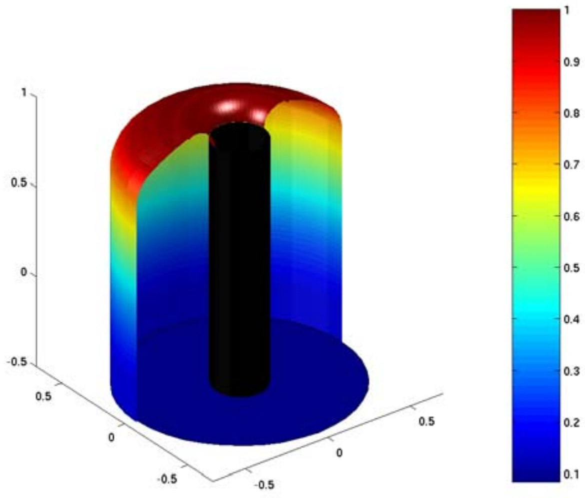
Function:

Stock enters the vacuum chamber through a nozzle as a free jet hitting the top of the dome where rotation is induced by guiding vanes. The stock swirls down in a thin layer on the inside wall of the chamber and the gas bubbles migrate to the interface under the action of the centrifugal force.

RESULTS FROM SHALLOW WATER MODEL



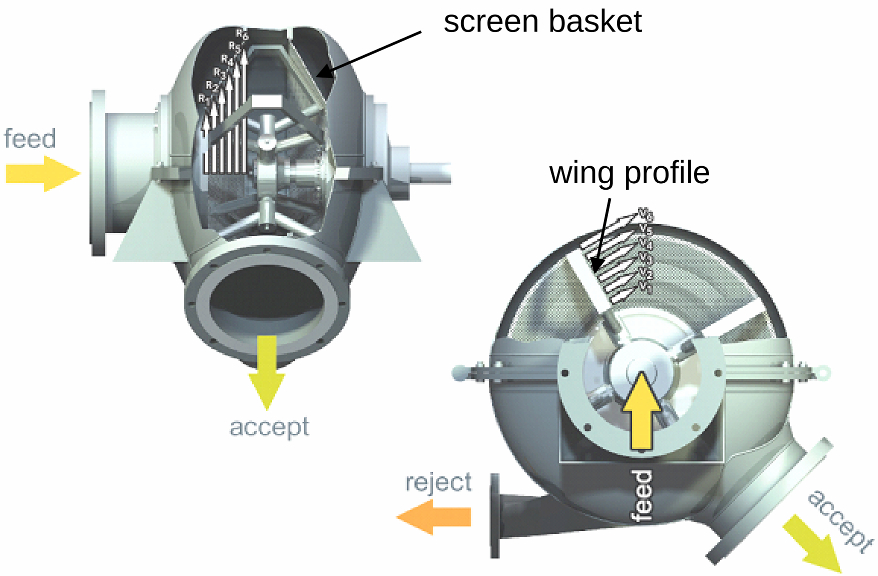
streamlines



relative gas content

No consideration to the effect of fibers

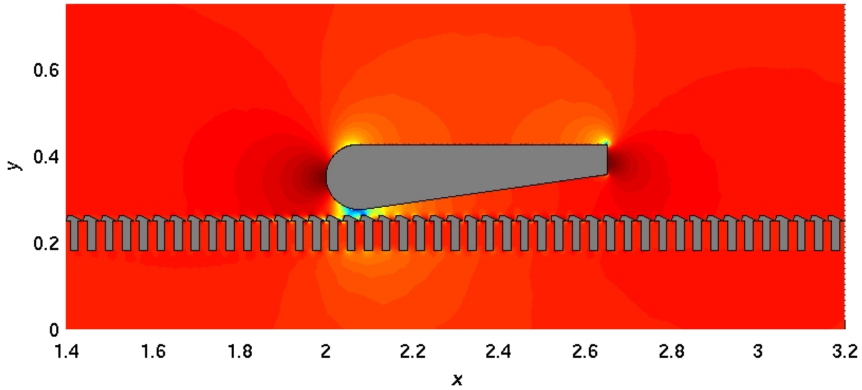
RADISCREEN - SCREENING

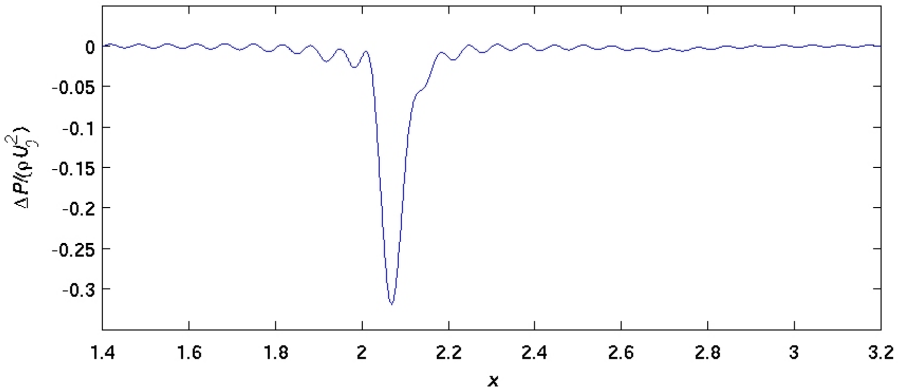


Function:

Particles are separated according to size by passing the stock through a screen with well-defined apertures. The apertures are kept clean through suction pulses generated by a streamlined body sweeping along the surface of the screen-basket.

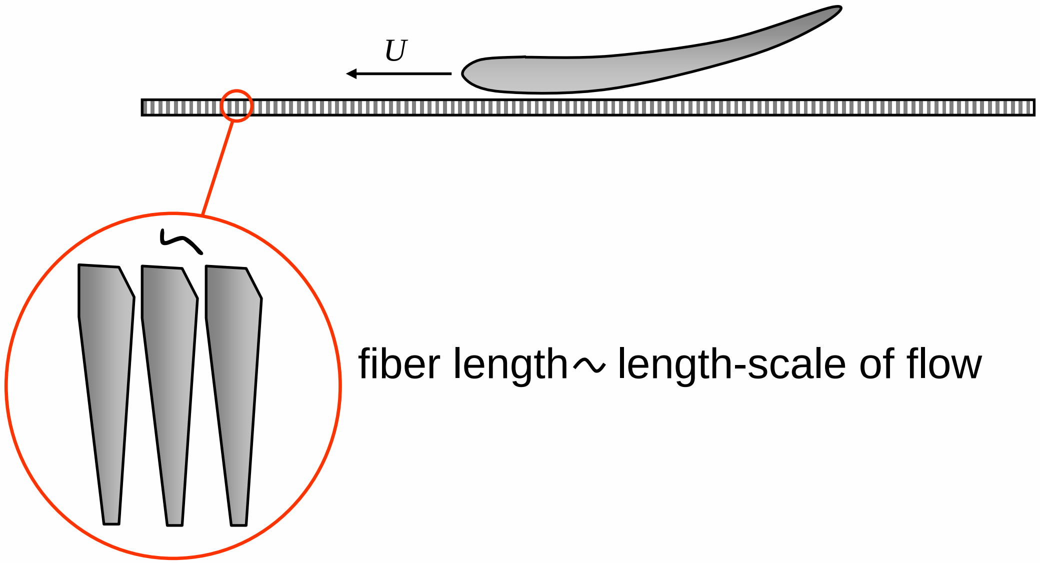
POTENTIAL FLOW SOLUTION





pressure pulse across screen

CONTINUUM LIMIT



fiber length $\sim$ length-scale of flow

Some insight may be gained from alternative models: hinged rods or spheres

FUTURE RESEARCH - EXPERIMENTAL

- Quantify effects of interaction between fibers and turbulence through measurements (i.e. UVP, high speed photography)

  i. Complement existing measurements of yield stress

  ii. Complement existing measurements of wall-layer characteristics

  iii. Measure energy spectra from grid turbulence in dilute and semi-dilute fiber suspensions

  iv. Measure tendency towards flocculation/deflocculation in grid turbulence, turbulent flow through planar and axially symmetric contractions and turbulent shear flow.

FUTURE RESEARCH – NUMERICAL WORK

- Include yield stress and modified wall-layer model in mean-flow momentum equation
- Include a fiber-induced energy-sink term in T.K.E./R.S.T. equation
- Model the required closures in the transport equations for the mean crowding number and its variance based on the results of measurements outlined in iv.
- Implement models in CFX, FLUENT or preferably OPEN FOAM