Towards Efficient Fibre Fractionation Equipment

Fractionation of Fibre Pulp in a Hydrodynamic Fractionation Device

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Pulp Fractionation: Why and How?

- Process efficiency
  - e.g. decrease energy consumption by fractionated refining of pulp

- Defined and/or improved paper properties for a fixed fines content

- Novel products
  - e.g. use of paper fines as MCC source
  - e.g. long fibres for improving strength of polymers

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Fractionation Process

Is

Action

Want
Agenda

(1) Hydrodynamic Fractionation Mechanism
   (i) Fibre Network Formation in Channel
   (ii) Fluid Separation by Side-Channel

(2) Hydrodynamic Fractionation Device

(3) Experimental Investigation
   (i) Image Analysis and Prediction
   (ii) Operational Design Space
   (iii) Fibre Suspension Flow

(4) Conclusion and Outlook
Mechanism 1 | Fibre Network Formation

- **Flexible fibres** in suspension flow aggregate and form *flocs*

- Floc formation and network strength depend on
  - fibre flexibility (fibre coarseness $cs$)
  - fibre length ($L_1$)
  - fibre concentration ($C$)

- Crowding number $N_{CW}$
  \[ N_{CW} = 5 \frac{C L_1^2}{cs} \]


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Mechanism 1 | Fibre Network Formation

- **Flexible fibres** in suspension flow aggregate and form **flocs**

- **Regime** of fibre suspension flow depends on flow rate / **Reynolds number**:
  - plug flow
  - annular plug flow
  - fluidized fibre flow

- **Fluid shear** has to overcome network **yield strength**

Increasing Reynolds number $Re$

- Dense fibre network
- Loose fibre network

Mechanism 2 | Fluid Separation by Side Channel

- Separation of fluid via a side channel
  - **exit layer** divides accept from reject
  - **particles entrained** in accept are **removed**

- **Increase** of accept flow
  - increases the removal efficiency, however
  - deteriorates the fractionation efficiency

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Hydrodynamic Fractionation Principle

- Hydrodynamic Fractionation utilizes fibre network formation to separate fibres from fines

- Flow rate is adjusted to realize annular plug flow

- Accept flow rate is adjusted to remove gap fluid only

Increasing Reynolds number $Re$

Bad | Good | Bad

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Hydrodynamic Fractionation Device for laboratory tests

- Rectangular channel 15 by 3 mm
- Back facing separation channel, 780 mm downstream
- Purge option for plug-free continuous operation
- Feed and accept flow rate separately controlled
Hydrodynamic Fractionation Device

- **Flow regime** identified via high-speed imaging
- Determine exit layer height $H^*$ relative to network interface
- Fractionation performance: evaluate the grade efficiency $T(l_{\text{Fibre}})$, and
- total **fines removal** versus fibre loss

$$ H^* = \phi^+ = \frac{m(\text{Accept})}{m(\text{Feed})} $$

$$ T(l_{\text{Fibre}}) = 1 - \frac{\text{Accept}(l_{\text{Fibre}})}{\text{Feed}(l_{\text{Fibre}})} $$
Experiments at channel Reynolds numbers $Re$ of 1300, 2500, and 3700

Acquisition frequency adjusted to flow rate: consistent fibre images
Image based prediction of the grade efficiency

Goal: optimum fractionation

Setting: Reynolds number

Image analysis:
- Average grey value
  - Re 1300: 0.20
  - Re 2500: 0.10
  - Re 3700: 0.02

Wall
Exit layer
HDF | Fibre Motion in Channel Flow

➢ Image based prediction of the grade efficiency

➢ **Goal:** optimum fractionation

➢ **Setting:** Reynolds number

➢ **Image analysis:** average grey value

➢ **Prediction** of fractionation performance from image analysis
HDF | Fractionation Performance

Separation Benchmark Definition

- Test pulp: unrefined, chemical sulphite pulp, 100% spruce, bleached and washed from Sappi Gratkorn,
- Fibre concentration 0.1%: $N_{CW}$ 9.5
- Variation of feed and accept flow rate:
  - Reynolds number $Re$ (flow regime), and
  - Accept flow rate $\Phi^+$ setting exit layer height
- Fractionation results summarized in design space, and
- Compared to the flow regime

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Operational Design Space

- Conclusions on the fractionation performance:
  1. More fines are removed
  2. Fibres more sensitive to $Re$
  3. Best fractionation at low $Re$

![Diagram showing fractionation performance](image-url)
HDF | Fractionation Performance

Operational Design Space

- Conclusions on the fractionation performance:
  1. More fines are removed
  2. Fibres more sensitive to Re
  3. Best fractionation at low Re

- Process parameter selection for desired performance

- Operational window to balance changes in feed flow rate (Re) by setting accept

Fines < 0.2 mm

Fibres > 0.2 mm

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Experimental Cases

Reynolds number $Re_{1300}$

$\phi^+$

0.02 0.05 0.10 0.15 0.20

Wall Interface Exit Layer

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Experimental Cases

Reynolds number $Re$ 1300

<table>
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HDF | Fibre Suspension Flow

Experimental Cases

Reynolds number $Re = 1300$

$\Phi^+ = 0.02, 0.05, 0.10, 0.15, 0.20$

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HDF | Fibre Suspension Flow

Experimental Cases

Reynolds number $Re$ 2500

$\phi^+$

0.02 0.05 0.10 0.15 0.20

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Experimental Cases

Reynolds number $Re$ 2500

$\phi^+$ values:
- $0.02$
- $0.05$
- $0.10$
- $0.15$
- $0.20$

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Experimental Cases

Reynolds number $Re = 3700$

Fines

- $\phi^+ = 0.02$
- $\phi^+ = 0.05$
- $\phi^+ = 0.10$
- $\phi^+ = 0.15$
- $\phi^+ = 0.20$

Fibre

Wall

Exit Layer

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HDF | Fibre Suspension Flow

Experimental Cases

Reynolds number $Re \ 3700$

$\phi^+ \ \ \ \ \phi^+ \ \ \ \ \phi^+$

$0.02 \ \ \ \ \ 0.05 \ \ \ \ 0.10 \ \ \ \ 0.15 \ \ \ \ 0.20$

Mass flow per fibre length class for different exit layer heights

$\text{Rel. Mass Removal} = \frac{\text{Accept} \cdot C_{\text{Accept}} \cdot \Delta Q_{i,\text{Accept}}}{\text{Feed} \cdot C_{\text{Feed}} \cdot \Delta Q_{i,\text{Feed}}}$

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Variation of accept flow rate $\phi^+$ allows investigation of exit layer height $H^*$ variation on fibres and fines removal.

Fines are not homogeneously distributed across channel height!

![Graphs showing exit layer height $H^*$ vs. relative mass removal for different Reynolds numbers (Re 3700, Re 2500, Re 1300)].

- Homogeneous distribution
- Fines 0 - 0.2 mm
- Fibre 0.2 - 1 mm
- Fibre 1 - 5 mm
HDF | Conclusion

➢ **Hydrodynamic Fractionation** describes fractionation of fines from fibres where
   ➢ fines are excluded from **network** formed by **long fibres**, and the **fines rich suspension** is removed.

➢ Fractionation performance is dominated by the **relative position** of the **exit layer** and the **network-fluid interface**.
   ➢ The **network-suspension interface** position is a function of the **network strength** and the Reynolds number **Re**.
   ➢ Image analysis can be used to determine the network-suspension interface.
   ➢ The exit layer position is set by the **accept flow rate** $\Phi^+$.

Increasing Reynolds number $Re$

Reject

Accept

Bad  Good  Bad
Open scientific questions, that are subject of current research are:

➢ What is the impact of fibre network strength on the fractionation?
   ➢ Fractionation of softwood-hardwood mixtures

➢ What is the nature of fines in the accept as a function of process and pulp parameters?
   ➢ Accept fines fraction >> Britt Jar tester
   ➢ Fines are studied by use of light microscopy and customized evaluation algorithms
   ➢ Method: Melanie Mayr, Tuesday, Session 3
PROJECT MEMBERS

Industrial partners:

- Norske Skog
- Bruck
- mondi
- heinzelpulp
- sappi

Scientific Partners:

- BOKU (University of Natural Resources and Life Sciences, Vienna)
- TU Graz
- Wegener Center
- UNIGRAZ
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