OPTIMAL FIBER FRACTIONATION FOR WOOD-BASED BIOREFINERIES

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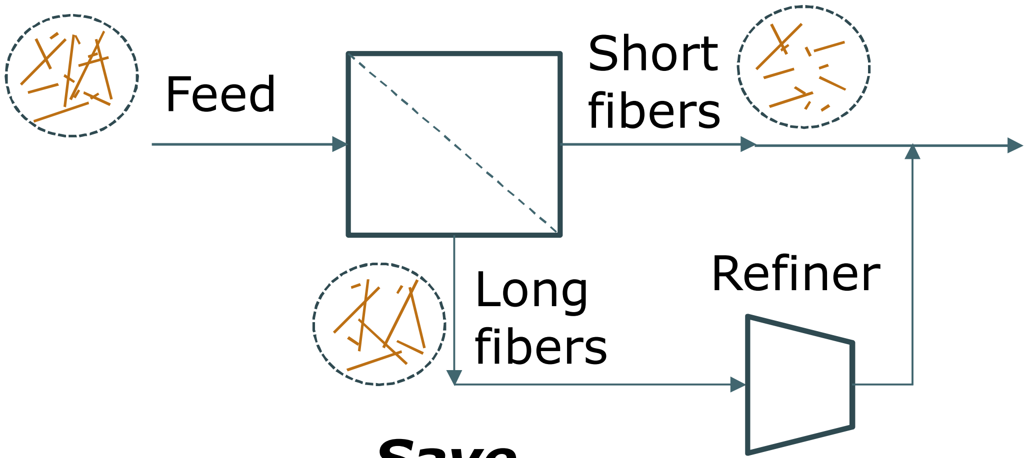
2020-09-21, WCPT9

13+2 min

MOTIVATION

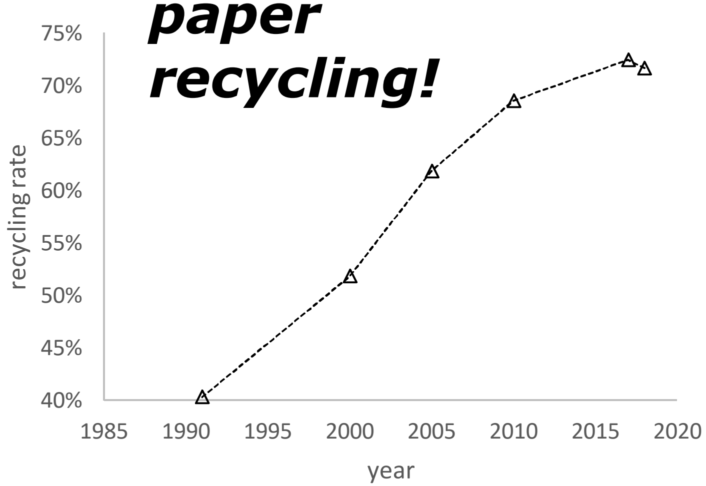
Fractionation-based stock preparation concepts

Selective refining



Save energy!

Improve paper recycling!

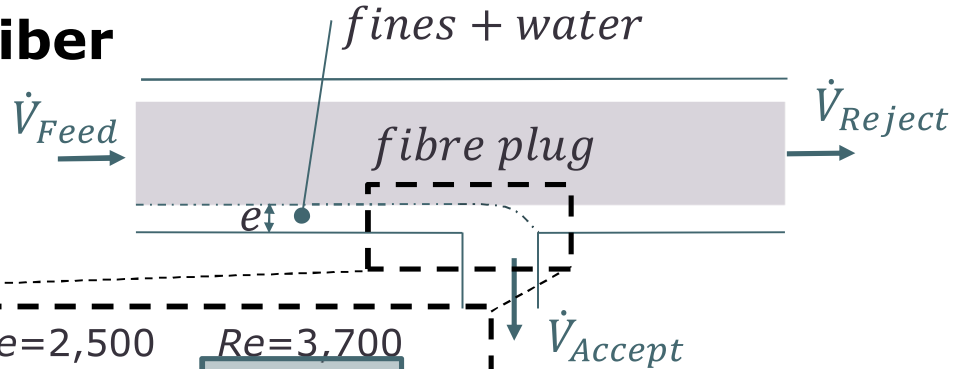


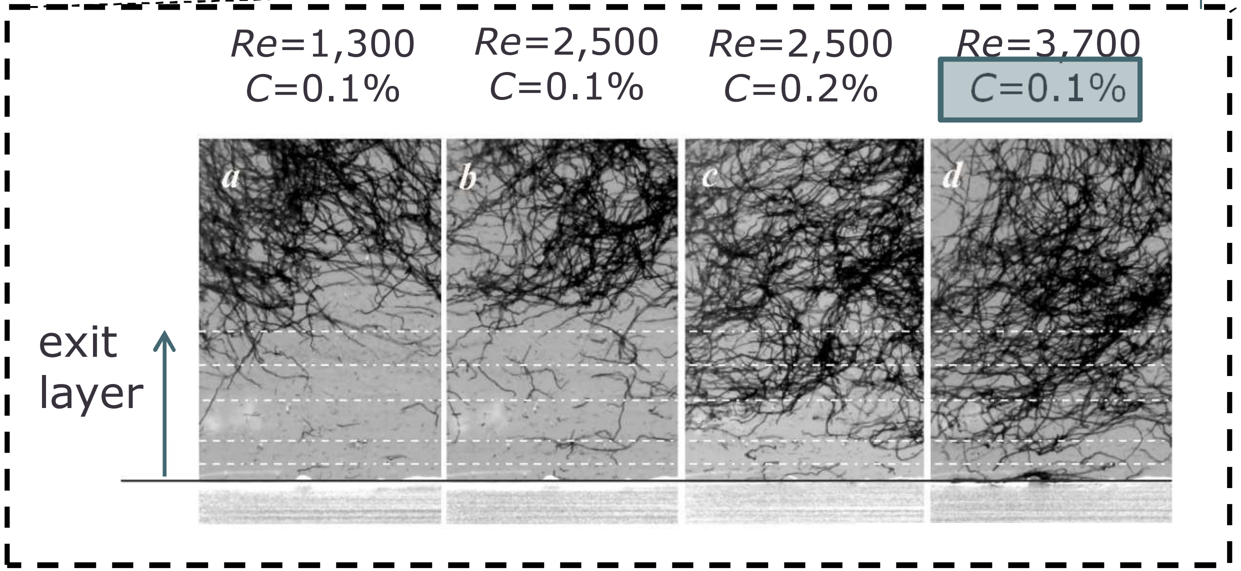
Key statistics European pulp & paper industry, CEPI (2018)

MOTIVATION

Principe of hydrodynamic fiber fractionation (*HDF*)

Redlinger-Pohn et al., 2017, 2020 (doi:10.1007/s10570-020-03443-9)

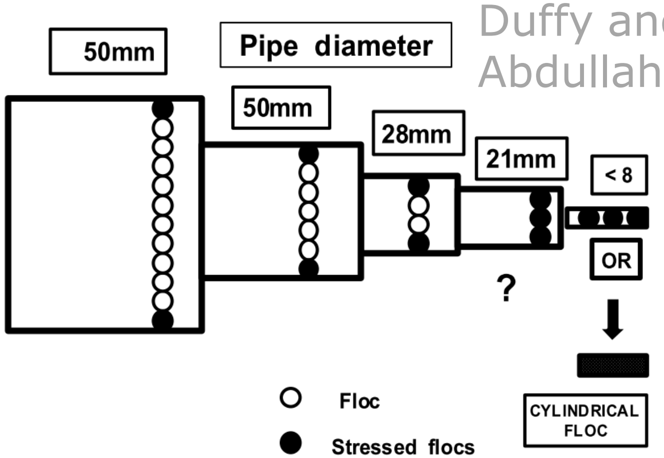




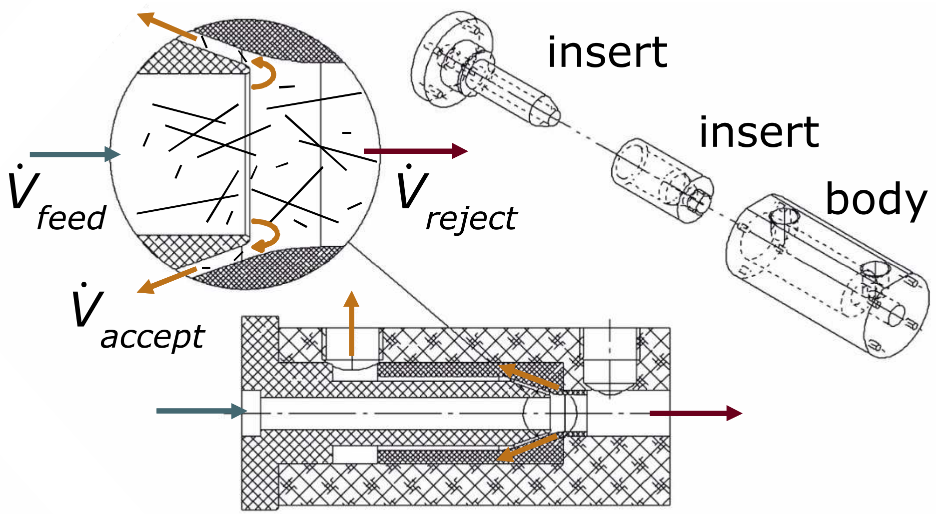
!!TOO DILUTE!!

MINIFRAC: A DOWNSIZING APPROACH

miniFRAC: a downsized HDF



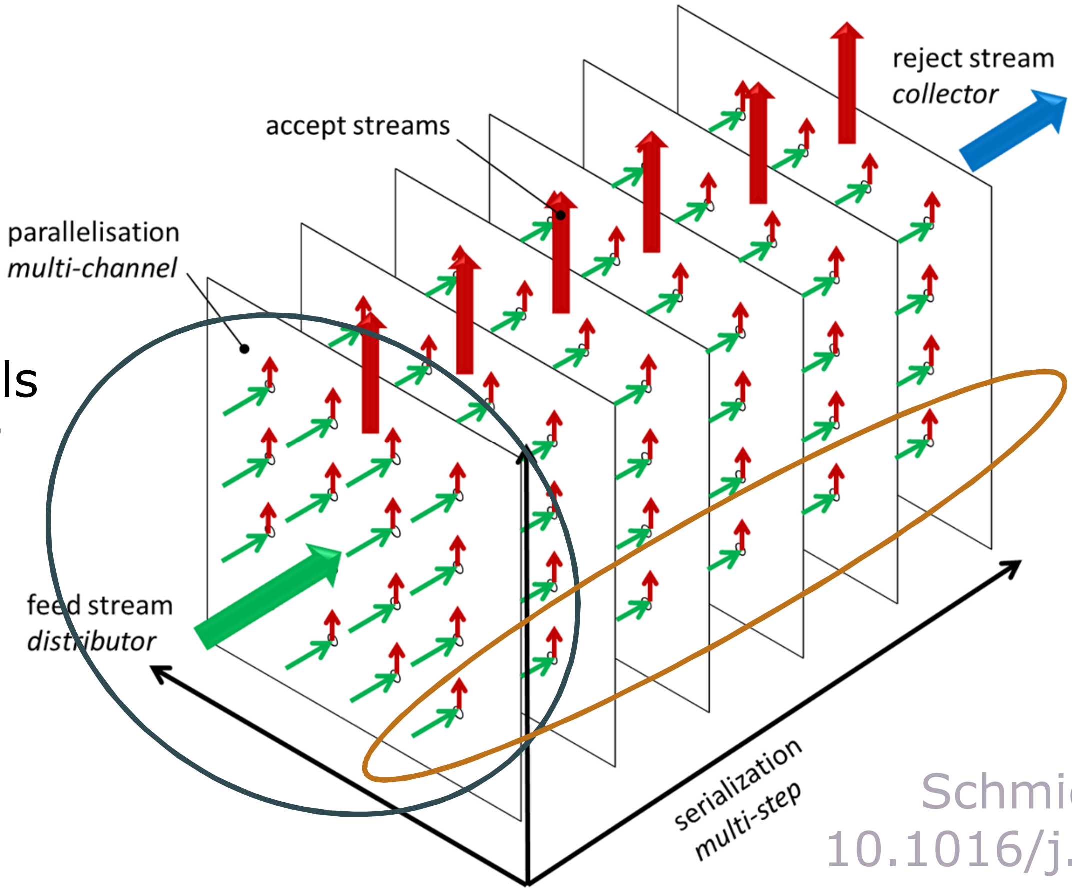
Duffy and Abdullah, 2003



- **Single floc regime**
  - $D_{floc}<D_{channel}$ $(D_{channel}<7L_{fiber})$

SCALE-UP TOWARDS AN INDUSTRIAL PROCESS

Pilot plant
- 16 channels
- distributor
- collector

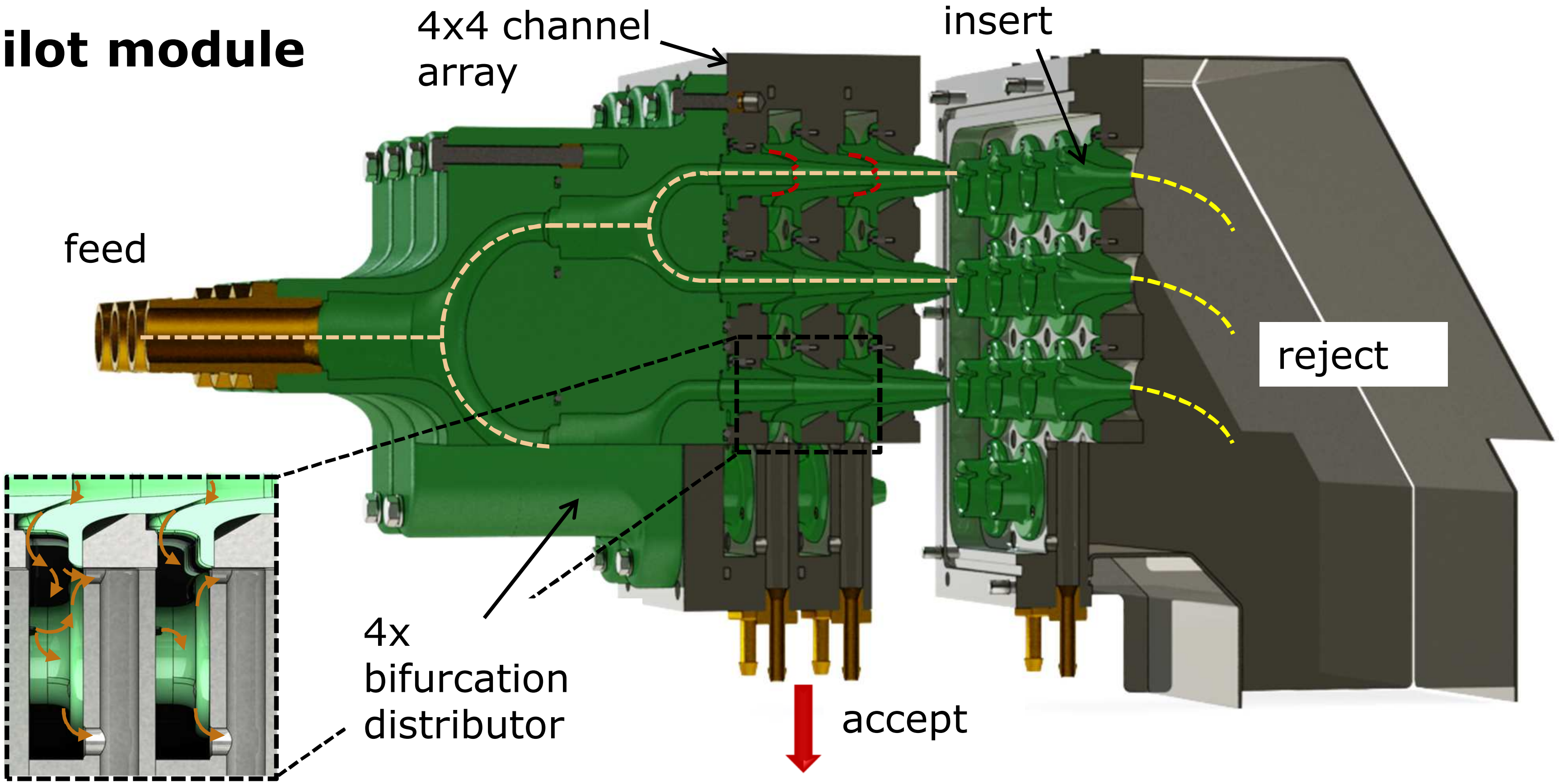


Multi-step experiment
- 20 steps
- collector strategy

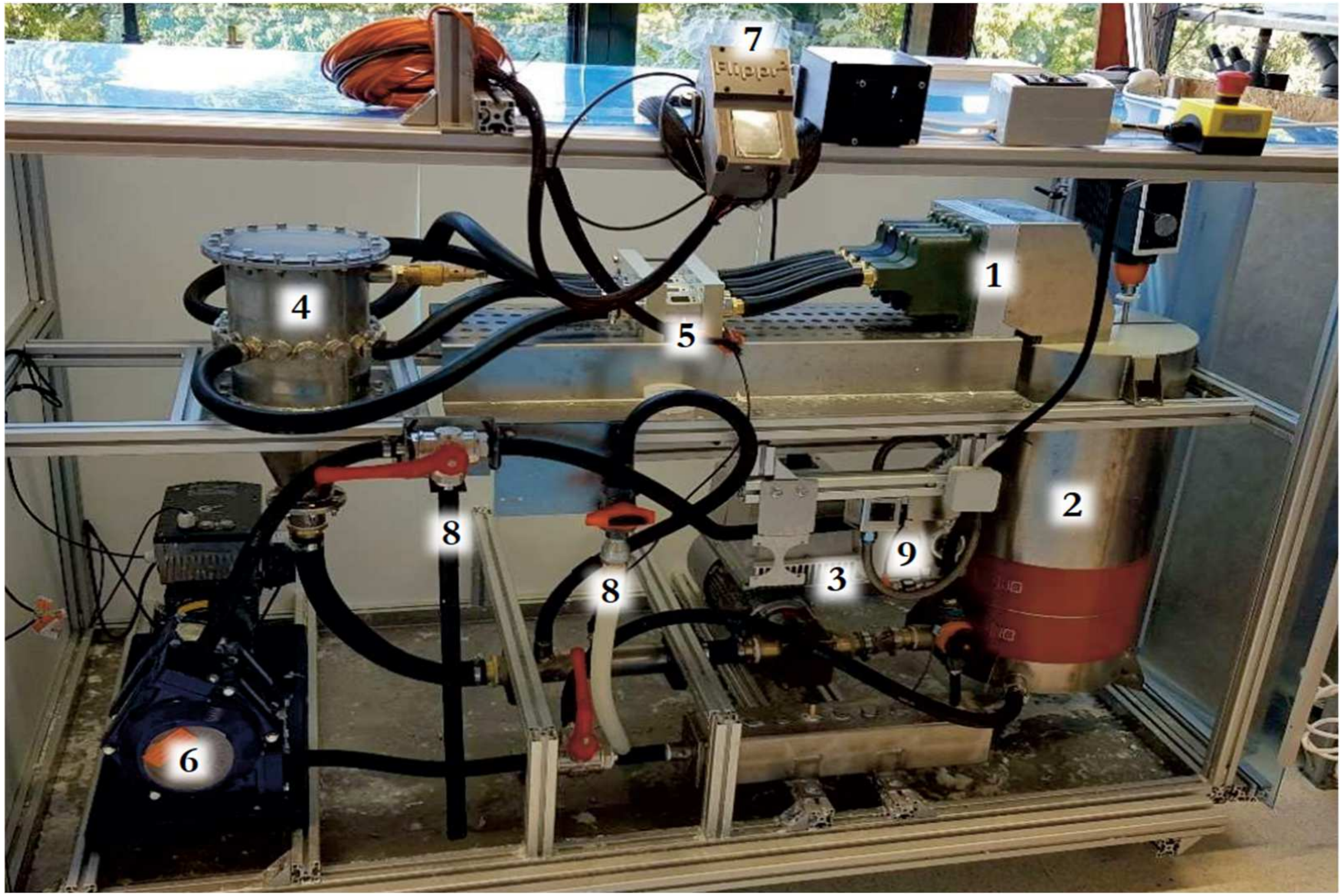
Zachl, 2019
Schaub, 2020
Schmid et al., 2020 (doi: 10.1016/j.cep.2020.107965)

SCALE-UP TOWARDS AN INDUSTRIAL PROCESS

Pilot module



SCALE-UP TOWARDS AN INDUSTRIAL PROCESS



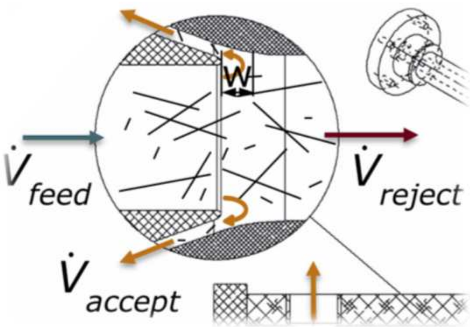
SCALE-UP TOWARDS AN INDUSTRIAL PROCESS

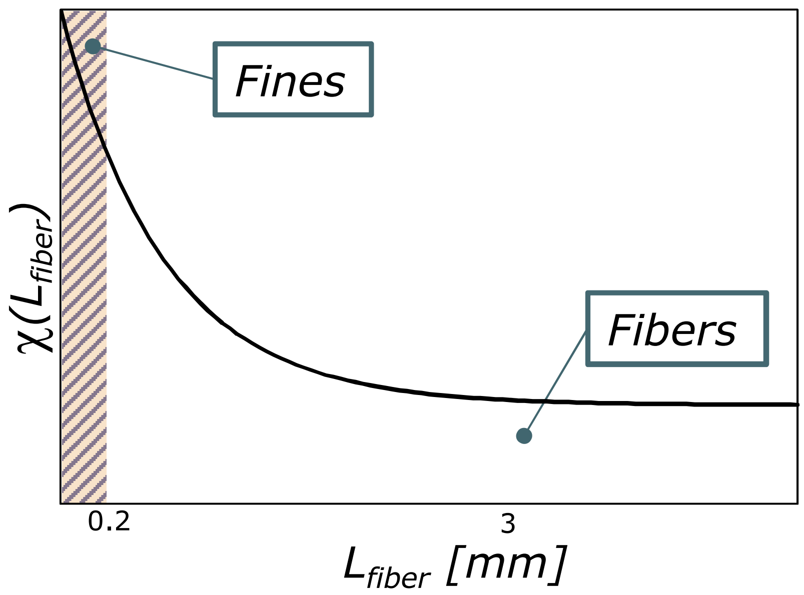
Fractionation capacity

$$\chi_i = \frac{\dot{m}_{fiber,Accept}}{\dot{m}_{fiber,Feed}}$$

$$\chi_i(L_{fiber}) = \frac{\dot{m}_{fiber,Accept}(L_{fiber})}{\dot{m}_{fiber,Feed}(L_{fiber})}$$

$$\phi^{+} = \frac{\dot{V}_{accept}}{\dot{V}_{feed}}$$





SCALE-UP TOWARDS AN INDUSTRIAL PROCESS

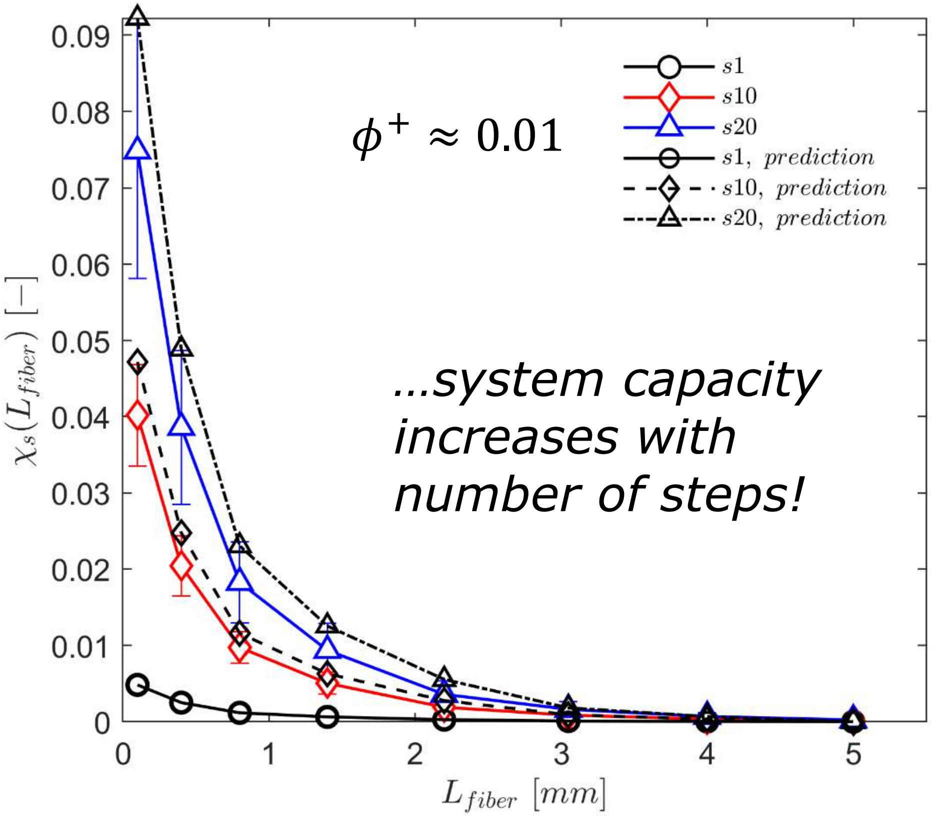
Multi-step experiment

- Series connection of fractionators (connected by the coarse fractions)

$$T_{tot}(L_{fibre}) = \prod_i T_i(L_{fibre})$$

$$\chi_i(L_{fibre}) = 1 - T_i(L_{fibre})$$

$$\chi_{tot}(L_{fibre}) = 1 - \prod_i \left(1 - \chi_i(L_{fibre})\right)$$

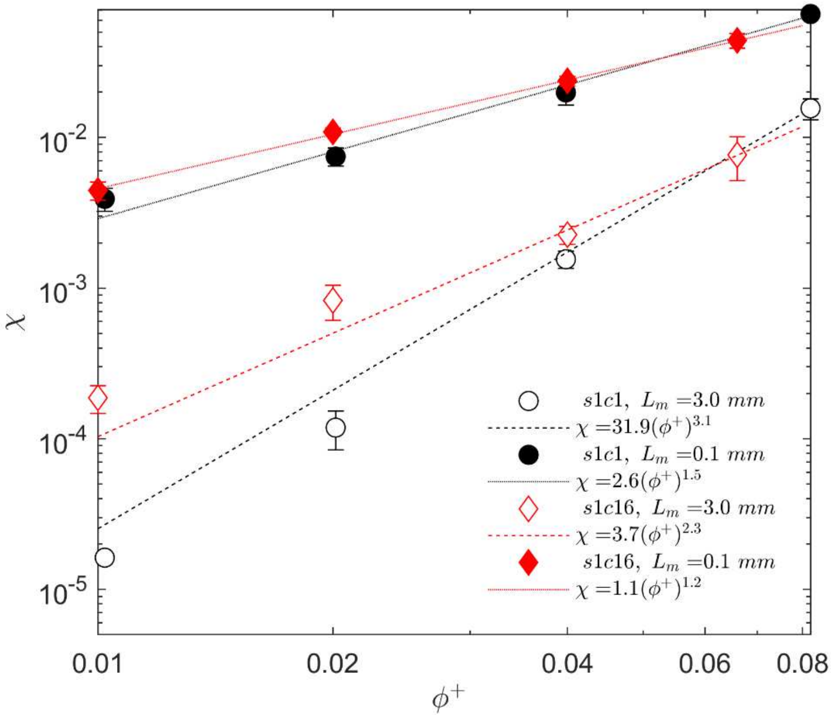


…system capacity increases with number of steps!

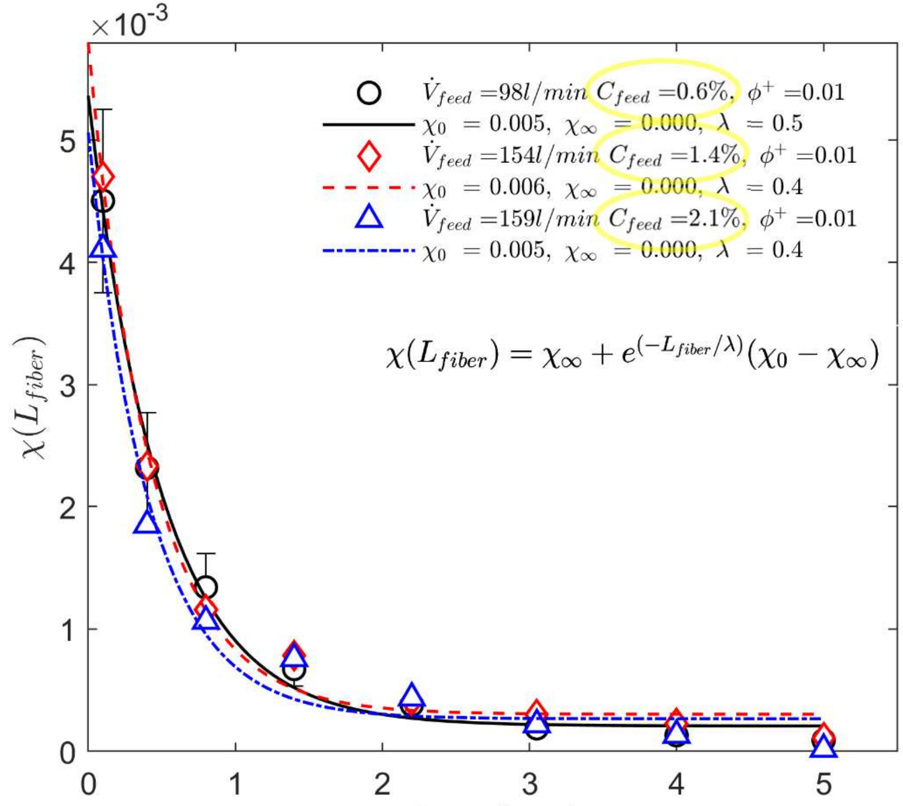
SCALE-UP TOWARDS AN INDUSTRIAL PROCESS

Pilot module

…vs single channel experiment



…increasing the feed mass flow rate



OPTIMIZATION STUDY

Objective Function (MA =Monetary Assets)

benefit [MA/t] fractionation capacity (yield)

$$R_{frac}^{tot}(i) = \dot{m}_{feed} Pr_{acc}\, \varsigma^{acc}(i)\, \chi_{tot,n_i} + \dot{m}_{feed} Pr_{rej}\, \varsigma_{rej}^{excl}(i)\left(1-\chi_{tot,n_i}\right) \quad \left[{}^{MA}\!/_{h}\right]$$

product quality metrics

no fractionation „offsets“

$$R_{net}(i) = R_{frac}^{tot}(i) - \underbrace{\dot{m}_{feed}\left(Pr_{acc}\, sf\, \chi_{tot,n_i} + Pr_{rej}\, \chi_{tot,n_i}\left(1-\chi_{tot,n_i}\right)\right)}_{\text{no fractionation benefit rate}} \quad \left[{}^{MA}\!/_{h}\right]$$

energy cost [MA/kWh]

$$f(i) = \underbrace{\dot{m}_{feed}\, Pr_{e}\, e_{feed}^{C_{\max}}(i)}_{\text{energy cost rate}} - R_{net}(i) \quad \left[{}^{MA}\!/_{h}\right]$$

specific energy demand [kWh/t]

Schmid et al., 2020
(Nordic PP Res. J.)

OPTIMIZATION STUDY

Constraints

$$C_{feed}^{\max} = c_9 \left(\frac{\dot{V}_{rej}}{n} \right)^2 + c_{10} \left(\frac{\dot{V}_{rej}}{n} \right) + c_{11} \quad ; \quad C[\%], \dot{V}[l / \min]$$

max. feed consistency = 2.6%

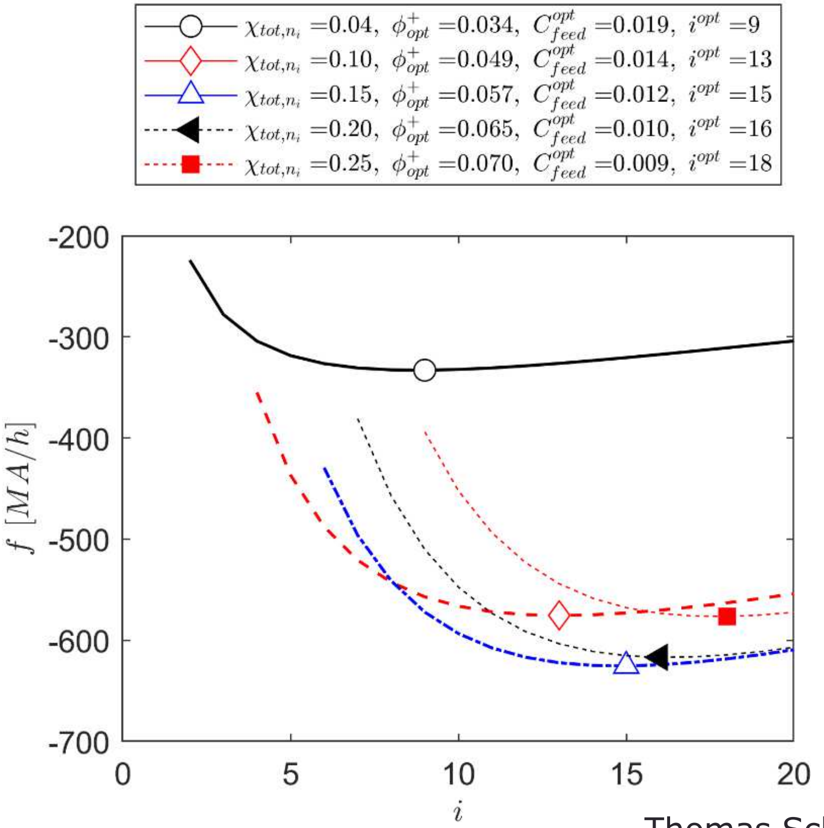
$C_{rej}^{\max}$ **max. reject consistency = 2.5%**

Base Case Scenario

- 180 parallel channels
- 1,800 l/min feed flow rate
- Pr_e = 1 MA/kWh
- Pr_{acc} = 100 MA/t, Pr_{rej} = 100 MA/t

OPTIMIZATION STUDY

Effect of total fractionation capacity on Optimum

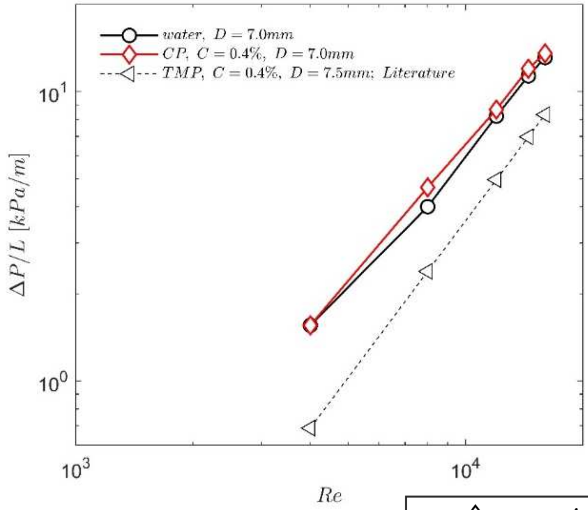


- maximum profitability for a **total fractionation capacity of approximately 0.15** for the chosen base case scenario
- optimum accept ratio ϕ^+ **of approximately 0.06**
- **15 steps** are optimal

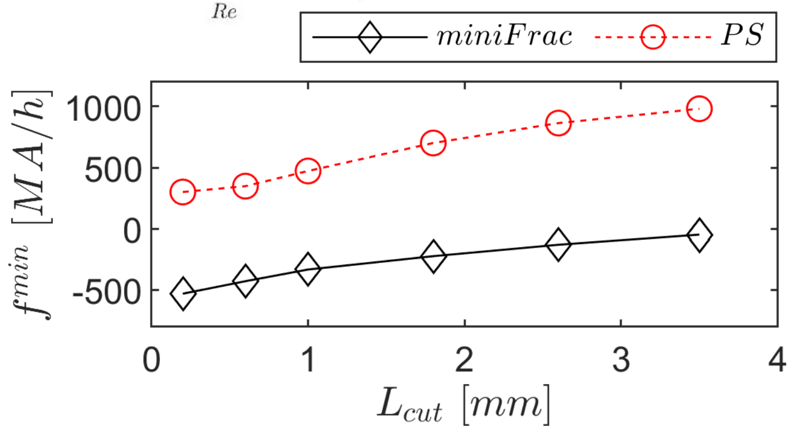
Schmid et al., 2020
(Nordic PP Res. J.)

CONCLUSIONS

- miniFrac – **the benefits of downsizing**
  - pressure drop suspension = pressure drop of water
  - mini-channel enhances fiber fractionation {≠f(*Re*)}



- **optimized miniFrac**
  - less than 20 steps yield optimum
  - accept ratio should be chosen comparably high
  - certain loss of fibres into accept has to be accepted
  - can challenge pressure screens



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Flippr²

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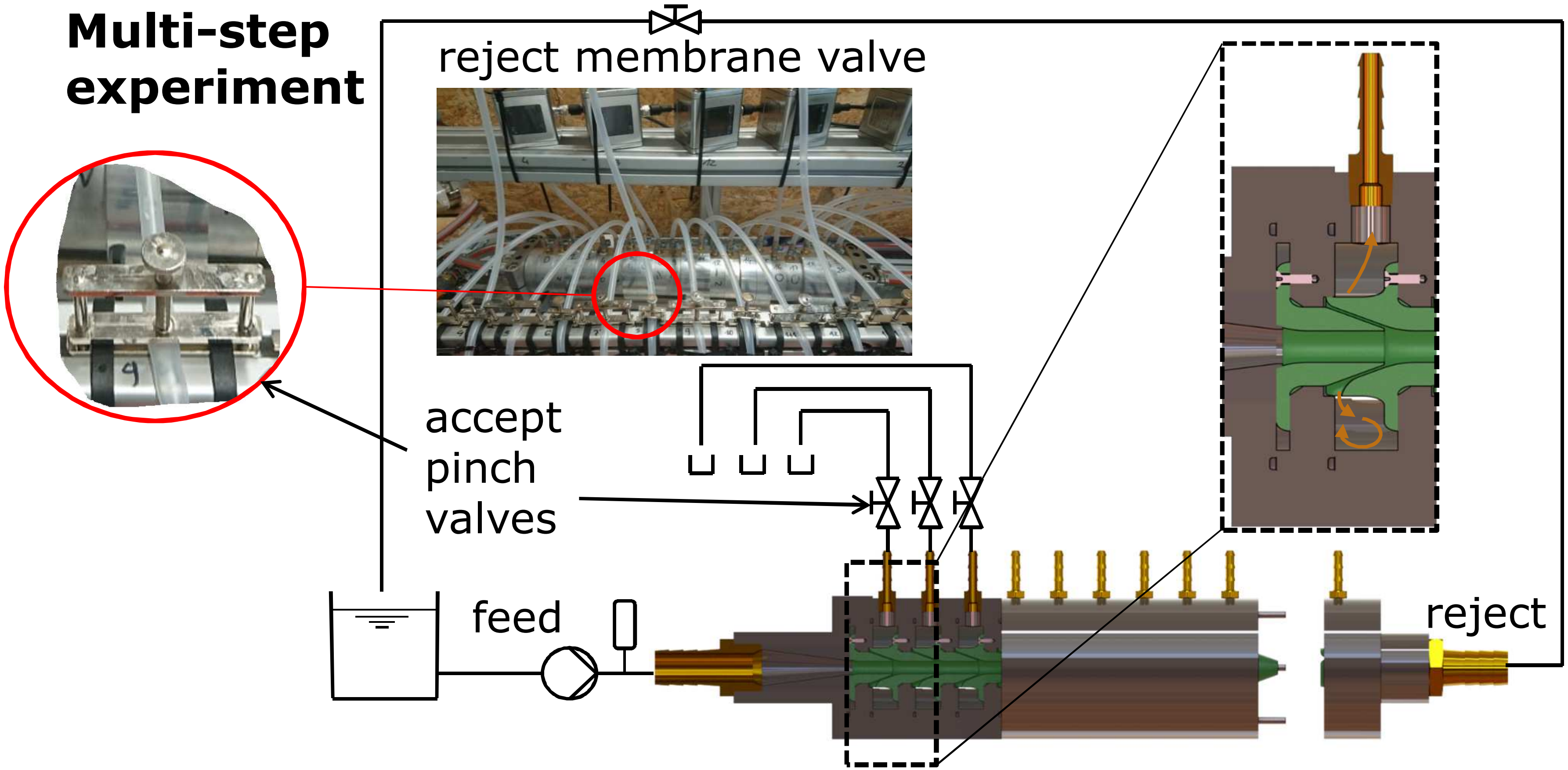
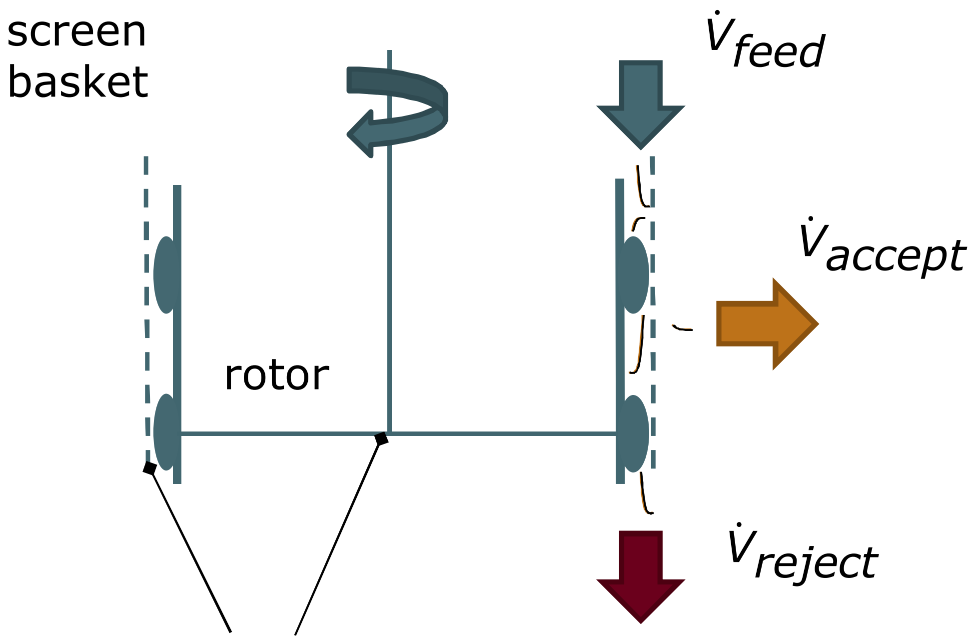
SCALE-UP TOWARDS AN INDUSTRIAL PROCESS

Multi-step experiment



MOTIVATION

Pressure Screen

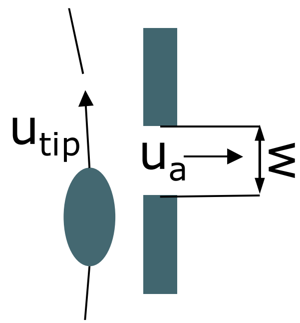


- **wear parts**

- **high** energy consumption

$P \sim u_{tip}^3$ Delfel, 2011

- **Selectivity** →← **Capacity**



Selectivity ↗

u_a ↘, w ↘

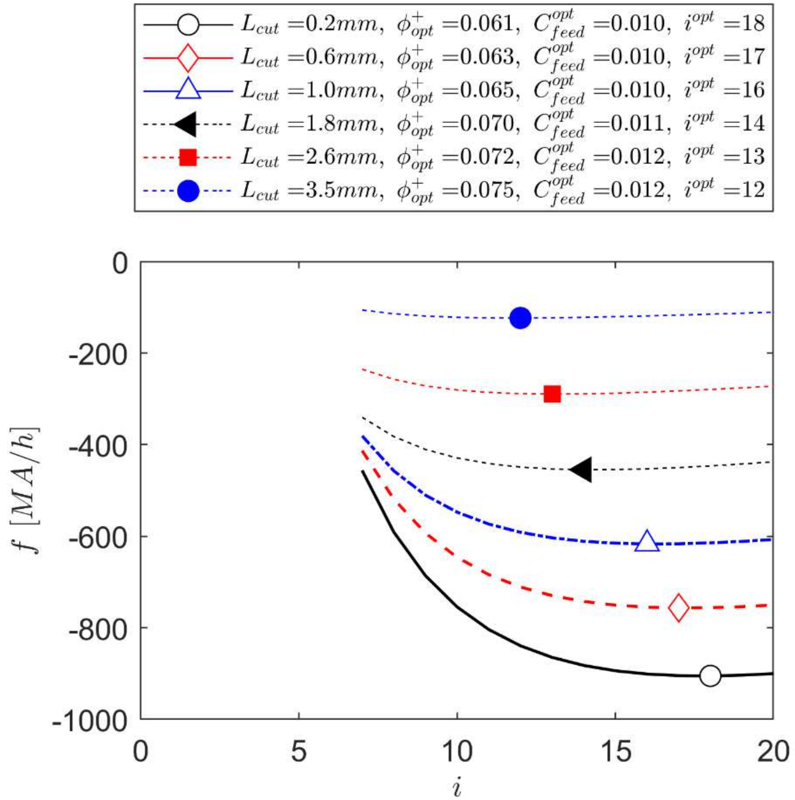
Capacity ↗

u_{tip} ↗, u_a ↗, w ↗

Olson, 2001
Jokinen, 2007
Salem et al., 2014

OPTIMIZATION STUDY

Effect of cut size on Optimum Design Point



- **profitable** based on OpEx **for all realistic steps numbers**
- between 12 and 18 steps yield optimum (**base case: 16 steps, 1% feed consistency**)
- ***L_{cut}* affects** optimum significantly