Towards Simulation-based Engineering of Fibre Fractionation Equipment

State of the Art Open-Source Simulation Tools

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Agenda

(1) Intro & State of the Art
- (i) What is Simulated-Based Engineering?
- (ii) Fibre Modeling

(2) A New Open-Source Fibre Simulation Code
- (i) Code and Modeling Approach
- (ii) Fibre Behavior in Classical Flow Situations

(3) Case study: Can we Predict Fibre Segregation in Coiled Tubes?

(4) Conclusion & Outlook

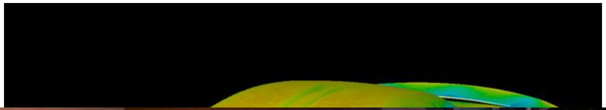





IPPT FLIPPR team

What is Simulation Based Engineering?

Why not in the pulp &



Source: www.teslamotors.com

Engineering by trial and error – the 20th century approach for design

Simulation guided engineering – 21st century approach for efficient engineering

Fibre Modeling

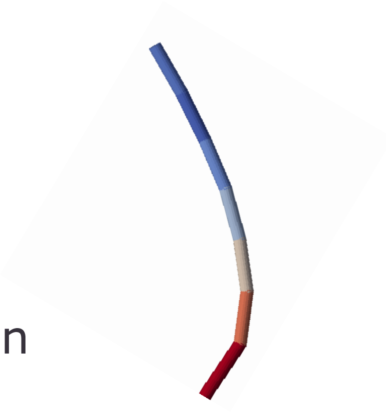
Two approaches found in the literature. **Multi-cylinder** where fibre is modelled by joined cylinders or as **stiff spheroids**.

Multi-cylinder approach [1]

Fibres are flexible and deformable

Stiffness needs to be tuned to data

Expensive calculation

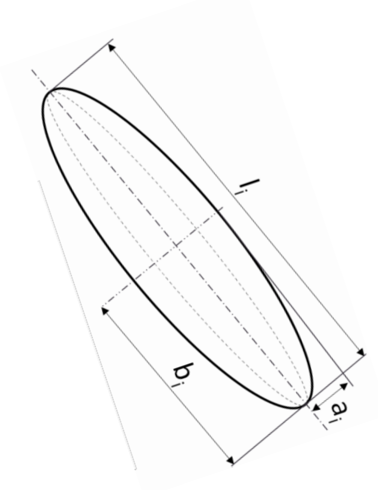


Spheroid approach [2]

Fibres are stiff

Easier and cheaper calculation of fibre wall and fibre fibre interaction

Used for suspension of fibres



[1] J. Andric, et.al., Acta Mech. 224 (2013) 2359-2374

[2] C. Marchioli, et.al., Physics of Fluids 22 (2010) 033301-1 – 033301-14

Code and Modeling Approach

1 – Multipurpose Continuum Solvers

- OpenFOAM®
- CFDEM®
- Palabos
- ANSYS Fluent
- AVL Fire®

2 – Multipurpose Lagrangian Solvers

- Yade / WooDEM
- LAMMPS / LIGGHTS®
- SimPARTIX®
- EDEM
- Itasca PFC

Open-source

Selection Criteria for Fibre Applications

(1) **Collision handling** for non-spherical particles

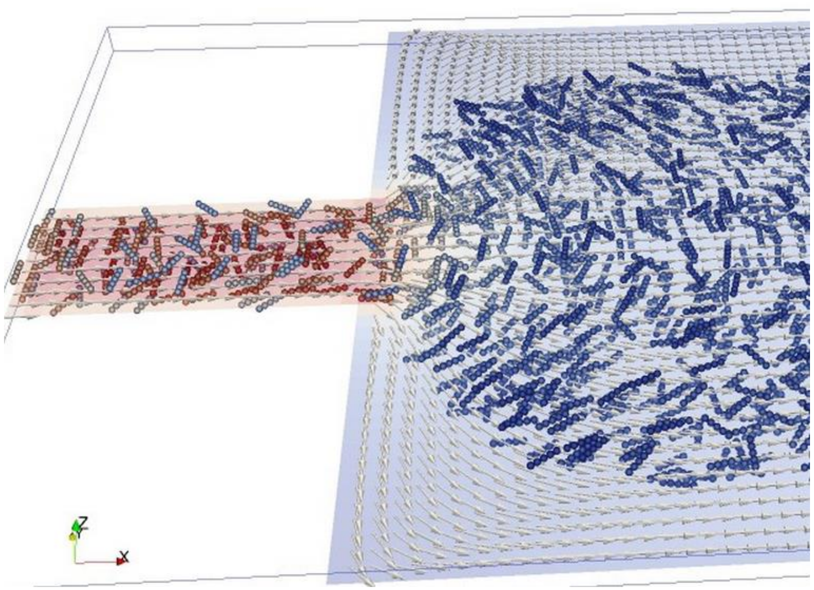
(2) **Flexible and deformable** particles

(3) Advanced **coupling models** (i.e., for the fluid-particle interaction forces and torques)

(4) Efficient **parallelization** for Euler-Lagrange co-simulations

Code and Modeling Approach

LIGGGHTS® & CFDEM®



Free stream of fibre suspension,
© DCS Computing GmbH

Implemented into LIGGGTHS® & CFDEM®

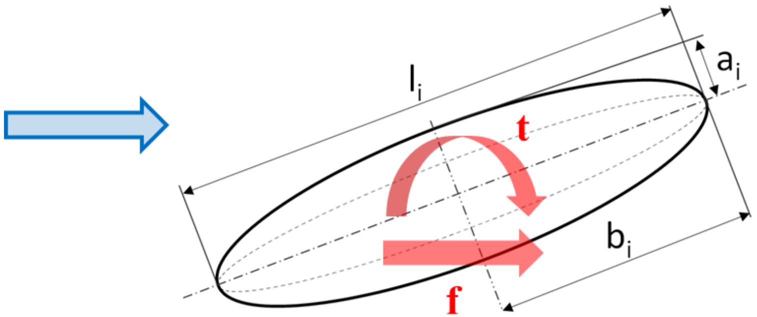
(1) Multisphere approach to model rigid fibres (drawback: low efficiency & "rough" particles)

(2) "POEMS" package to model **flexible particles** (multicylinder approach)

(3) Cohesion forces (van der Walls forces, liquid bridges, etc.)

Code and Modeling Approach

LIGGGHTS® & CFDEM®



Rigid fibre represented as spheroid in suspension flow. Forces and torque on the fibre are indicated in red

Our Contribution to LIGGGHTS® & CFDEM®

(4) Fibre-wall interactions

(5) Fibre-Fibre interaction

(6) Lubrication forces between fibres and fibre-wall

(7) Surface **roughness effects**

(8) Implicit **fibre-fluid** drag and torque interaction

Fibre Behavior in Classical Flow Situations

Case (1) – Fibre in Shear Flow (Jeffery Orbit).

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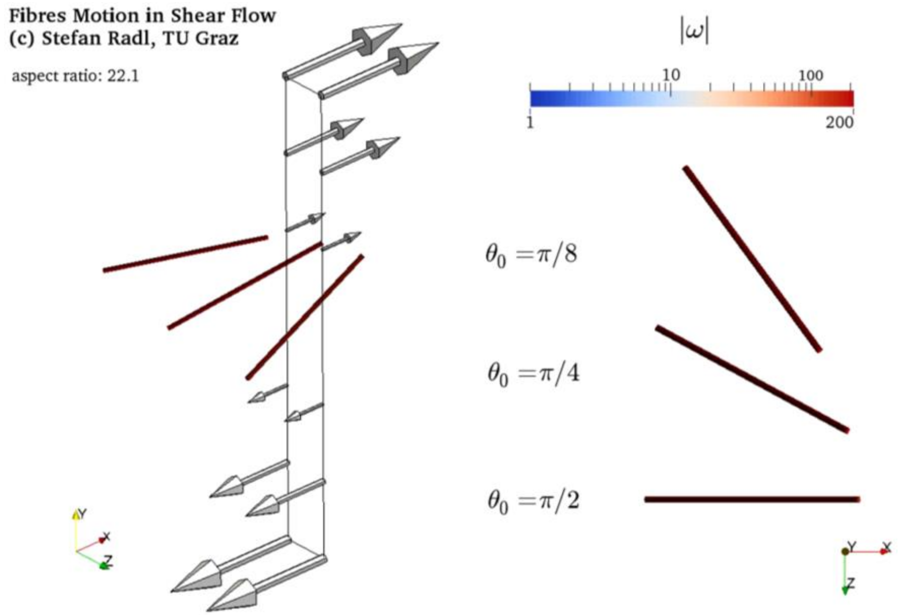
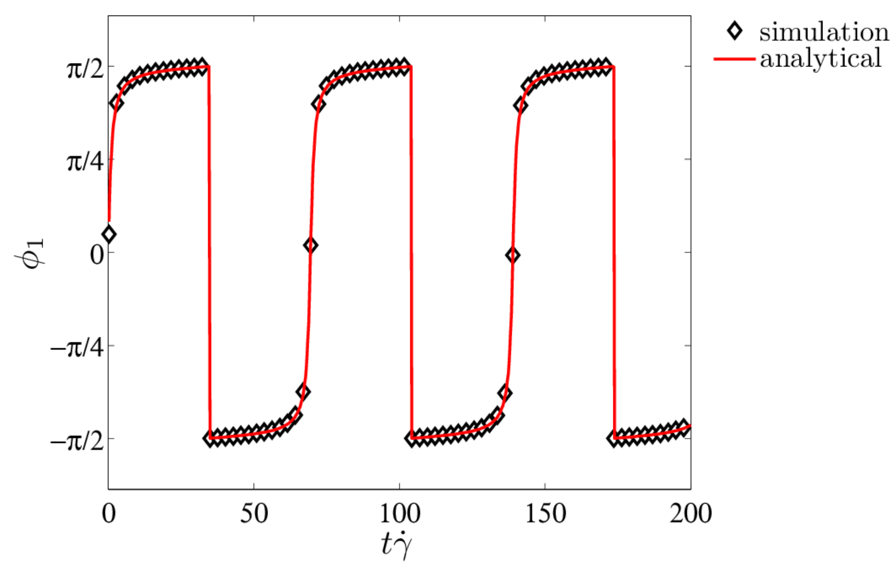


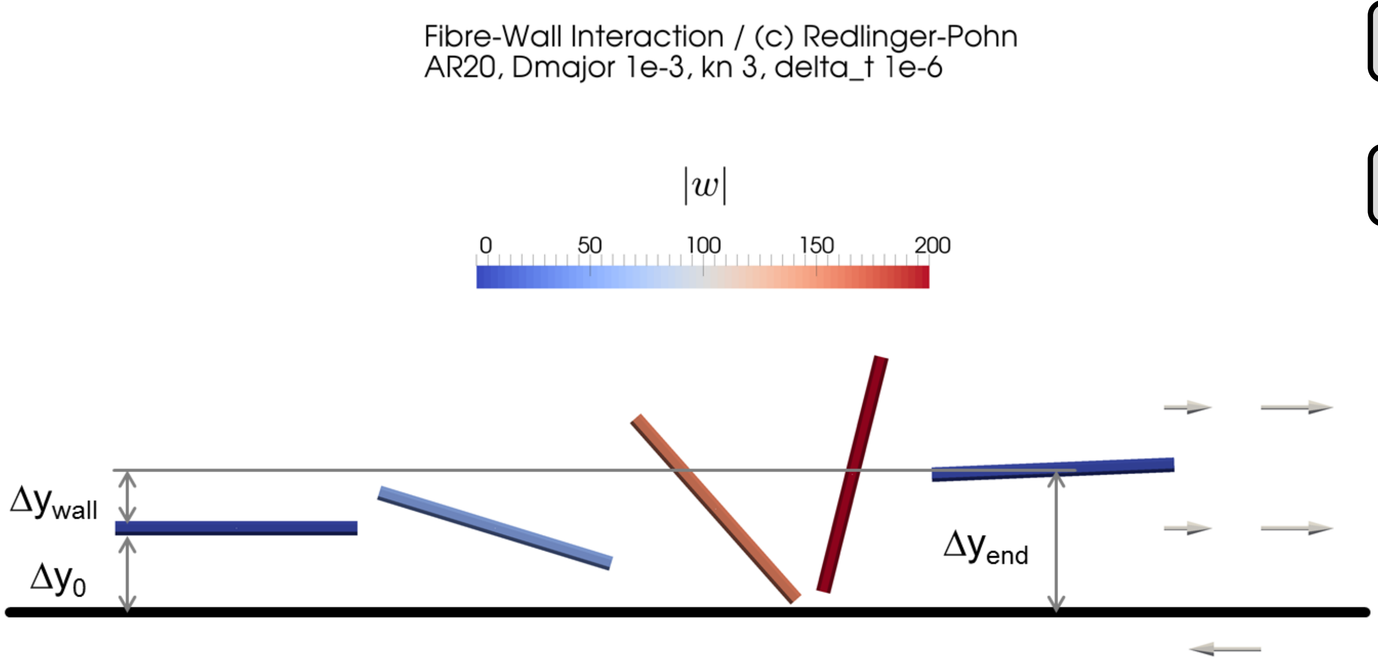


Fibre Behavior in Classical Flow Situations

Case (2) – Fibre/Wall Interaction (fibre close to walls).

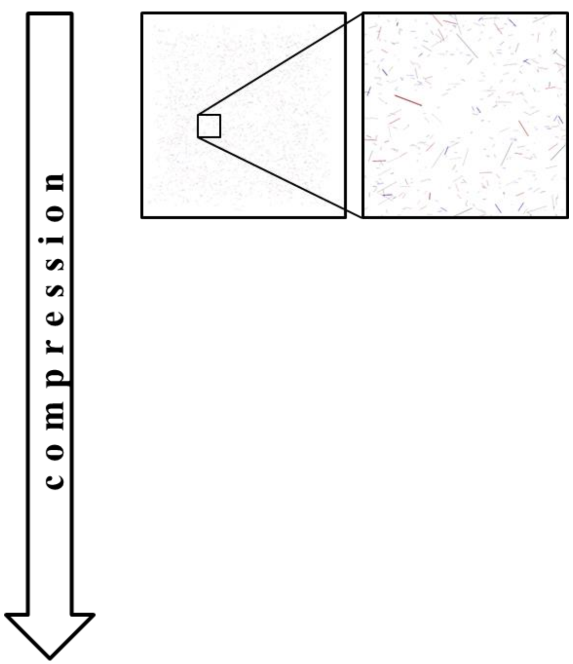
Δy_0 = 0.35 D_{major}

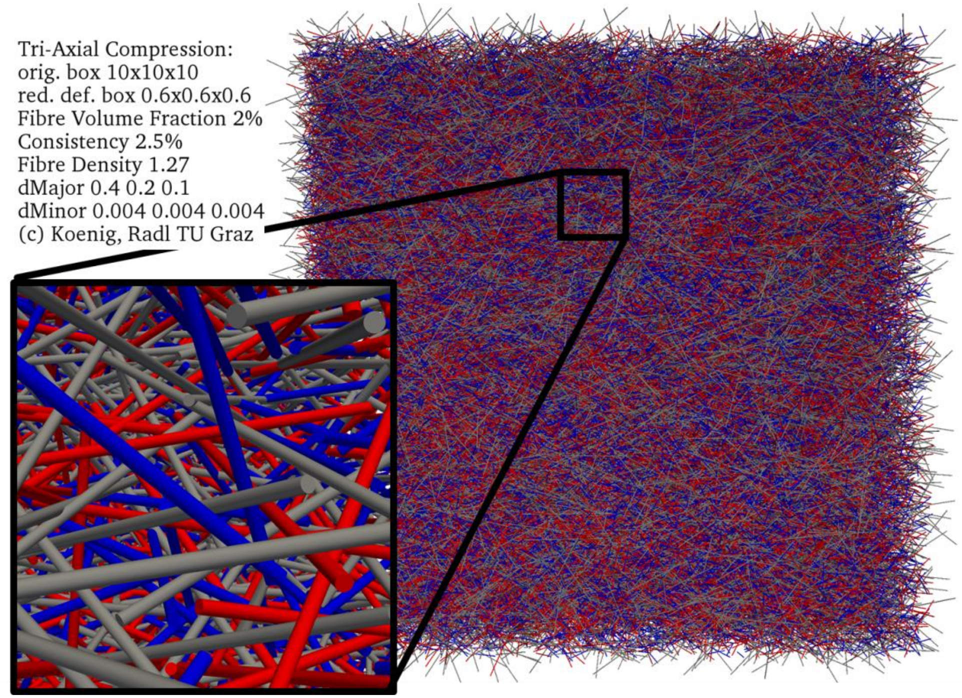
Δy_0 = 0.15 D_{major}



Fibre Behavior in Classical Flow Situations

Case (3) – Fibre/Fibre Interaction (formation of flocks from thin suspension).

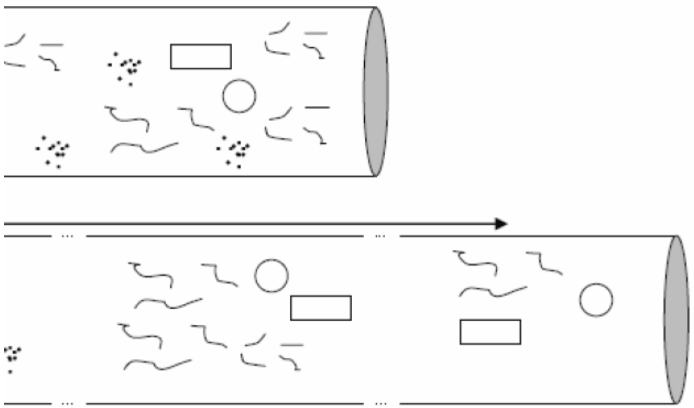




Case study: Can we Predict Fibre Segregation in Coiled Tubes?

Fibre suspension flow in coiled tubes is common process in any paper mill. From experimental studies with a coiled tube it is known that

- ✓ **fibres segregate** according to their length [1].
- ✓ However, the segregation mechanism **is not understood**.
- ✓ Currently: **black-box model**
- ✓ Hypothesis: **turbulent fluctuations** cause separation.

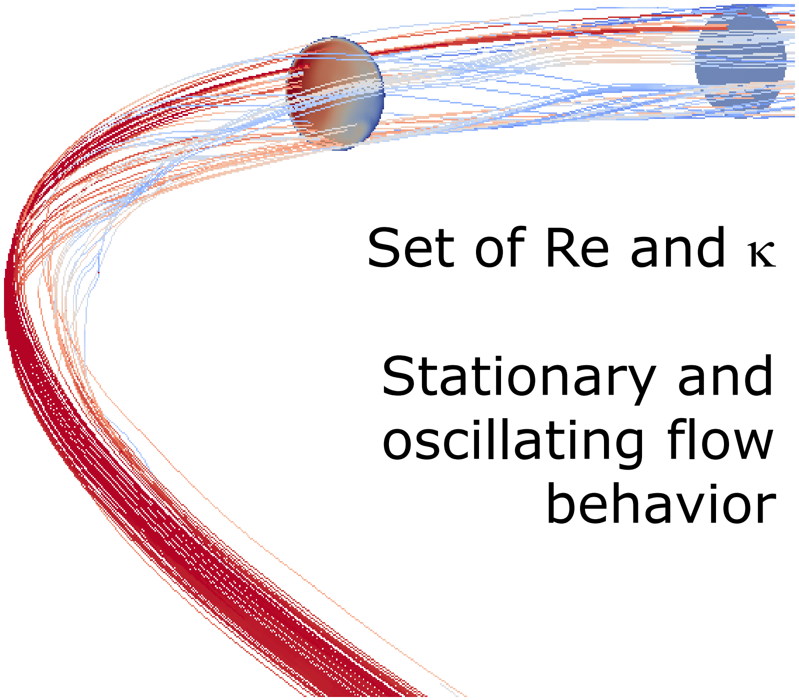


Schematic description of tube flow fractionation [1]

[1] O. Laitinnen, BioResources 6 (2011) 672-685

Case study: Can we Predict Fibre Segregation in Coiled Tubes?

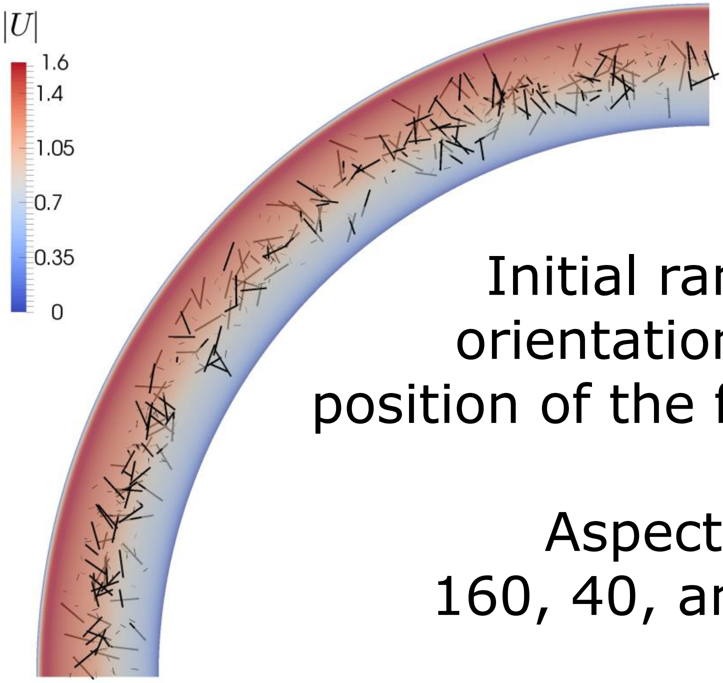
Step 1: CFD Simulation to provide fluid flow



Set of Re and κ

Stationary and oscillating flow behavior

Step 2: Add the fibres to the flow field



Initial random orientation and position of the fibres

Aspect ratio 160, 40, and 20

Case study: Can we Predict Fibre Segregation in Coiled Tubes?

Preliminary simulation results using CFDEM® of fibre suspension flow in curved pipes shows:

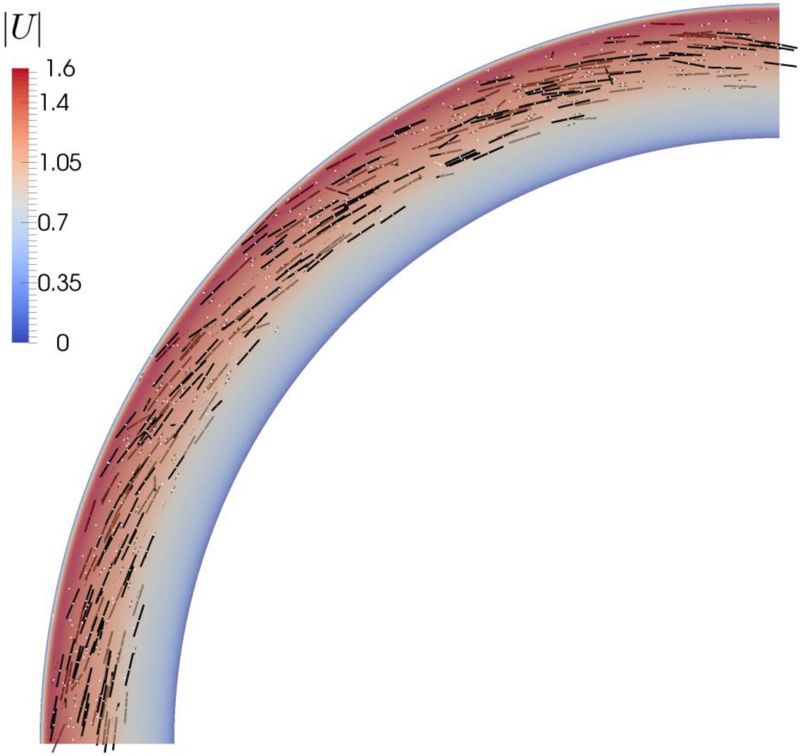
(i) areas of preferred fibre **accumulation**

(ii) Preferential fibre **orientation** in the flow and relative to the wall

Ongoing work focuses on analysis of

(i) fibre **trajectories and speed**, and

(ii) fibre **residence time distribution**



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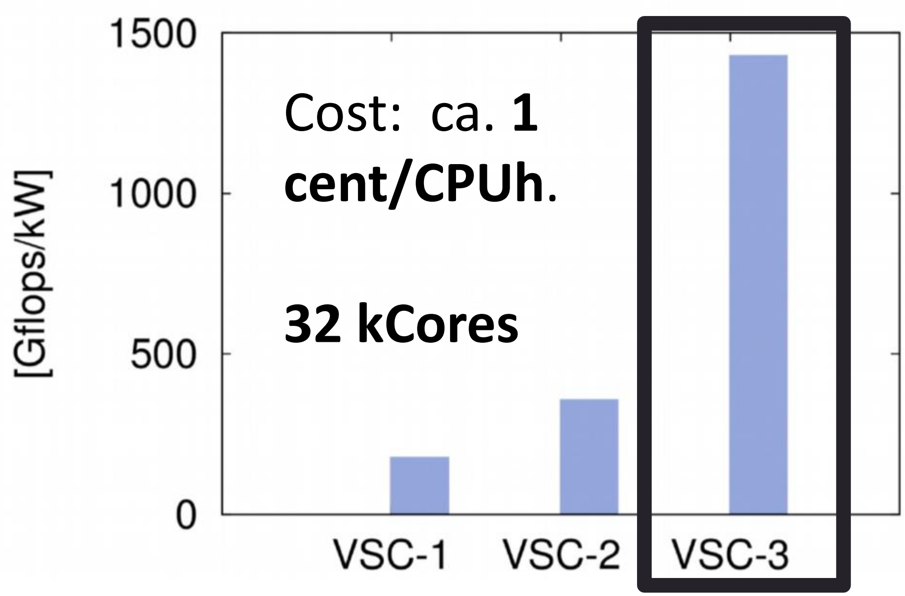
Conclusion & Outlook

- ✓ **Fibre/wall model implemented** in CFDEM® and tested.
- ✓ Improved **fibre-fluid coupling allows larger time steps**.
- ✓ **Fractionation of fibres** based on their length in coiled tubes was successfully **simulated** for the first time.
- ✓ Simulations provide insight (fibre orientation / speed / residence time distributions) and allow the rational design and optimization of **fractionation equipment**.

Conclusion & Outlook

- ✓ Modeling of fibres **challenging** (aspect ratio, fibre flexibility)
- ✓ Dedicated high-quality **open-source codes are** key for wide spread use (www.cfdem.com)
- ✓ **Scientific computing** grows rapidly in Austria
- ✓ **Computing speed & cost** now acceptable (dcluster, VSC-3).



Efficiency and cost of Vienna HPC clusters [1].

[1] M. Stöhr, J. Zabloudil, AHPC 2015.

PROJECT MEMBERS

Industrial partners:

Scientific Partners:

FUNDING PARTNERS

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