CFD Modelling of Fibre Suspension Flow in a Rotating Machinery with Complex Geometry

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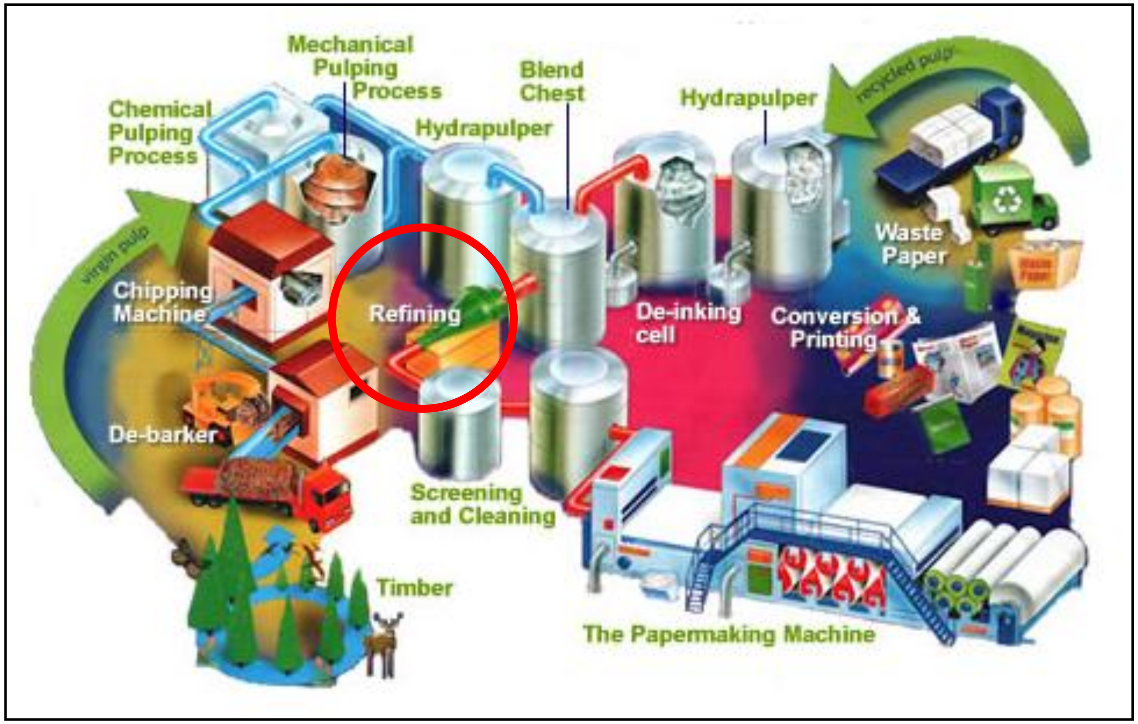
Plan of the presentation

1 Introduction

The papermaking process may be divided into several sections:

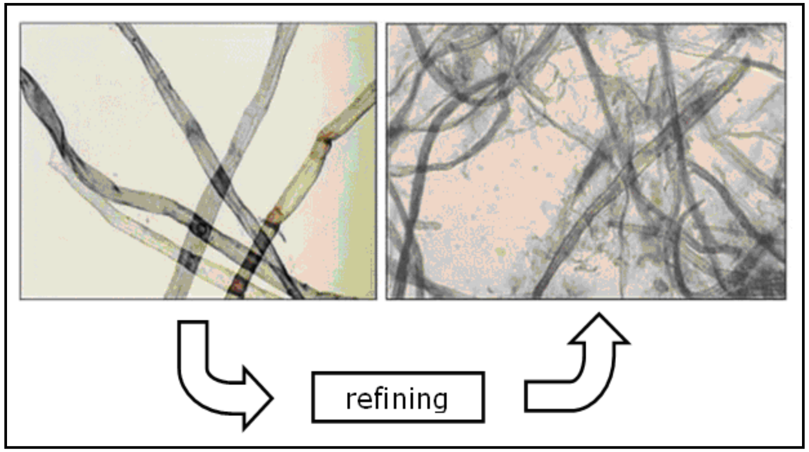
- **stock preparation**
  - slushing and deflaking
  - screening
  - cleaning
  - **refining**
  - …
- **approach flow**
  - dose and mix
  - supply continuous suspension flow
- **paper machine**
  - headbox
  - wire section
  - dryer section
  - press section
  - …



1 Introduction

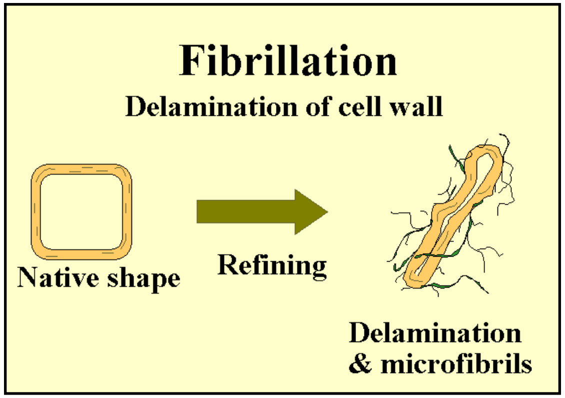
What is refining?

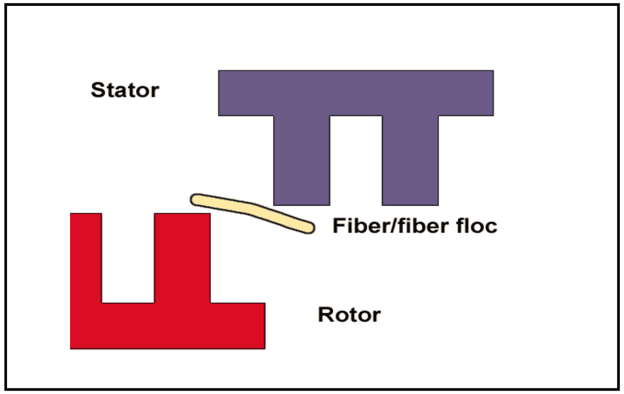
Refining is a part of **stock preparation** process and its main objective is to „design" the fibres to match the desired requirements.



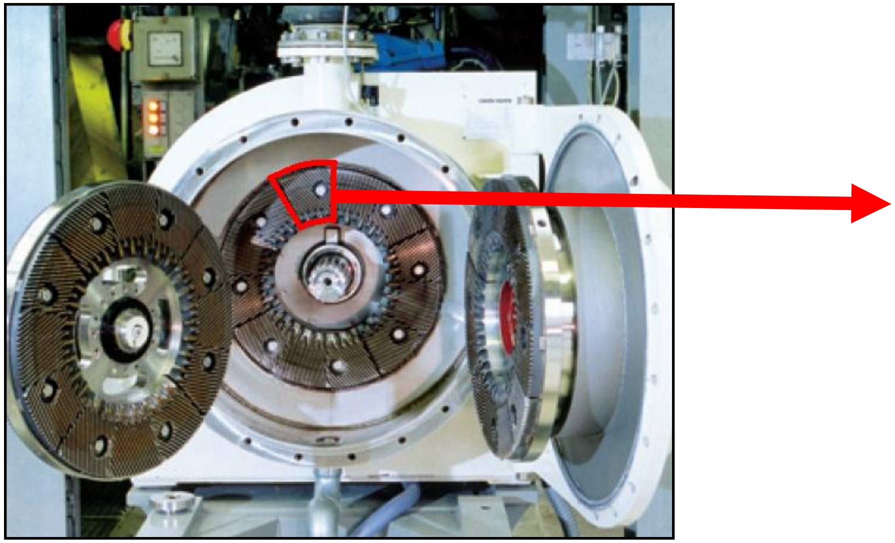
fibres structure changes permanently, they may be shortened, split lengthwise, collapsed or fibrillated

mechanical treatment of fibres with metallic bars with presence of water





2.1 Geometry



real refiner

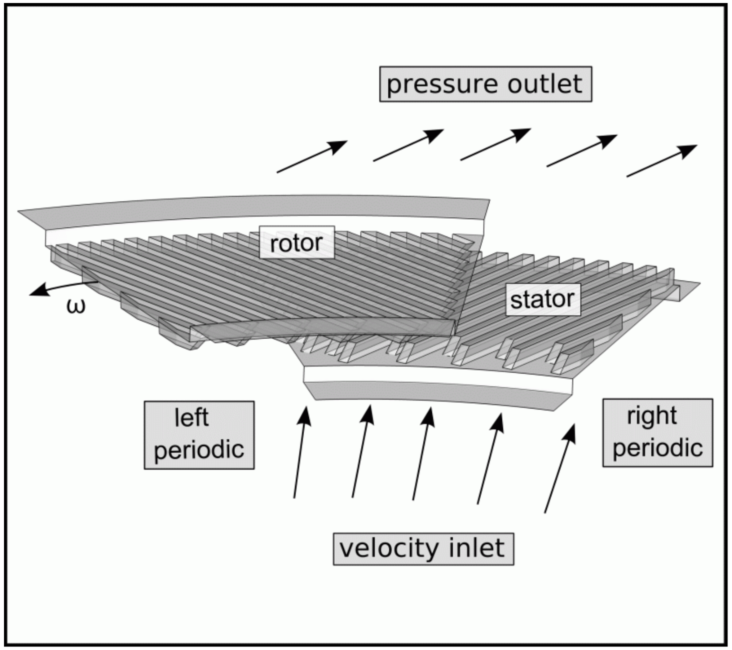
computer model

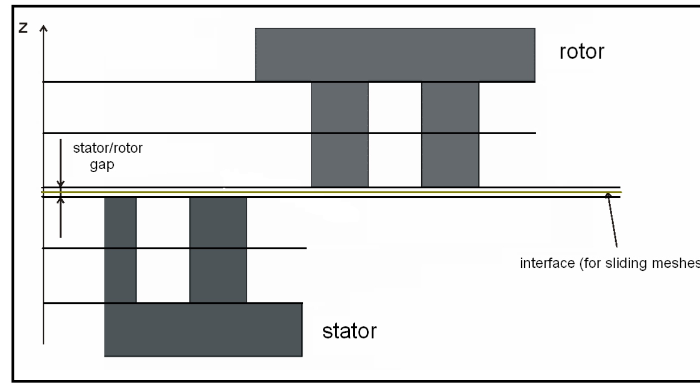
Geometry – assumptions

- neglected axial part of inlet, radial inlet applied
- axisymmetric outlet (instead of point outlet)
- periodicity of disks geometry allows to consider only one segment (30 degrees of angular extent)
- stator and rotor are identical

2.2 Boundary conditions

Boundary conditions of the flow model





- mass flow rate through machine – 1000 l/min
- rotational speed – 1000 rpm
- gap clearance – 100 μm

2.3 Model assumptions

- flow character assumed to be laminar (according to relevant literature);
- pulp suspenions treated as a single-phase continuum;
- pulp concerned as Newtonian and non-Newtonian fluid
- fiber-fiber and fiber-wall interactions are neglected, main goal was to analyse flow field pattern

constant apparent viscosity

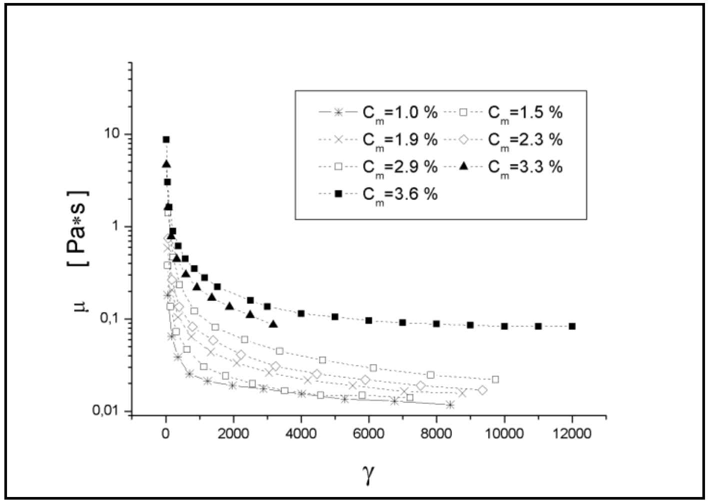
source [1]

$$\mu_a = 0.371 \ \frac{kg}{m \cdot s} \rightarrow C_m = 4 \ \%$$

$$\mu_{water} = 0.001 \ \frac{kg}{m \cdot s}$$

rheological pulp model

source [2]

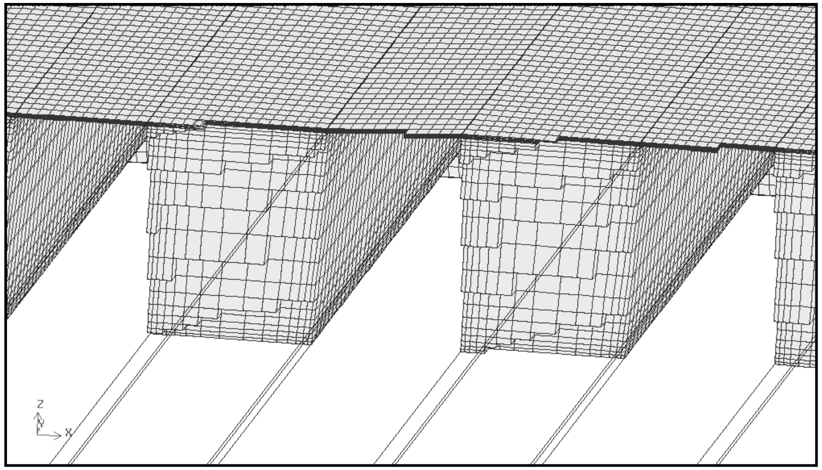


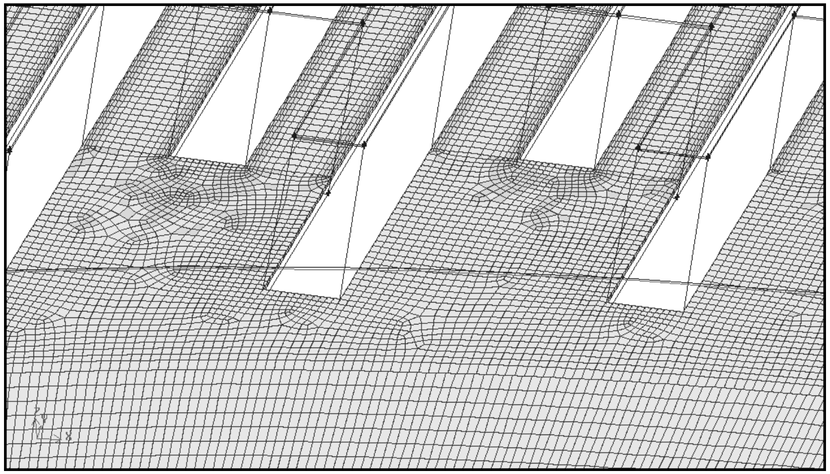
$$\mu = f(\gamma)$$

[1] Radoslavova D., Silvy J., Roux J.C.: "The concept of apparent viscosity of pulp for beating analysis and the developement of the paper properties"
[2] Ventura C., Garcia F., Ferreira P.J., Rasteiro M.G.: "Dynamic Factor - A parameter to characterize pulp rheology"

2.4 Computational mesh

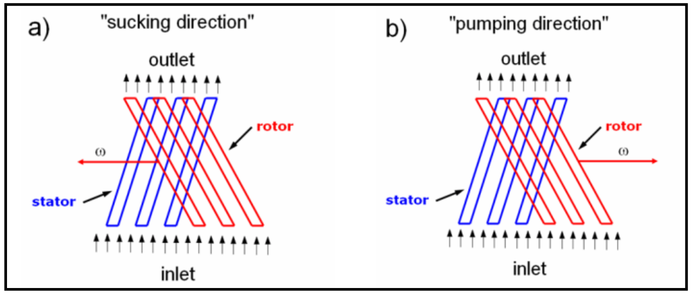
- **mesh type: hexahedral, multi-block structure**
- **mesh size: 6 million of cells**
- **geometry and mesh were generated in automated way with the use of specially developed code in GAMBIT 2.4.6 (useful for parametric study)**
- **simulations were performed with the use of FLUENT 6.3.26, post-processing done in Tecplot 360 2008**
- **extremely long computational time (several weeks)**
- **huge computer resources needed (parellel computing with multiprocessor machines – own resources and The Academic Computer Centre CYFRONET AGH resources)**



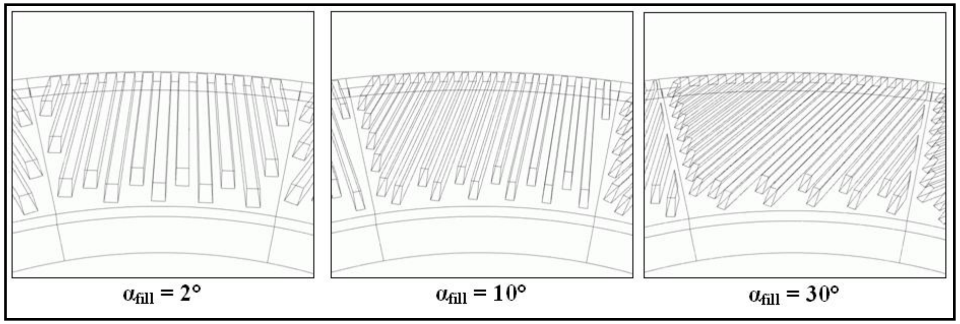


3 Performed simulations

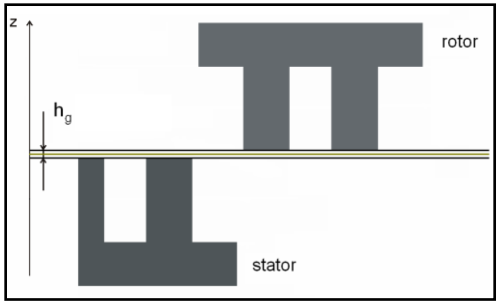
- direction of rotation



- filling angle influence



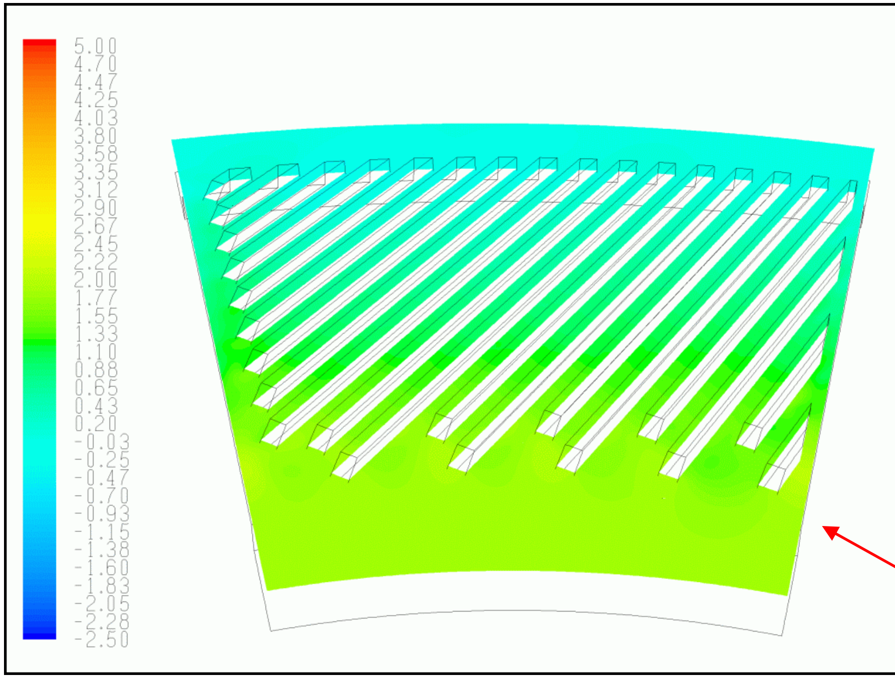
- gap clearance influence (100 µm, 200 µm, 400 µm)



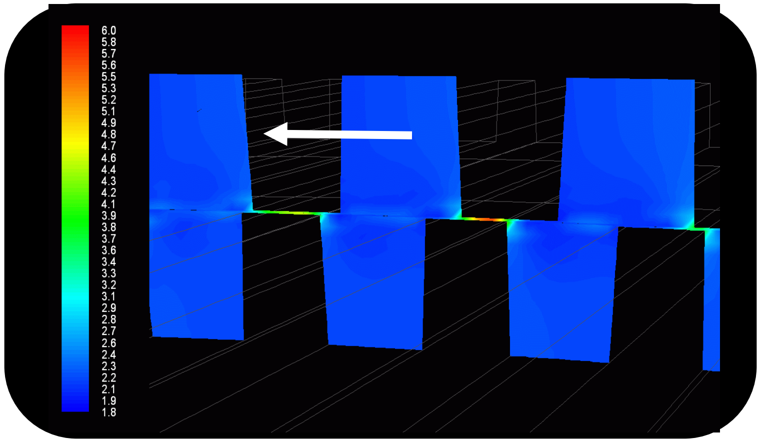
- material properties

$$\mu = const \qquad \mu = f(\dot{\gamma})$$

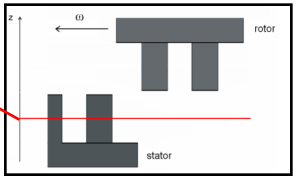
3.1 Refiner flow pattern



static pressure dirtibution [bar] at the centre of the stator bars



static pressure dirtibution [bar] at cross section through stator and rotor



$\alpha_{fill} = 30$
gap = 100 μm
sucking direction
Newtonian fluid, μ = const

<u>pressure varies linearly with radial distance</u>

<u>pressure pulses inside the gap region</u>

3.1 Refiner flow pattern

vortex flow inside the grooves

velocity vectors

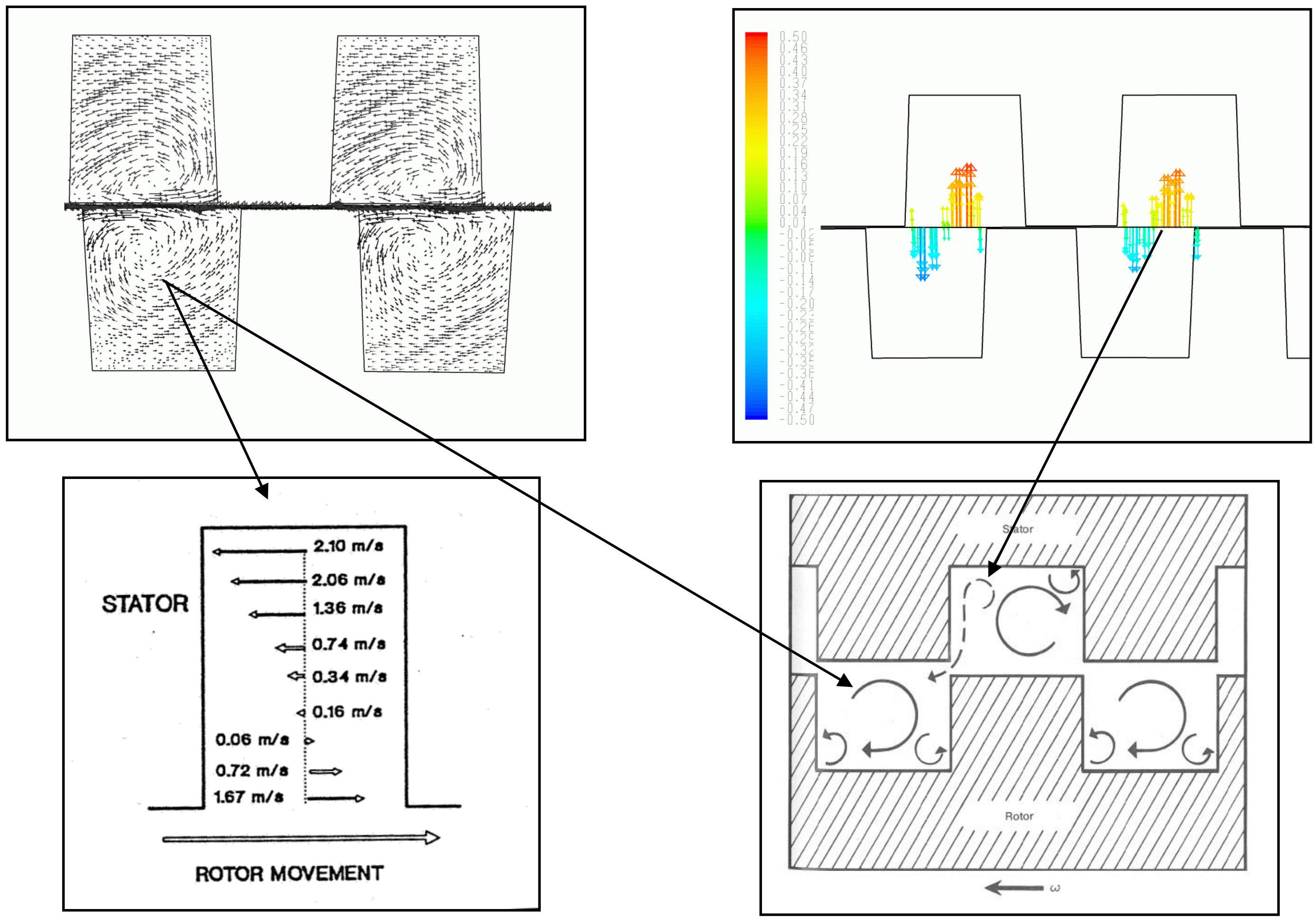
axial component of velocity vectors

numerical

simulation

literature

(experiment - LDA)



Lumianen

Fox et al.

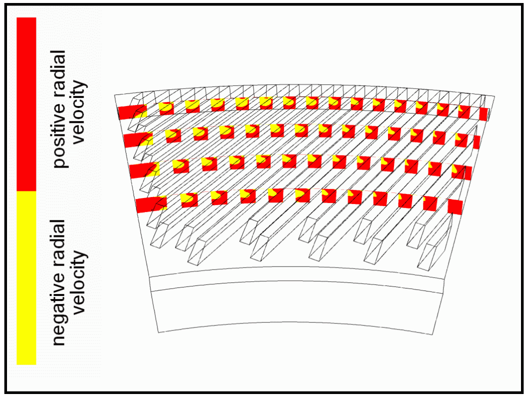
3.1 Refiner flow pattern

streamtracers for a frozen time

backflows:

- **streams coming from the outlet to the inlet inside the <u>stator</u> grooves**
- **contribute to the internal circulation increasing probability of fiber/bar impact (refining effect)**

3.2 Direction of rotation influence

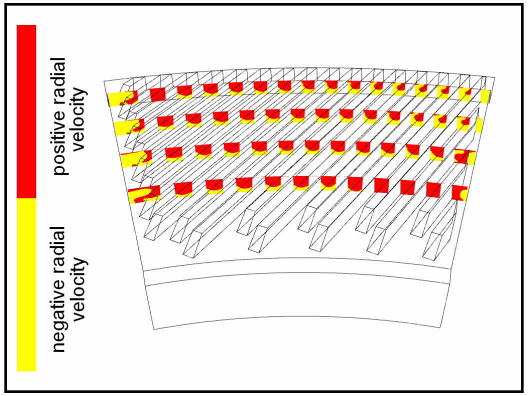


radial velocity at cross section at constant radius

pumping direction

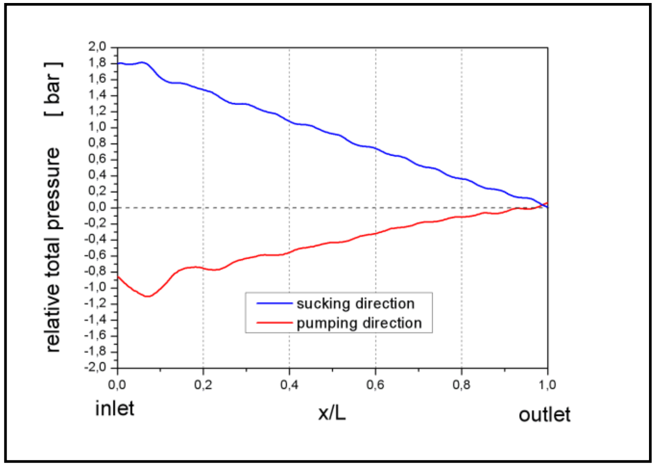
strongly non-uniform mass flow rate distribution

higher backflows for sucking direction case

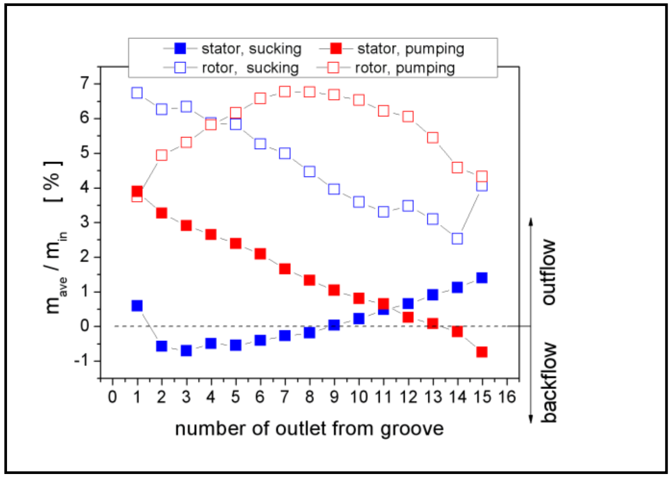


radial velocity at cross section at constant radius

sucking direction

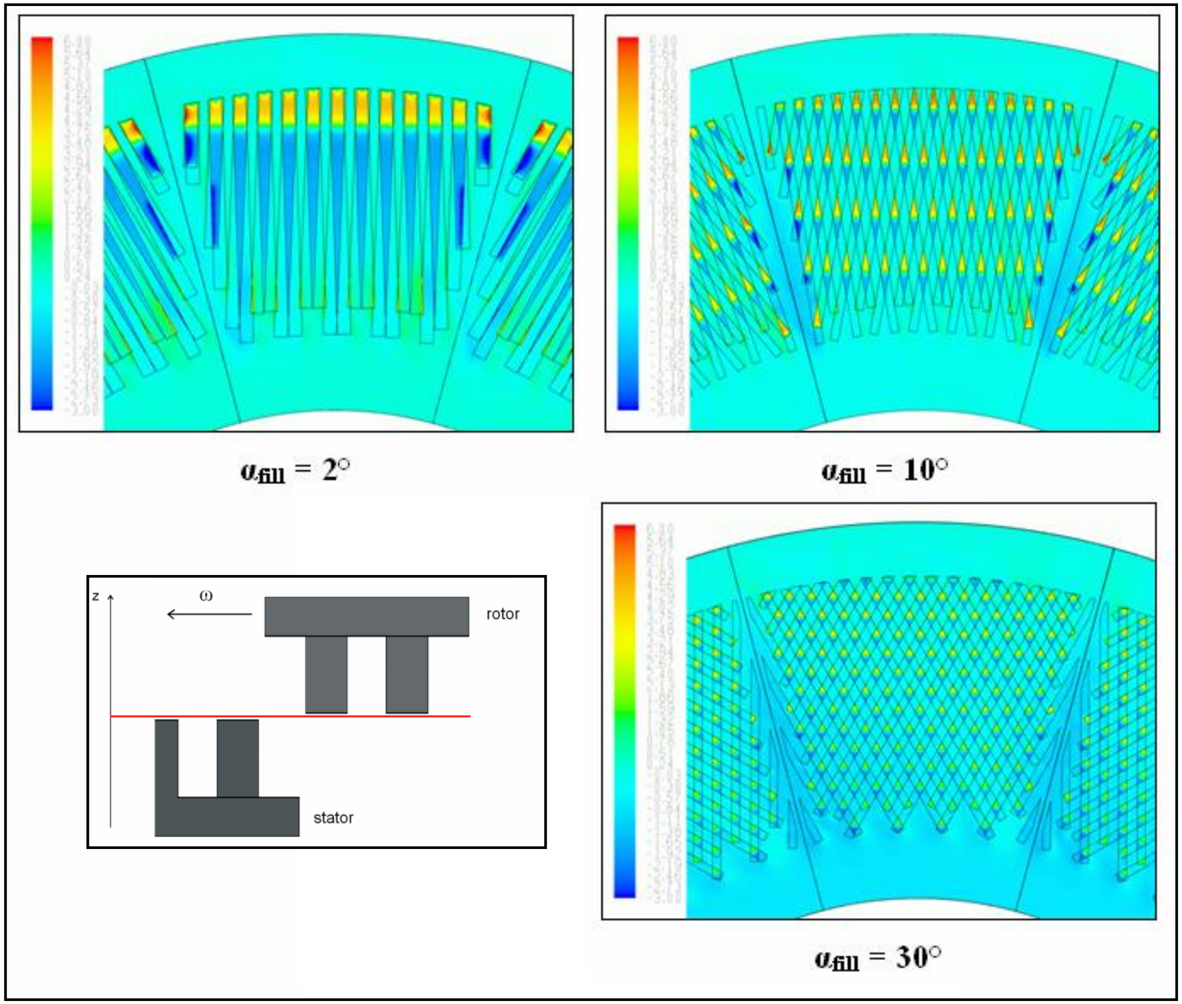


pressure variation along groove

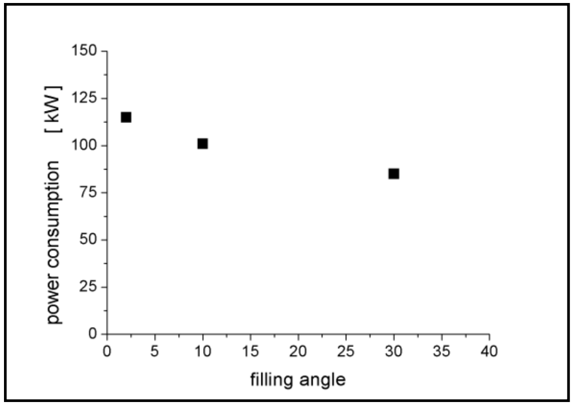


average mass flow rates at the filling outlet

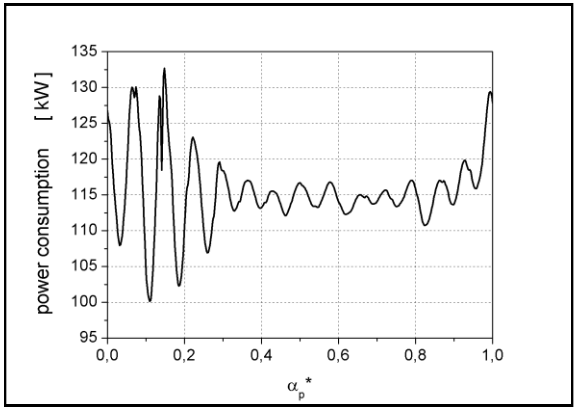
3.3 Filling angle influence



static pressure distribution at the centre of the gap



average power demand

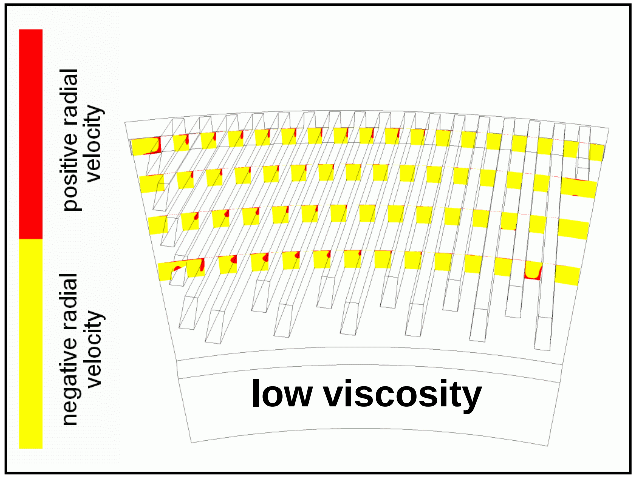


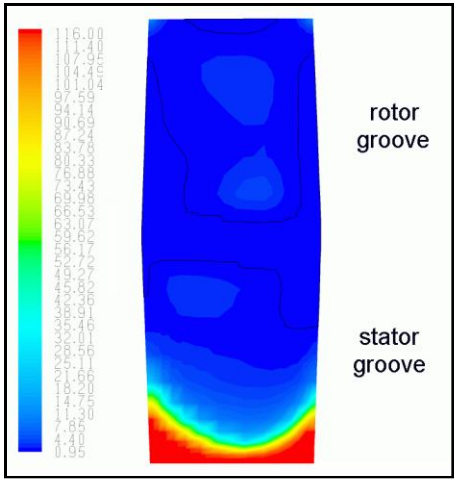
power variation in time for

α_{fill} = 2 case

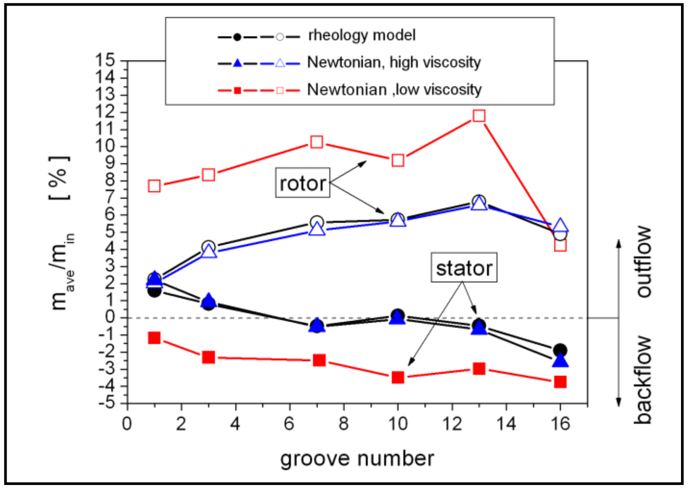
3.5 Material properties influence

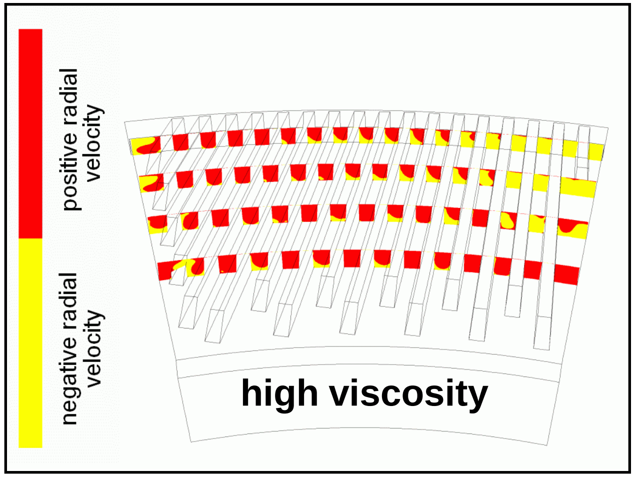
$\mu = const$ $\mu = f(\dot{\gamma})$





average mass flow rates

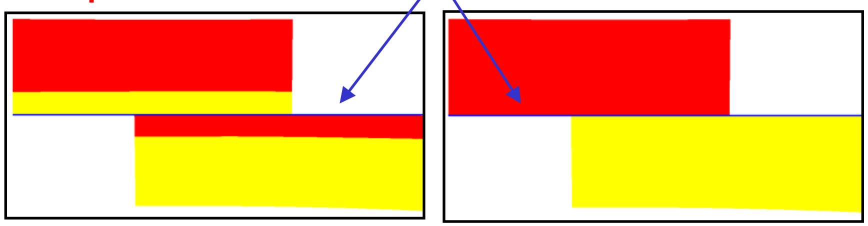


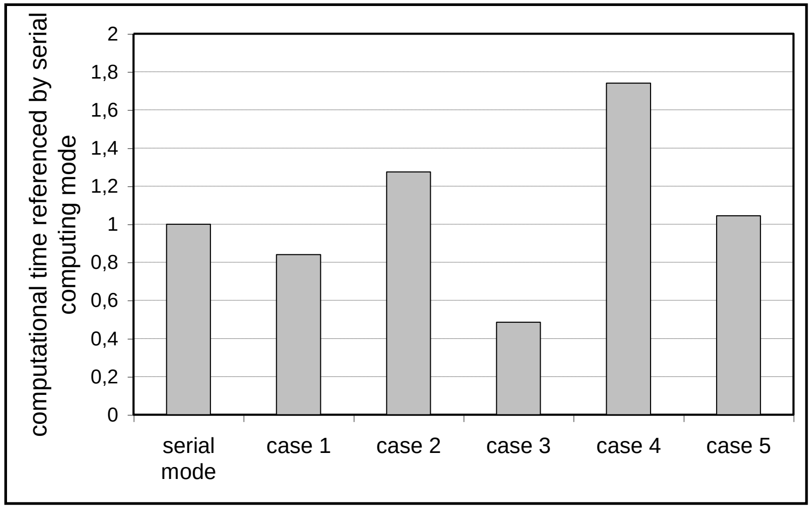


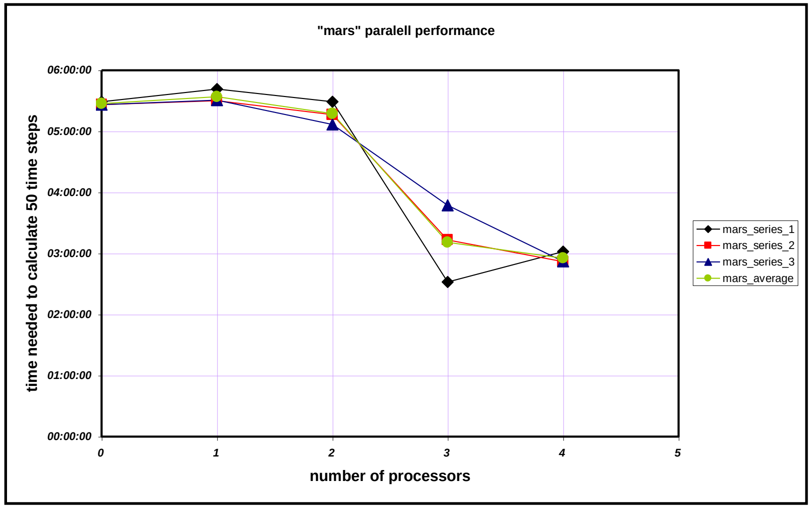
- lower viscosity – intensification of the backflows in the stator
- introduction of rheology increases the relevance of the model (but it is not crucial)

4 Parallel computing

case 1 – Cartesian Z, AZ – off, EGI – off
case 2 – Cartesian Z, AZ – off, EGI – on
case 3 – Cartesian Z, AZ – on, EGI – off
case 4 – Cartesian Z, AZ – on, EGI – on
case 5 – Principal Axes - automatic







- **parition method has a great influence on the computational time – test has to be made before main simulations**
- **use of cluster machines clearly decrease computational time**

4. Summary

Adequate numerical model:

1) pulp can be treated as a single phase continuum
2) laminar flow character has been confirmed

Features of the flow field pattern:

- mass transfer through the filling is mainly done by the rotor
- existence of the backflows in the stator
- mass flow rate distributions stongly non-uniform and rotor position dependent
- parametric study showed strong influence of key geometrical parameters as well as material pulp properties on the flow pattern and intensity of internal recirculation

All the conclusion are limited to the model used in the present study (neglected housing, single-phase character of the medium ,...)

Acknowledgments

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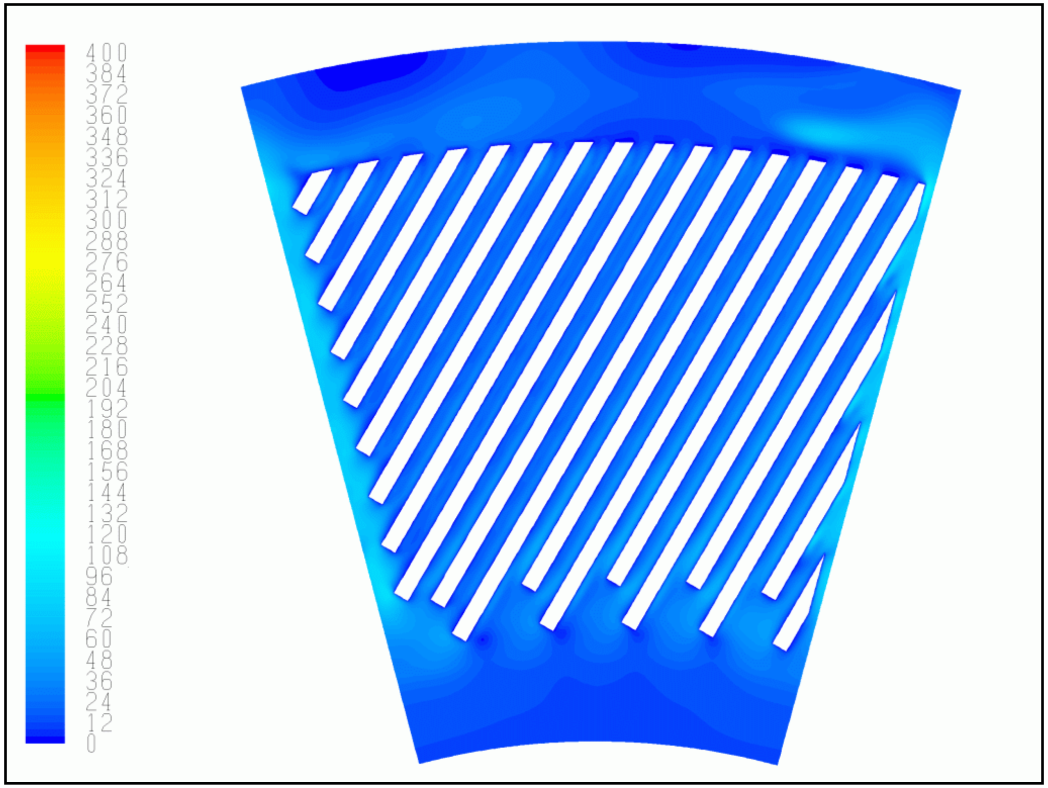
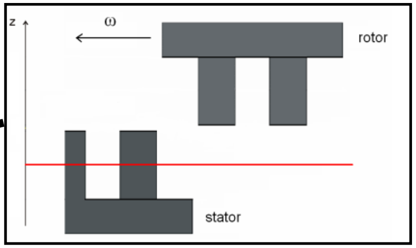
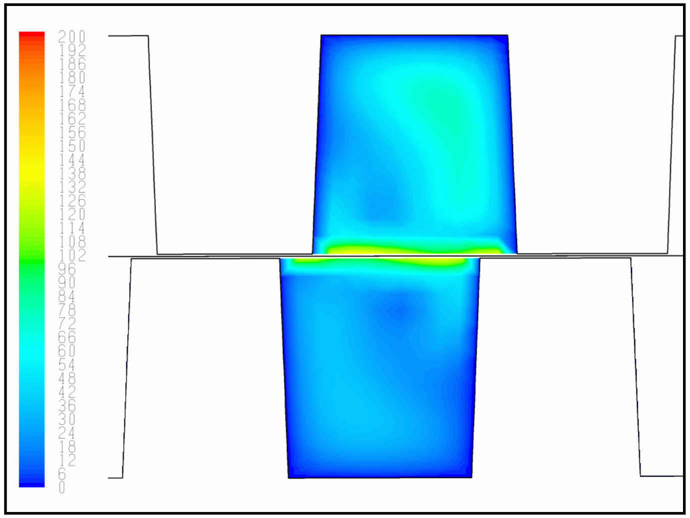
Thank you for your attention

Additional

Reynolds number distributions

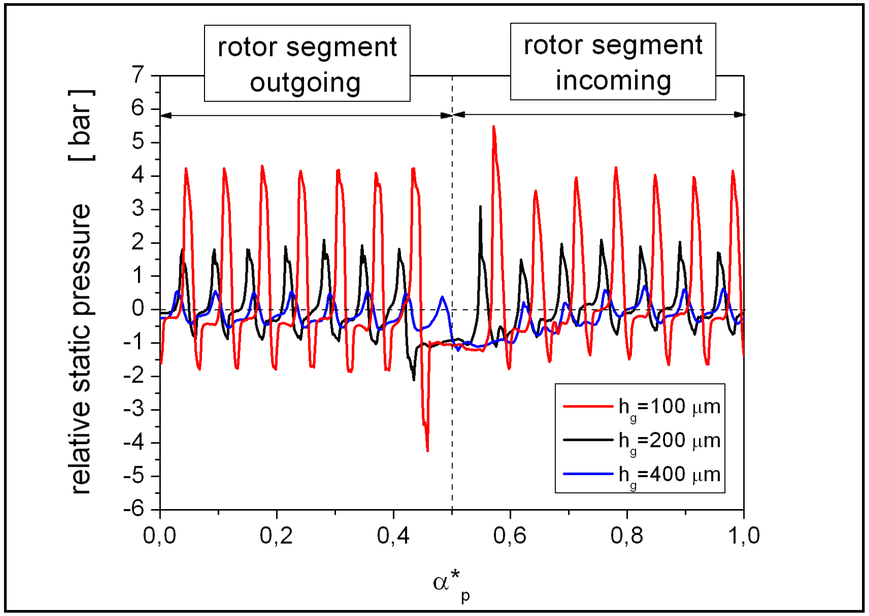




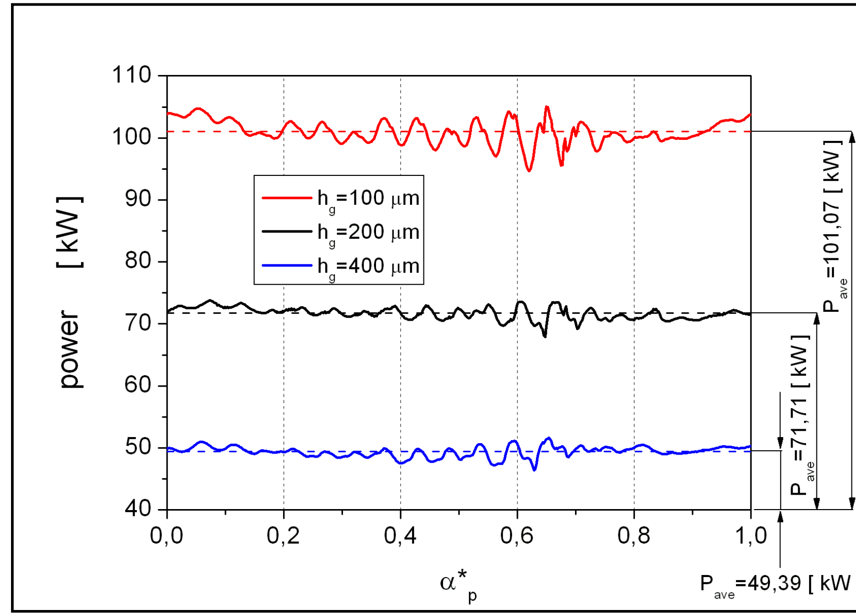


Re number is low enough to justify the laminar flow character assumption

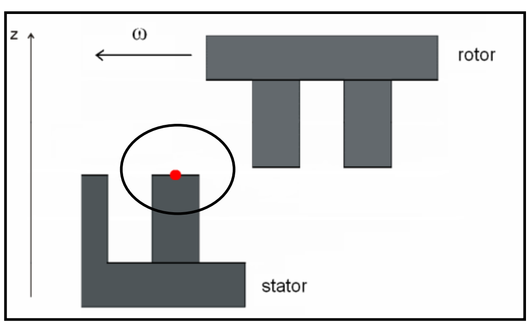
3 Gap clearance influence



static pressure variation at the point loacted in the stator bar along with the phase shift



power variation along with the phase shift



- increase of gap size leads to the damping of the pressure peaks
- over 2 times smaller power consuption for gap equal to 400 μm than for 100 μm