COST Action - FP1005

joint

7nd MC/WG Meeting

6th ERCOFTAC SIG43 Workshop

"Fibre suspension flow modelling - a key for innovation and competitiveness in the pulp & paper industry"

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EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

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Presentation Outline

- Brief Introduction to Electrical Impedance Tomography.
- Pilot Rig testing:

  A) Eucalyptus fibers.

  B) Pine fibers.

  C) Flow velocity estimation

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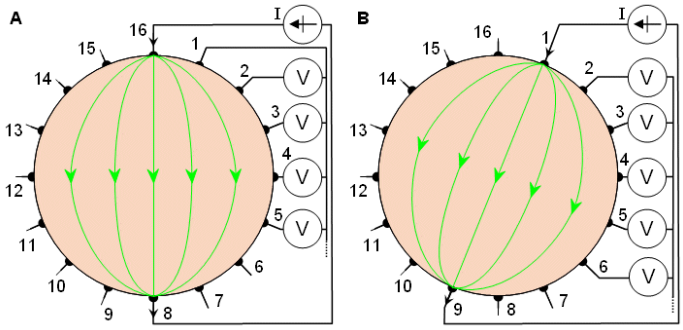
Electrical Impedance Tomography overview

In the development of accurate models for suspension related processes, prior knowledge of several flow characteristics is essential, such as spatial distribution of phases, flow regimen, interfacial area, and relative velocity between phases, amongst others.



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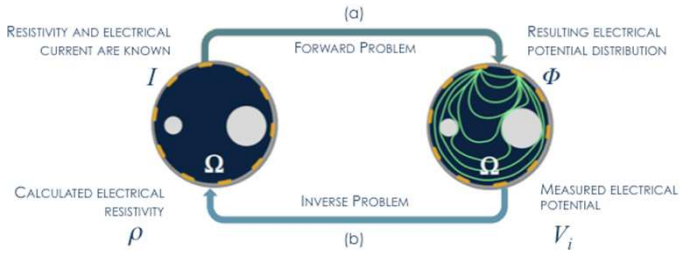
Mathematical Formulation

Complete Electrode Model (CEM)



Regularized Gauss-Newton algorithm

For all described tests a mesh with 2304 triangular elements and 1201 nodes was used (opposite injection and adjacent measuring was used).

In the reconstructed images of the conductivity distribution in the tube cross section, the electrode number corresponding to higher vertical position is electrode number 1, and a more darker blue colour corresponds to a lower conductivity region, which is due to the presence of a higher quantity of fibres in that same area of the pipe section, while yellow or red colours identify higher conductivities region, corresponding to the presence of a much lower quantity of fibres in that same area of the pipe section.

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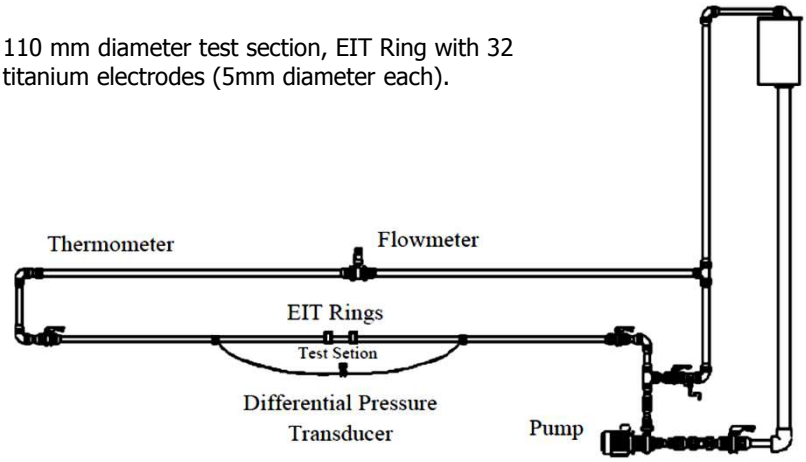
Experimental Setup

PILOT RIG overview (DEQ-FCTUC)

110 mm diameter test section, EIT Ring with 32 titanium electrodes (5mm diameter each).



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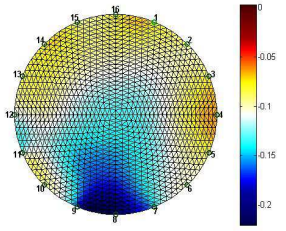
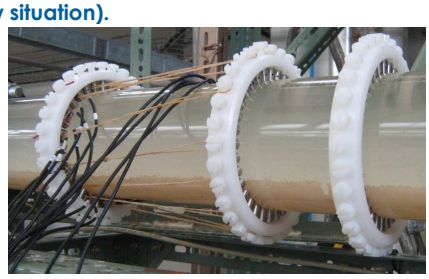
Pilot Rig tests I

Flow speed of 0 m/s and 2.8% concentration (w/w) (adjacent injection and measuring for this zero flow situation).





TEST CONDITIONS

Flow speed of 0.5, 1, 1.5, 2, 2.5, 3 m/s. Eucaliptus short fibers, with na average lenght of around 0.706 mm, and with concentrations of ± 3.7, 3.06, 2.45, 1.89, 1.5 and 1% (w/w).

Reference medium: NaCl doped water (conductivity 1200 µS/cm).

Applied excitation: $2V_{pp}$ at 10KHz

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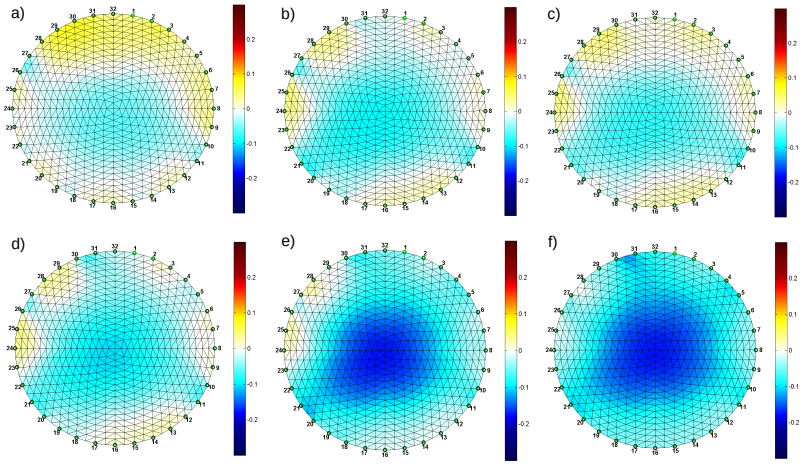
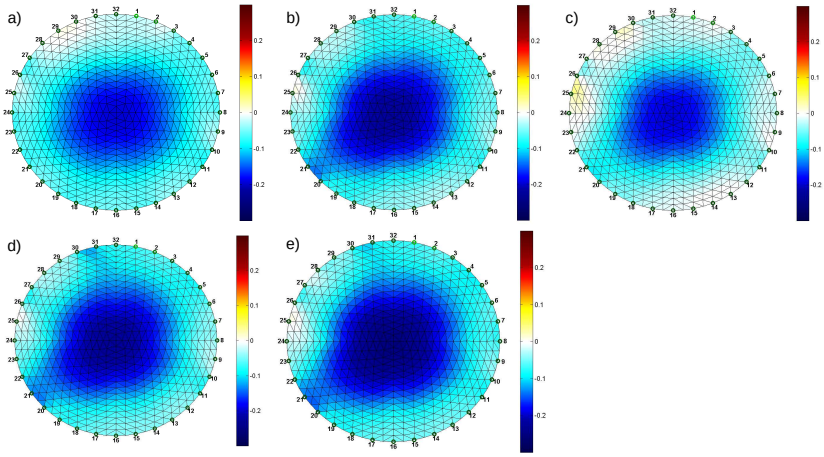
Pilot Rig tests I
Results (constant concentration).



Fibers concentration of 3.06% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 1.5 m/s; d)2 m/s; f) 2.5 m/s; g) 3 m/s

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Pilot Rig tests I
Results (constant concentration).



Fibers concentration of 1.5% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 1.5 m/s; d)2 m/s; e) 2.5 m/s.

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Eucalyptus fibers data analysis.

- For the 3.06% fibre flow concentration and for the lower velocities, between 0.5 and 1.5 m/s, the fibers are more or less homogeneously dispersed along the pipe section: when the velocity of the flow is increased to 2 m/s, the fibres, start already to get concentrated in the centre of the pipe section, and with further increments of the flow velocity the fibers get ,increasingly concentrated in the centre of the pipe section.

- For the 1.5% fibers dilution, the fiber distribution exhibits a behaviour very likely with what was expected. Indeed, at the lowest velocities the fibers are now even more agglomerated in the centre region of the pipe section and their agglomeration in the pipe centre keeps increasing with velocity.

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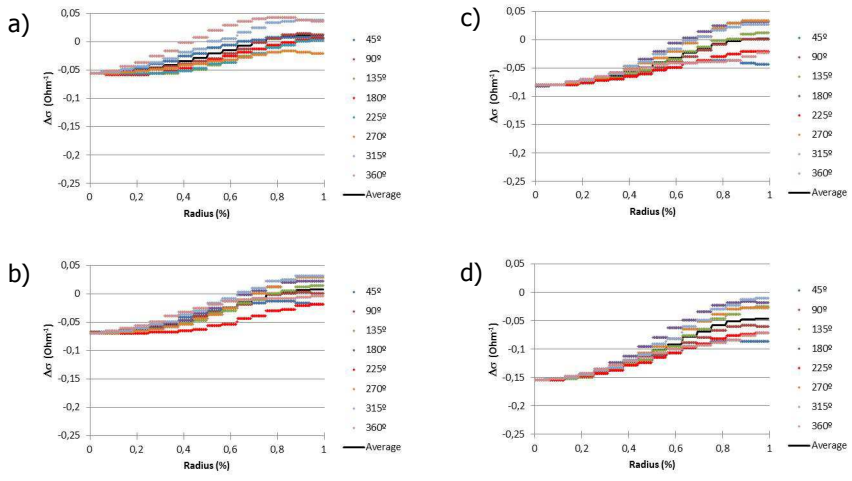
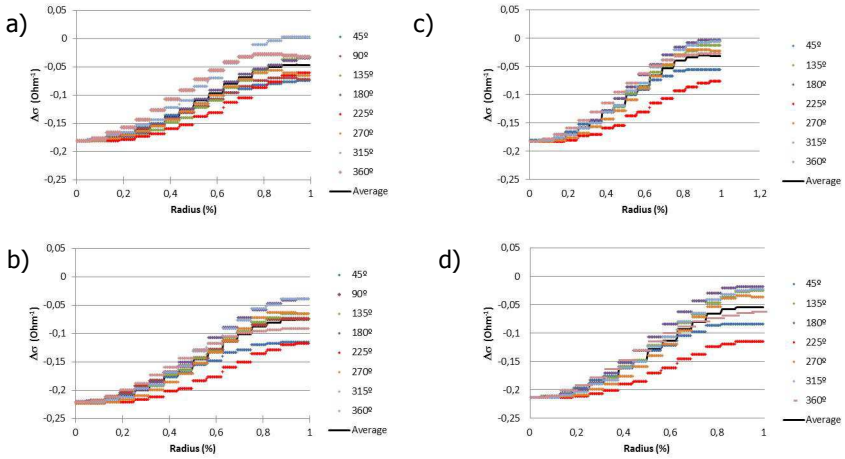
Pilot Rig tests I
Radial profiles (constant concentration).



EIT radial profiles obtained with a concentration of 3.06% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 2 m/s; d) 3 m/s.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Pilot Rig tests I
Radial profiles (constant concentration).



EIT radial profiles obtained with a concentration of 1.5% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 1.5 m/s; d) 2.5 m/s;.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Eucalyptus profiles brief analysis.

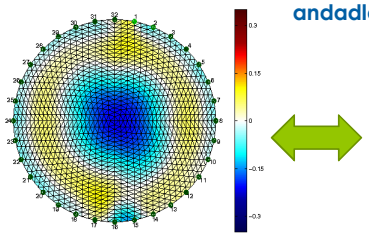
- For the 3.06% concentration, it is observed that as velocity increases the fibers that initially are more dispersed along the tube section (along the full radius range the overall conductivity variation is narrower than the found for the following flow velocities), start to continuously get more agglomerated in the centre of the pipe, and so consequently the suspension exhibits a plug type flow as expected. In fact when comparing the values of the conductivity for the region near the centre of the pipe (smaller radius percentages), it can be seen that they decrease as velocity increases, indicating higher number of fibers agglomerated in that region. The latter is reinforced when comparing the conductivity values for more or less half the radius of the pipe section: it can be seen that they also decrease as velocity increase confirming that larger quantities of fibers are present in that zone of the pipe.

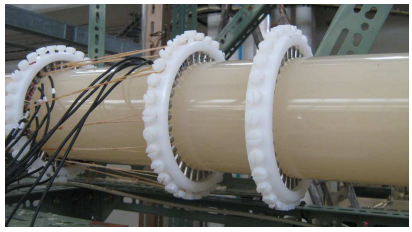
- For the last fiber suspension concentration of 1.5%, and since we are in the presence of a low fiber concentration, the outcome of the flow velocity in getting the fibers together is visible starting with the lowest tested velocity. Indeed, the profile for the velocity of 0.5 m/s already presents a large overall conductivity variation along the entire radius range, and as velocity is raised it gets enlarging, confirming that the fibers keep on getting agglomerated at the centre of the pipe, and so displaying a plug type flow.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Pilot Rig tests II

Flow speed of 2.6 m/s and 2.8% Eucalyptus fibers concentration (w/w) (opposite injection andadlacent measuring).





TEST CONDITIONS

Flow speed of 0.5, 1, 1.5, 2, 2.5, 3 m/s. Pine long **stiff** fibers, with na average lenght of around 2.18 mm, and with concentrations of ± 1, 1.5 and 2.35 % (w/w).

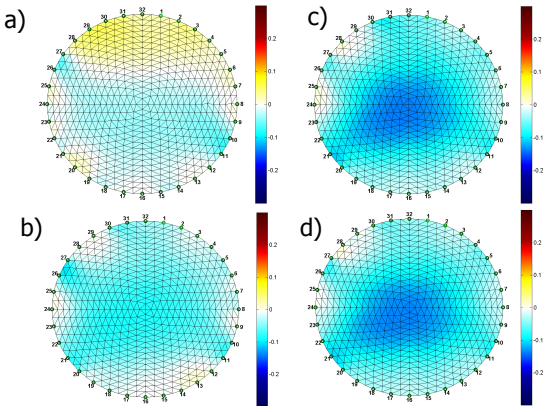
Reference medium: NaCl doped water (conductivity 1200 µS/cm).

Applied excitation: $2V_{pp}$ at 10KHz

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Pilot Rig tests II
Results (constant concentration).

For the highest fibre flow concentration and for the lower velocities, between 0.5 and 1 m/s, the fibers are more or less homogeneously dispersed along the pipe section: when the velocity of the flow is increased to 2 m/s, the fibres, start already to get concentrated in the centre of the pipe section, and with further increments of the flow velocity the fibers get ,increasingly concentrated in the centre of the pipe section.

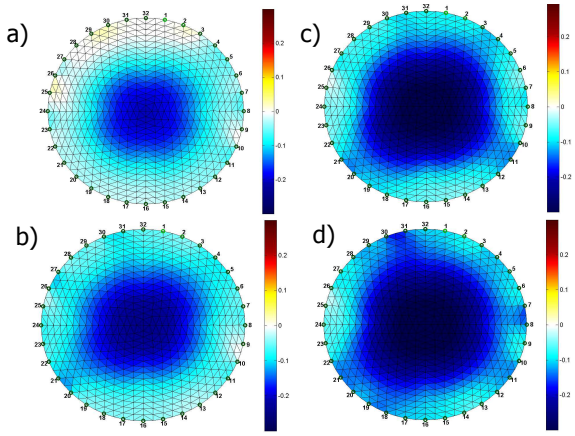


Fibers concentration of 2.35% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 2 m/s; d) 3 m/s.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Pilot Rig tests II
Results (constant concentration).

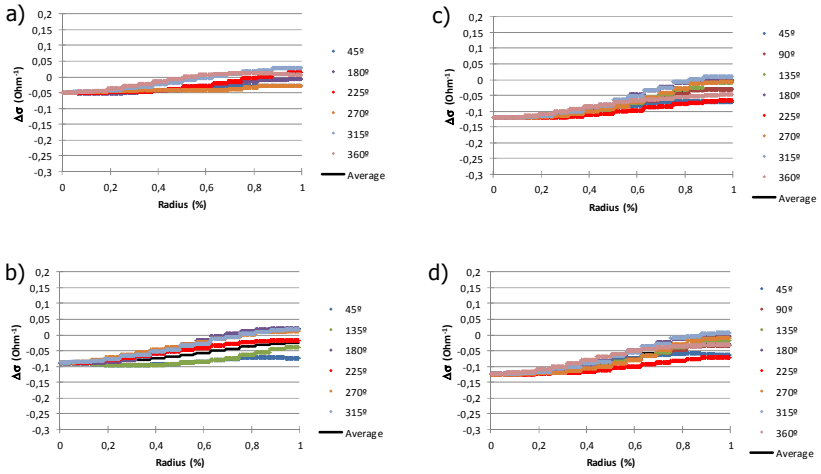
For the lowest fibers dilution, the fiber distribution exhibits a behaviour very likely with what was expected. Indeed, at the lowest velocities the fibers are now even more agglomerated in the centre region of the pipe section and their agglomeration in the pipe centre keeps increasing with velocity.



Fibers concentration of 1% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 2 m/s.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

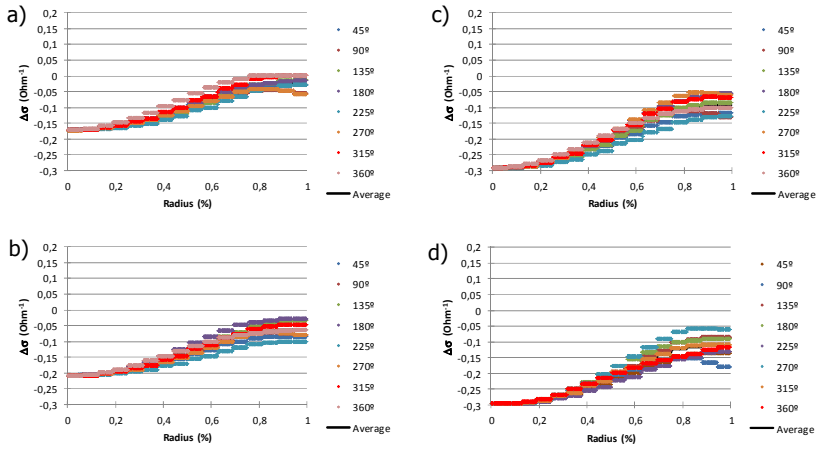
Pilot Rig tests II
Radial profiles (constant concentration).



EIT radial profiles obtained with a concentration of 2.35% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 2 m/s; d) 3 m/s.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Pilot Rig tests II
Radial profiles (constant concentration).



EIT radial profiles obtained with a concentration of 1% (w/w) with increasing flow velocity: a) 0.5 m/s; b) 1 m/s; c) 2 m/s; d) 3 m/s.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

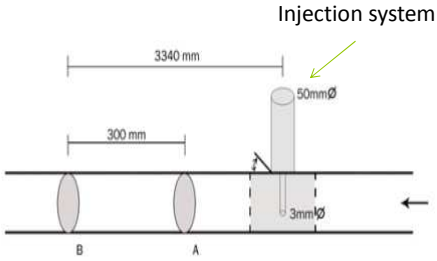
Pine profiles brief analysis.

- For the highest concentration of 2.35%, it is observed that as velocity increases the fibers that initially are more dispersed along the tube section (along the full radius range the overall conductivity variation is narrower than the found for the following flow velocities), start to continuously get more agglomerated in the centre of the pipe, and so consequently the suspension exhibits a plug type flow as expected. In fact when comparing the values of the conductivity for the region near the centre of the pipe (smaller radius percentages), it can be seen that they decrease as velocity increases, indicating higher number of fibers agglomerated in that region.
- For the fiber suspension concentration of 1%, and once we are in the presence of a low fiber concentration, the consequence of the flow velocity in getting the fibers together is visible starting with the lowest tested velocity. Without a doubt, the profile for the velocity of 0.5 m/s by now presents a larger overall conductivity variation along the entire radius range, and as velocity is raised it gets enlarging, confirming that the fibers keep on getting agglomerated at the centre of the pipe, and so displaying a plug type flow.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Flow velocity estimation: Pilot Rig tests

Schematic of the relative position of the EIT electrodes sections and injection inlet



Tipically Electrical tomography may be an alternative for determination of the velocity profile in non-transparent systems. By using dual EIT planes and cross-correlation, EIT can also be used to determine the velocity profile in a pipe.

reference medium: NaCl doped water (conductivity 1200 µS/cm).

Applied excitation: $2V_{pp}$ at 10KHz

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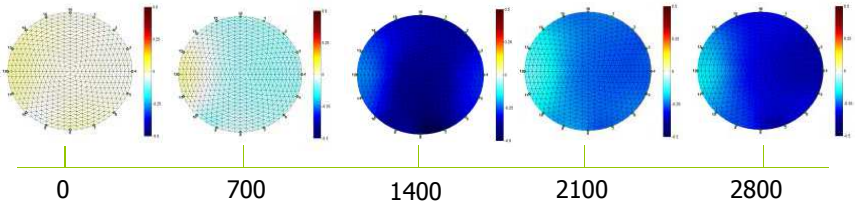
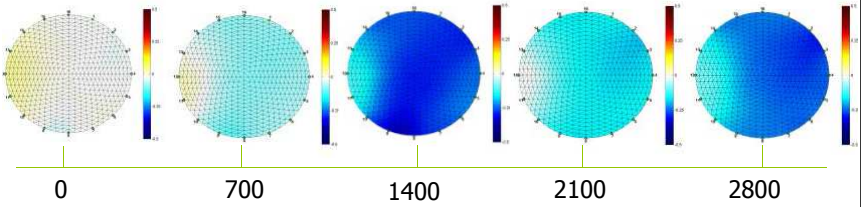
Velocity estimation - results

Eucalyptus fiber dilution of 1% and velocity of 0.25 m/s (timeline unit: ms).

Ring A





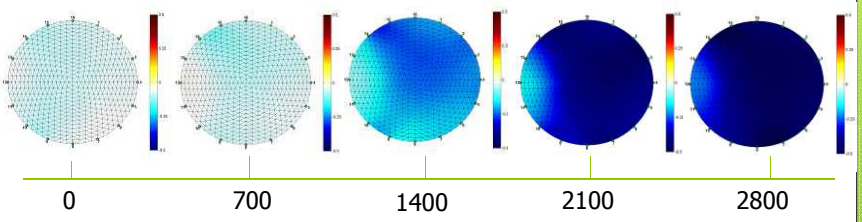
Ring B

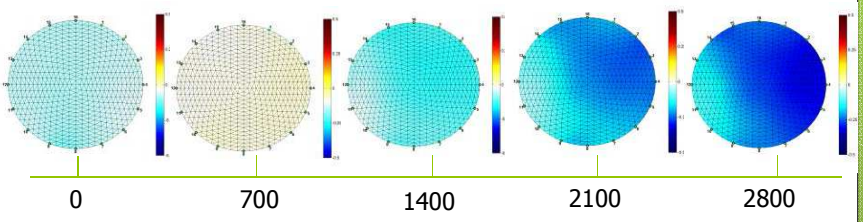
EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Velocity estimation - results

Eucalyptus fiber dilution of 1% and velocity of 0.5 m/s (timeline unit: ms).

Ring A





Ring B

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Flow velocity estimation

AS can be seen from the previous results the maximum interleaved switching between the two EIT systems is not fast enough to allow to attain the needed sensitivity (0.7 s for 1 set of data for both EIT test sections): the initial hardware design of the systems did not contemplate this operation mode, and consequently the flagged software solution delays significantly the all procedure, not allowing to use it.

So instead of using the complete set of EIT projections, a decision of using only the first projection and 16 electrodes for each ring, was made: first the potential differences of each pair of the first projection with no marker injection in the flow were acquired; afterwards they were subtracted to the measured voltage differences obtained during the trials with NaCl injection. Finally, the sum of the module of those differences was computed. For each suspension velocity and fiber concentration tested, several injection trials were done, to verify the reproducibility of this approach.

reference medium: NaCl doped water (conductivity 1200 µS/cm).

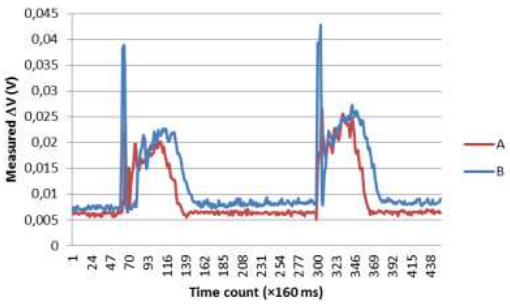
Applied excitation: $2V_{pp}$ at 10KHz

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Velocity estimation - results

Table of fiber concentrations and flow velocities used for the velocity estimation tests.

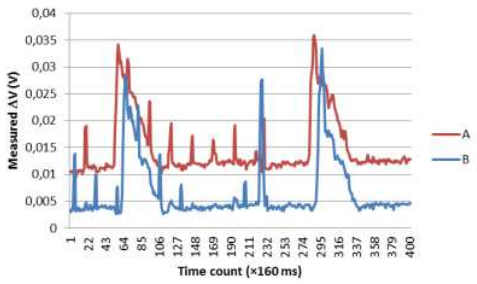
Concentrations (W/W)	Flow velocities (m/s)
2.6	0.25, 0.5
2	0.25, 0.5, 0.75, 1
1	0.25, 0.5, 0.75, 1



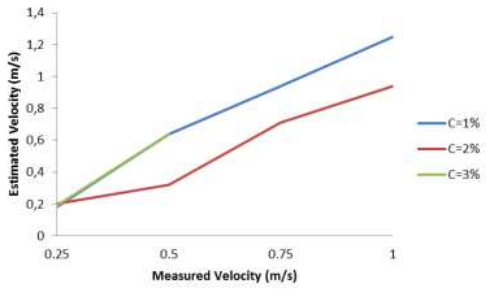
EIT injection test trials for fiber suspension concentrations of 1% at the velocity of 0.25 m/s.

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Velocity estimation - results



EIT injection test trials for fiber suspension concentrations 2%, at the velocity of 0.25 m/s.



Estimated velocity versus measured velocity for all tested fiber concentrations.

Next steps

- Further tests in pilot rig regarding velocity and concentration changes using other fibers (natural ones and synthetic ones).

EIT use latest advances: pulp suspensions distribution characterisation and suspensions velocity estimation.

Thank you for you attention