Research Activity at CEMPS
University of Exeter

Status at 29 March 2012

Outline

Micro-scale simulations:

- Evaluation of permeability coefficient
- Evaluation of convection coefficient
- Evaluation of geometric properties

Micro-scale simulation

Simulations have been performed on sample S3 (*duocel aluminium 40ppi 3-5%density*) considering three meshes having different sizes:

- 10x10x10 mm: this was used for a sensitivity analysis on the porosity level of the reconstructed geometry, considering 3 levels: lower (rd 3%), mean (rd 4%), upper(rd 5%);

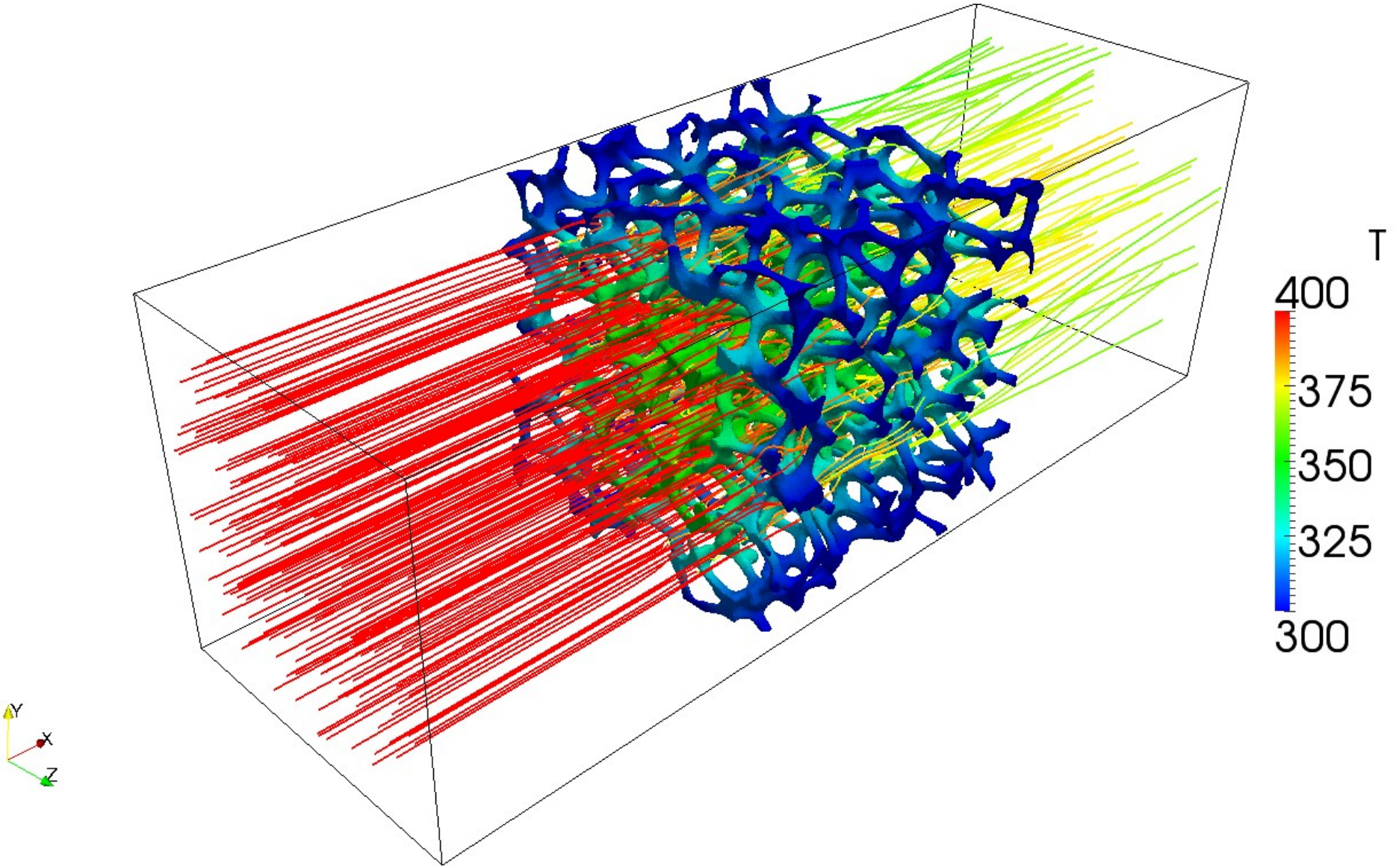
- 30x10x10 mm: this was used for computing the thermo-fluid-dynamic properties considering different portions of the sample (the whole sample, sections along axial directions, portions of samples in different locations);

- quarter of sample: in order to have a direct term of comparison with a macro-scale model.

TODO:
- half sample
- whole sample

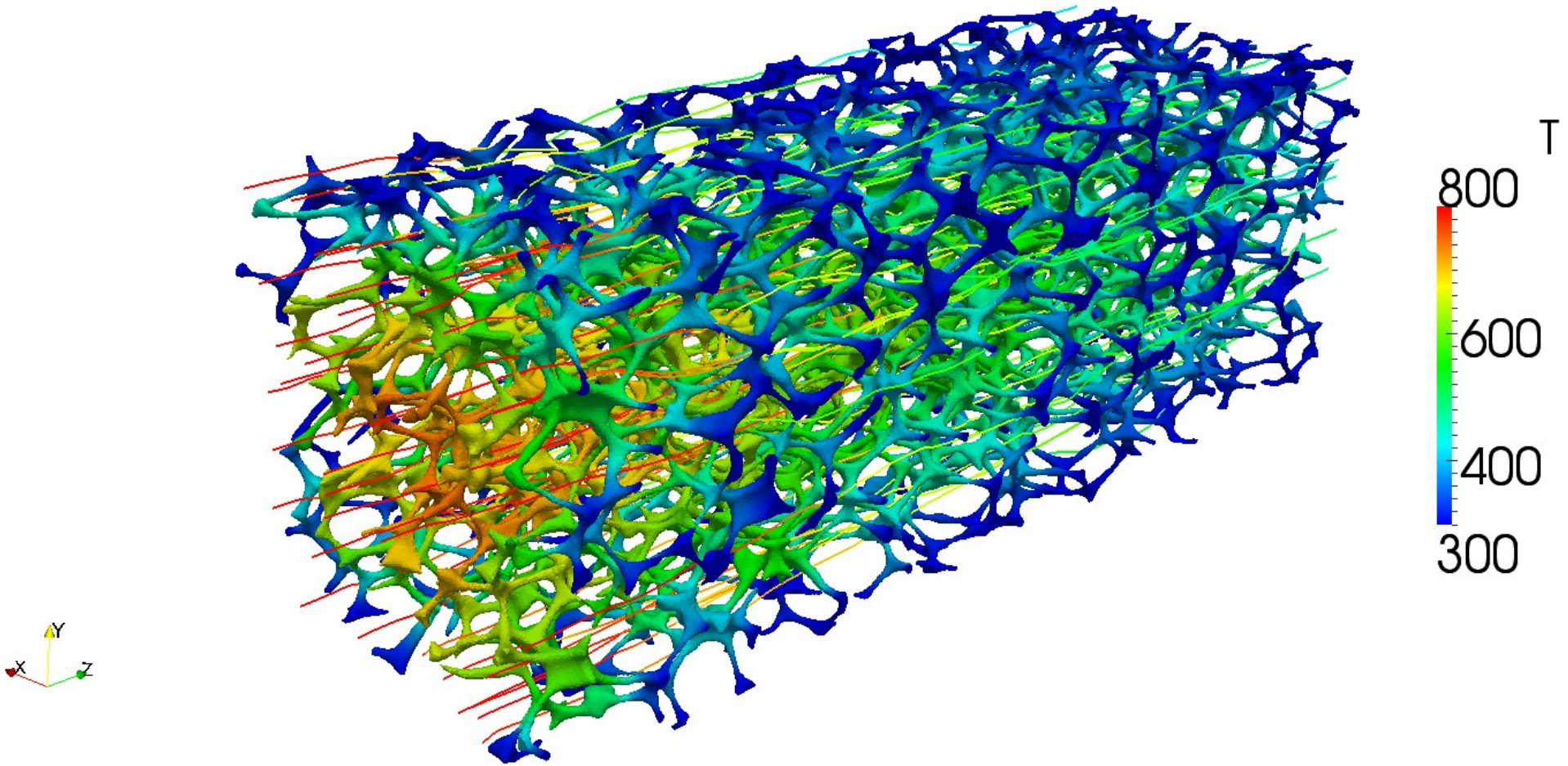
Meshes

S3foam-sample 10x10x10mm



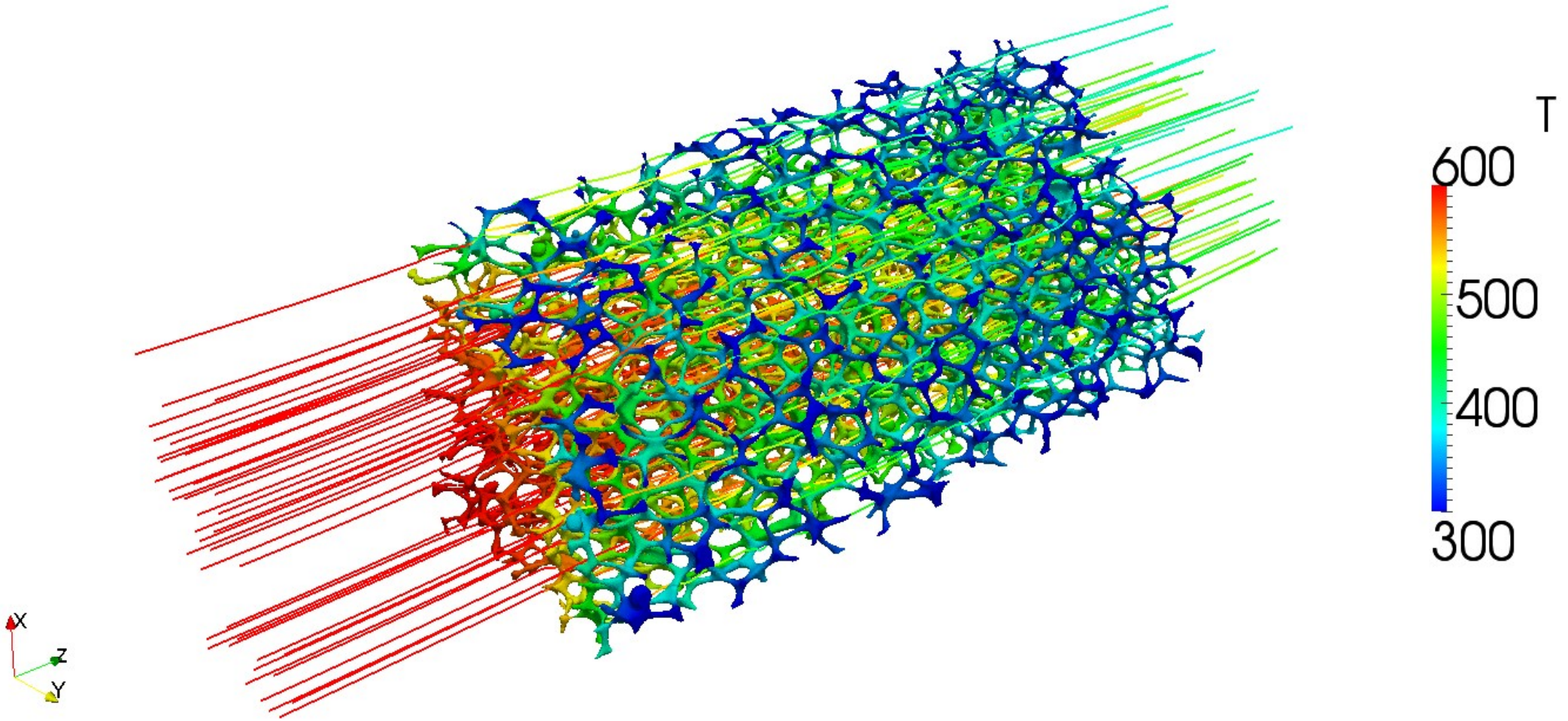
Meshes

S3foam-sample 30x10x10mm



Meshes

S3foam-quarter



Permeability and Heat Transfer Equations

- Pressure drop: Darcy equation:

$$\Delta P = \frac{\mu w}{K} U$$

- Heat transfer:
  - Conductive:

$$Q_{cond} = \frac{kA}{\Delta L}\left(T_1 - T_2\right)$$

  - Convective:

$$Q_{conv} = hA_s\left(T_f - T_s\right)$$

- Need to define averaged quantities over the fluid and solid regions.

Averaged properties and Non-Dimensional Numbers

Definition of averaged quantities:

- over the fluid: $\bar{q}_f = \frac{1}{V_f} \int_{V_f} q_f \, dV$
- over the solid: $\bar{q}_s = \frac{1}{V_s} \int_{V_s} q_s \, dV$

Non-dimensional numbers:

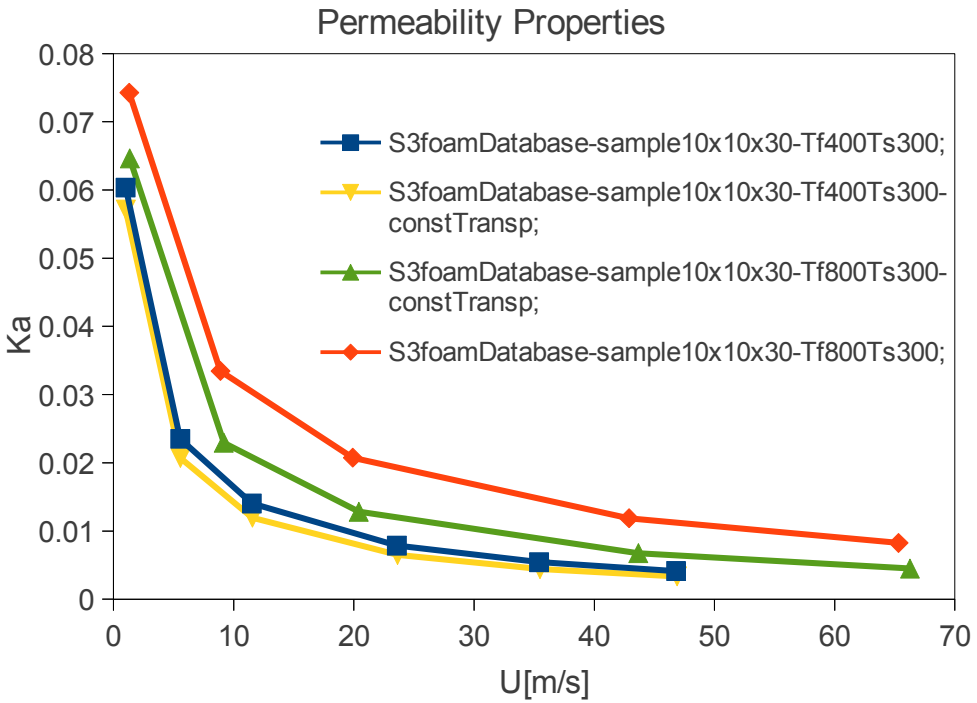
- Re: Reynold number
- Pr: Prandtl number
- Nu: Nusselt number
- Ka: adimensional permeabilty, should be the same for similar foams having different pore sizes.

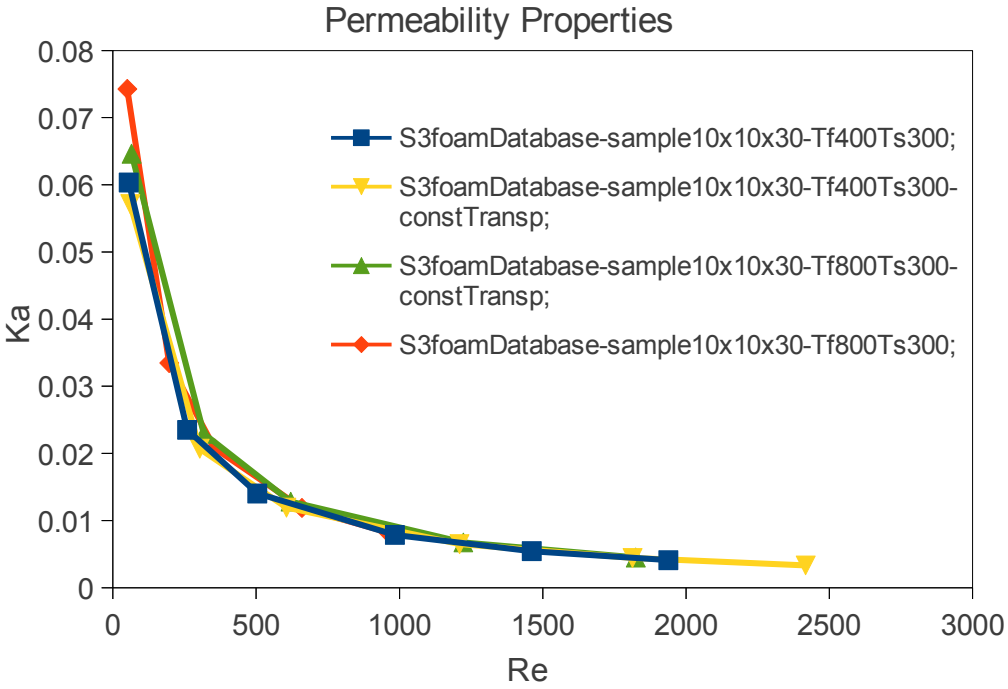
- The definition of Re, Nu, Ka requires to introduce a characteristic dimension of the porous media. Some authors adopted the square root of the permeability, however this is not a good choice since permeability is not a geometrical properties but it depends on both geometrical and fluid-dynamics properties (it is function of Re) → need to define a characteristic dimension based on geometrical properties (pore size or hole size)

Permeability

Simulations on case 10x10x10mm and 30x10x10mm have shown that:

- Permeability is a function of Re (not of velocity as I previously supposed)
- The function Ka-Re remains the same if the properties of the fluid changes (temperatures, viscosity)
- To be proved: the function Ka-Re remains the same for foams that have similar structure but different pore size?





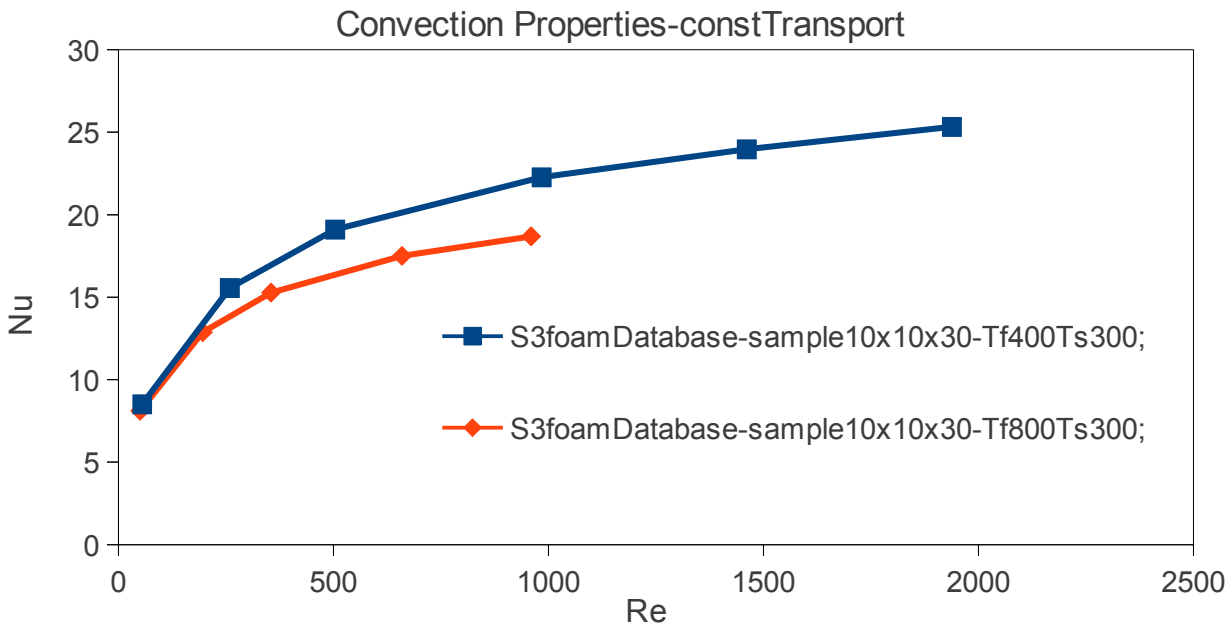
Convection

Convection is described by Nusselt coefficient that should be a function of (only?) Reynolds and Prantl. This means that Nu should be the same if I consider cases under different conditions but having the same Re and Pr.

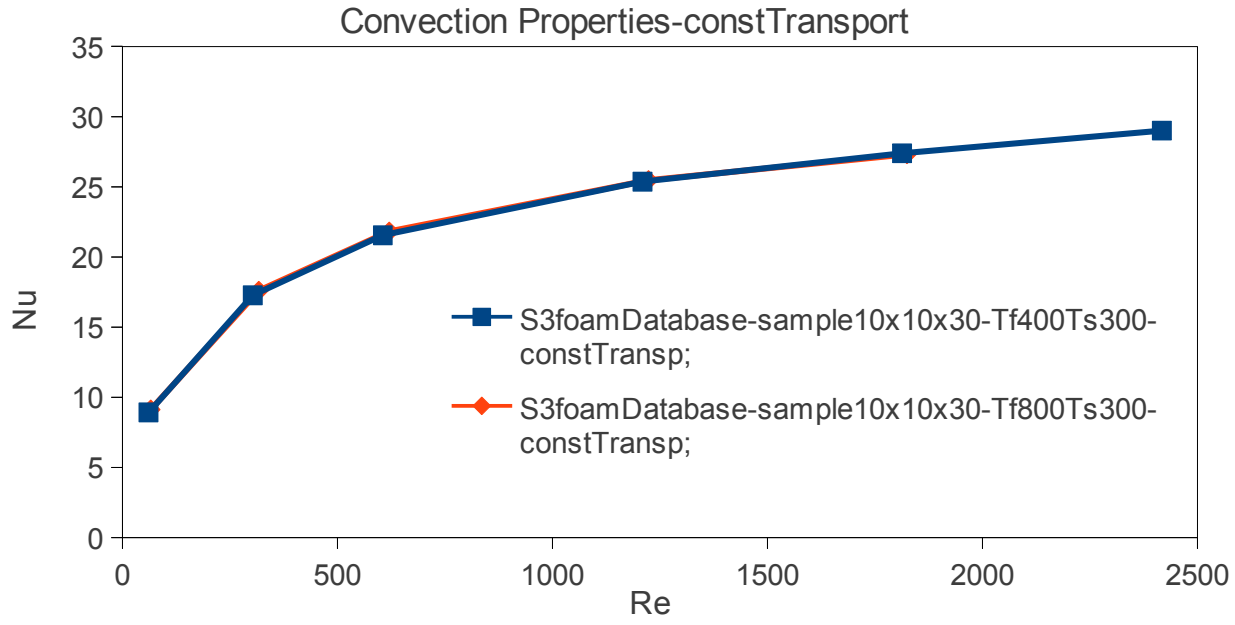
Simulations on case 10x10x10mm and 30x10x10mm have shown that:

- Nu is not always a function of only Re and Pr, depending on the transport model adopted
- If constant transport (μ = const, Pr=const) is considered Nu is a function of Re only
- If sutherland transport (μ = f(T)) is considered this is no longer true, but under different thermal condition Nu assumes different value even if Re and Pr are constant.

Convection



Sutherland transport model



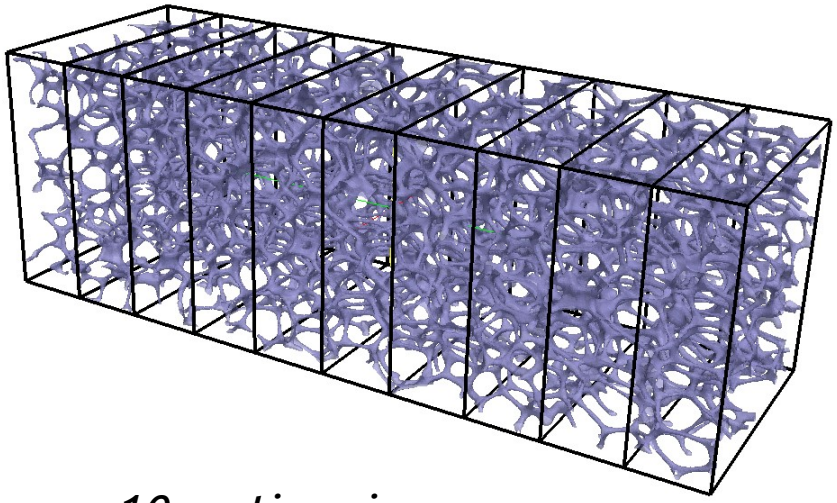
Constant transport model

Dependence of the Nu on the position inside the sample

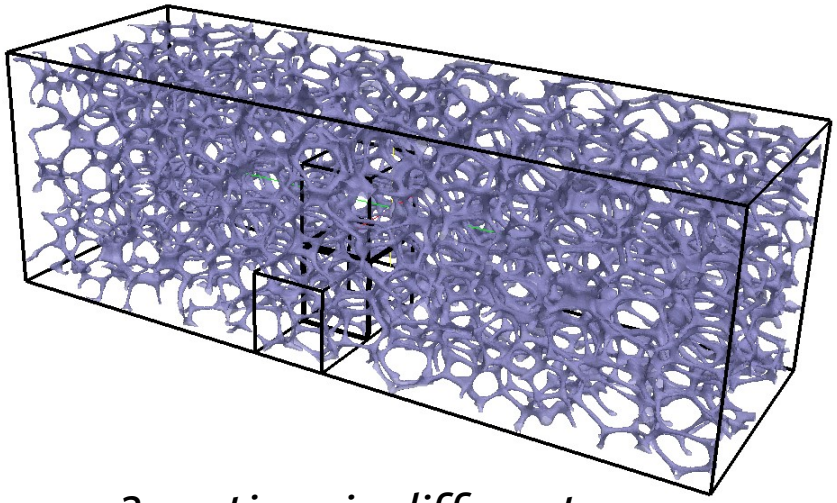
In order to investigate the dependence of the Nu coefficient on the position of the control volume adopted for the averaging the 30x10x10 mesh has been considered.

Several cell zone has been created in order to evaluate Nu in different positions:

- The sample has been divided in 10 section along the x direction (Δx = 3mm)
- Three portion of the 5th section has been considered for investigating the effect of the different thermal gradient across the section.

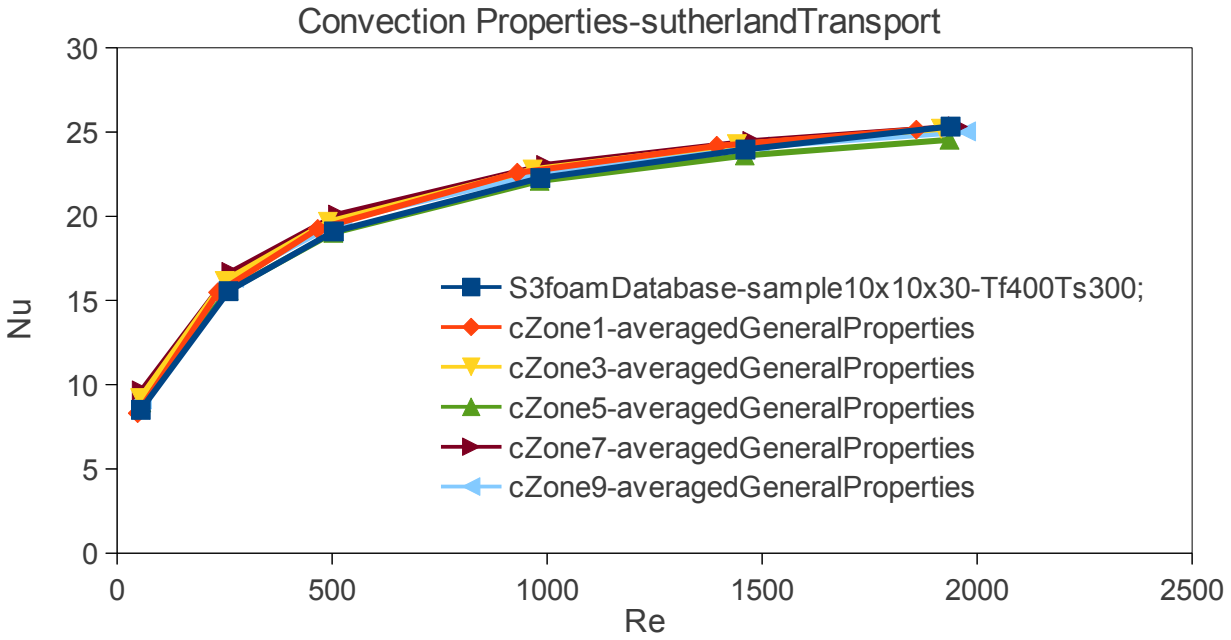


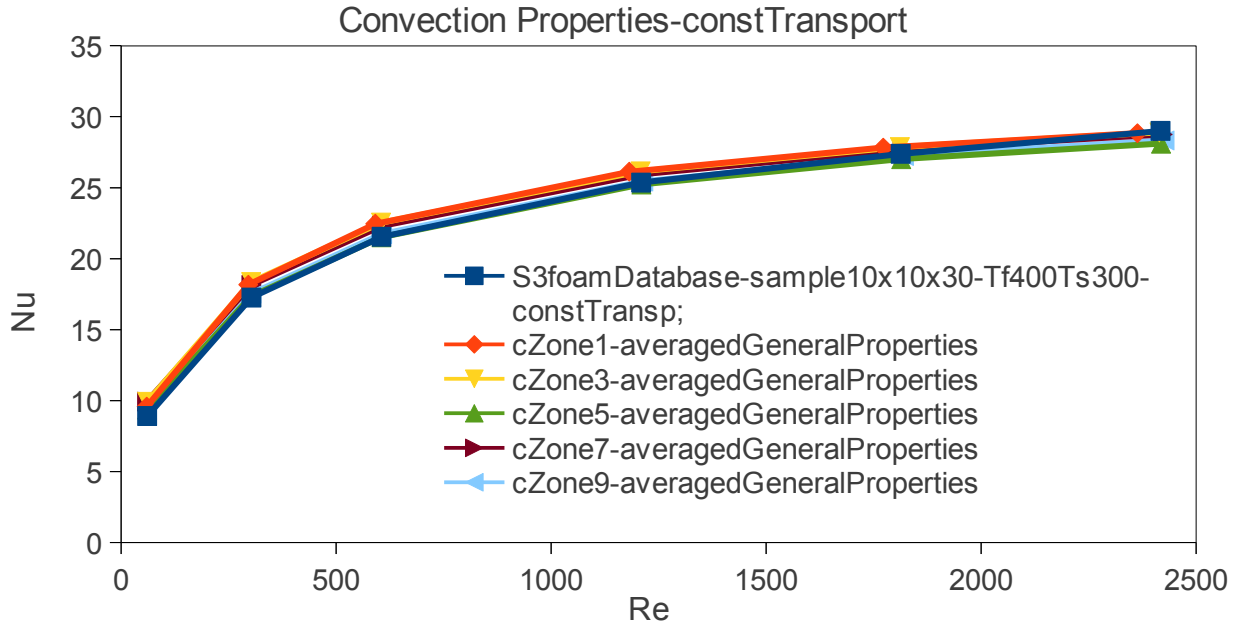
10 sections in axial direction



3 portions in different positions on 5th section

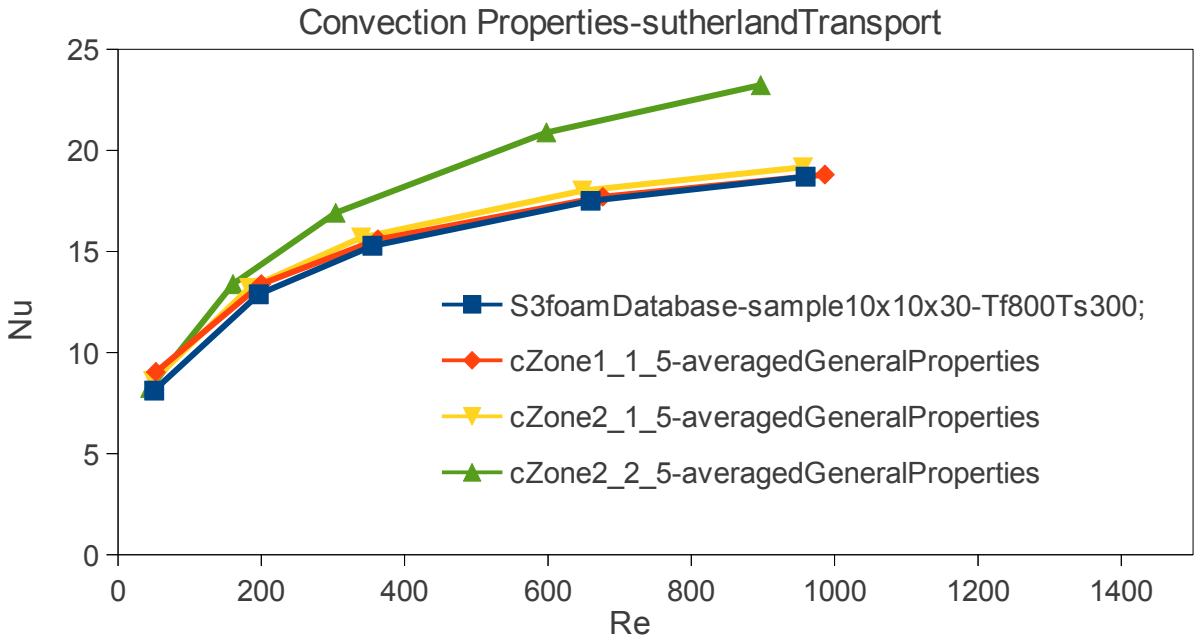
Dependence of the Nu on the position inside the sample

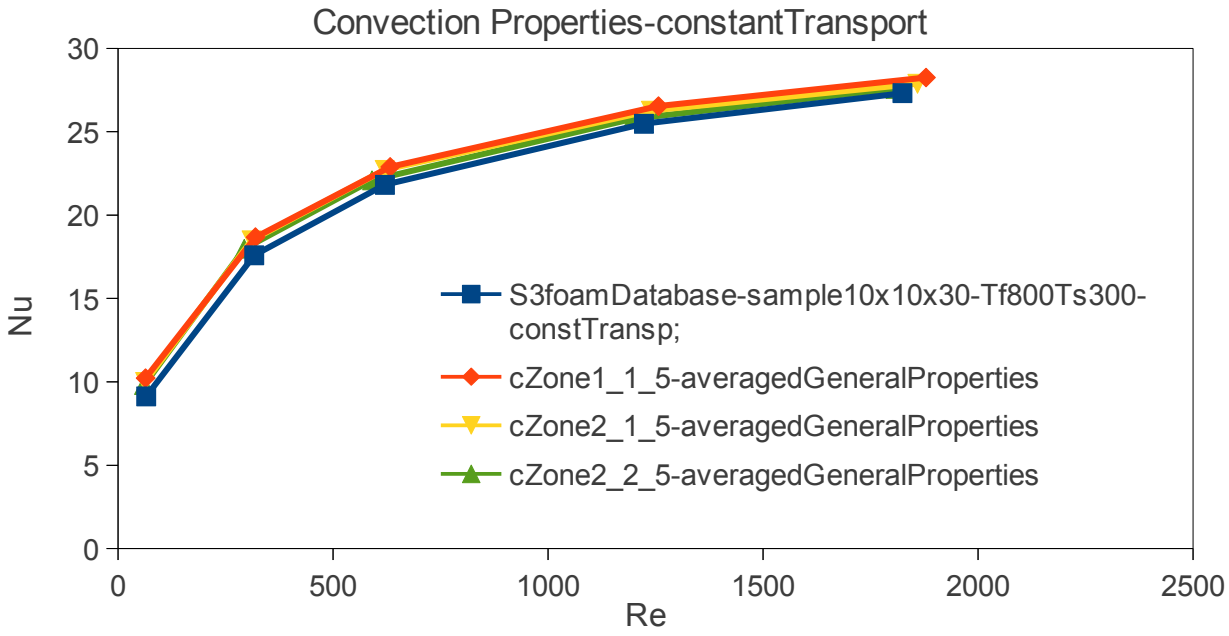




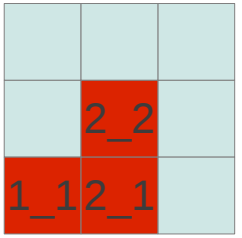
Nu in different section along the axial direction: Nu(Re) is constant for both sutherland and constant transport model.

Dependence of the Nu on the position inside the sample



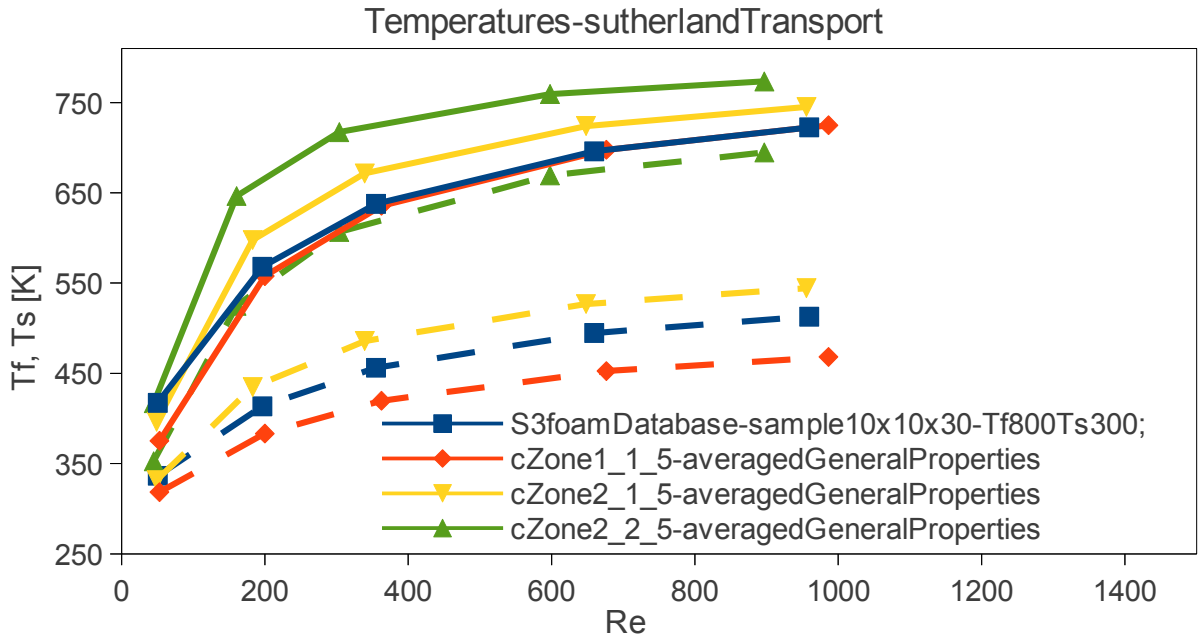


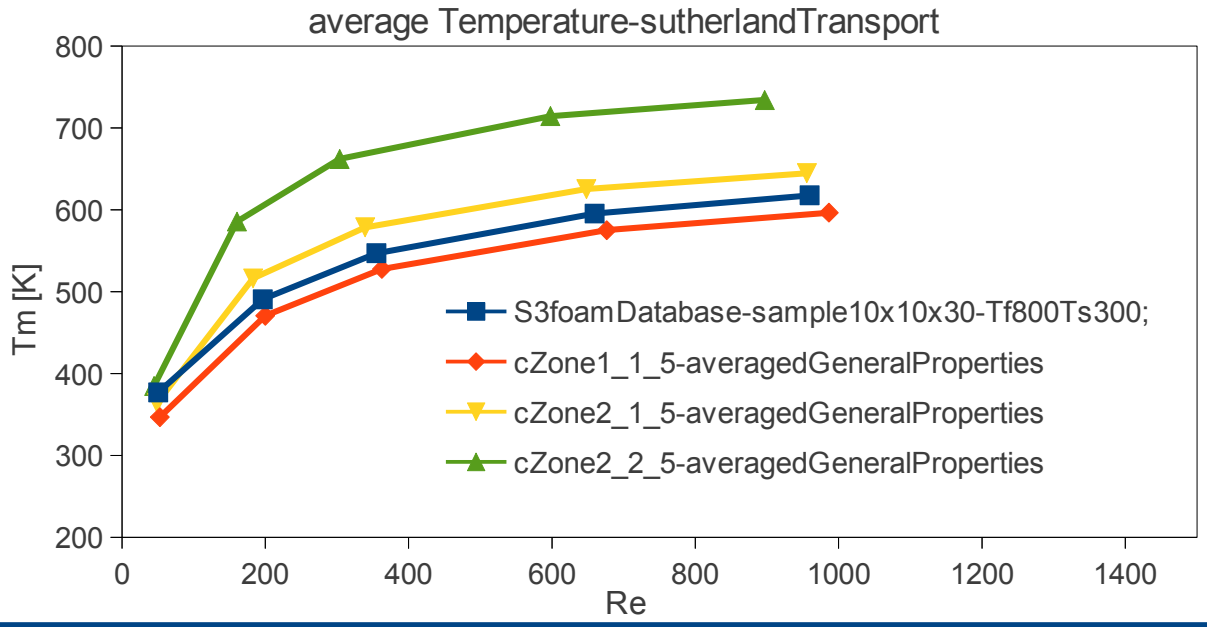
Nu in different position on section 5:



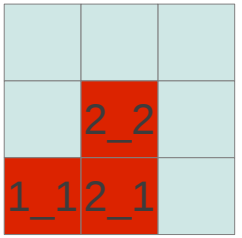
Nu(Re) is constant for constant transport model while it is not for sutherland. This is due to the fact that the fluid temperature in the film region is higher in the central region than in the boundary → the fluid thermal conductivity change!

Dependence of the Nu on the position inside the sample





Position on section 5:



The fluid temperature in the film region is considerably higher in the central region than in the boundary → the fluid thermal conductivity change!

The thermal conductivity evaluated at the film temperature should be used instead of the averaged conductivity. WIP!

To Summarize:

Micro-scale simulations:

- Evaluation of permeability coefficient:
  DONE: check of validity of relation Ka-Re under different flow condition
  TODO: check of validity of relation Ka-Re with similar foams having different characteristic size

- Evaluation of convection coefficient:
  DONE: check of validity of relation Nu-Re (Pr=const) in case of constant transport model; understood why it is not working with sutherland
  TODO: extension to the case of a generic transport model

- Evaluation of geometric properties:
  DONE: sensitivity analysis for different relative density, extraction of porosity and surface to volume ratio.
  TODO: calculation of a mean characteristic dimension of the foam cell starting from *.stl geometry (now the pore per inch information is used, but it is something with an certain level of uncertainties – I have already something in mind).