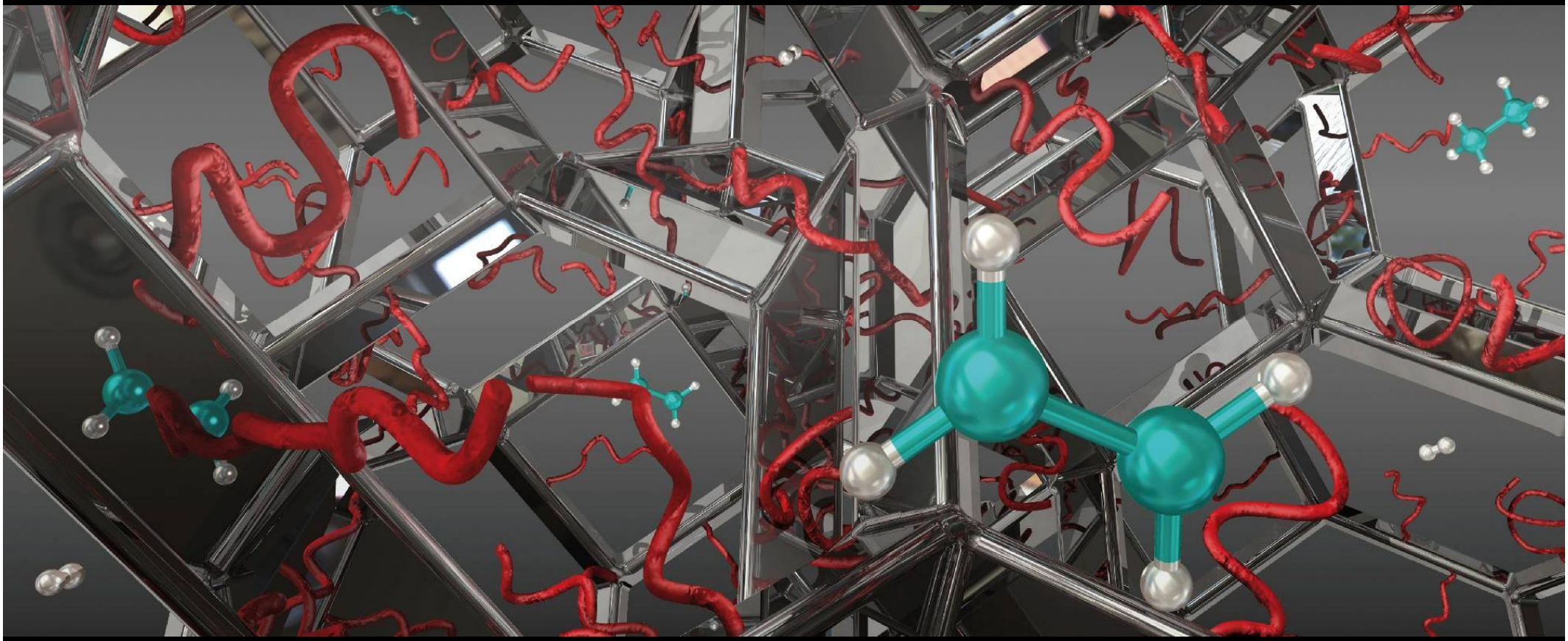
Hairy Foam: Carbon nanofibers on solid foam as catalyst support

Synthesis, mass transfer, and reactor modeling



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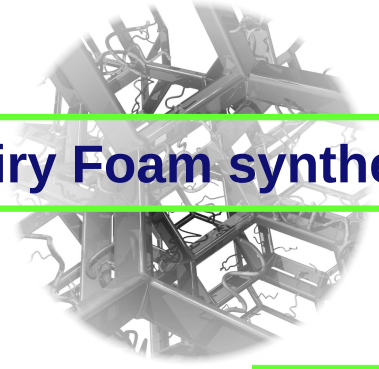
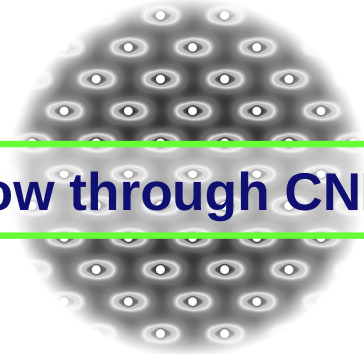
Overview PhD research

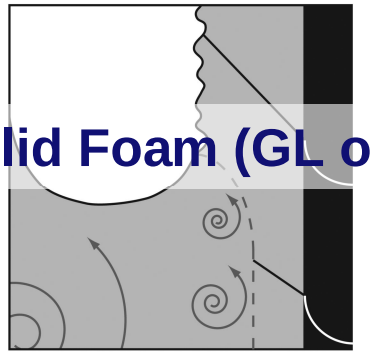


Hairy Foam synthesis

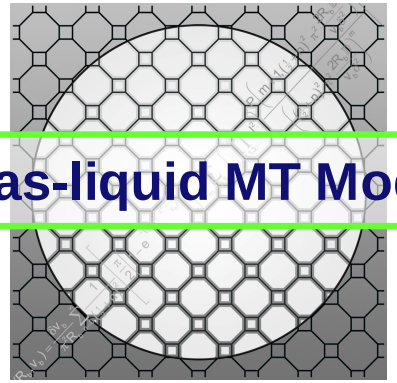
Liquid-Solid MT Hairy Foam



Liquid flow through CNF layers



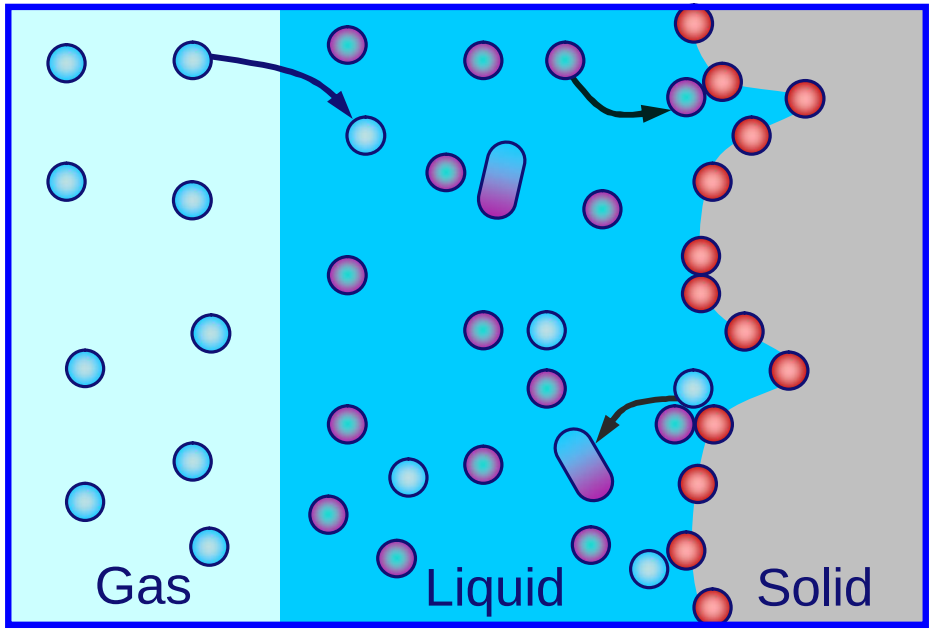
LS MT Solid Foam (GL operated)

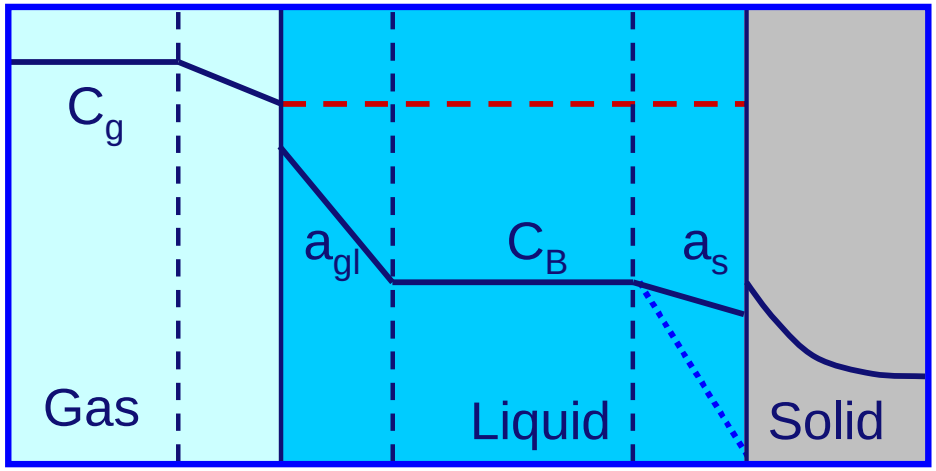


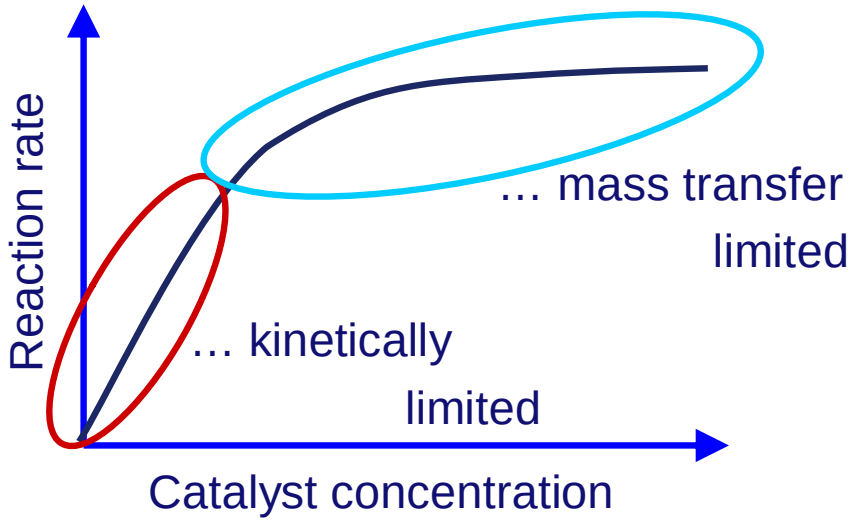
Gas-liquid MT Model

Reactor packing comparison

Gas-Liquid-Solid reactions



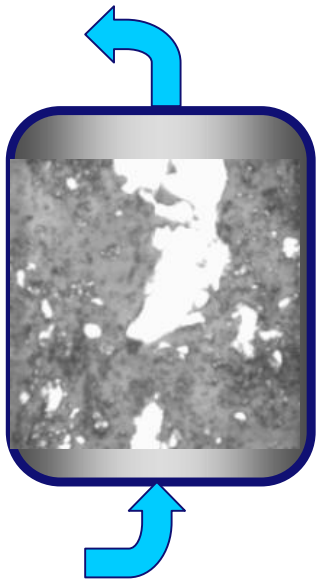




- Control reaction rate by:
  - Sufficient amount of catalyst
  - Accessibility of the catalyst
  - High mass transfer rates
  - Controlled hydrodynamics

Multiphase reactors

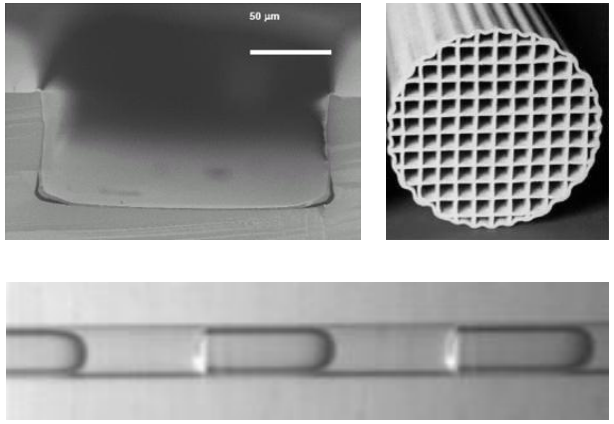
Bubble Columns



Packed Beds

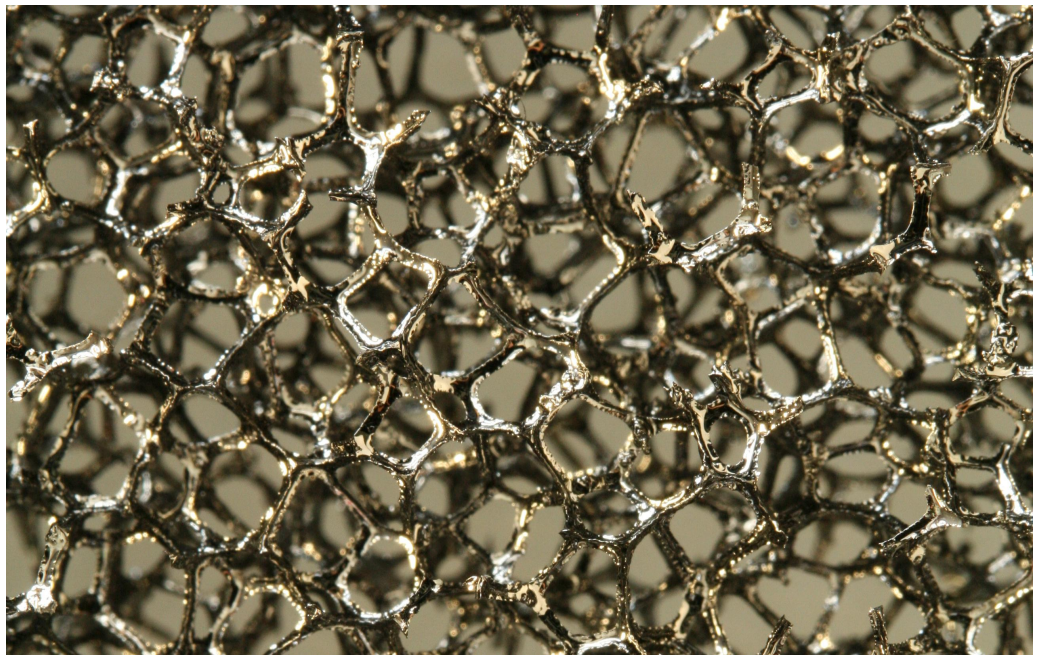
- Widely applied in industry:
  - Hydrogenations
  - Oxidations
  - Waste water treatment
  - Fischer Tropsch
  - Etc…..

Microreactors and monoliths

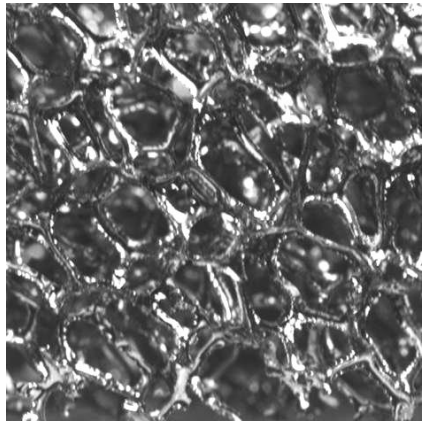


New type of packing: Solid Foam

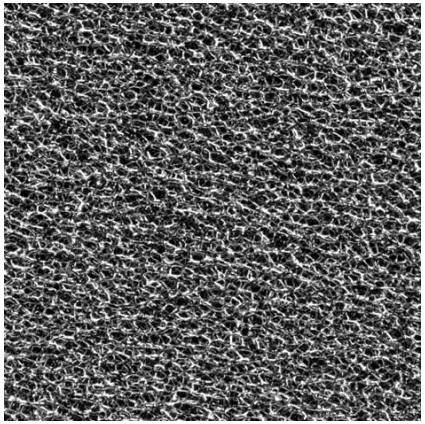
- Reticulated network of struts
  - Low degree of back mixing
- Very open structure
  - Low pressure drop
- High external surface area
  - High mass transfer rates
- Available in several “grades” so-called PPI number



10 PPI



100 PPI



Solid Foam as catalyst support?

Solid Foam

…low pressure drop

…high mass transfer rates!!!

…effective use of reactor volume!!!

High (“internal”) surface area needed

- Wash-coat
- Surface roughening
- Or……

Solid Foam as catalyst support?

Solid Foam

…low pressure drop

…high mass transfer rates!!!

…effective use of reactor volume!!!

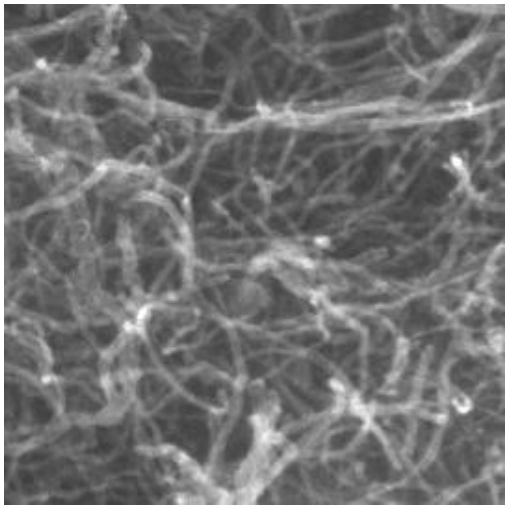
Hairy Foam

HOLD ON!!
…area for catalyst deposition?

The Hairy Foam principle – part I

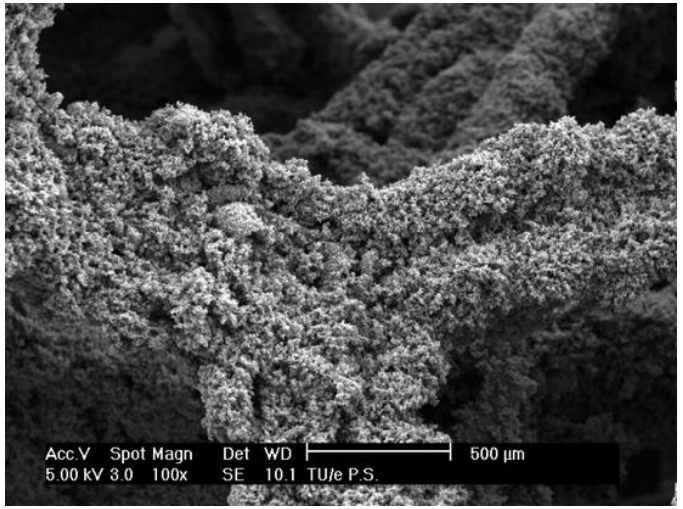
Solid Foam

+



Carbon nanofibers

=



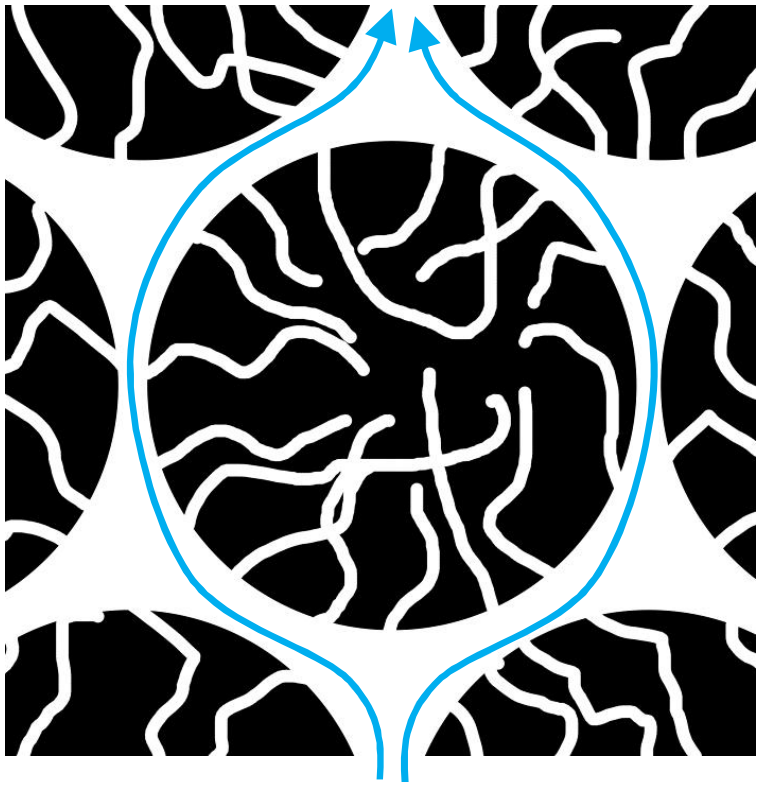
Hairy Foam

Combining the advantages of Solid Foam
and
increasing surface area with high accessibility

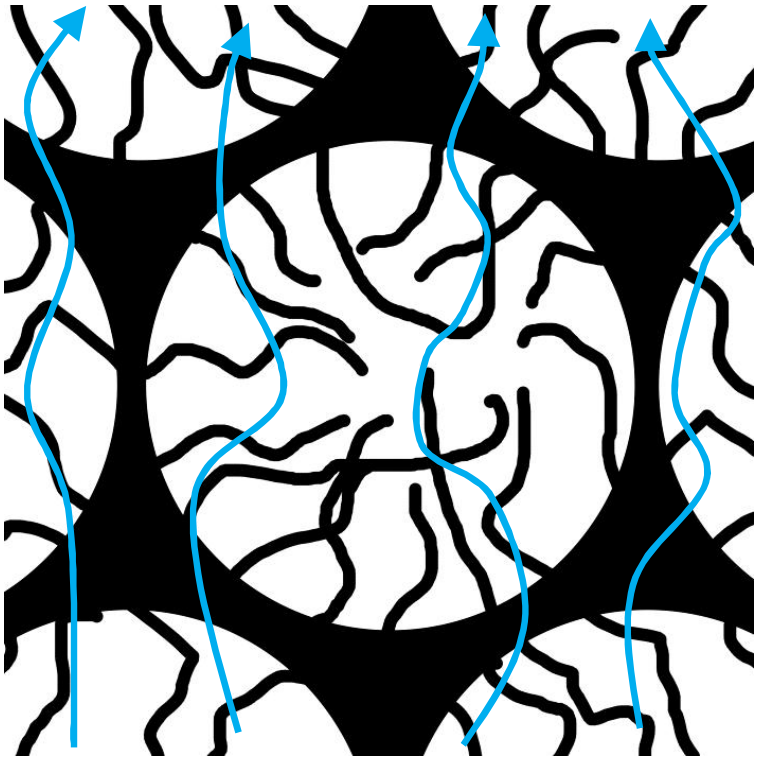
The Hairy Foam principle – part II

Hairy Foam can be seen as an

Inverse packed bed with porous particles:



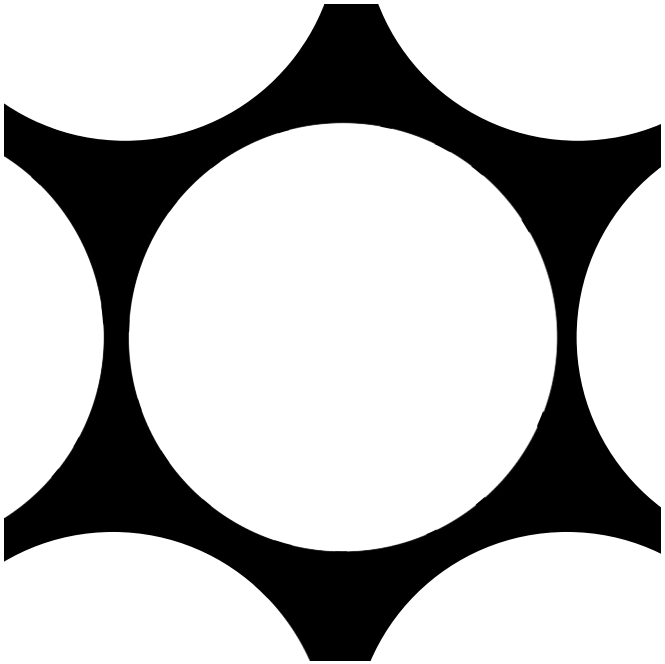
Porous packed bed



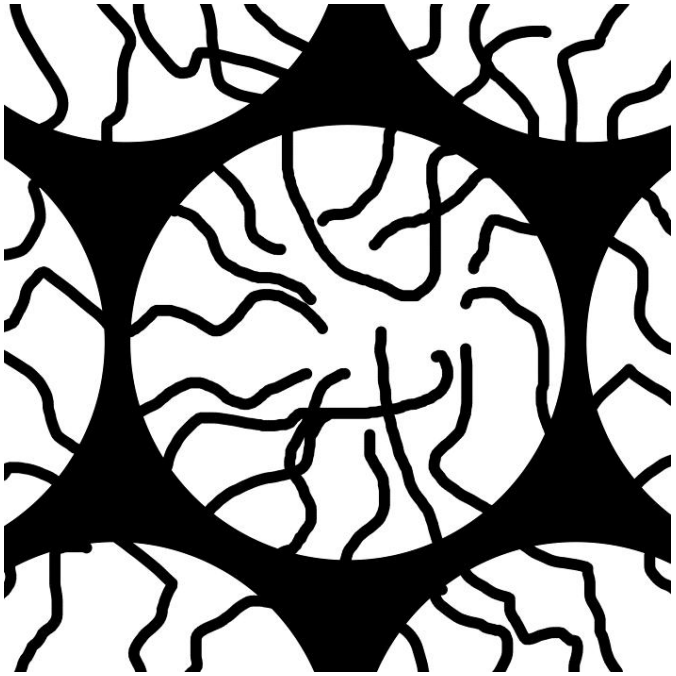
Hairy Foam

Where to start…

From Solid Foam

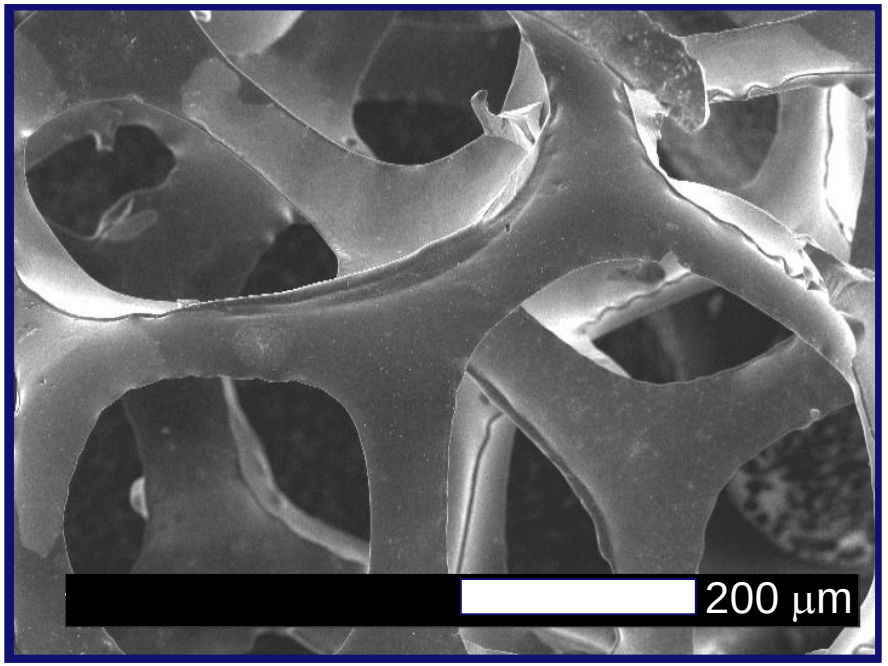


To Hairy Foam

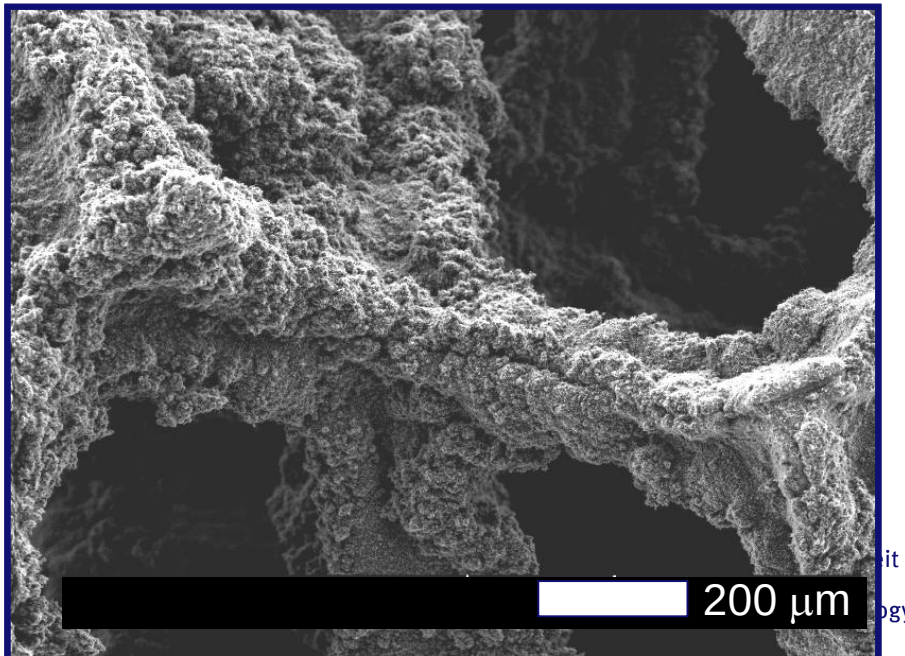


From Solid Foam to Hairy Foam

- Carbon foam fully covered with layer of CNFs: **Hairy Foam**



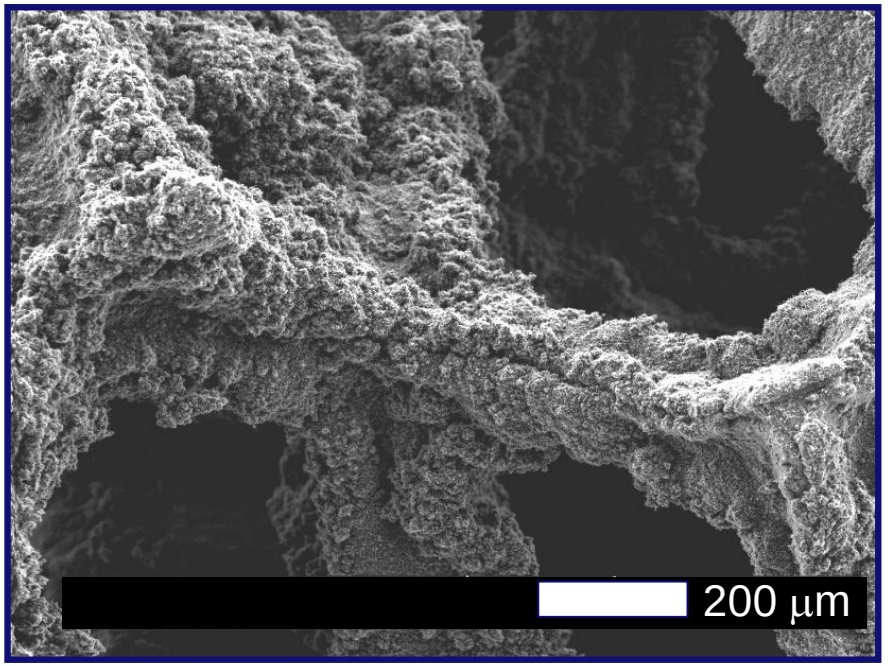
- Surface area increase of more than 1000x
  - 0.12 $m^2 g^{-1}$ → 146 $m^2 g^{-1}$



- The road to catalysis is open…

From Solid Foam to Hairy Foam

- Carbon foam fully covered with layer of CNFs: **Hairy Foam**



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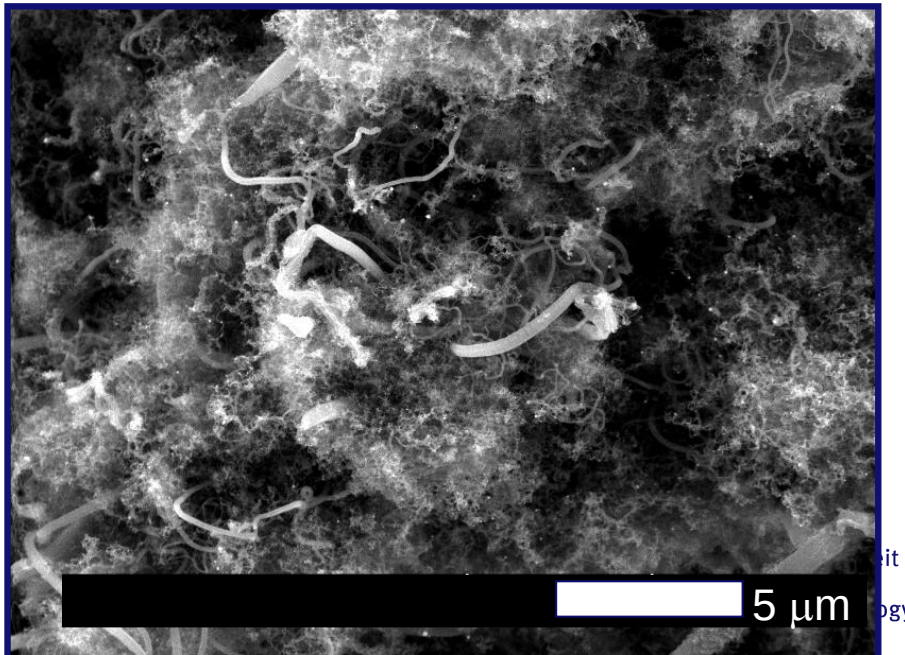
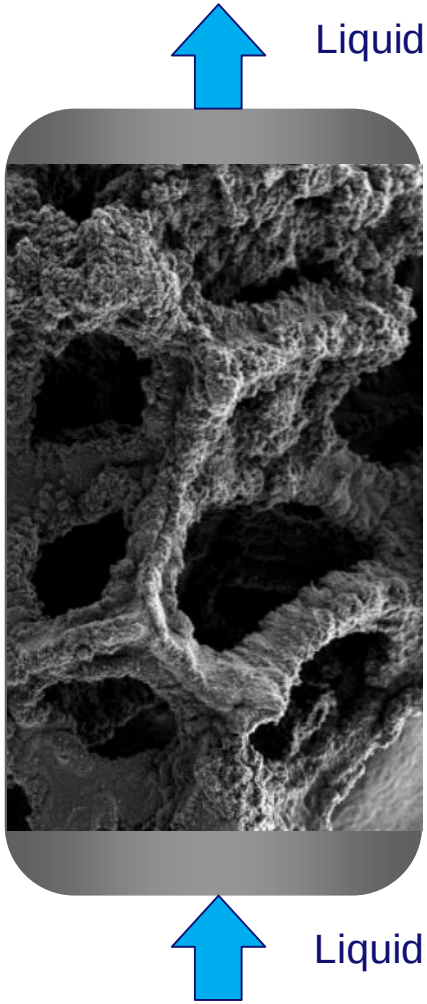


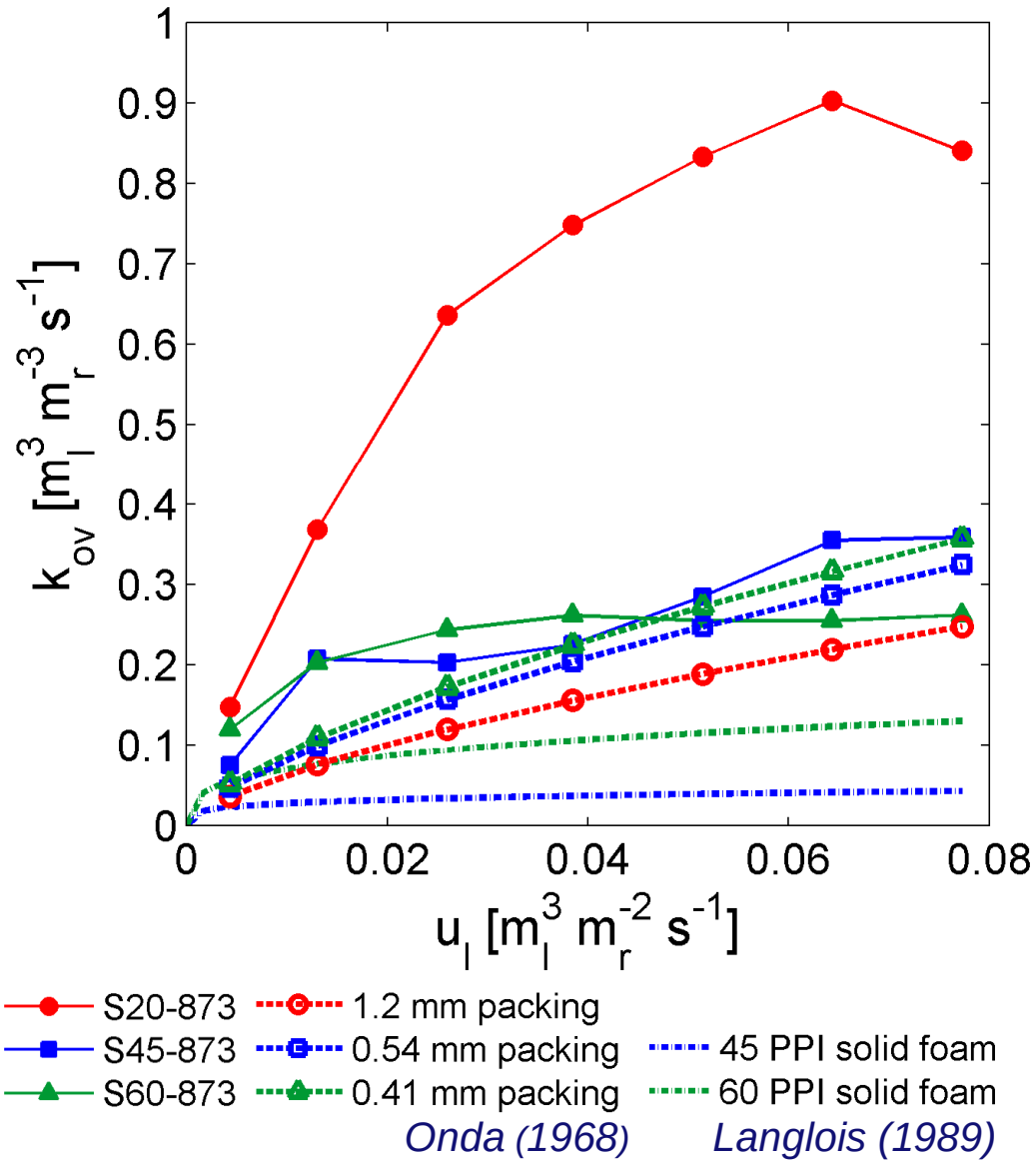
- The road to catalysis is open…

Hairy Foam as a catalyst support



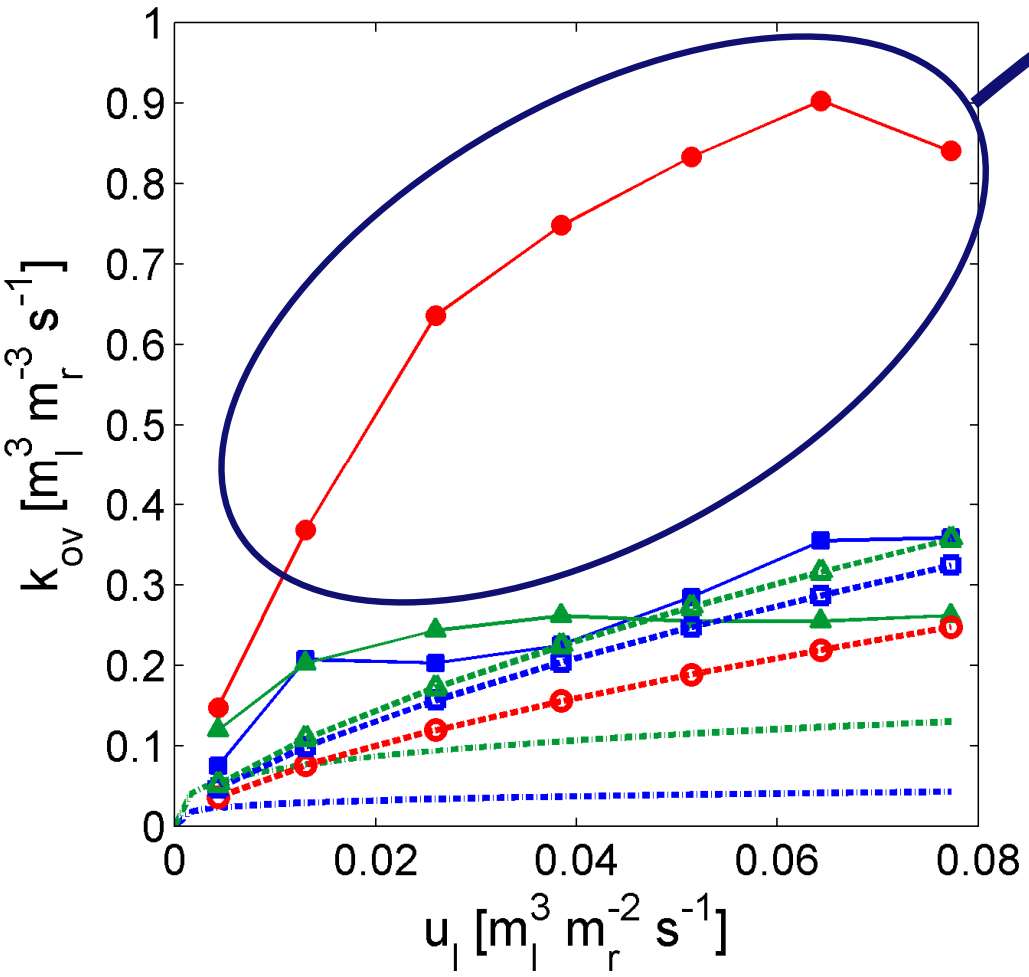
- Pd-catalyzed liquid phase oxidation of sodium formate

Hairy Foam as a catalyst support

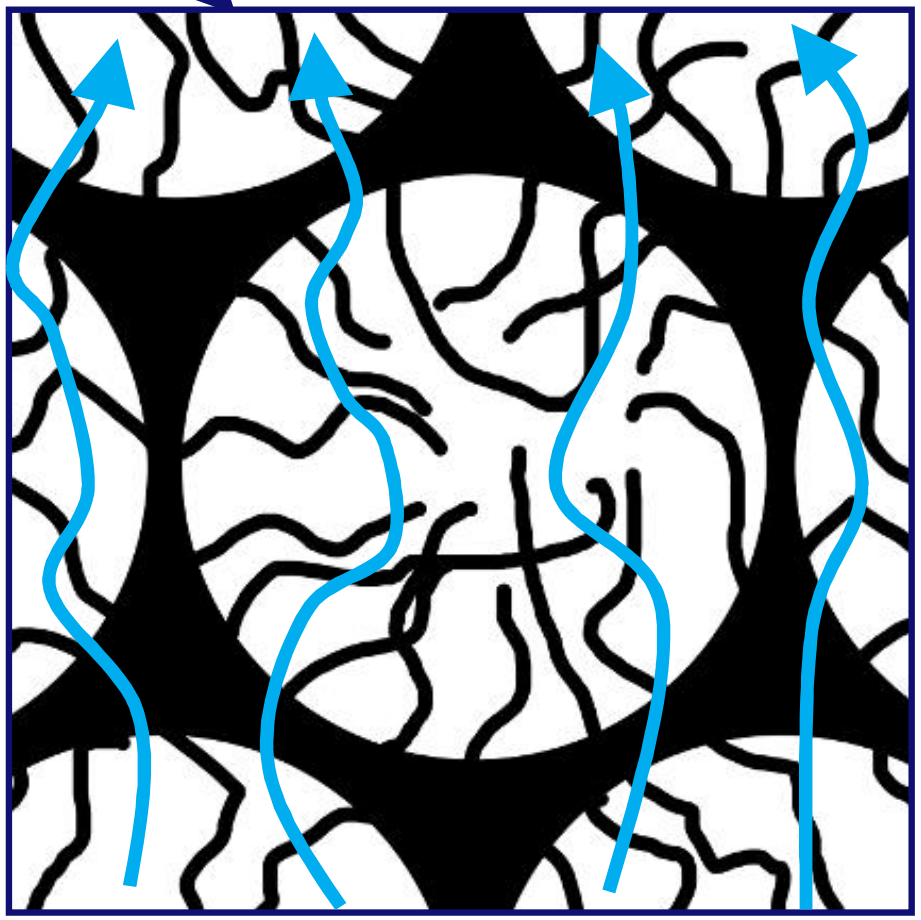


- Pd-catalyzed liquid phase oxidation of sodium formate
- 20 PPI Hairy Foam show highest values for k_{ov}
- 45 and 60 PPI show similar values for k_{ov}
- Hairy Foam:
  - At least competes with packed bed
  - Outperforms Solid Foam

Hairy Foam as a catalyst support

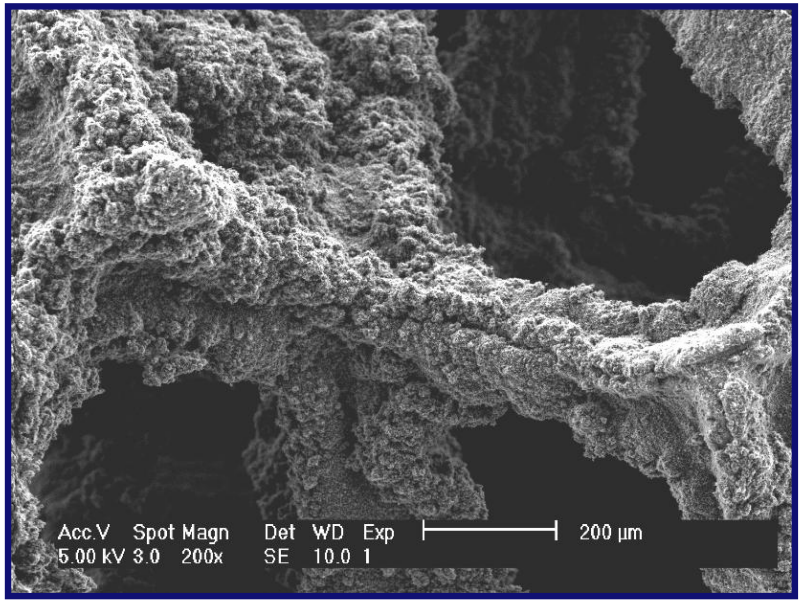


Liquid flow through CNFs?

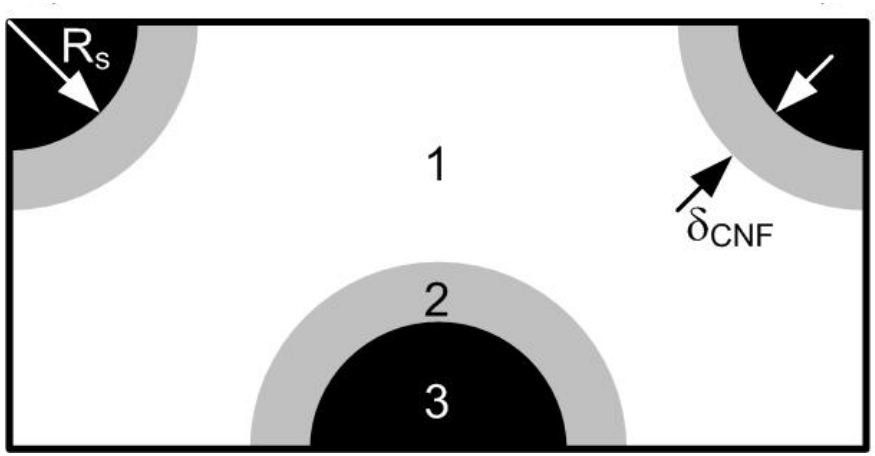


Is fluid flowing through the CNF layer?

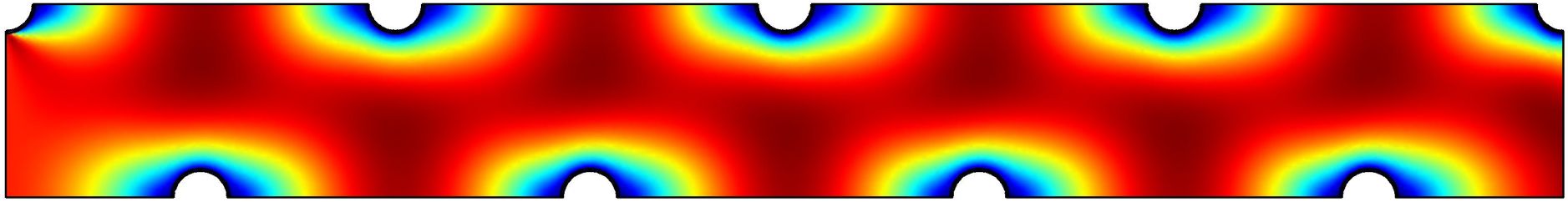
Hairy Foam



2D - Hairy Foam

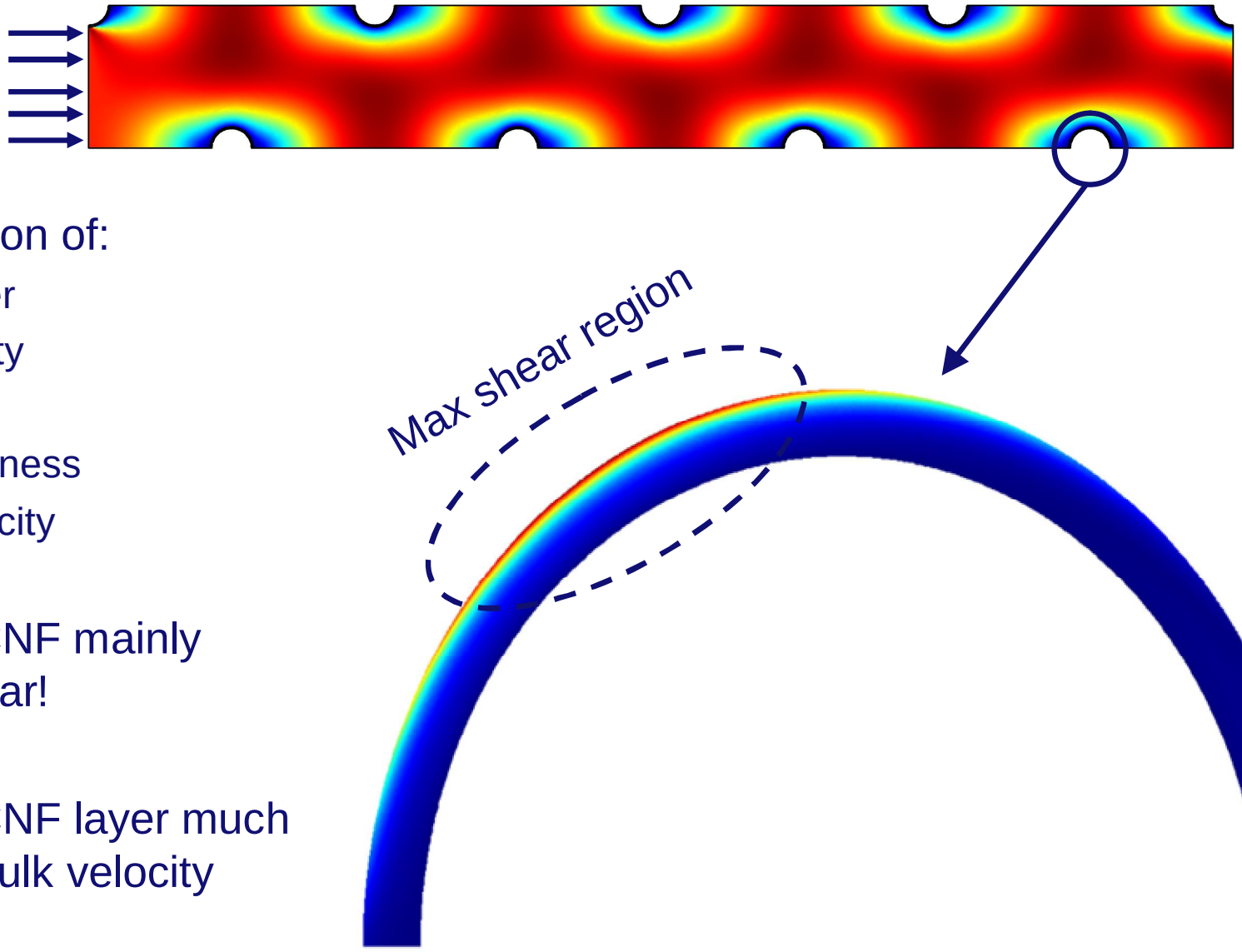


CFD



Fluid flow through the CNF layer

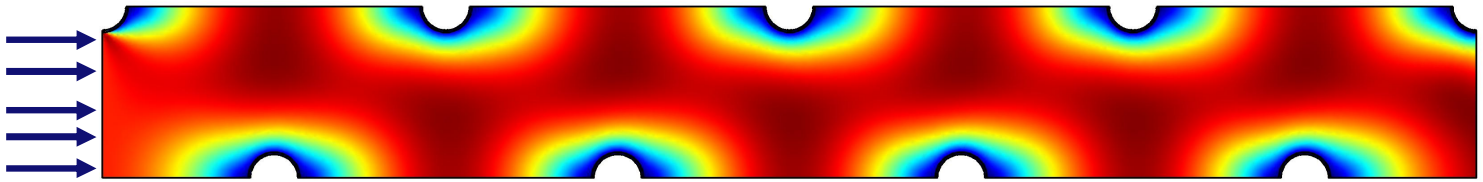
u_{in} = 0.001 – 0.1 m s^{-1}

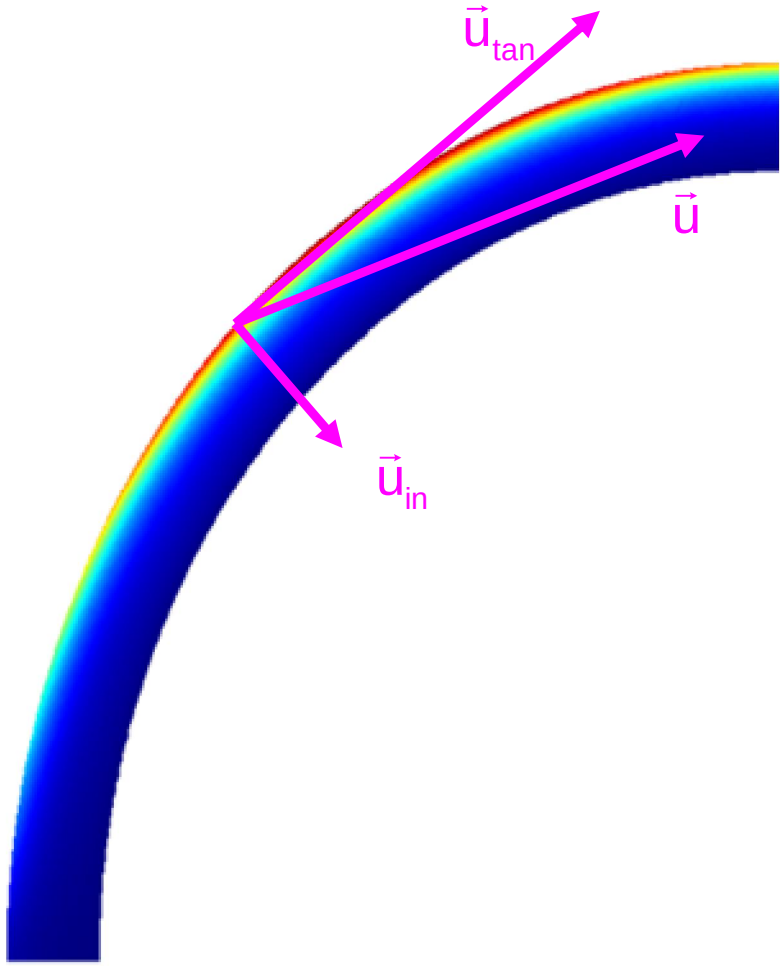


- Study variation of:
  - PPI number
  - Permeability
  - Porosity
  - Layer thickness
  - Liquid velocity
- Velocity in CNF mainly result of shear!
- Velocity in CNF layer much lower than bulk velocity

Fluid flow versus mass transfer…

u_{in} = 0.001 – 0.1 m s^{-1}





- Use velocity field to determine amount of fluid entering the CNF layer
- No mass transfer enhancement expected!
- Due to the low velocity in the CNF also no diffusion enhancement is expected!

Fluid flow versus mass transfer…

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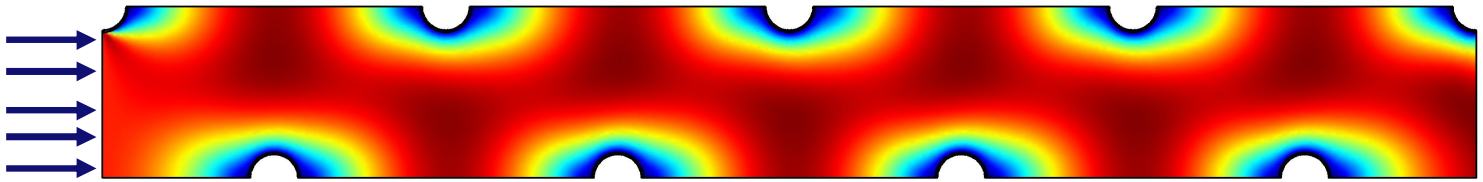

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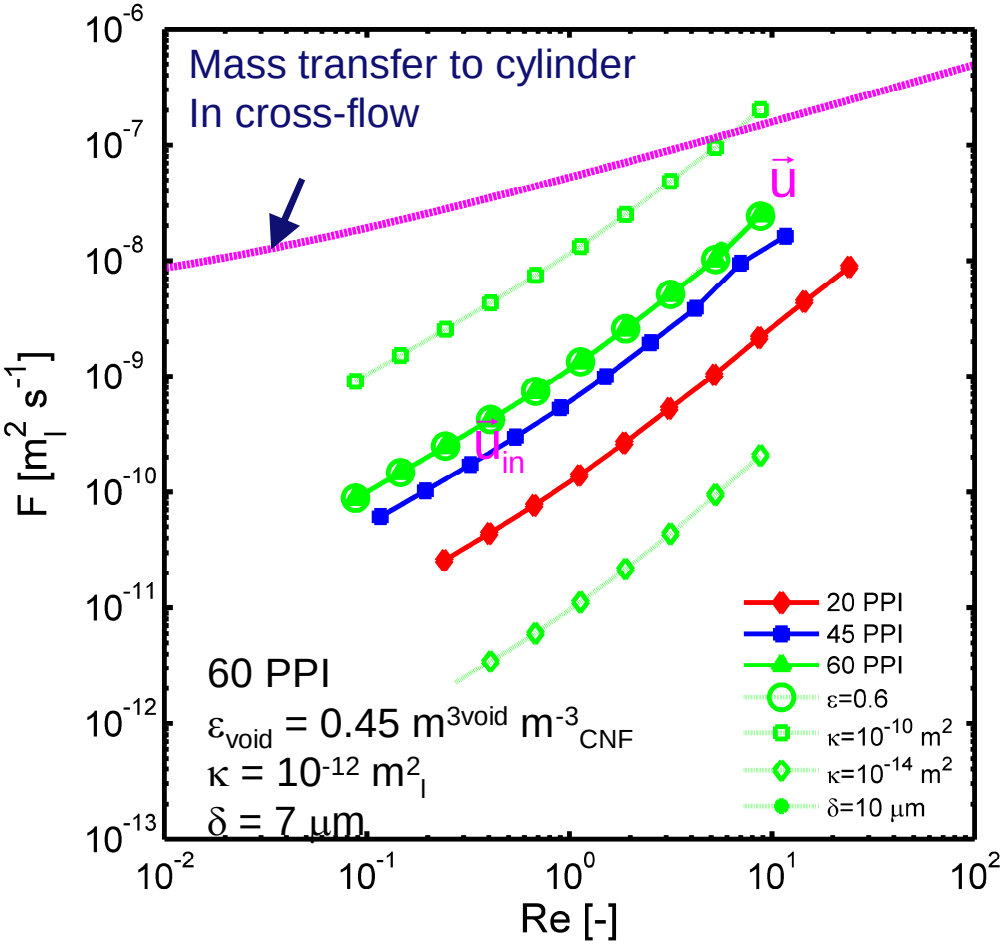
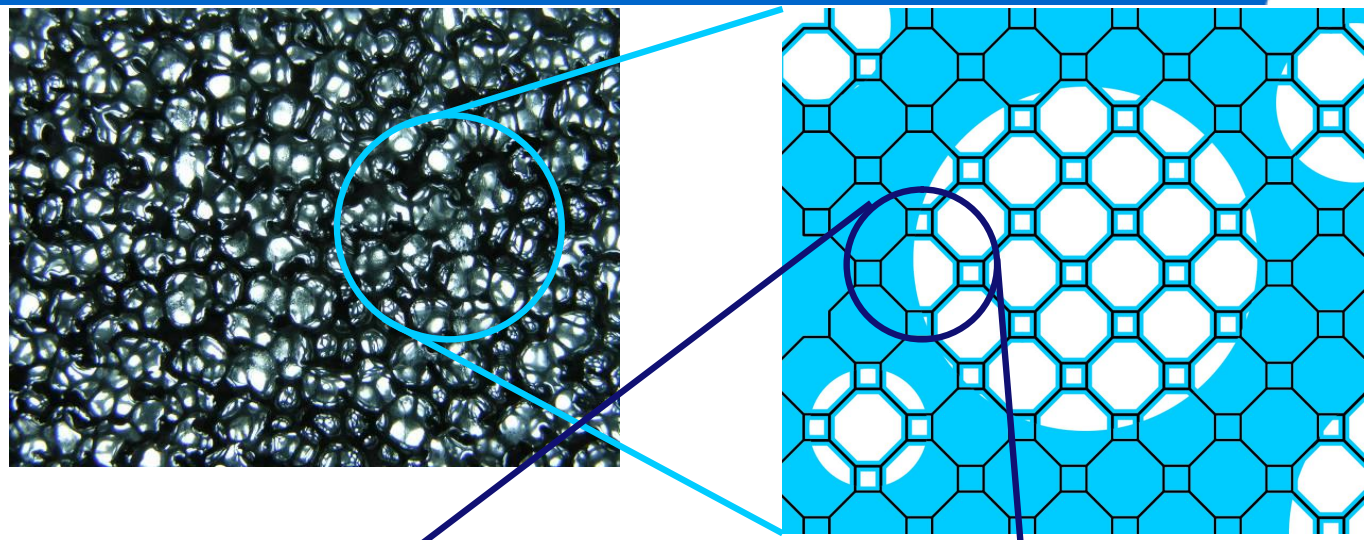
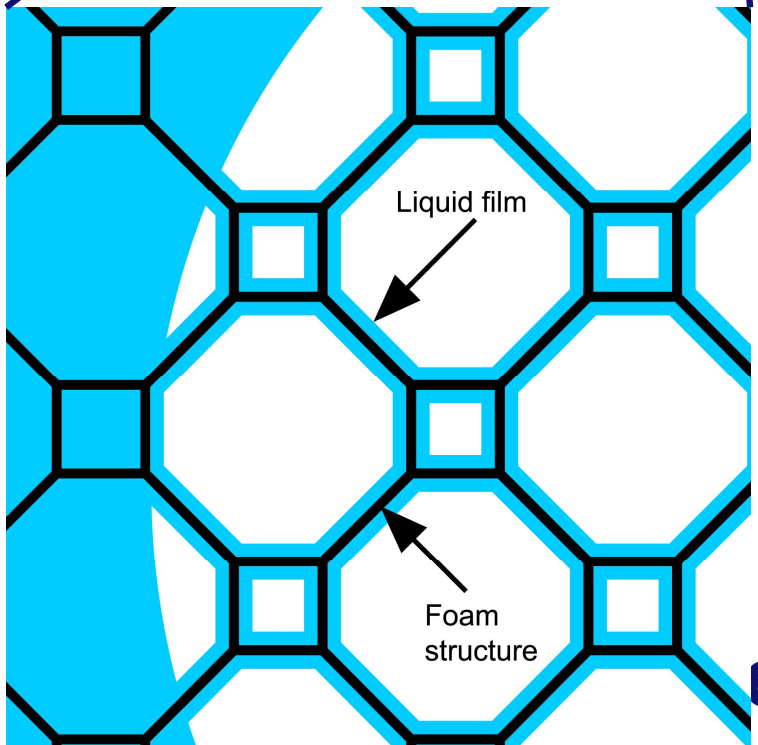


What about Gas-Liquid Mass Transfer





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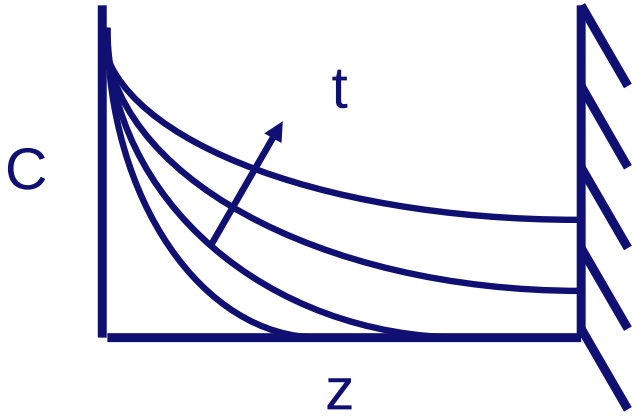
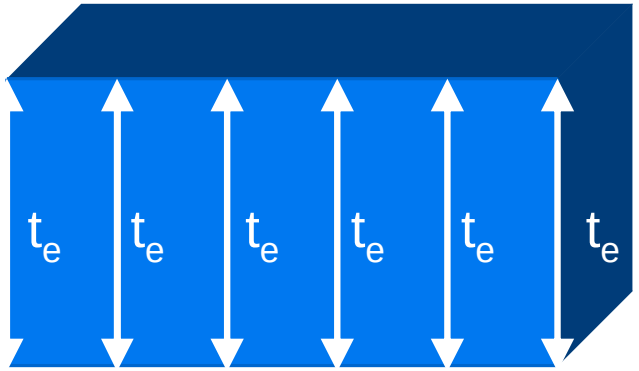
Gas Liquid Mass Transfer in Foam

Concentration in the liquid film:



Mass transfer

Classical theory:



Gas Liquid Mass Transfer in Foam

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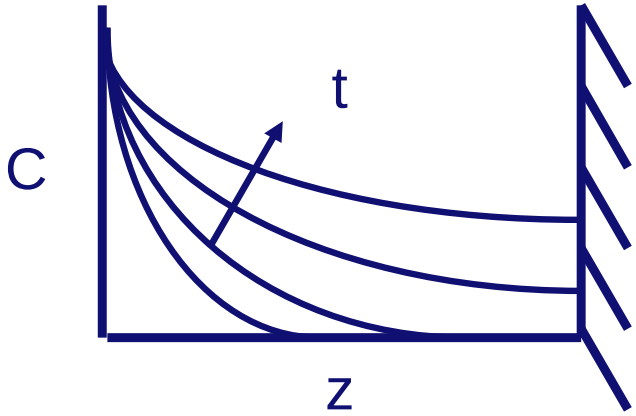
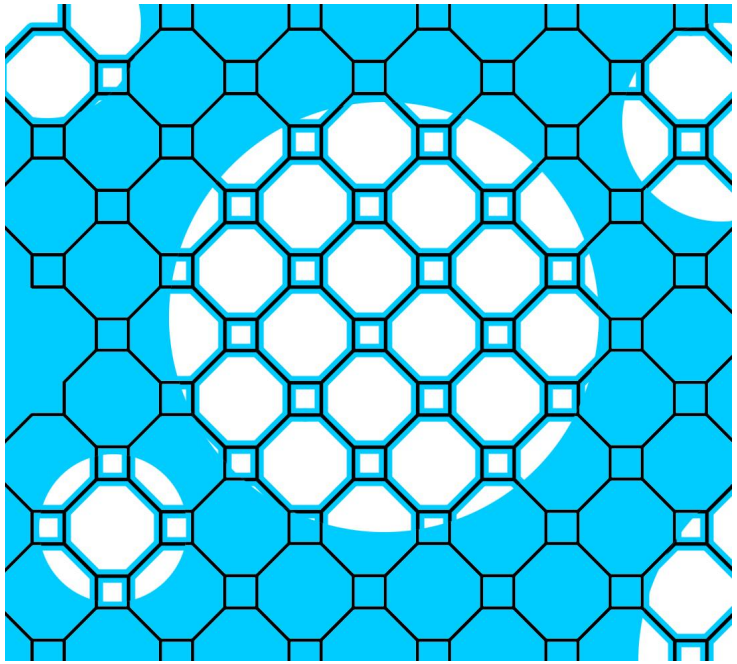
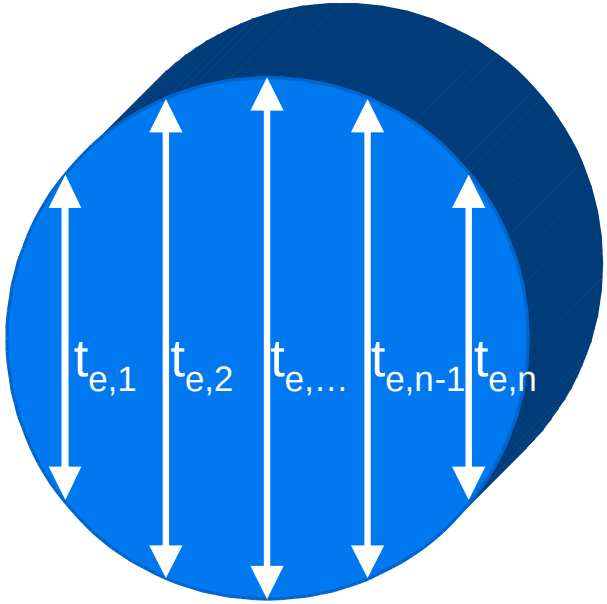
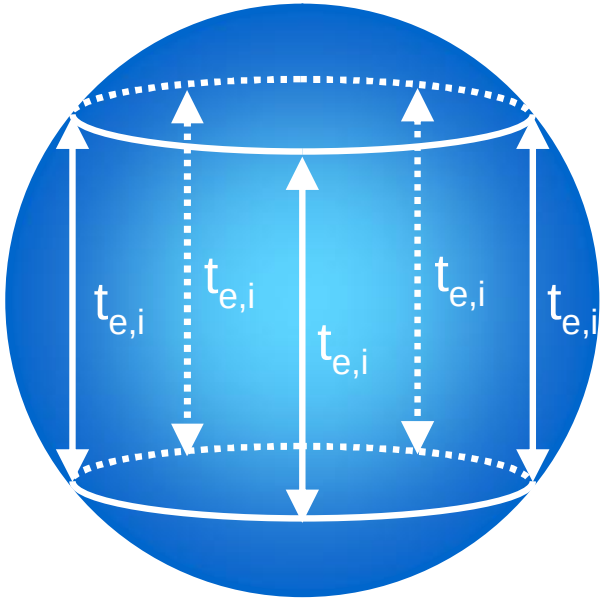




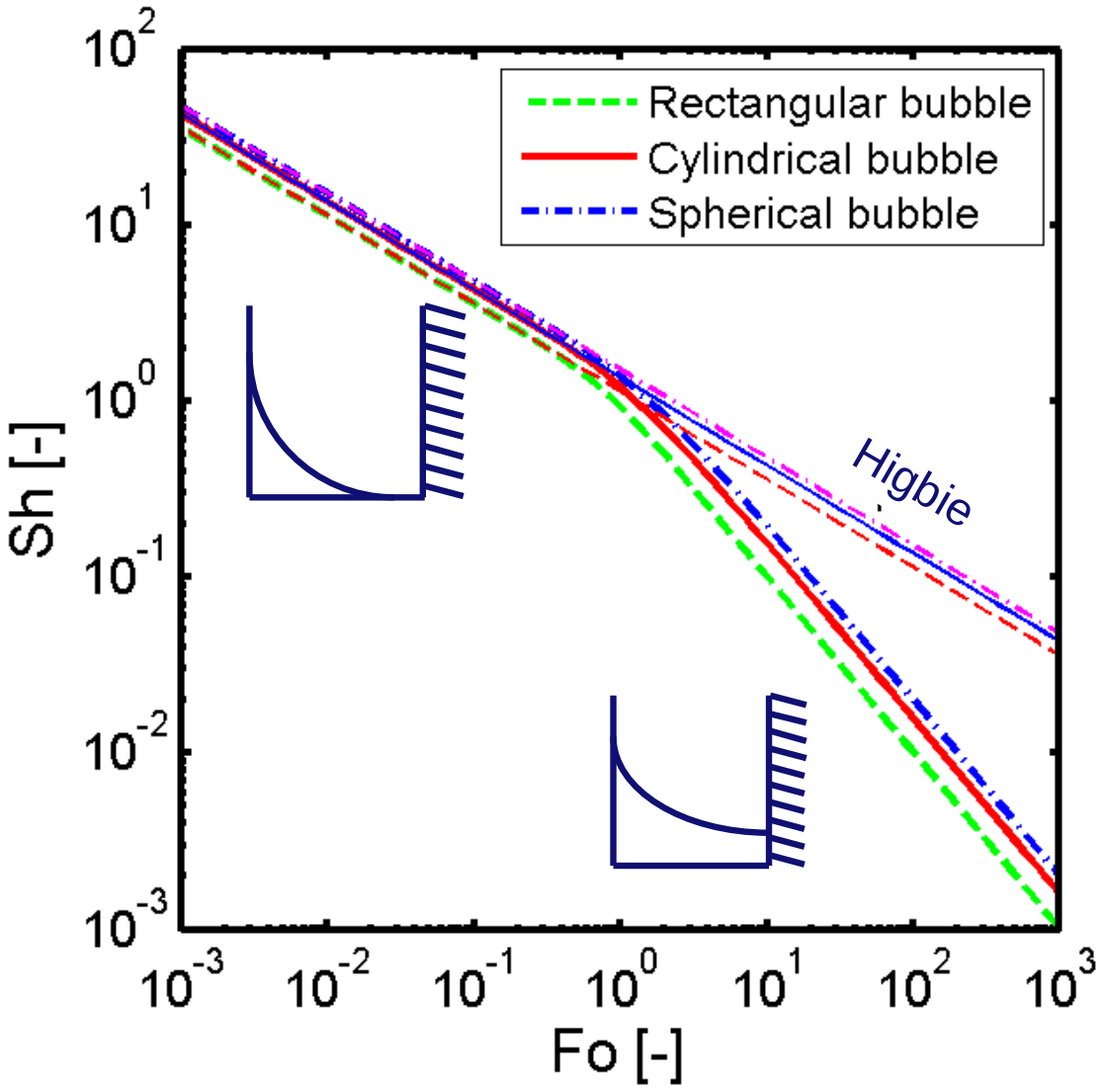
- Bubble geometry:
  - Cylindrical
  - Spherical





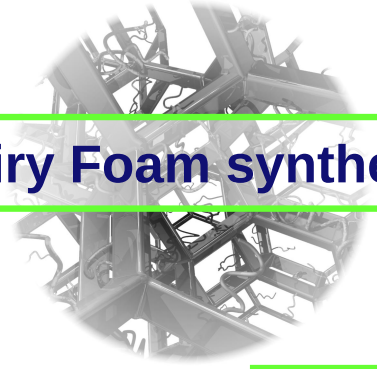
Gas Liquid Mass Transfer in Foam

- Extension of classical theory
- Short and long contact times in one theory
- Reduction of model to engineering correlation
- Easy prediction of MT for:
  - Packings
  - Microreactors
  - ...



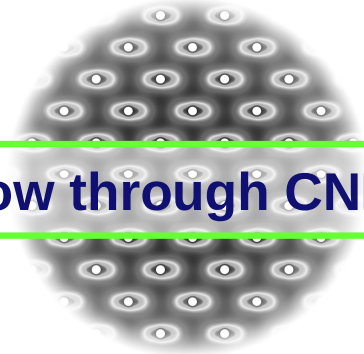
Overview PhD Research

Hairy Foam synthesis

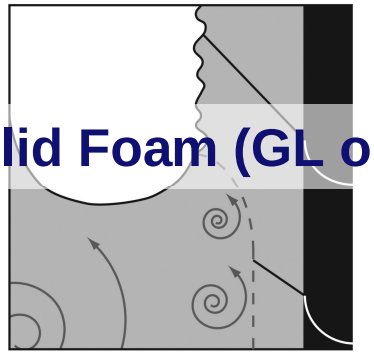


Liquid-Solid MT Hairy Foam

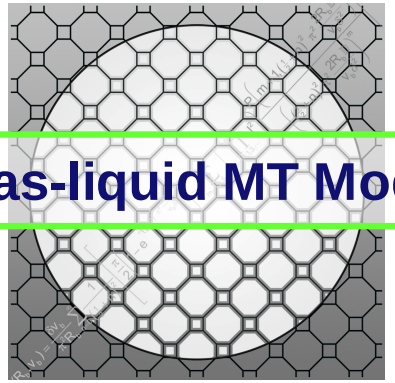
Liquid flow through CNF layers



LS MT Solid Foam (GL operated)



Gas-liquid MT Model



Reactor packing comparison

Download thesis at: **http://alexandria.tue.nl/extra2/200613105.pdf**

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- Dr. Mart de Croon
- Dr.ir. Xander Nijhuis
- Denise Tjallema

- Dr.ir. Maurice Warnier
- Dr.ir. Marco Meeuwse
- Dr.ir. Niek Zuidhof
- Ir. Stijn de Loos
- Ir. Joost Rooze

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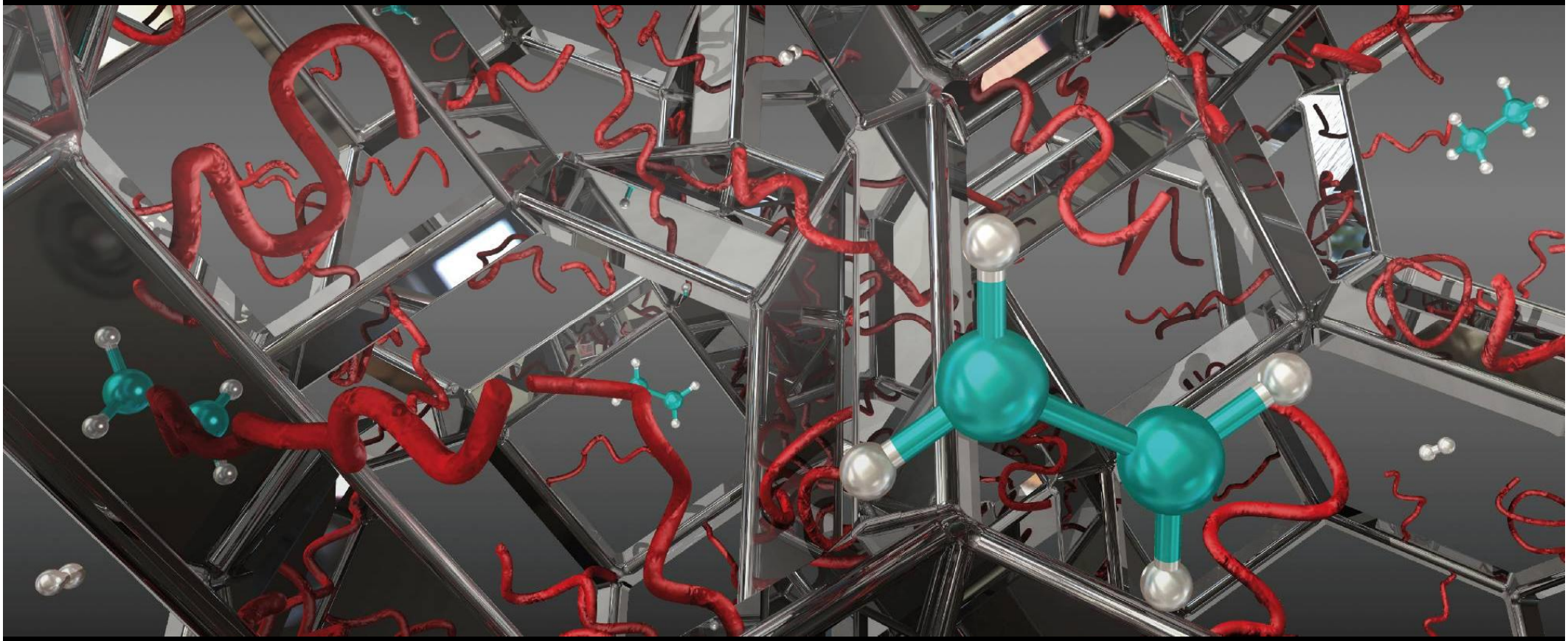
Ir. Hirsa Maria Torres Galvis
Ir. Jovan Jovanovic
Ir. Jessica Vaessen
Michiel de Beer
Ir. Sander Fievez
Ir. Job Vissers

Hairy Foam: Carbon nanofibers on solid foam as catalyst support

Synthesis, mass transfer, and reactor modeling



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