Single Phase CFD Simulation and Experimental Validation for Advanced Nuclear Components: Multi-scale Flow Structure Measurements

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Experiments and CFD Code Applications to Nuclear Reactor Safety

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Outline

- **I**ntroduction ---Validation—Validation--- Validation
  - Multiscale Phenomena
  - Local Measurements
- **P**article **I**mage **V**elocimetry
  - Matching Refractive Index
  - Experimental set-up
- **M**easurements in **V**arious **R**eactor **C**omponents
  - Pebble Bed Packed Reactor
  - Lower Plenum Mixing of GCR
  - Bundles
- **C**onclusion

Introduction

- In the Advanced Gas Cooled Pebble Bed Reactors for nuclear power generation, the fuel is presented in the form of spherical coated particles.
- The energy transfer phenomenon requires detailed understanding of the flow and temperature fields around the spherical fuel pebbles.
- Many of the macroscopic processes that affect material transport in porous media are manifestations of the flow behavior of the system at the microscopic scale (at the scale of an individual pore volume)

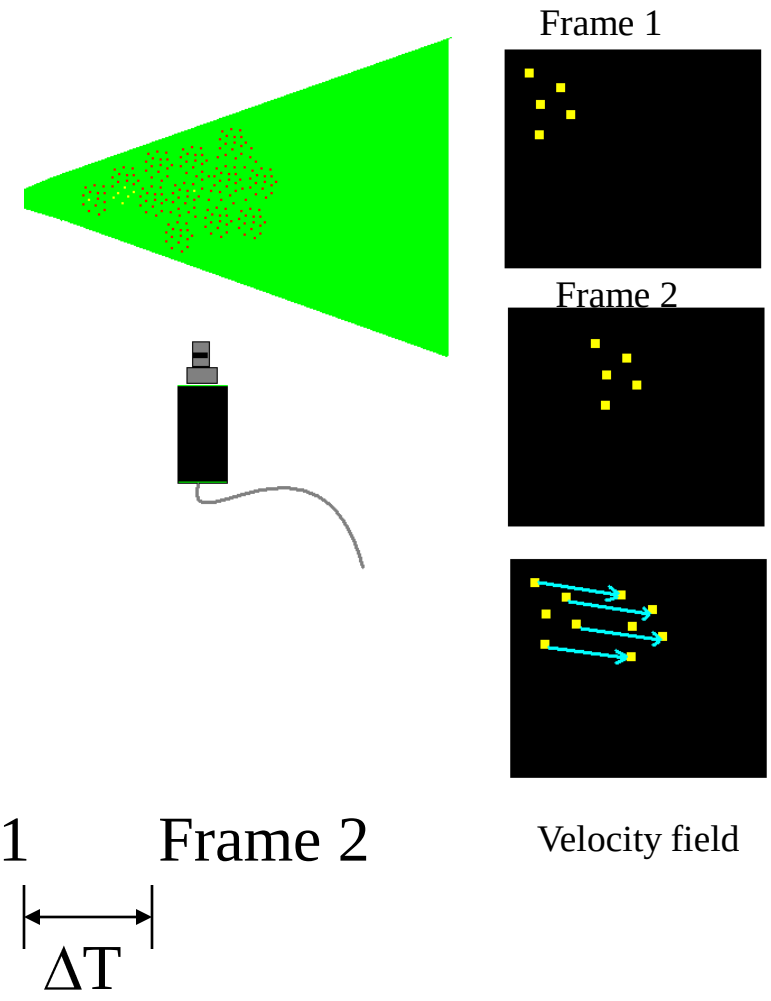
- Dispersion, for example, is the result of the cumulative effects of a number of micro-scale phenomena, including the mixing caused by solid obstructions in the flow path, the incomplete connectivity of the medium, eddies in the medium, and recirculation caused by regional pressure gradients.

- Predictive macroscopic transport theory uses volume averages of micro-scale flow.

- Multipoint measurements with spatial resolution are necessary to permit visualization of complex flow patterns and to provide data at high enough spatial density to allow volume averaging

Particle Image Velocimetry (PIV)

- Optical method (Non-intrusive)
- Velocity fields
- Spatial resolution
- Time resolution (DPIV)
- Capability of studying two-phase
- flows



5 mm

PMMA beads

D/d=6.6

56 mm

Square column

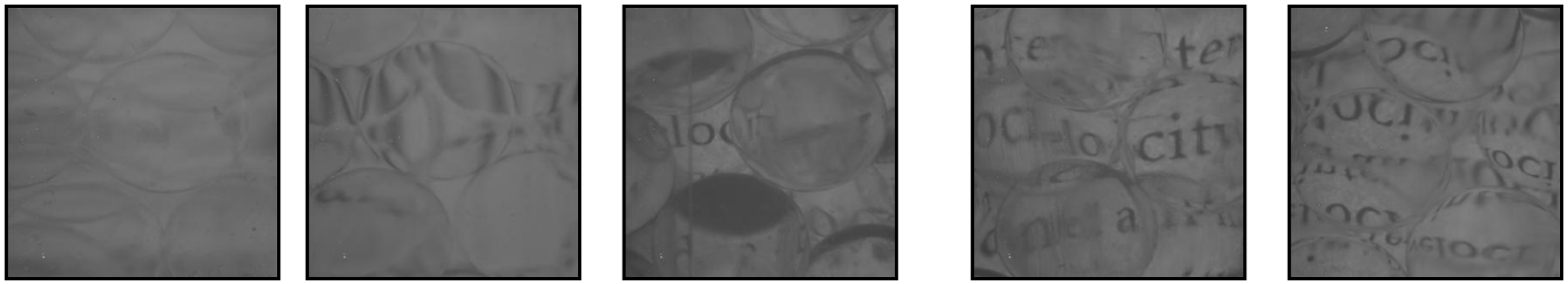
L/D=14.5

Refractive Index Solids

Material	Refractive Index	Reference
Boroscilicate (Pyrex)	1.47-1.49	Budwig
Optical Glasses	1.45-1.96	Budwig
Acrylic (PMMA)	1.49	Budwig
Polycarbonate	1.58	Budwig
FEP	1.33	-
Teflon AF	1.29-1.31	-
K8 glass	1.51	Pokusaev
Styrene - divinyl-benzene	1.5903	Adrian
Silica gel	1.452	Adrian
Fused quartz	1.4584	-

Matching Refractive Index

Ethyl-Benzyl

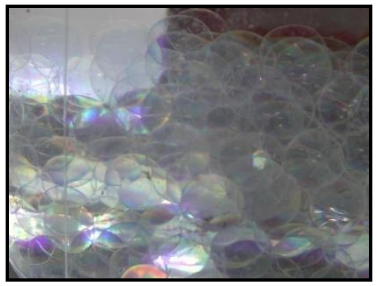


Viscosity

Density

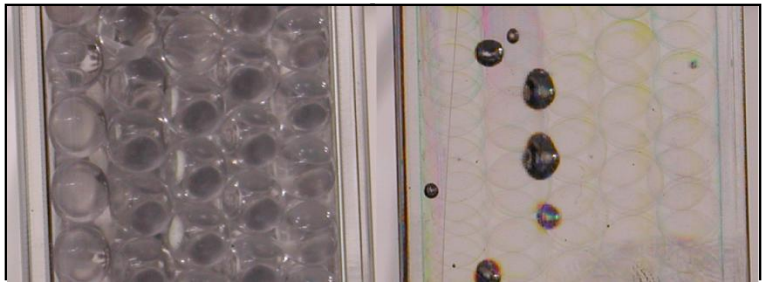
Surface tension

Others



Diethyl-phthalate

Air

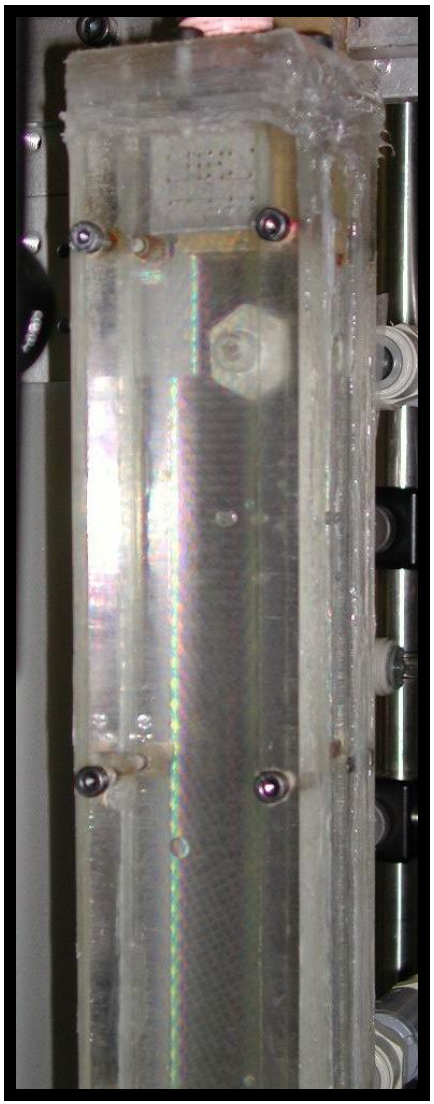


Para-cymene

Air

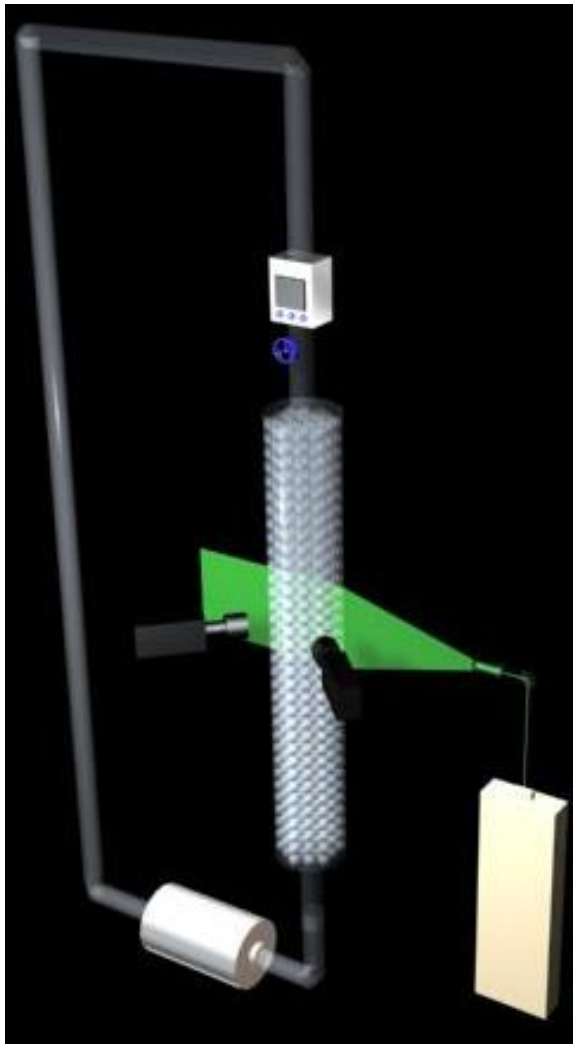
Water

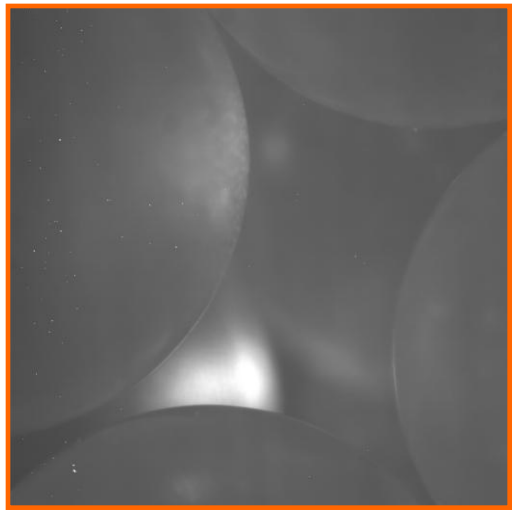
P-cymene



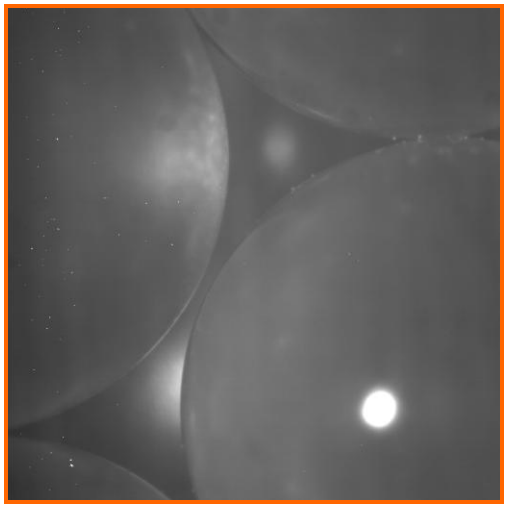
Experimental set-up

- Polymethyl methacrylate square channel (3.1 cm x 3.1 cm x 45cm)
- Close loop
- 4.7 mm diameter PMMA beads
- Para-Cymene 99% as working fluid
- 6 μm particle seeding
- High speed/ high resolution camera (4800 fps)
- Measurements at the center plane





I.



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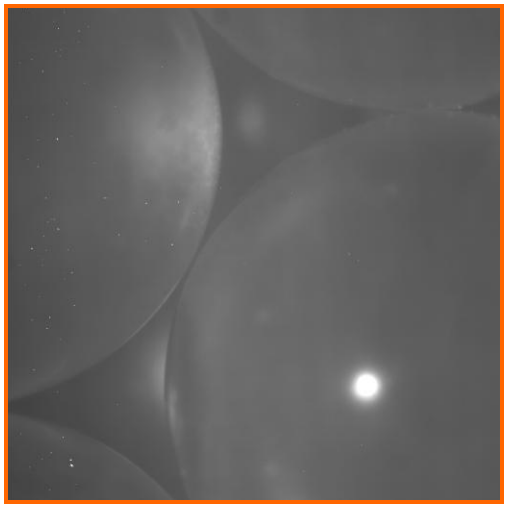

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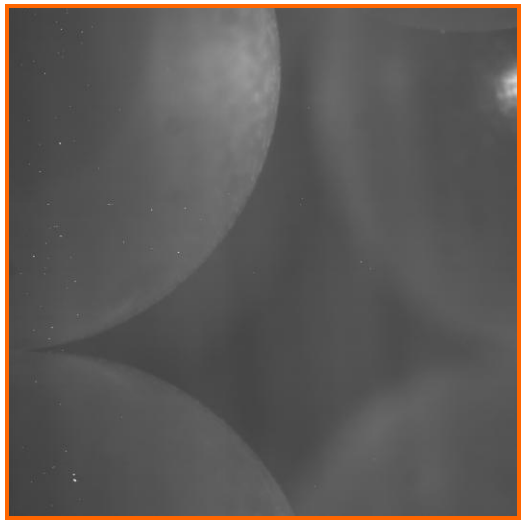

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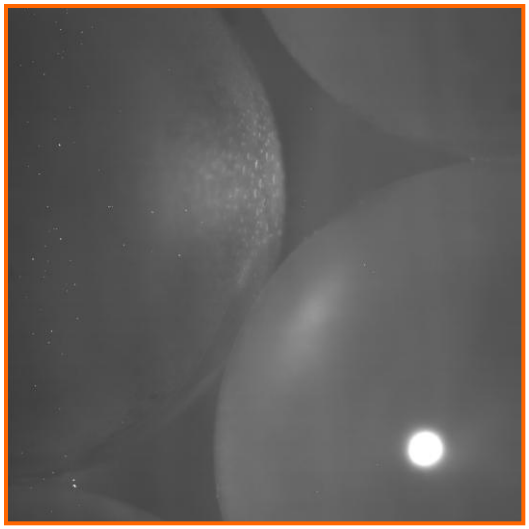
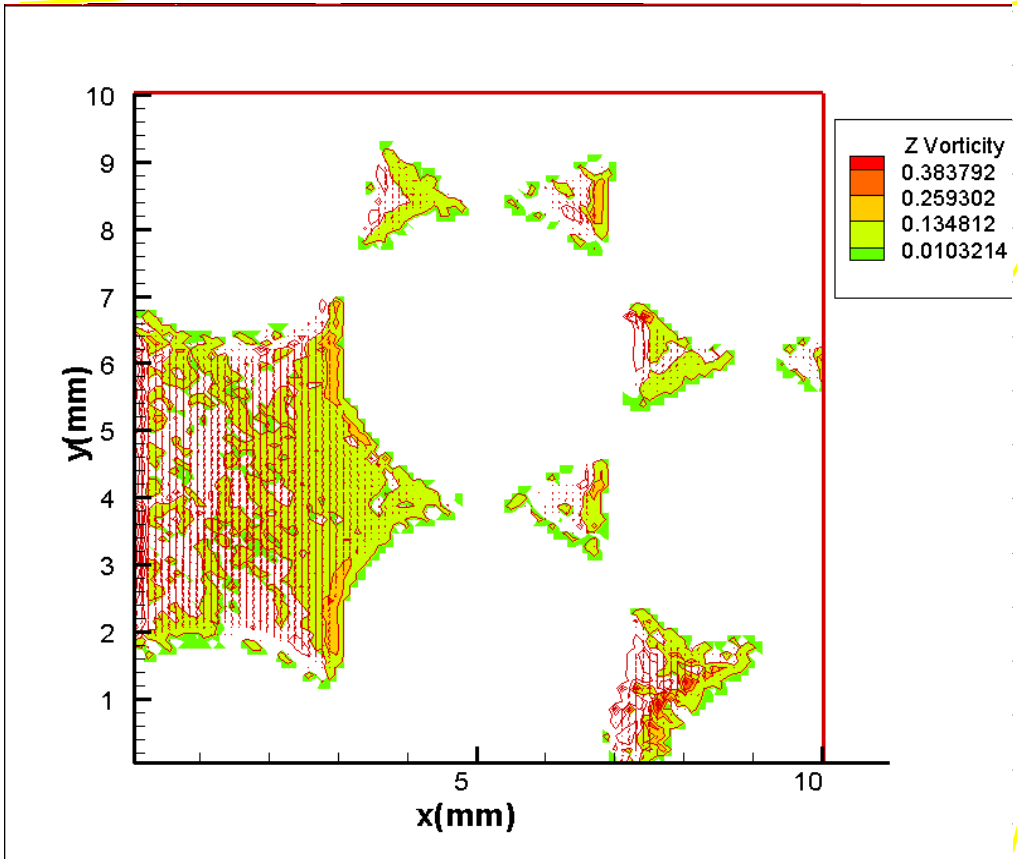
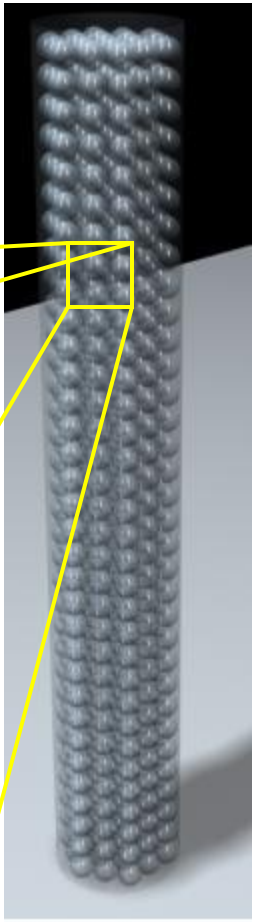


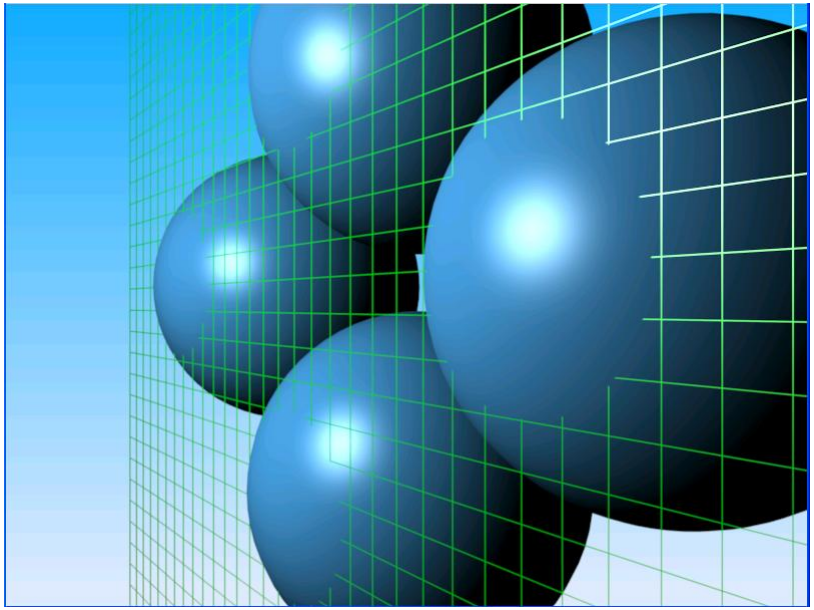
V.

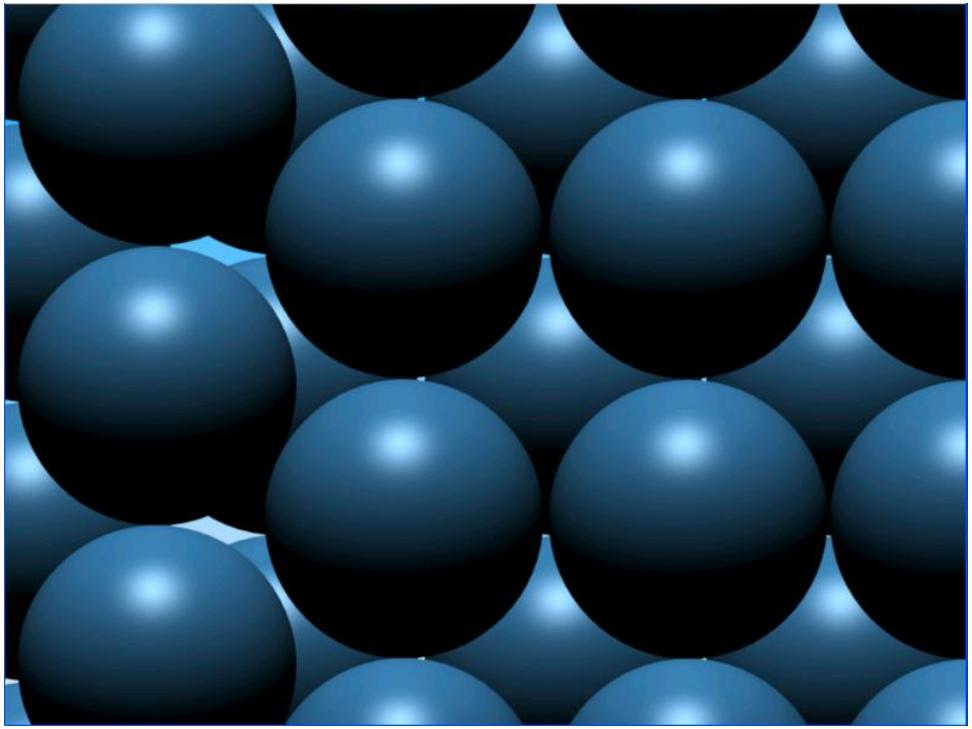
Results


Z Vorticity
0.383792
0.259302
0.134812
0.0103214
y(mm)
x(mm)
1
2
3
4
5
6
7
8
9
10
5
10



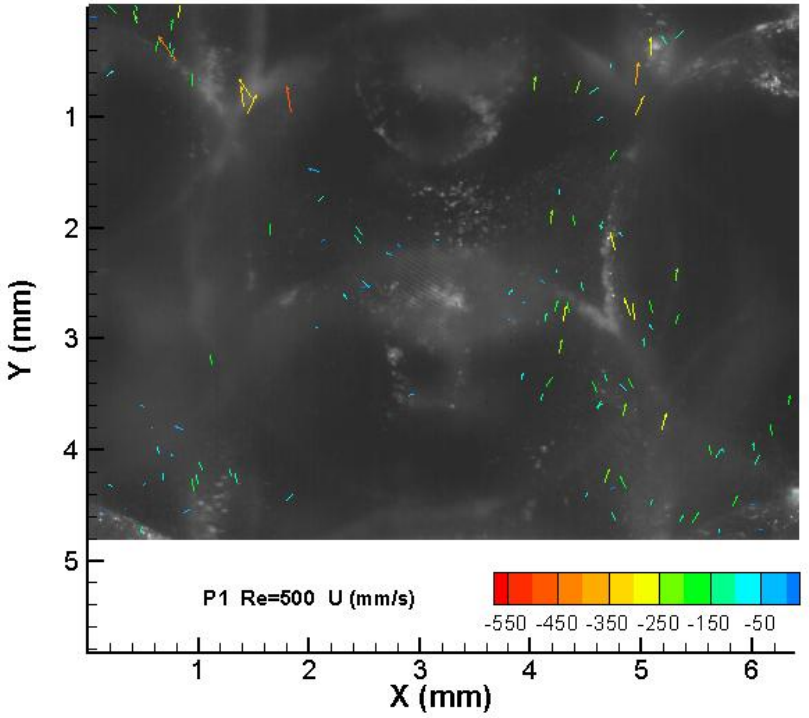
Multiscale measurements



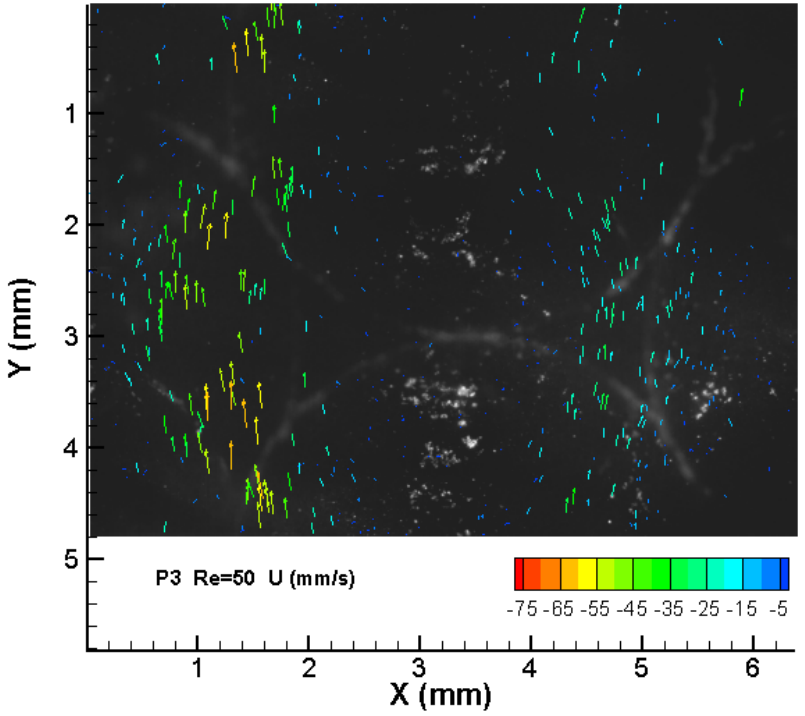


Flow behavior for Re=500 (Pore1)

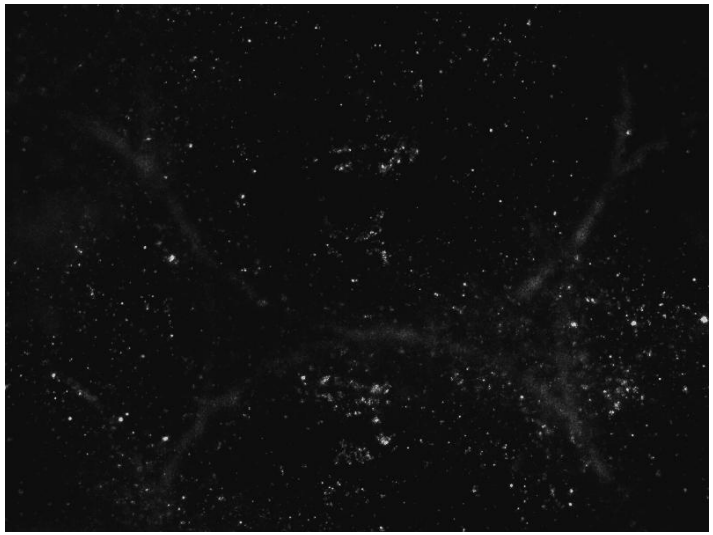
Play

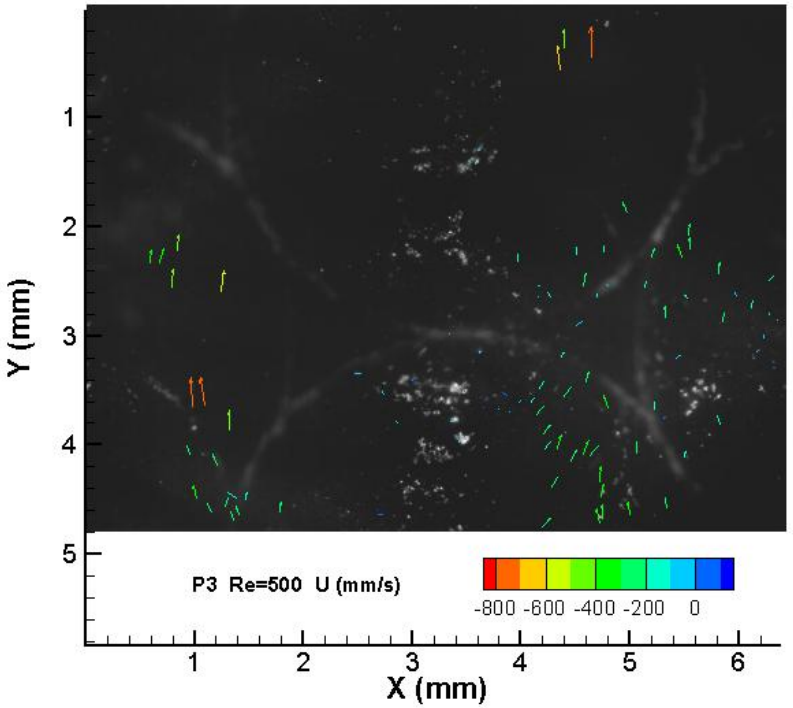


Flow behavior for Re=50 (Pore 3)

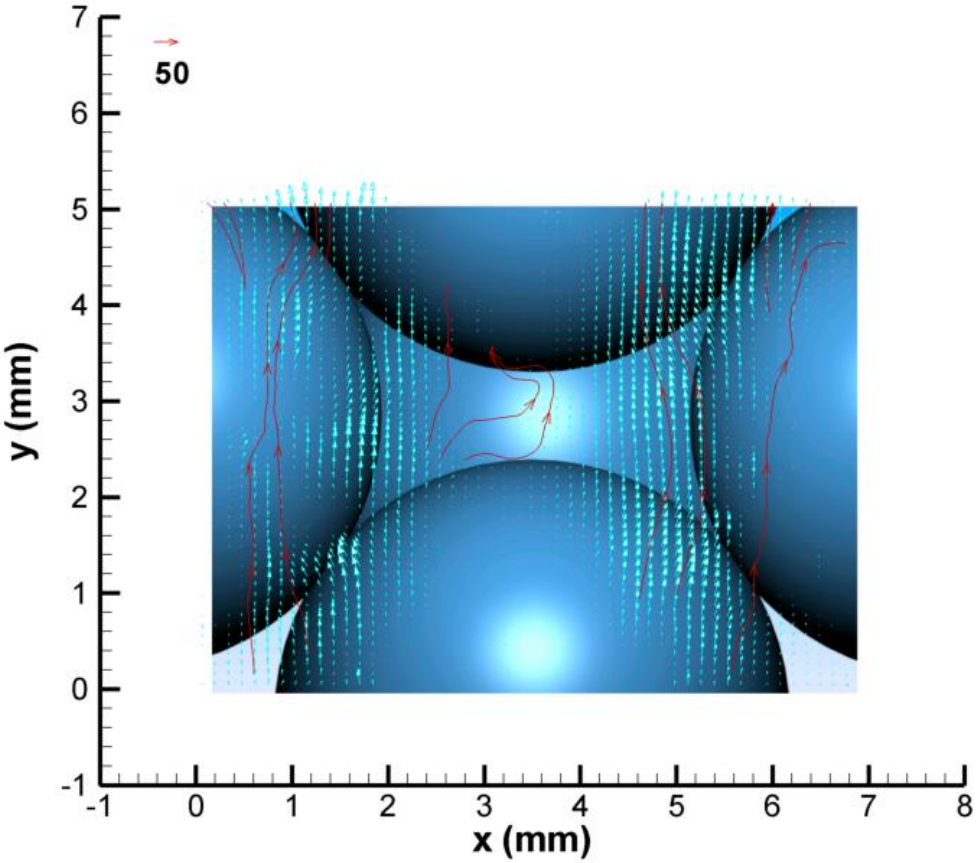


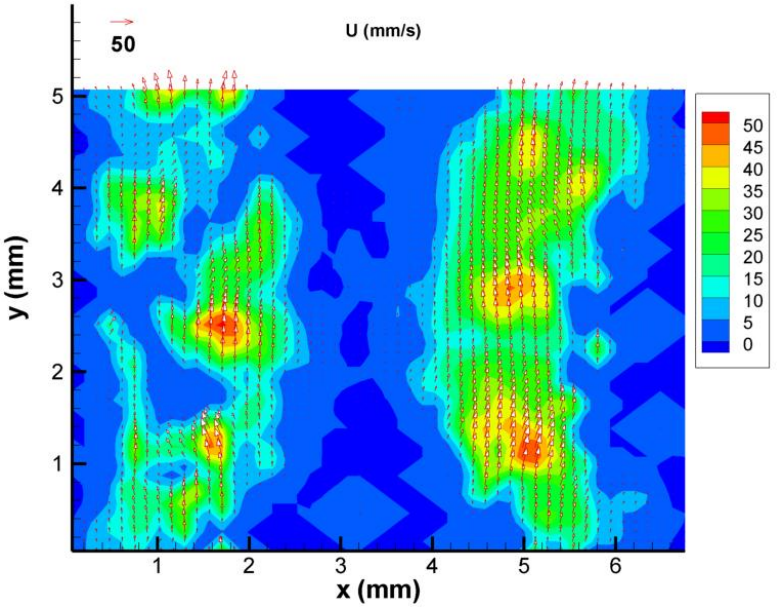
Flow behavior for Re=500 (pore 3)

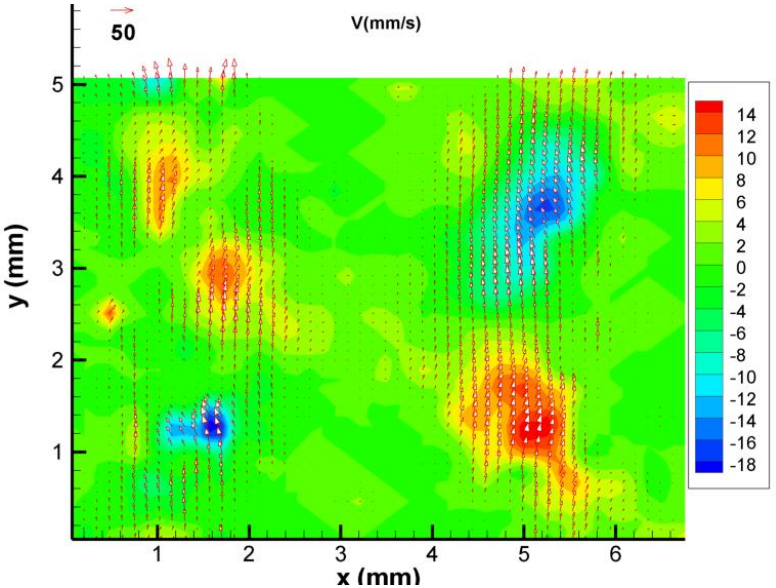




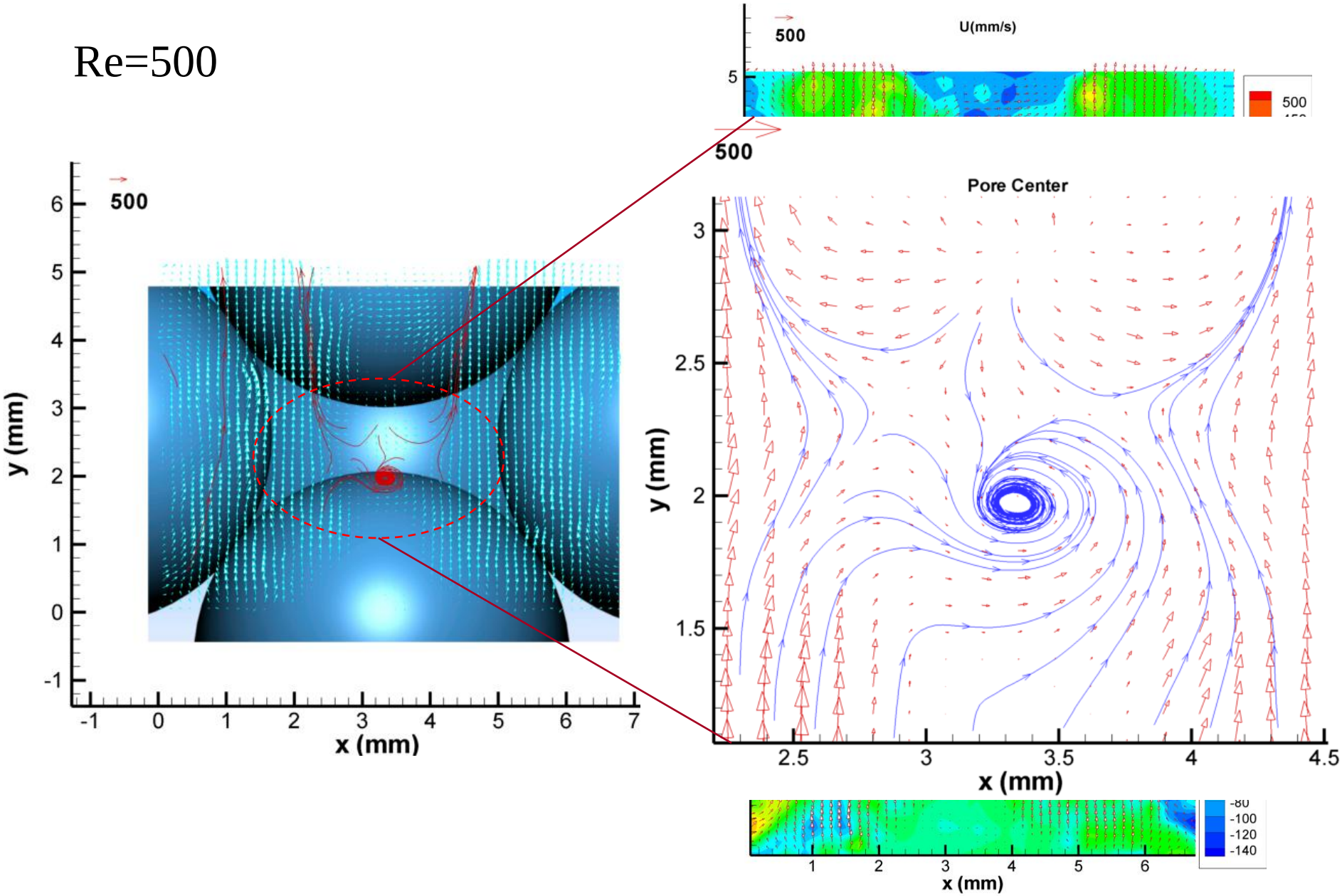
Re=50



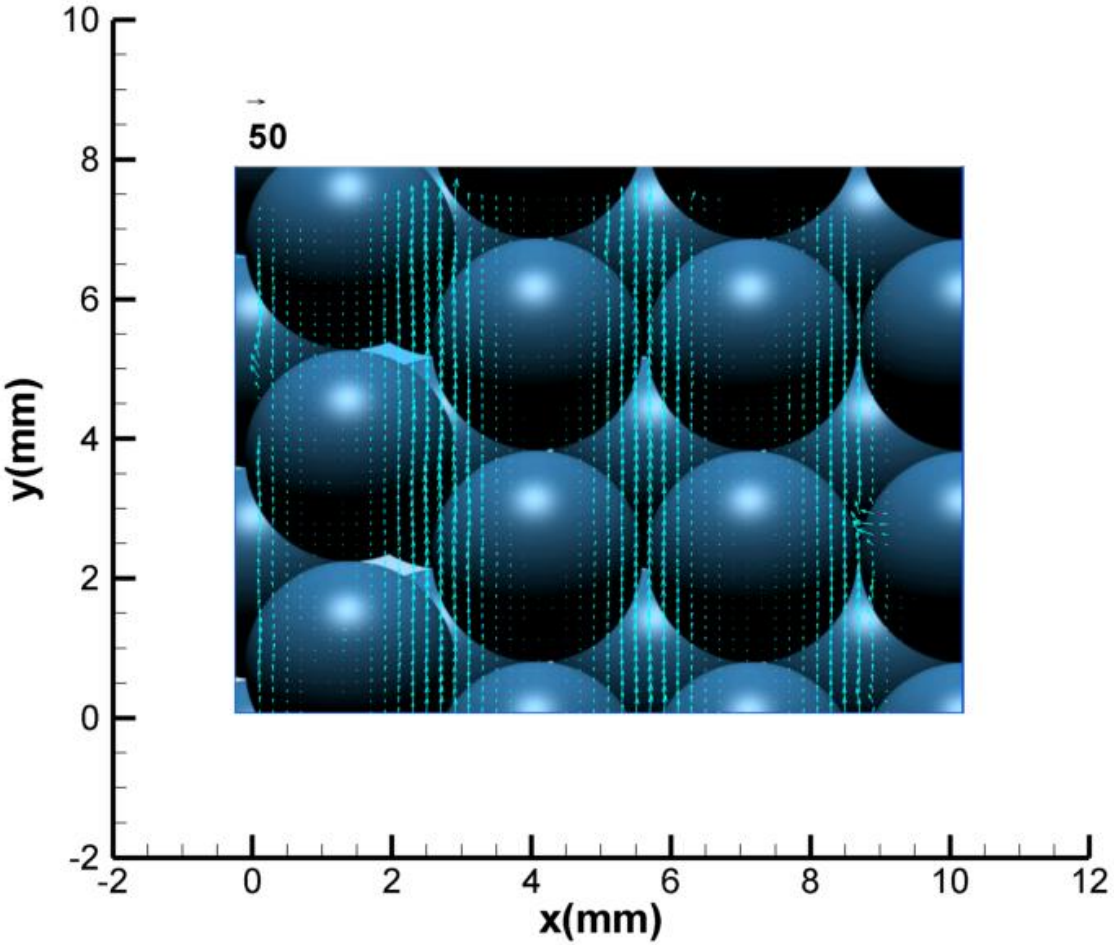




Re=500



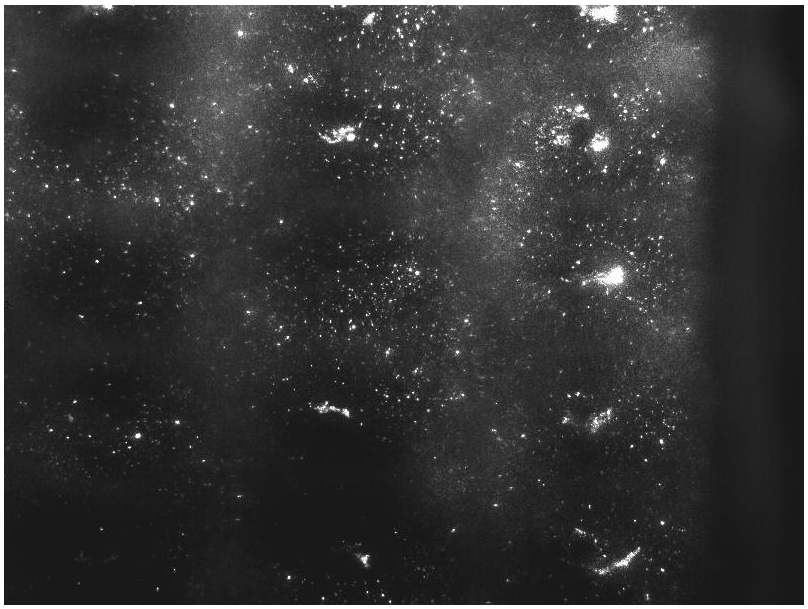
Pore representation of second viewing area



Re= 50

Flow

Re=500



Flow

Conclusions

- Effective use of non-invasive methods in packed beds (pore level).
- Successful determination of interstitial velocity field
- Flow visualization allows a better understanding of physical phenomena involved.
- Working fluid allows the possibility of mass and heat transfer studies in packed bed reactors.
- Evidence of recirculation zones at pore level suggest the prediction of “micro-hot-spots” in pebble bed reactors.

Questions?

Experimental set-up