High temperature endoscopic-laser PIV/DIA technique for the study of hydrodynamics of gas-solid fluidized beds

High Temperature Endoscopic-Laser PIV/DIA Technique for the Study of Hydrodynamics of Gas-Solid Fluidized Beds

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Department of Chemical Engineering & Chemistry

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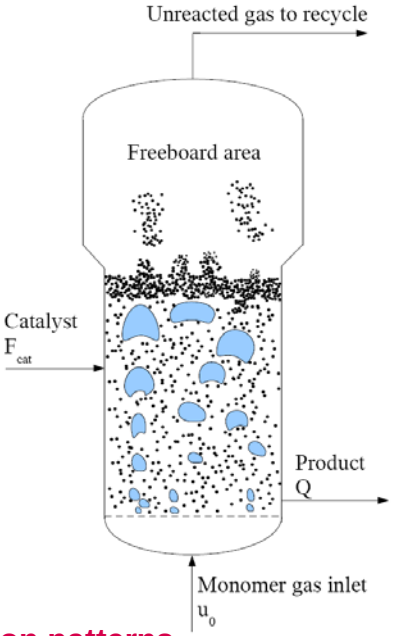
Where innovation starts

Contents

- Motivation
  - Why high temperature Hydrodynamics?
- PIV/DIA
  - Working principle?
- Novel high temperature PIV/DIA
  - How to extend PIV/DIA?
  - Validation
  - Demonstration
- Conclusions and future work

Motivation

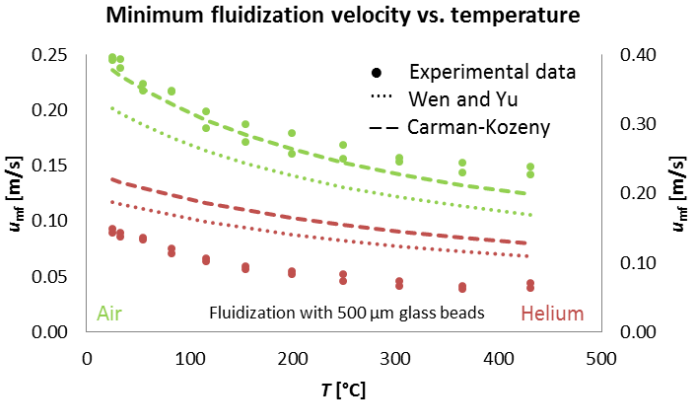
- **Wide spread industrial application**
  - **Catalytic oil cracking**
  - **Chemical Looping**
  - **Polymerization**
  - **.....**
  - **High temperature process > 500°C**
- **Features**
  - **Vigorous solids mixing**
  - **Strong bubble and emulsion phase interaction**
  - **Excellent heat and mass transfer**
  - **Performance dependent on hydrodynamics**
  - **Design relies on constitutive equations (K-L model)**



- **Gaps**
  - **Scarce quantitative information of macro scale circulation patterns**
  - **Experimental research on hydrodynamics focused on emulsion OR bubble phase**
  - **Constitutive equations obtained and validated at low temperatures with air**

Motivation

- **Quality of minimum fluidization velocity predictions**



RESEARCH GOAL

- **Study the hydrodynamics at elevated temperatures**
  - **Effect explained by gas viscosity and density? Inter particle interaction?**

Characterization of bubble hold up and internal solids circulation.
Available techniques?

⇒ No suitable correlation (among at least 63 available) exists that can predict the minimum fluidization velocity of different gas mixtures at elevated temperatures!

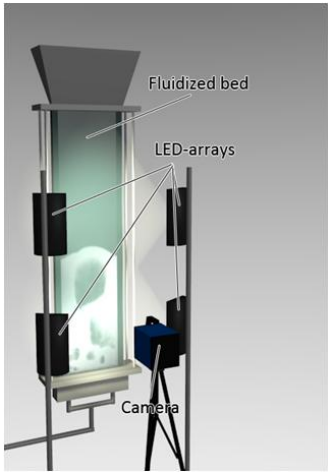
⇒ Note that all other correlations to describe hydrodynamics depend on u_{mf} !

Measurement techniques

- **Capacitance probes**
  - + 3-D characterization
  - - Invasive, several sampling points
  - - Hard to calibrate
  - - Correlate frequency to a bubble or particle

- **Radioactive Tracking Tomography**
  - + 3-D characterization
  - - Hard to describe bubble hold up
  - - Use of radioactive material, safety

- **Particle Image Velocimetry (PIV) & Digital Image Analysis (DIA)**
  - + Non-invasive technique,
  - + Whole field of measurement (bubble hold up and solids circulation)
  - - Optical access, restricted to pseudo 2-D



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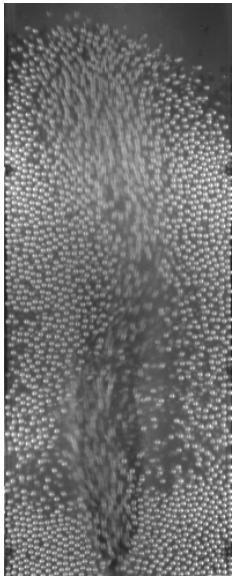
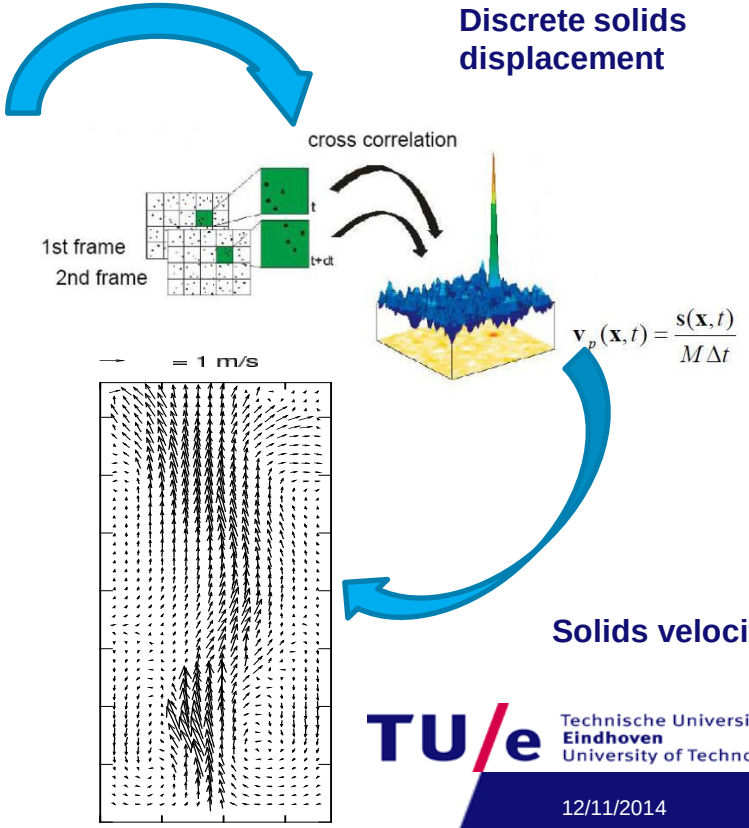
Coupling PIV and DIA

PIV: Particle Image Velocimetry

Pseudo 2D PIV setup with visual high speed camera (2016 x 2016 px @1600 Hz)

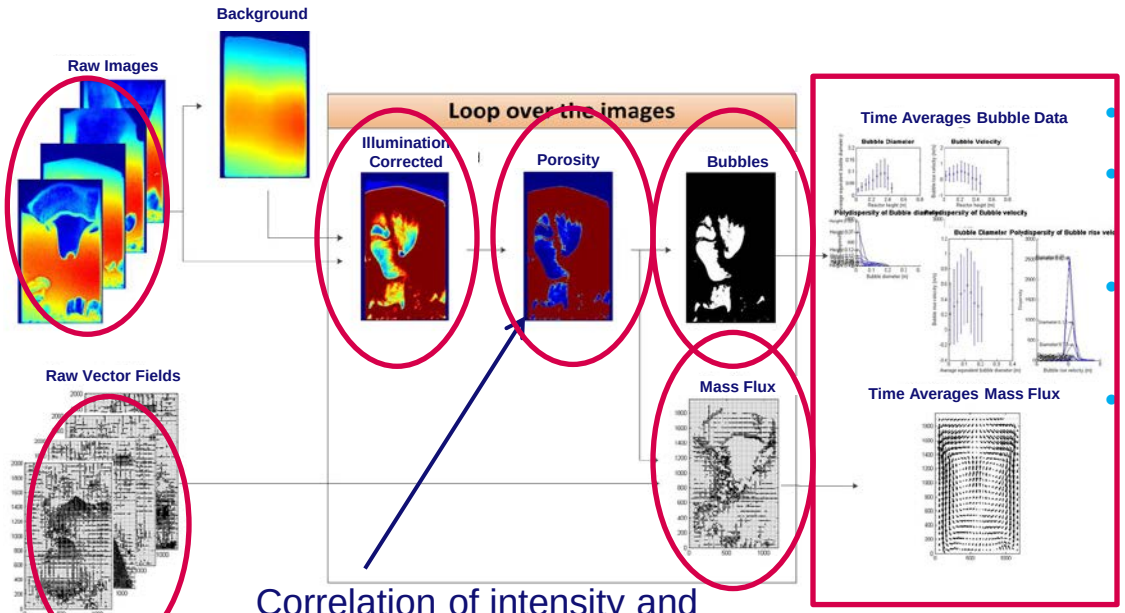


Double frame with small time delay (Δt = 1 ms)



Coupling PIV and DIA

Digital Image Analysis (DIA)



Correlation of intensity and porosity, based on DPM simulations [de Jong et al]

- In-house Matlab script
- Distinghuishes between bubble and emultion phase
- Conversion of pixel intensity to bed porosity
- Bubbles can be tracked

How to extend PIV/DIA to high temperature?

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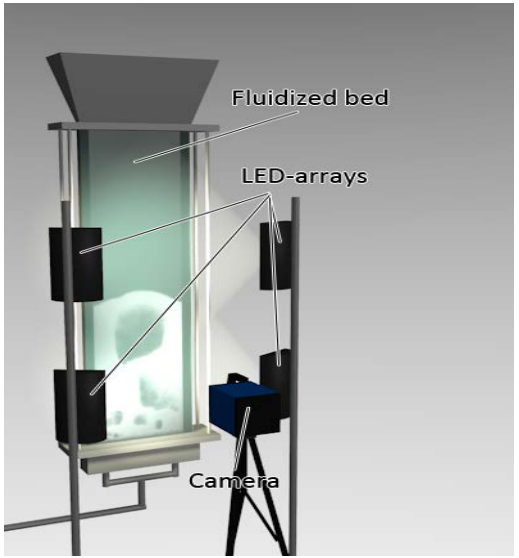
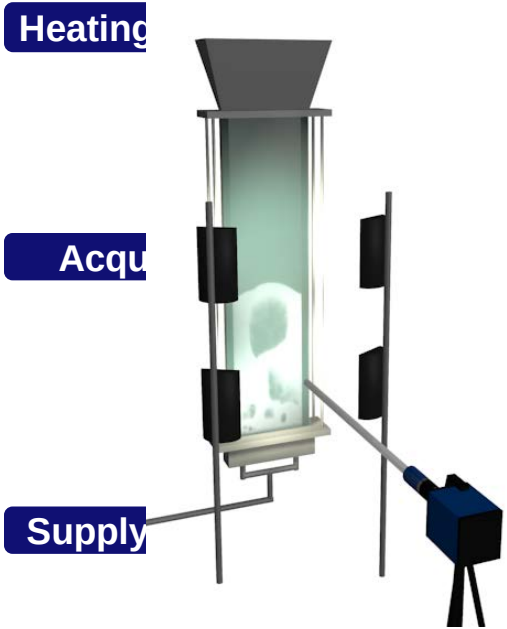
PIV/DIA at High Temperature



LED PIV/DIA



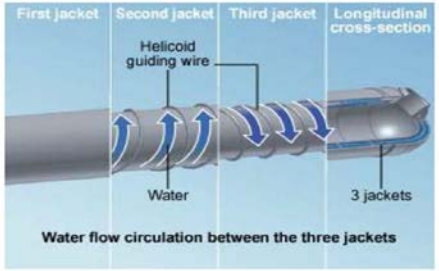
→ Heat losses
↓
Furnace

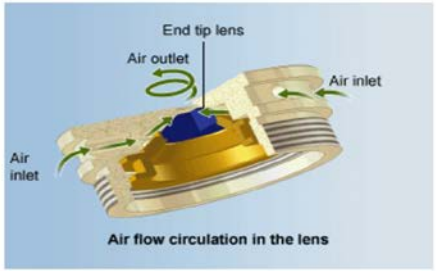
→ Camera outside
↓
Endoscope

→ Led lights

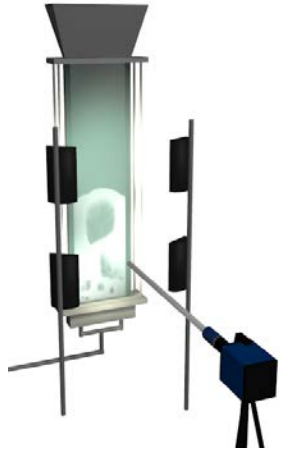
→ Laser

Endoscopic PIV/DIA

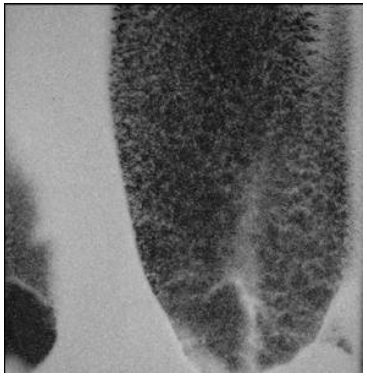




- Can we run PIV/DIA?



Without Endoscope

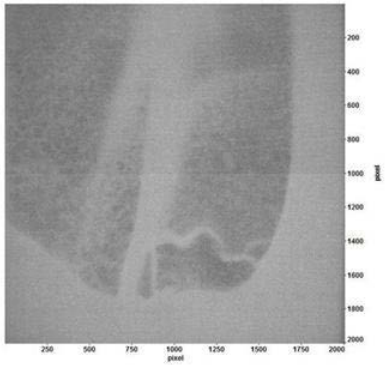


at room Temperature

5x inter frame time

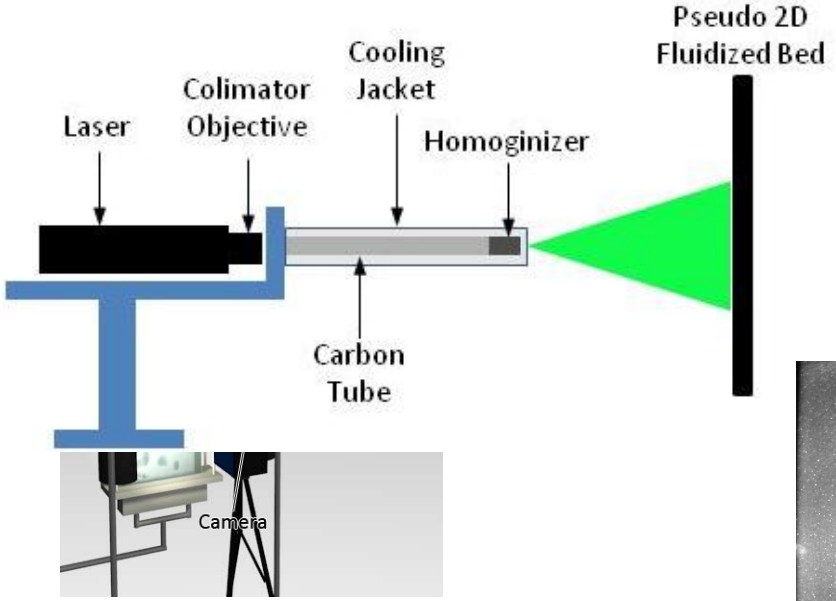
20x exposure time

With Endoscope

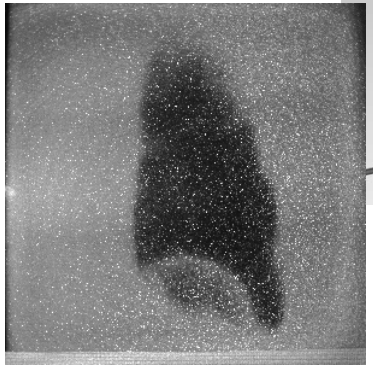


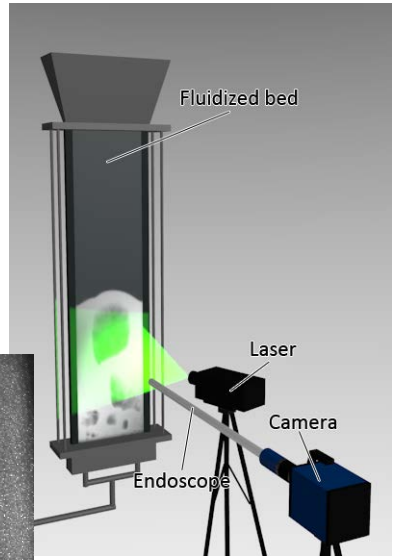
FAIL TO RUN PIV/DIA
MORE ILLUMINATION REQUIRED

Endoscopic-Laser PIV/DIA (ePIV/DIA)



inate the
lized bed

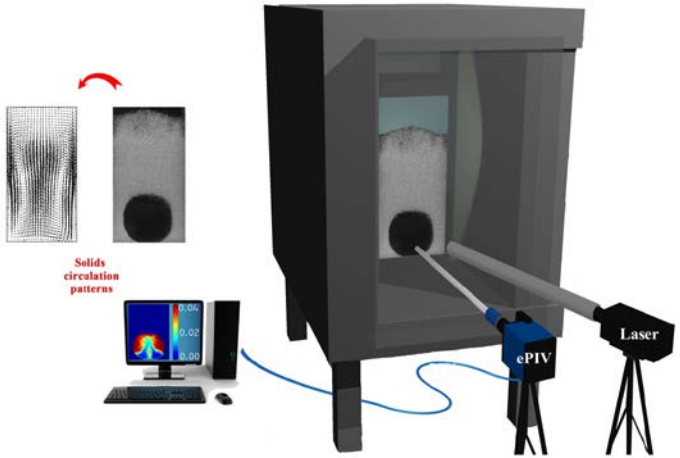




High Temperature ePIV/DIA

- **Extension of PIV/DIA/IR to high temperatures and reactive conditions!**

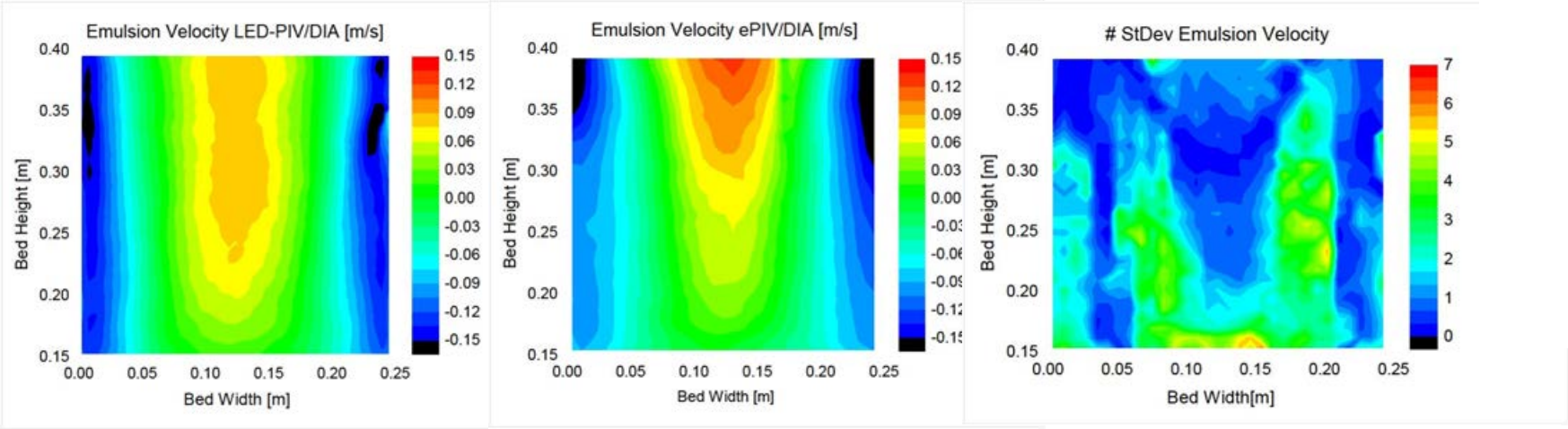
  Essential to have non-invasive, whole-field measurements of gas and solids phases simultaneously!



DOES IT WORK?

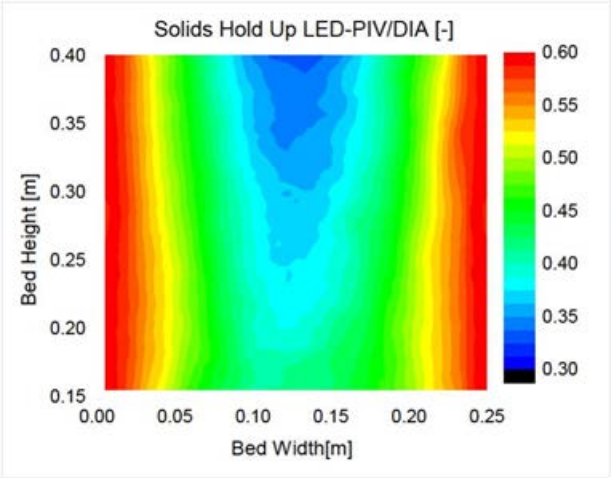
Validation

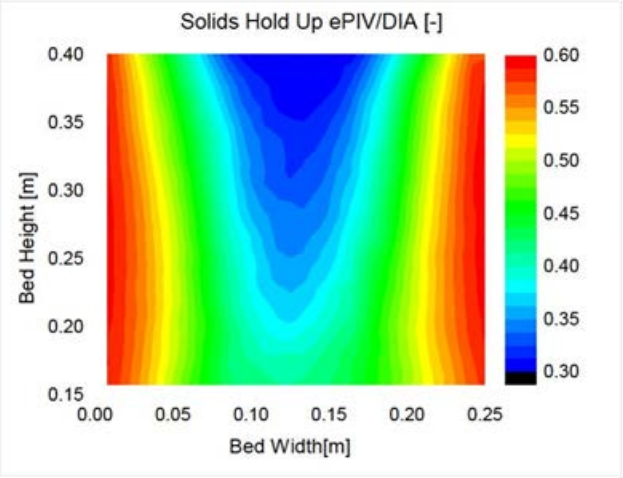
Time Averaged Emulsion Velocity at room temperature

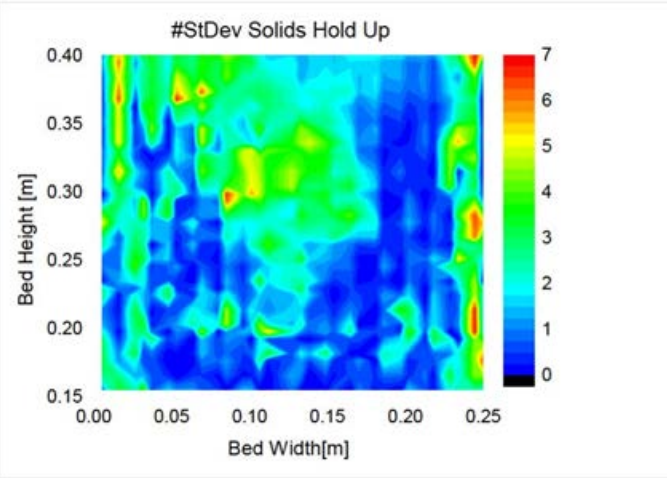


Validation

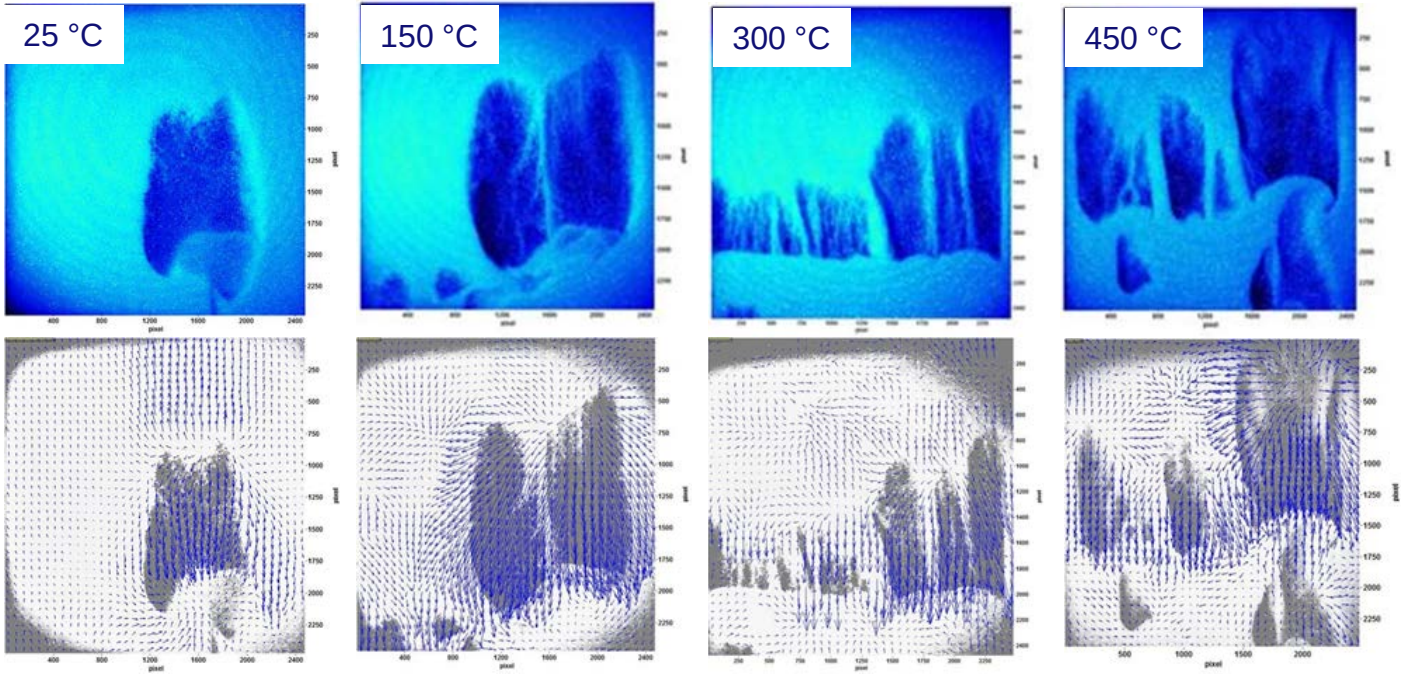
Time Averaged Emulsion Velocity at room temperature







Demonstration HT-ePIV/DIA



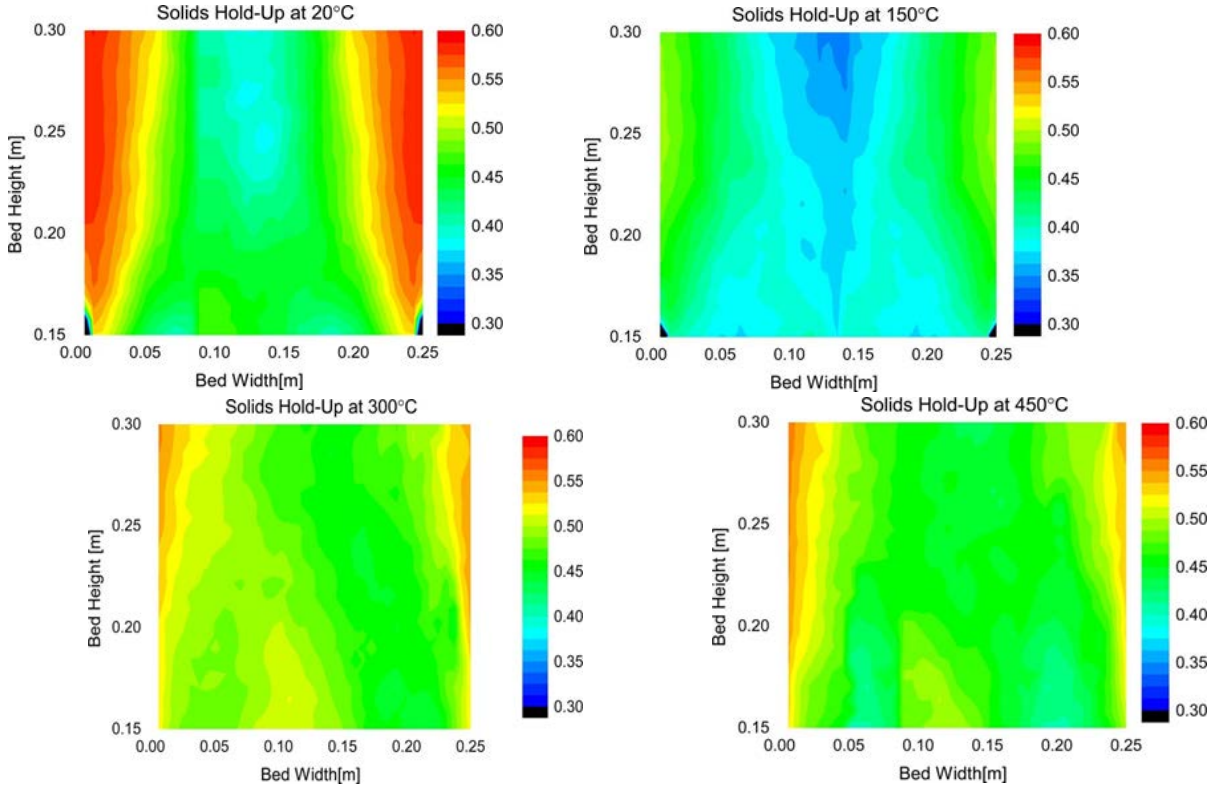
$u = 3u_{mf}$

⇒ u_{mf} measured at different temperatures

⇒ Completely different bubble behaviour as function of temperature!!!

⇒ **Adaptation of closures required!**

Demonstration HT-ePIV/DIA



⇒ Expected similar porosity

⇒ Completely different bubble behaviour as function of temperature!!!

⇒ Porosity estimation need to be revized!!!!

High Temperature ePIV/DIA

CONCLUSION

- Development and demonstration of the novel non-invasive High Temperature ePIV/DIA
- Difference in bubble behavior
- Closures have to revised

FUTURE WORK

- **Record larger area of the fluidized bed (whole bed if possible)**
- **Influence of temperature on hydrodynamics - bubble properties and solids circulation (different particles and gases)**
- **……..**

Acknowledgements

ADEM PROJECT for the financial support

Technicians at SMR group (Joris, Joost, Lee)

Master students Jeroen, Sven,Jason

High Temperature ePIV/DIA

THANKS FOR YOUR ATTENTION!!!!!!

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QUESTIONS?

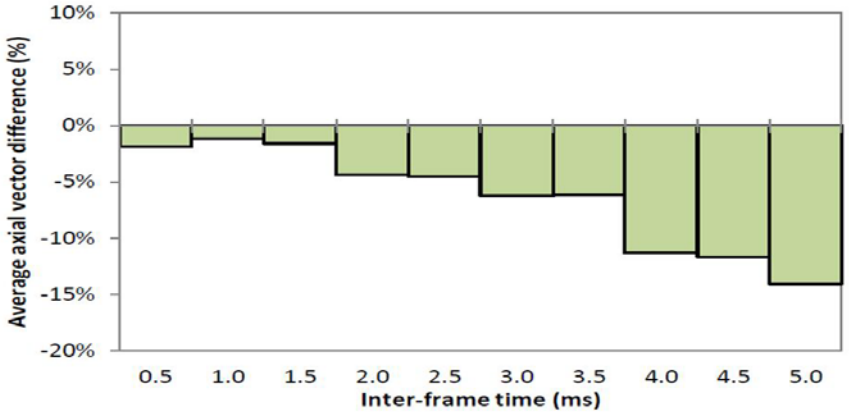
a d e m Innovation Lab

A Green Deal in Energy Materials

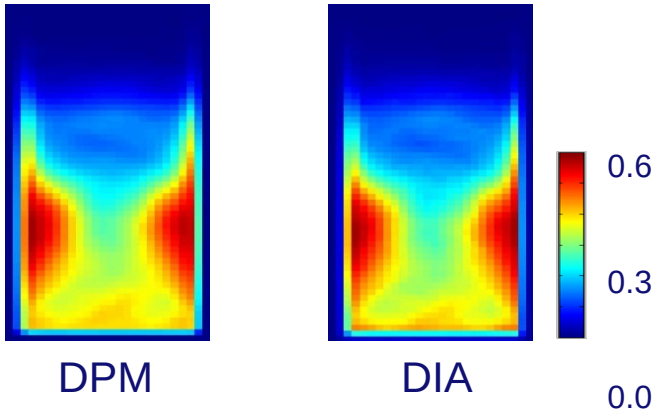
Multiphase Reactors Group
Department of Chemical Engineering & Chemistry

PIV/DIA validation

- Artificial images from DPM simulation
  + Exact location of particles



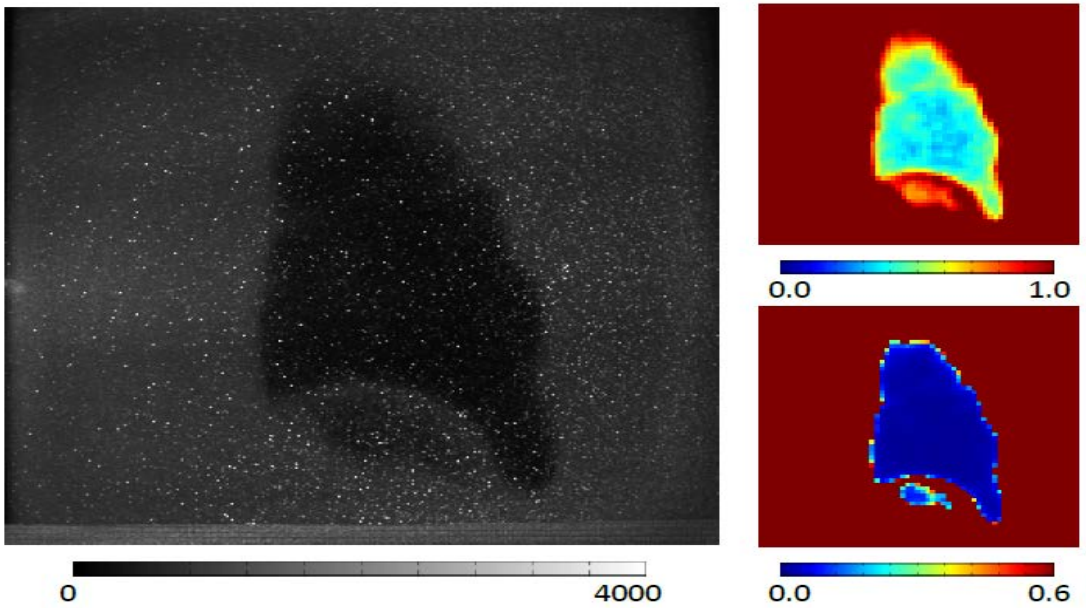
Time average porosity plot



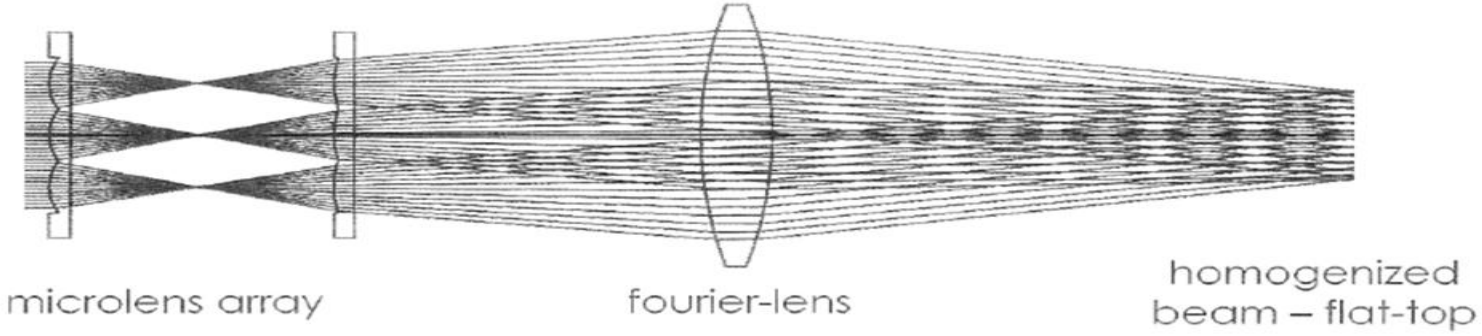
DPM DIA

Endoscopic-Laser PIV/DIA

Porosity Plots – Bubble hold up at room temperature



Homoginizer



Bayerisches Laserzentrum