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Experimental and simulation study on heat transfer in fluidized beds with heat production: An integrated DIA/PIV/IR technique and CFD-DEM

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[DPI Project # 751 Predictive Modeling of Polyolefin Reactors]

Experimental and simulation study on heat transfer in fluidized beds with heat production

Zizi Li

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Content

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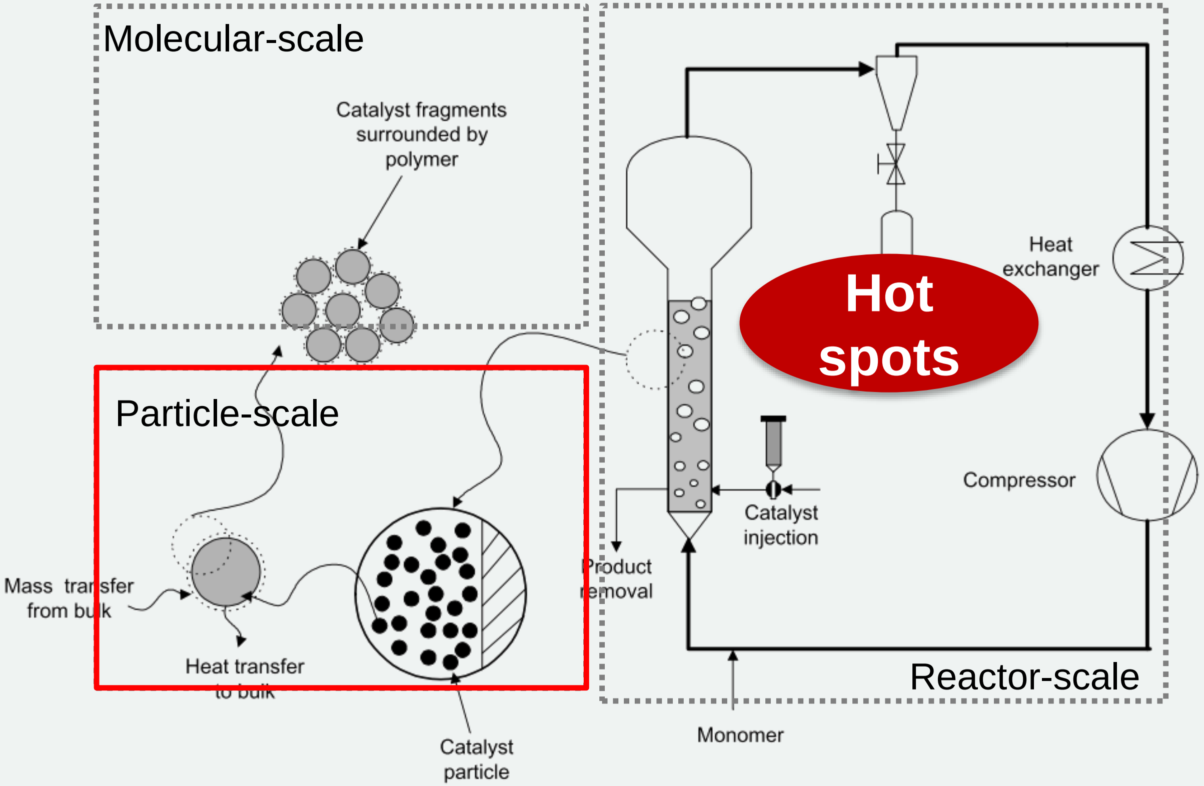
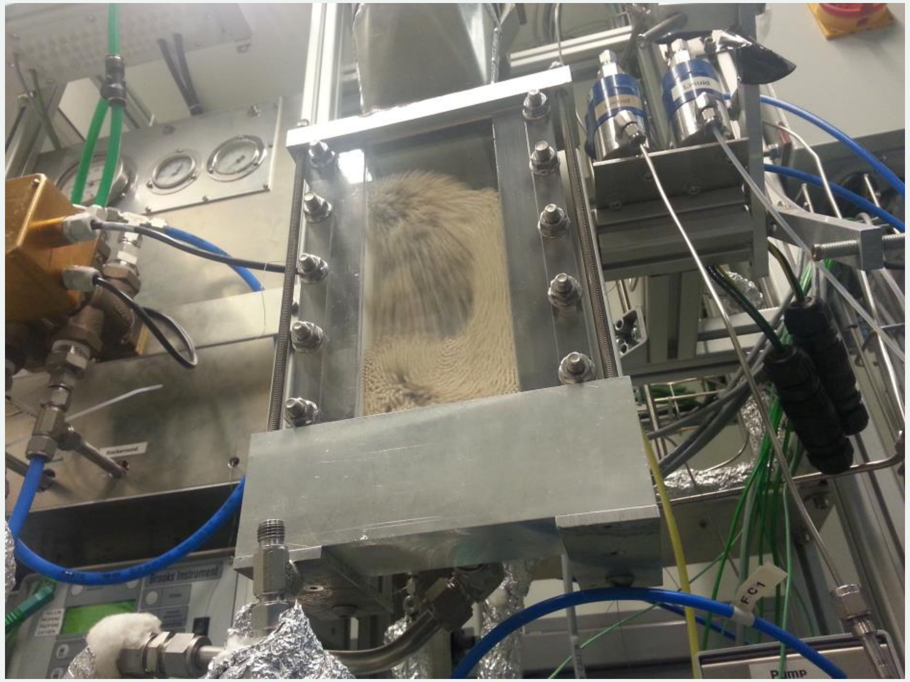
- **Modeling of the particle temperature in fluidized bed**
  - Ideal CSTR model and Discrete Particle Model (DPM)
- **Conclusion**

Project background

Polymerization process

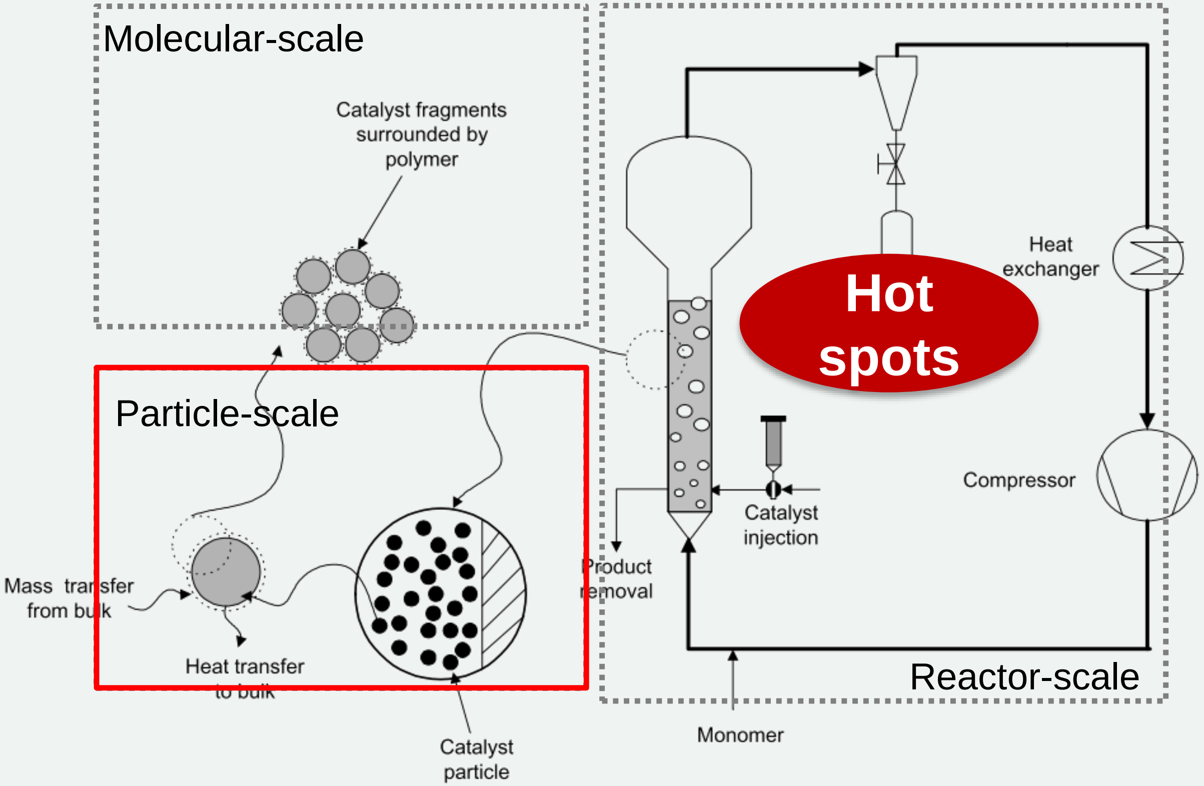


Several characteristic length scales in a fluid bed reactor for catalytic olefin polymerization.

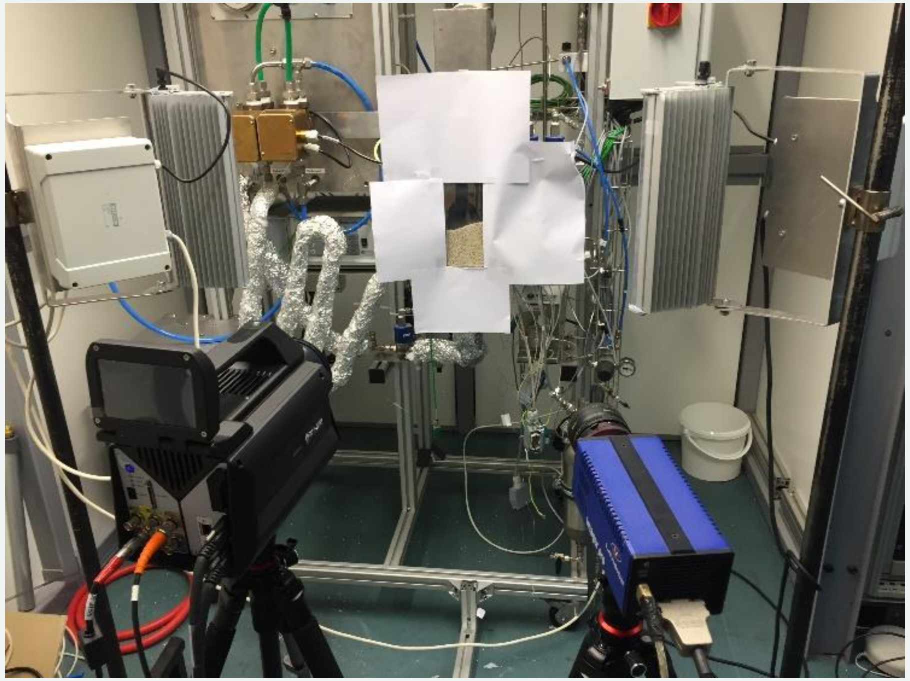


Project background

Polymerization process

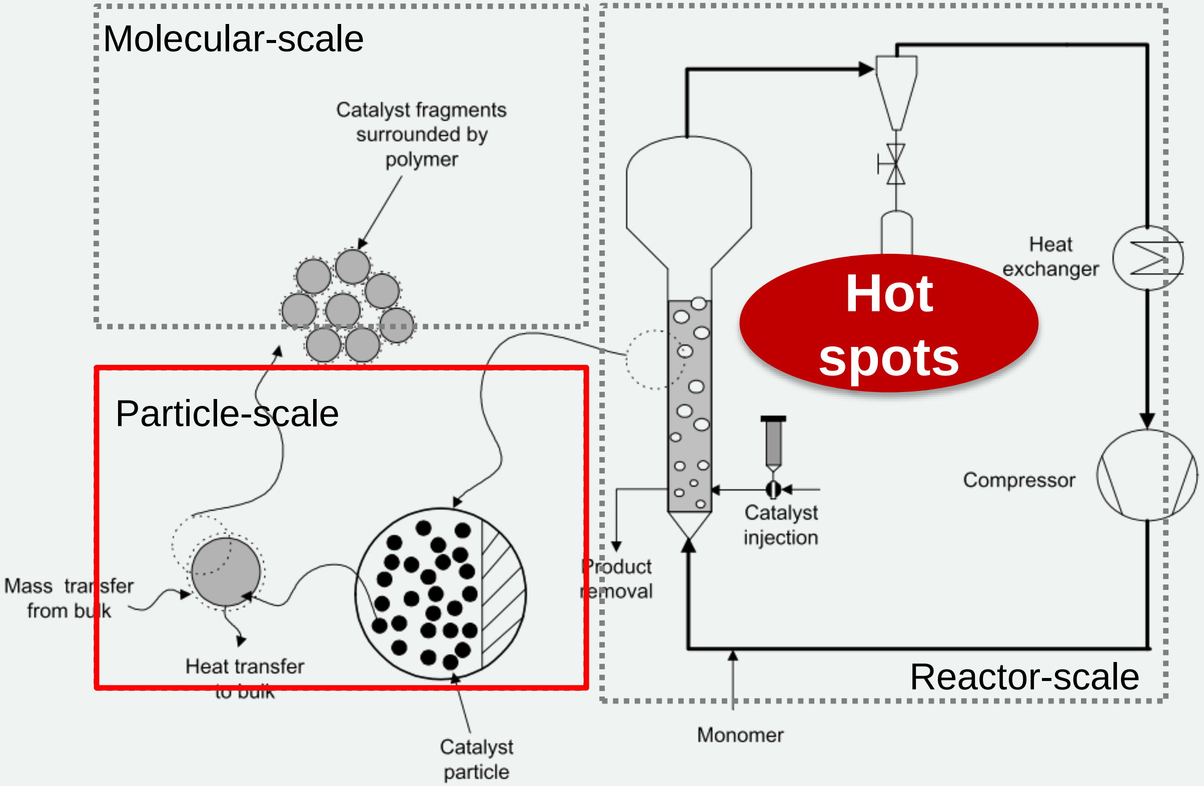


Several characteristic length scales in a fluid bed reactor for catalytic olefin polymerization.



Project background

Polymerization process



Several characteristic length scales in a fluid bed reactor for catalytic olefin polymerization.

Heat source: zeolite 13X CO_2 adsorption $(Q_{ads} = r\Delta H_{ads})$

Characterization of zeolites 13X CO_2 adsorption

$$(Q_{ads} = k_{ads}\,(q - qe)^n \Delta H_{ads})$$

Rate of adsorption

Adsorption equilibrium

Reaction enthalpy

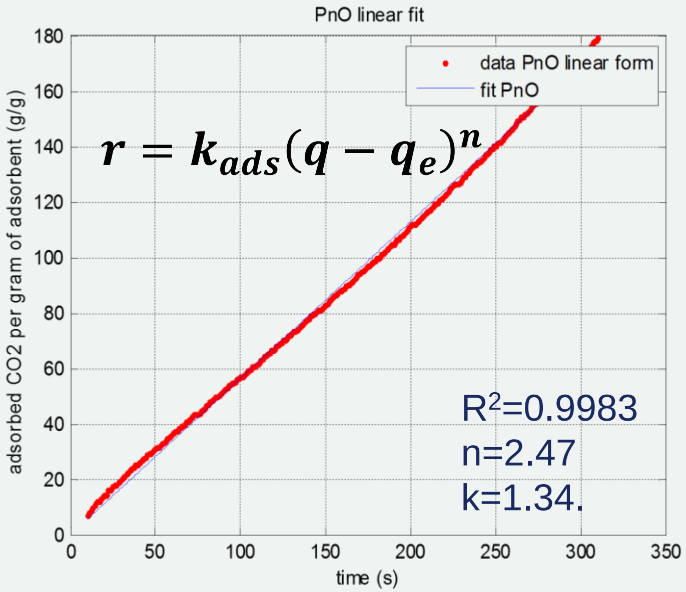


Figure 1. pseudo-nth-order fitting of the adsorption rate from TGA measurements.

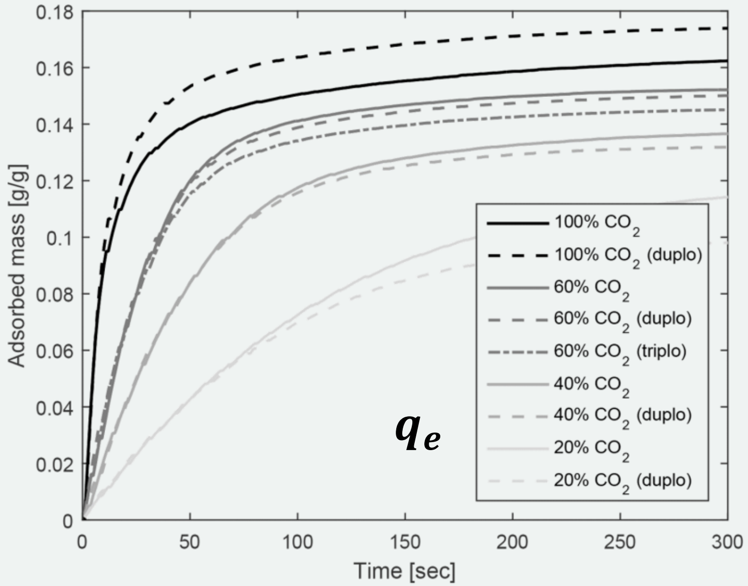


Figure 2. TGA measurement for adsorption equilibrium in atmospheric condition with different CO_2 concentration.

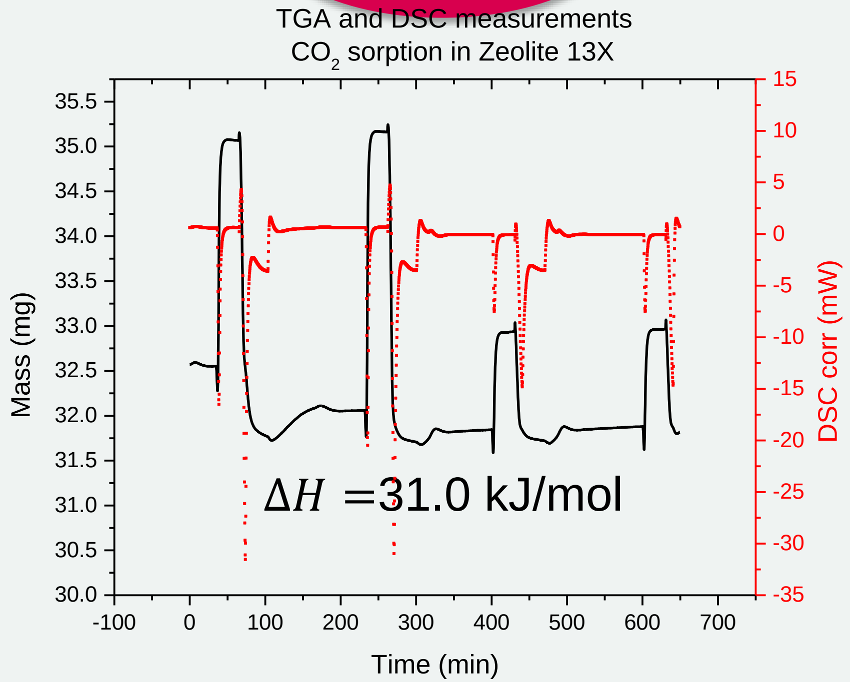
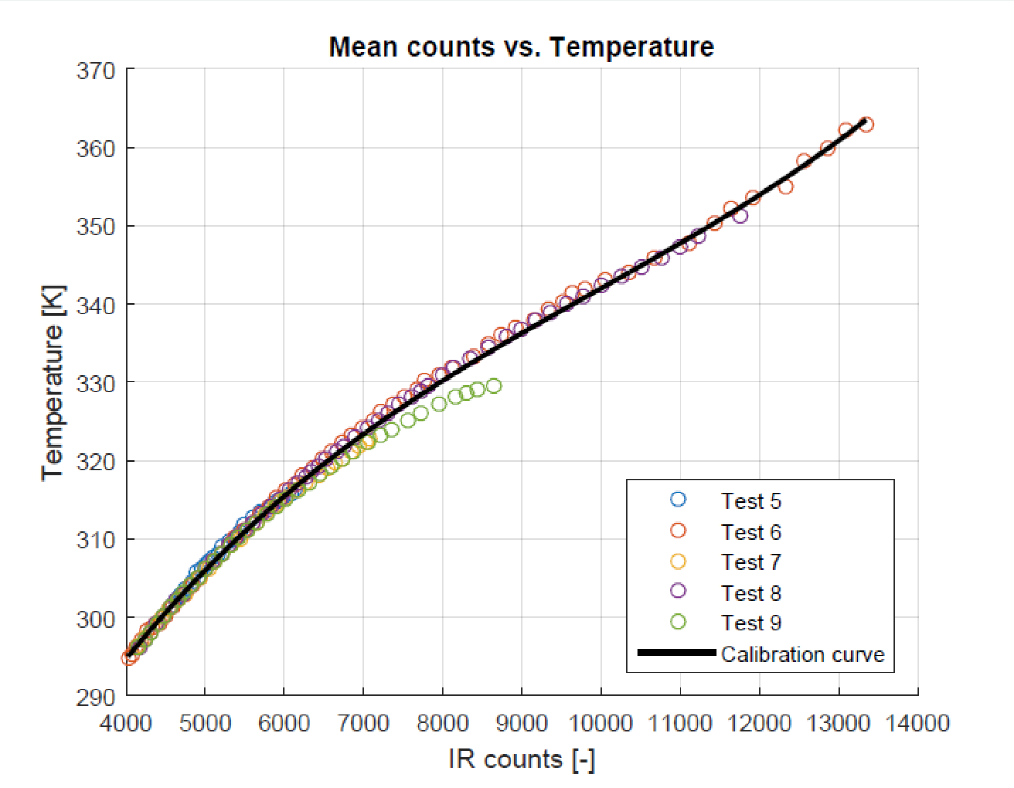


Figure 3. TGA-DSC measurements. TG results: kinetics model. STA: adsorption enthalpy.

Experimental set-up and digital image analysis

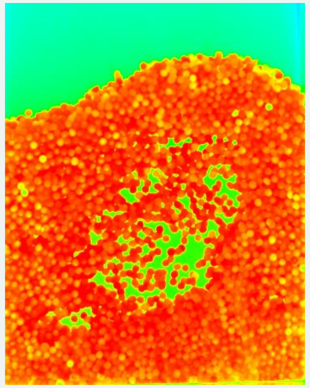
Camera calibration

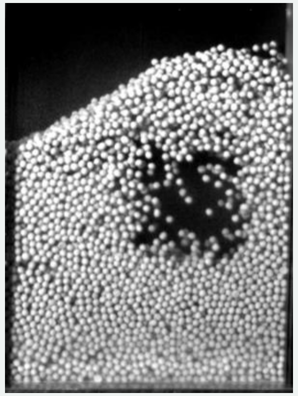
Experimental set-up and digital image analysis



Infrared camera
1280 x 1024 pixels

High speed visual camera
(540x1024 pixels)





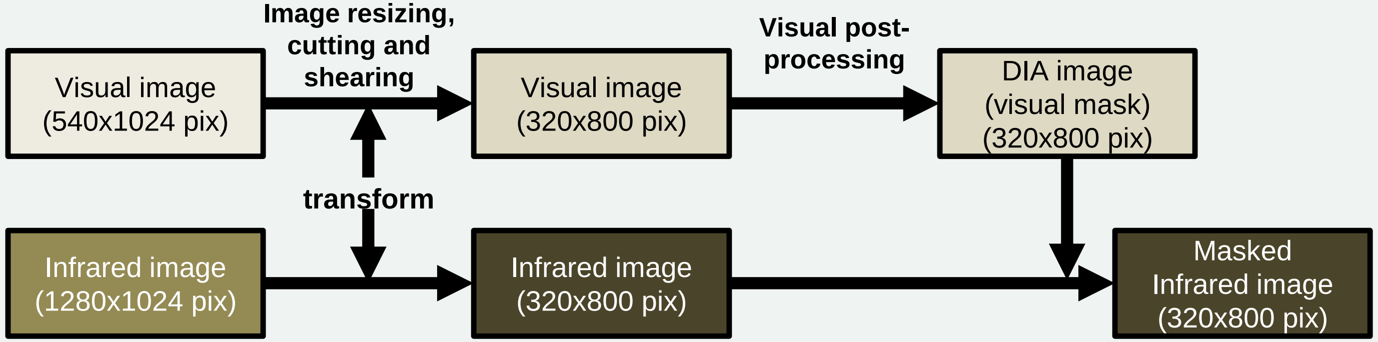
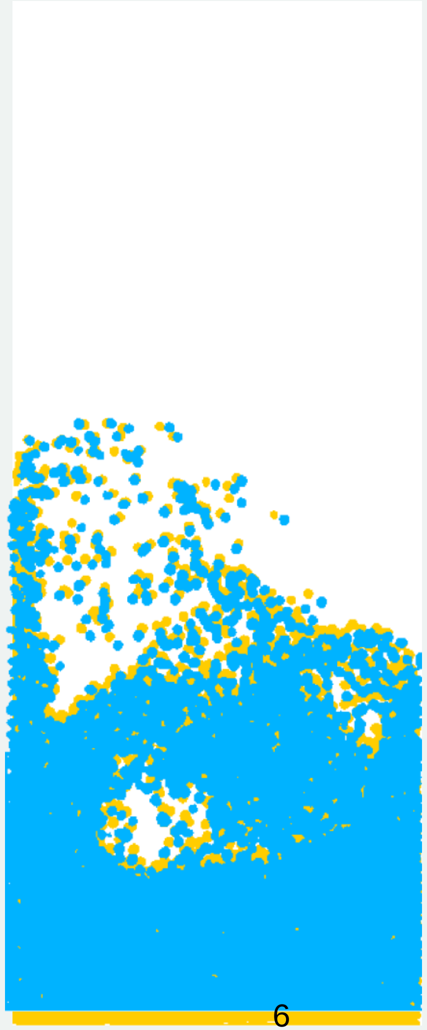


Image processing



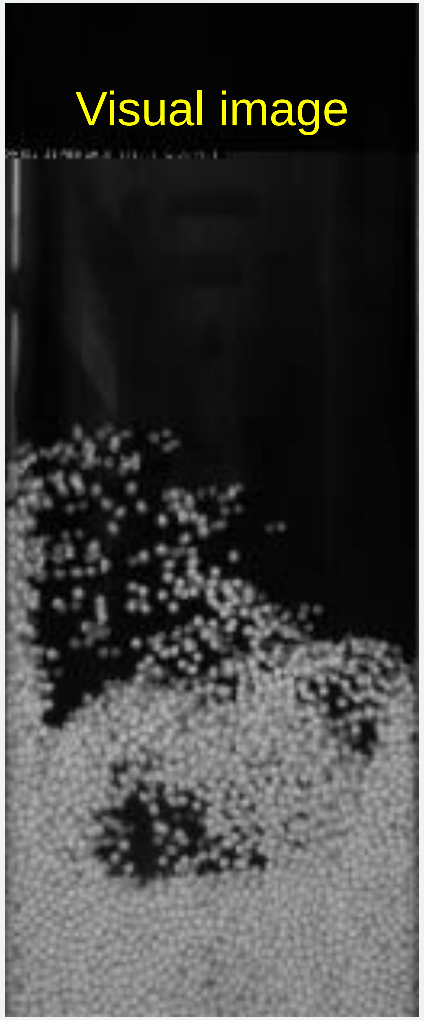
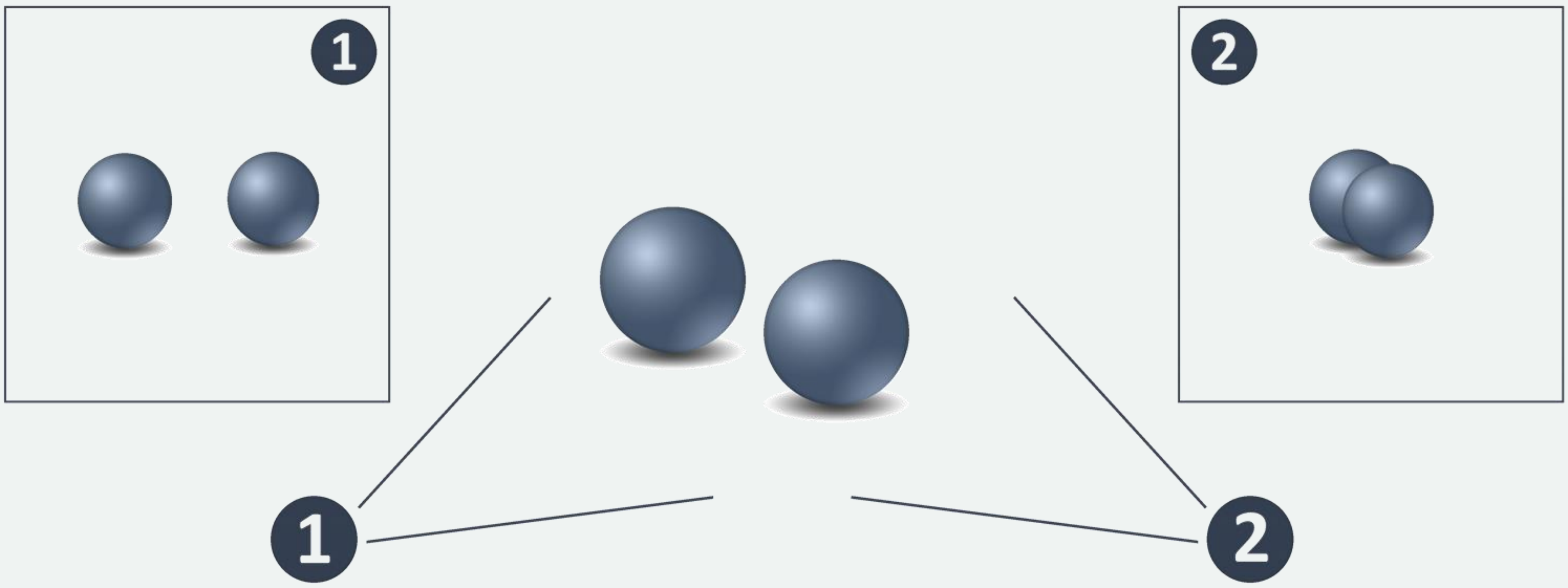
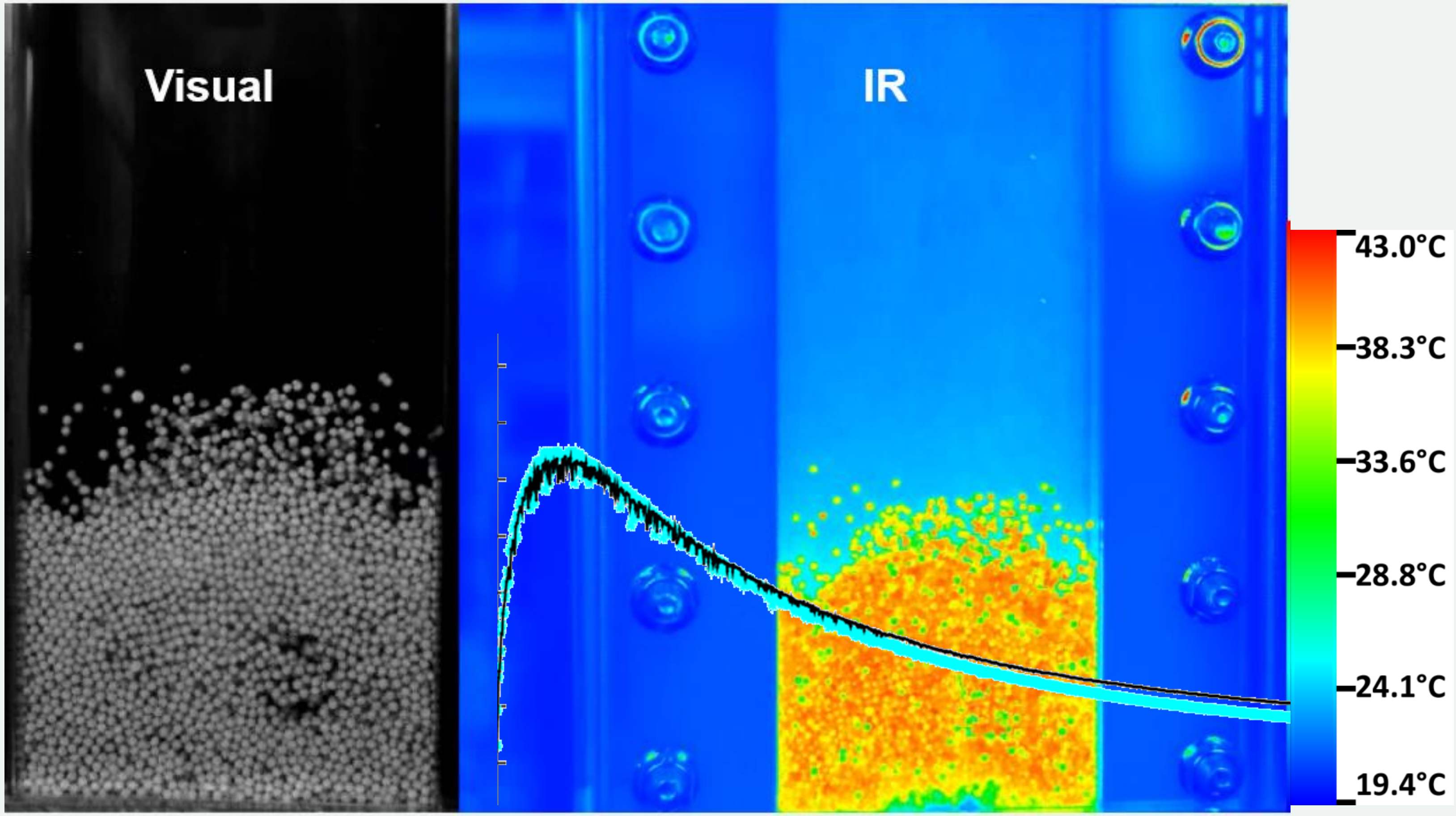


Image processing



Fluidization experiments



With N_2

Initializing fluidization

(u_0=0.73 m/s, u_{mf}=0.53 m/s)

Switch to N_2/ CO_2 mixture

Heat up

(u_0=1.2 m/s)

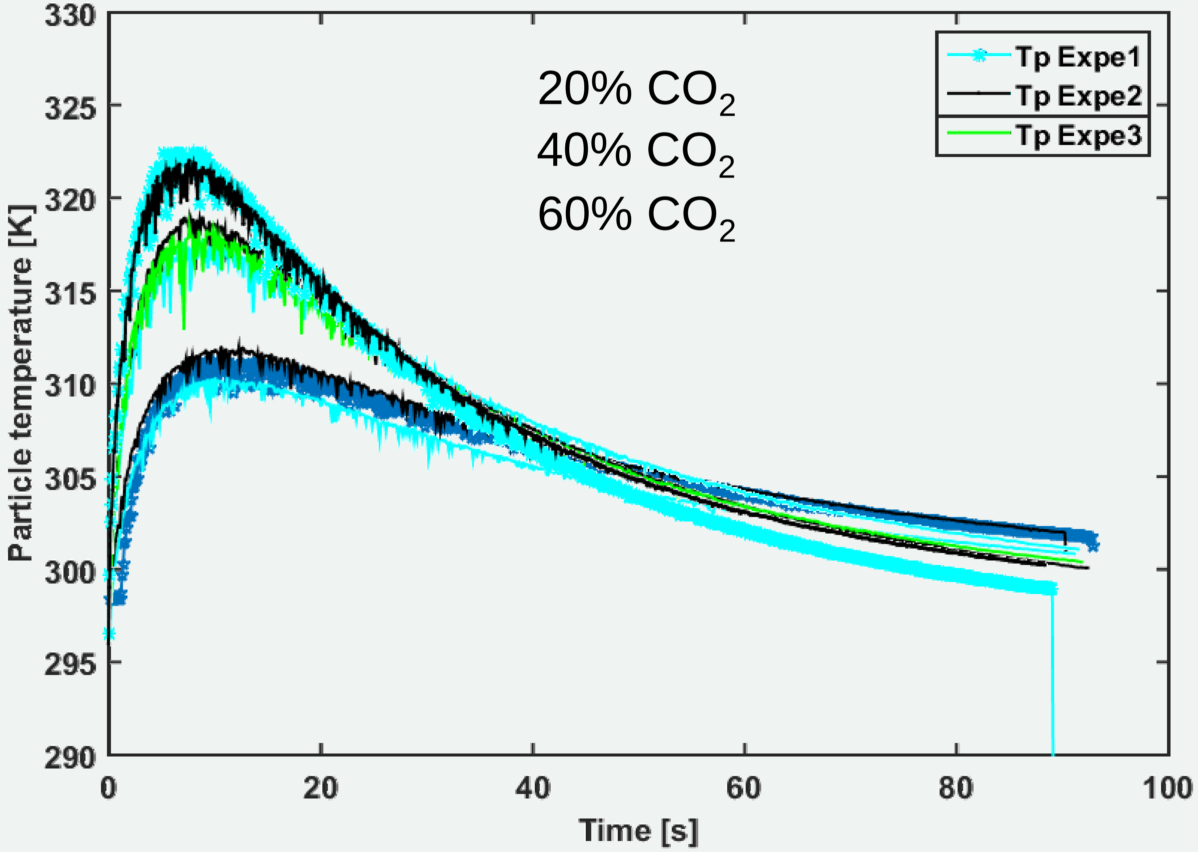
With N_2/ CO_2 mixture

Cool down

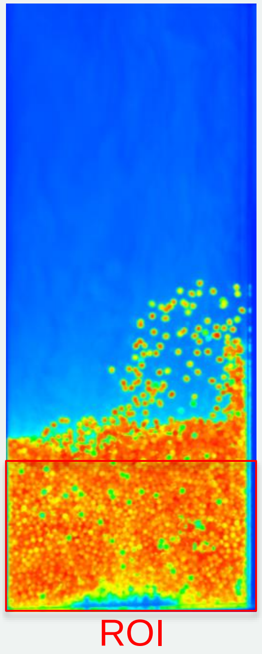
(u_0=1.2 m/s)

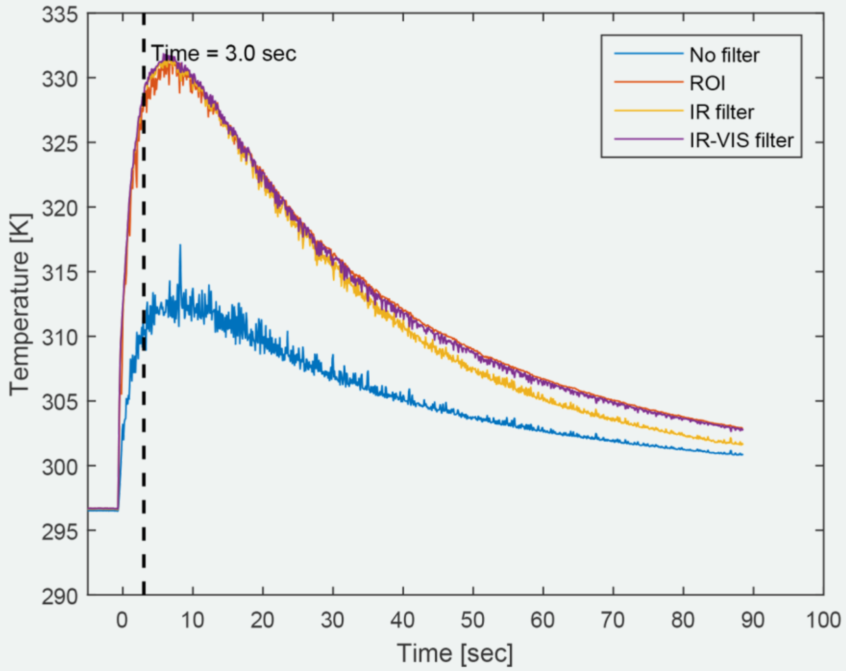
Particle temperature evolution

Control the heat source by changing the concentration of CO_2 in the gas mixture



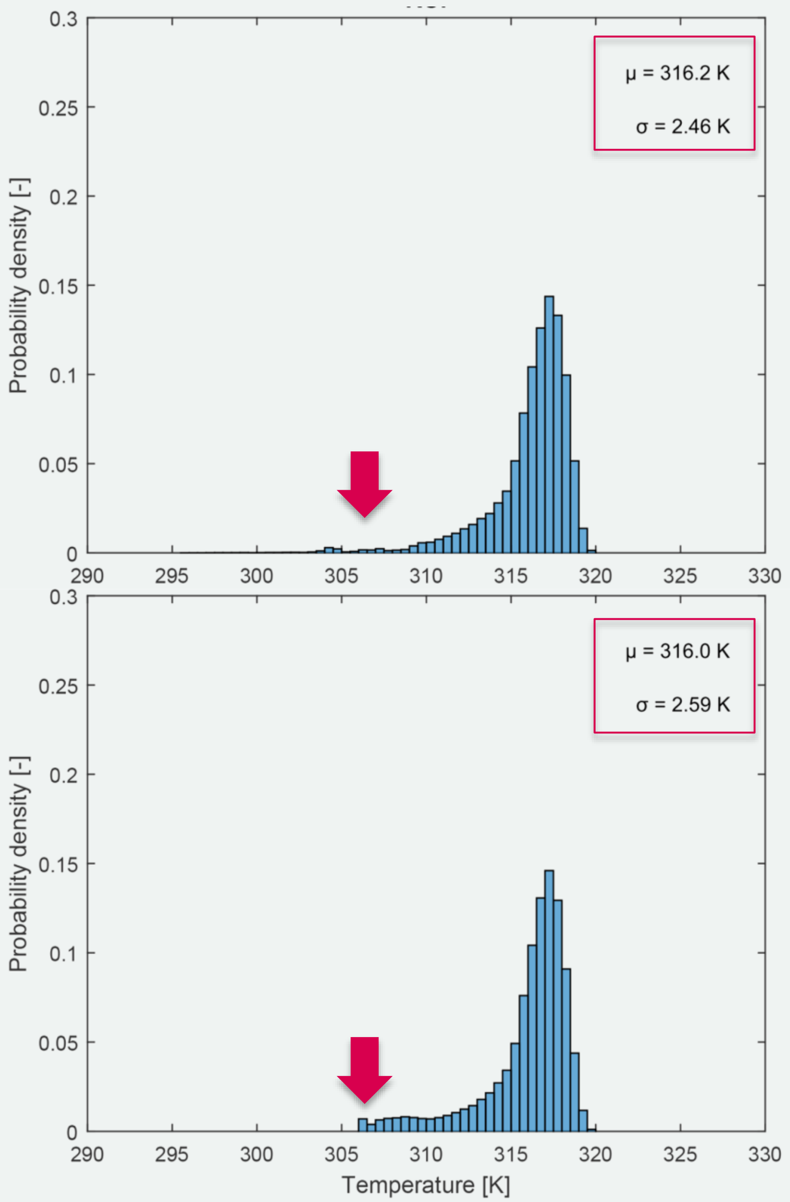
Digital image analysis



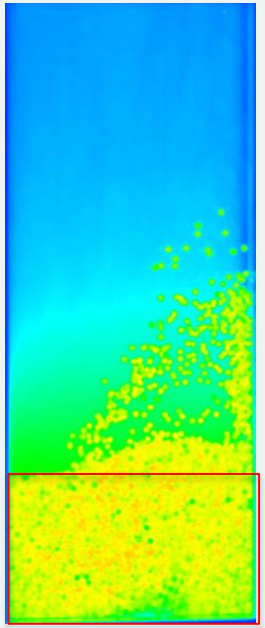


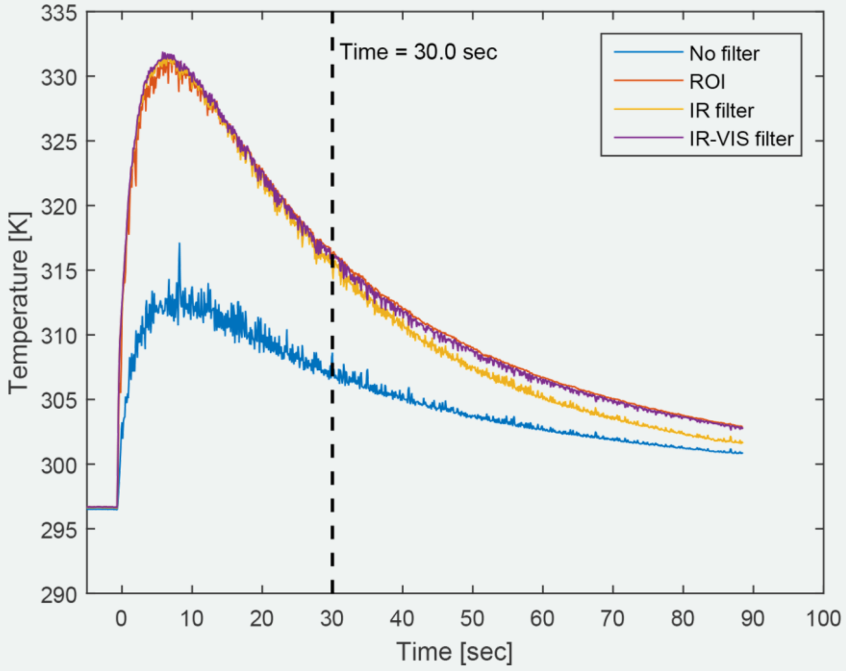
IR filter

Visual mask



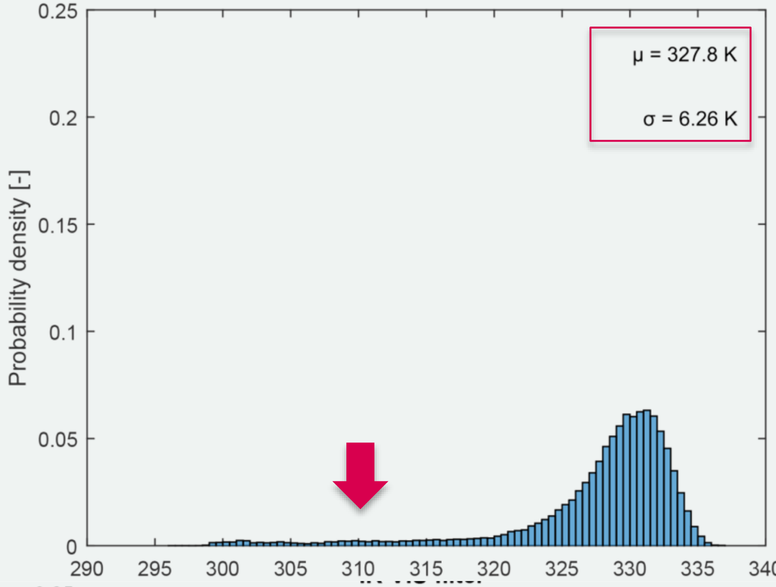
Digital image analysis

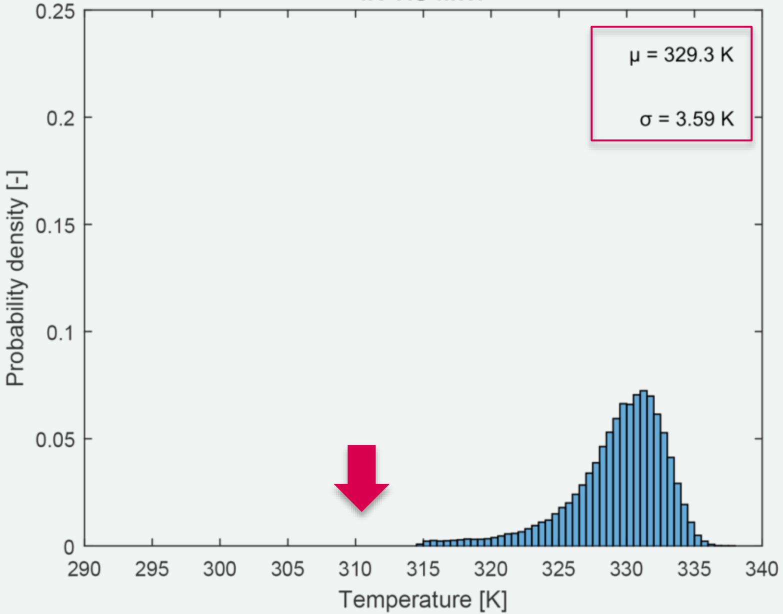




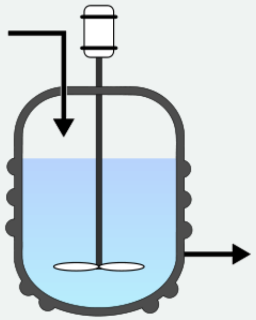
IR filter

Visual mask

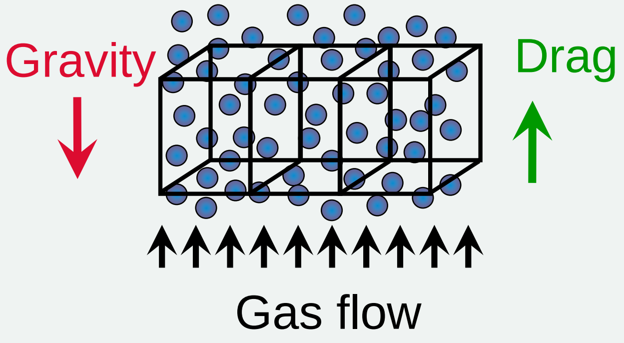




Models



CSTR Model



CFD-DEM

Both solid and gas phases are well-mixed

$$\frac{\partial}{\partial t}\varepsilon\rho_g\mathbf{u}+\nabla\cdot\varepsilon\rho_g\mathbf{u}\mathbf{u}=-\varepsilon\nabla p-\nabla\cdot\varepsilon\boldsymbol{\tau}_g-S_p+\varepsilon\rho_g\mathbf{g}$$

$$m_a\frac{d\mathbf{v}_a}{dt}=\mathbf{F}_d+\mathbf{F}_p+\mathbf{F}_g+\mathbf{F}_c$$

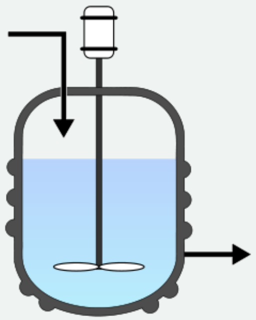
$$\varepsilon_g\rho_g C_{p,g}V_B\frac{dT_g}{dt}=V_B h_{pg}a_s(T_p-T_g)+u_g A_B C_{p,g}\rho_g(T_g^{in}-T_g^{out})+Q_{loss}$$

$$(1-\varepsilon_g)\rho_p C_{p,p}\frac{dT_p}{dt}=a_s h_{gp}(T_g-T_p)+\frac{dq}{dt}m_p\Delta H_{ads}$$

$$C_{p,g}\left[\frac{\partial(\varepsilon_g\rho_g T_g)}{\partial t}+(\nabla\cdot\varepsilon_g\rho_g\mathbf{u}_g T_g)\right]=-(\nabla\cdot\varepsilon_g\mathbf{q})+Q_p+Q_{loss}$$

$$\rho_p V_p C_{p,p}\frac{dT_p}{dt}=-hA_p\left(T_{p,a}-T_g\right)+\frac{dq}{dt}m_p\Delta H_{ads}$$

Model fitting results: CSTR

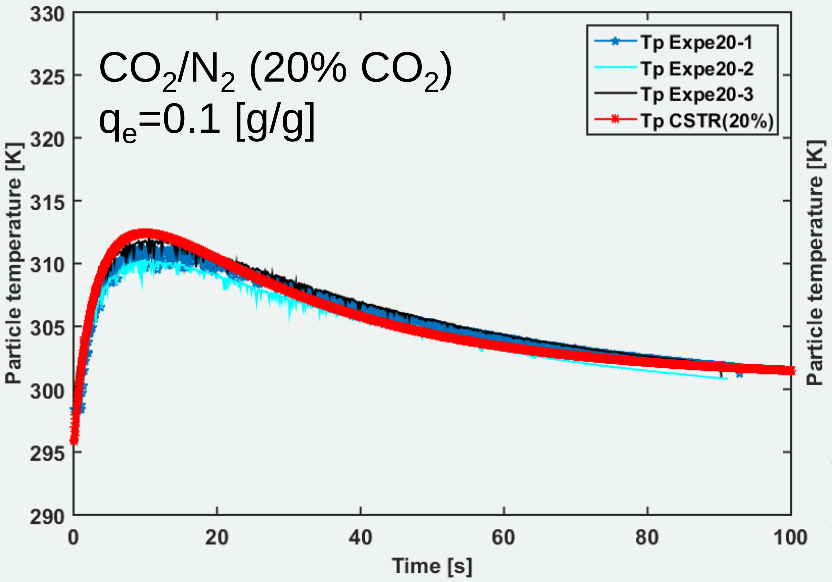


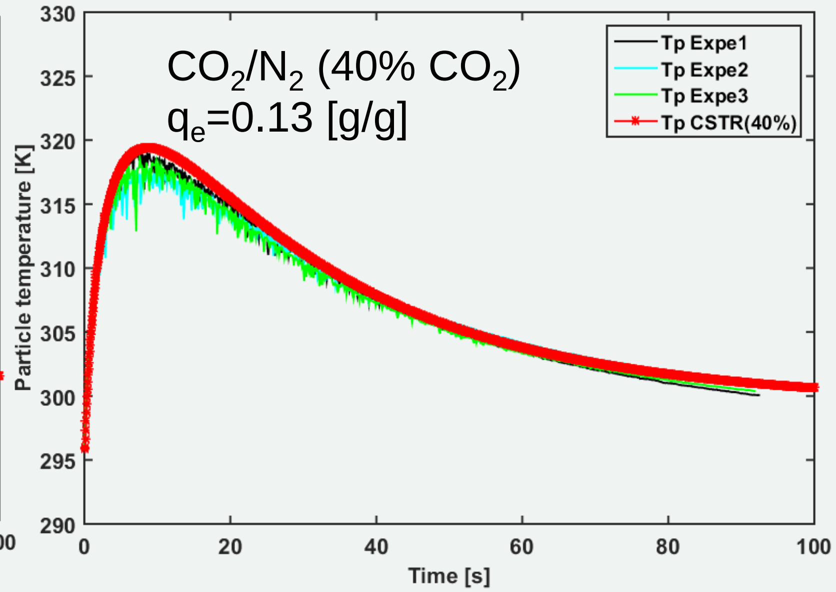
$$\varepsilon_g \rho_g C_{p,g} V_B \frac{dT_g}{dt} = V_B h_{pg} a_s (T_p - T_g) + u_g A_B C_{p,g} \rho_g (T_g^{in} - T_g^{out}) + Q_{loss}$$

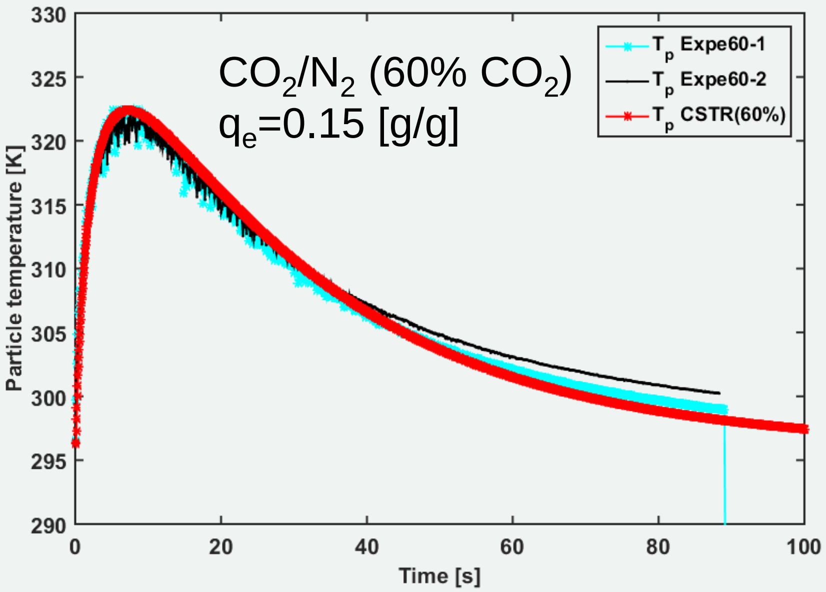
$$(1-\varepsilon_g)\rho_p C_{p,p} \frac{dT_p}{dt} = a_s h_{gp} (T_g - T_p) + \frac{dq}{dt} m_p \Delta H_{ads}$$

$$\frac{dq}{dt} = k_{ads} (q - q_e)^{nads}$$

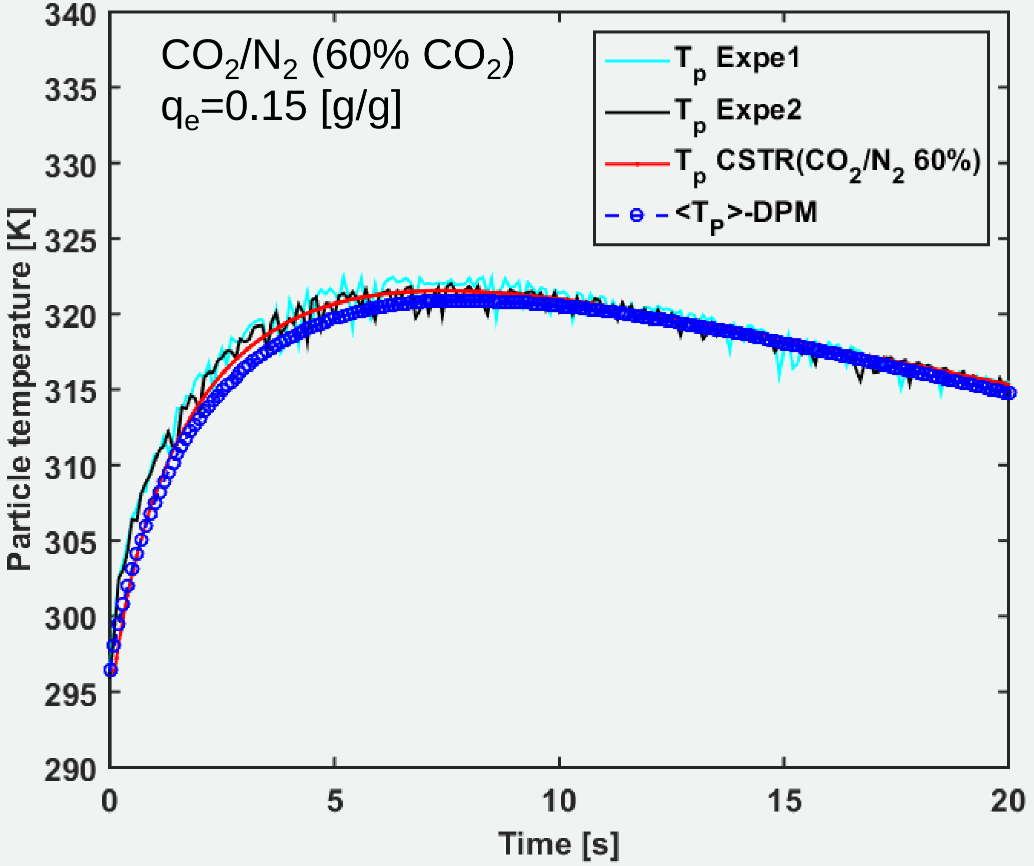
$$Q_{loss} = h_{bw} (T_g - T_w)$$

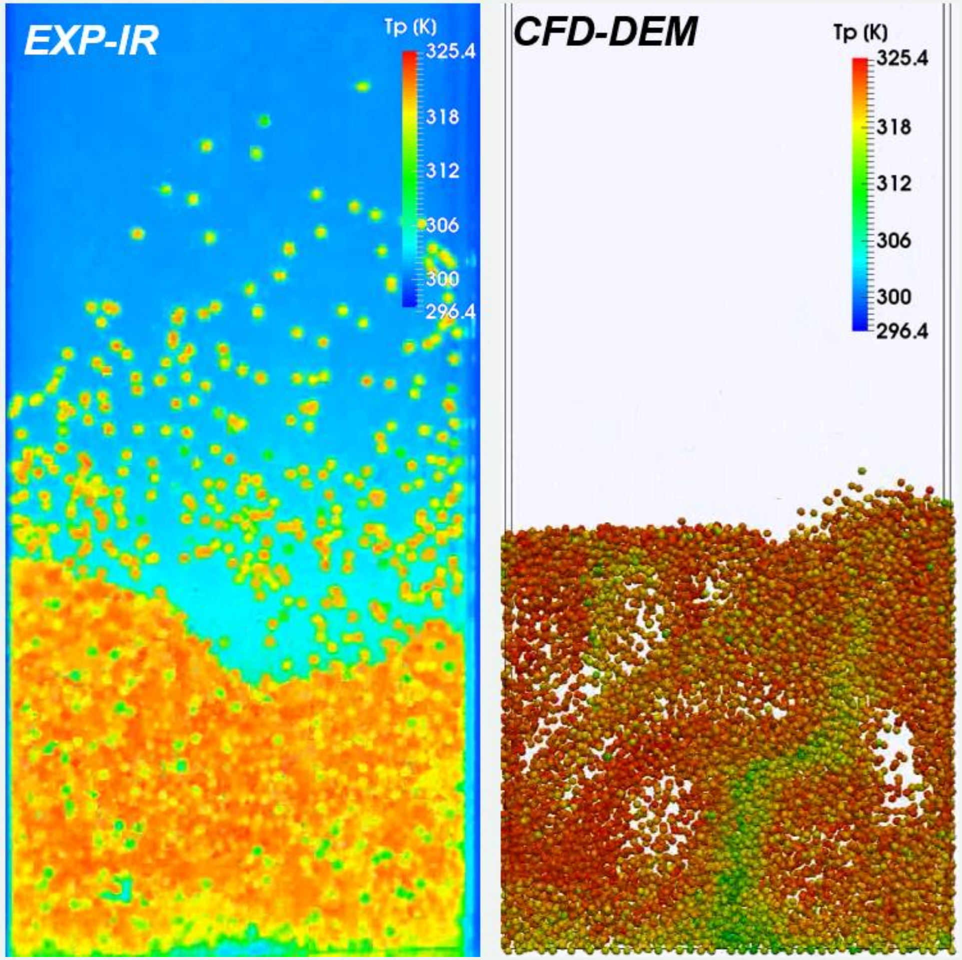






One to one comparison with DPM





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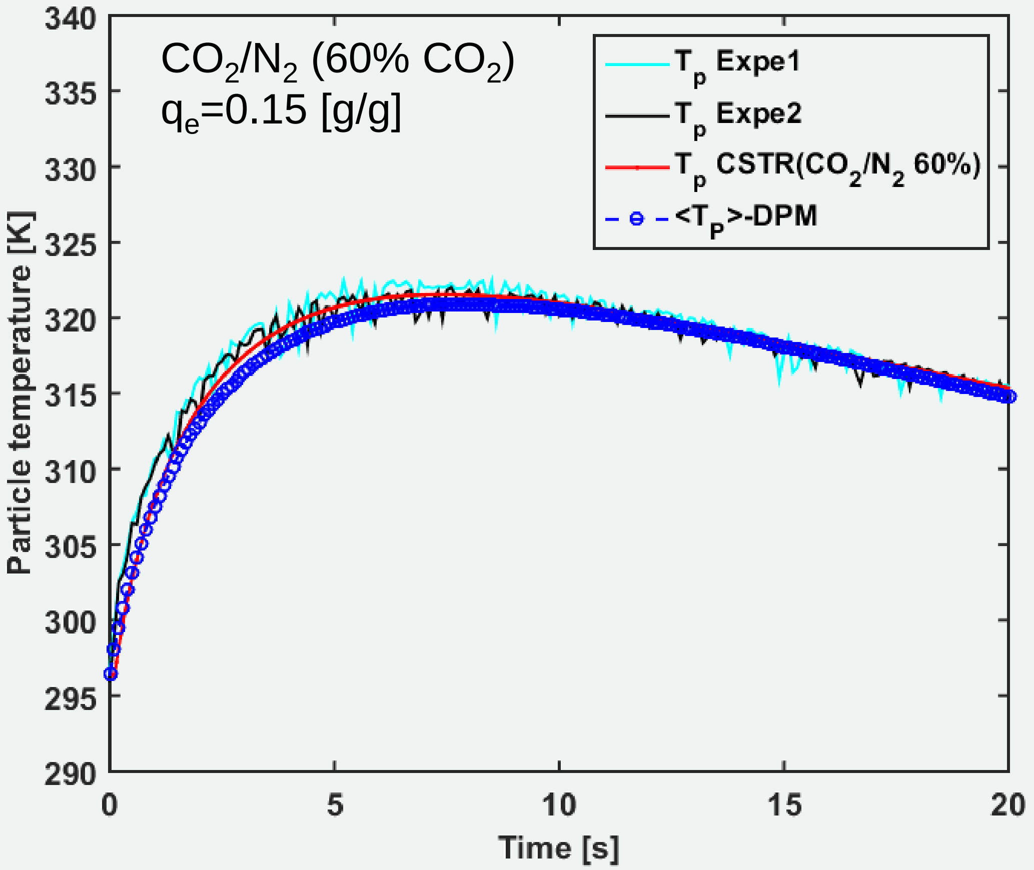

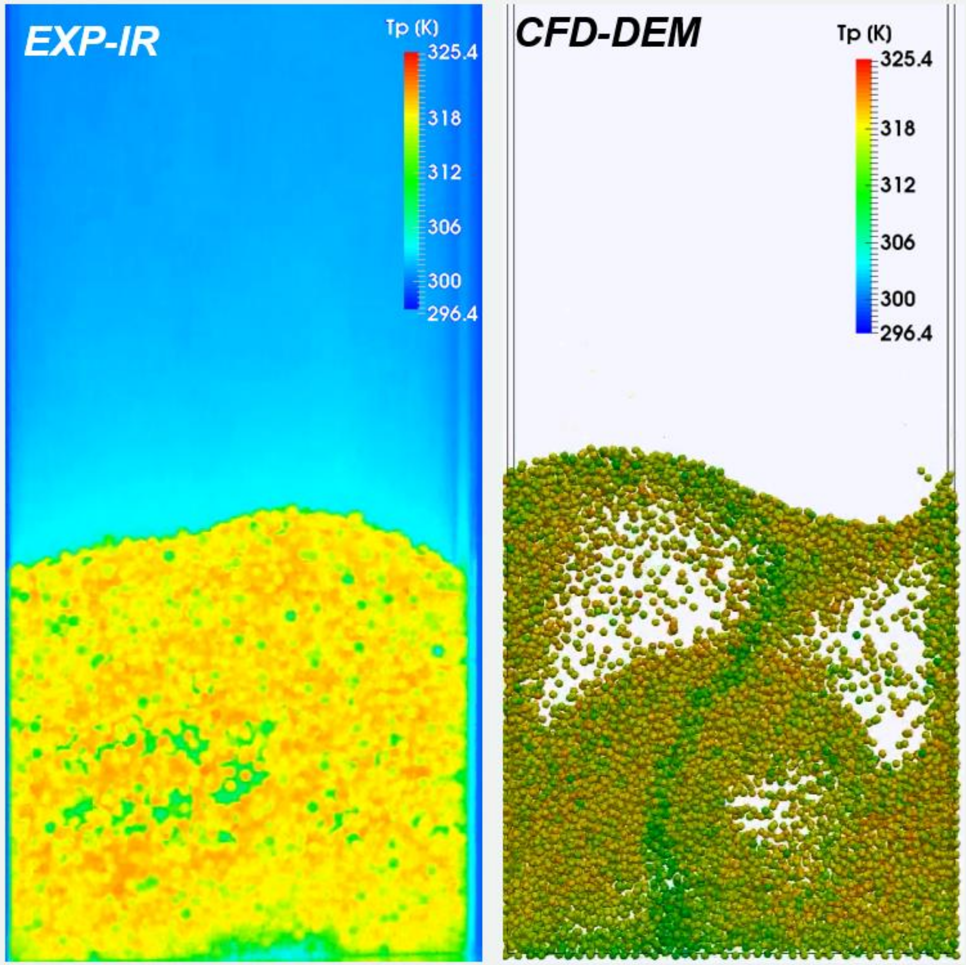

Conclusions

- A non-intrusive visual technique combined with high speed IR camera and visual camera has been utilized to visualize the particle temperature distribution in a fluidized bed with a heat source from adsorption.
- The spatial-averaged particle temperature evolution obtained from processing of experimental results using visual image mask technique, was used to verify a CSTR model and further more to validate CFD-DEM.
- Compare to the experiment, CFD-DEM can well capture the spatial particle temperature distribution and particle temperature evolution.

Acknowledgment

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Thanks
for your attention!