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Simulation of plastic pyrolysis in fluidized bed

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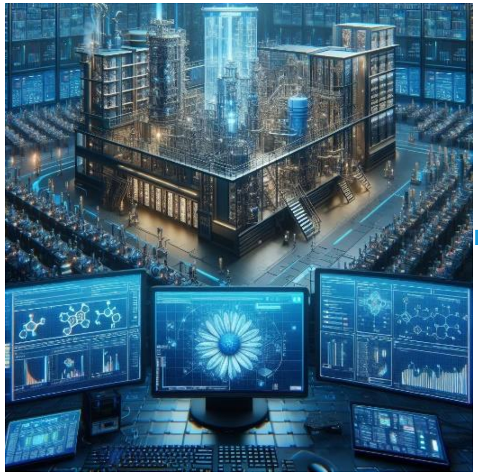
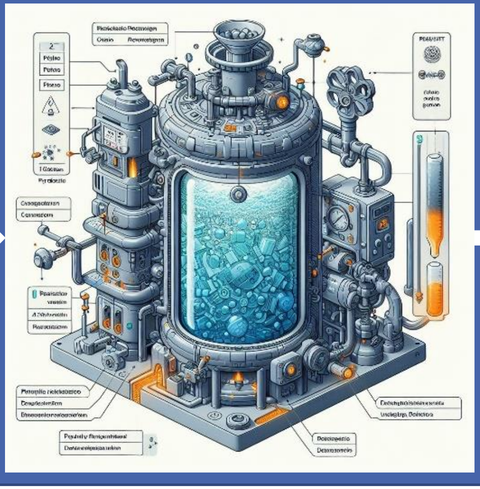
Digital twins



Mixed plastic waste

Prolysis plant



Pyrolysis oil

Recycled plastics

Outline

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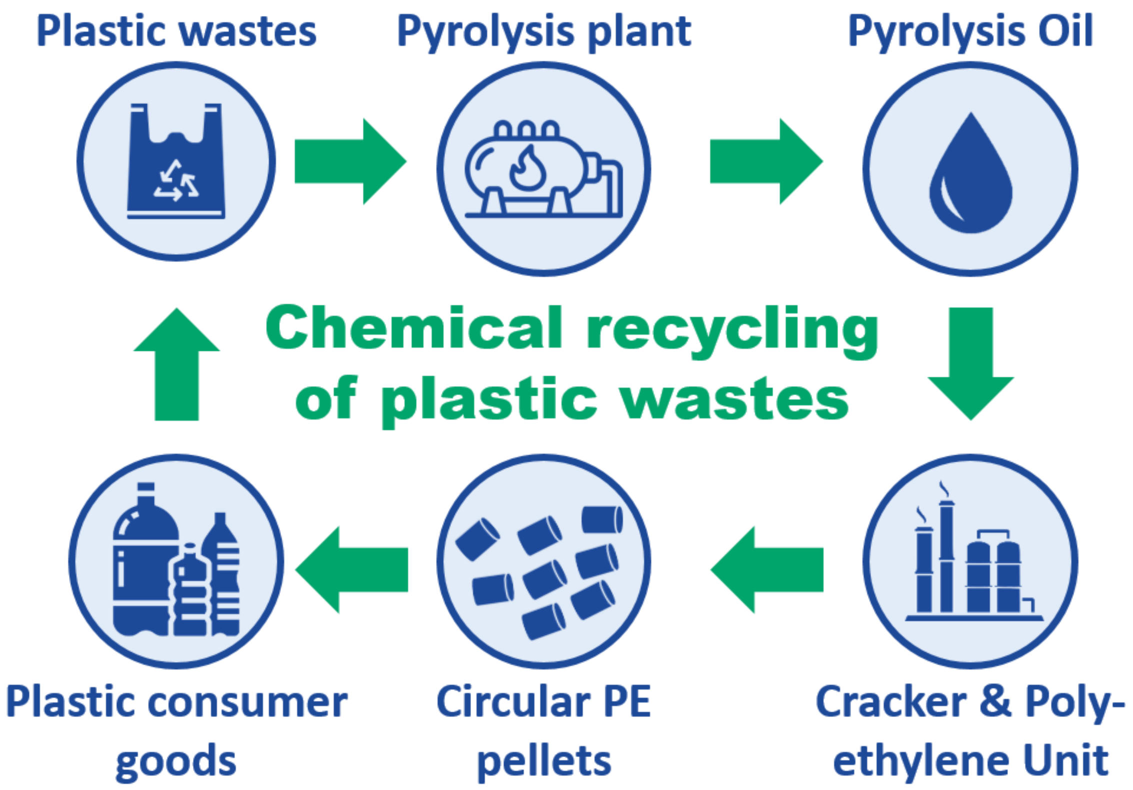
- ❑ Motivation
- ❑ Numerical Setups
- ❑ Results → Hydrodynamics, Heat transfer, Pyrolysis
- ❑ Summary

Why Chemical Recycling

- **~ 400 Mt plastic wastes per year**
  - **9% recycled**, 69% landfilled and incinerated, 22% mismanaged
  - Contaminated and mixed plastics cannot be recycled by **mechanical recycling**
- **Solution: chemical recycling via pyrolysis**
  - Promising in lab-scale experiments
  - Challenges: process control, economic viability, **scale-up**
- **Objectives**
  - Simulation of plastic pyrolysis in **fluidized bed**
  - Heat transfer vs. pyrolysis reaction

Pyrolysis: degradation of plastic polymers at high temperature into their chemical building blocks



Simulation setups

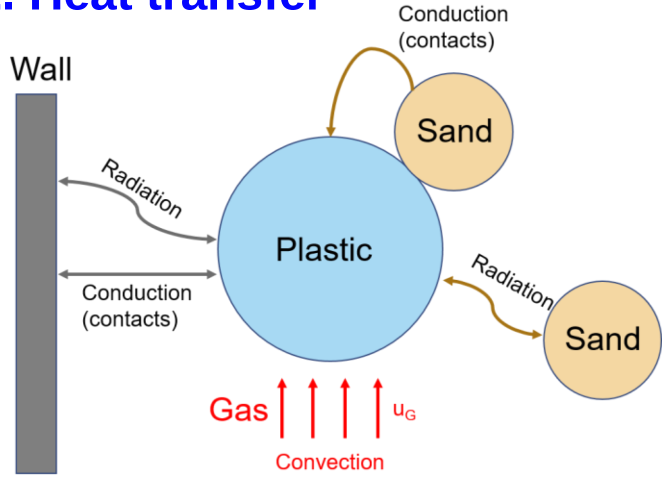
❑ Fluidized bed at lab-scale

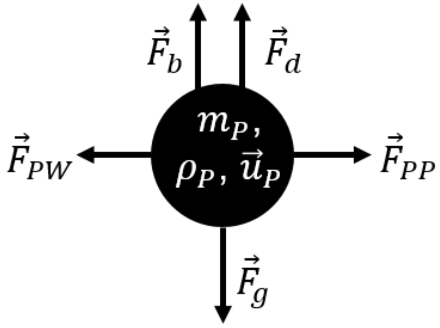
- Cylinder: $d = 5\ \text{cm}, L = 60\ \text{cm}$
- Bed material: sand/695 g
- Sand/PSD: $d_S = 0.23\ \text{mm}$
- Fluidizing agent: N_2
- LDPE: monodisperse
- Fluidizing agent: N_2

❑ Challenges

1. Euler-Lagrange/4-way
2. Contact heat transfer
3. Single-step reaction

2. Heat transfer





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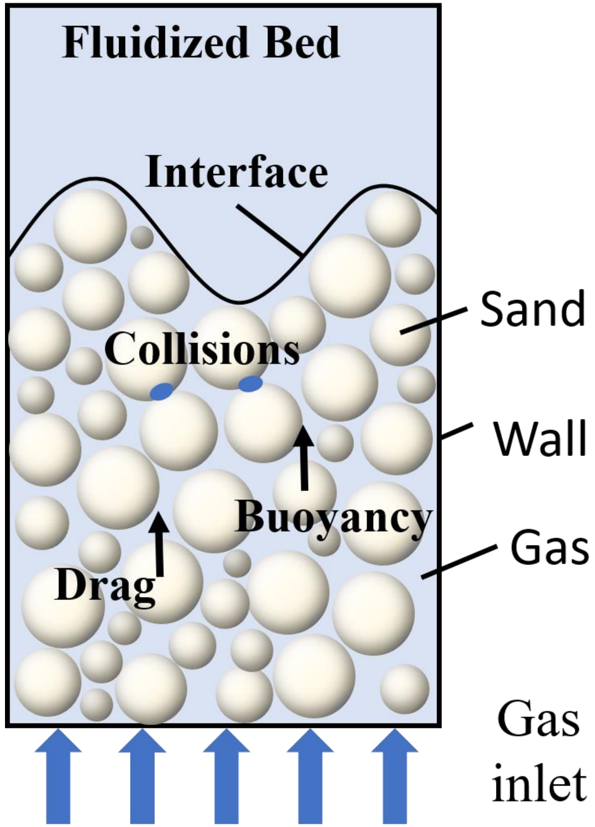
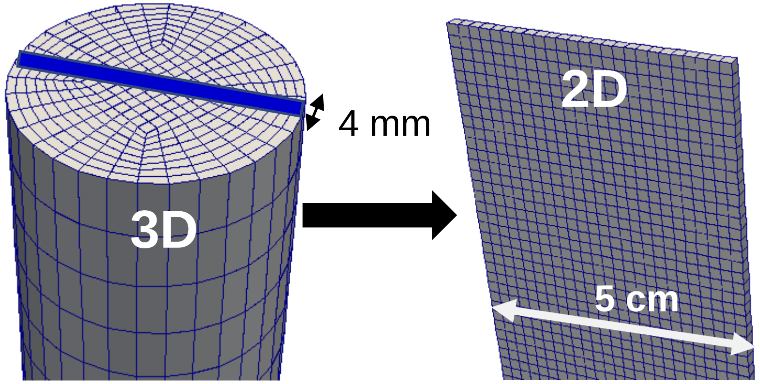
1. Hydrodynamics



3. Pyrolysis time

	Physical time	Wall clock time
Cold (3D)	10 s	1 d
Reac. (3D)	20 min	120 d



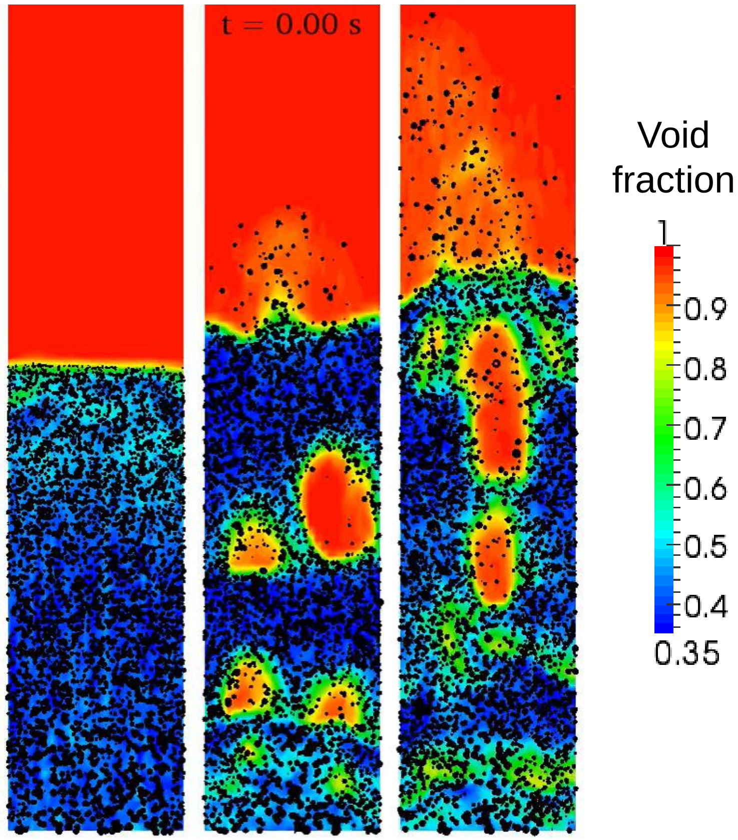
$V_{2D} = 0.1V_{3D}$

Hydrodynamics

- Cold fluidized bed: good agreement with experiments and between 2D/3D setups

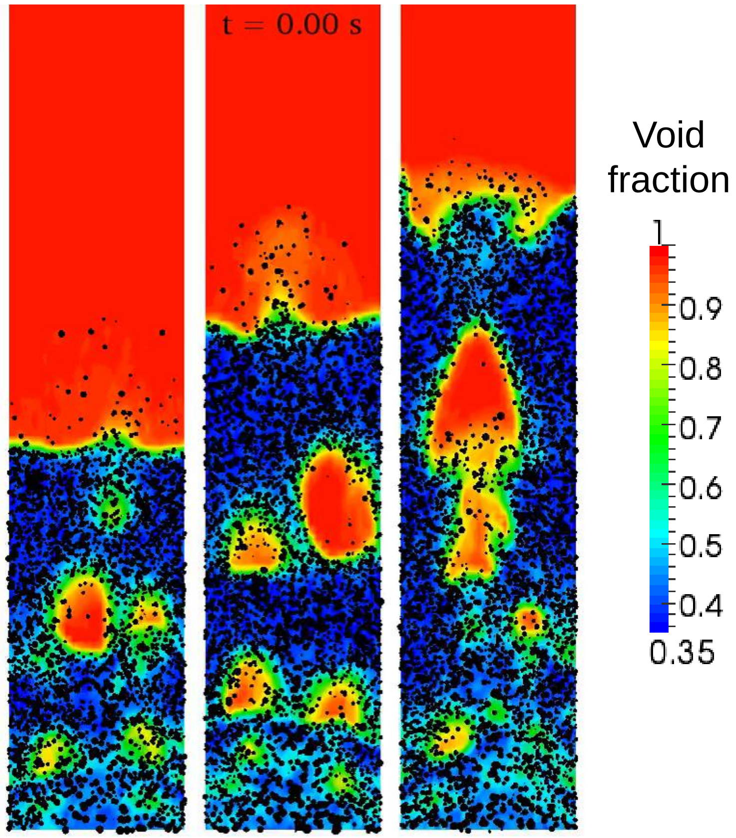
Superficial velocity $u_g \uparrow$

14 cm/s **21 cm/s** **30 cm/s**

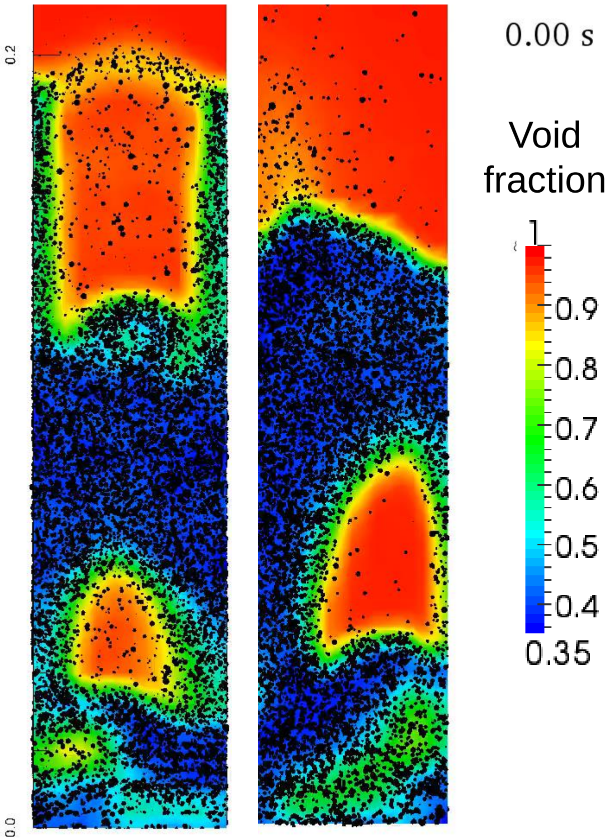


Bed inventory $m_s \uparrow$

293 g **390 g** **488 g**

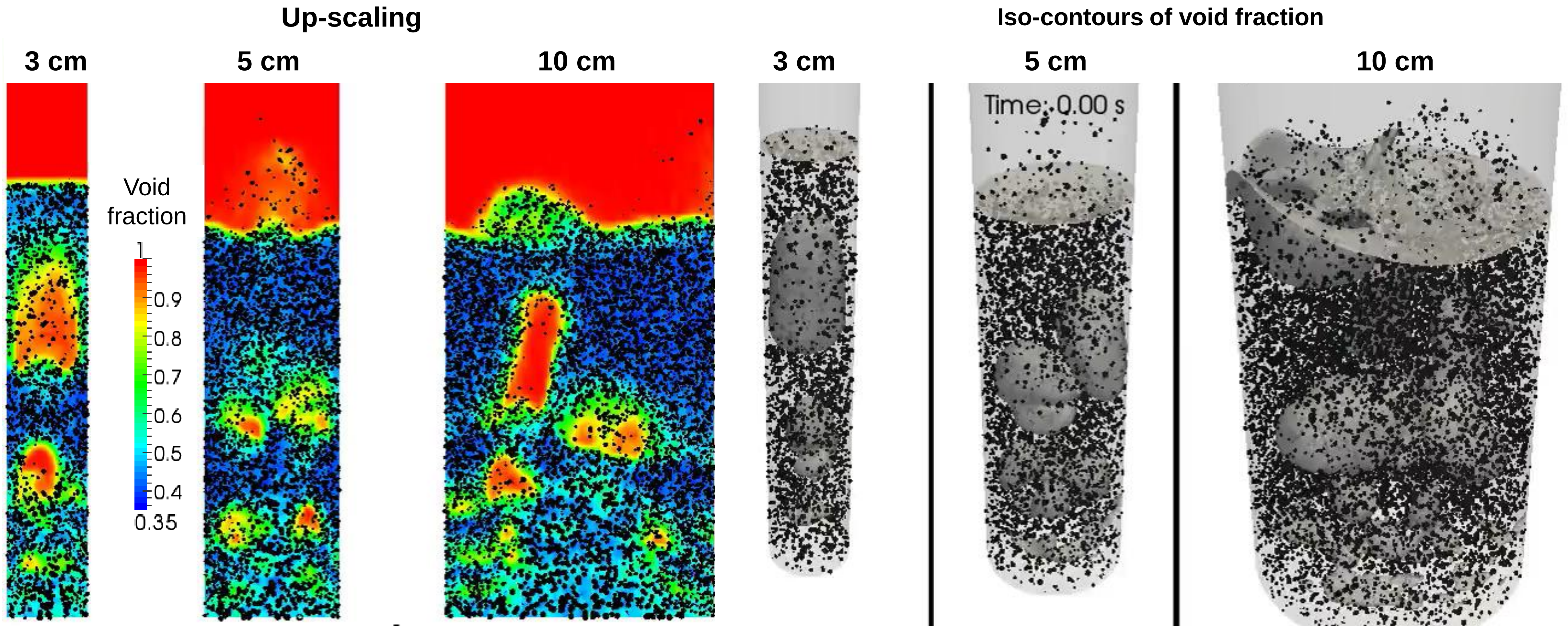


2D **3D**



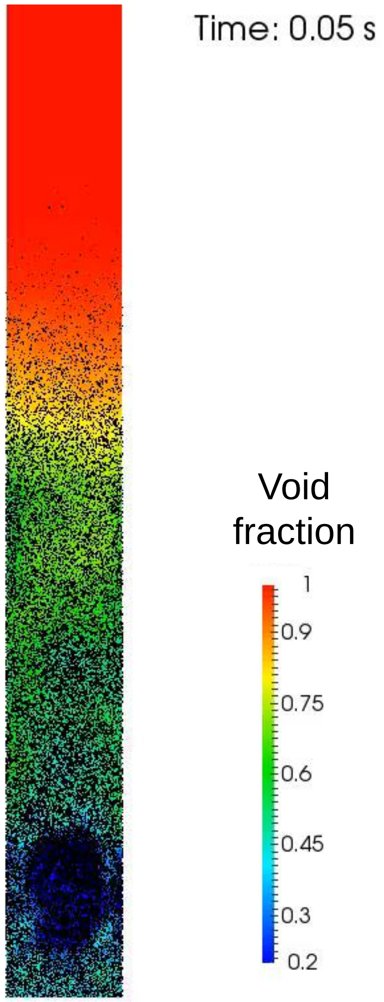
Hydrodynamics

- Enhanced bubble formation for **up-scaled** fluidized bed



Operating conditions for plastic pyrolysis

	[mm]	[m/s]	[%]	[°C]
Reference case:	**2**	**0.212**	**2**	**500**
Particle diameter:	1.5	0.212	2	500
	2.5	0.212	2	500
Superficial velocity:	2	0.153	2	500
	2	0.297	2	500
Share of plastics:	2	0.212	1	500
	2	0.212	4	500
Reactor temperature	2	0.212	2	470
	2	0.212	2	530

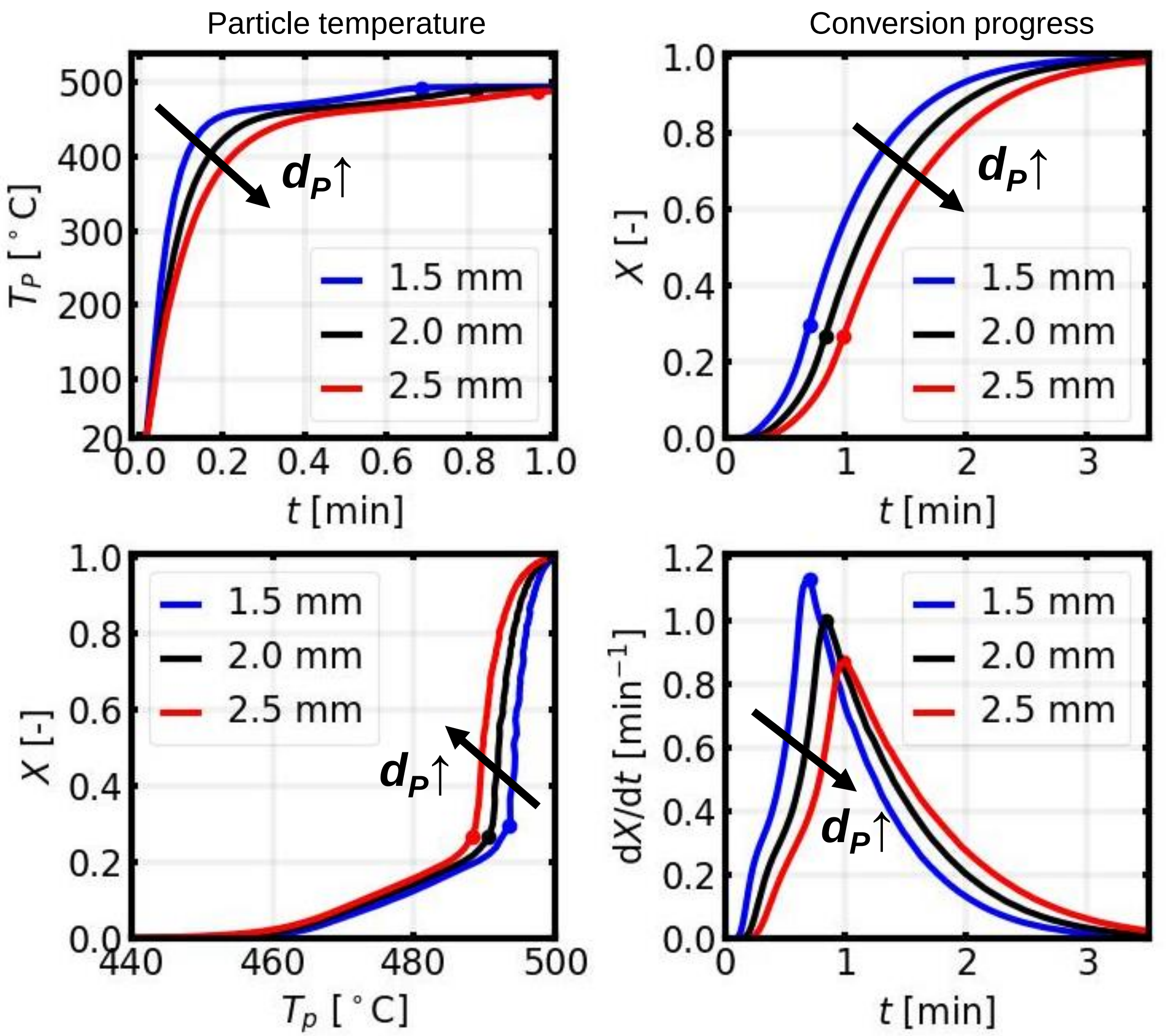


Effect of particle size

- **$d_P \uparrow$ leads to**
  - slower heating
  - slower conversion
  - smaller pyrolysis temperature
  - smaller reaction rate
- **Faster conversion at enhanced heating**

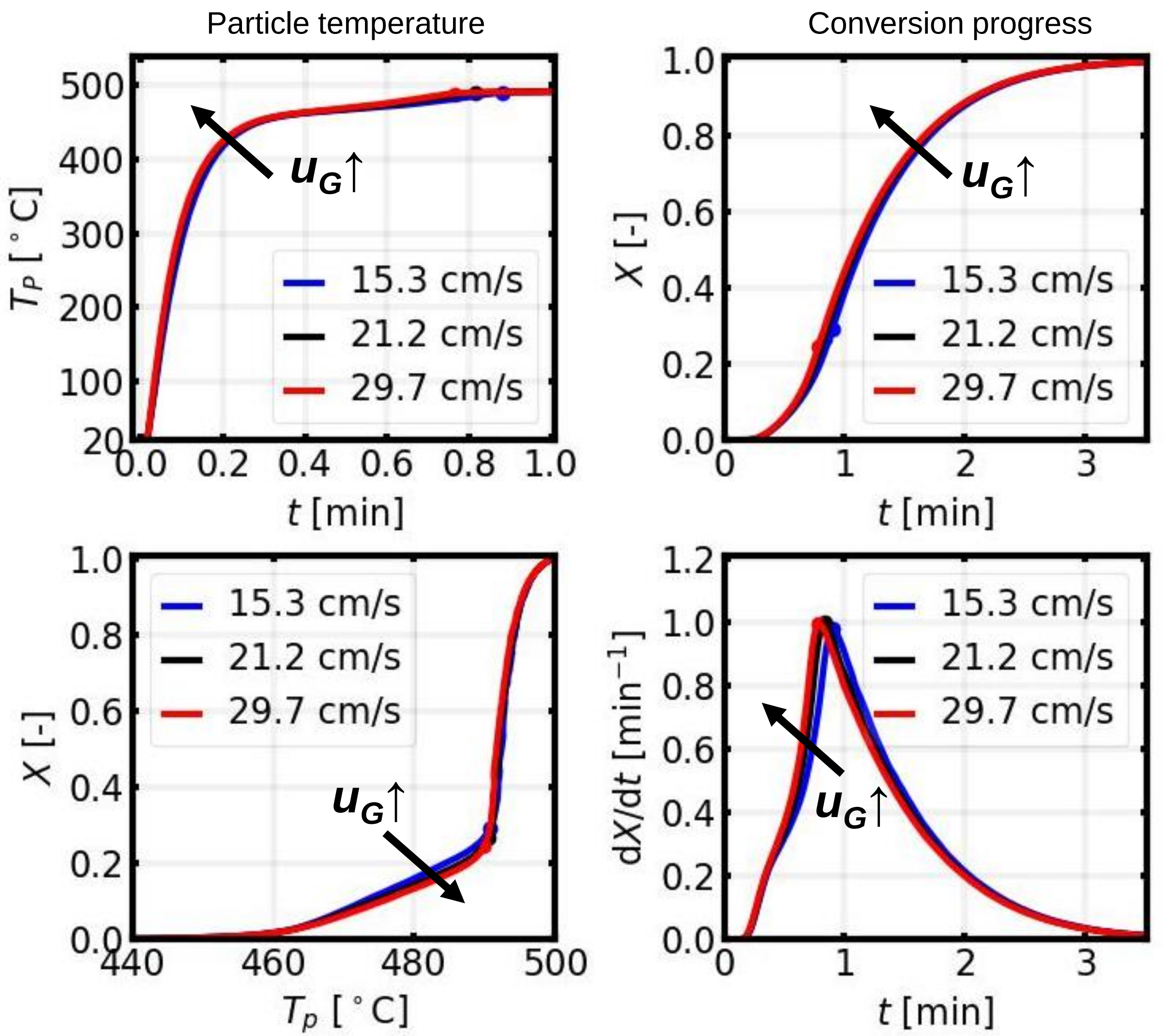
Heat transfer coefficient: $\alpha = \frac{Nu \cdot \lambda}{d_p}$

Conversion progress: $X = \frac{m_{p,0} - m_p}{m_{p,0}}$



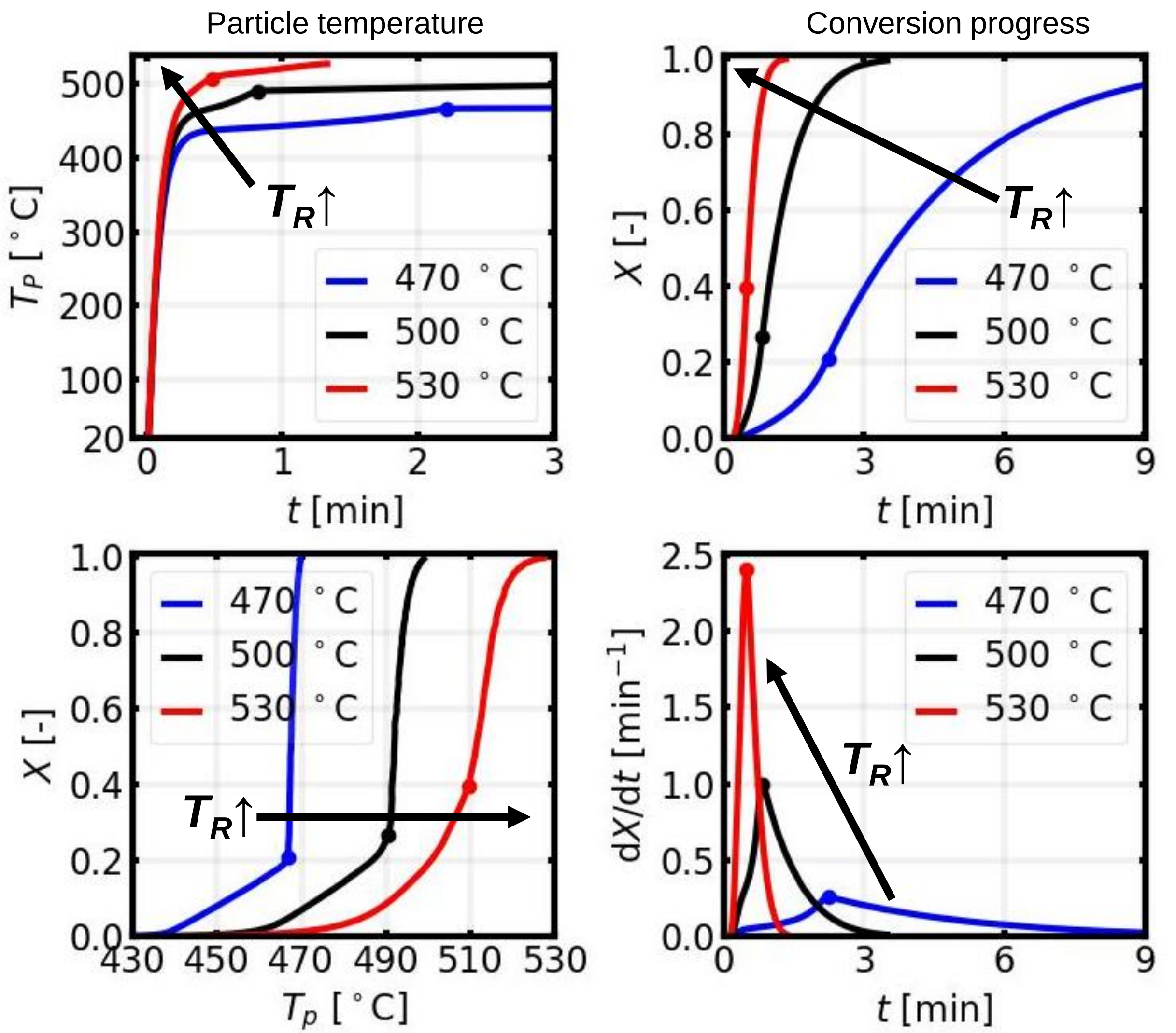
Effect of superficial velocity

- **Subordinate influence of u_G**
- Note: strong impact of u_G on pyrolysis products



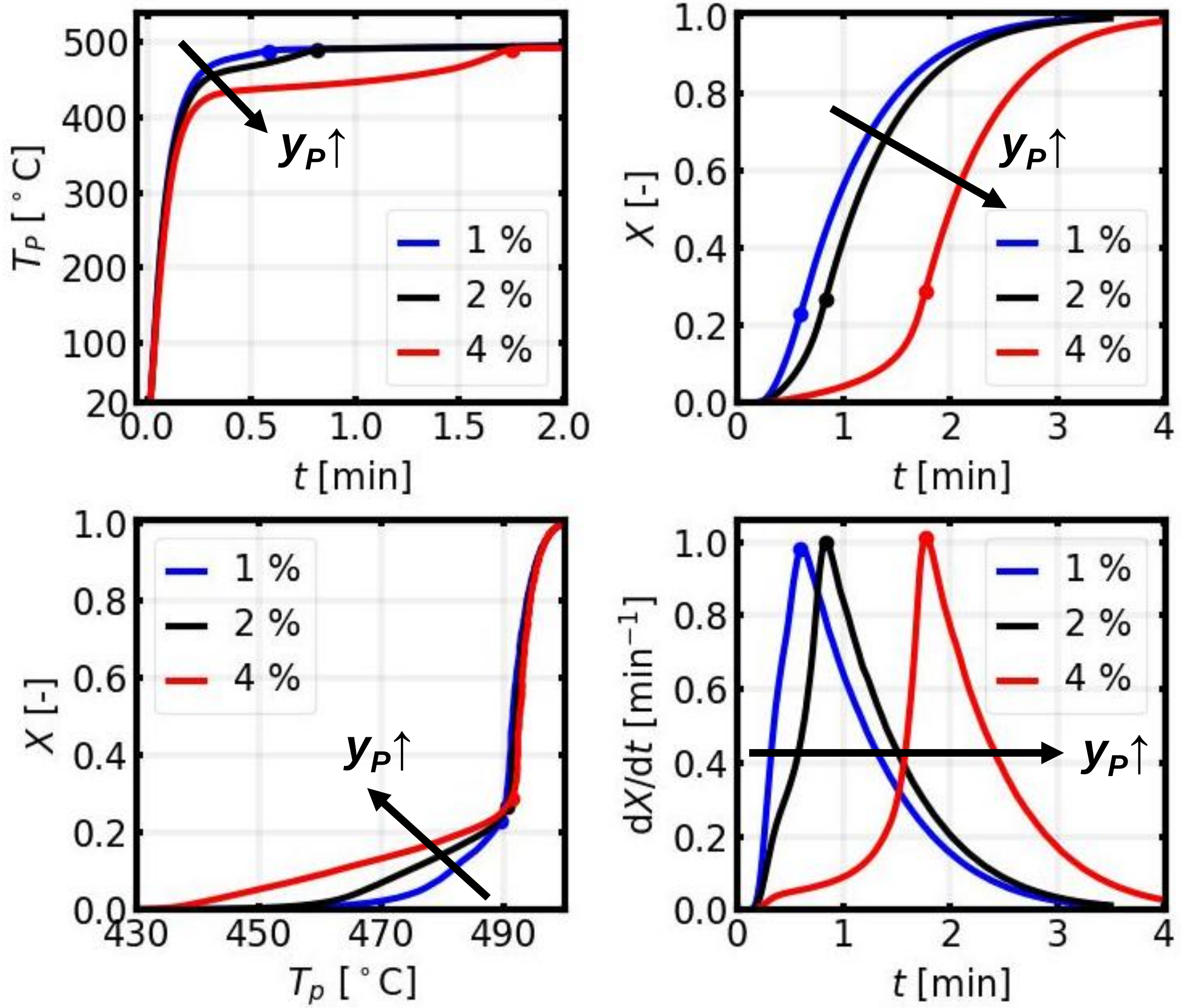
Effect of reactor temperature

- T_R ↑ **leads to**
  - faster heating
  - faster conversion
  - higher pyrolysis temperature
  - larger reaction rate



Effect of share of plastics

- **y_P↑ leads to**
  - slower heating
  - slower/delayed conversion
  - more conversion in low T-range
  - slightly higher pyrolysis temperature
  - slightly higher conversion rate



Single particle in hot gas and fluidized bed

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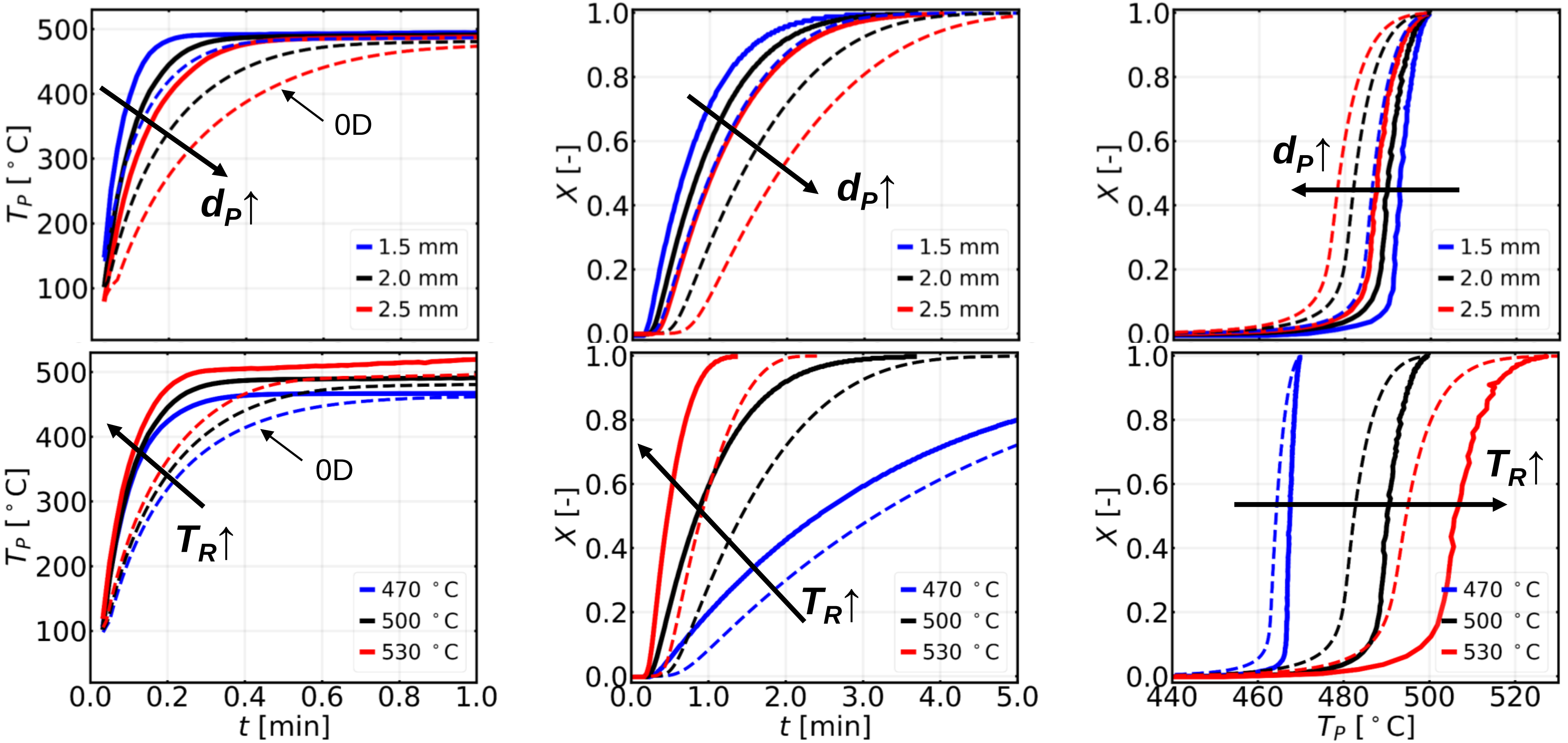
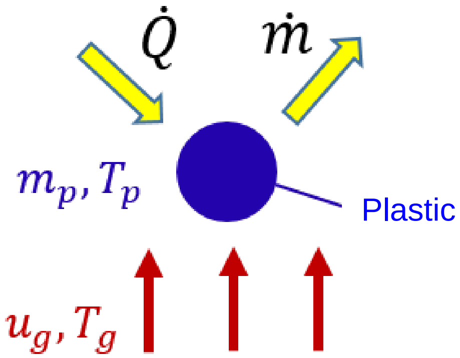
- Faster heating/pyrolysis in fluidized bed

→ Prediction of pyrolysis behavior based on 0D simulation?



0D setup



$$-\frac{dm_p}{dt} = \dot{r},$$

$$m_p c_{p,p} \frac{dT_p}{dt} =$$

$$\alpha A_p \left(T_g - T_p\right) - \Delta h_r \dot{r}$$

$\dot{r}$ – reaction rate

α – heat transfer coefficient

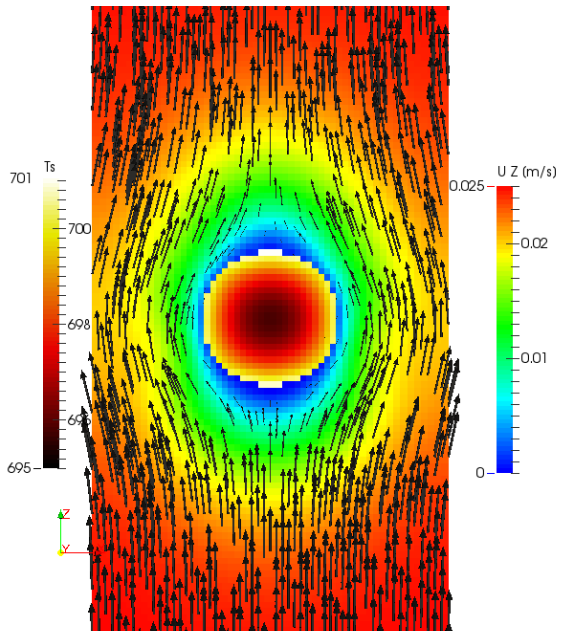
Summary

- ❑ Simulation of plastic pyrolysis in fluidized bed
    - hydrodynamics, heat transfer, slow chemistry
- ❑ Influence of operating conditions
- ❑ Heat transfer vs. pyrolysis reaction
- ❑ Faster conversion due to enhanced heating

Outlook

- ❑ Detailed kinetics, mixed plastics, up-scaling, melting, continuous feeding, thermally thick/non-ideal particles

Particle-resolved simulation



Up-scaling

5 cm 10 cm

Thank you!

Heat Transfer – Validation

- Good agreement between 2D/3D setups and simulations using different no. of LPs

Lagrange parcels	0.47 mil.	0.94 mil.
h_B [cm]	42.5	43.0
Δp [mbar]	38.3	38.3
$\bar{k}_S$ [mJ/kg]	85.6	89.2
$\bar{\alpha}$ [W/m²/K]	234	235
Comput. time. [h]	0.33	0.62

Gas phase	2D	3D
h_B [cm]	42.5	39.2
Δp [mbar]	38.3	36.0
$\bar{k}_S$ [mJ/kg]	85.6	89.2
$\bar{\alpha}$ [W/m²/K]	234	235
Comput. time. [h]	0.33	3.22