Modeling the impact of bubbling bed hydrodynamics on the yield oscillations of biomass fast pyrolysis tar

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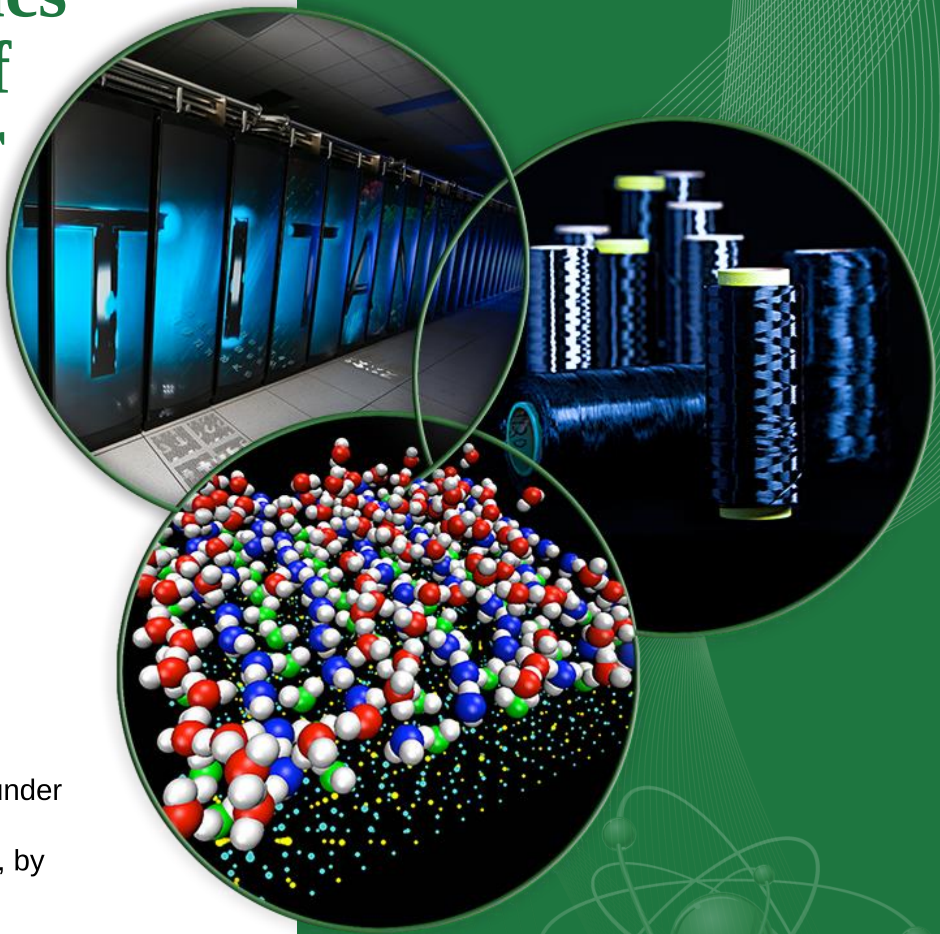

Presented at the 2015 NETL Workshop on Multiphase Flow Science, Morgantown, West Virginia, August 12, 2015

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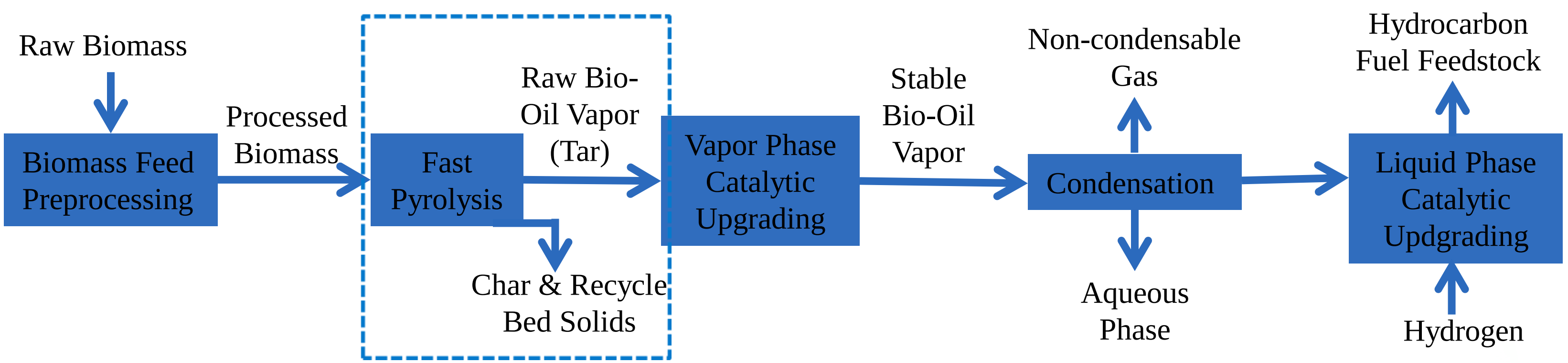
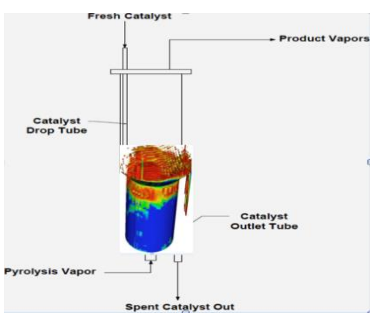
Background and motivation

One of the leading candidate thermochemical technologies for biomass based fuels is fast pyrolysis with catalytic upgrading



Focus of this talk



Performance of upgrading reactor
highly depends on tar yield and its oscillation
(refer to Jack Ziegler's presentation)

Important to study
temporal yield oscillation of tar

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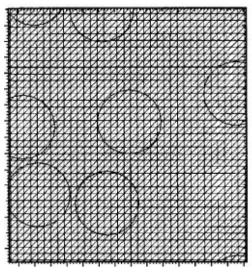
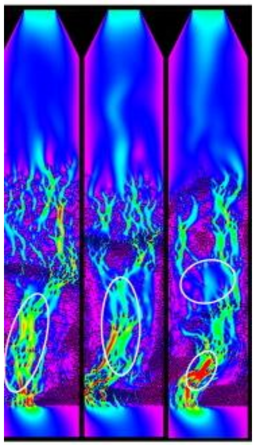
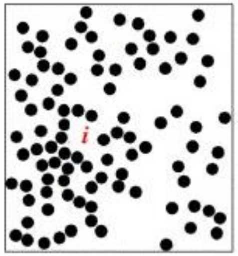
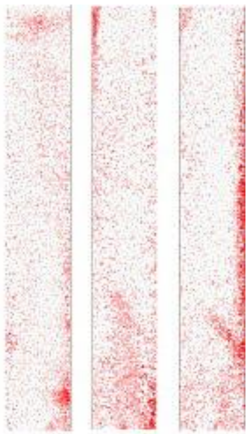
Objective: Estimate the transient properties of the exit vapor stream going to catalytic VPU

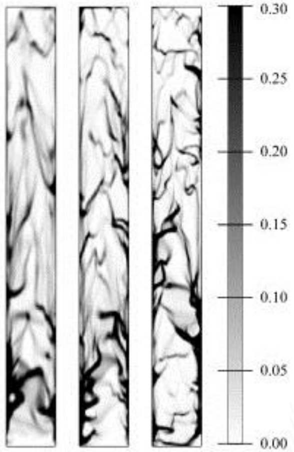
The multi-fluid computational approach can achieve this objective with reduced computational demand











Implemented in MFIX

Direct numerical simulation:
most accurate but
most computationally intensive

Discrete particle modeling:
less accurate but still
computationally intensive

Multi-fluid model:
computationally economic

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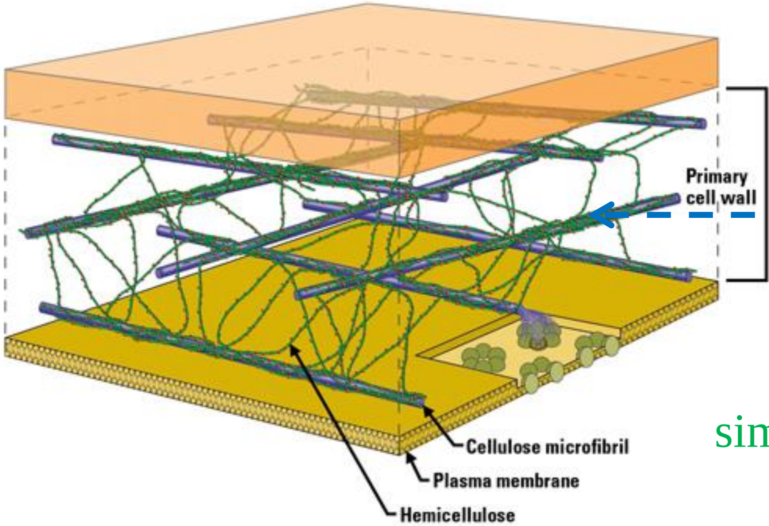
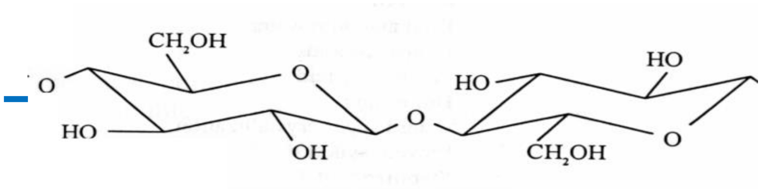
Approach: Include reaction kinetics along with heat transfer and fluid dynamics

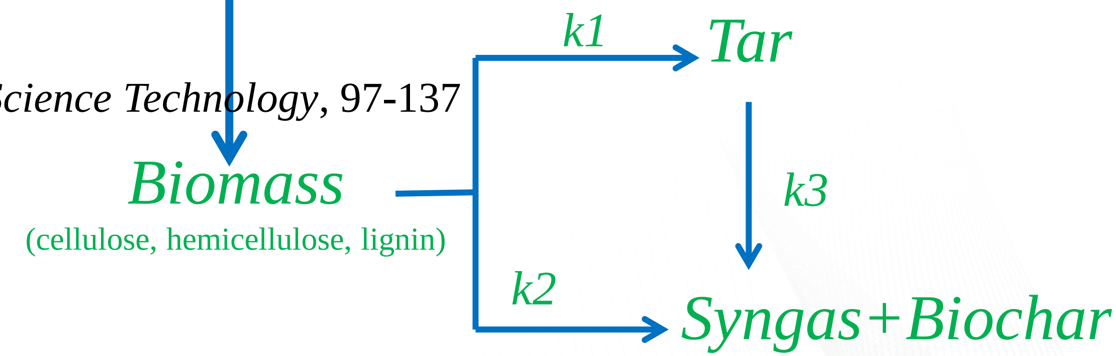
Challenge: Biomass pyrolysis kinetics are extremely complex due to the chemical composition and physical microstructure of biomass



Miller and Bellan, 1997, *Combustion Science Technology*, 97-137



simplified kinetics



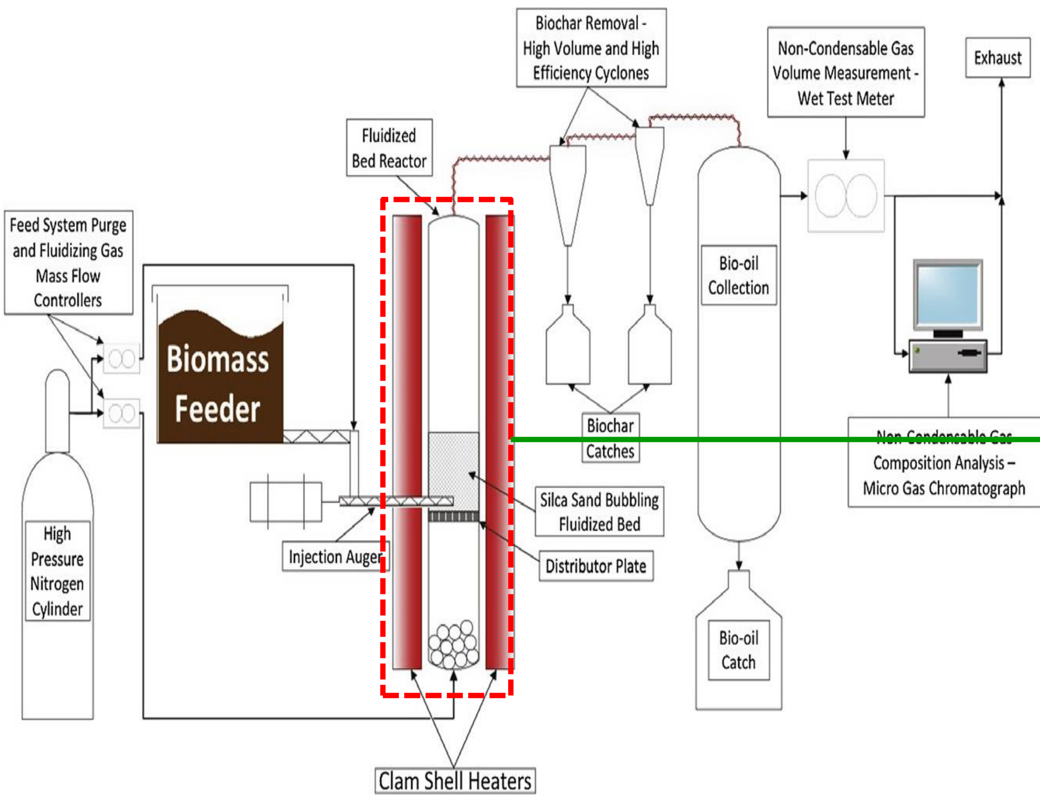
First-order irreversible Arrhenius rate

$$\frac{dm_i}{dt} = -mk_i$$

$$k_i = A_i \exp(-E_i / RT)$$

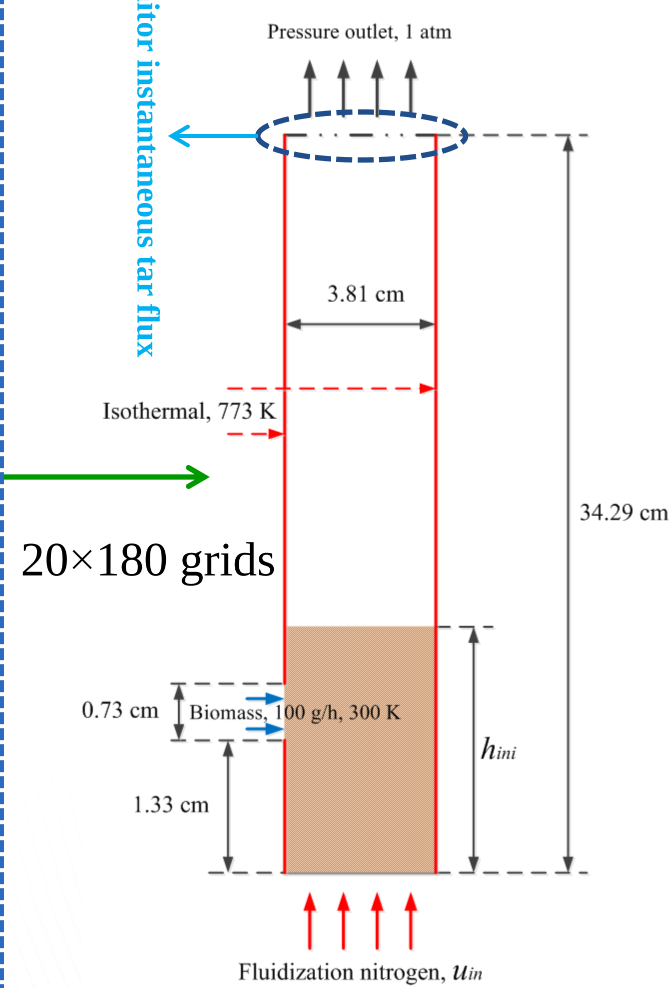
Initial test case: Experimental lab-scale bubbling bed pyrolysis reactor at Iowa State University

Experimental



A laboratory-scale bubbling bed at Iowa State University
Xue, et al., 2012, *Fuel*, 957-969

Numerical(2D)



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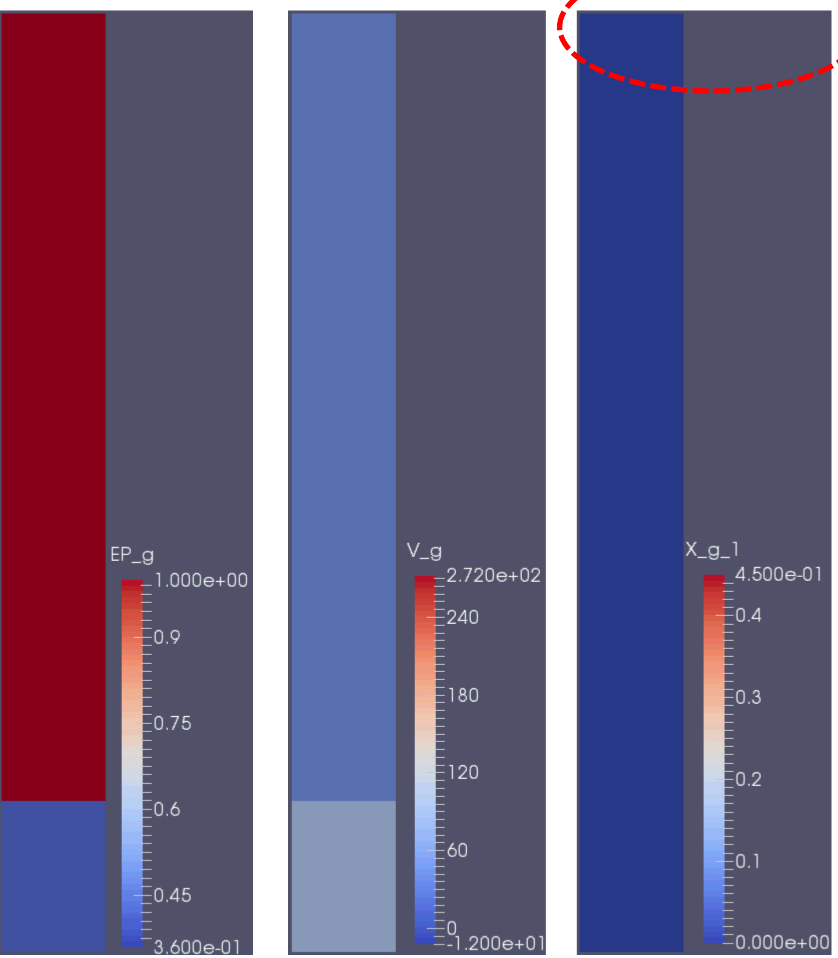
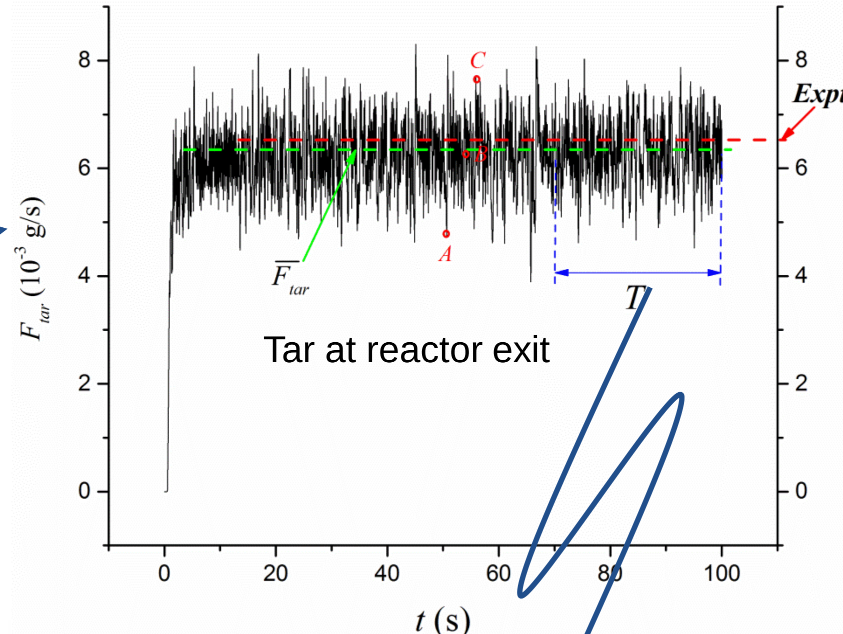
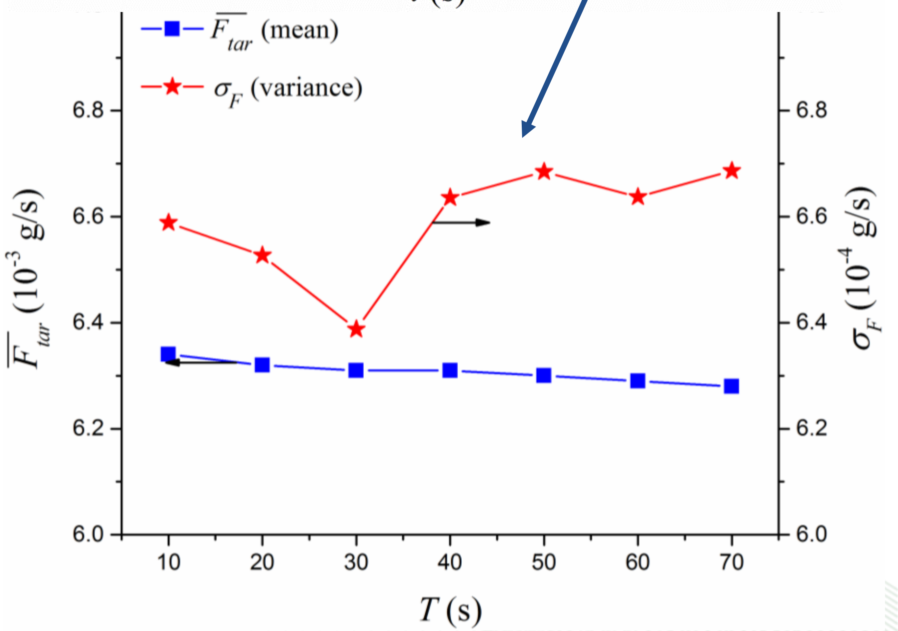
Results (1): Large temporal variations predicted in bio-oil (tar) concentration throughout the reactor

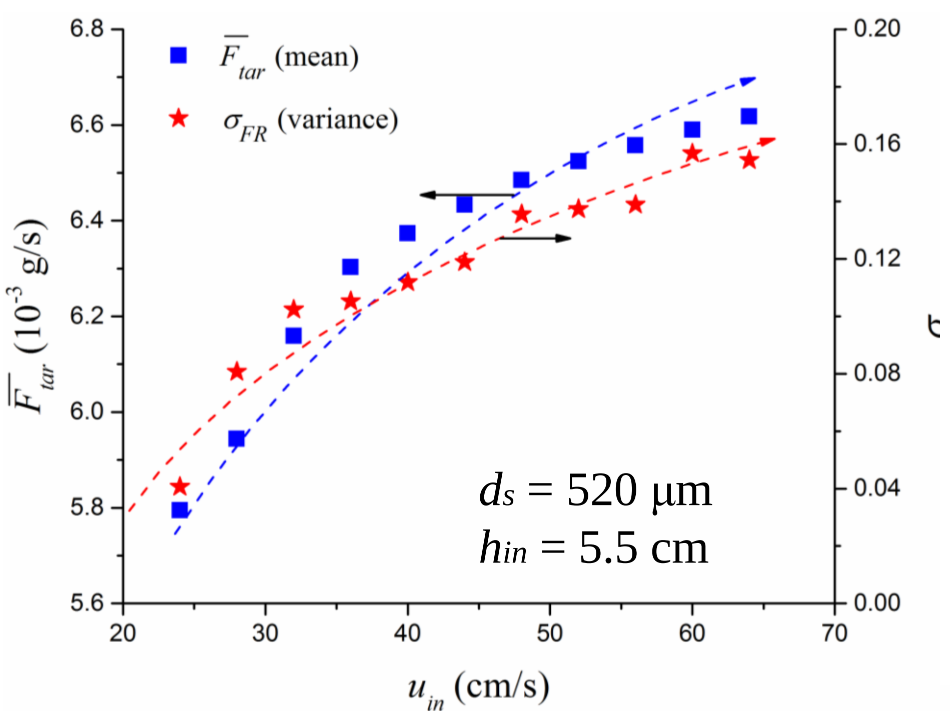


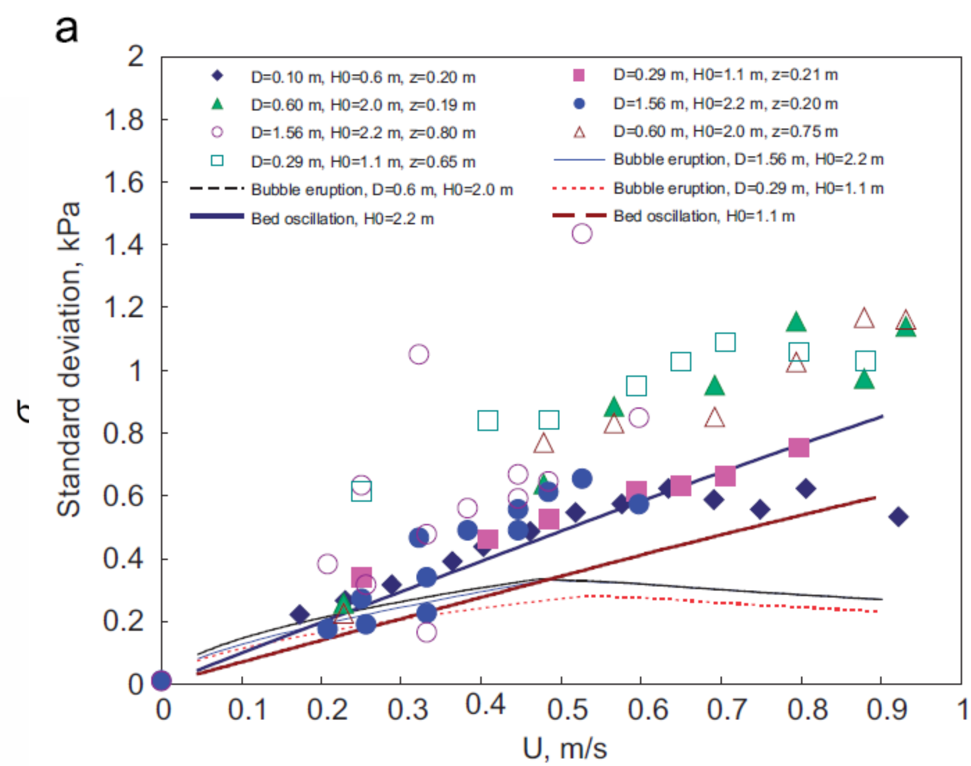
Voidage Gas velocity Tar fraction





Results (2): Exit tar fluctuations appear to increase by a power law with inlet gas flow





Standard deviation of pressure fluctuation increases as u_{in}, Bi, 2007, Chemical Engineering Science, 3473-3493

$$\sigma_{FR} = a(u_{in} - u_{mf})^{0.4} + b(u_{in} - u_{mf})$$

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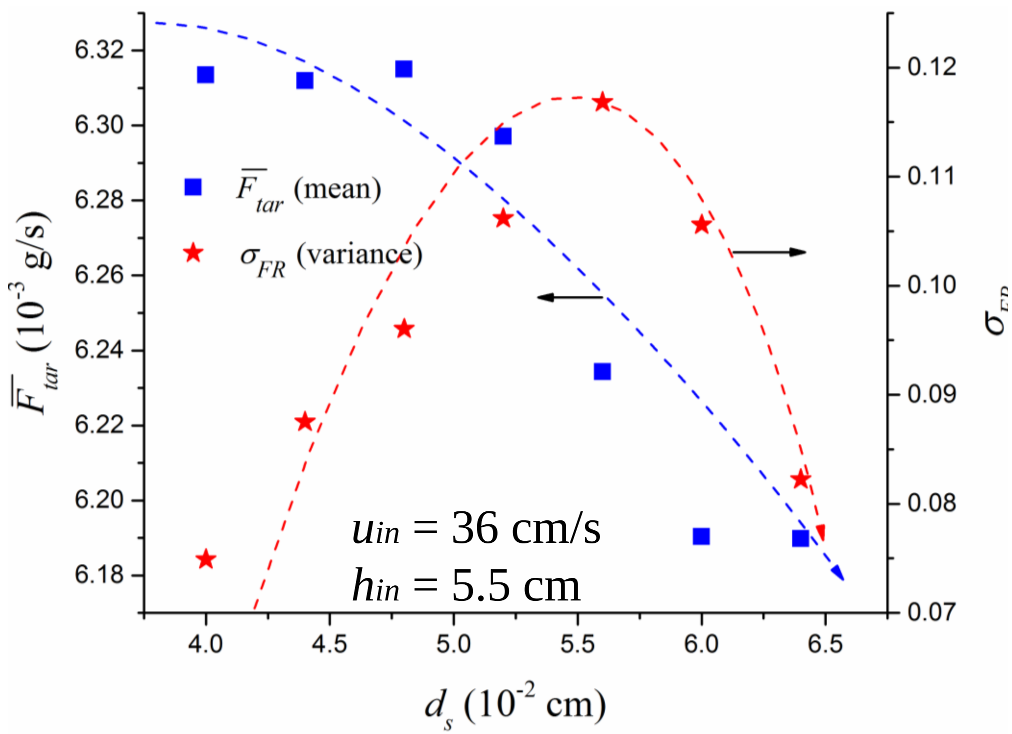
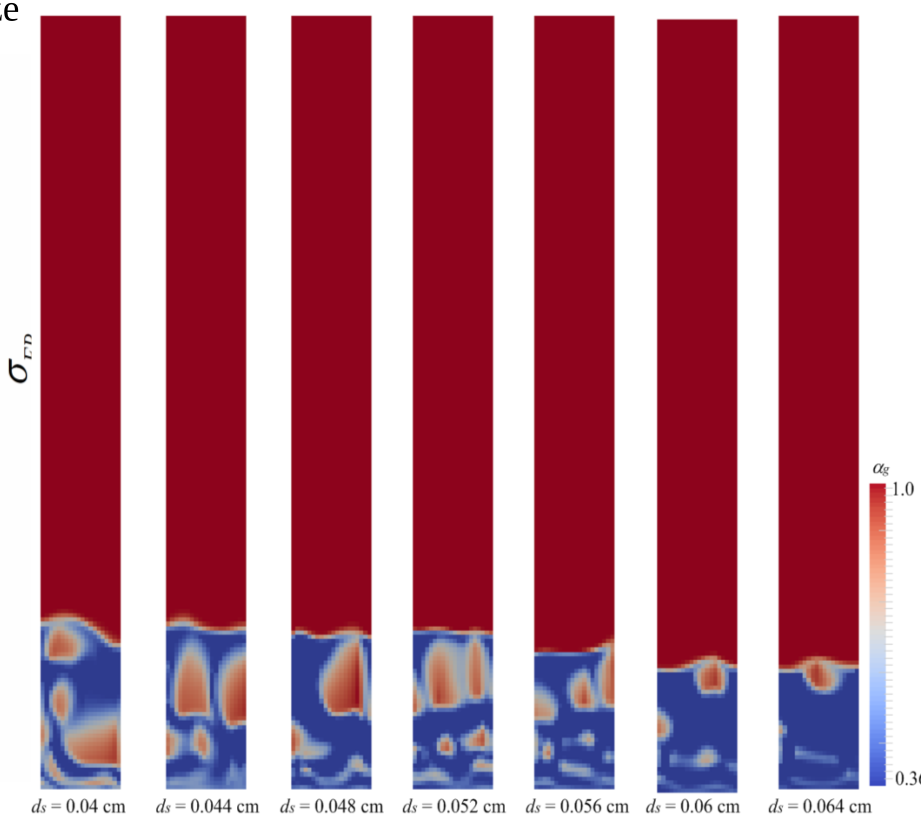
Results (3): Exit tar fluctuations follow a different trend with bed particle size

- Mean exit tar level drops with bed particle size
- But exit tar variations peak at an intermediate particle size





Qualitative observations:

- ❖ Smaller bed particles leads to greater bed expansion
- ❖ Amplitude of oscillation may be correlated with onset of slugging
- ❖ Freely bubbling state seems to correlate with smaller oscillations

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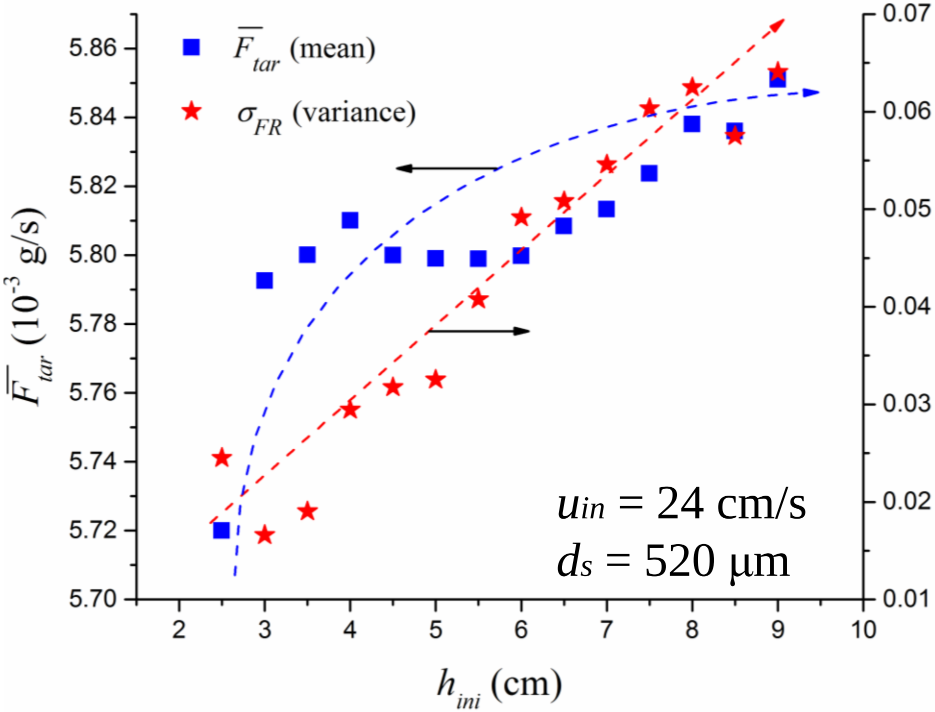
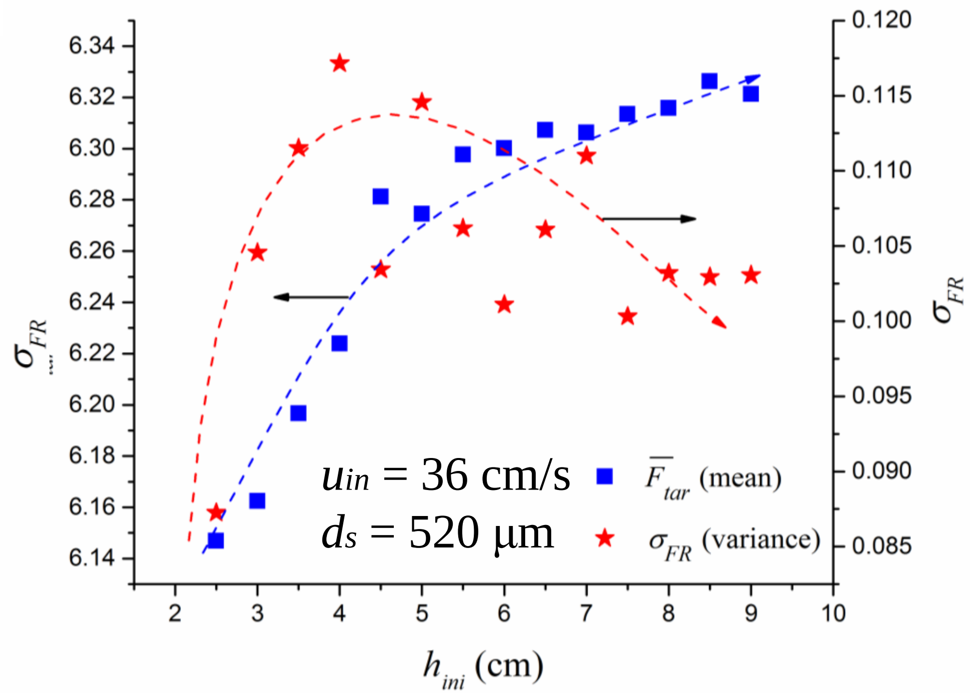
Results (4): Exit tar levels also vary with static bed height

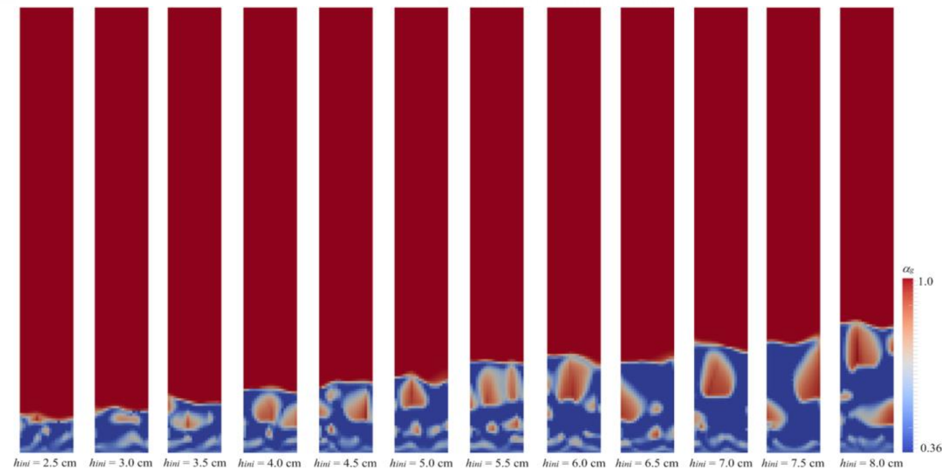
- Mean exit tar level appears to reach a plateau
- But exit tar variations continue to rise





Other Observations:

- ❖ Increased height correlates with bigger oscillations
- ❖ Transition to slugging seems to be a factor in the oscillations amplitudes and scatter



Conclusions and future plans

- **2D multi-fluid simulations appear to capture the dynamic trends in the exit vapor from fluidized-bed biomass fast pyrolysis with acceptable computational demand**
- **Bed hydrodynamics have a huge influence on the temporal oscillations in the raw bio-oil vapor; thus pyrolyzer design and operation can significantly affect the downstream VPU reactor**
- **Hydrodynamic transitions related to slugging need to be thoroughly understood (more studies on slugging can be found in our poster)**
- **Additional simulation studies are needed to resolve the controlling factors**
- **The base of experiments used to validate the simulations needs to be expanded (especially for larger beds)**

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THANK YOU FOR YOUR ATTENTION