Benchmarking a Novel 0-D Model Against Data from Two-Fluid Model Simulations of a Wet Fluidized Bed

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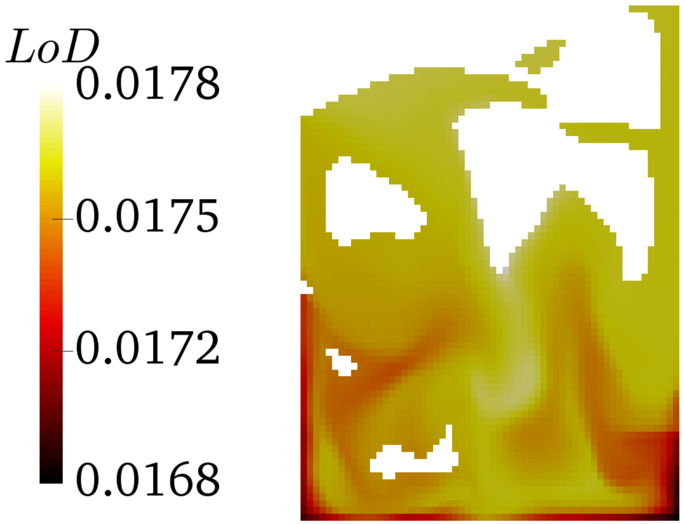

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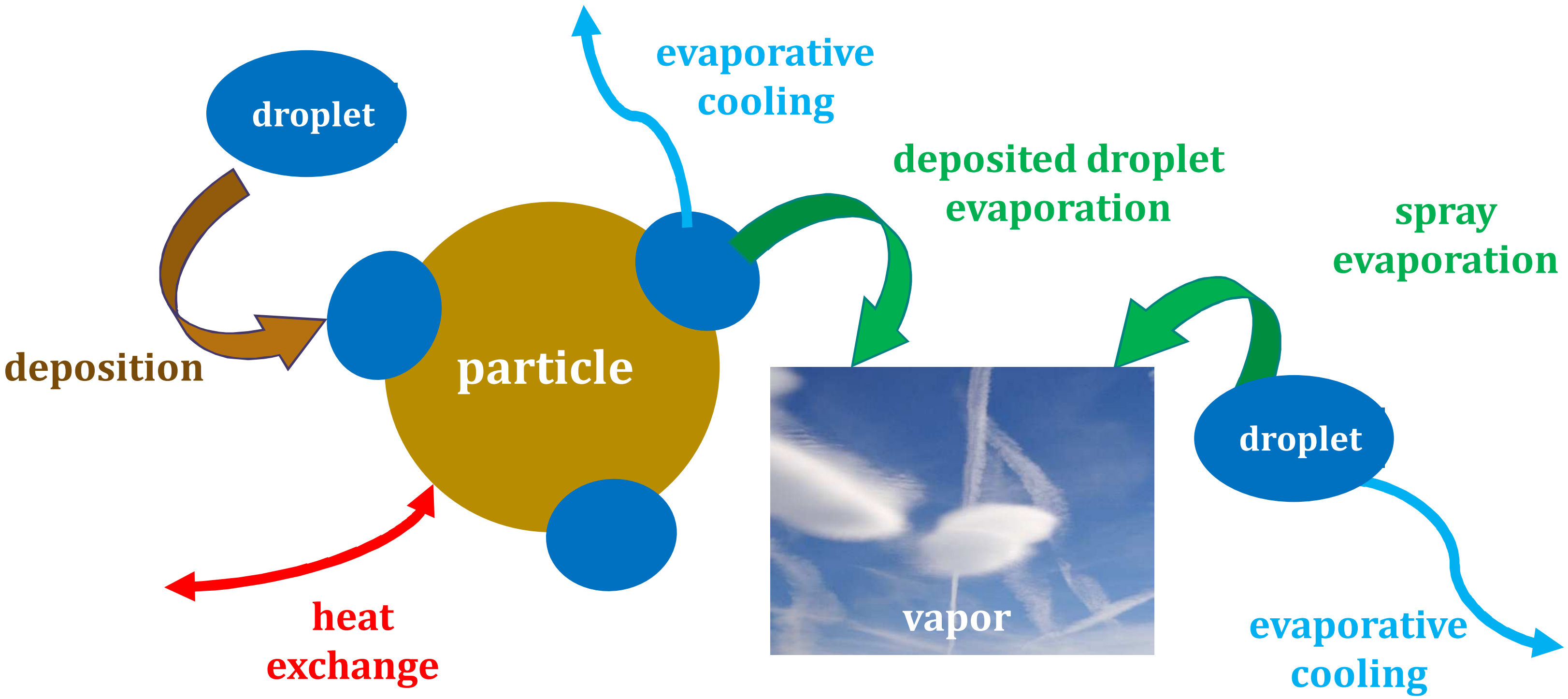
Phenomena governing wet fluidized beds (WFBs)



https://www.glatt.com

Askarishahi et al. (2017), AIChE Journal, 63:2569-2587
Askarishahi (2018). PhD thesis, TU Graz.
https://github.com/CFDEMproject

Motivation

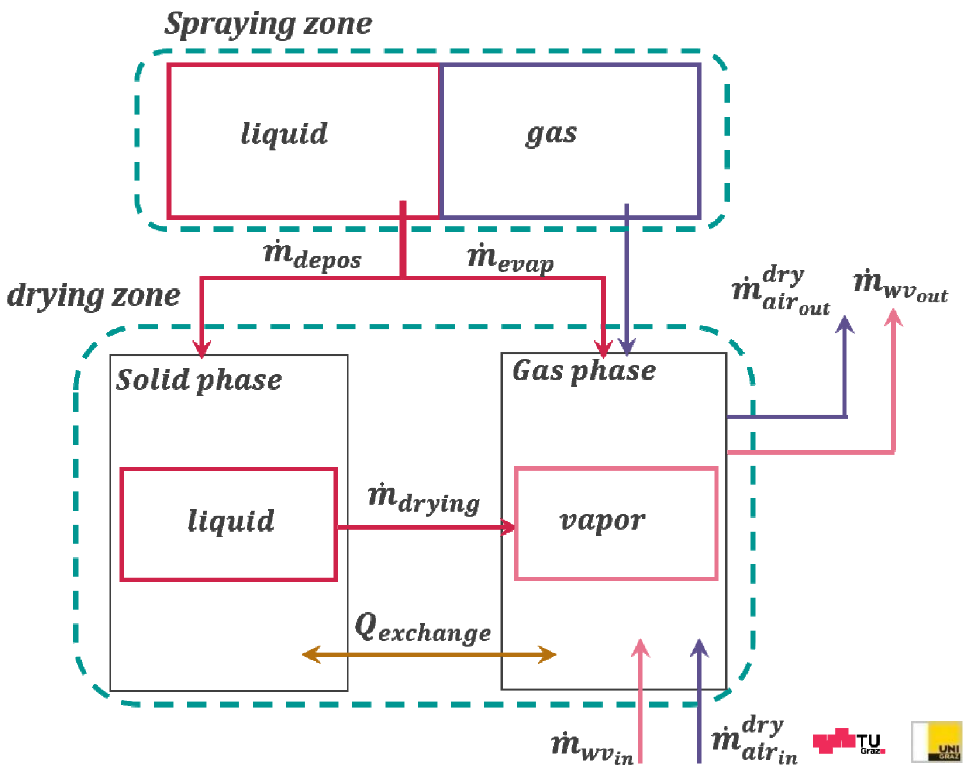
developing a toolset (CFD-DEM/TFM/0D) to predict WFB performance

Euler-Euler-Euler Approach
Two-Fluid Model (CFD-TFM)

→ **Compartment (0D) model**

Multiphase Flow with Interphase eXchanges

https://mfix.netl.doe.gov



Model implementation
mass balance for **water (liquid)**

+ standard models for continuity, momentum & heat, KTGF + *μ-I* rheology, Schneiderbauer stress BCs

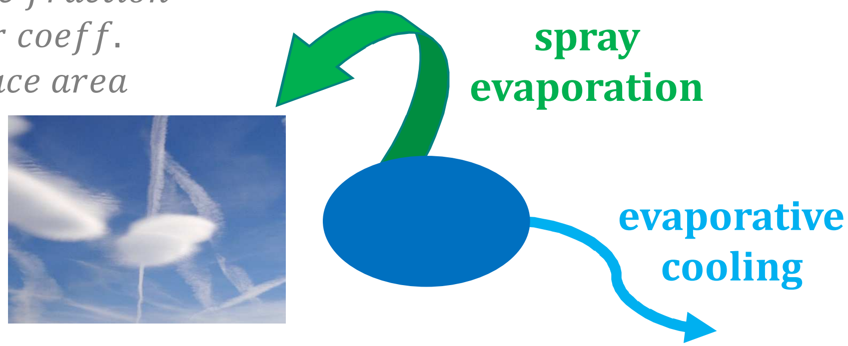
$$\frac{\partial}{\partial t}(\varepsilon_g \rho_g x_{wl}) + \nabla \cdot (\varepsilon_g \rho_g x_{wl} \boldsymbol{u_g}) = \nabla \cdot (D_{gn} \nabla \varepsilon_g \rho_g x_{wl}) + \dot{S}_{spray} - \dot{S}_{evap} - \dot{S}_{depos}$$

Accumulation — Convection — Dispersion — Source — Sinks

Droplet evaporation

$$\dot{S}_{evap} = (\rho_{w,sat} - \rho_f \mu_{wv}) a_d \beta_d \varepsilon_d$$

μ_{wv}: vapor mass loading
$\rho_{w,sat}$: saturation density
ε_d: droplet volume fraction
β_d: mass transfer coeff.
a_d: sepcific surface area

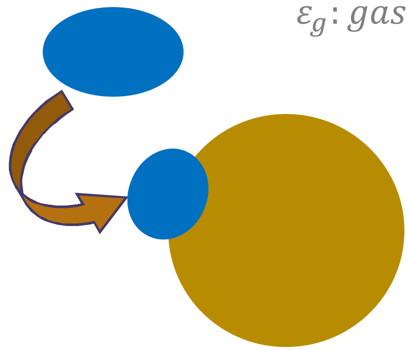


Droplet deposition

$$\dot{s}_{depos} = -\boldsymbol{\lambda} |\boldsymbol{u}_d - \boldsymbol{u}_p| \mu_{wl} \varepsilon_g \rho_g$$

$\boldsymbol{\lambda}$: Filtration coefficient after **Kolakaluri's Model**

μ_{wl}: liquid mass loading
ε_g: gas volume fraction



Kolakaluri, R. (2013). PhD dissertation, Iowa State University

Model implementation
mass balance for **water vapor**

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g x_{wv}\right) + \nabla \cdot \left(\varepsilon_g \rho_g x_{wv} \boldsymbol{u_g}\right) = \nabla \cdot \left(D_{gn} \nabla \varepsilon_g \rho_g x_{wv}\right) + \dot{S}_{dry} + \dot{S}_{evap}$$

Accumulation — Convection — Diffusion/Dispersion — Sources

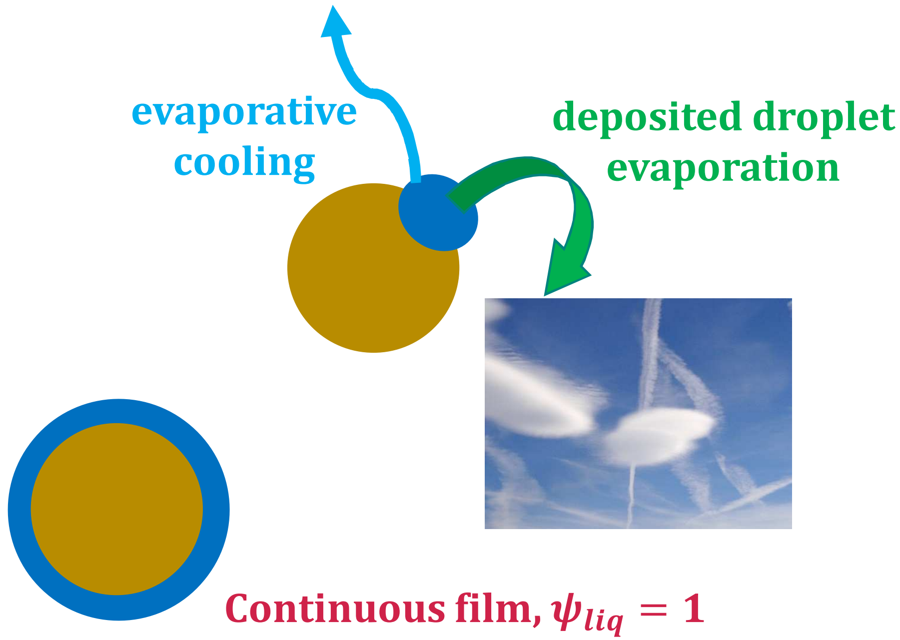
Particle drying

$$\dot{S}_{dry} = \left(\rho_{w,sat} - \rho_g \mu_{wv}\right) a_p \boldsymbol{\psi_{liq}} \beta_p \varepsilon_s$$

$\boldsymbol{\psi_{liq}}$: *Particle surface coverage after* **Kariuki's Model**

$$\psi_{liq} = 1 - [1 - f]^{\Phi_p / f}$$

μ_{wv}: *vapor mass loading*
$\rho_{w,sat}$: *saturation density*
φ_d: *droplet volume fraction*
β_p : *mass transfer coeff.*
a_p: *sepcific surface area*
f : *droplet foot print area*
Φ_p: *coating number*



Kariuki et al, *Chemical Engineering Science.* 2013;92:134-145.

CFD-TFM

fluidized bed
performance assessment

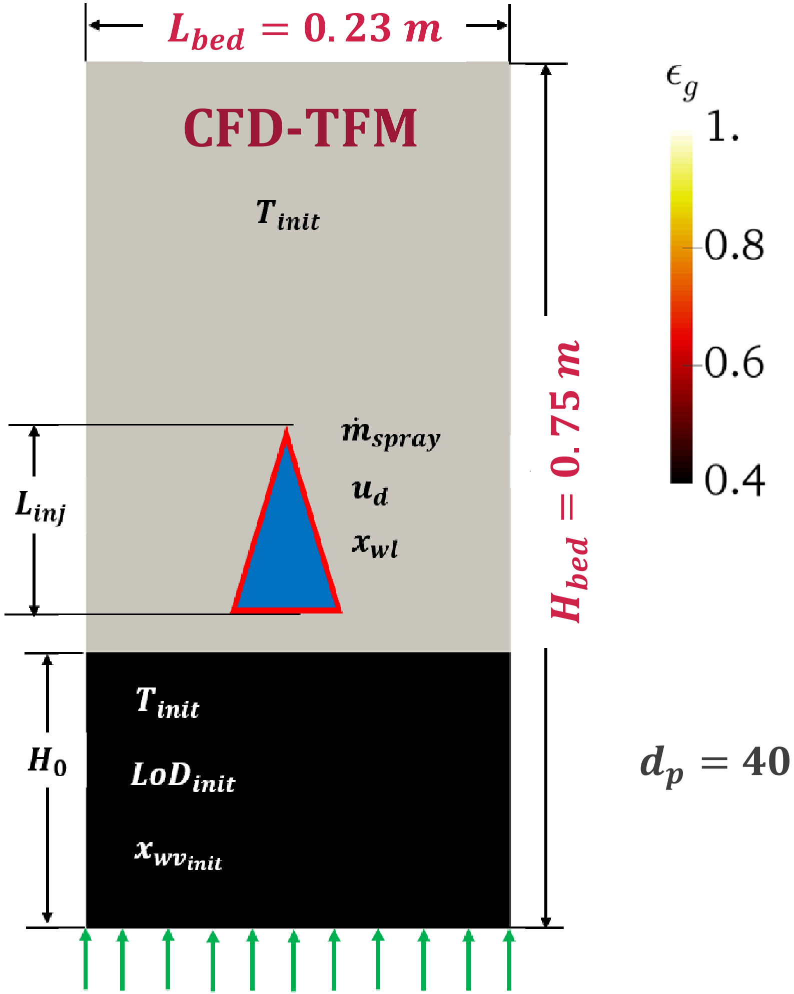
CFD-TFM simulation
Setup and operating parameters

https://www.glatt.com

Conical spray zone

$d_d = 20 \mu m$

$u_d = 7\ m/s$

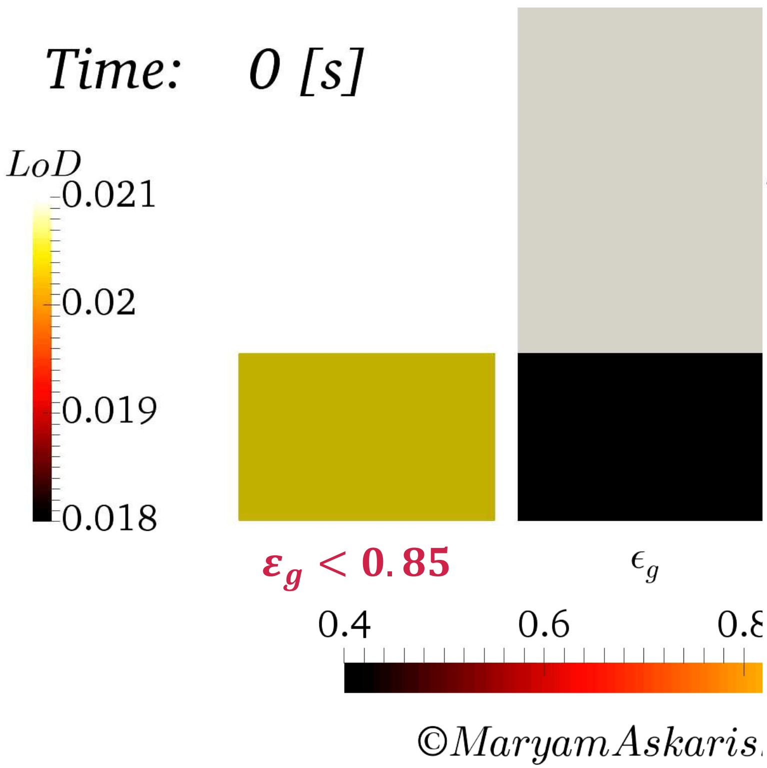


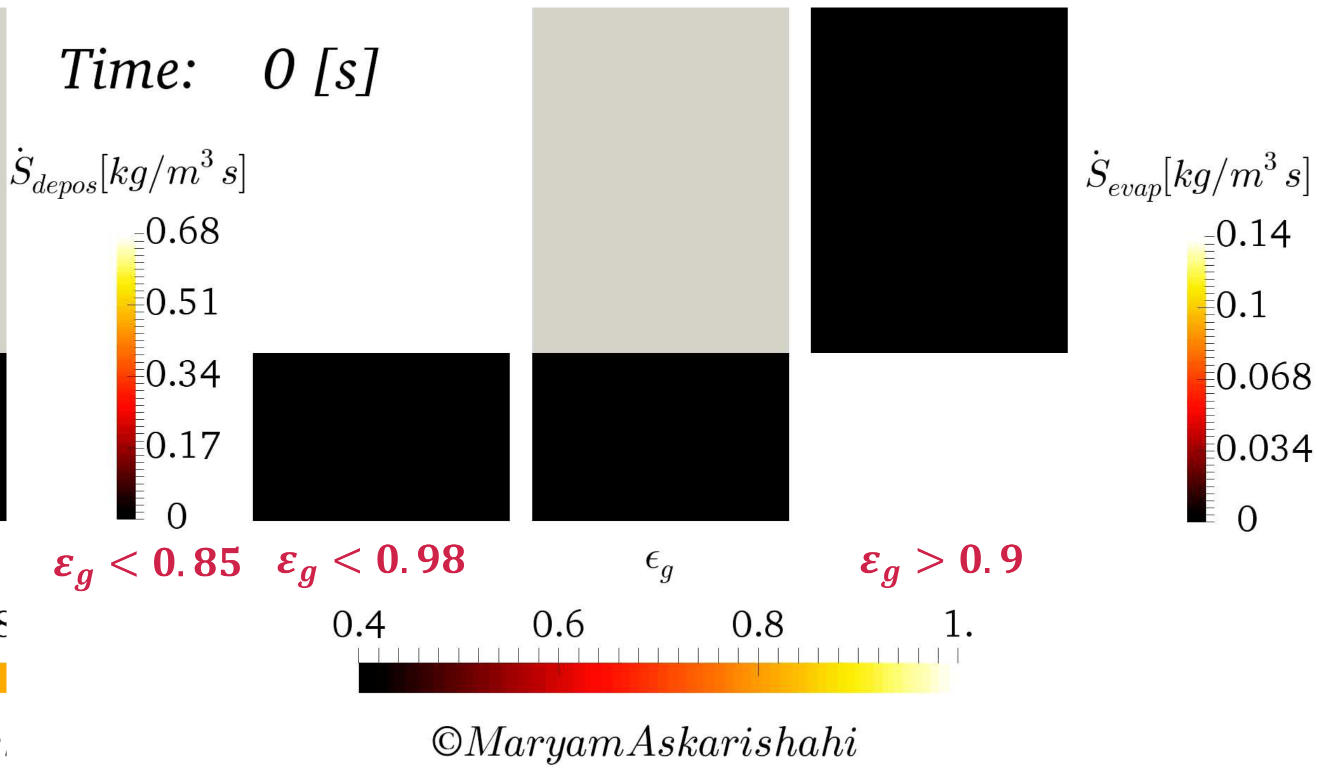
$d_p = 400\ \mu m$

$T_g = 333\ K$

$u_g = 0.5\ m/s$

Qualitative performance of WFB





$\varepsilon_g < 0.85$ $\varepsilon_g < 0.85$ $\varepsilon_g < 0.98$ $\varepsilon_g > 0.9$

CFD-TFM

the degree
of uniformity

Uniformity of bed
How to assess?

Is it possible to represent the bed ***performance*** with the ***single values***?

Temperature* | *LoD* | *vapor content

How uniform is the distribution in the bed?

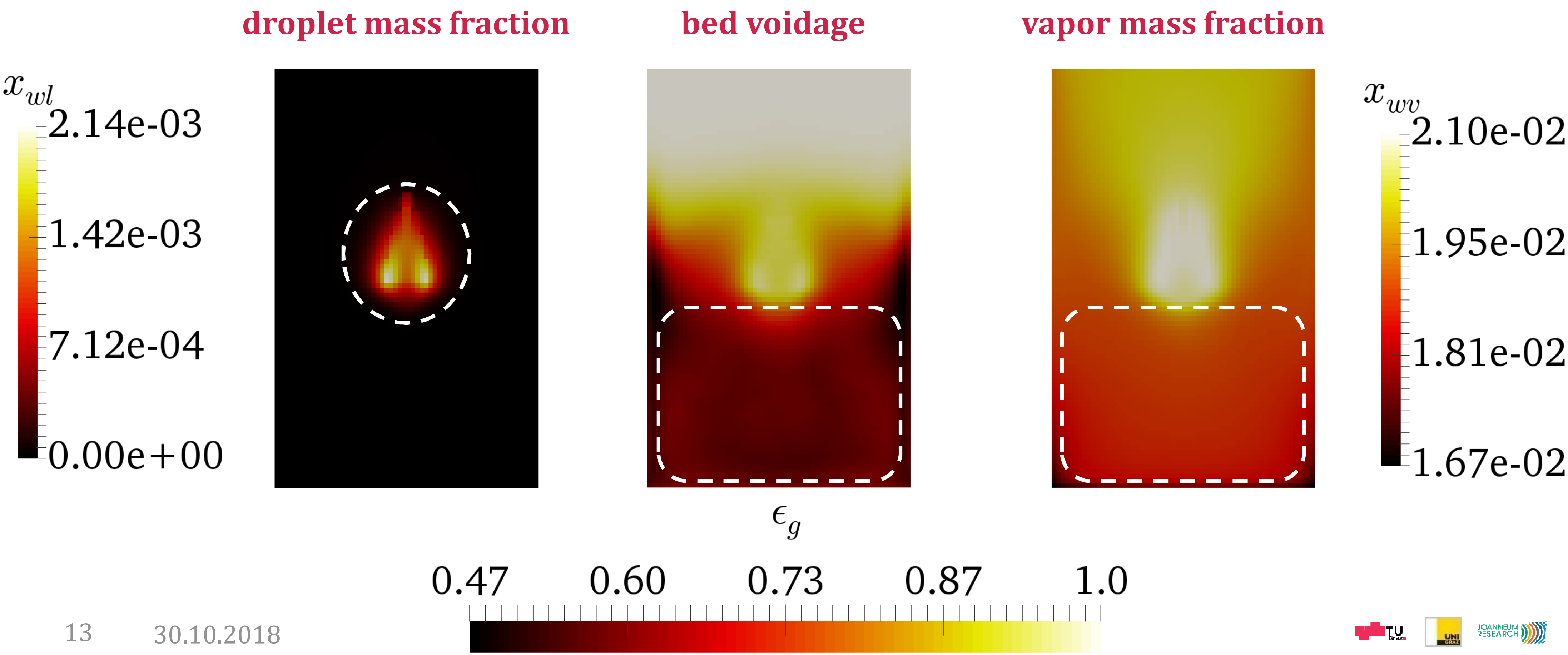
Qualitative

The time-averaged ***contour-plots*** for the ***exchange rates*** and the ***flow properties***

Quantitative

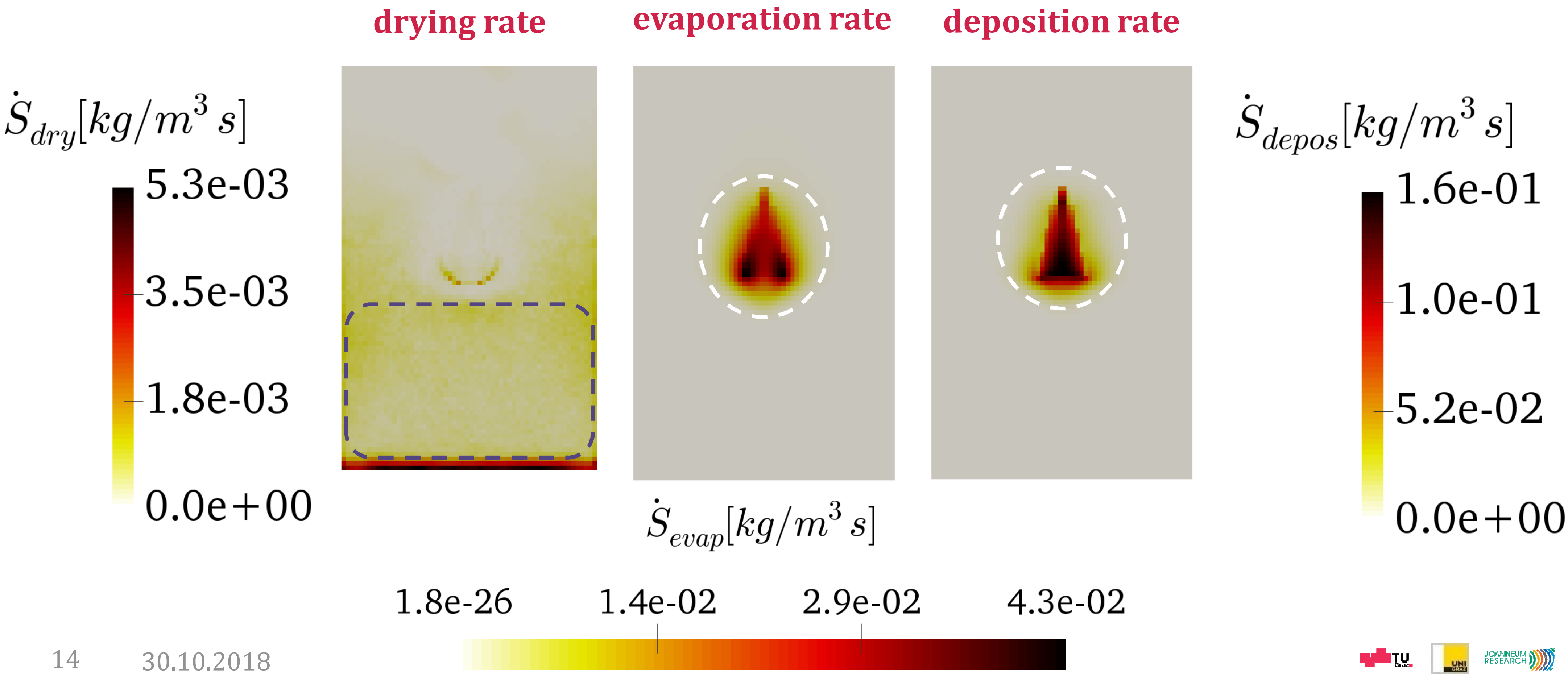
The ***uniformity degree*** through LoD and temperature ***standard deviation***

Uniformity degree: **Qualitative** examination
Time-averaged flow property distribution



Uniformity degree: **Qualitative** examination

Time-averaged exchange rate distribution

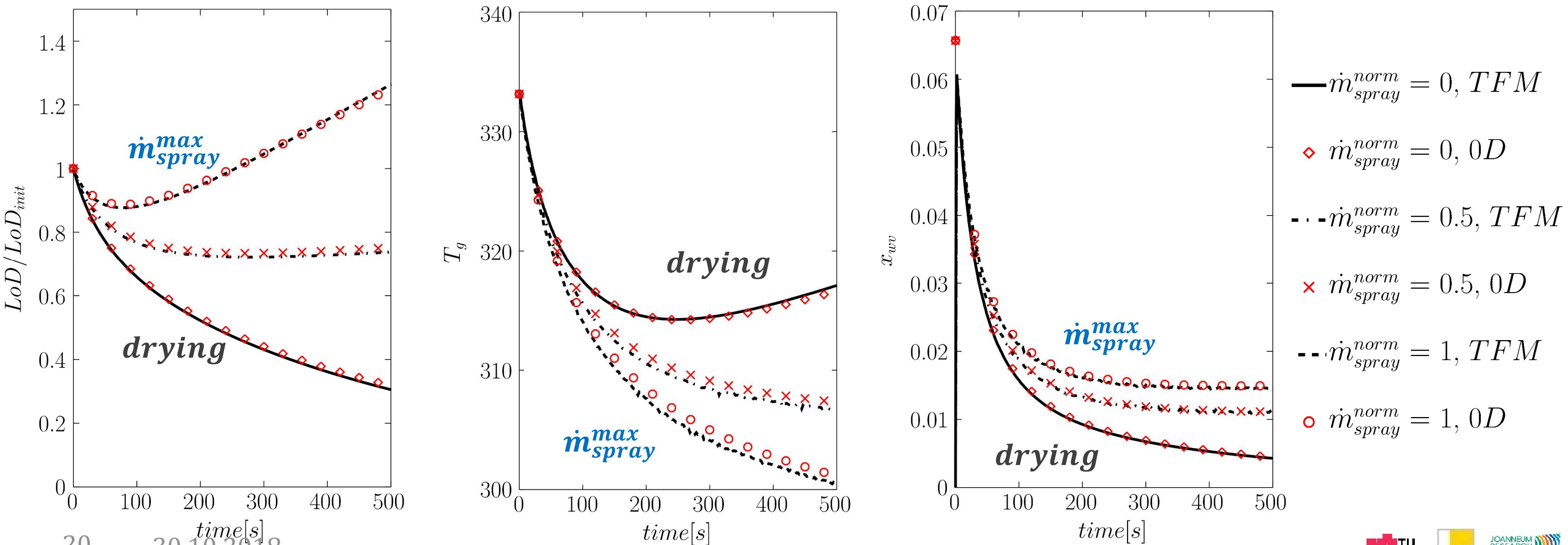


CFD-TFM versus 0D model

0D model validity against TFM approach effect of spray rate

$\dot{m}_{spray}^{norm}$ is defined as the ratio of spray rate to the maximum spray rate ($RH_{out} = 100\%$)

particle LoD **gas temperature** **gas vapor content**



0D model validity against TFM approach
effect of spray rate

—— $H_0/L_{bed} = 0.65,\ TFM$

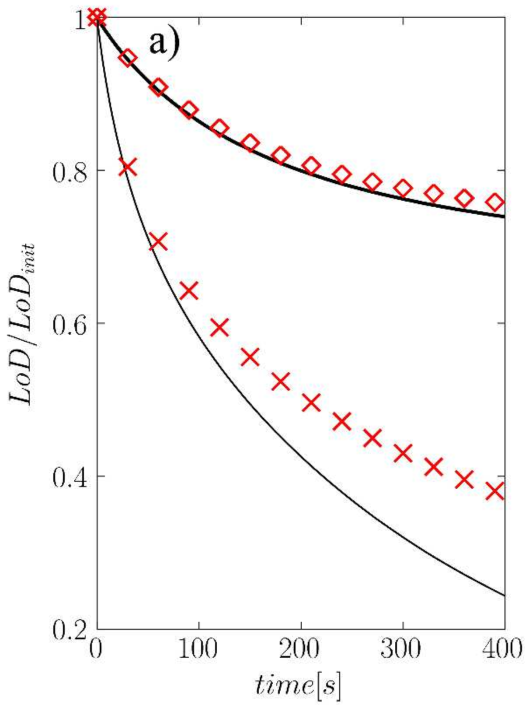
◇ $H_0/L_{bed} = 0.65,\ 0D$

— $H_0/L_{bed} = 0.15,\ TFM$

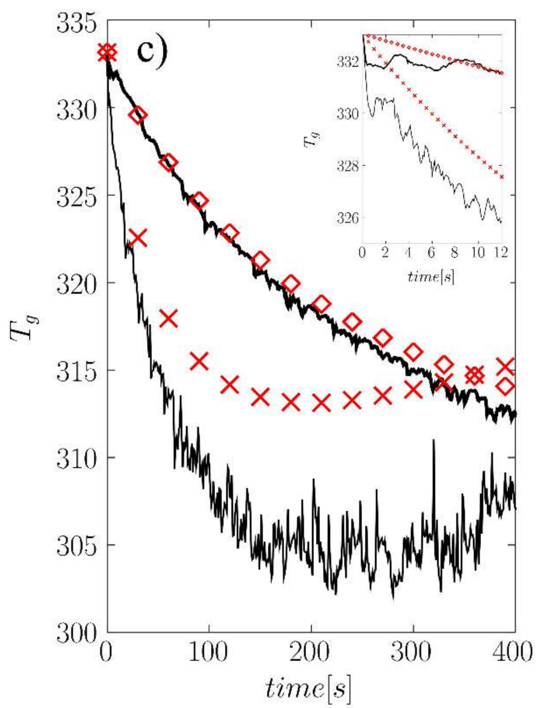
× $H_0/L_{bed} = 0.15,\ 0D$

Effect of bed aspect ratio

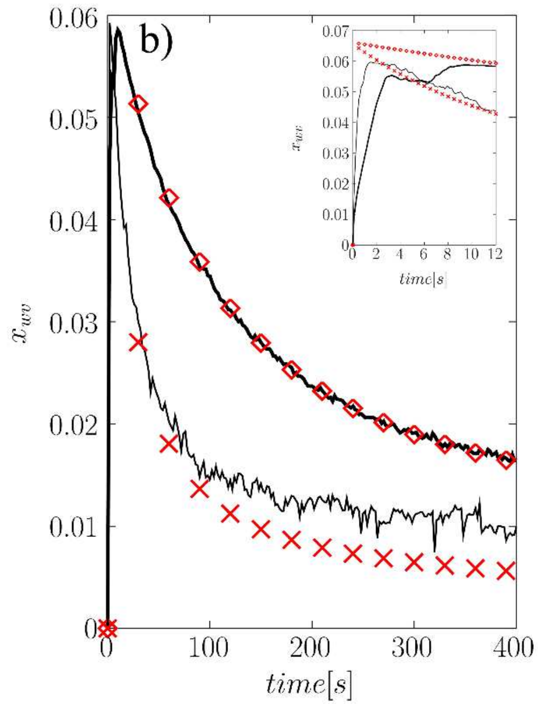
particle LoD



gas temperature



gas vapor content



Conclusions and outlooks

Development of a ***0D model*** based on the results of ***TFM simulation***

Formation of two ***phenomenon-specific zones***

Quantification of ***"well-mixed-ness"*** via the ***degree of uniformity*** for LoD and temperature

demonstration of the 0D model validity on fulfilling the criteria for ***"well-mixed" condition***

Validation and integration of ***cohesion*** comes next

Thank you for your attention!

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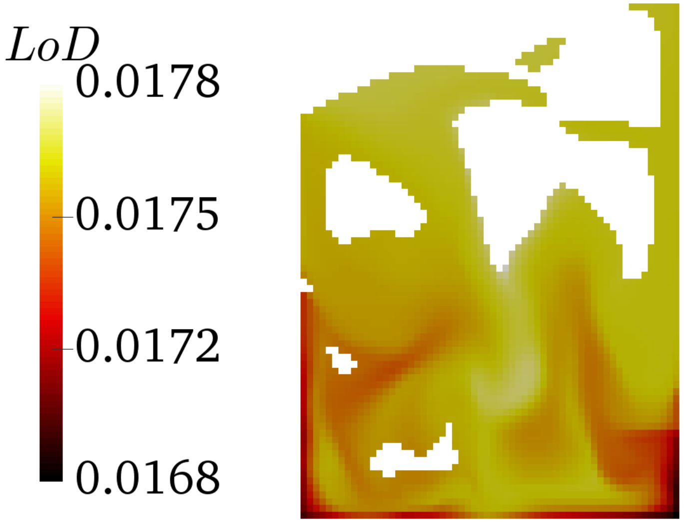

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