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# Simulation of fuel particles motion in a 2D fluidized bed using a hybrid-model considering wall friction

L.M. Garcia-Gutierrez
*University Carlos III of Madrid; Department of Thermal and Fluid Engineering Av. de la Universidad, 30, 28911 Leganés, Madrid, Spain*, lmgarcia@ing.uc3m.es

F. Hernández-Jiménez
*University Carlos III of Madrid; Department of Thermal and Fluid Engineering,Av. de la Universidad, 30, 28911 Leganés, Madrid, Spain*

A. Soria-Verdugo
*University Carlos III of Madrid; Department of Thermal and Fluid Engineering,Av. de la Universidad, 30, 28911 Leganés, Madrid, Spain*

A. Acosta-Iborra
*University Carlos III of Madrid; Department of Thermal and Fluid Engineering,Av. de la Universidad, 30, 28911 Leganés, Madrid, Spain*

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ISE RESEARCH GROUP
CARLOS III UNIVERSITY
(MADRID, SPAIN)

Energy Systems Engineering
Research group

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2. Numerical model
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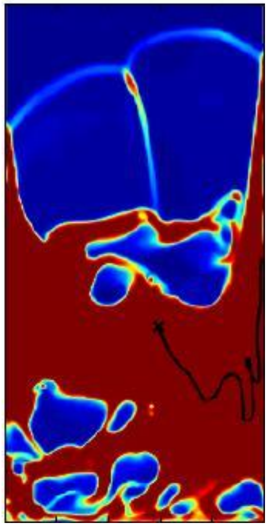
# *Motivation*

- The motion of fuel particles is a key issue on the performance of fluidized bed reactors.



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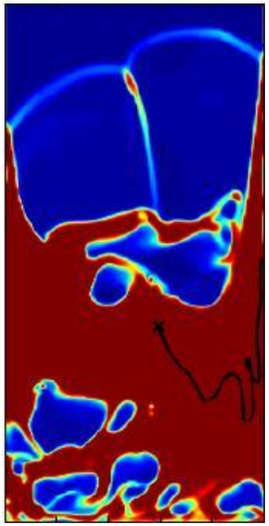
- The motion of fuel particles is a key issue on the performance of fluidized bed reactors.

- The rising and sinking velocity and the residence time of the fuel particle in the bed are relevant parameters in fluidized bed reactor operation.



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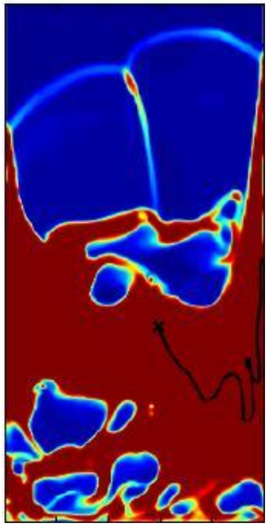

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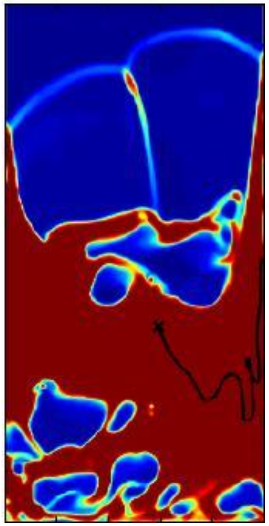
- The motion of a non-reactive fuel particle in a pseudo-2D bubbling fluidized bed at ambient conditions is simulated employing a hybrid-model.
- The accuracy of the 2D simulation is improved by introducing a friction term that accounts the effect of the front and back walls of the bed.



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- The motion of fuel particles is a key issue on the performance of fluidized bed reactors.
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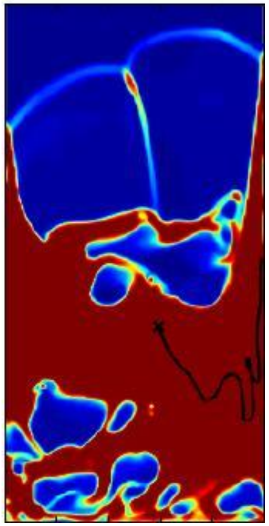
- The accuracy of the 2D simulation is improved by introducing a friction term that accounts the effect of the front and back walls of the bed.
- The simulations will be compared with experimental results obtained from the literature.



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# Hybrid-model

- The hybrid-model (TFM-DEM) implemented in the code MFIX was employed:
  - Dense and gas phases: Two-Fluid Model (TFM).
  - Fuel particles: Discrete Element Method (DEM).
- The continuum phases with the fuel particles behavior is fully coupled (TFM-DEM) [1].

Momentum conservation equations for gas and solid phases (TFM):

$$\frac{\partial}{\partial t}(\alpha_g \rho_g \vec{v_g}) + \nabla \cdot (\alpha_g \rho_g \vec{v_g} \vec{v_g}) = -\alpha_g \nabla p + \nabla \cdot \overline{\overline{\tau_g}} + \alpha_g \rho_g \vec{g} + K_{gs}(\vec{v_s} - \vec{v_g}) + \boldsymbol{K_{pg}(\vec{v_p} - \vec{v_g})}$$

$$\frac{\partial}{\partial t}(\alpha_s \rho_s \vec{v_s}) + \nabla \cdot (\alpha_s \rho_s \vec{v_s} \vec{v_s}) = -\alpha_s \nabla p - \nabla p_s + \nabla \cdot \overline{\overline{\tau_s}} + \alpha_s \rho_s \vec{g} + K_{gs}(\vec{v_g} - \vec{v_s}) + \boldsymbol{K_{ps}(\vec{v_p} - \vec{v_s})}$$

where the terms $\boldsymbol{K_{pg}(\vec{v_p} - \vec{v_g})}$ and $\boldsymbol{K_{ps}(\vec{v_p} - \vec{v_s})}$ describe the interaction between the fuel particle and the gas and solid phases.

[1] Hernández-Jiménez et al. 2015. Fully coupled TFM-DEM simulations to study the motion of fuel particles in a fluidized bed. *Chem. Eng. Sci.* 134, 57-66..

# *Friction term*

- New friction term obtained experimentally [2] is introduced in the hybrid-model on the continuum solid phase accounting for the effect of the front and back walls of the bed [3].

**Momentum conservation equation for the solid phase (TFM) in 2D:**

$$\frac{\partial}{\partial t}(\alpha_s \rho_s \vec{v_s}) + \nabla \cdot (\alpha_s \rho_s \vec{v_s} \vec{v_s})$$
$$= -\alpha_s \nabla p - \nabla p_s + \nabla \cdot \overline{\overline{\tau_s}} + \alpha_s \rho_s \vec{g} + K_{gs}(\vec{v_g} - \vec{v_s}) + K_{ps}(\vec{v_p} - \vec{v_s}) - \boxed{\vec{\boldsymbol{f}}_{\boldsymbol{fric}}}$$

$$\vec{f}_{fric} = \frac{\vec{F}_{fric,front} + \vec{F}_{fric,back}}{A_{loc} Z} = \frac{2cA_{loc}\vec{v_s}}{A_{loc}Z} = \frac{2c\vec{v_s}}{Z} \qquad c = 6.2\frac{d_s^2 \rho_s g^{1/2}}{Z^{3/2}} + 5.6 \cdot 10^{-2} \rho_s Z^{1/2} g^{1/2}$$

The wall friction term depends on the bed thickness, $Z$, gravity, $g$, particle diameter, $d_s$; particle density, $\rho_s$ and is proportional to the solid velocity, $v_s$.

[2] Hernández-Jiménez et al. 2013. Experimental quantification of the particle-wall frictional forces in pseudo-2D gas fluidised beds. *Chem. Eng. Sci.* 102, 257-267.
[3] Hernández-Jiménez et al. 2016. Development of an empirical wall-friction model for 2D simulations of pseudo-2D bubbling fluidized beds. *Adv. Powder Technol.* 27, 521-530.

# Simulation set-up

The simulations are carried out in a pseudo-2D bubbling fluidized bed:

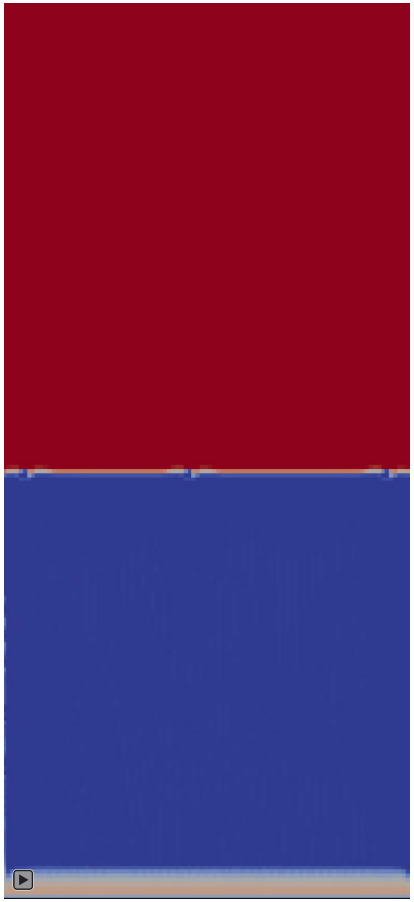
- **Three identical fuel particles** are simulated in order to obtain more representative statistical data.
- **Two simulations** are compared with experimental results (**EXP**) reported in [4]:
  - Without friction term (**SIM**).
  - With friction term (**SIM fric**).

| Bed material and gas characteristics | |
|---|---|
| Bed width, [m] | 0.5 |
| Bed thickness, [m] | 0.01 |
| Static bed height, $h_0$ [m] | 0.5 |
| Particles density, [kg/m$^3$] | 2500 |
| Particle diameter, [$\mu$m] | 700 |
| **Discrete fuel particles parameters** | |
| Density, [kg/m$^3$] | 1230 |
| Particle diameter, [cm] | 1.06 |
| **Operational conditions** | |
| Minimum fluidization velocity, $U_{mf}$ [m/s] | 0.32 |
| Dimensionless gas velocity, $U/U_{mf}$ [-] | 2.5 |

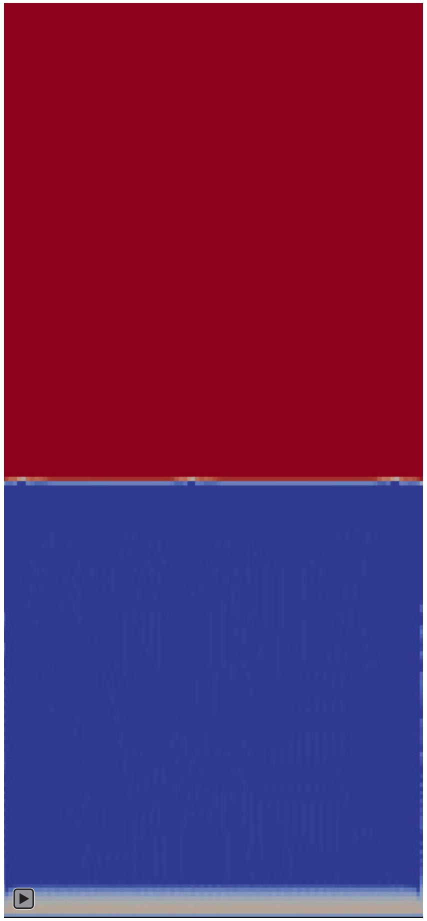
[4] Soria-Verdugo et al. 2011. Buoyancy effects on objects moving in a bubbling fluidized bed. *Chem. Eng. Sci.* 134, 57-66.

# Simulation set-up

- Comparison between simulation without and with the wall friction term.



Simulation without friction term



Simulation with friction term

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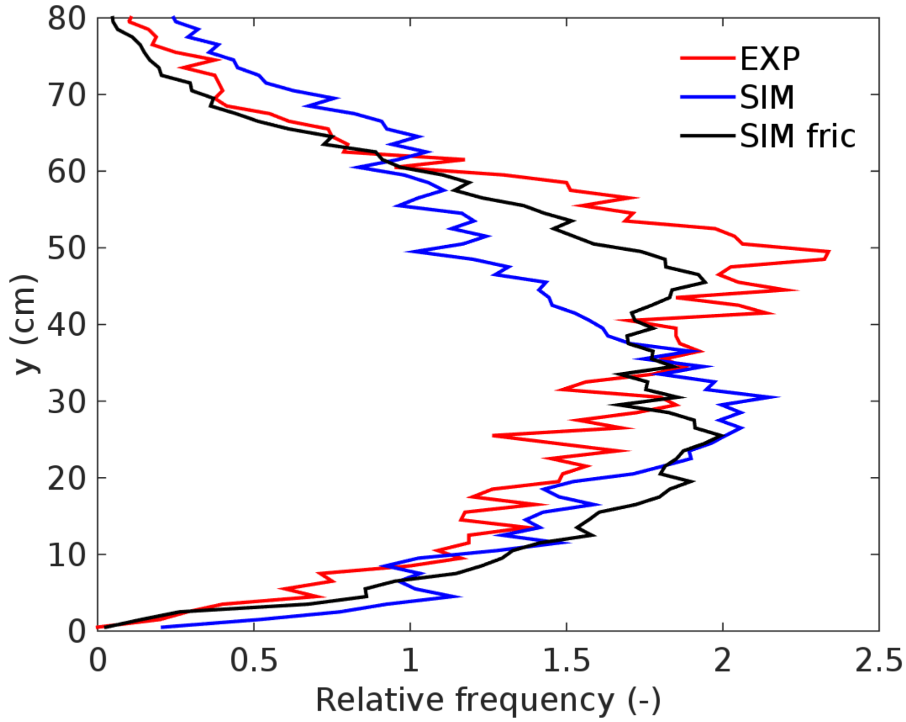
# *Fuel particle location*

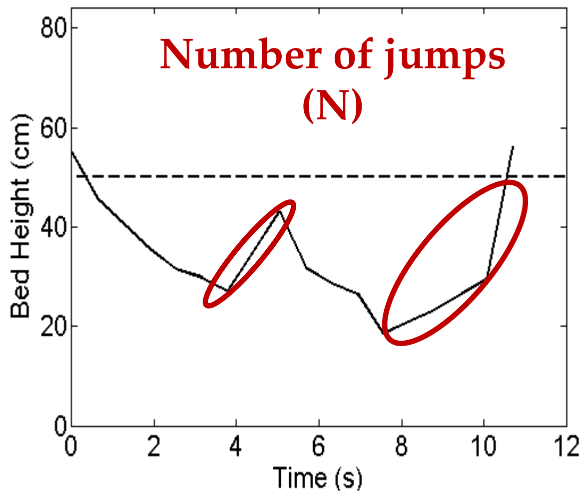
Relative frequency of finding the fuel particle at a certain height.




- The height of the bed was discretized in slices of 1 cm.
- Reasonable good agreement between the experimental results and both simulation approaches.
- The simulation **with the friction term improves** the vertical location of the fuel particle.

# *Fuel particle behavior*

Relative frequency ($P_N$) of number of jumps needed by a fuel particle to get the bed surface.




- In a rising process, an object with proper circulation in the whole bed reaches the bed surface in a several small "jumps" [5].

[5] Soria-Verdugo et al. 2011. Circulation of an object immersed in a bubbling fluidized bed. *Chem. Eng. Sci.* 66, 2833-2841.

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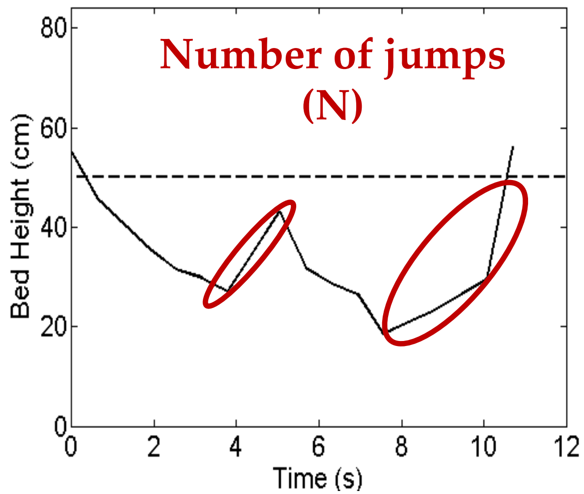


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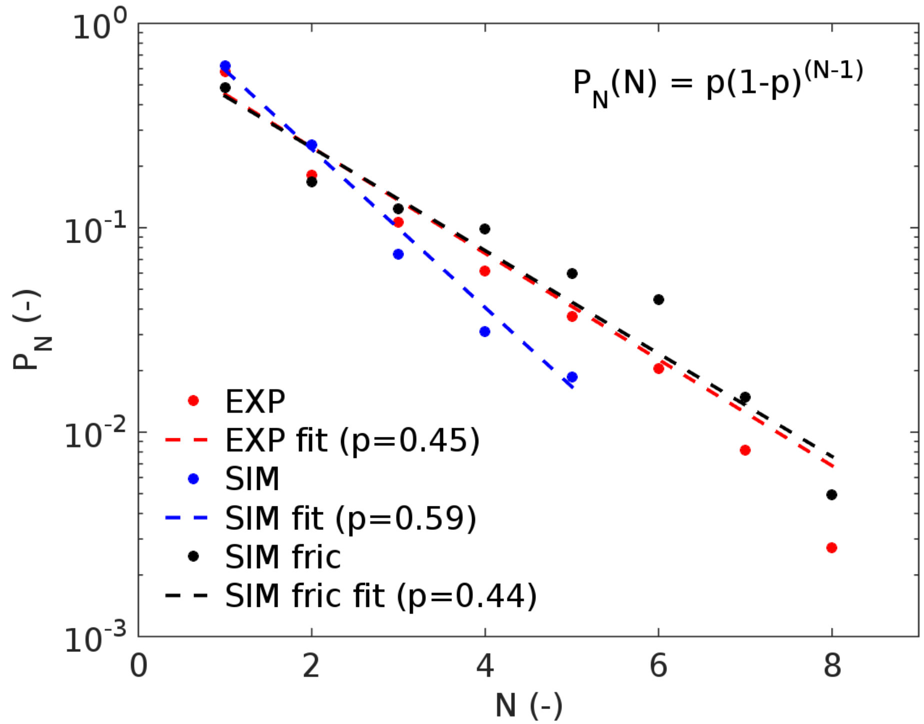
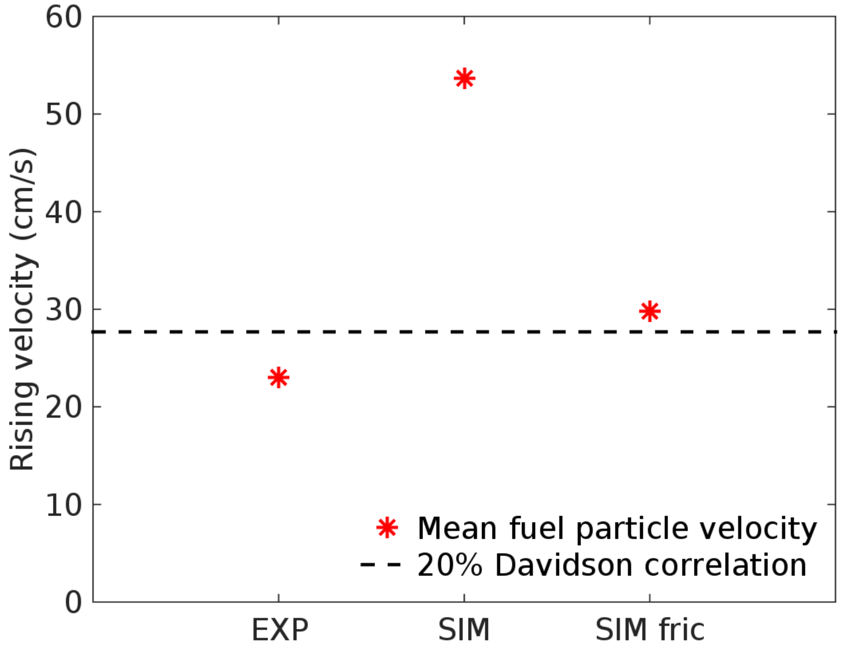


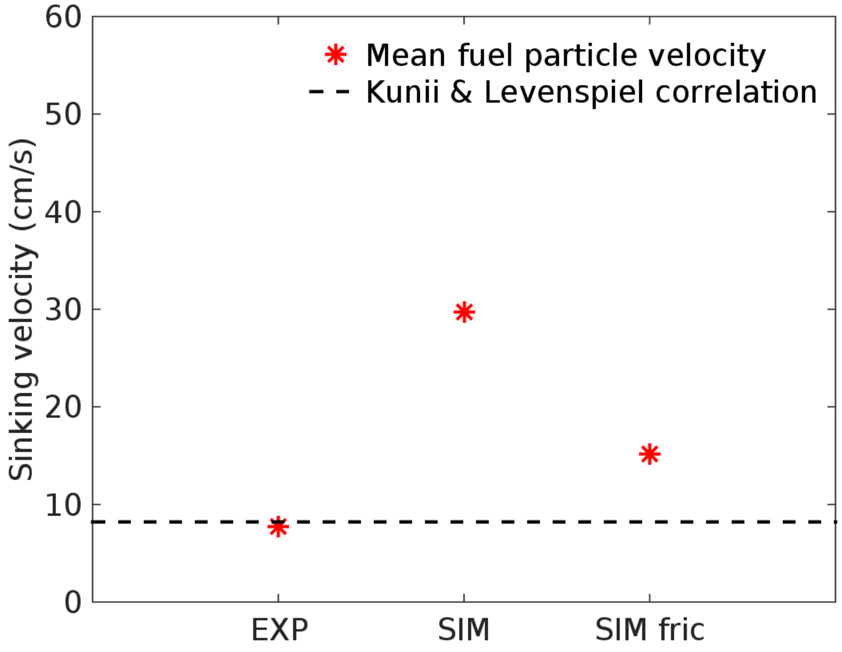

- The relative frequency of number of jumps needed by a fuel particle to get the bed surface follows a **geometrical equation** [5].

[5] Soria-Verdugo et al. 2011. Circulation of an object immersed in a bubbling fluidized bed. *Chem. Eng. Sci.* 66, 2833-2841.

# Rising and sinking velocity

Mean rising and sinking velocity of the fuel particle.



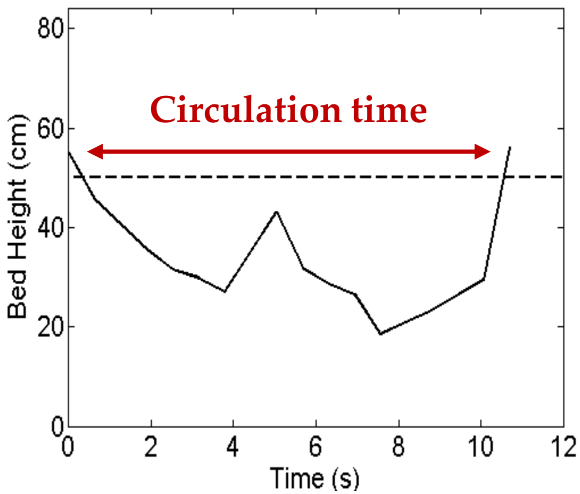

- The mean rising velocity was compared with 20% of the mean bubble velocity using the Davidson correlation [5, 6].

- The mean sinking velocity was compared with the Kunni & Levenspiel correlation for the dense phase velocity [5].

[5] Soria-Verdugo et al. 2011. Circulation of an object immersed in a bubbling fluidized bed. *Chem. Eng. Sci.* 66, 2833-2841.
[6] F. Fotovat, J. Chaouki, 2015. Characterization of the upward motion of an object immersed in a bubbling fluidized bed of fine particles, Chem. Eng. J. 280, 26-35.

# Circulation time

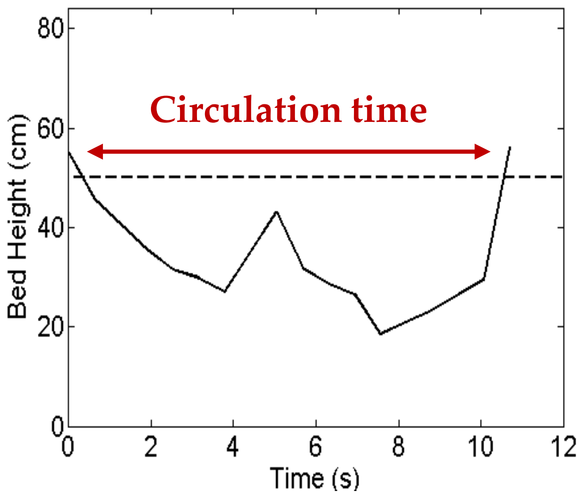
Circulation time of the fuel particle in a cycle.

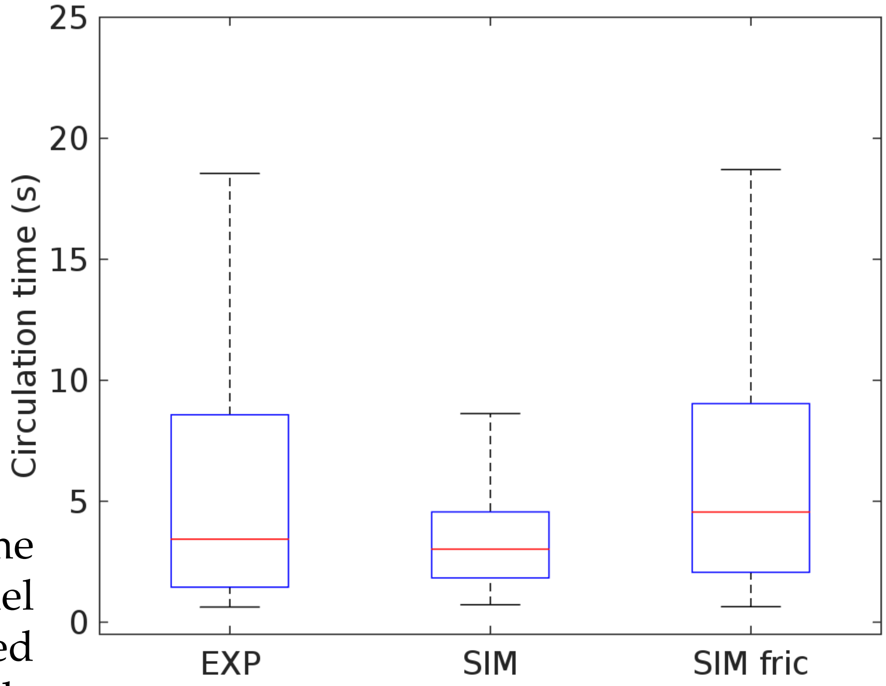



The circulation time of a fuel particle is the time interval between the instant at which the fuel particle sinks into the dense bed from the bed surface and the instant at which the particle returns to the bed surface.

# Circulation time

Circulation time of the fuel particle in a cycle.




The circulation time of a fuel particle is the time interval between the instant at which the fuel particle sinks into the dense bed from the bed surface and the instant at which the particle returns to the bed surface.

**The simulations with the friction term are capable of reproducing the distribution of the circulation time with very good accuracy.**

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# Conclusions

- The motion of a fuel particle was simulated using a fully coupled hybrid-model (TFM-DEM).
- A new friction term accounting the effect of the front and back walls of the bed was introduced in the numerical model.
- The simulations with the friction term clearly improve the motion of a fuel particle in the pseudo-2D bubbling fluidized bed, in particular:
  - ❑ The location of the fuel particle at a certain height.
  - ❑ The number of jumps needed by a fuel particle to reach the bed surface.
  - ❑ The mean rising and sinking velocity of the fuel particle.
  - ❑ The circulation time of the fuel particle.

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# Thank you for your attention

# Box plot

The statistical results are presented using box plots. In a box plot, the distribution of the data is represented by several statistical parameters and outlying data: the median, the lower and the upper quartiles (representing 25% and 75% respectively of the population), a confidence interval (the upper limit is the upper quartile plus 1.5 times the inter-quartile range and lower limit is the lower quartile minus 1.5 times the inter-quartile range), and outliers (corresponding with the data lies out of upper confidence interval limit)