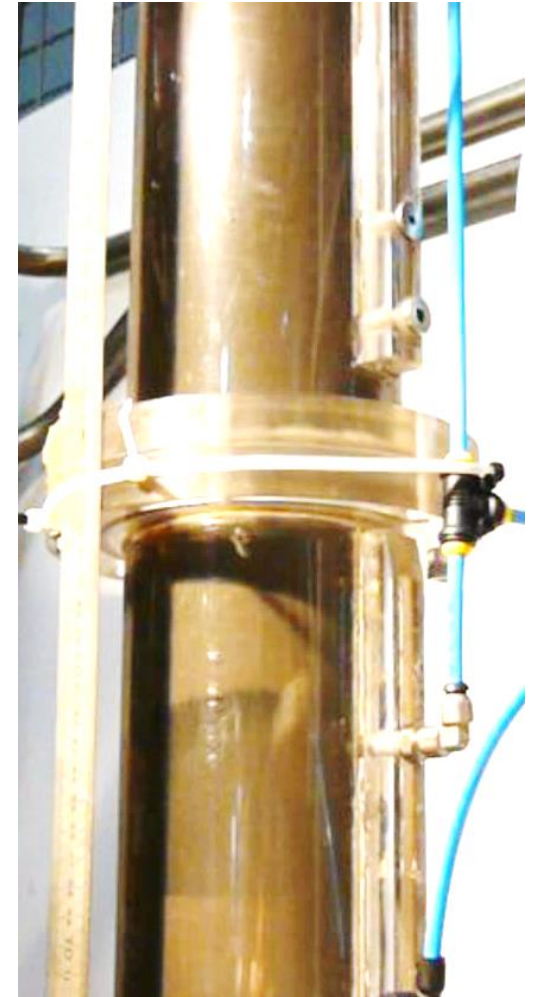


Comparison of CFD models in predicting the fluidization behavior of Geldart B particles

*Sina Tebianian, Benjamin Amblard, Stephane Bertholin,
Ann Forret, Thierry Gauthier*

BARRACUDA
VIRTUAL REACTOR®

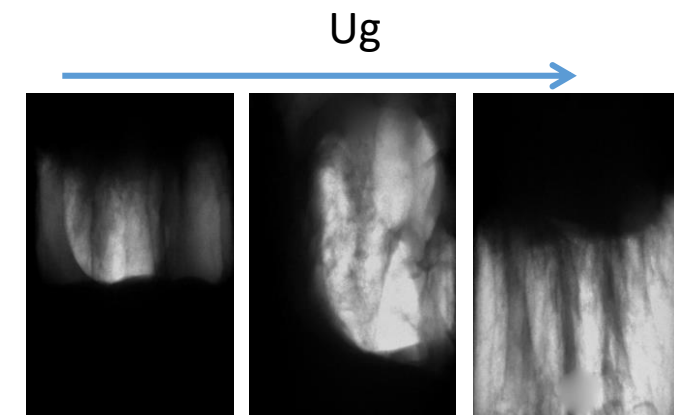
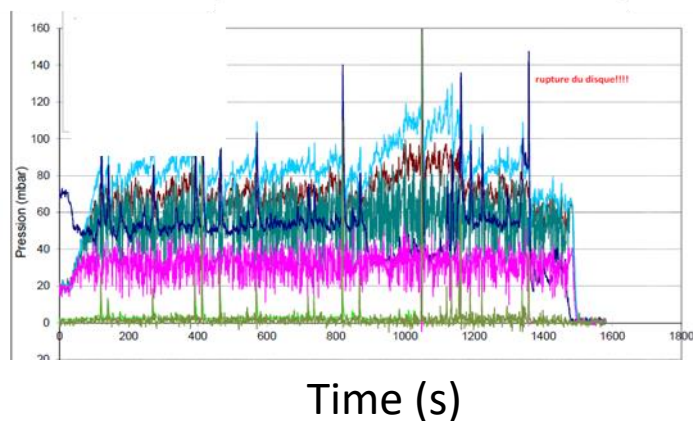
USERS' CONFERENCE
June 27–28, 2019



- Introduction
- CFD approaches
- Results
- Conclusions

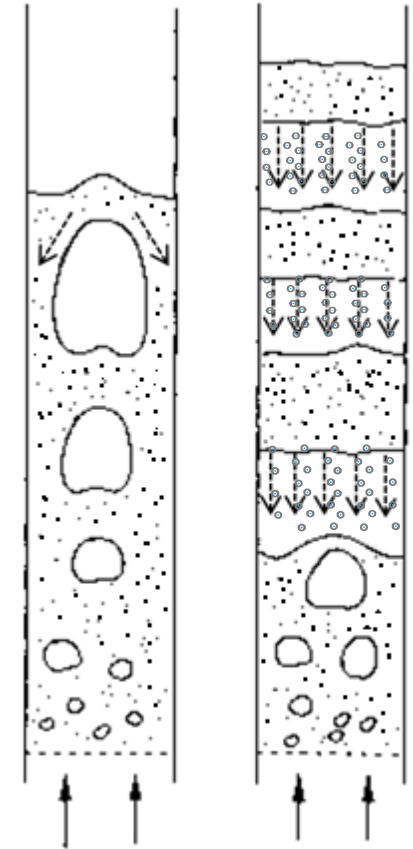
- Introduction
- CFD approaches
- Results
- Conclusions

- Slugging phenomena may cause serious problems when operating at laboratory or pilot scale causing difficulty in design and scale-up.
- It is also of interest to test the capability of CFD models in detecting different conditions.
- Grace (1982) provided the necessary conditions for slugging:
 - The average bubble diameter $> 2/3$ of D_{column} ;
 - The $U_g > U_{ms}$ (Stewart and Davidson (1967));
 - The $U_g < U_c$;
 - The bed should be sufficiently deep (Darton et al. (1977)).

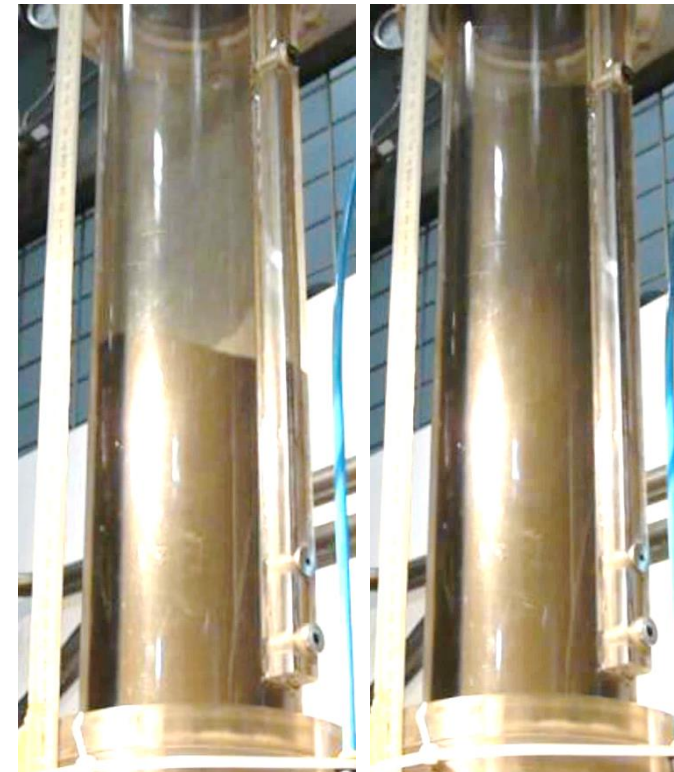
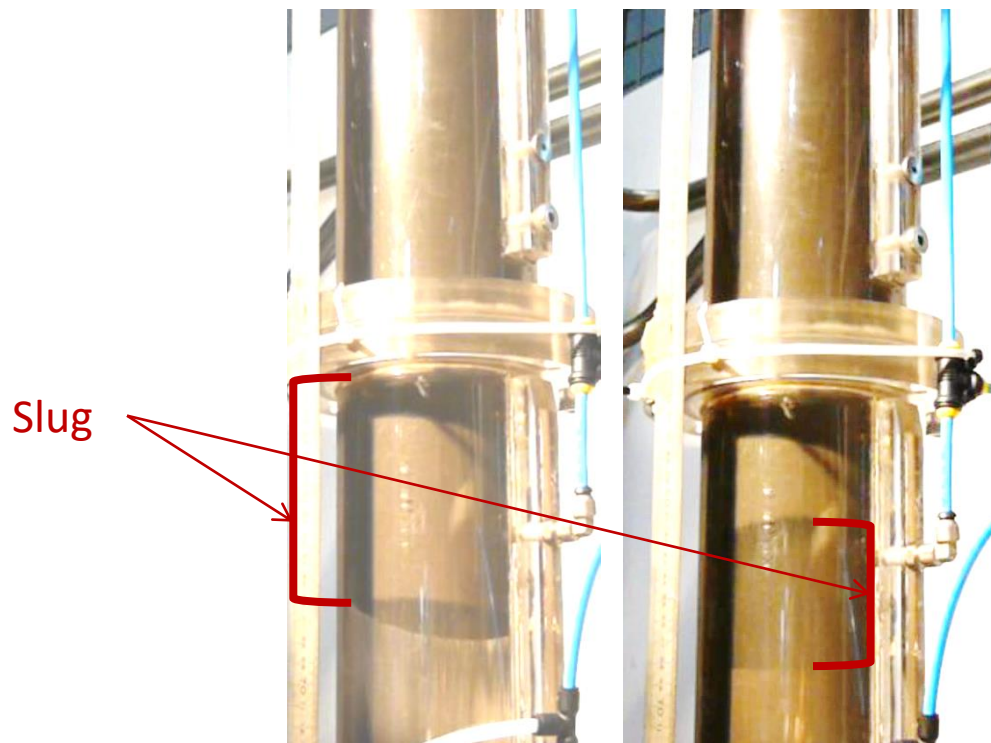


Tebianian, S. (2015). PhD dissertation

- Round-nosed
 - Round-nosed gas slugs rising through the dense phase which flow downwards in an annular region surrounding the slug
 - Observed also for gas-liquid systems
 - Particles easy to be fluidized (Geldart A and B)
 - 1Hz
- Square-nosed
 - Slugs that occupying the entire cross section of the column
 - Cohesive particles of angular shape
 - Columns with smooth wall
 - Similar to experiments with angle of internal friction (β) (*Thiel and Potter (1977)*)
 - Pressure fluctuations are mainly caused by the disintegration of rising plugs, followed by the precipitation of the particles (*Noordergraaf et al. (1987)*) .
 - 0.4 Hz
- Criteria of slugging (Grace 1982) do not provide the type of slugging
- Commercial CFD codes can predict the hydrodynamics?



- Experiments were performed at IFPEN in a 0.1 m I.D. column with Manganese Oxide of $d_{p50} = 250\mu\text{m}$ and $\rho_p = 3300 \text{ kg/m}^3$ with $U_g = 0.25\text{m/s}$
- Square-nosed slugging with high bed level fluctuations were observed

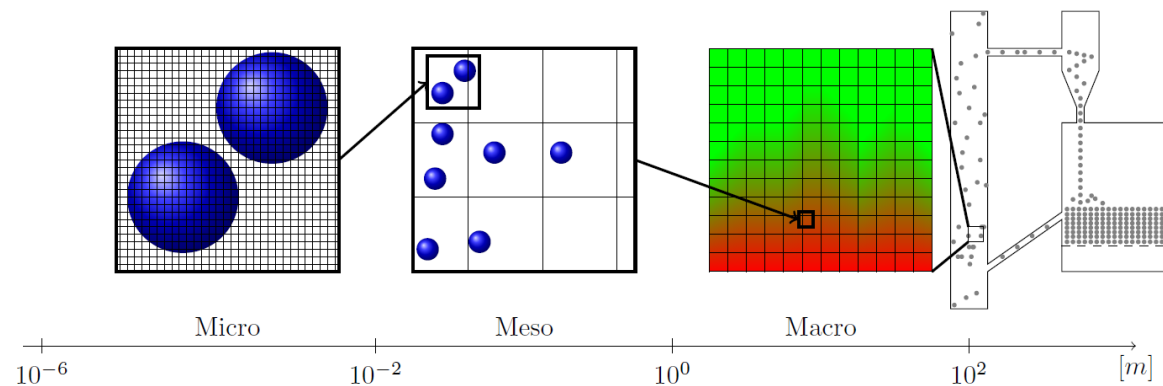




- Introduction
- CFD approaches
- Results
- Conclusions

Available modeling approaches:

- Direct Numerical Simulation: 10^3 - 10^4 particles
 - No drag correlation and particle-particle collisions detected and modeled
- CFD-DEM simulation: 10^7 - 10^8 particles
 - Drag correlation needed and particle-particle collisions detected and modeled
- Euler-Euler / MP-PIC approaches: no limit in number of particles
 - Drag correlation and particle/particle interaction models needed



- Simulation of interest: From 10^8 (pilot scale) to 10^{12} (industrial scale) particles
 - MP-PIC method chosen

● Eulerian-Eulerian

- Both gas and solids phases are considered as a continuum (equations of mass and momentum)

$$\frac{\partial}{\partial t}(\alpha_k \rho_k) + \frac{\partial}{\partial x_i}(\alpha_k \rho_k U_{k,i}) = 0$$

$$\frac{\partial}{\partial t} \rho_k \alpha_k U_{k,i} + \frac{\partial}{\partial x_j} \rho_k \alpha_k U_{k,i} U_{k,j} = -\alpha_k \frac{\partial P_g}{\partial x_i} + I_{k,i} - \frac{\partial \Sigma_{kij}}{\partial x_j} + \alpha_k \rho_k g_i$$

Solid stress tensor with similar analogy of a fluid

$$\Sigma_{p,ij} = \left[P_p - \lambda_p \frac{\partial U_{p,m}}{\partial x_m} \right] \delta_{ij} - \mu_p \left[\frac{\partial U_{p,j}}{\partial x_i} + \frac{\partial U_{p,i}}{\partial x_j} - \frac{2}{3} \delta_{ij} \frac{\partial U_{p,m}}{\partial x_m} \right]$$

Interactions expressed with a drag equation

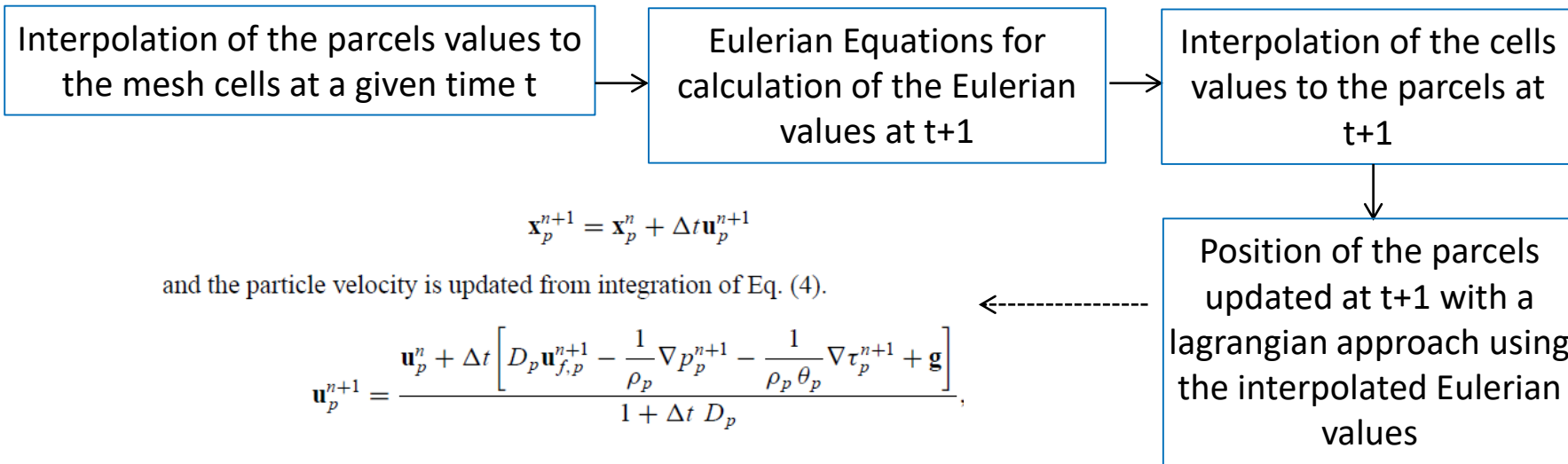
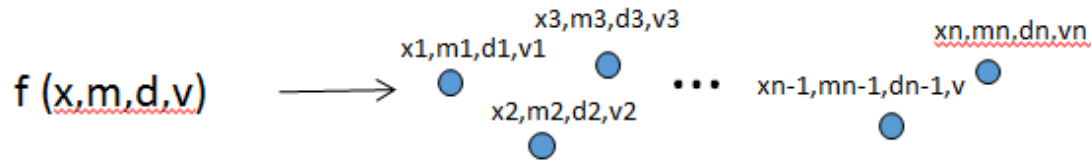
$$I_{g,i} = -I_{p,i} = \frac{\alpha_p \rho_p}{\tau_p} V_{r,i} \quad \text{with} \quad \begin{cases} \tau_p = \frac{4}{3} \frac{\rho_p}{\rho_g} \frac{d_p}{C_D |\mathbf{v}_r|} \\ C_D = \frac{24}{Re_p} \left[1 + 0.15 Re_p^{0.687} \right] \alpha_g^{-1.7} \\ Re_p = \frac{d_p |\mathbf{v}_r|}{\nu_g} \end{cases}$$

● MP-PIC (transport of a distribution function in an Eulerian Frame)

$$\frac{\partial(\theta \rho_s \mathbf{u}_s)}{\partial t} + \nabla_x \cdot (\theta \rho_s \mathbf{u}_s \mathbf{u}_s) + \nabla_x \tau + \theta \nabla_x p$$

$$= \theta \rho_s \mathbf{g} + \int \int f m D(\mathbf{u}_G - \mathbf{v}) dm dv - \nabla_x \cdot \left[\int \int f m (\mathbf{v} - \mathbf{u}_s) (\mathbf{v} - \mathbf{u}_s) dm dv \right]$$

● Discretization of the distribution function in n parcels



- MP-PIC (transport of a distribution function in a Eulerian Frame)

$$\begin{aligned} \frac{\partial(\theta\rho_s\mathbf{u}_s)}{\partial t} + \nabla_x \cdot (\theta\rho_s\mathbf{u}_s\mathbf{u}_s) + \nabla_x \tau + \theta\nabla_x p \\ = \theta\rho_s\mathbf{g} + \int \int f m D(\mathbf{u}_G - \mathbf{v}) dm dv - \nabla_x \cdot \left[\int \int f m (\mathbf{v} - \mathbf{u}_s)(\mathbf{v} - \mathbf{u}_s) dm dv \right] \end{aligned}$$

- Discretization of the distribution function in n parcels

- Advantages:

- Particle size distribution taken into account for a low computational cost
- Access to interesting Lagrangian data (cloud velocity, position, mass, composition, ...)

● MP-PIC

● Two sub grid models

- Drag model
- The solid stress tensor

$$\frac{\partial(\theta\rho_s\mathbf{u}_s)}{\partial t} + \nabla_x \cdot (\theta\rho_s\mathbf{u}_s\mathbf{u}_s) + \nabla_x \tau + \theta\nabla_x p$$

$$= \theta\rho_s\mathbf{g} + \int \int f m D(\mathbf{u}_G - \mathbf{v}) dm dv - \nabla_x \cdot \left[\int \int f m (\mathbf{v} - \mathbf{u}_s)(\mathbf{v} - \mathbf{u}_s) dm dv \right]$$

Example Barracuda solid tensor does not allow for off-diagonal components

$$\tau(\theta_p) = \frac{10P_s\theta_p^\beta}{\max[\theta_{cp} - \theta_p, \varepsilon(1 - \theta_p)]} \quad \theta_{cp} = \frac{\text{Bulk Density}}{\text{Particle Density}}$$

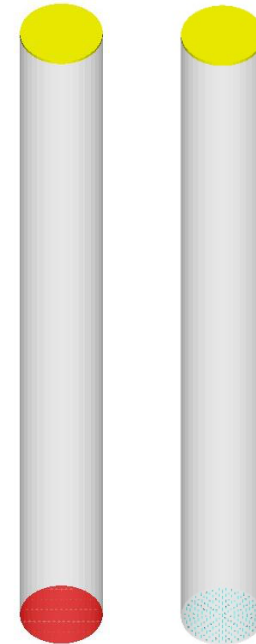
Particle normal stress model advanced options

Ps constant	1
B constant	3
Eps constant	1e-08
Fraction of average velocity	0.8

CFD

- Barracuda
- Fluent
 - Dense discrete particle model (DDPM)-KTGF (similar to MP-PIC)
- Gidaspow drag law; No-Slip wall conditions

NEW ENERGIES



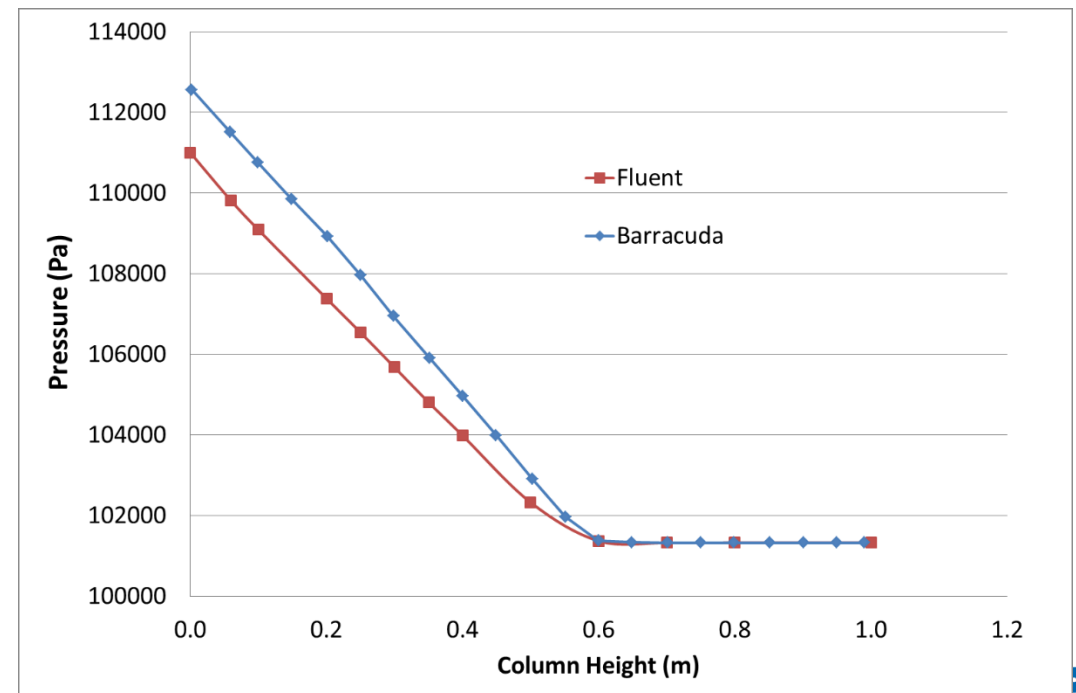
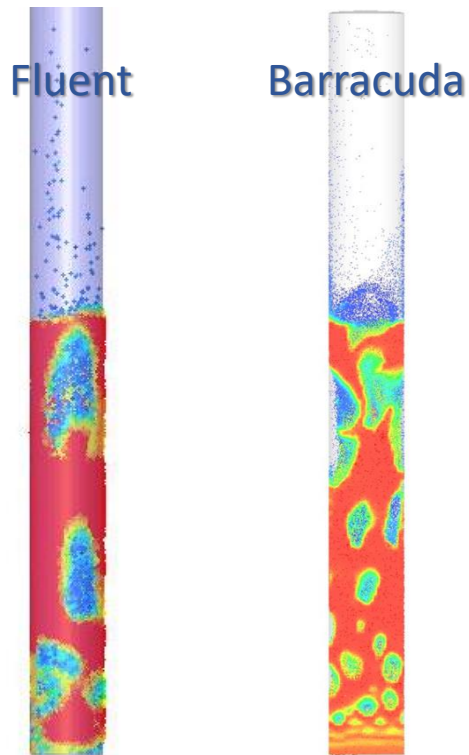
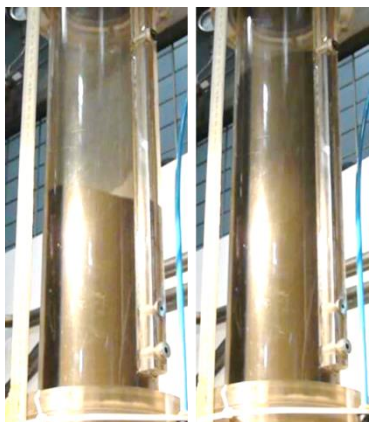
Column Diameter	10 cm
Cells	150000
Solid mass	7.6 kg
Exit pressure	101325 Pa
Ug	0.25 m/s

- Introduction
- CFD approaches
- **Results**
- Conclusions

COMPARISON FLUENT BARRACUDA

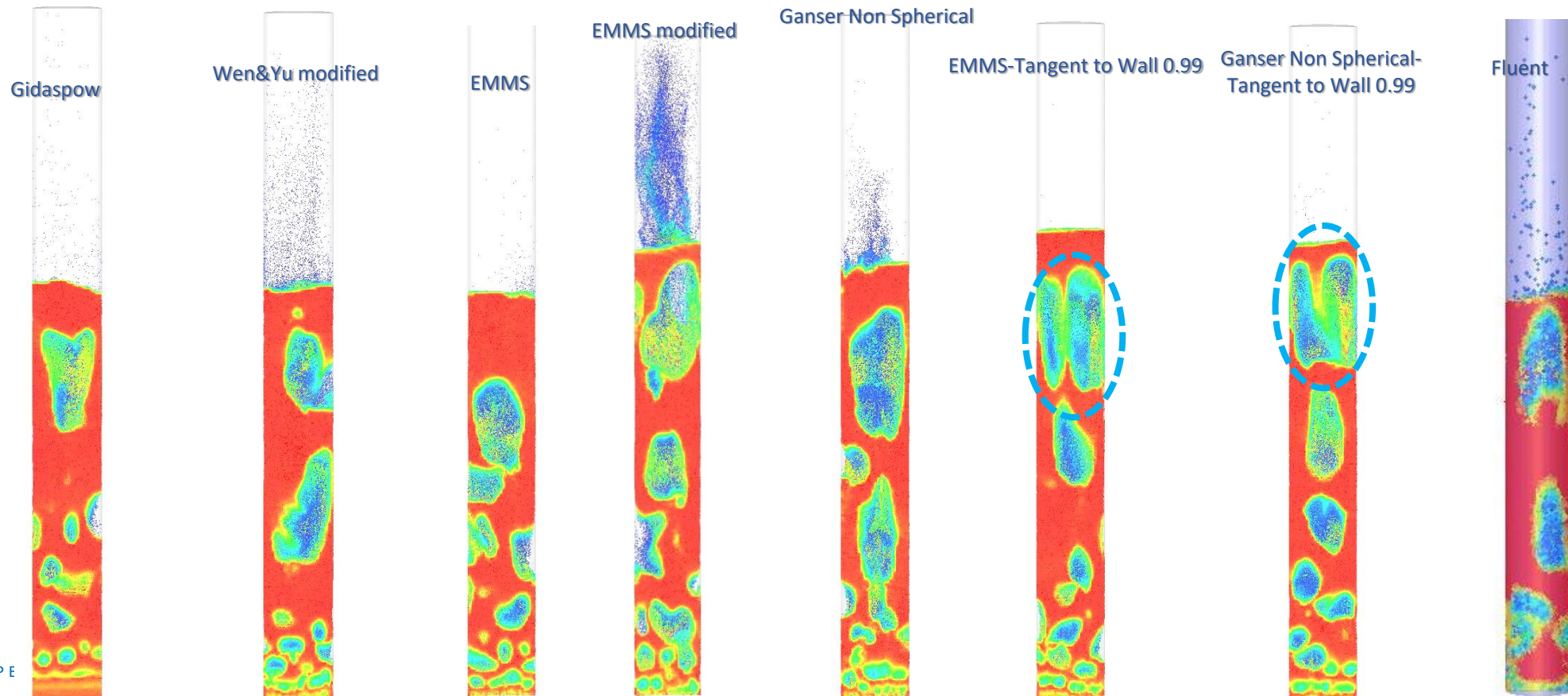
- Significant differences between the experimental results and CFD.
- Barracuda and Fluent provide similar bed levels but the other parameters are quite different.

	ρ_{bed} (kg/m ³)	Average Voidage	Bed level (m)	Standard deviation of pressure fluctuations (Pa)
Experiments	1500	0.55	0.65	800
Barracuda (injection points)	1670	0.49	0.58	1200
Simulation Fluent (uniform injection)	1716	0.48	0.57	1380



BARRACUDA DRAG LAW - WALL CONDITIONS

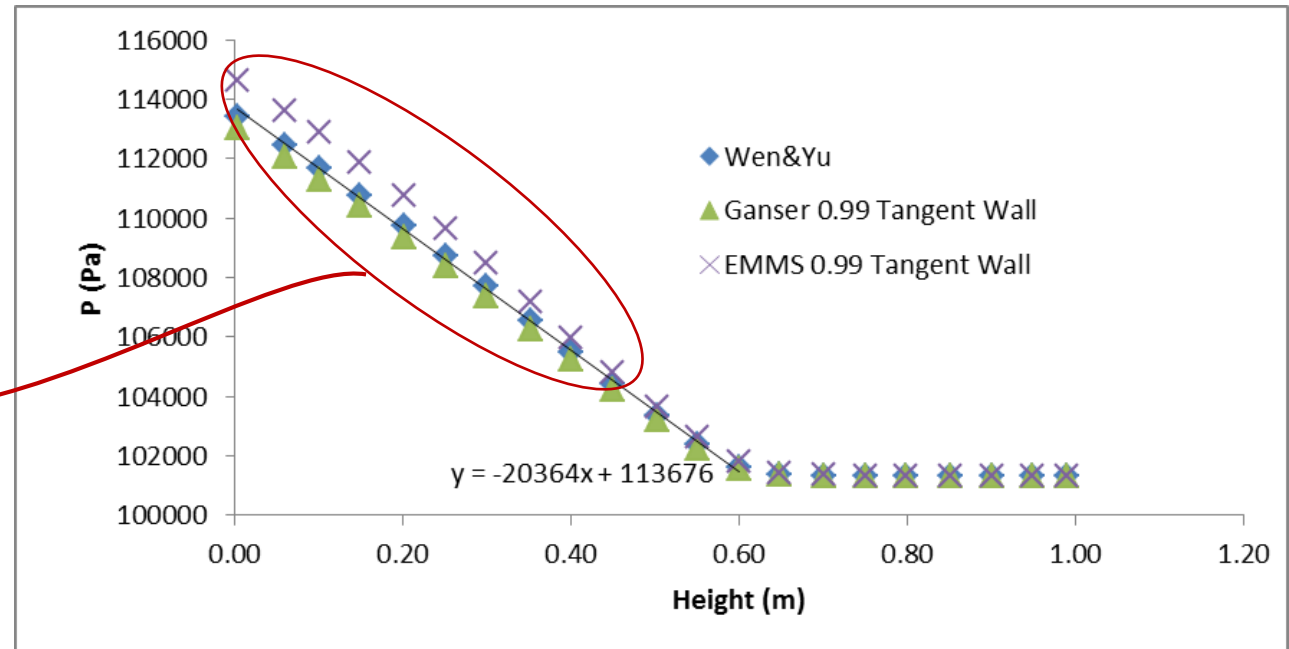
- Barracuda:
 - Limitation for changing particle stress model
 - We changed some parameters such as Drag law, particle-wall interaction and sphericity to see its effect of type of slugging.
- If not indicated : Sphericity 0.7 and Tangent to Wall momentum retention of 0.5



- Fair agreement of bed level but not the pressure fluctuations

	ρ_{bed} (kg/m ³)	Average Voidage	Bed level (m)	Standard deviation of pressure fluctuations (Pa)
Experiments	1500	0.55	0.65	800
Ganser Free Slip	1586	0.52	0.61	1380
EMMS Free Slip	1550	0.53	0.62	2990

Same bed height but different pressure drops: slugging feature or a numerical issue?



- Square-nosed slugging is a valuable way to assess the capabilities of CFD codes in detecting particle-particle interactions.
- Qualitative square-nosed structures were produced occasionally by Barracuda with free slip conditions .
- However, we cannot claim that either of the codes is able to predict this behaviour.
- Barracuda
 - Shear stress forces that can result in particles locking are not taken into account.
- Parameters that can affect the results
 - Drag law
 - Wall conditions
 - Intra-particle interactions
- How can we improve this?

Innovating for energy

Find us on:

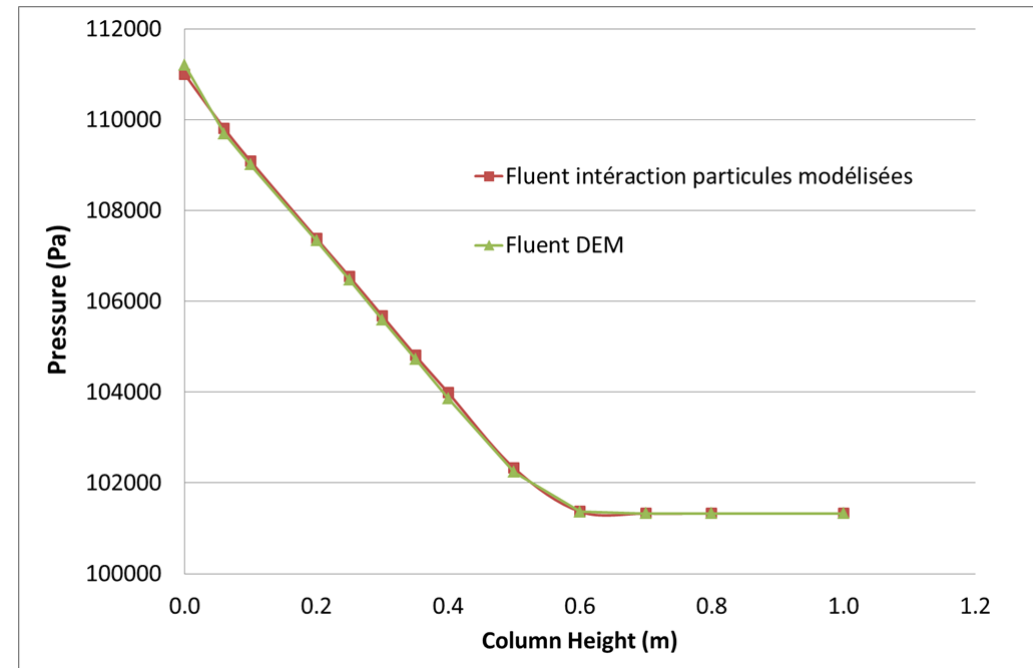
 www.ifpenergiesnouvelles.com

 [@IFPENinnovation](https://twitter.com/IFPENinnovation)

sina.tebianian@ifpen.fr



- No difference between the two approaches.
- The two approaches are quite different in terms of particle-particle interaction and calculation time.
- Does Fluent DEM code take into account the particle-particle interactions?



	ρ_{bed} (kg/m ³)	Average Voidage	Bed level (m)	Standard deviation of pressure fluctuations (Pa)
Experiments	1500	0.55	0.65	800
Barracuda (injection points)	1725	0.48	0.57	1380
Simulation Fluent (uniform injection)	1740	0.47	0.56	1380