Development of a CFD-DEM Model in Non-inertial Frame for Solid-Liquid Mixing Applications

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GPS Génie par la simulation — SBES Simulation - Based Engineering Science

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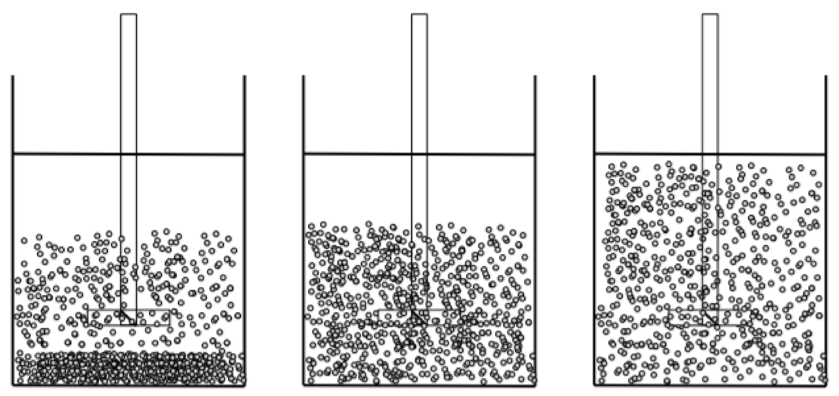
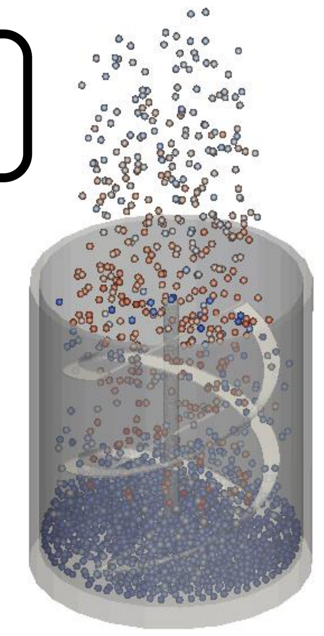
SOLID-LIQUID MIXING

Multiphase mixing objective is to maximise contact between phases

The principal factor to caracterize solid-liquid mixing is Njs : Just Suspended Speed → Complete suspension





PROBLEMATIC

Some industrial applications for solid-liquid mixing take place in the laminar regime which requires the use of more complicated impellers geometries like the Double Helical Ribbon (DHR) which generates complex flow, that implies new challenges for the modelisation.

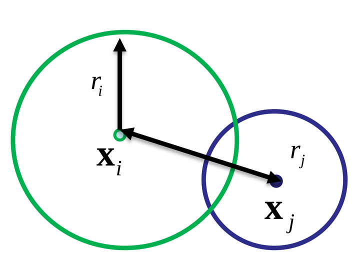
OBJECTIVE

Develop a CFD-DEM in the rotational frame (Lagrangian frame) linked to the impeller in order to fix the CFD grid which offers plenty of new diverse applications.

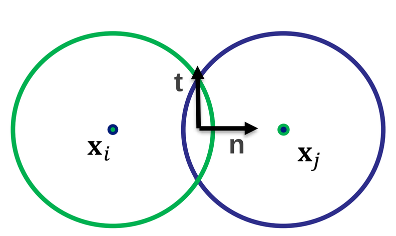
DISCRETE ELEMENT METHOD

Lagrangian approach where each particle is considered as a discrete entity in order to model granular flows

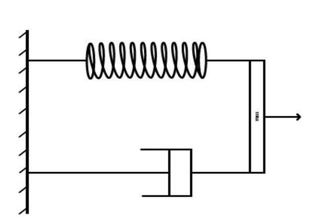
Detect Collisions → Calculate Overlap → Calculate Force → Calculate position & velocity



$$\|\mathbf{x}_i - \mathbf{x}_j\| < r_i + r_j$$



$$\begin{cases} \|\boldsymbol{\delta}_{n,ij}\| = \left((r_i + r_j) - d_{ij}\right) \\ \boldsymbol{\delta}_{t,ij} = \int_{t_i}^{t} \mathbf{v}_{t,ij}\, dt \end{cases}$$



Simplectic Integrator: **Velocity Verlet**

$$\begin{cases} \mathbf{x}_i^{t+\Delta t} = \mathbf{x}_i^{t} + \Delta t\, \mathbf{v}_i^{t+\frac{\Delta t}{2}} \\ \mathbf{v}_i^{t+\Delta t} = \mathbf{v}_i^{t+\frac{\Delta t}{2}} + \Delta t \dfrac{\mathbf{F}_{total,i}(t+\Delta t)}{m_i} \end{cases}$$

$$\boldsymbol{f}_{\text{contact},ij} = -k_n \boldsymbol{\delta}_{n,ij} - \gamma_n \mathbf{v}_{n,ij} - k_t \boldsymbol{\delta}_{n,ij} - \gamma_t \mathbf{v}_{t,ij}$$

EQUATIONS IN NON-INERTIAL FRAME

$$\frac{\partial \rho_f \epsilon_f \boldsymbol{u}}{\partial t} + \nabla \cdot (\rho_f \epsilon_f \boldsymbol{u} \otimes \mathbf{u}) = -\epsilon_f \nabla \mathrm{p} + \nabla \cdot \tau - \boldsymbol{f}_{pf} + \boldsymbol{f}_{inertial}$$

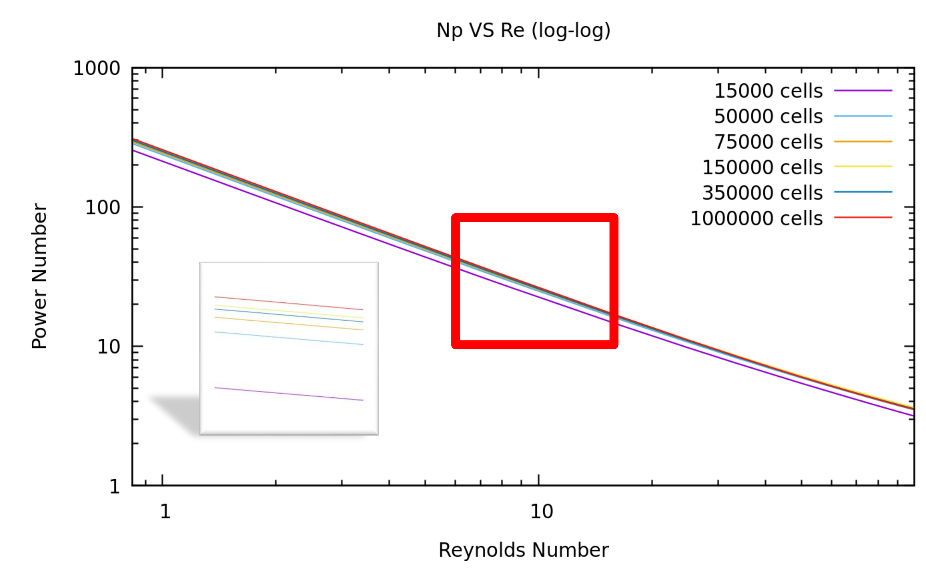
$$m_i \frac{d\boldsymbol{v}_i}{dt} = \sum_j \boldsymbol{f}_{c,ij} + \boldsymbol{f}_{p,ij} + \boldsymbol{f}_{inertial,i}$$

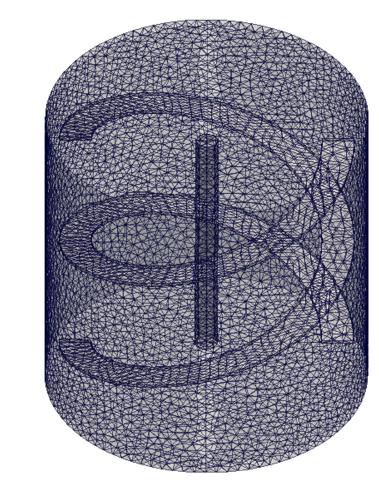
$$\boldsymbol{f}_{inertial} = \underbrace{\alpha\, \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \boldsymbol{r})}_{Centrifugal} - \underbrace{2\, \alpha\, \boldsymbol{\Omega} \times \boldsymbol{v}}_{Coriolis} + \alpha \boldsymbol{g} \qquad \alpha \leftrightarrow \begin{cases} \rho_f \\ m_i \end{cases}$$

METHODOLOGY

- **Generate the mesh of the geometry with a convergence study**
- **Test the possibility to do DEM in non inertial frame**
- **Test the existing CFD solver for rotating frame**
- **Make a new PISO Solver for CFD-DEM in rotating frame**
- **Make a parameter study on viscosity, volume fraction of solid and density in order to understand the best use of Double Helical Ribbon**

MESH VALIDATION



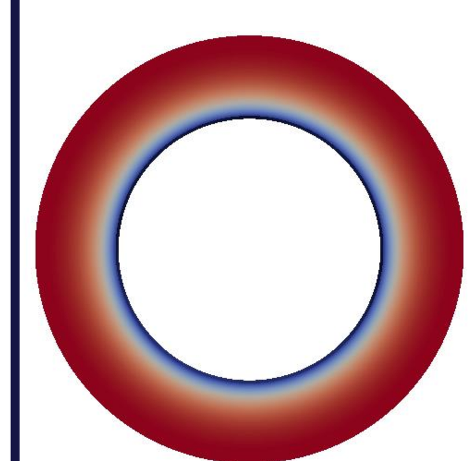


75 000 cells

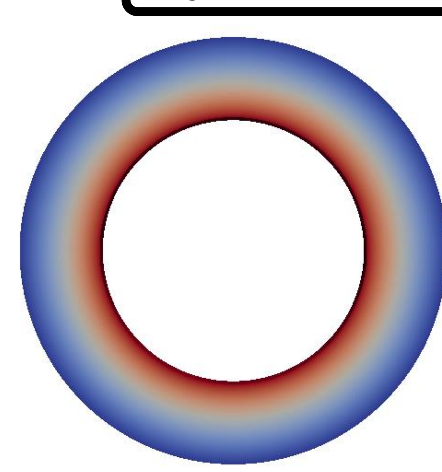
CFD SOLVERS VALIDATION

There are solvers in rotating frame in OpenFoam but we have to be sure of their implementation.

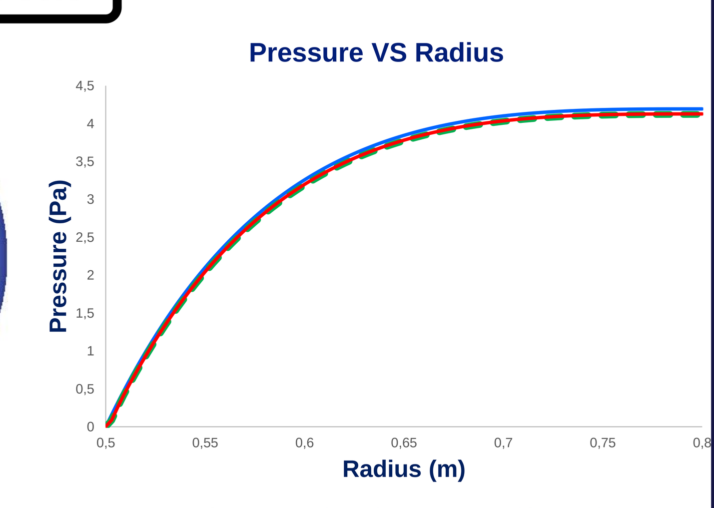
Cylindrical Couette



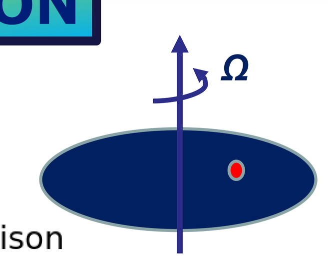
Pressure SRF & Simple

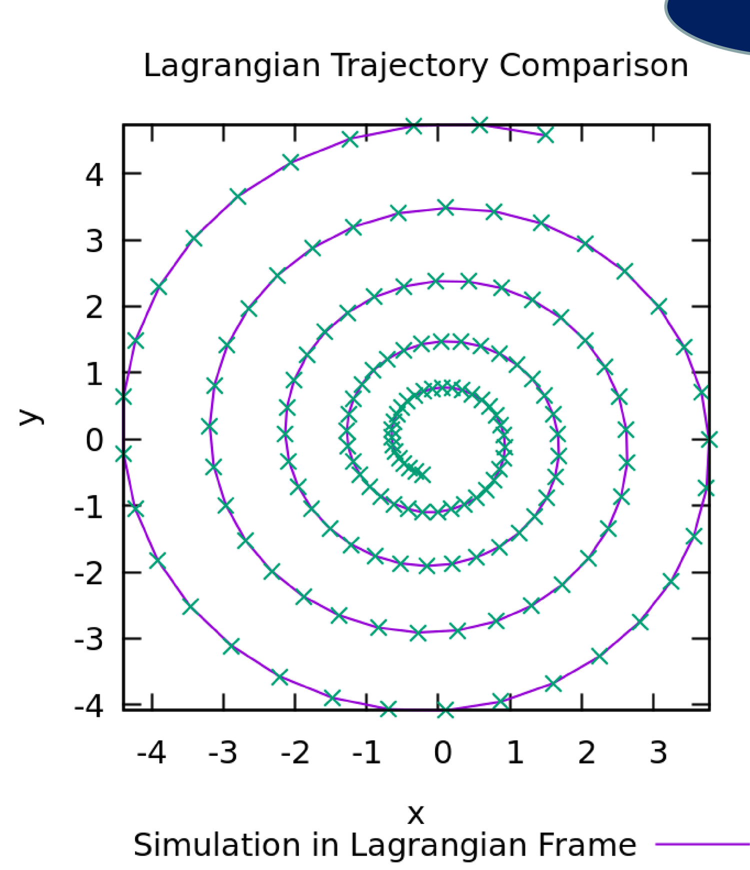


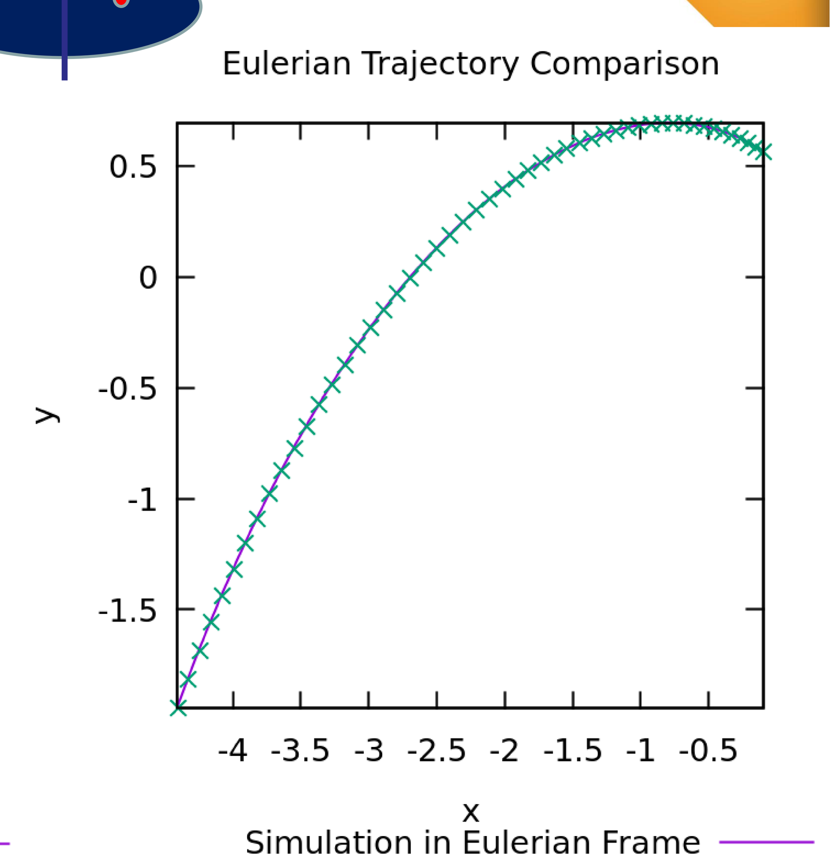
Velocity SRF & Simple



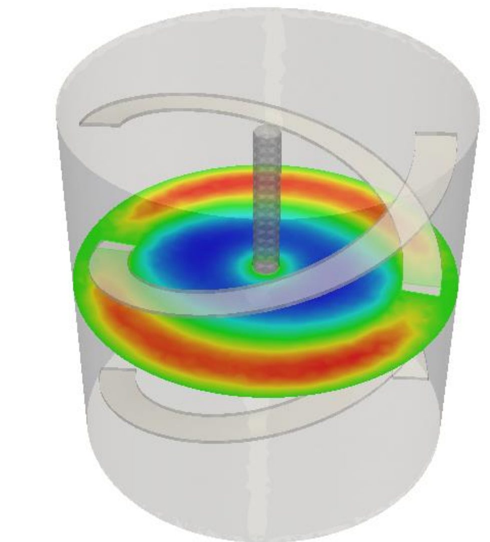
DEM VERIFICATION



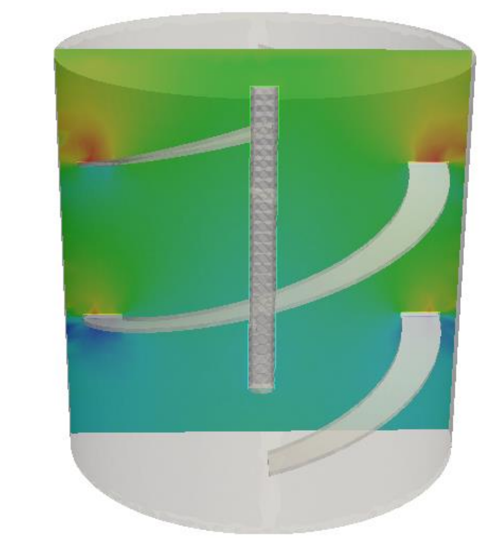




PRELIMINARY RESULTS



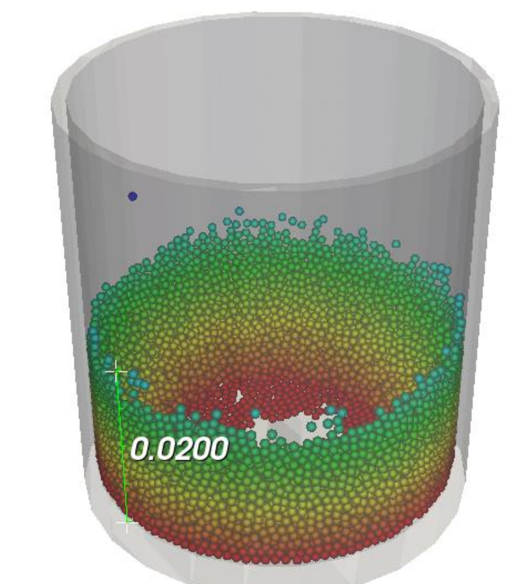
Velocity Vz



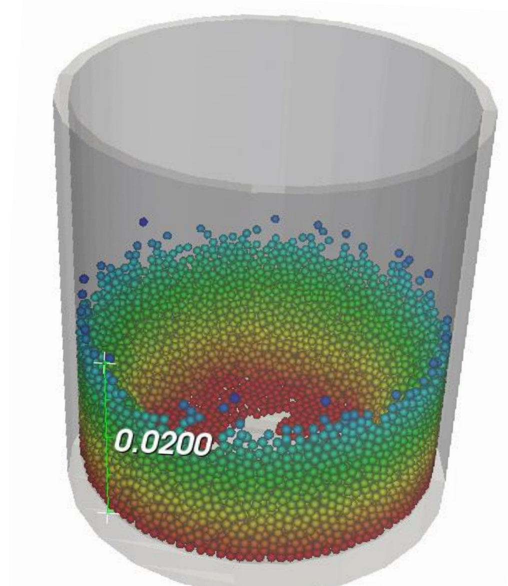
Pressure

CFD

Pressure results without particles are coherent with experimental measurement



Eulerian Frame



Lagangian Frame

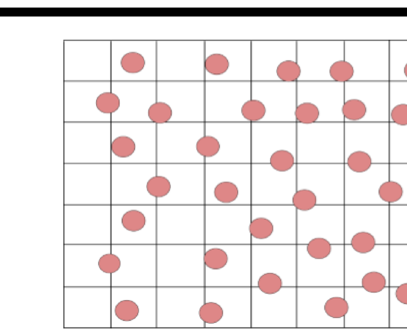
DEM

Same height of particles in the two Frames

CONCLUSIONS AND CFD-DEM APPROACH

All the preliminary results for the DEM and the CFD are conclusive → GO TO CFD-DEM

Unresolved CFD-DEM:
The fluid is solved at a scale coarser than particles → Allow simulation with 10^8 particles



Particles-Fluid Interaction:
Which forces should be taken into account?

Drag Force
Virtual Mass Force
Basset Force
Saffman Force
Magnus Force

NOMENCLATURE

k_n:	Normal elastic coefficient
k_t:	Tangential elastic coefficient
γ_n:	Normal damp coefficient
γ_t:	Tangential damp coefficient
δ_n:	Normal Overlap
δ_t:	Tangential Overlap
ρ_f:	Liquid density
ϵ_f:	Void fraction
$f_{c,ij}$:	Contact force between particle i and j
$f_{pf,i}$:	Interaction force between fluid and particle i
τ:	Stress tensor
Ω:	Rotation vector
SRF:	Single rotating Frame
CFD:	Computational Fluid Method
DEM:	Discrete Element Method

ACKNOWLEDGMENTS

NSERC CRSNG — FONCER — compute • calcul CANADA — Calcul Québec