A Two Grid Formulation for Fluid-Particle Systems using the Discrete Element Method.

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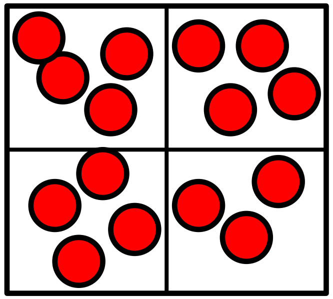
Outline

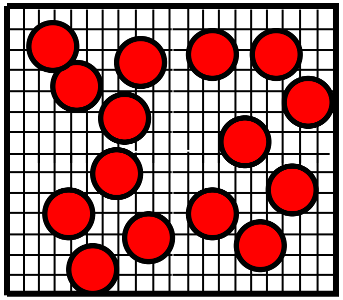
- **Motivation**
- **Objectives**
- **Methodology**
- **Two Grid Formulation**
- **Results**
- **Conclusion**

Motivation

- Conventional DEM-CFD framework uses a single grid approach.
- Particles require coarser grid to maintain smoothness in local solid volume fraction and avoid instability.
- Fine scale fluid features like turbulence, wall shear stress and heat transfer coefficient at immersed surfaces require finer grids for better resolution.
- Difficult to resolve flows with large sized particles and high flow velocities like jets in jetting fluidized beds.
- Difficult to resolve small geometrical features influencing the flow with conventional DEM-CFD framework.



Coarse Grid



Fine Grid

Objectives

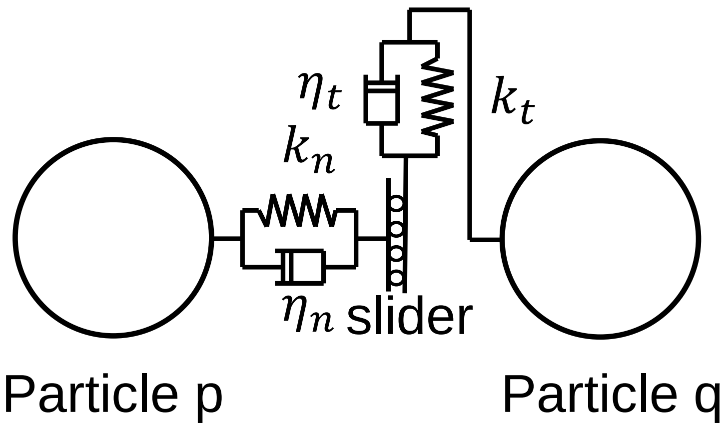
- **Develop and implement the two-grid framework for DEM-CFD in our in-house code GenIDLEST.**
- **Perform and validate two-grid simulations, not possible with single grid framework on jetting fluidized bed setup.**
- **Avoid instability faced in single grid framework for flow conditions like jets, if the particle size becomes comparable to jet size in jetting fluidized beds.**

Methodology

- **Soft Sphere DEM**
- **Linear Spring-Mass Dashpot**

Normal Force $\vec{f}_{n,pq} = -k_n \vec{\delta}_{n,pq} - \eta_n \vec{v}_{n,pq}$

Tangential Force $\vec{f}_{t,pq} = -k_t \vec{\delta}_{t,pq} - \eta_t \vec{v}_{t,pq}$



- **Model B (Gidaspow)**

Continuity $\nabla.(\varepsilon \rho_g \vec{u}) = 0$

Momentum

$$\frac{\partial(\varepsilon \rho_g \vec{u})}{\partial t} + \nabla.\left(\varepsilon \rho_g \vec{u}\vec{u}\right) = -\nabla p + \nabla.\left(\varepsilon \overline{\tau}_g\right) - \frac{1}{V_{fluid_{cell}}} \sum_N \frac{V_p \beta}{(1-\varepsilon)} \left(\vec{u} - \vec{v}_p\right) + \rho_g \vec{g}$$

- **Ergun, Wen & Yu Drag Correlations**

Ergun, 1952

$$\beta = 150 \frac{(1-\varepsilon)^2 \mu_g}{\varepsilon d_p^2} + 1.75(1-\varepsilon)\frac{\rho_g}{d_p}\left|\vec{u} - \vec{v}_p\right| \ if\ (\varepsilon < 0.8)$$

Wen and Yu, 1966

$$\beta = \frac{3}{4} C_D \frac{\varepsilon(1-\varepsilon)}{d_p} \rho_g \left|\vec{u} - \vec{v}_p\right| \varepsilon^{-2.65} \ if\ (\varepsilon \geq 0.8)$$

- **Fractional Step Time Marching**

Two-grid formulation

Continuity and momentum equations are solved in fine fluid grid

Fluid velocities are mapped from fluid grid to coarser particle grid

$$\vec{u}_{pg} = \frac{\sum_{1}^{N_{fg}} \vec{u}_{fg}}{N_{fg}}$$

Particles are advanced in time and void fractions are calculated in the coarser particle grid

$$\varepsilon_{pg} = 1 - \frac{\sum_{1}^{Np} V_p}{V_{pg}}$$

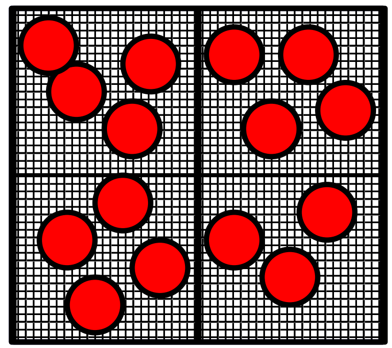
Drag forces on the particles are calculated in the particle grid

$$\vec{F}_{p,pg\_drag} = function(\varepsilon_{pg}, \vec{u}_{pg}, d_p)$$

Drag forces and void fractions are mapped back from coarser particle grid to finer fluid grid

$$\vec{F}_{fg\_drag} = -\left(\sum_{Np} F_{p,pg\_drag}\right) \times \frac{V_{fg}}{V_{pg}}$$

$$\varepsilon_{fg} = \varepsilon_{pg}$$

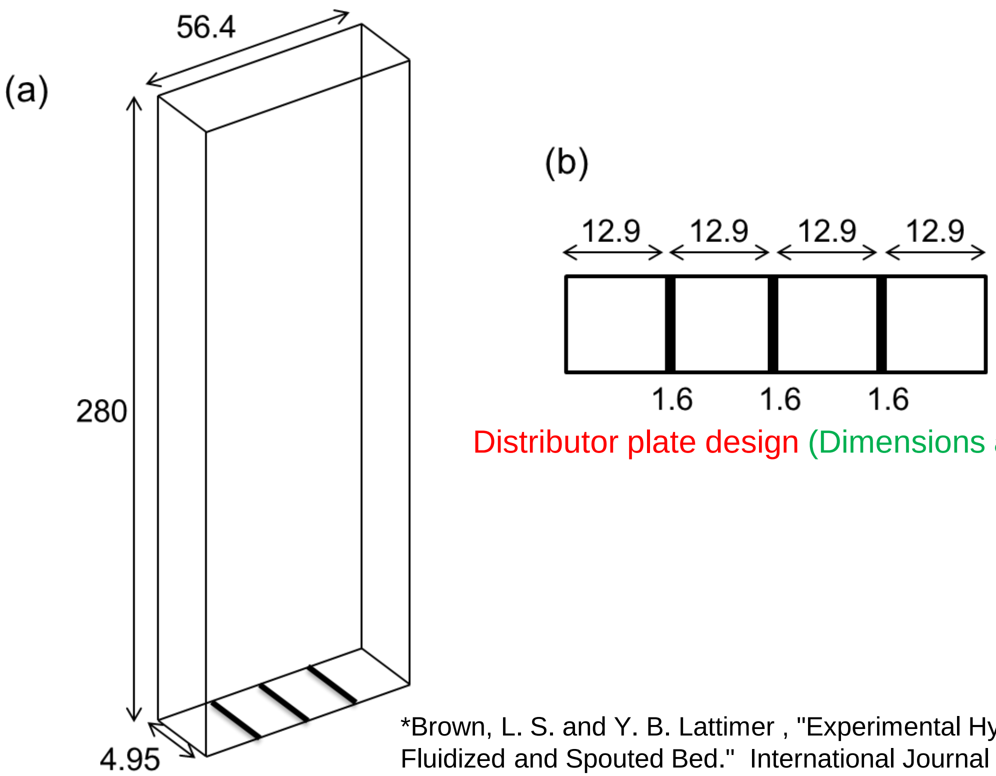


Calculations done on fluid grid | Mapping involving fluid and particle grid | Calculations done on particle grid

Flow diagram of fluid-particle grid mapping in two-grid framework

Computational Details

- **3D simulations performed on a small lab scale fluidized bed setup*.**



Distributor plate design (Dimensions are in mm)

*Brown, L. S. and Y. B. Lattimer , "Experimental Hydrodynamics of Multiple Jet Systems in a Fluidized and Spouted Bed." International Journal of Multiphase Flow, submitted.

Particle and DEM Properties

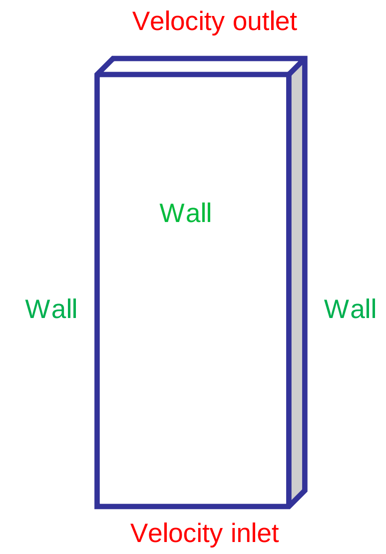
Particle properties	
Material	Glass
Diameter	750 microns
Number of particles	50,000
Density	2500 kg/m^3
Coefficient of friction	0.10
Minimum fluidization velocity	0.43 m/s
Spring constant (k_n,k_t)	800 N/m
Coefficient of restitution	0.90

Grid Details

Jet details	
Number of jets	1,2 and 3
Superficial velocity	0.699 m/s(1.60U_{mf}), 1.294 m/s(3U_{mf})
Jet width	1.6 mm

Fluid grid details	
Along height	200 cells (Δy=1.40 mm)
Along width	175 cells (Δx=0.322 mm)
Along depth	4 cells (Δz=1.2375 mm)

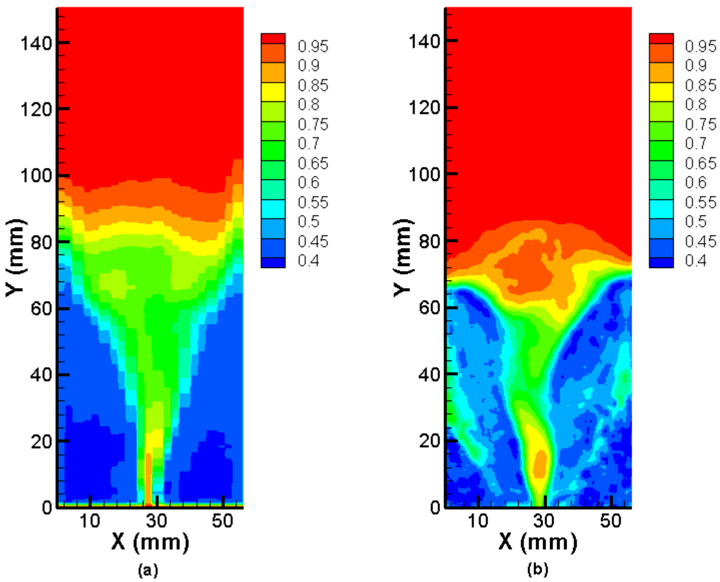
Particle grid details	
$\Delta x = \Delta y = \Delta z = 3d_p$ = 2.25 mm	Fluid grid size for single grid framework



Results – Single Jet 1.60 U_{mf}

(Time averaged for 3 s)

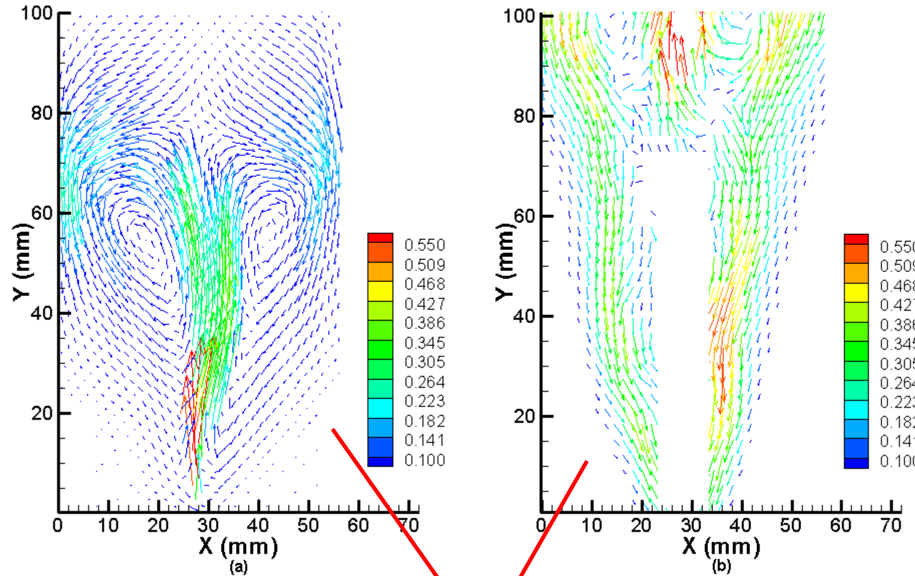
Void Fraction Contour



Simulation

Experiment

Velocity Vectors (colored by velocity magnitude)



Simulation

Dead Zones

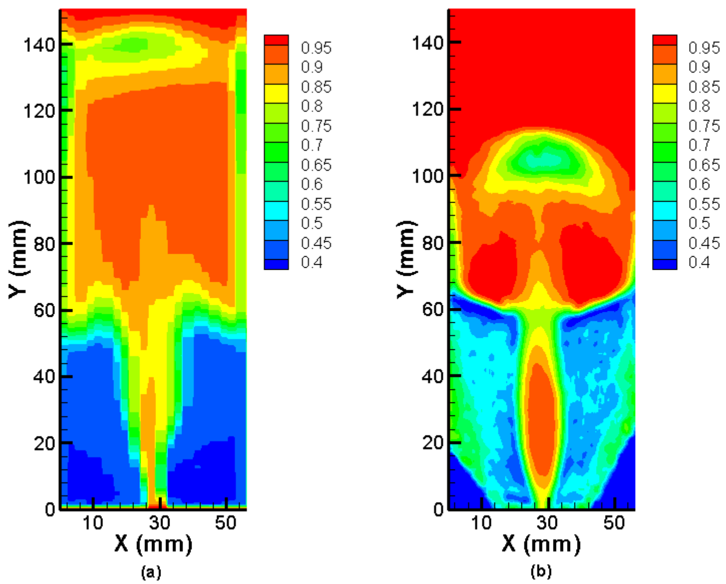
Experiment

- The results are time averaged for 3 seconds after the first 5 seconds.
- The experimental velocity vectors inside the jet are masked as the PIV resolution is not sufficient to capture the high particle velocities inside the jet.
- Void fractions compare closely to the experiment.
- Dead zones are higher in experiment compared to simulation.

Results – Single Jet 3.0 U_{mf}

(Time averaged for 3 s)

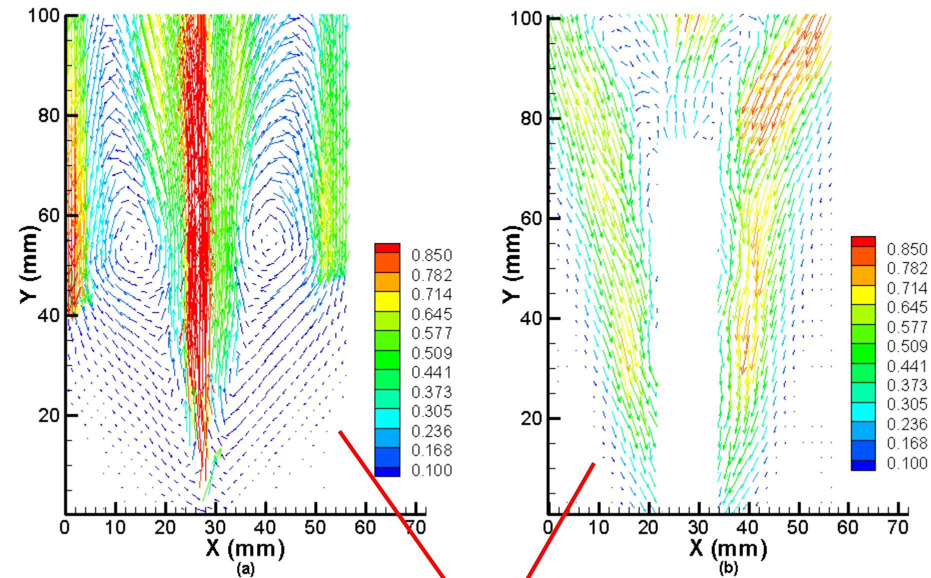
Void Fraction Contour



Simulation

Experiment

Velocity Vectors (colored by velocity magnitude)



Simulation

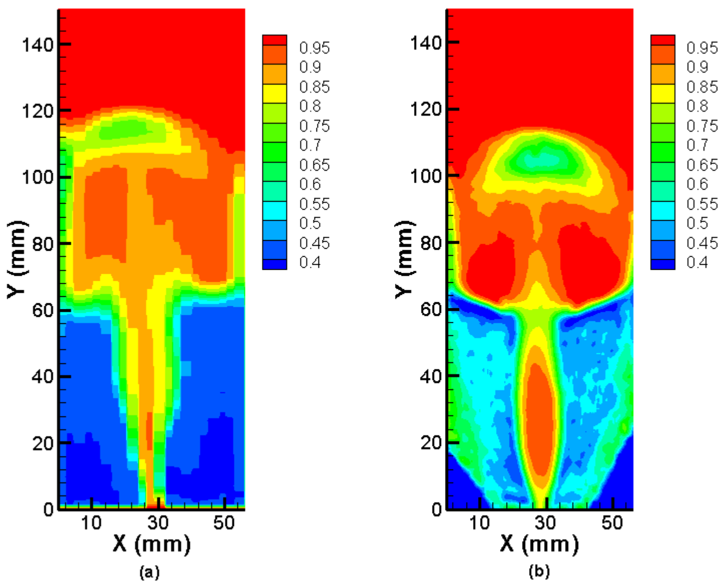
Dead Zones

Experiment

- Fountain formation can be seen in both the experiment and simulation.
- The simulation over predicts the fountain height.
- This is due to higher particle-wall friction present in experiment.
- High central particle velocities can be seen in the simulation.

Results – Single Jet
3.0 U_{mf} with higher wall friction
(Time averaged for 3 s)

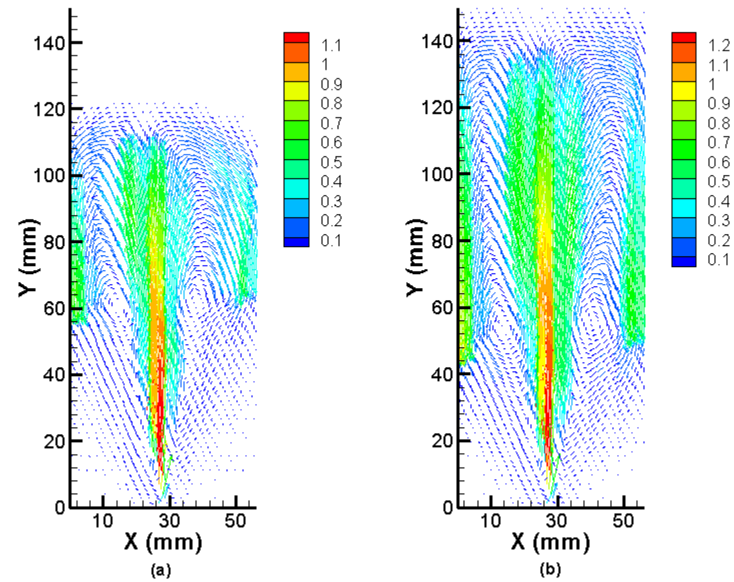
Void Fraction Contour



Simulation

Experiment

Comparison of Velocity Vectors (colored by velocity magnitude)



Simulation with wall-particle Friction coeff. = 0.5

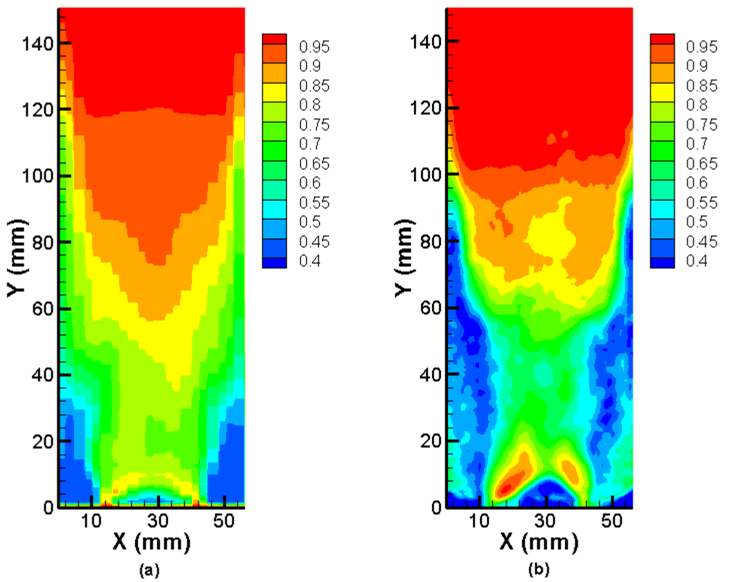
Simulation with wall-particle Friction coeff. = 0.1

- A single case to test the effect of wall-particle friction has been shown.
- The wall-particle friction coefficient has been increased to 0.5 from 0.1.
- The cluster of particles/fountain has come down and compares closely with experiment.
- A slightly higher dead zone formation can be observed in the velocity vectors.

Results – Multiple Jets 3.0 U_{mf}

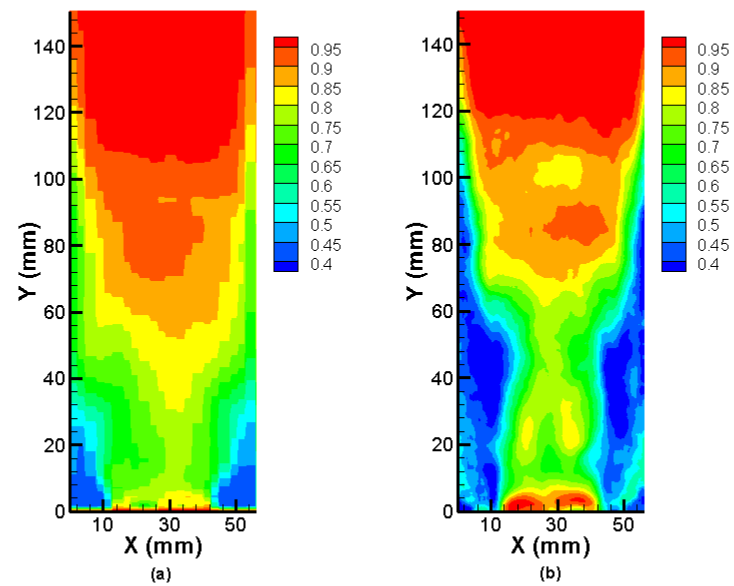
(Time averaged for 3 s)

Void Fraction Contour (Double Jets)



Simulation Experiment

Void Fraction Contour (Triple Jets)



Simulation Experiment

- Experimental PIV is not suited to capture velocity vectors for multiple jets.
- Void fraction profiles compare well with the experiments.
- Parabolic void fraction profiles can be seen for both the simulations and experiments.
- Lower wall-particle friction leads to smaller dead zones in the simulations.
- Bed expansion is comparable with the experiments.

Conclusions

- The commonly used single grid approach in coupled CFD-DEM calculations is limited by the requirement of having coarser fluid grid for stability.
- To overcome this limitation, a two-grid method has been implemented and tested on jetting fluidized beds.
- For the 3 U_{mf} and single jet case, DEM predicts a higher fountain height compared to the experiment.
- Much better agreement of the predicted fountain height with the experiment is achieved with a higher wall-particle friction coefficient.
- Overall, the trends predicted by the two-grid scheme are in agreement with experimental observations, particularly for multiple jets. The single grid framework was tried with this setup and it became unstable.

THANK YOU

Questions?