Drag Calculation Coupling with Clustering Phenomenon for Gas-solid Circulating Fluidized Bed Risers

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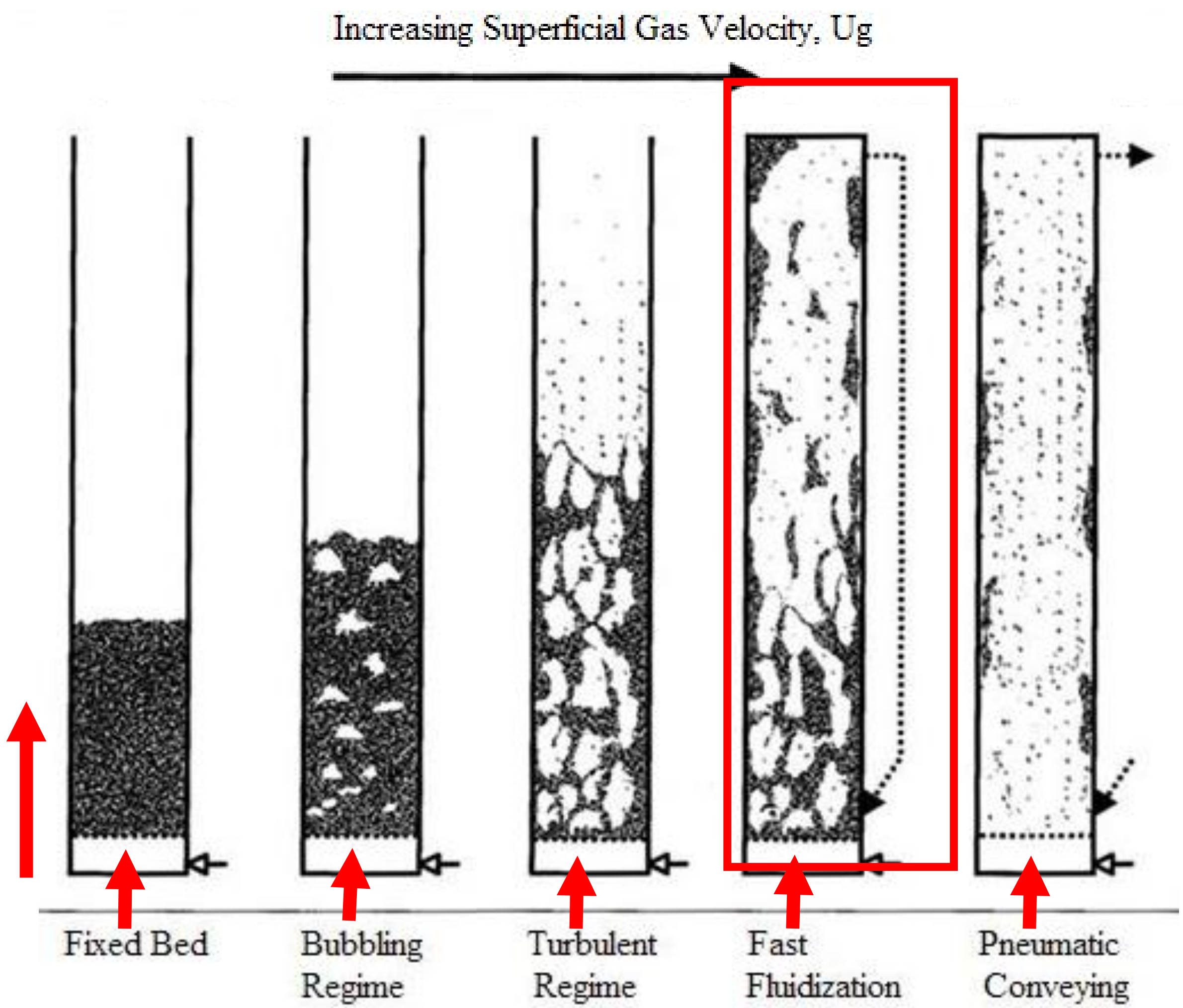
Outline

1. Introduction
2. CFD model descriptions
3. The concept of cluster-driven drag calculation
4. Configuration of the CFB riser
5. Results of hydrodynamic simulations
6. Conclusions

Various Gas–Solid Fluidized Beds



Fast fluidization provides

1. enhanced heat and mass transfer
2. independent control of gas and particles
3. high productivity

Escudero, David Roberto, "Bed height and material density effects on fluidized bed hydrodynamics" (2010). Graduate Theses and Dissertations. 11656.

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Applications

FCC

Coal and biomass Gasification

Calcination

Coal and biomass Combustion

Gas absorption

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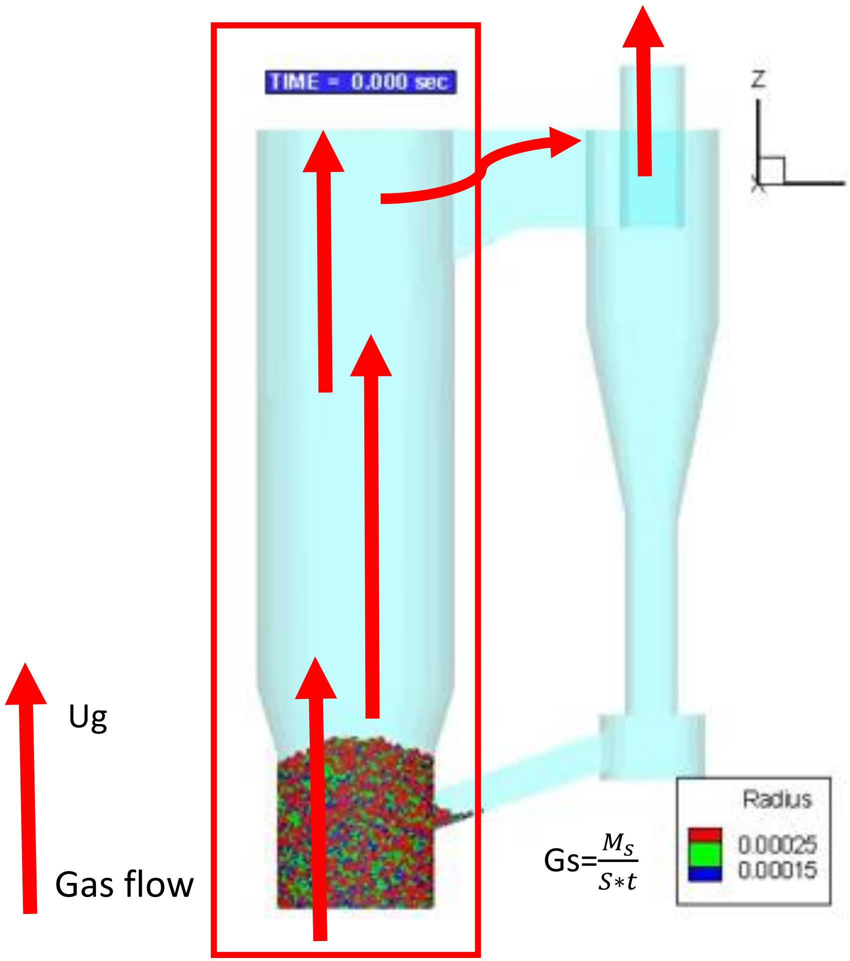
CFB apparatus



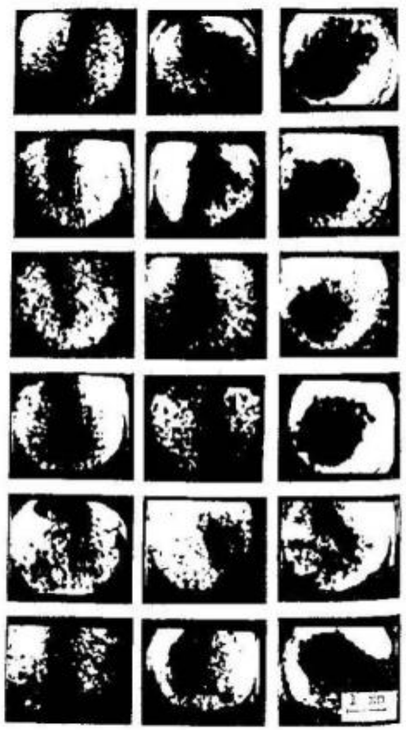
https://www.youtube.com/watch?v=EB0r6A5VxFU

Reactions:

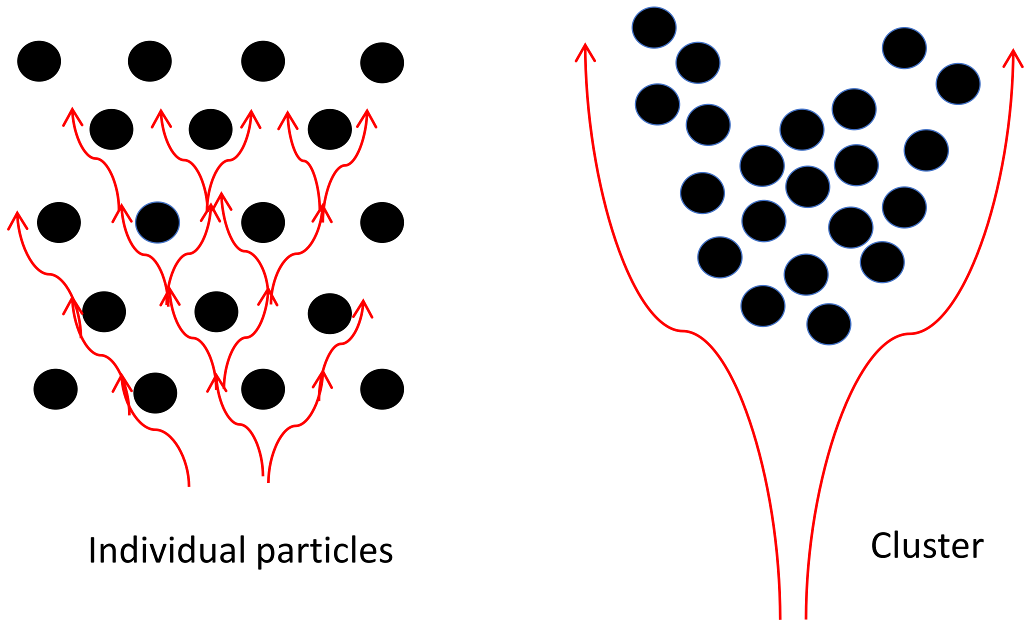
- Gas-reactant
  Particles-catalyst
  FCC
- Gas-reactant A
  Particles-reactant B
  Gasification, Combustion

The gas-particle interaction is crucial for the reactor performance.

Gas-particle interaction



Li, H., Xia, Y., Tung, Y., & Kwauk, M. (1991). *Micro-visualization of clusters in a fast fluidized bed. Powder Technology, 66(3), 231-235..*



Clusters influence the gas-particle interaction in the particle level.

Heat and mass transfer, back mixing, residence time....

Drag models in CFD

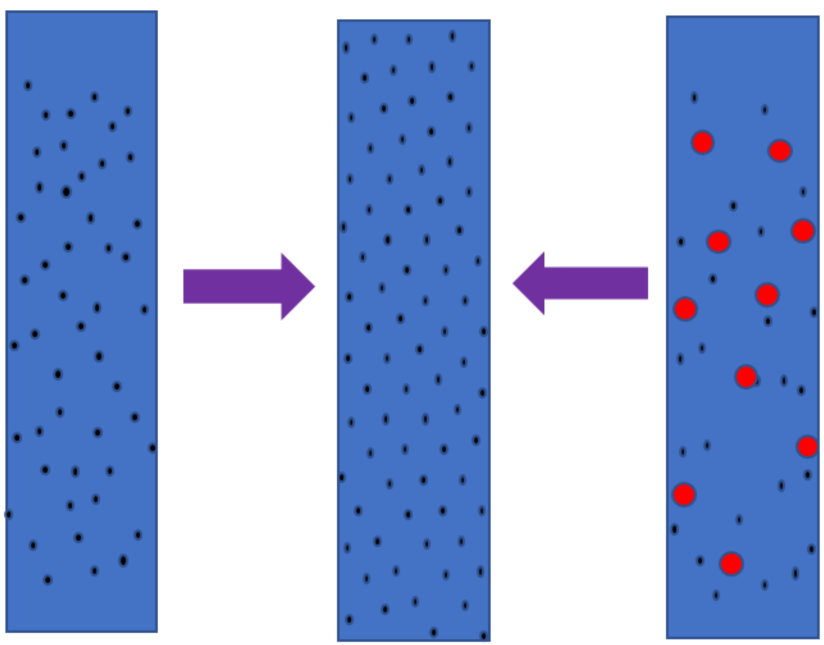
Modifications of drag model

Basic hydrodynamic EE approach coupled with KTGF CFD model

a realistic way to bridge the gap

$$D_F(\varepsilon_s, Re, \phi) = D_{ideal}\underbrace{(\varepsilon_s, Re, \phi)}_{\text{Properties of single particles}} \text{ x f } (\varepsilon_s, Re, \phi)$$

Validated CFD models



CFD model with drag modifications

Ideal gas-solids system

Drag model with a cluster phase

Drag models in CFD

Modifications of drag model

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$$D_F(\varepsilon_s, Re, \phi) = \underbrace{D_{ideal}(\varepsilon_s, Re, \phi)}_{\text{Properties of single particles}} \text{ x f } (\varepsilon_s, Re, \phi)$$

Validated CFD models

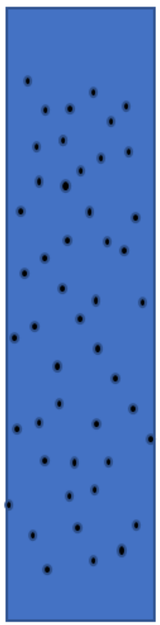
Our new approach:

present the clusters directly

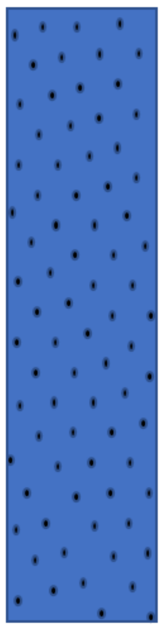
$$D_F(\varepsilon_s, Re, \phi) = D_{ideal}\underbrace{(\varepsilon_s, Re, \phi)}$$

Cluster size
Cluster density
Gs.c

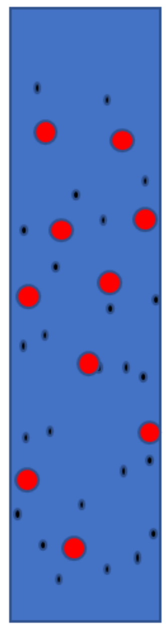
Image & wavelet analysis of micro-scale flow mechanism from the same group



CFD model with drag modifications



Ideal gas-solids system



Drag model with a cluster phase

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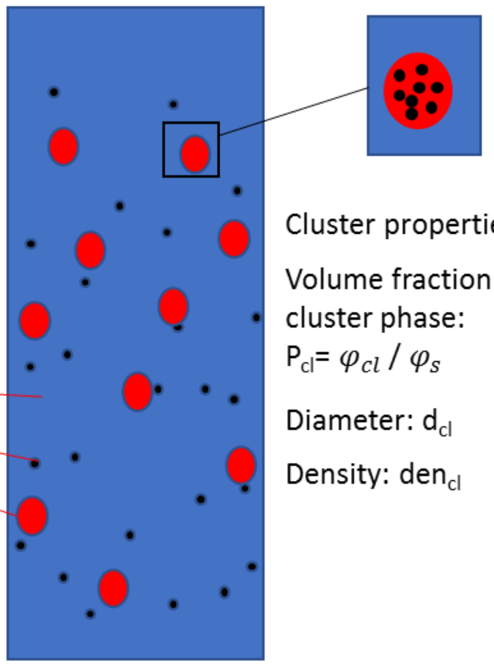
Cluster-driven drag calculation:

Assumption: clusters are stable spherical clouds of single particles existing in the bed (core clusters)

CFB riser



In the gas-solids system:
pure gas,
FCC single particles,
Clusters(FCC and gas)

Cluster properties:

Volume fraction of cluster phase:
$P_{cl} = \varphi_{cl} / \varphi_s$

Diameter: d_{cl}

Density: den_{cl}

Two classes:

class 1(FCC phase): FCC single particles

class 2(cluster phase): cluster phase

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Gas-solids two-fluid model description

The interactions between the gas and solids – drag calculation

Drag model used as the benchmark:

- Syamlal and O'Brien drag model:
- $\mathrm{Kgs} = \frac{3\alpha_s\alpha_g\rho_g}{4v_{r,s}^2 d_s}\left(0.63 + \frac{4.8}{\sqrt{\frac{Re_s}{v_{r,s}}}}\right)^2 \left(\frac{Re_s}{v_{r,s}}\right)|\vec{v_s} - \vec{v_g}|$
- Based on the measurements of the particle terminal velocity

The proposed drag calculation:

- Cluster-driven drag calculation
- Include the clustering effects in the drag calculation,
- Cluster size (d_{cl}), solid concentration in cluster (den_{cl}), and the percentage of the total solids captured in the cluster phase (P_{cl}) are collected from the averaged statistical data via image & wavelet analysis.

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Theory of multi-phase flows – CFD approaches

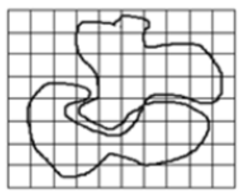
Eulerian-Eulerian

Fluids

$$\rho \frac{DV}{DT} = \nabla \bullet \sigma + f$$

Solids

$$\rho \frac{DV}{DT} = \nabla \bullet \sigma + f$$



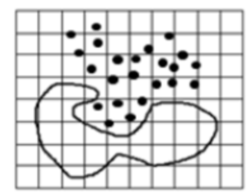
Eulerian-Lagrangian

Fluids

$$\rho \frac{DV}{DT} = \nabla \bullet \sigma + f$$

Solids

$$F = ma$$



Eulerian-Eulerian (E-E) approach:

- Both gas and solids phases: interpenetrating continua
- Costs less
- Implement the conception of kinetic theory of granular phase (KTGP)

Eulerian-Lagrangian (E-L) approach:

- Gas-phase: continuum phase, solids-phase: discrete phase
- Trace the movements of every single particle
- High computational cost and time

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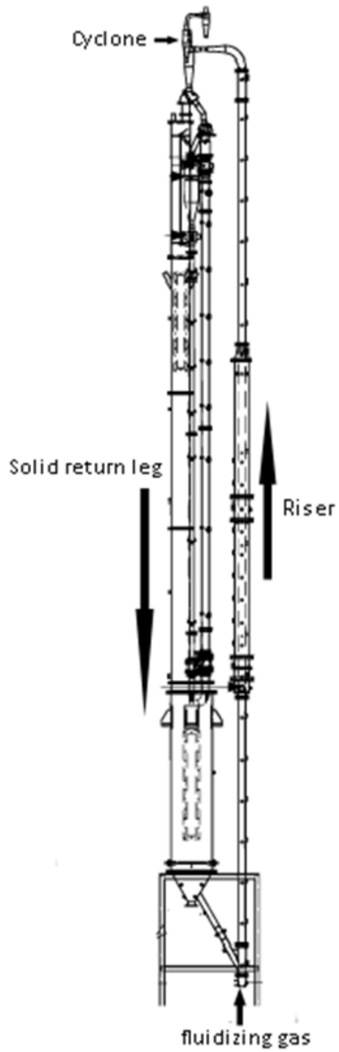
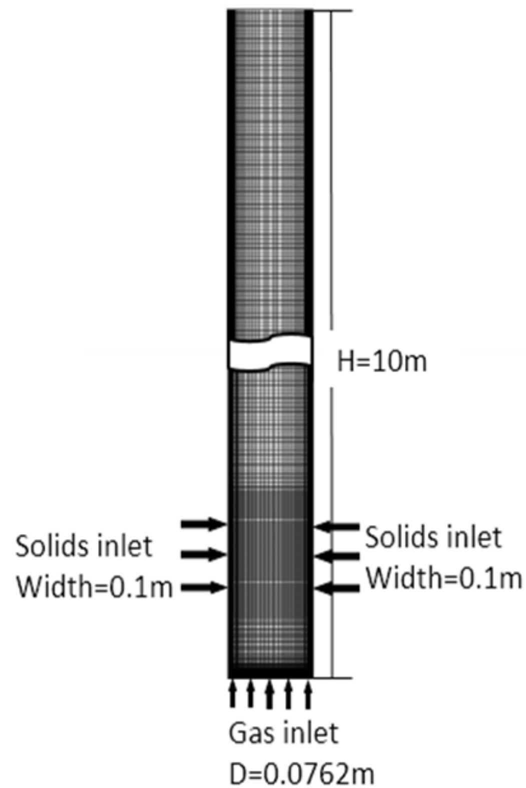
Configuration of the CFB riser

Mesh and solver of the CFB riser

- A quad grid system with finer mesh near the wall and the inlet
- Second order discretization scheme for turbulent kinetic energy and turbulent dissipation rate and other convection terms
- QUICK for momentum equation
- Convergence criterion:5e-04



Configuration of the CFB riser
(Li 2010)



Mesh for the calculation domain in the testing riser

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Operating conditions

- The transient E-E approach coupled with the kinetic theory of granular flow

Summaries of operating conditions	
Gas density (kg/m3)	1.225
Particle density (kg/m^3)	1500
Particle diameter (µm)	67
Superficial gas velocity (m/s)	2-9
Particle circulation rate (kg/m^2· s)	50-700
Particle-particle restitution coefficient	0.95
Specularity coefficient	0.0001

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Boundary conditions

Inlet	
Gas phase	Jet profile of velocity inlet Gas velocity=Ug/ ((1-ε_s) × opening ratio of the gas distributor) where εs is the solids volume fraction.
Solids phase	Uniform velocity inlet Solids velocity=Gs/ ($\varepsilon_s \times \rho_s$)
Wall	
Gas phase	No-slip velocity
Solids phase	Partial slip Specularity coefficient: 0.0001 Particle-wall restitution coefficient: 0.9
Outlet	
Gas phase	Outflow
Solids phase	Outflow

Summary of CFD cases for simulation

Case #	Ug, m/s	Gs, kg/m^{2}s	Drag calculation	Cluster diameter, d_{cl}, m	Custer solids holdup, ε_{cl}	Solids portion in clusters, p
1	5	100	Syamlal-O'brien model (OS)	NA	NA	NA
2	5	100	Schiller&Naumann model	NA	NA	NA
3	5	100	Gidaspow model	NA	NA	NA
4	5	100	Cluster driven model	0.006	0.052	0.5
5	5	300	Syamlal-O'brien model (OS)	NA	NA	NA
6	5	300	Cluster driven model	0.0052	0.185	0.5
7	7	300	Syamlal-O'brien model (OS)	NA	NA	NA
8	7	300	Cluster driven model	0.0051	0.1196	0.5

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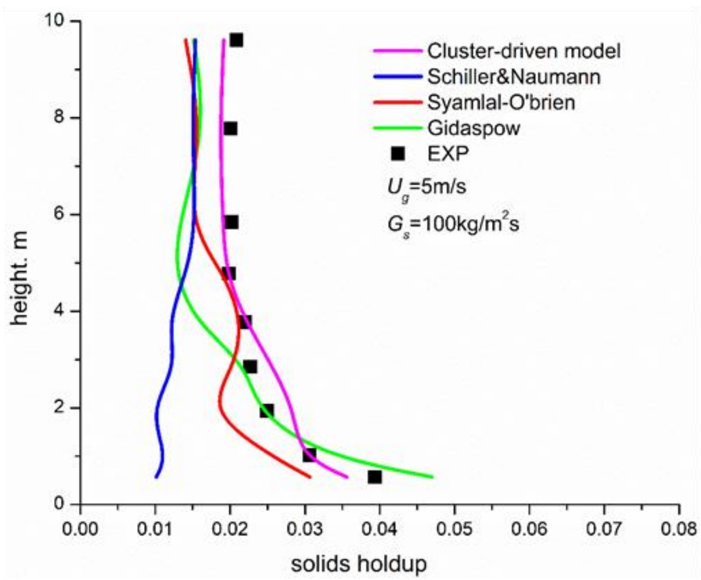
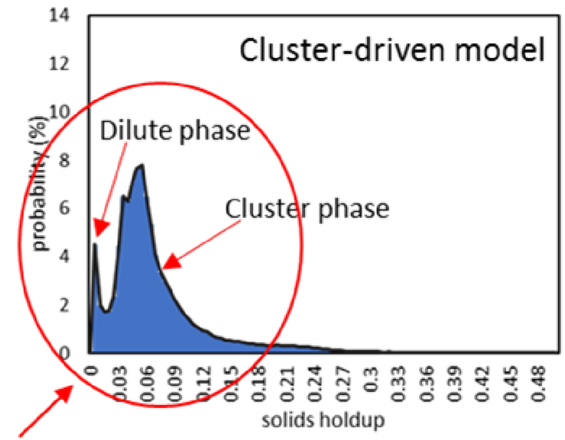
Results of hydrodynamic simulations – model validation

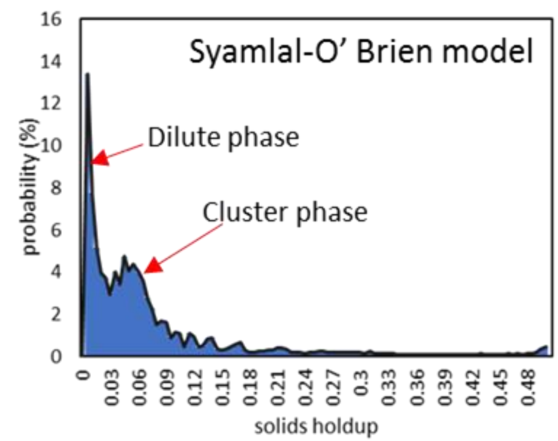


Comparison of numerical results from axial solid holdup profiles by different drag models

Good agreement with the experimental data
As well as the commonly used drag calculatior



Higher fraction of particles
in forms of clusters



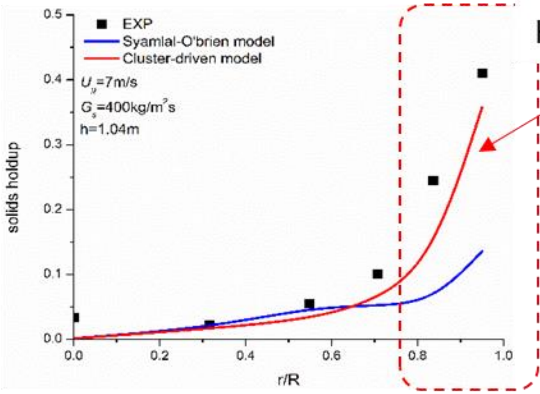
Probability density distribution of overall solids holdup in the CFB riser

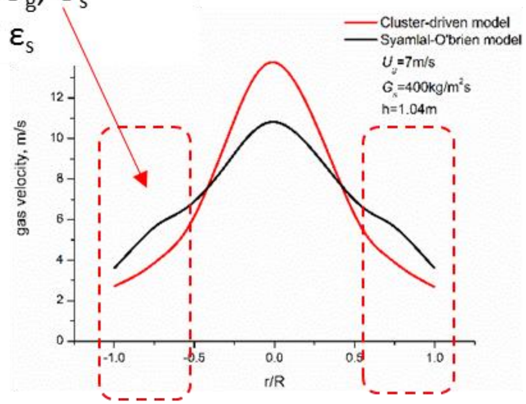
Results of hydrodynamic simulations

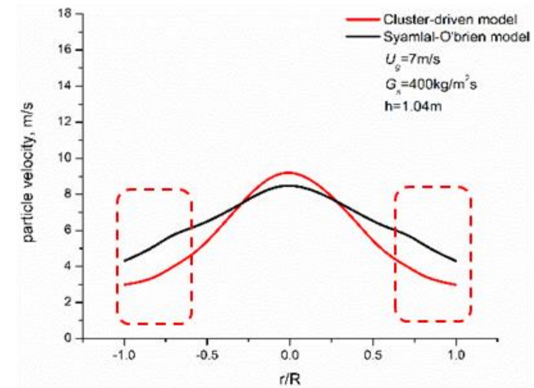
— Local flow structures in CFB riser

In the developing region

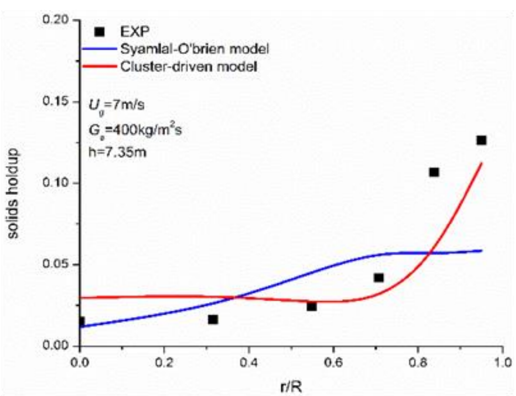
Lower U_g, U_s
Higher ε_s





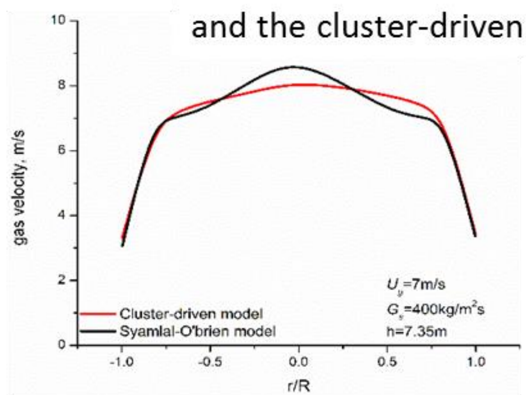


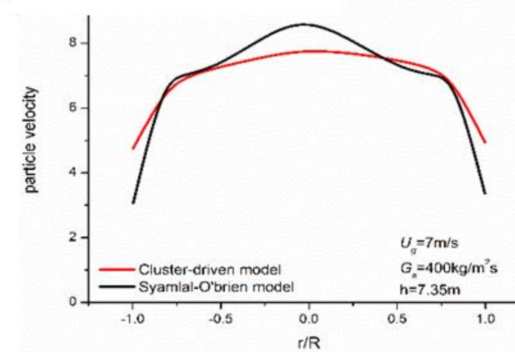
In the fully developed region



Core-annulus radial profile of solids holdup

Simulation results are close between SO model and the cluster-driven model





Parabolic profiles of gas and solids velocities

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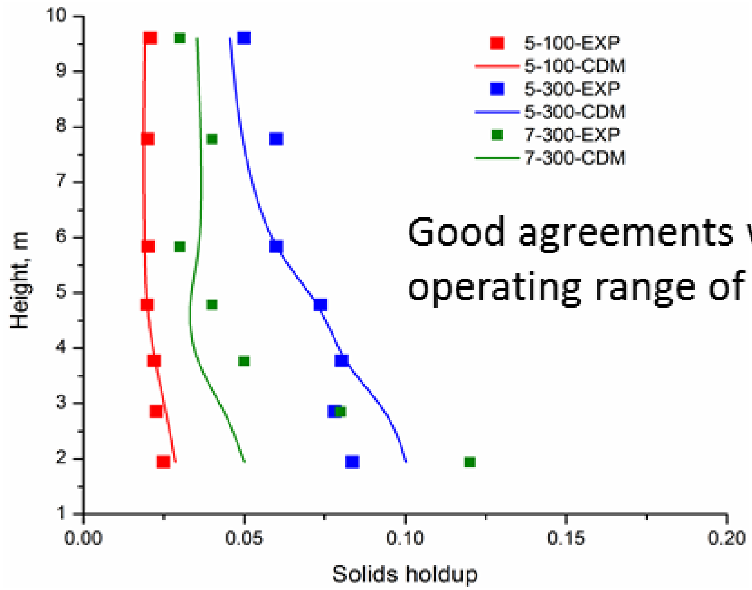
Results of hydrodynamic simulations

— General flow structures in CFB riser



Good agreements within a wide operating range of the CFB riser

Axial profiles of solids holdup under different operating conditions by the proposed drag calculation

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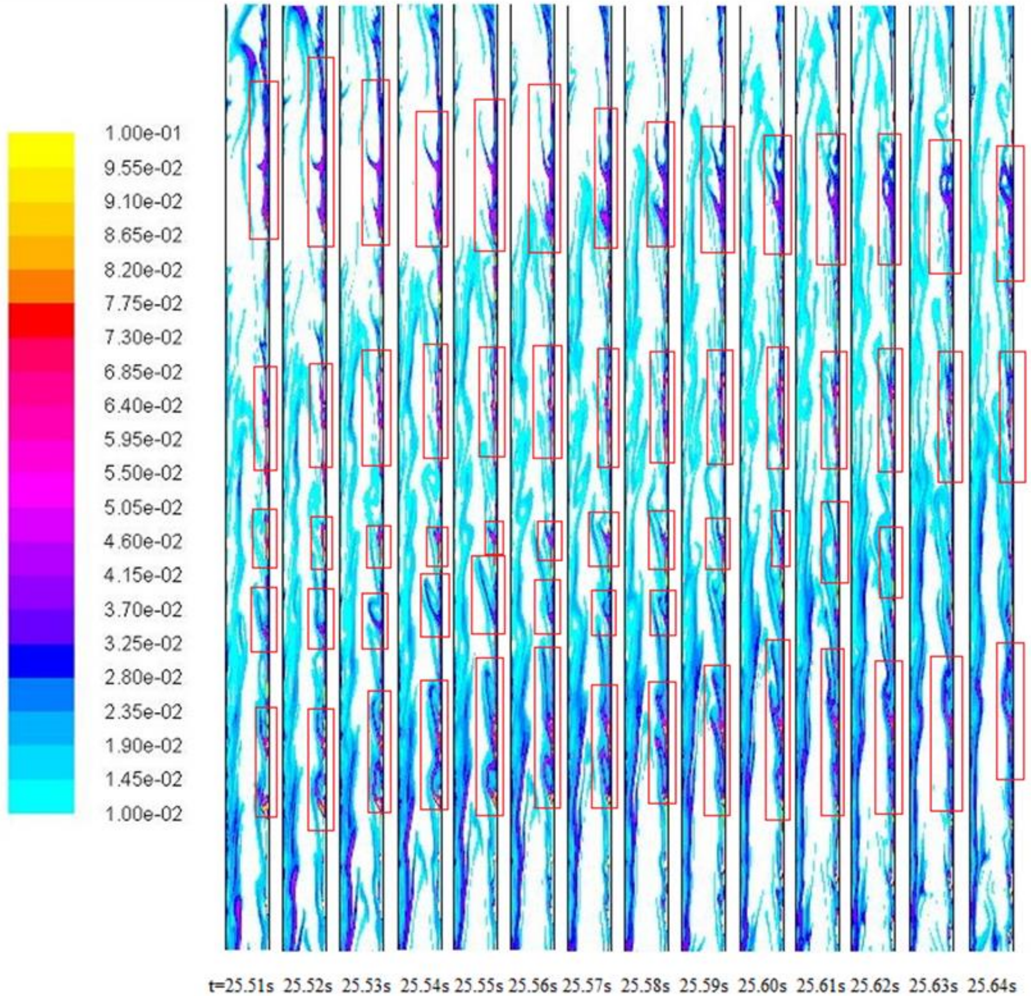
The fidelity of modelling work

—Compared with images

Clustering strands at wall



CFD results

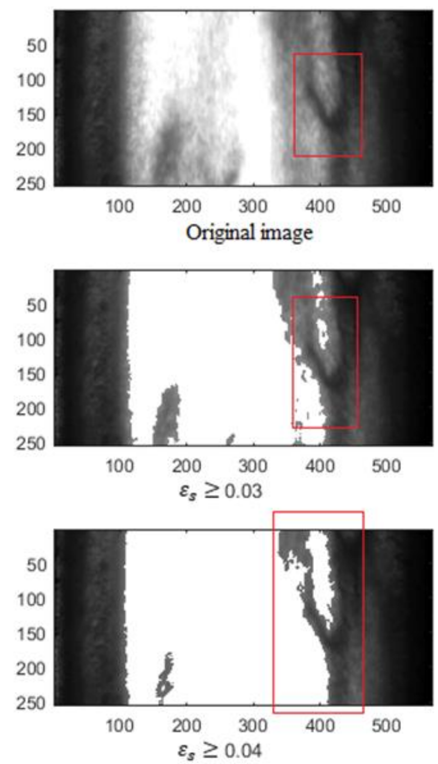


Image processing results

Conclusions

- A cluster-driven drag calculation model is applied into the Eulerian-Eulerian two-fluid model to numerically study the gas-solids circulating fluidized bed riser.
- Statistical data of the particle clusters such as cluster diameter, average solid concentration of clusters, and the portion of solids in form of clusters are collected by image processing & wavelet analysis, and are employed into the drag calculation of clusters.
- Improvements are made by employing more realistic properties of clusters in the cluster-driven drag calculation, such as a good agreement of the axial solids holdup profile with the experimental data and a better agreement of local solids distribution especially in the wall region of the riser.

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рахмат
danke
謝謝
ngiyabonga
teşekkür ederim
spas
Баярлалаа
mersi
kia ora
barka
welalin
tack
mahalo
tapadh leat
faafetai lava
vinaka
dank je
misaotra
paldies
grazzi
kiitos
dankie
спасибі
blagodaram
matondo
nandri
dhanyavad
maururu
thank you
gracias
köszönöm
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dankon
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ありがとう
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ευχαριστώ
diolch
dhanyavadagalu
shukriya
mercê
তোমাকে ধন্যবাদ
감사합니다
xièxie
merci