Fluidization Characteristics of Spherocylindrical Particles and Binary Mixtures
Experiment and CFD-DEM Simulation

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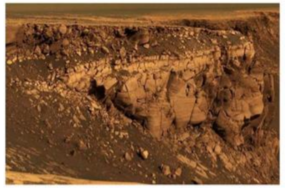
I. Background

- **High particulate yield:** In 2017, global production of particulate matter had exceeded **17 billion tonnes**.
- **Large proportion of non-spherical particles:** Non-spherical particles account for **70%** of total particulate matter (cylindrical, spherocylindrical, ellipsoidal, polyhedral, etc.).
- **Wide range of application areas:** Energy, chemicals, agriculture, pharmaceuticals, food, mining, etc.


Rock accumulation


ore roasting


Mineral conveying


Grain drying

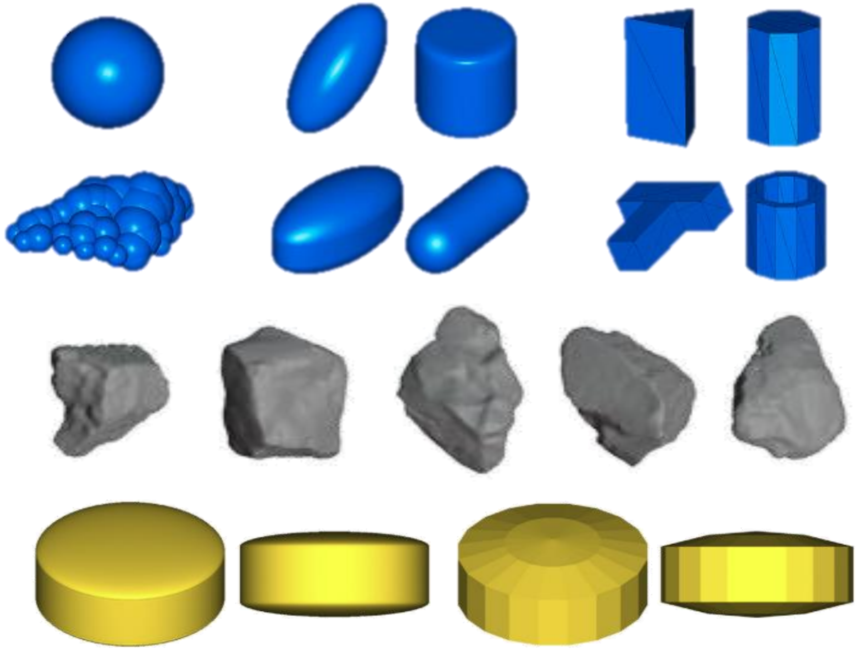

Biomass/waste combustion/gasification


Garbage grinding


Tablet coating


Airborne particle inhaling

Red blood cell flowing



I. Background

Gas-solid fluidized bed technology

- ✓ **Spouted bed:** A reactor that uses gas to pass through a layer of granular solids to keep the solid particles in a state of suspended motion and carry out a gas-solid phase reaction process.
- ✓ **Application scenarios:** Material drying, Tablet coating, Biomass/coal combustion, Gasification and pyrolysis, etc.
- ✓ **Advantages:** Better gas-solid contact, higher particle mixing efficiency, higher heat transfer efficiency, suitable for handling irregular and other unconventional particles.


Agricultural production

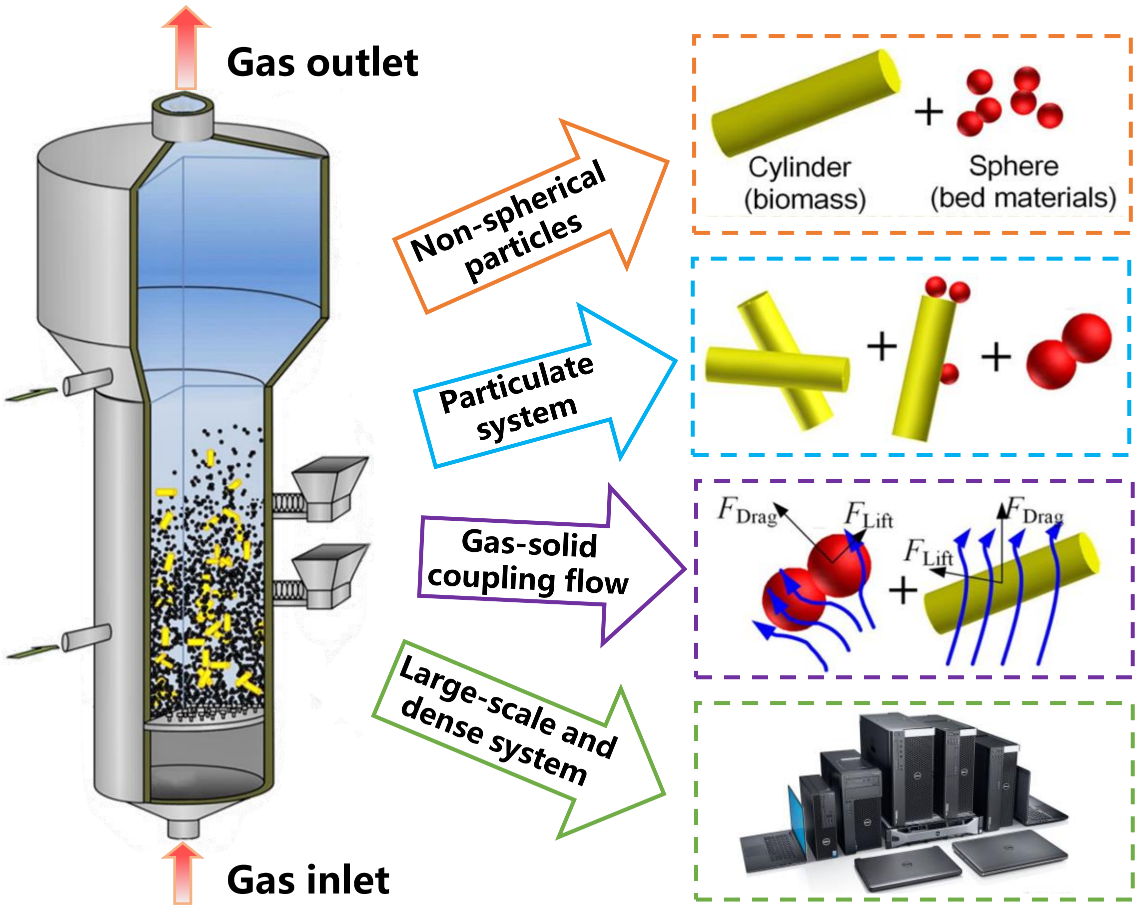

Food processing


Medicine manufacturing


Thermal response

I. Background

Biomass combustion and gasification



Schematic diagram of biomass fluidized bed gasifier (Zhong et al. 2016)

Gas - Spherical particles

Spherical particles-Spherical particles

⇩

Gas - Non-spherical particles

Non-spherical particles - Non-spherical particles

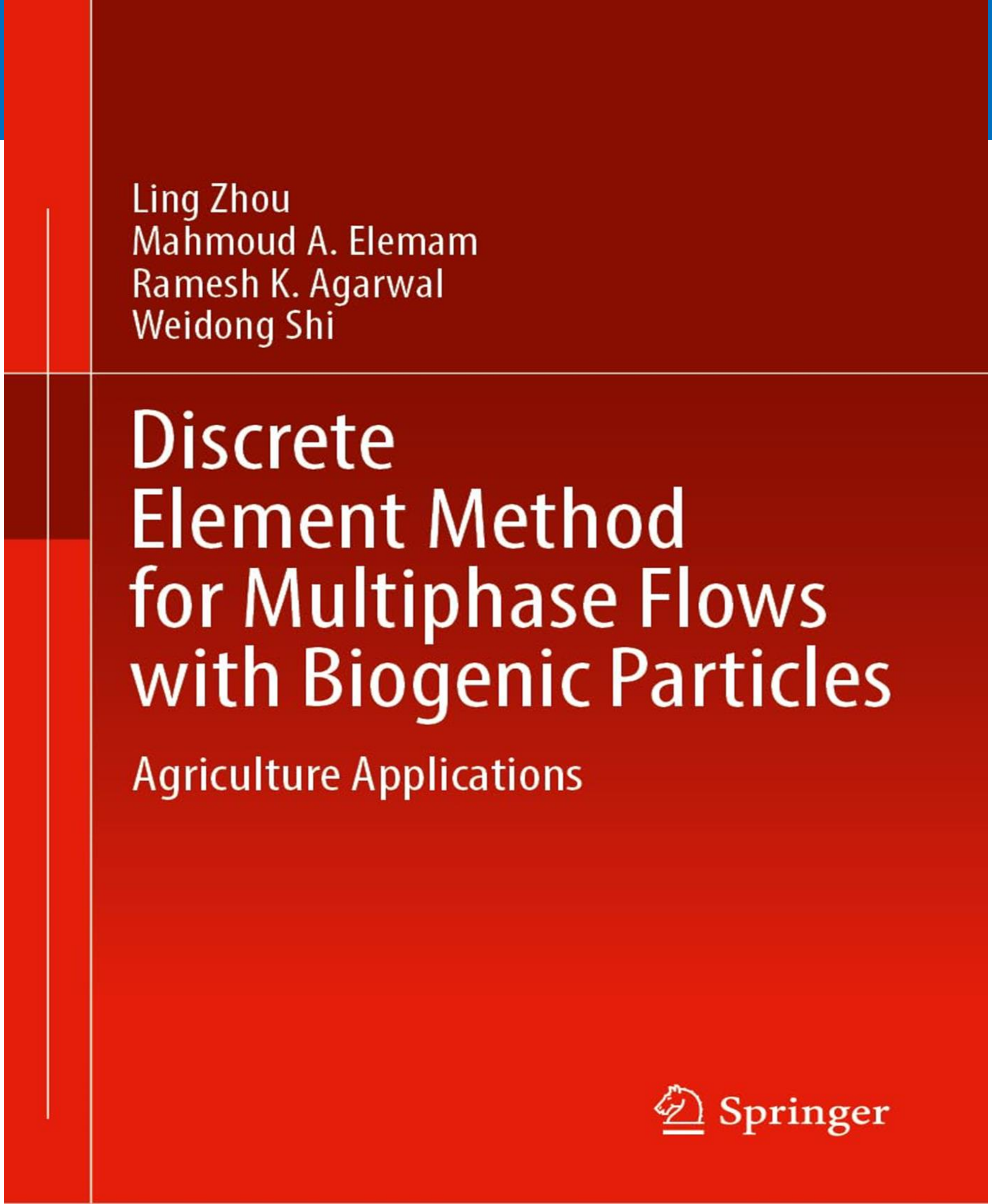
⇩

Gas-binary particle mixtures

Contact collision of particles of different shapes

One-component particles

Multi-component particles



Ling Zhou
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Weidong Shi

Discrete Element Method for Multiphase Flows with Biogenic Particles

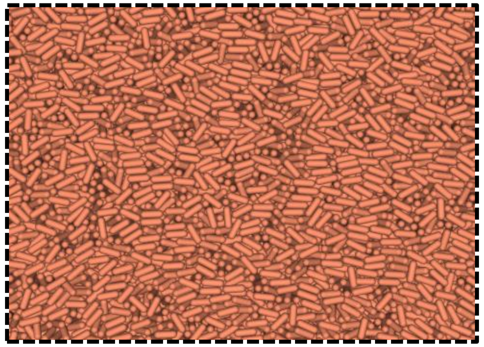
Agriculture Applications

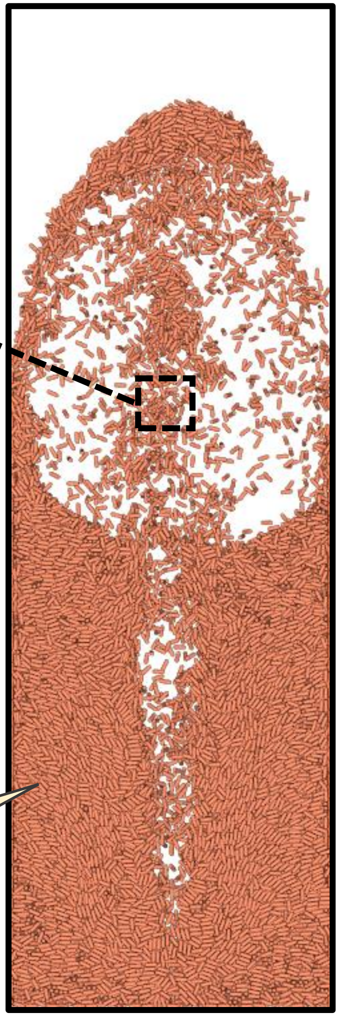
Springer

Research I : Single-Component Spherocylindrical Particles

- Particle void fraction
- Particle velocity
- Particle orientation
- Particle bed height
- Particle mixing

One-component spherocylindrical systems



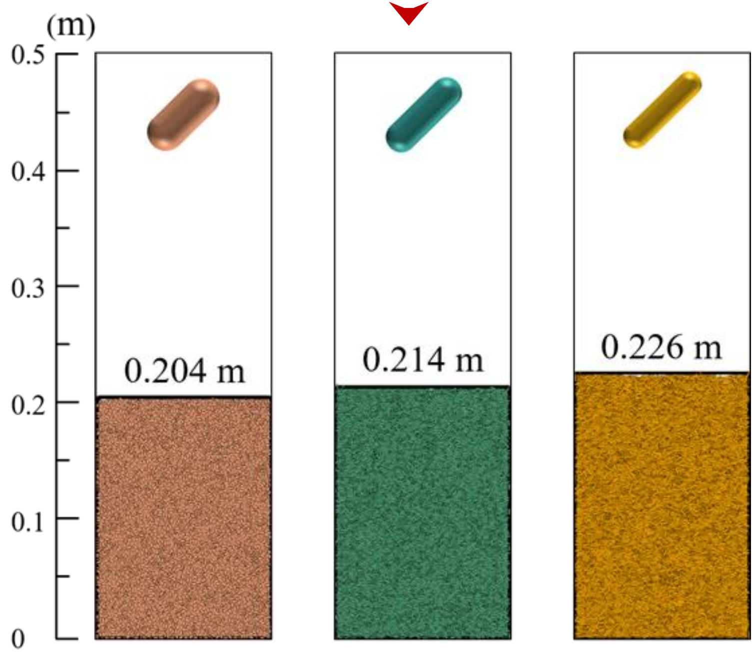


Different gas velocities

(Q_{m}=5 g/s、 6 g/s 、 7 g/s)

Different particle aspect ratios

(AR=2、 AR=3 、 AR=4)

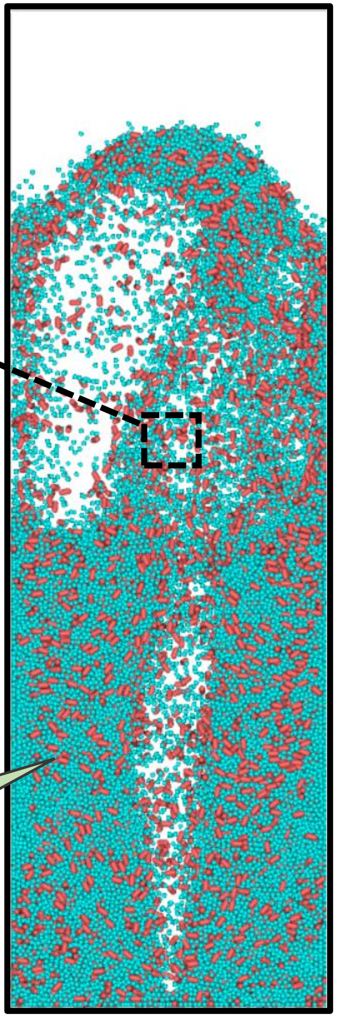


Initial stacking bed

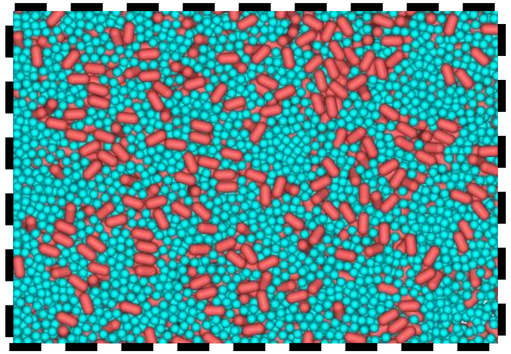
CFD Software: Fluent – DEM Software: ANSYS Rocky

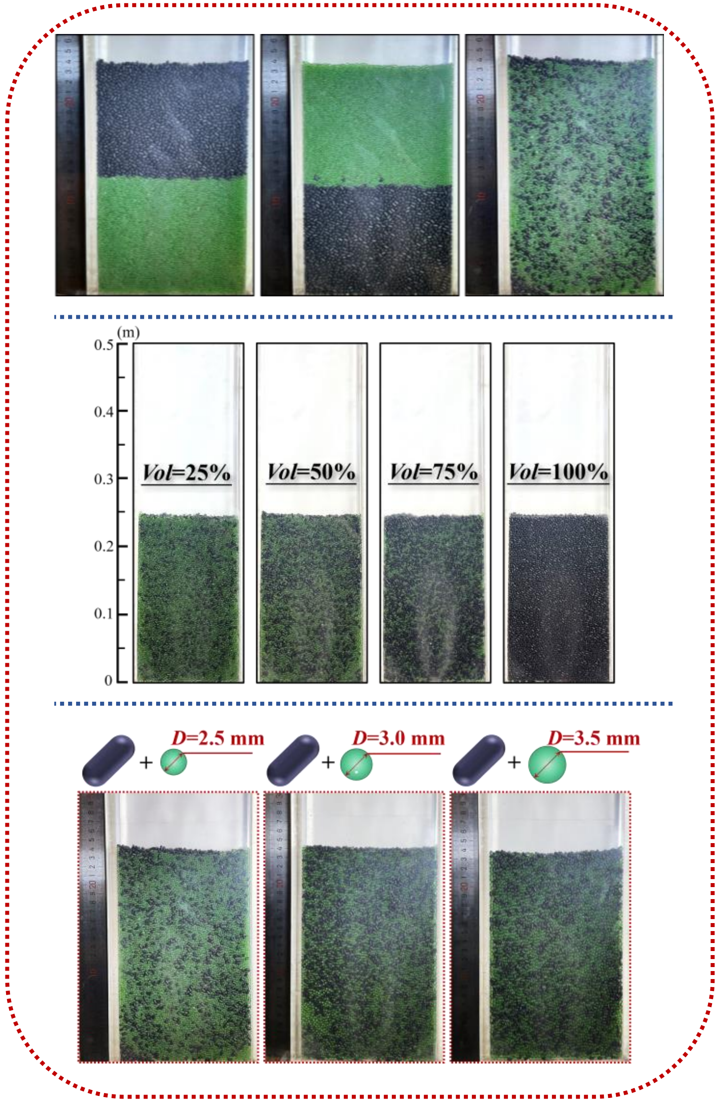
Research Ⅱ: Binary Particle Systems

- Void/volume fraction
- Kinetic energy
- Particle orientation
- Particle separation
- Particle drag force
- heat transfer



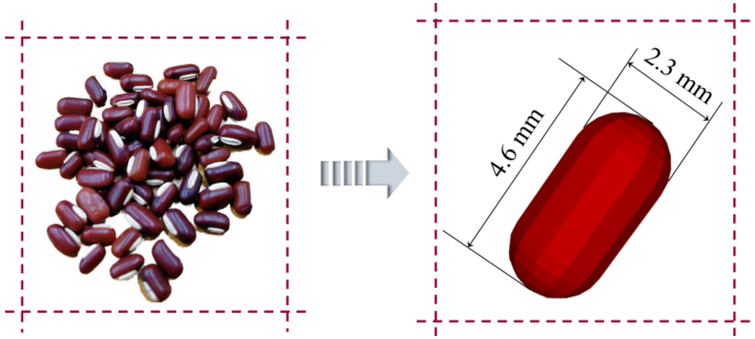
Mixing of spherocylindrical particles with spherical particles





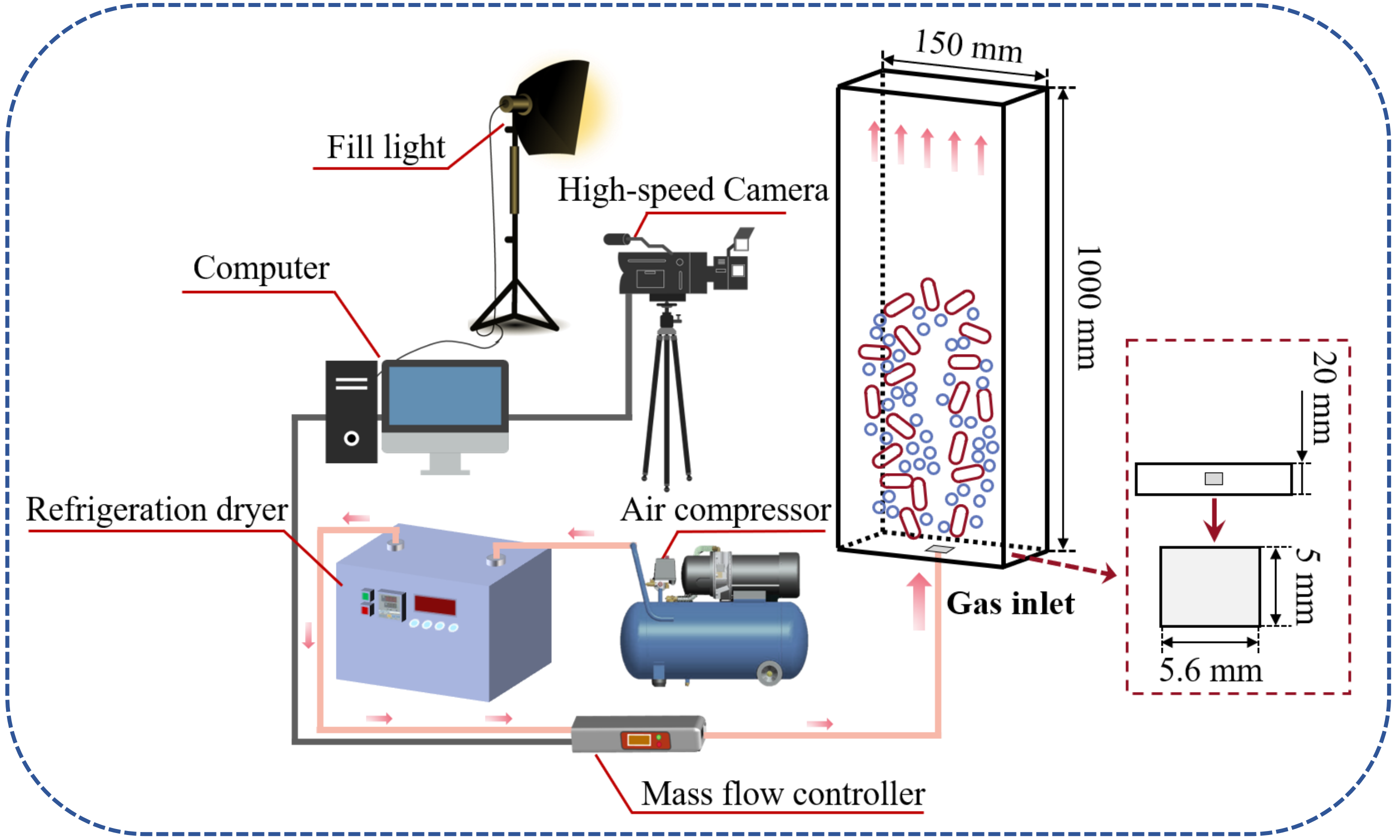
Different particle stacking modes / mixing ratios / particle sizes

Experimental Setup and its Schematic



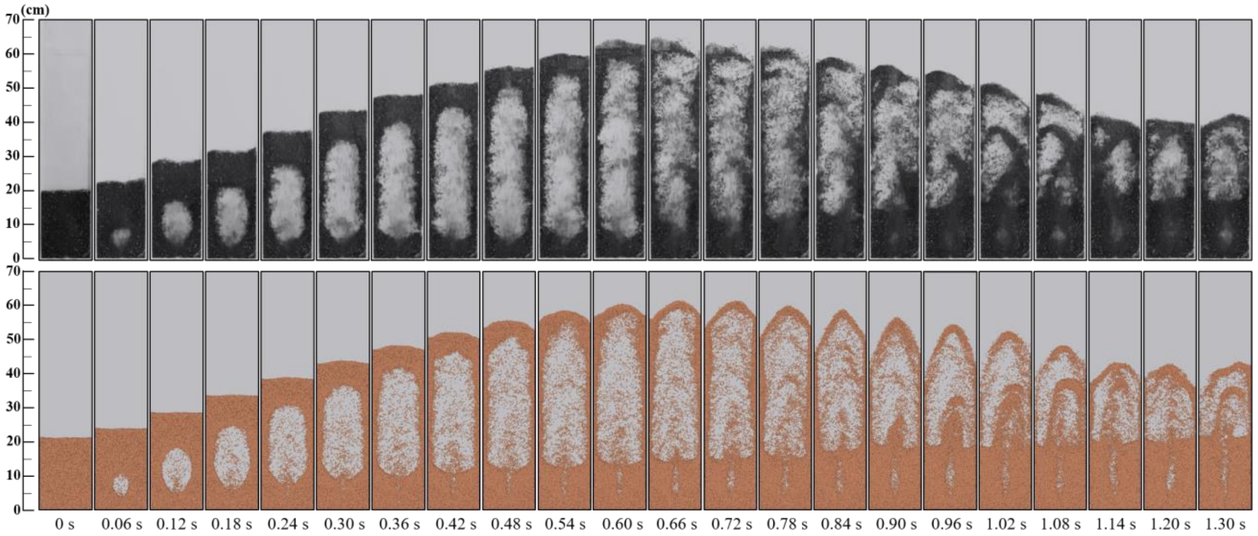
In the study of single component spherocylindrical particles, adzuki beans were used as experimental material

Spouted bed field test bench



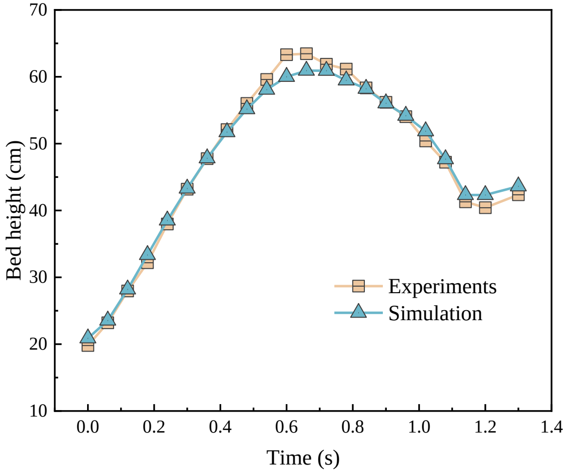
Schematic diagram of experiment

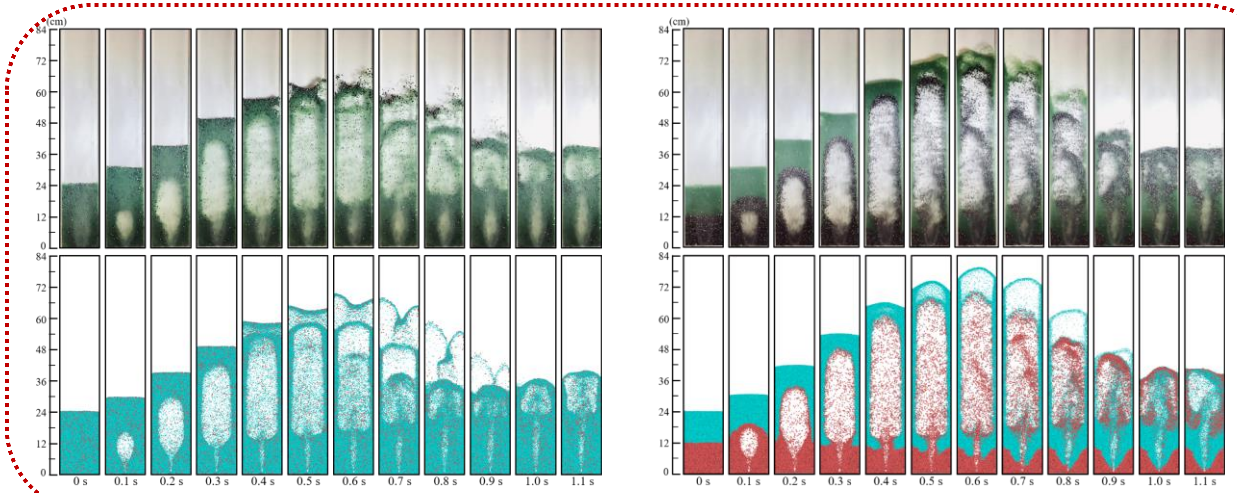
1. Model Validation



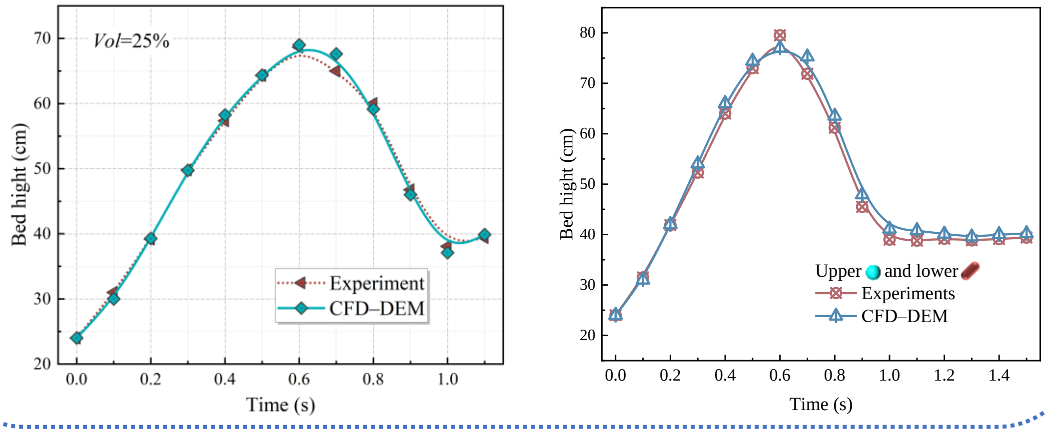
High-speed photographic experiments

One-component particle systems





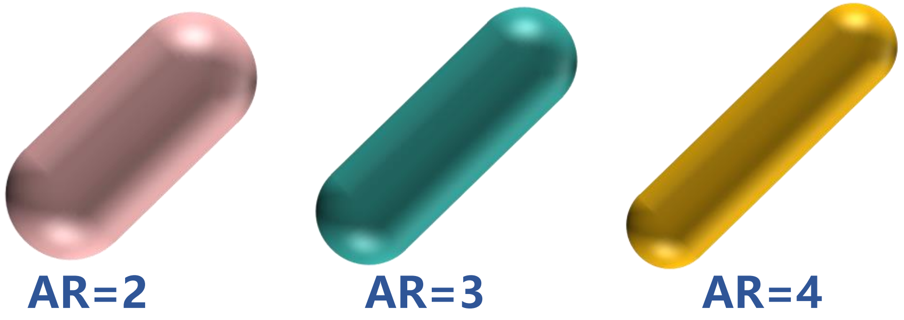
Binary particle systems



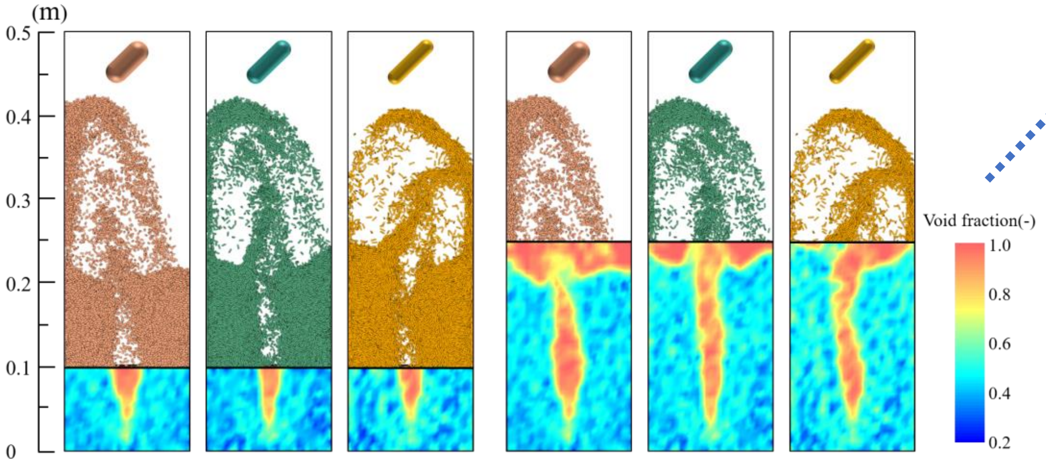
Bed height of particles in simulation compared to experiments

2. Particle/Volume Void Fraction

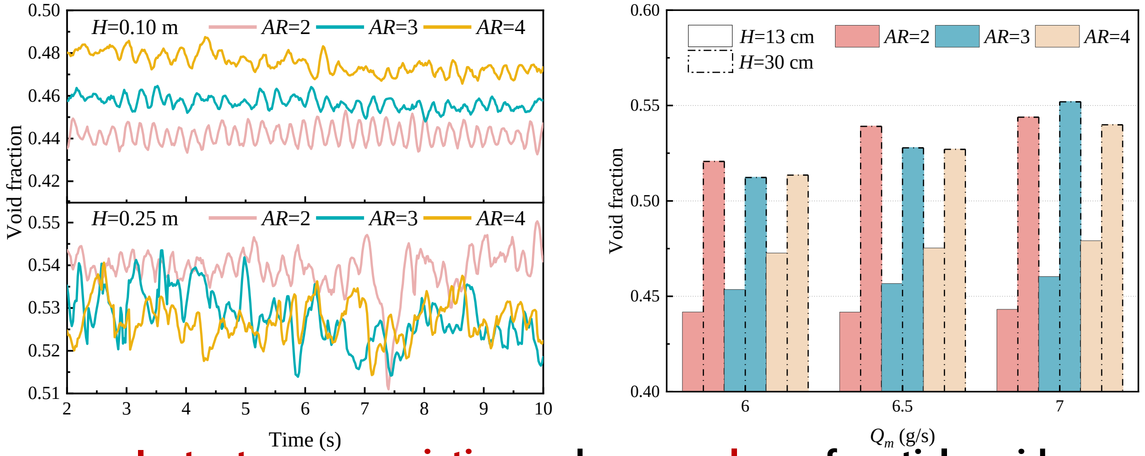
- **Particle void fraction**



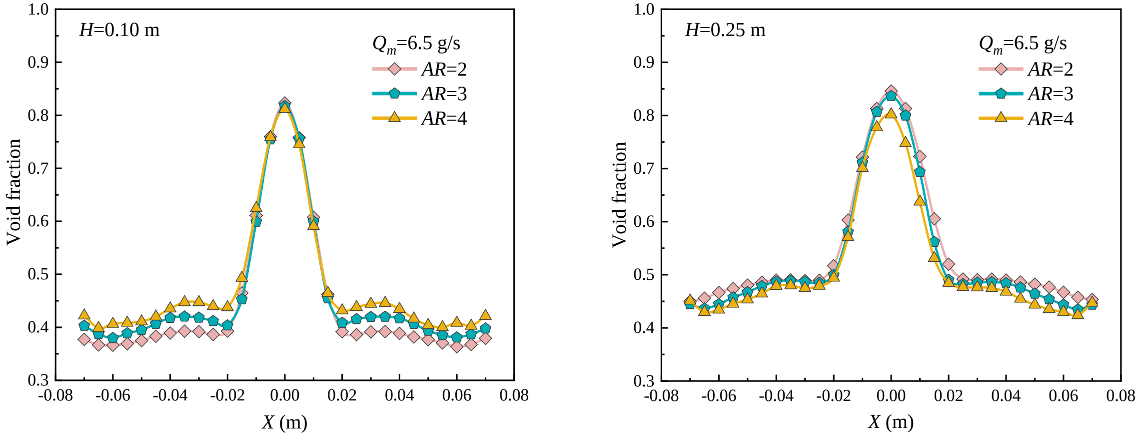
One-component spherocylindrical particles



Instantaneous distribution of particle void fraction



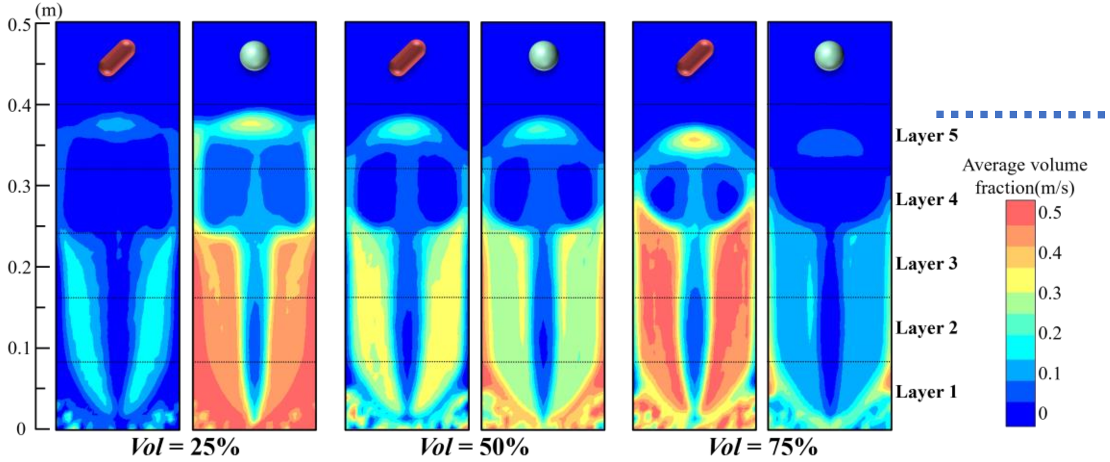
Instantaneous variation and mean values of particle void fraction

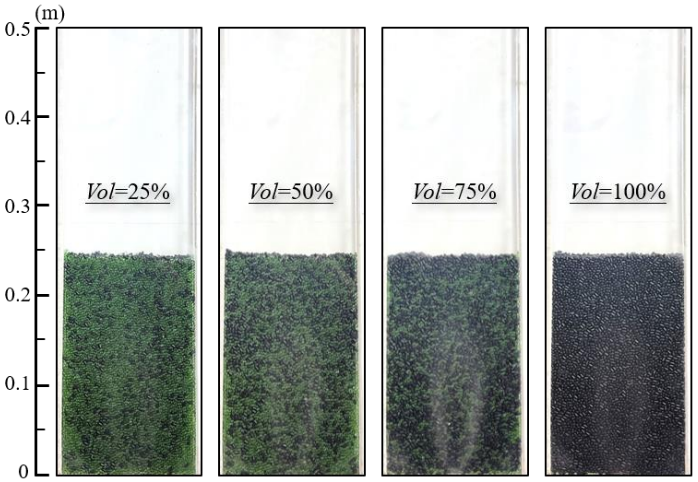


Radial distribution of particle void fraction

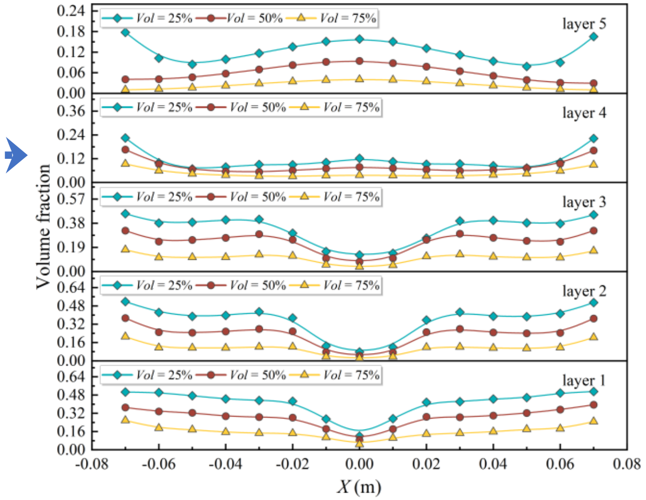
2. Particle Void/Volume Fraction

- **Particle volume fraction**

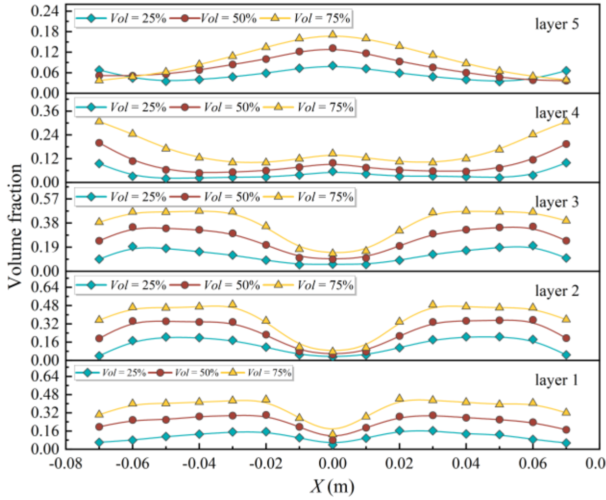


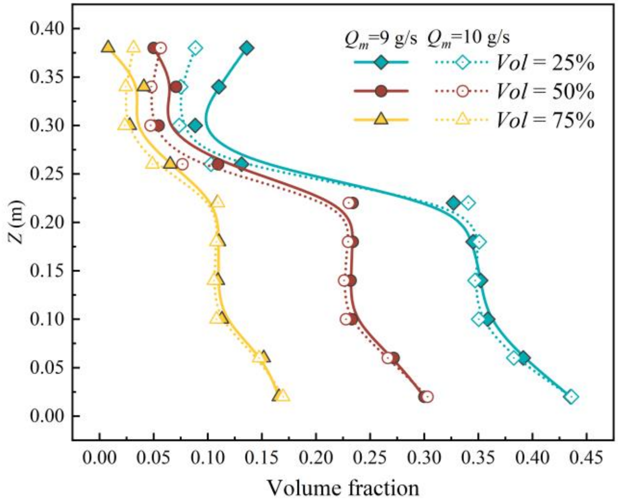


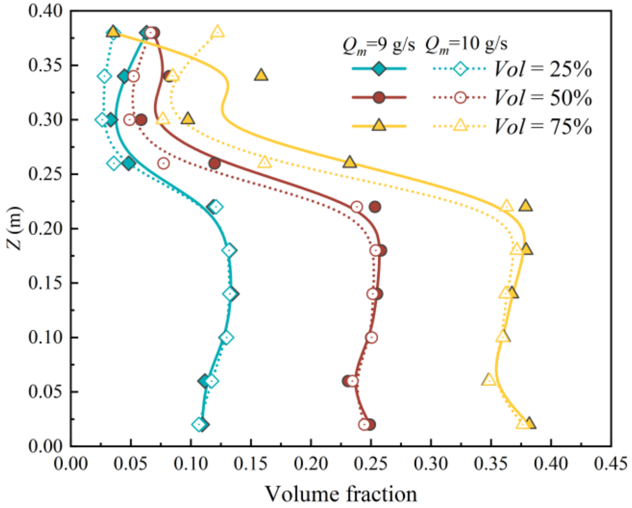
Spheres



Spherocylinders



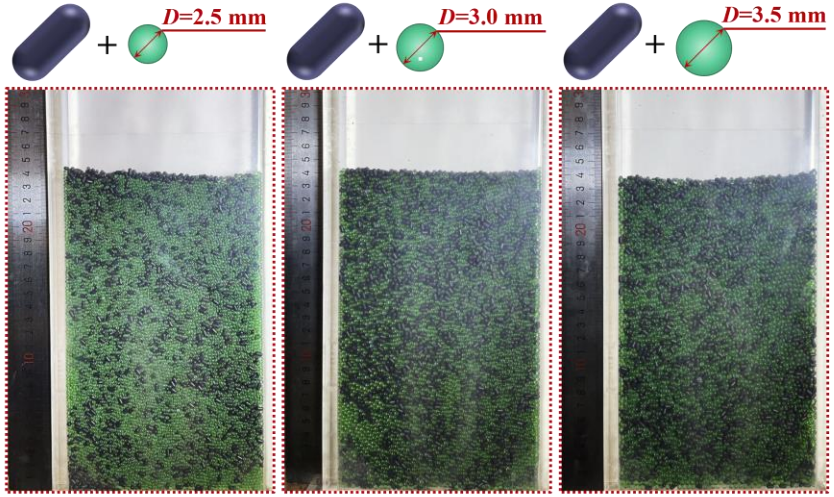


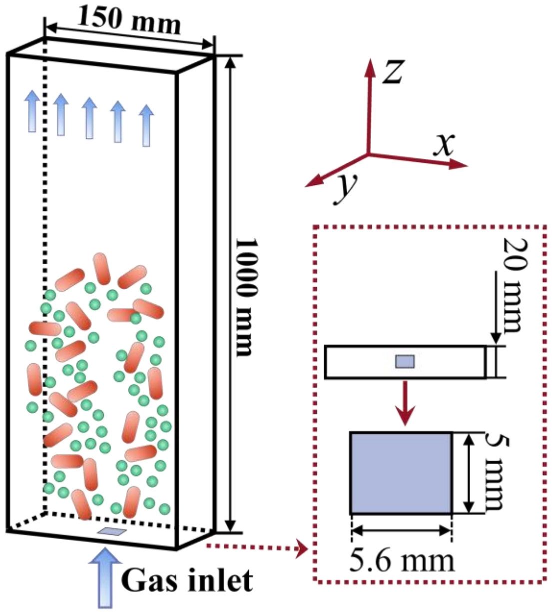


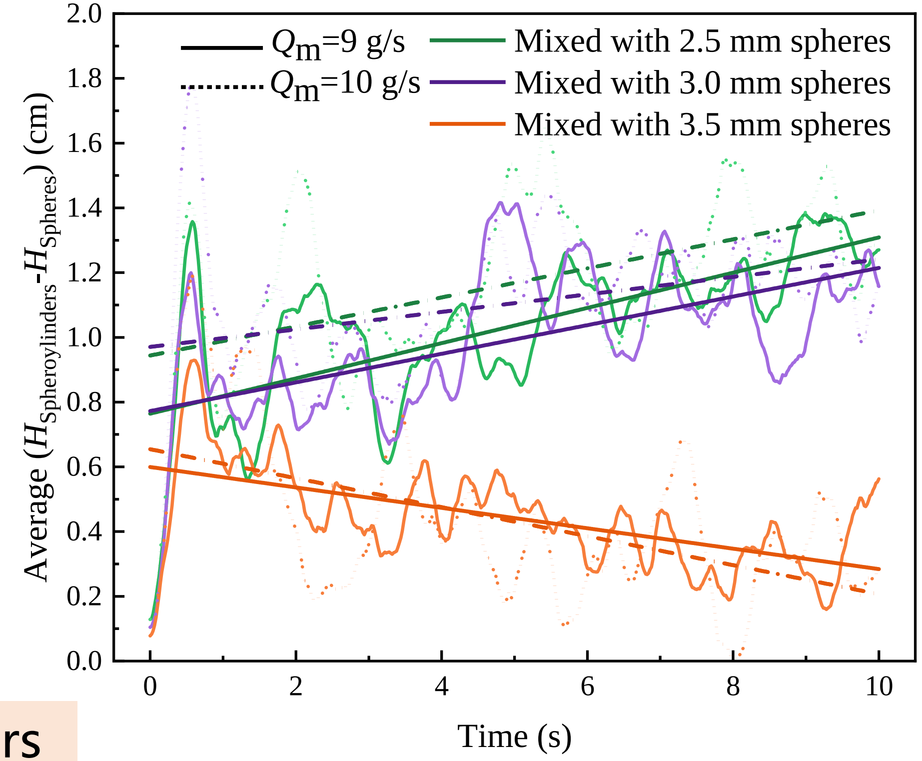
Binary particle systems with spherocylindrical particles and spheres at different mixing ratios (Vol=25%, 50%, 75%, 100%)

Axial and radial distribution of time-averaged void fraction of particles

3. Particle Separation (Binary Particle Systems)



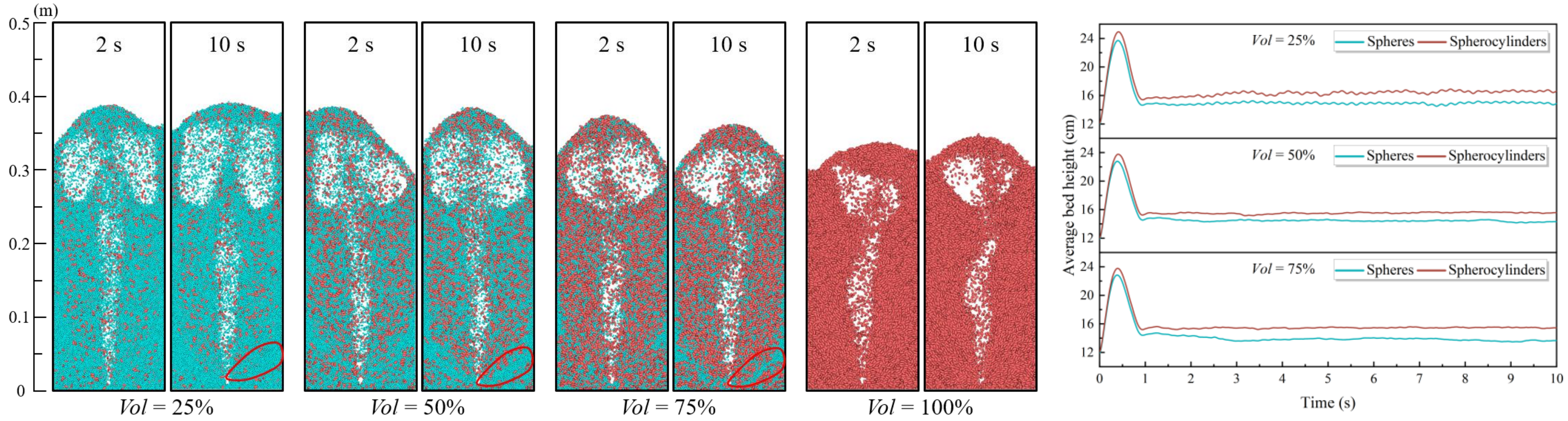




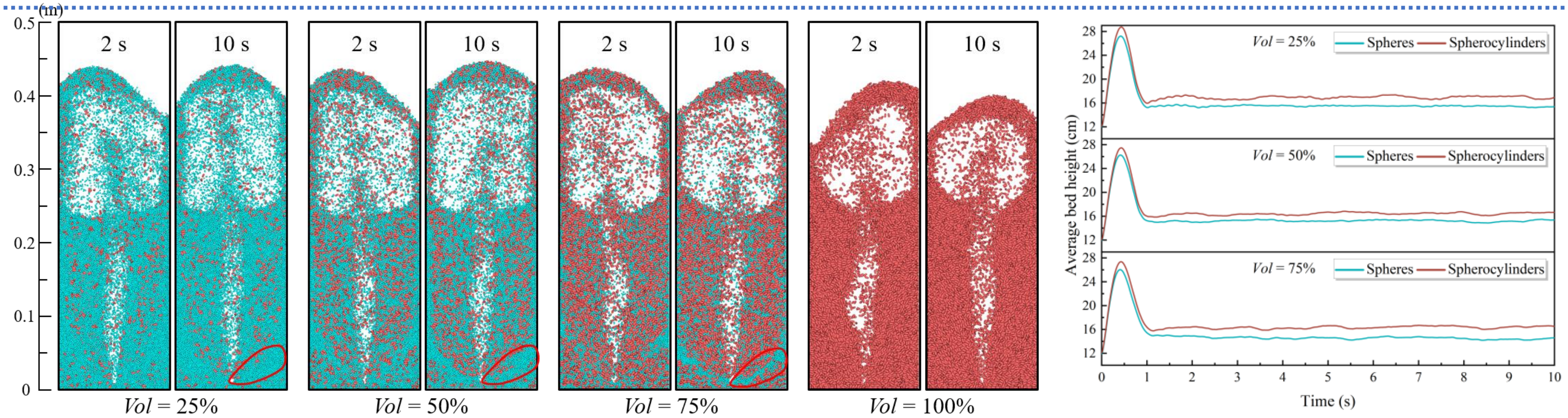
The larger the difference between the spherical particle diameters (d=2.5 mm and d=3.0 mm) and the spherocylindrical equivalent diameter (d_e=4.07 mm), the more pronounced is the separation phenomenon.

Instantaneous changes in the mean height difference for different particles

3. Particle Separation (Binary Particle Systems)

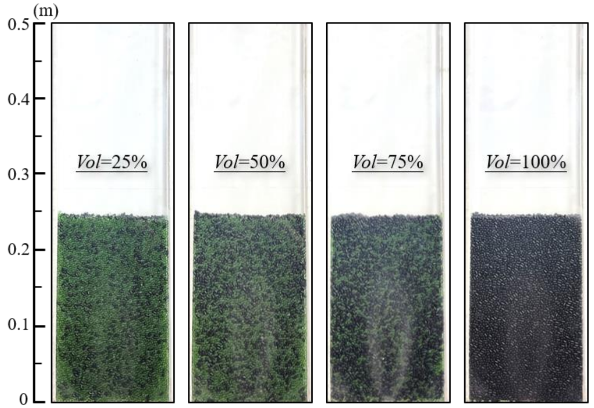


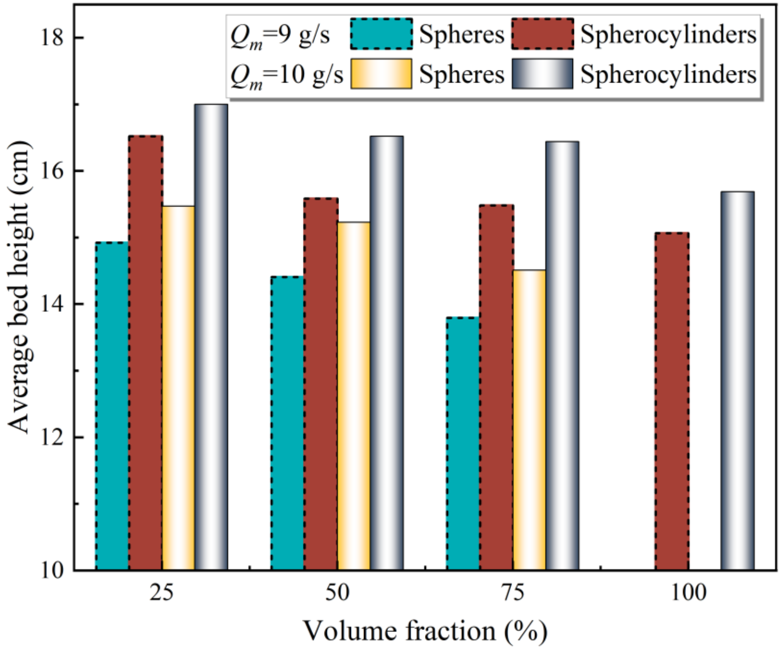
***Q*$_m$=9 g/s**



***Q*$_m$=10 g/s**

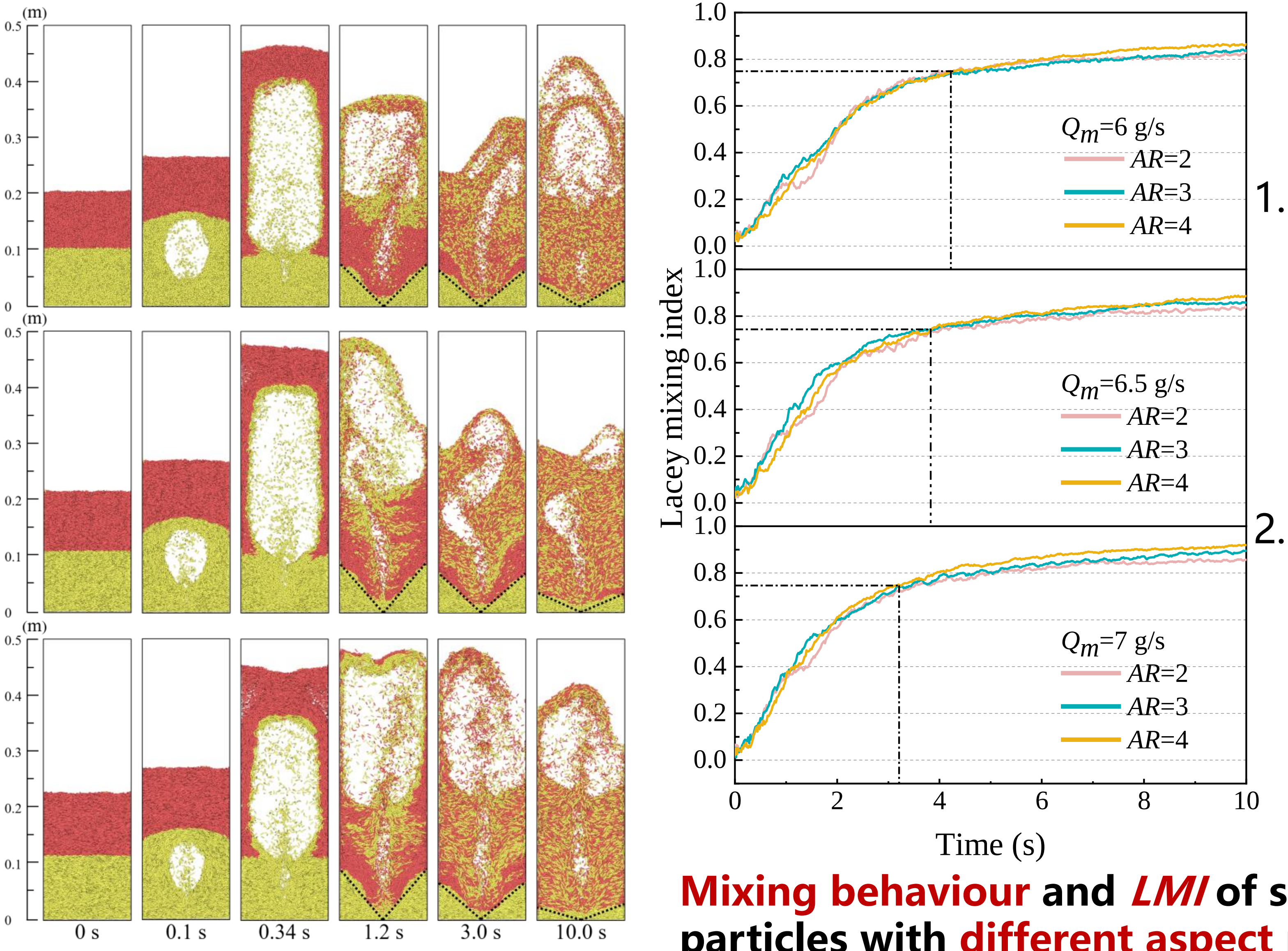
Particle Instantaneous Distribution





Average bed height for different particles

4. Particle Mixing (One-Component Particle System)



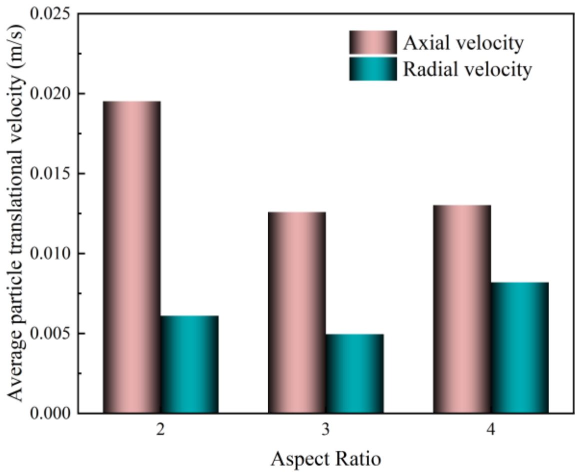
Mixing behaviour and *LMI* of spherocylindrical particles with different aspect ratios

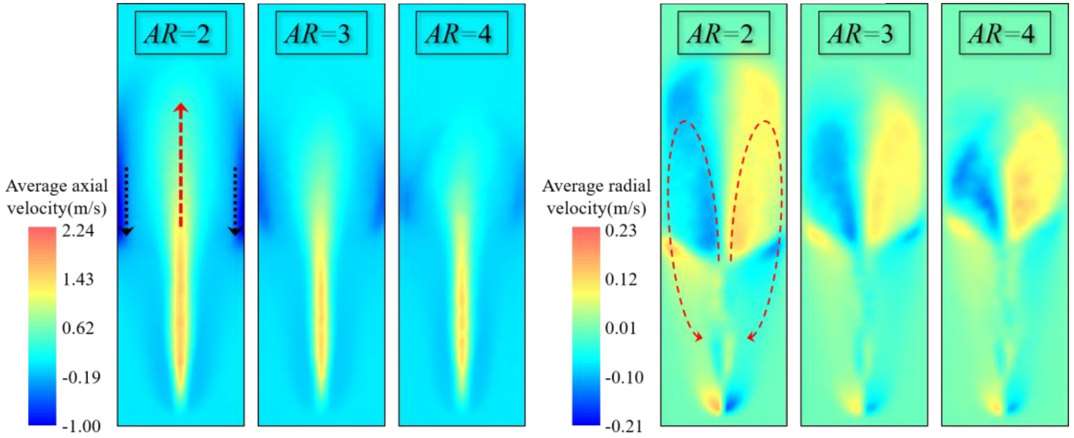
1. The larger the particle aspect ratio, the lower the particle height in the blind zone at the bottom of the bed, and the better the mixing quality of the particles.

2. Increased gas velocity facilitates particle mixing.

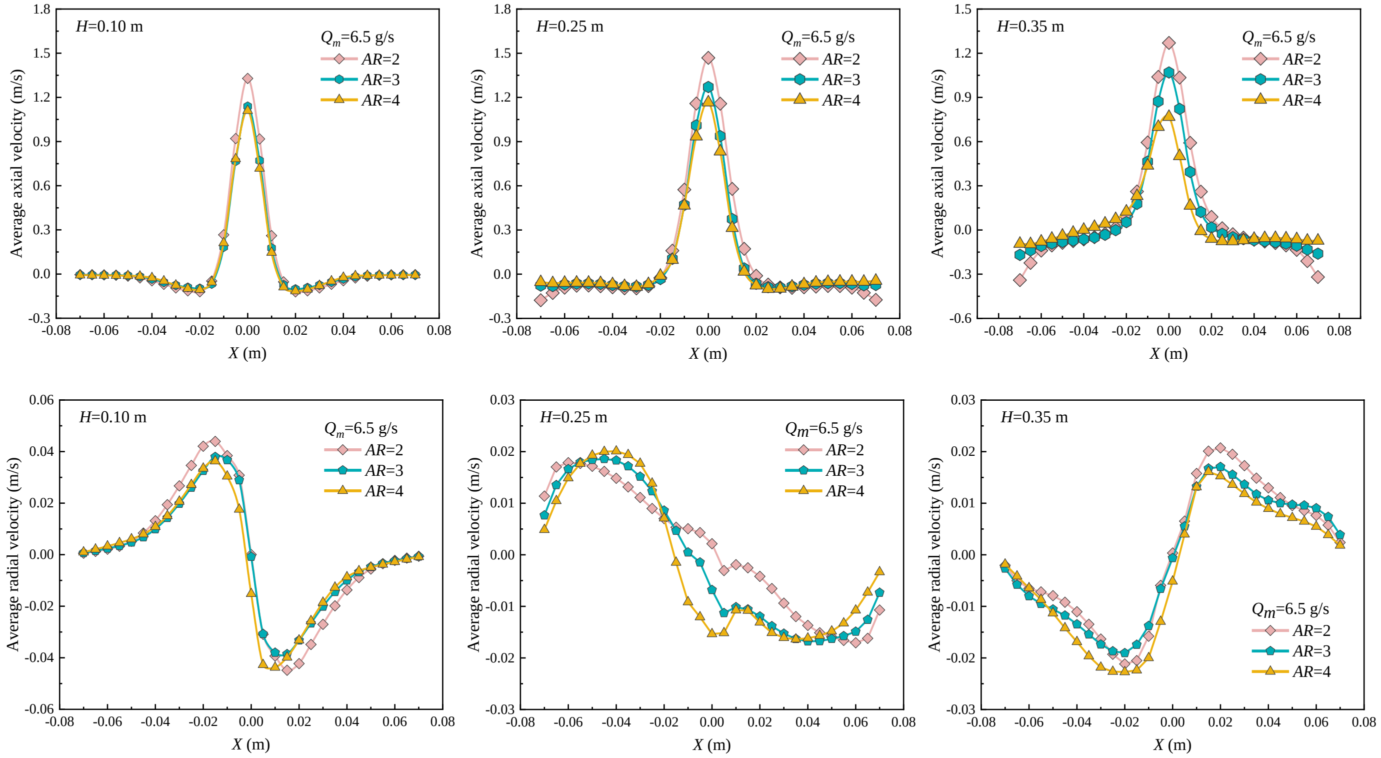
5. Particle Velocity & Kinetic Energy

- **Particle Velocity**





Time-averaged distribution of particle velocity (Z- and X-direction)

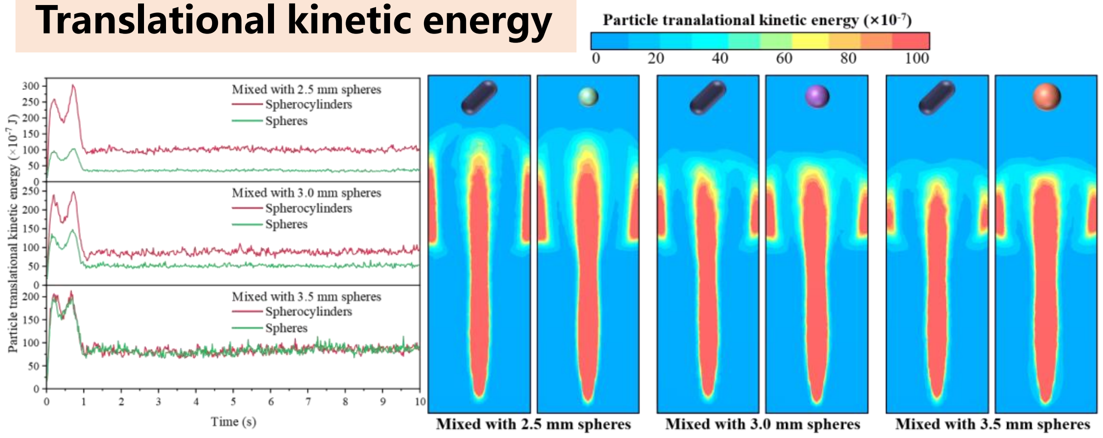


Horizontal distribution of Z- and X-direction velocities of spherocylindrical particles with different aspect ratios

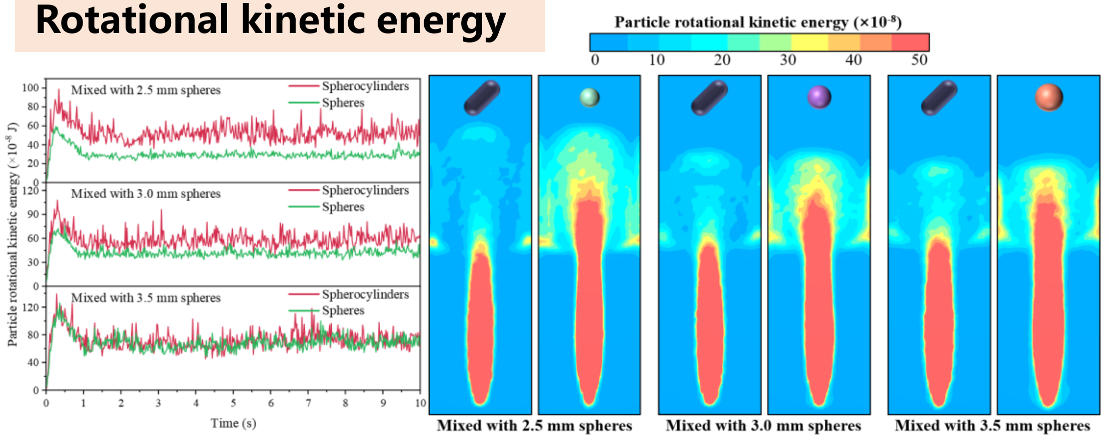
5. Particle Velocity & Kinetic Energy

- **Particle Kinetic Energy**

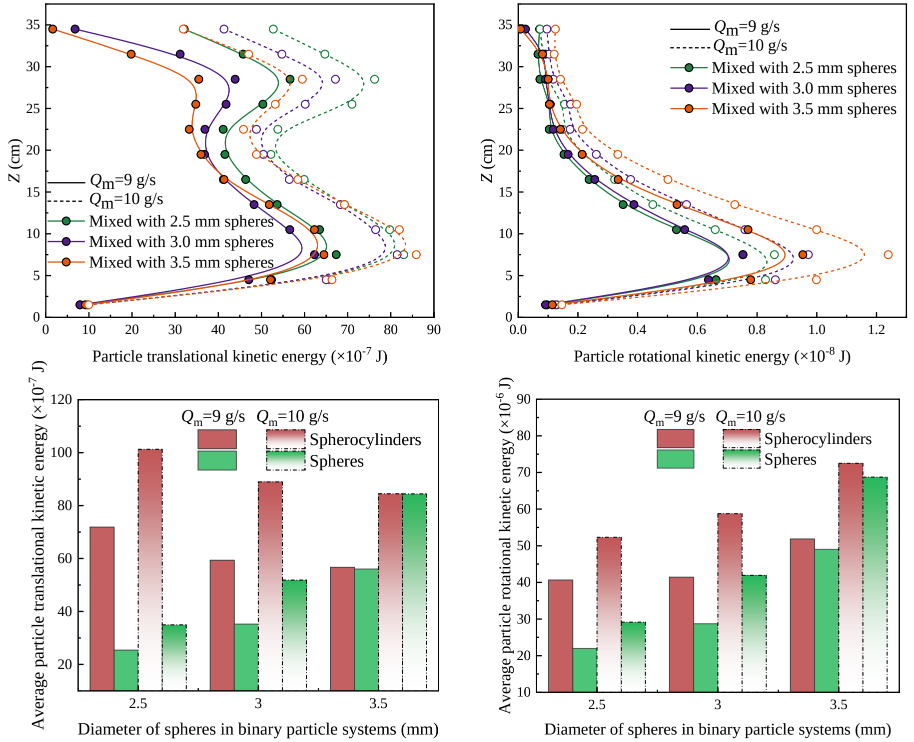
Translational kinetic energy



Rotational kinetic energy

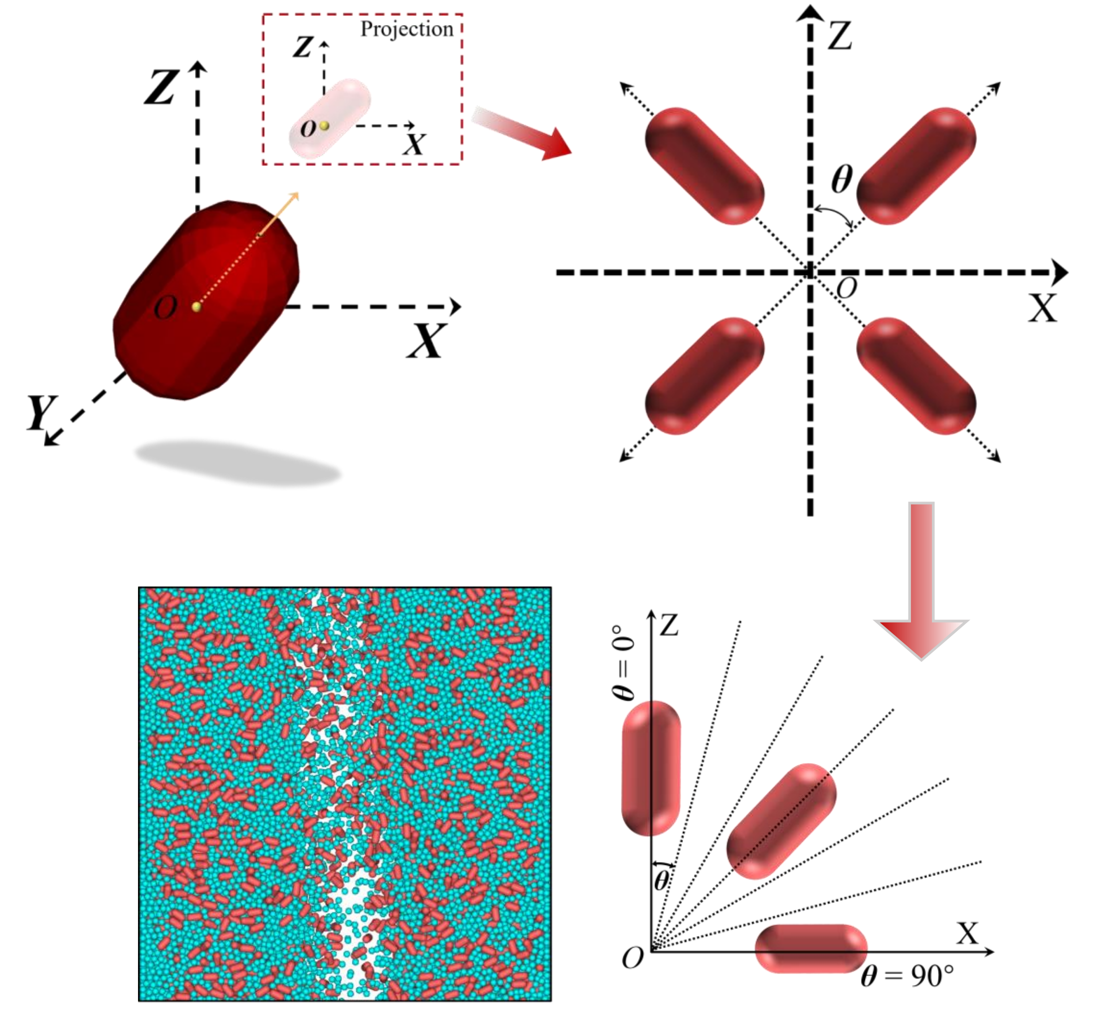


Instantaneous variation and time-averaged distribution of translational/rotational kinetic energy of particles



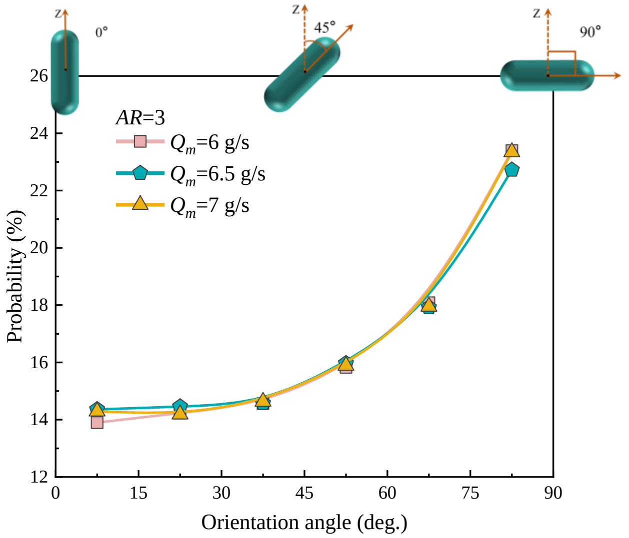
The **rotational kinetic energy** of both spherocylindrical and spherical particles increases as the diameter of spherical particles increases in a binary particle system. However, the **translational kinetic energy** of spherocylindrical particles decreases and the translational kinetic energy of spherical particles increases.

6. Particle Orientation

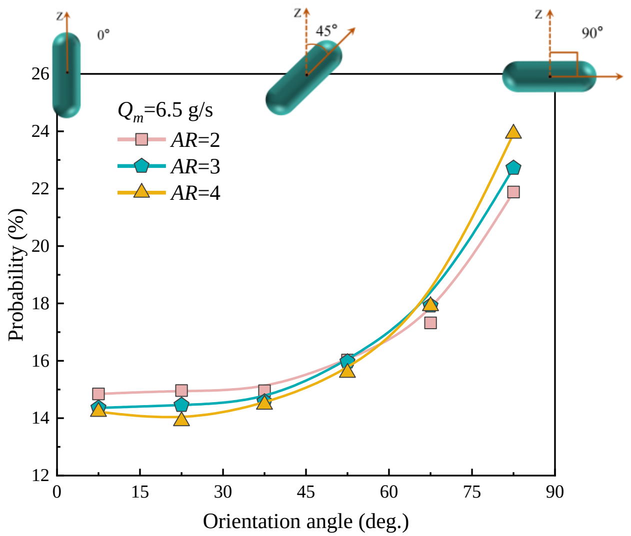


Schematic diagram of particle orientation angle

1. The preferential orientation of the spherocylindrical particles in the spouted bed is perpendicular to the Z-axis and increasing the gas velocity has little effect on the particle orientation distribution.
2. There was no significant correlation between aspect ratio and particle orientation distribution.



Different gas velocities

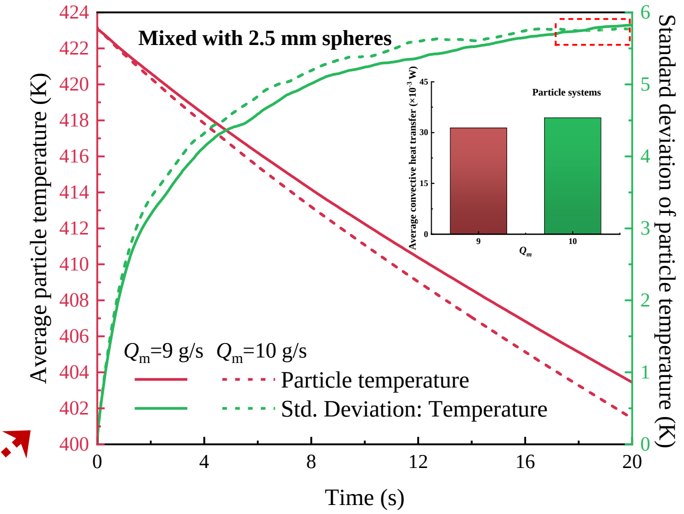


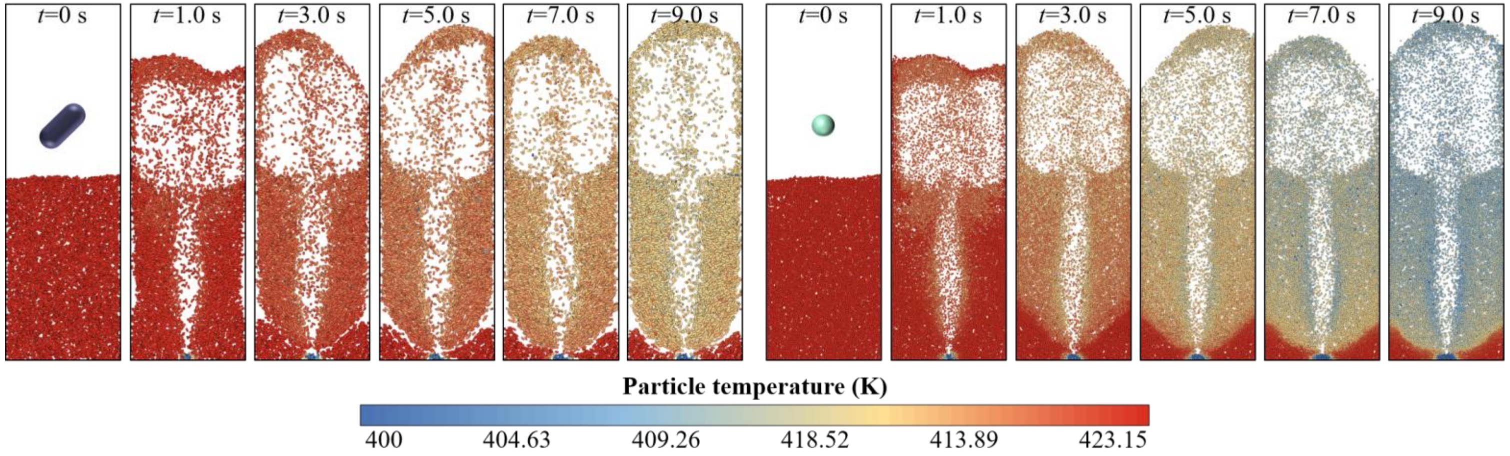
Different aspect ratios

7. Particle Heat Transfer

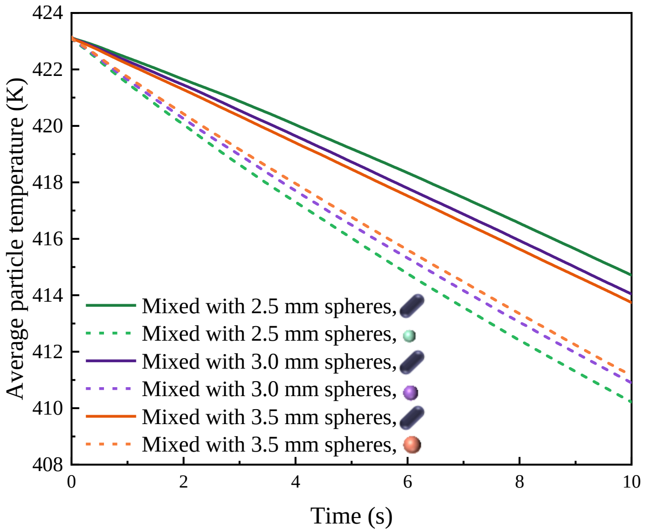
1. Increasing the gas velocity increases the rate of convective heat transfer from the particles, which aids in the cooling of the particle system.

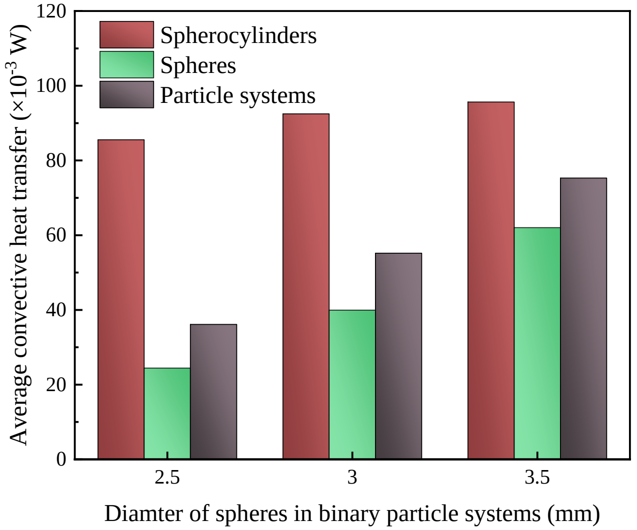
2. Increasing the gas velocity decreases the uniformity of the temperature distribution of the particles over a certain time range (as seen in the standard deviation of the temperature).



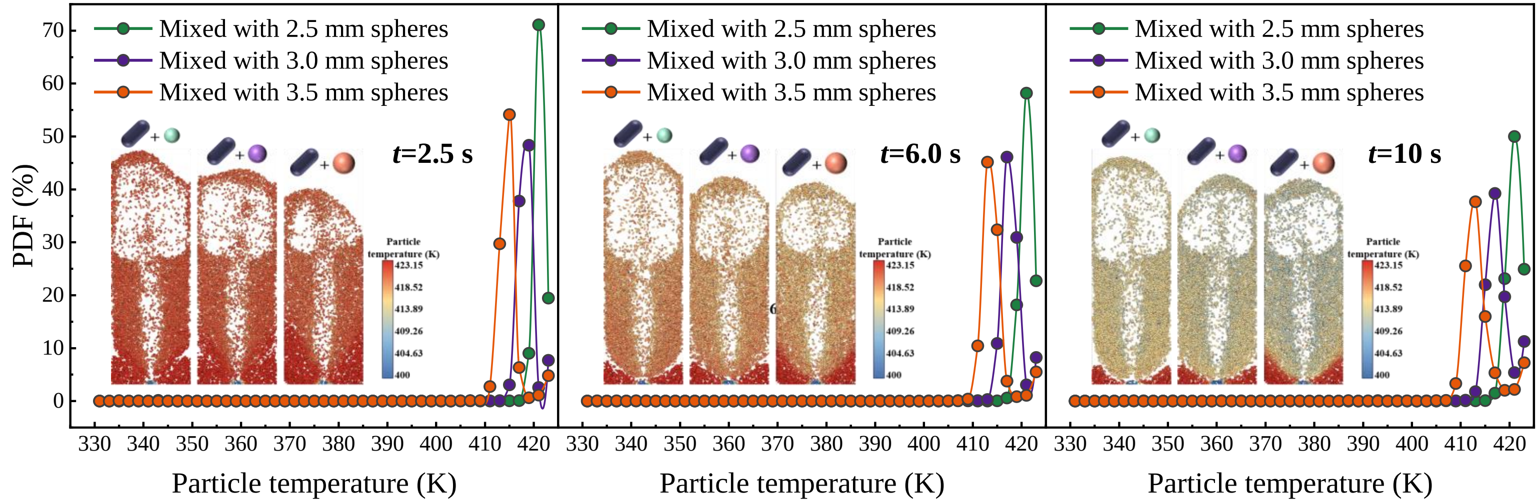


Temperature transient distributions of spherocylindrical particles and spherical particles (d=2.5 mm) in a binary particle



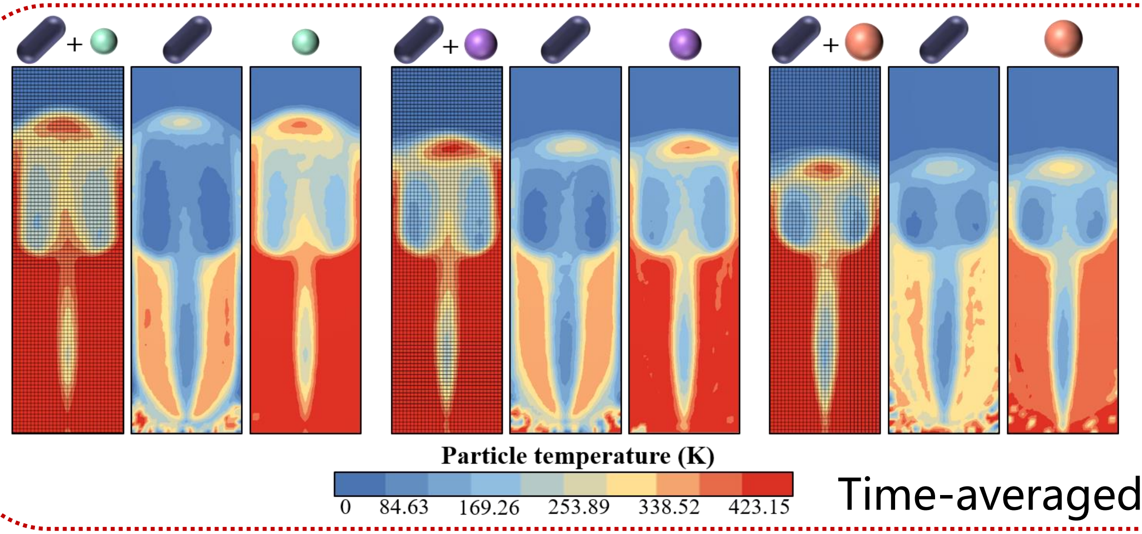


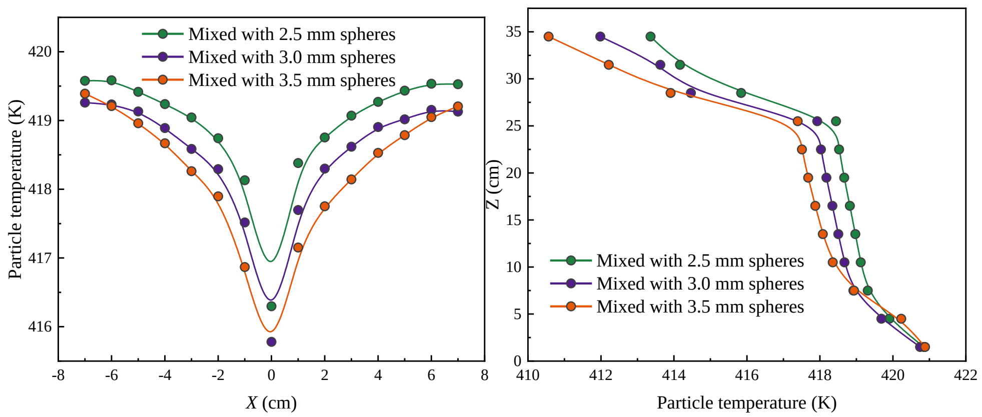
7. Particle Heat Transfer



Qm=10 g/s, temperature PDF distribution of spherocylindrical particles at different times

The peak of the spherocylindrical temperature PDF becomes flatter and gradually shifts to the left as the fluidization time increases

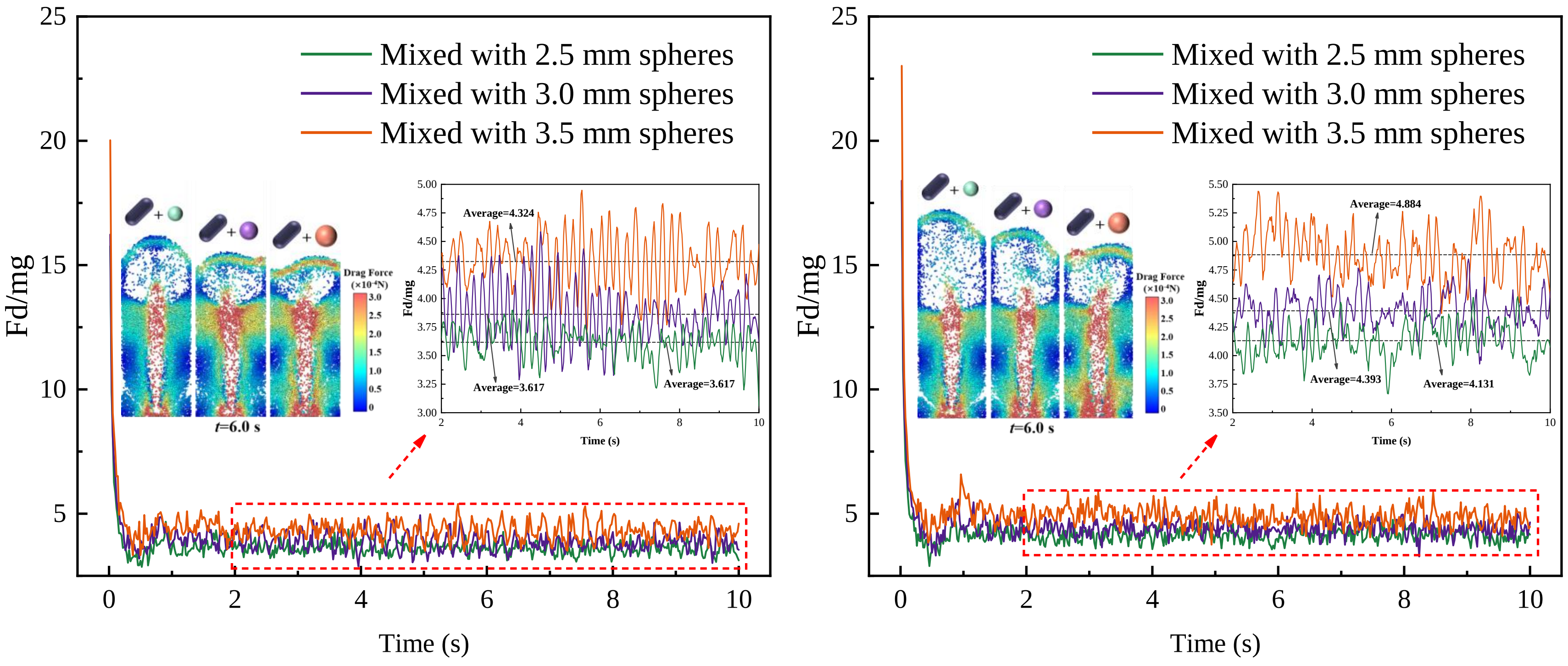




Time-averaged temperature distribution of different particles

8. Particle Drag Force

- **Particle drag force**



Q_m=9 g/s

Q_m=10 g/s

Instantaneous variation of F_d/mg for spherocylindrical particles in different binary particle systems

1. The larger the diameter of the spherical particles in a binary particle system, the larger the average force ratio (Fd/mg) of the spherocylindrical particles.
2. Increasing the gas velocity leads to a further increase in the spherocylindrical force ratio (Fd/mg).

9. Conclusions

- In this paper, the particle kinetic behavior and heat transfer characteristics of spherocylindrical particles mixed with spherical particles of different diameters are investigated using a coupled CFD-DEM method. Macroscopic and microscopic properties such as particle void fraction, particle collision, particle kinetic energy, drag force, and heat transfer are discussed.
- When the difference between the diameter of spherical particles and the equivalent diameter of spherocylindrical particles in the binary particle system is larger, the average height difference between spherocylindrical particles and spherical particles in the spouted bed becomes larger and larger during fluidization. Compared to spherocylindrical particles, spherical particles are more likely to aggregate at the bottom of the bed. The void fraction of spherocylindrical particles is larger, while the void fraction of spherical particles is smaller.
- When the diameter of spherical particles in a binary particle system increases, the rotational kinetic energy of both spherocylindrical and spherical particles increases. However, the mean translational kinetic energy of spherocylindrical particles decreases and the mean translational kinetic energy of spherical particles increases.

9. Conclusions

- When the difference between the diameter of spherical particles and the equivalent diameter of spherocylindrical particles in a binary particle system is larger, the number of average particle collisions among spherocylindrical particles decreases, and the number of average collisions among spherical particles increases. However, increasing the gas velocity results in a decrease in the number of particle collisions.
- Increasing the gas velocity helps the cooling of the particles but decreases the uniformity of the temperature distribution of the particles within a certain time frame. When the diameter of the spherical particles in the binary particle system is larger, it can accelerate the cooling rate of the spherocylindrical particle temperature but slows the cooling rate of the spherical particles. Furthermore, the amount of convective heat transfer between the two types of particles increases with the diameter of the spherical particles in the binary particle system.

Ramesh K. Agarwal · Yali Shao

Modeling and Simulation of Fluidized Bed Reactors for Chemical Looping Combustion

The book describes the clean coal technology of chemical looping combustion (CLC) for power generation with pure CO₂ capture. The focus of the book is on the modeling and simulation of CLC. It includes fundamental concepts behind CLC and considers all categories of fluidized beds and reactors, including a variety of oxygen carriers. The book includes process simulations with Aspen Plus® software using coal, natural gas, and biomass and computational fluid dynamics (CFD) simulations using both the Eulerian and Lagrangian methods. It describes various drag models, turbulence models, and kinetics models required for CFD simulations of CLC and covers single reactor, partial, and full-simulations, single/multi-stage as well as single-particle simulations, and CLC with reverse flow. A large number of examples for both process simulations using Aspen Plus and CFD simulations using a variety of fluidized beds/ reactors employing both the two-fluid and Computational Fluid Dynamics / Discrete Element Method (CFD-DEM) model are provided.

Modeling and Simulation of Fluidized Bed Reactors for Chemical Looping Combustion will be an invaluable reference for industry practitioners and researchers in academic and industrial R&D currently working on clean energy technologies and power generation with carbon capture.

- Provides a solid overview of the fundamental concepts behind CLC and fluidized beds and reactors;
- Describes drag, turbulence, and kinetics models;
- Includes process simulations using Aspen Plus® and CFD simulations.

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