NUMERICAL MODELLING OF SLURRY TRANSPORT FOR COARSE PARTICLES

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Content

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Goal of Research

- Observe the flow regimes for transporting coarse particles in the pipe
- Flow assurance – risk of blockage: the concentration and velocity profile in the pipe
- Comparison with previous research

CFD-DEM Numerical Method and verification

1. Fluid phase control equation (CFD part)

2. Solid phase control equation (DEM part)

3. The process of CFD-DEM coupling

4. Verification for accuracy

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1. Continuity equation and momentum equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0$$

$$\frac{\partial}{\partial t}(\rho \xi u_i)+\frac{\partial}{\partial}(\rho \xi u_i u_j)=-\xi\frac{\partial p}{\partial x_i}+\frac{\partial(\xi \tau_{ij})}{\partial x_j}+n_p\left(F_{drag}+F_{saffman}+F_{Magnus}\right)+\xi \rho g$$

2. k-ε turbulence model

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_K+G_b-\rho\varepsilon-Y_M+S_k$$

$$\frac{\partial(\rho g)}{\partial t}+\frac{\partial(\rho \varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_K+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_k$$

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Fluid-particle interaction forces:

$$\boldsymbol{F_{drag}} = \frac{1}{8} C_d \rho_f \pi d_P^2 \left(U^f - U^p\right)\left|U^f - U^p\right| f(e)$$

$$\boldsymbol{F_{Magnus}} = \frac{1}{2} C_{LM} \pi r^2 \rho_g \frac{\omega_r * u_r}{|\omega_r|}$$

$$\boldsymbol{F_{saffman}} = 6.46 C_{LS} r^2 \sqrt{\rho_g \eta} \frac{u_r D}{\sqrt{D}}$$

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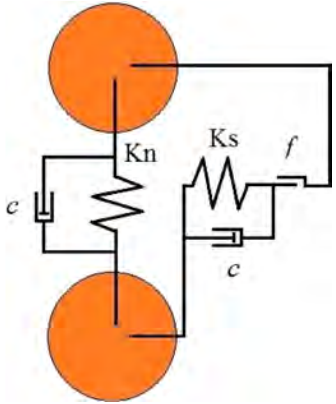
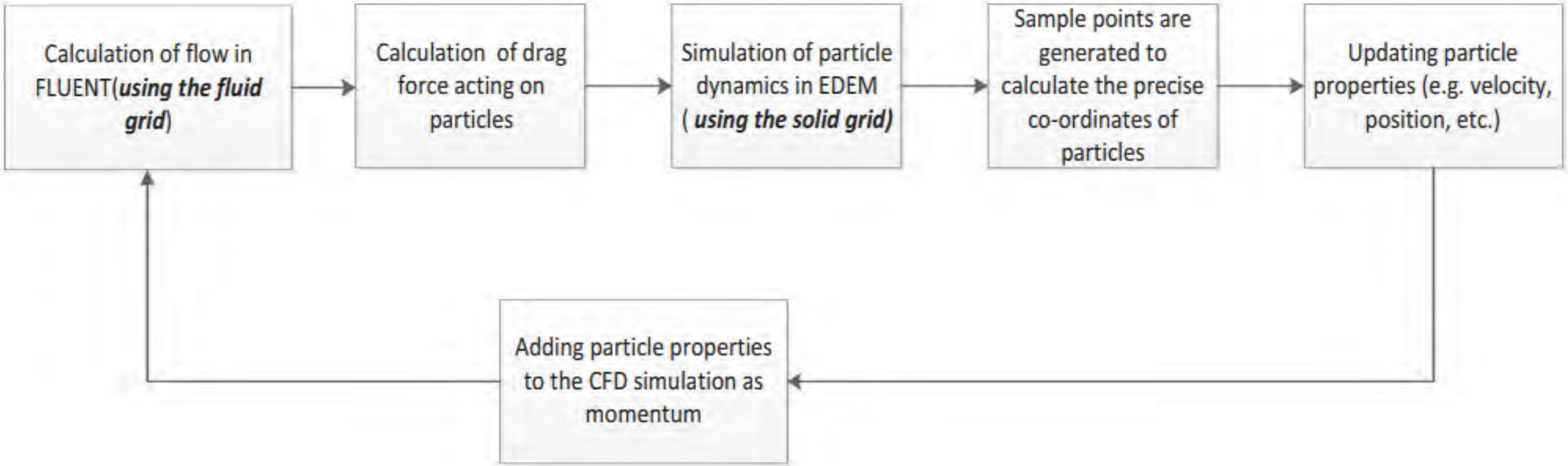
Each individual particle is calculated by using a softball model and the model is described by Newton's equations for translational and rotational motions as follows：

$$m_p \frac{dv_p}{dt} = F_{P\text{-}W} + F_{P\text{-}P} + F_{drag} + F_{saffman} + F_{Magnus} + m_p g$$



softball model

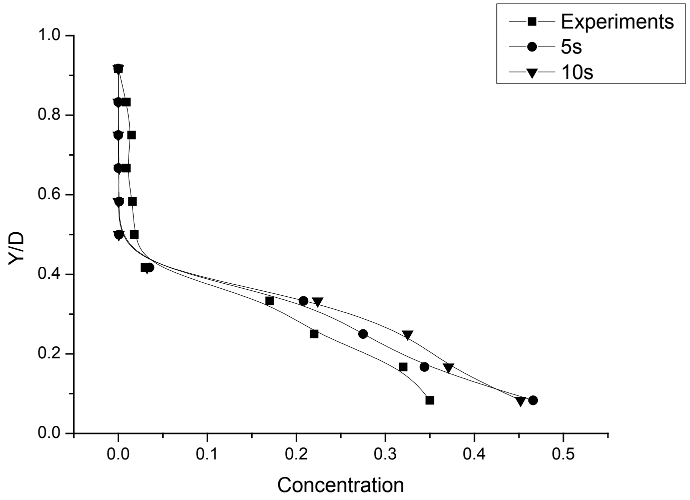
The process of using grids in CFD-DEM coupling calculation



Verification case

Verification case: experimental data of Vlasak (2014):

D_p = 0.1 m
d = 11 mm
V = 4.1 m/s
$D_p/d \approx 10$



C_v :

- linear at the lower part
- ≈0 at the upper part

The errors are within the allowable range

Simulation Setup

I. a horizontal pipe - diameter D= 15.24cm and a length of 7.5m,
II. the internal volume of the pipeline is meshed by 646,720 CFD fluid cells.
III. the line speed 2m/s, 5m/s and 8m/s,
IV. the particle size *d* is 10mm,
V. input volume concentration 10%.
VI. outlet pressure -> atmospheric

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Results & Analysis

I. Analysis of the flow regimes at different line speeds

II. Concentration distribution of particles

III. Velocity distribution of particles

IV. Non-spherical coarse particles

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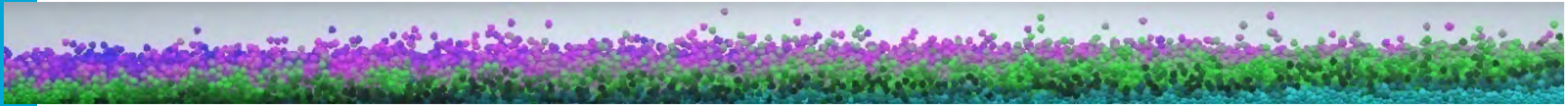
Analysis of the flow regime at different velocities

---change of the flow state of the slurry is not a transient phenomenon

(a) Incoming flow from the left: V=2 $m \cdot s^{-1}$, fixed bed flow regime (restricted flow state)

(b) Incoming flow from the: V=5 $m \cdot s^{-1}$, sliding bed flow regime (sliding friction-dominated flow state)



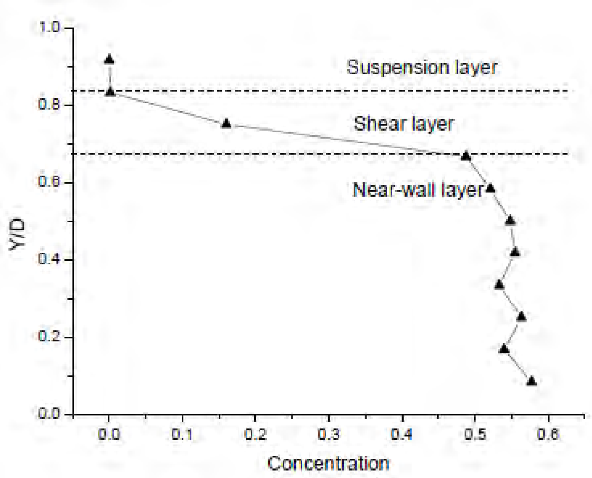
(c) Incoming flow from the left: V=8 $m \cdot s^{-1}$, sliding flow regime (collision-dominated flow state)

(d) Incoming flow from the left: V=10 $m \cdot s^{-1}$, sliding flow regime

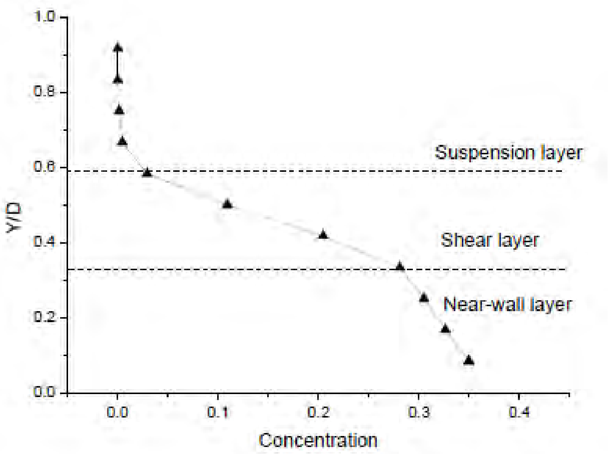
Analytical: SLDV =1.9m/s (fixed bed to the sliding bed)

LDV = 3.6m/s (the sliding bed to the sliding flow)

C_v profile



Concentration Profile in the cross-section at X = 4m with line speed of 5m/s (Sliding bed flow regime)



Concentration Profile in the cross-section at X = 4m with line speed of 8m/s (Sliding flow regime)

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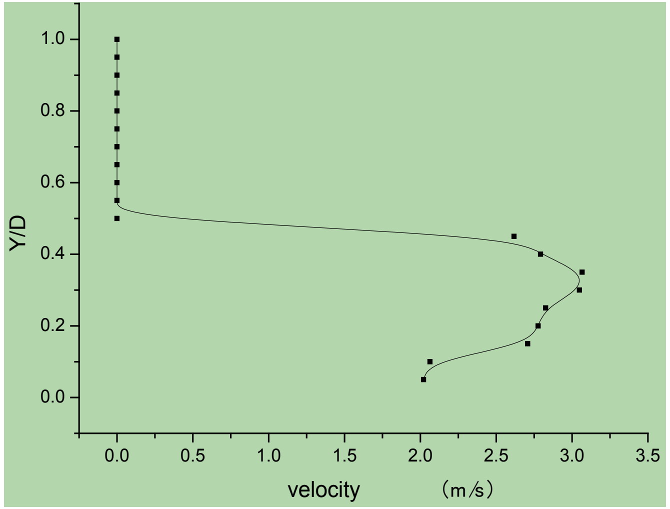
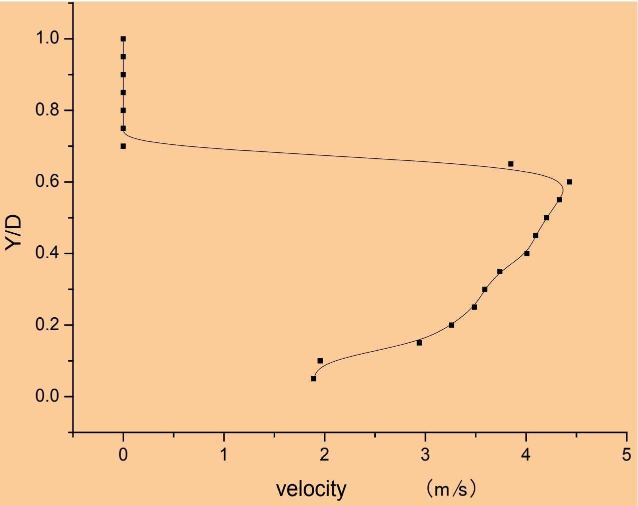
Velocity profile of the particles



sliding bed regime (V=5m/s)



sliding flow regime (V=8m/s).

the maximum velocity points appear near the transition interfaces between different layers

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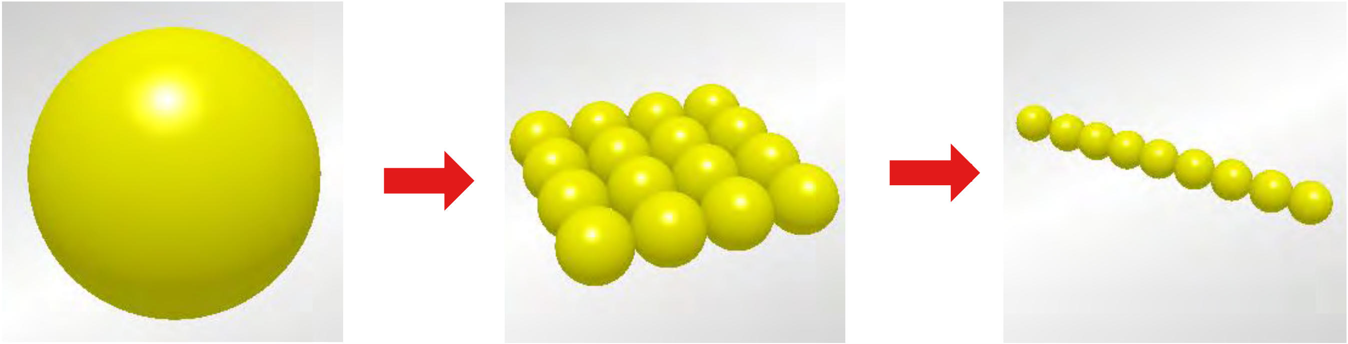
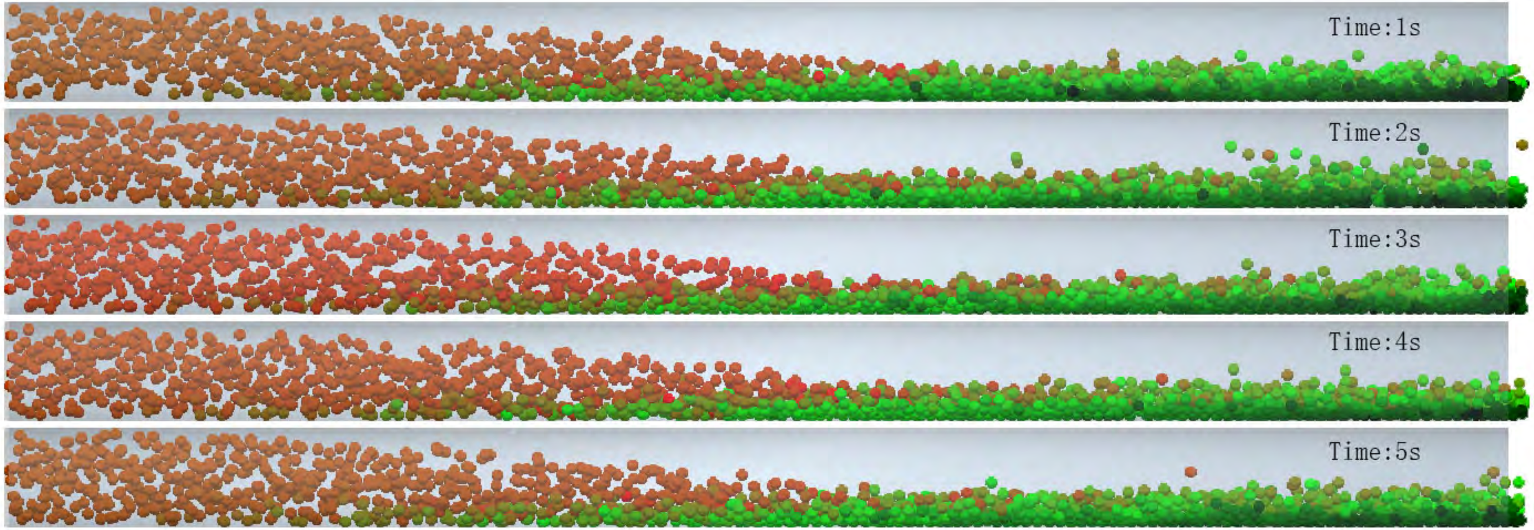
Non-spherical coarse particles in slurry transport



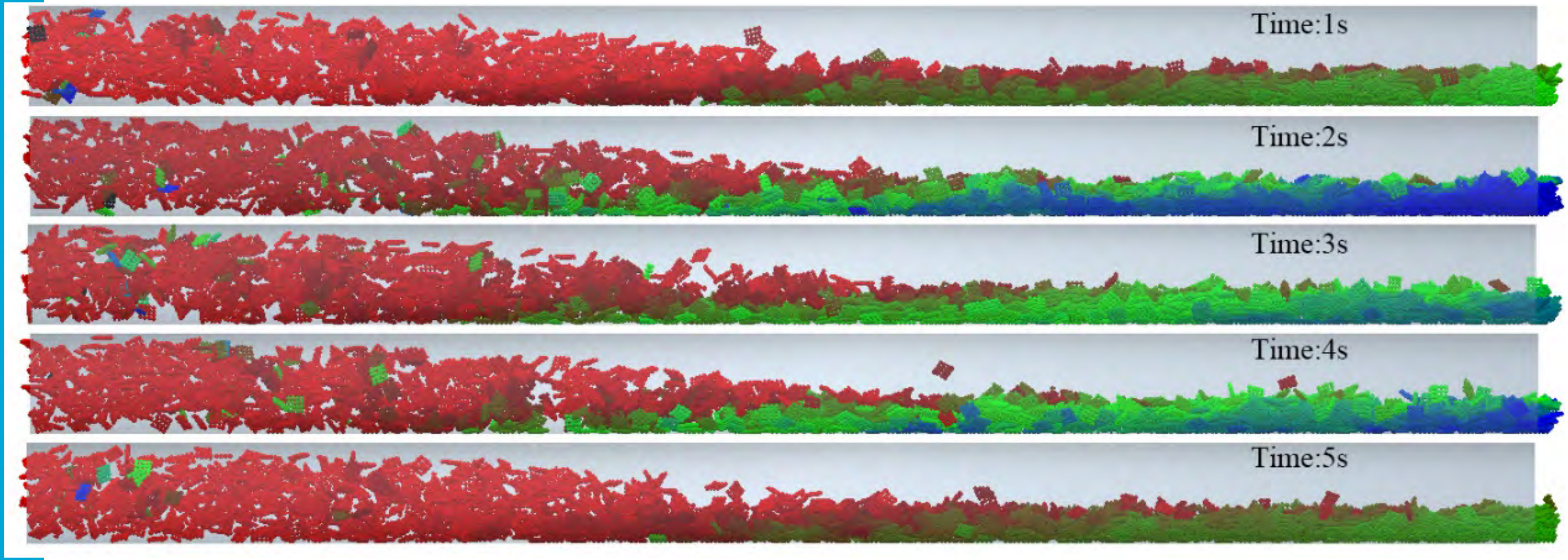
Heteromorphic / non-spherical Coarse-particles

Non-spherical coarse particles in slurry transport



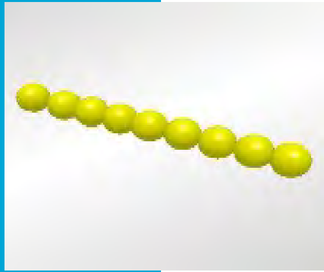
The sliding flow state of spherical coarse-particles at line speed (8m/s)

Non-spherical coarse particles in slurry transport



The sliding bed flow regime of flatty coarse-particles at line speed (8m/s)

Non-spherical coarse particles in slurry transport



The blockage of long coarse-particles at line speed (**8m/s**): flocculating + interlocking

Conclusion

In this study, the CFD-DEM coupling numerical simulation method is used to analyze the flow characteristics and flow transition process of coarse particles under different line speeds

CFD-DEM coupling can present the flow regimes of slurry transport for coarse particles very well

- SLDV matches well with DHLLDV
- LDV shows a certain error with DHLLVD

Long shaped particles is the biggest threat to flow assurance

The authors appreciate the help from Mr. Robert Ramsdell.

Thank you very much!