Numerical Simulation of Solid Mixing in a Dual Axis Blender

PE325

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Introduction

◆Background

- A dual axis blender is the machine which mixes powder by swing and rotation. This blender is applied in food and pharmaceutical industry.
- To assess this blender, it is necessary to evaluate mixing degree. However, the successive evaluation is difficult by experimental approach. Therefore, numerical simulation is essential to do it.

◆Previous Researches

- Basinskas and Sakai[1] discussed dependence of mixing efficiency on rotation speed and swing speed in a dual axis blender.
- Effect of cylinder length and particle density on mixing efficiency have not been investigated.

[1] Basinskas, G., & Sakai, M., *Powder Technology* (2016)

◆Research Purpose

- To optimize cylinder length in a dual axis blender, with investigating dependence of mixing efficiency on cylinder length
- To reveal mixing mechanism in a dual axis blender, with investigating effect of cylinder length and particle density on mixing efficiency

Numerical Simulation Method & Evaluation Index

◆Discrete Element Method[2]

In numerical simulation of powder behavior, discrete element method (DEM) is applied widely. In DEM, overlap between particles is allowed in particles collision. Contact force is modeled by spring, dash pot and friction slider. Governing equation is based on Newtonian equation of motion. (eq. (1),(2))

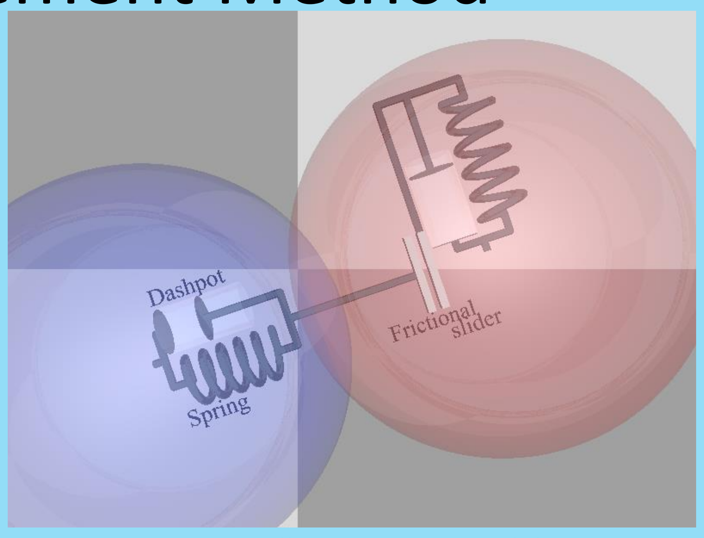

Fig. 1: Collision in DEM model

Translation : $m\dot{\boldsymbol{v}} = \sum \boldsymbol{F}_C + \boldsymbol{F}_g$ —(1)

Rotation : $I\dot{\boldsymbol{\omega}} = \sum \boldsymbol{T}$ —(2)

[2] Cundall, P.A., & Strack, O.D.L., *Geotechnique* (1979)

◆Lacey's Mixing Index[3]

Lacey's mixing index is used in many studies to evaluate mixing degree. Separating calculation area into cells, particle fraction is calculated in each cell. The variance of those values is normalized with maximum value and minimum value of variance.
0 represents separated state, and 1 represents well-mixed state.

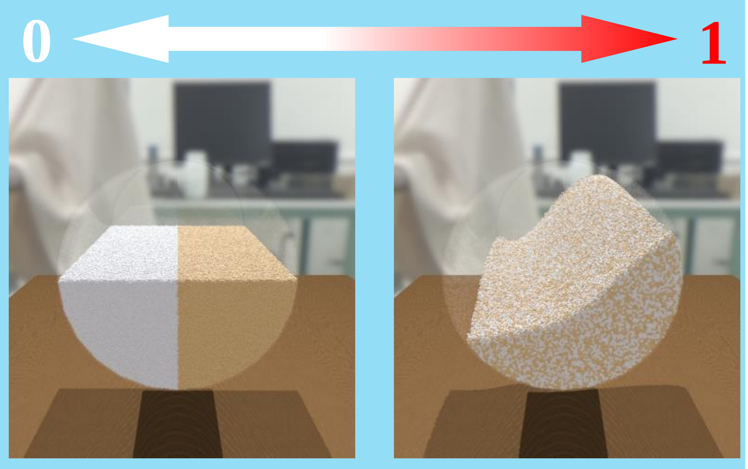

Fig. 2: Mixing state represented by mixing index 0 & 1

$$M = \frac{\sigma_{max}^2 - \sigma^2}{\sigma_{max}^2 - \sigma_{min}^2} \quad —(3)$$

where σ^2 is variance of particle fraction

[3]Lacey, P.M.C., *Journal of Applied Chemistry* (1954)

◆Granular Temperature[4]

Granular temperature is the index to evaluate diffusive mixing effect. Separating calculation area into cells, variance of particle velocity of i-axis is calculated in each cell. The mean value of variance of each axis is applied as granular temperature.
Higher value represents that particles' velocity are uneven.

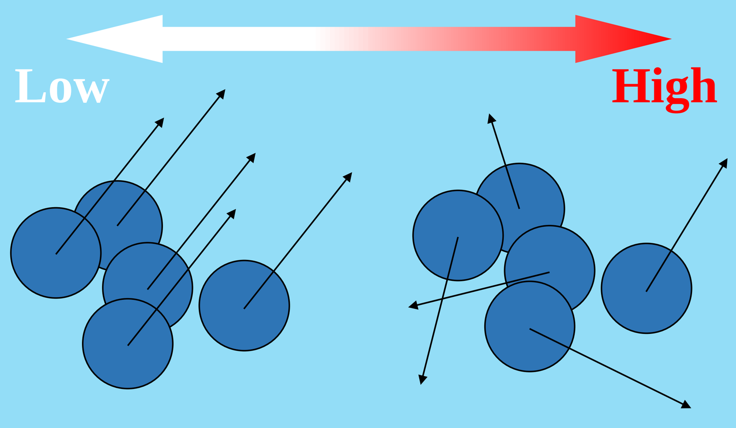

Fig. 3: Particles with high & low granular temperature

$$\theta_t = \frac{1}{3}\sum_{i=x,y,z} \sigma_{v_i}^2 \quad —(4)$$

[4] Liyan, S. et al, *Powder Technology* (2016)

Calculation Conditions

◆Common Conditions

- In this study, we use the blender shown in Fig.4.
- Revolution speed was set as 60 rpm, and pitch frequency was set as 0.5 Hz. Maximum angle of pitch was set as 15 degree.
- Distance between pitch axis and cylinder was set as 50 mm.
- Physical properties are shown on Table 1.
- Time step depends on particle density, so it was set in each case. Total simulation time was set as 12 seconds.

Table 1: Physical properties and calculation conditions

Physical prop.	unit	value	Calc. conditions	unit	value	Calc. conditions	unit	value
Restitution coef.	-	0.9	Calculation time	s	12	Revolution speed	rpm	60
Friction coef.	-	0.3	Particle diameter	m	1.0×10^{-3}	Pitch frequency	Hz	0.5
Spring coef.	N/m	1.0×10^{3}	Number of particles	-	7.0×10^{5}	Pitch angle	deg.	15
						Cylinder diameter	m	0.1

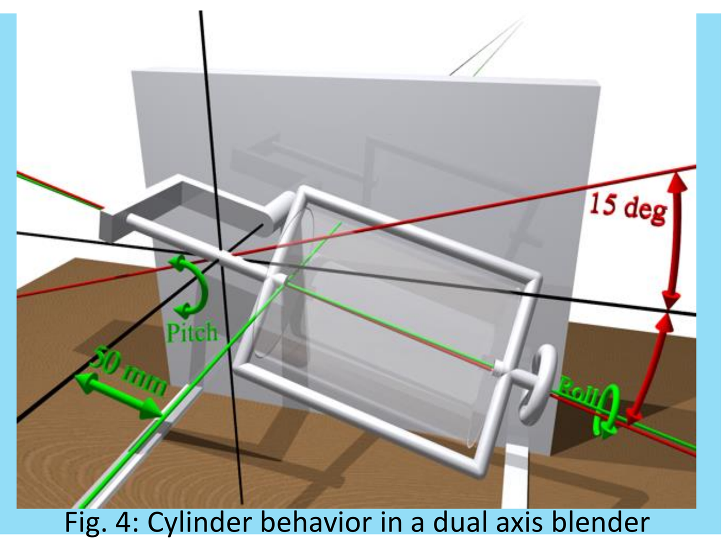

Fig. 4: Cylinder behavior in a dual axis blender

◆Case A: Dependency on Cylinder Length

- Calculation conditions were set as Table 2.

Table 2: Comparative properties in Case A

Comparative prop.	unit	Case A-1	Case A-2	Case A-3
Cylinder length	m	0.10	0.15	0.20
Particle density (Left)	kg/m³	2.50×10^{3}		
Particle density (Right)	kg/m³	1.25×10^{3}		
Time step	s	8.0×10^{-6}		
Iteration	-	1.5×10^{6}		

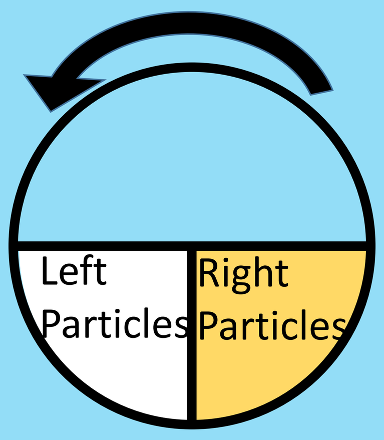

Fig. 5: Initial location in blender

◆Case B: Dependency on Particle Density

- Calculation conditions were set as Table 3.

Table 3: Comparative properties in Case B

Comparative prop.	unit	Case B-1	Case B-2	Case B-3
Cylinder length	m	0.15		
Particle density (Left)	kg/m³	2.50×10^{3}	5.00×10^{3}	5.00×10^{3}
Particle density (Right)	kg/m³	1.25×10^{3}	1.25×10^{3}	2.50×10^{3}
Time step	s	8.0×10^{-6}	1.0×10^{-5}	1.6×10^{-5}
Iteration	-	1.5×10^{6}	1.2×10^{6}	7.5×10^{5}

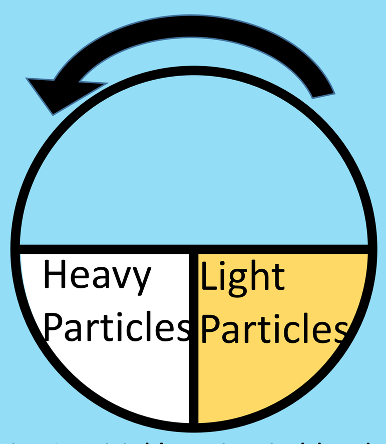

Fig. 6: Initial location in blender

Results & Discussion

◆Case A

- Mixing index was higher in order of 150 mm, 200 mm and 100 mm.
- Longer cylinder may cause convective and shear mixing effect, but mixing efficiency was not higher in order of cylinder length.
- This result showed that diffusive effect was dominant in this mixing system.

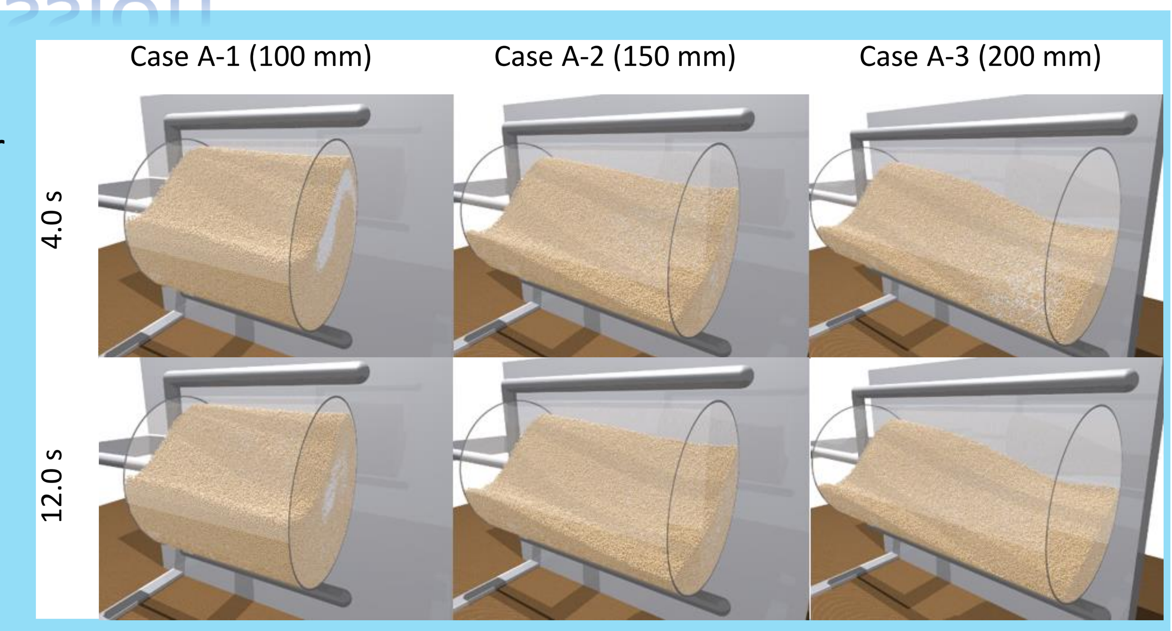

Fig. 7: Mixing state in Case A

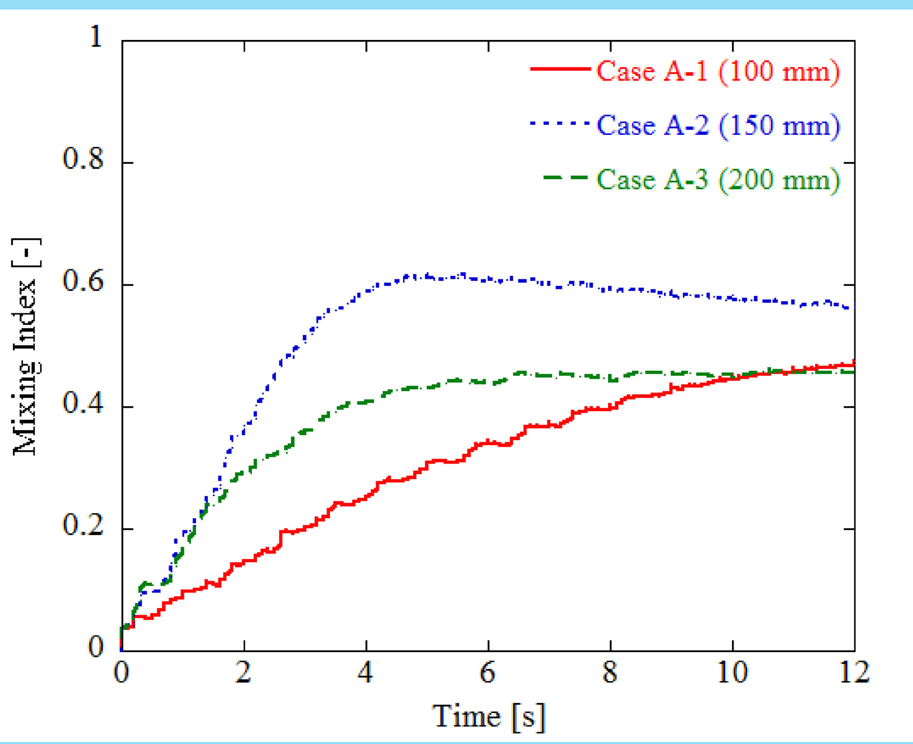

Fig. 8: Transitional change of mixing index in Case A

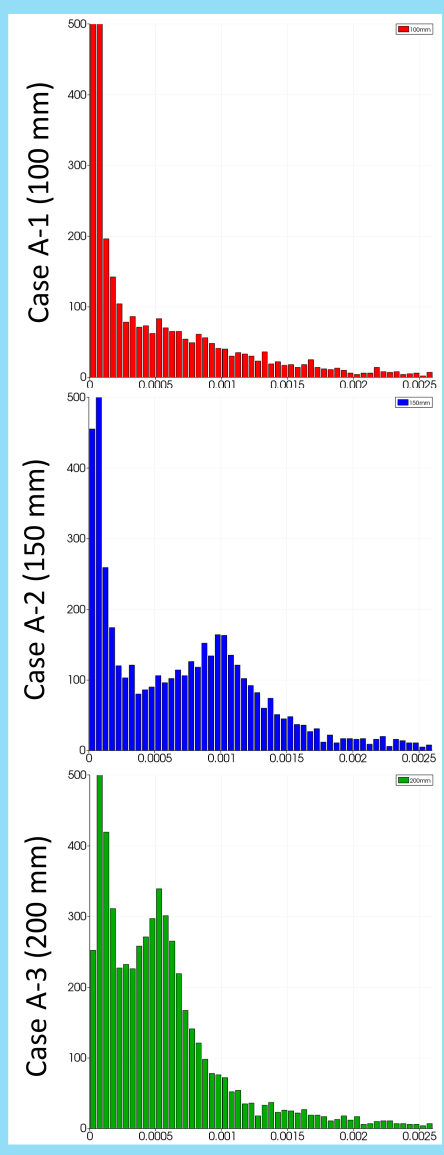

Fig. 9: Distribution of granular temperature in Case A

- Granular temperature is suitable index in this situation.
- In Case A-2 and A-3, distribution of granular temperature showed a peak. It was around 0.001 in Case A-2, but it was around 0.0005 in Case A-3.
- Mixing efficiency was affected by the profile of granular temperature, which was influenced by filling rate.
- In these conditions, optimal cylinder length was around 150 mm.

◆Case B

- According to Fig. 10, all states looked similarly from outside, but their inner parts were different, judged by mixing index. (Fig. 11)
- Mixing index in Case B-1 was similar to that in Case B-3, and they were much higher than that in Case B-2.

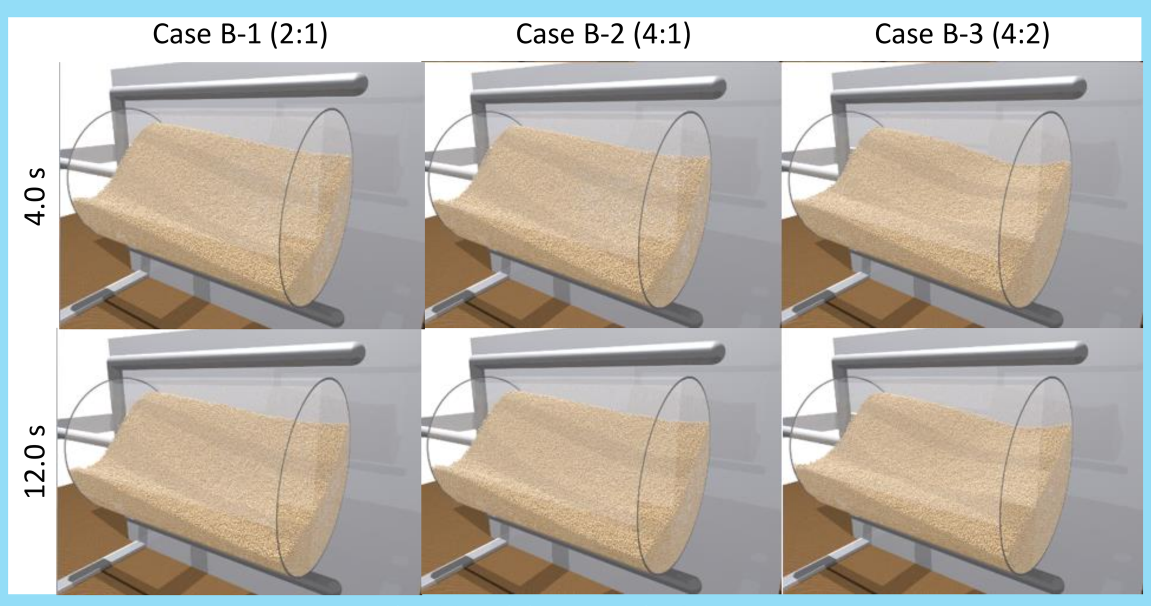

Fig. 10: Mixing state in Case B

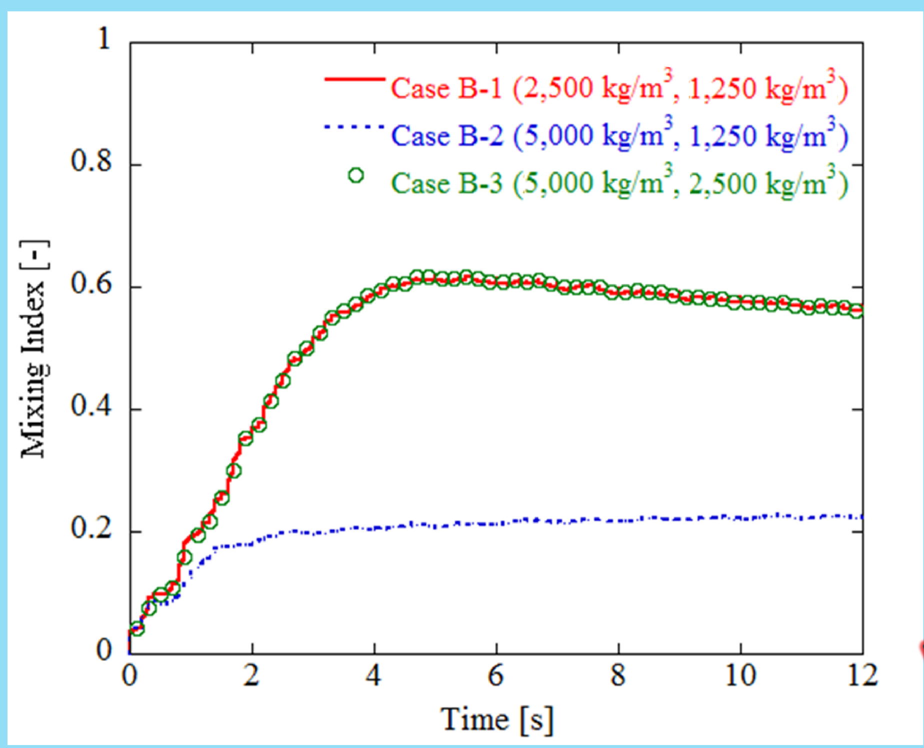

Fig. 11: Transitional change of mixing index in Case B

- In Case B-2, mixing index was reached only about 0.2, so this blender could not mix Case B-2 well, due to the segregation.
- If density ratio was high (at least 4:1), particles were difficult to be mixed in this system.
- Case B-1 and B-3 varied in difference between left and right particle density, so mixing efficiency did not depends on density difference.
- This results showed that density ratio determined mixing efficiency.

Conclusions

- Mixing efficiency depends on cylinder length.
- Optimal cylinder length is approximately 150 mm, in this condition.
- Diffusive mixing effect is dominant element in this mixing system.
- A dual axis blender could not mix particles with large density ratio well.
- Density ratio determined mixing efficiency of this system.