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Analysis of a Fluid Energy Mill (FEM) by Gas-Solid Two Phase Flow Simulation

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Outline

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- Theoretical Model
- Simulation Setup
- Simulation Results
- Conclusion
- References

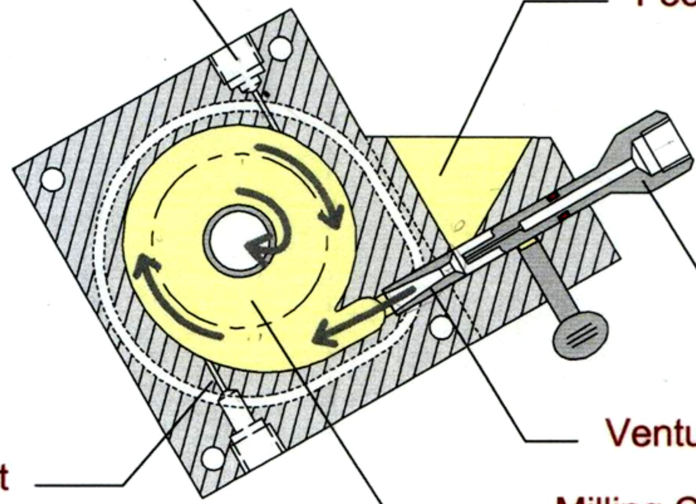
Introduction

- The size reduction in the Fluid Energy Mill is achieved by intensive particulate collisions inside the gas-solid two-phase flow.

- This study focuses on the two-phase flow inside the FEM.

- The three-dimensional particulate motions and collisions inside a FEM were simulated by coupling the Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD), where particle-particle interactions were taken into consideration.

Experiment Setup



The cross-section view of the Sturtevant Qualification FEM.

	KCl	Steel
Poisson's Ratio	0.5	0.31
Shear Modulus (*Pa*)	6.24E+09	7.30E+10
Density (kg/m^3)	1990	7750

Material properties for the DEM-CFD coupling simulations

Theoretical Model

- Gas Phase (CFD)
  - FLUENT (Ansys Inc. Canonsburg, PA), a widely used commercial Computational Fluid Dynamics (CFD) software.
  - The Reynolds Averaged Navier-Stokes equations.
  - The κ - ε turbulent model.
- Solid Phase (DEM)
  - Discrete Element Method (DEM).
  - EDEM (DEM Solutions (USA) Inc., Lebanon, New Hampshire).
- DEM-CFD Coupling
  - Including the transfer of the momentum but excluding the heat transfer.
  - Employing the Lagrangian model due to the computation load and the low particulate volume fraction.

Simulation Setup

- Single-phase gas flow was simulated under five different operating conditions, as listed in the following Table.

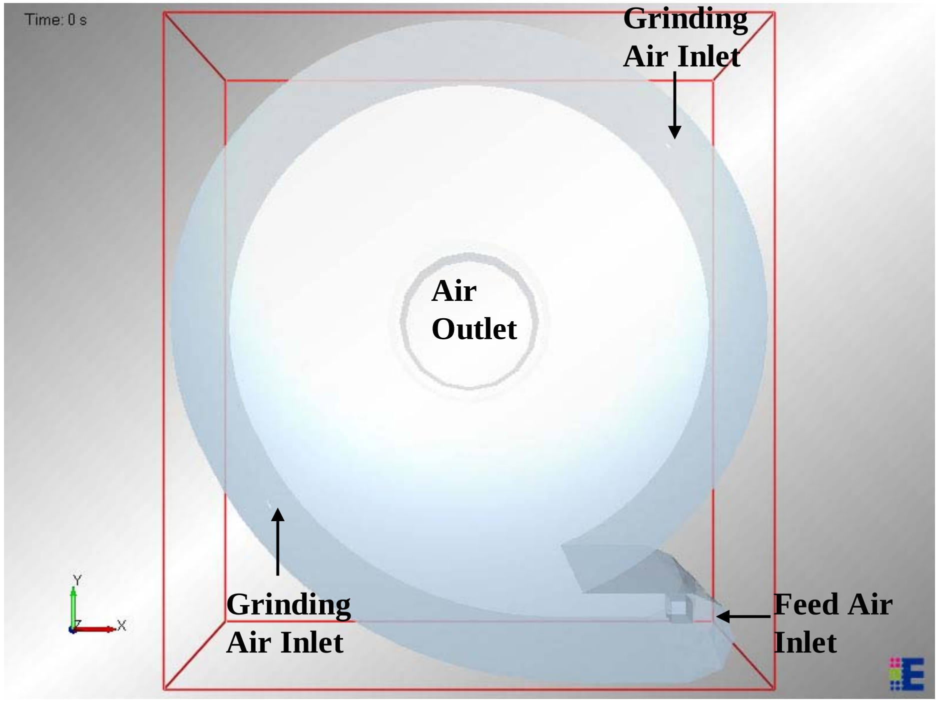
Case	Grind Air Pressure (*kPa*)	Feed Air Pressure (*kPa*)
1	137.8	137.8
2	206.8	206.8
3	275.8	275.8
4	344.7	344.7
5	413.7	413.7

Five different operating conditions investigated in this study

Simulation Setup

- Three air inlet nozzles were not considered in the coupling simulation and only the main chamber was investigated.

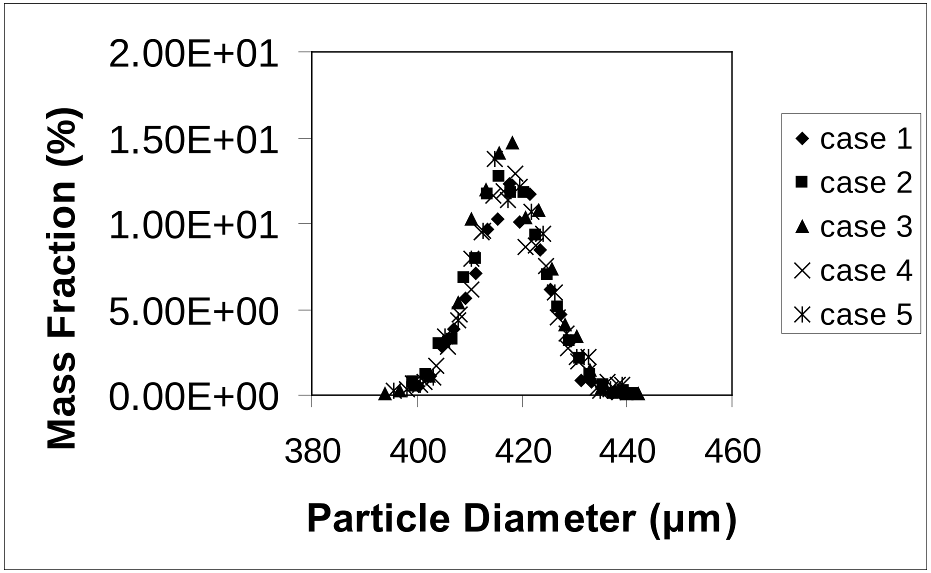
- The cubic box at the entrance of the feed air is a virtual geometry used to generate particles with the mean particle size of 420 µm.



Geometry of the grinding chamber for two-phase simulation.

Simulation Results

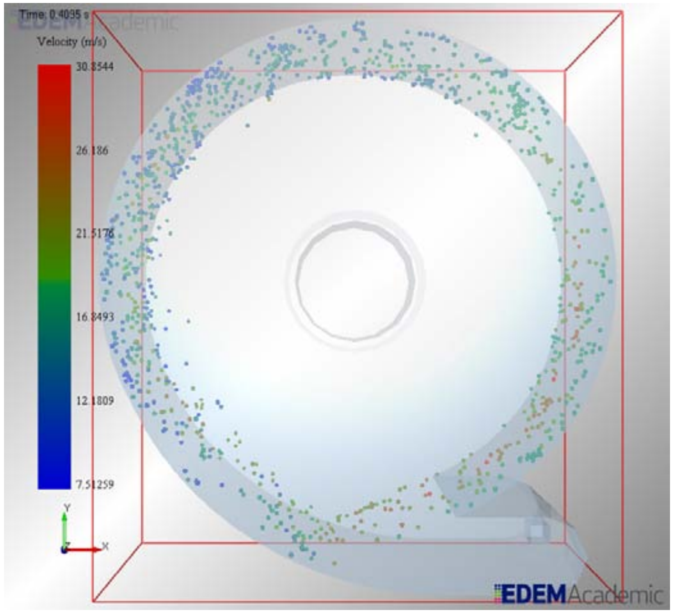
- Particle Generation
  - 1,000 spherical KCl particles were generated at a rate of 10,000 per second.
  - The KCl particles were set to have a mean particle size of 420 μm and follow a normal distribution.



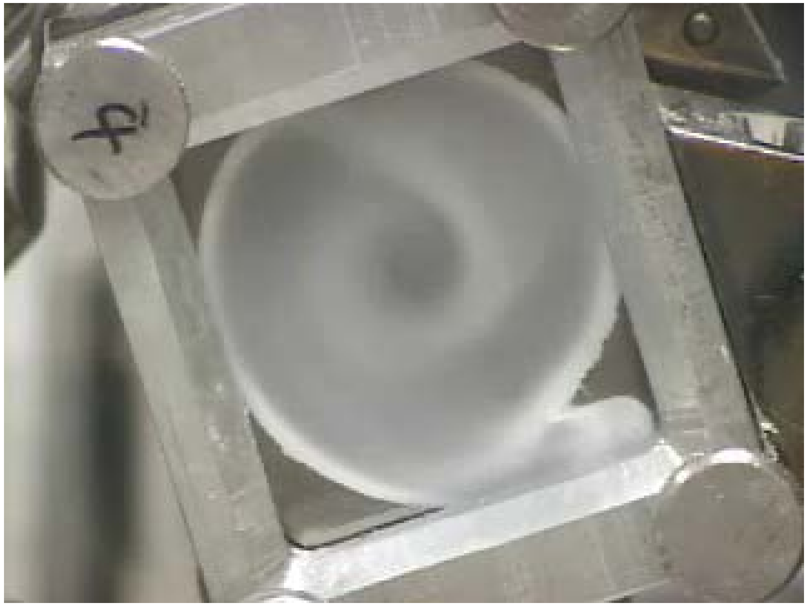
Size distributions of the particles used in the five cases.

Simulation Results

- Particle Motions
  - The particles were driven to the peripheral wall.



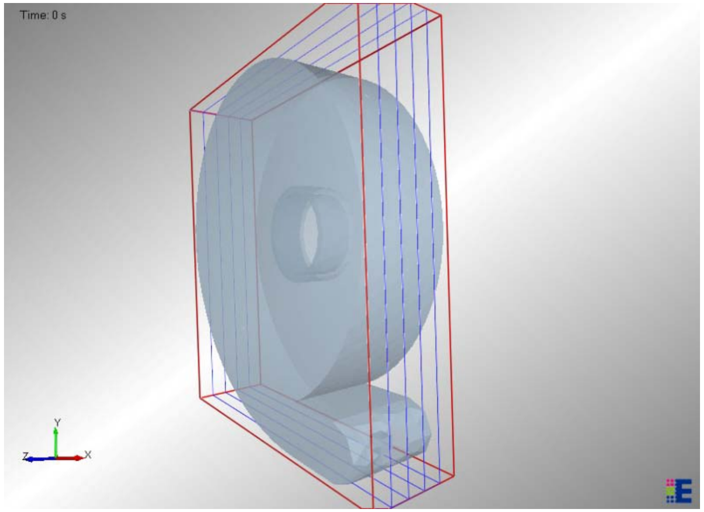
Particle flow pattern after the particle generation under the condition of Case 2.



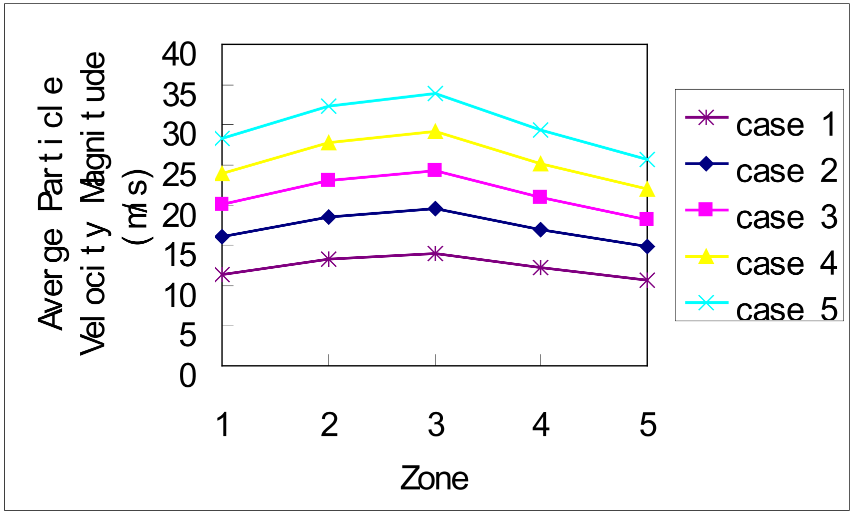
Inside view of the grinding process at steady state.

Simulation Results

- The grinding chamber was evenly divided into five zones along Z direction.
- Zone 3 has the maximum average particle velocity, independent of the operation pressure.



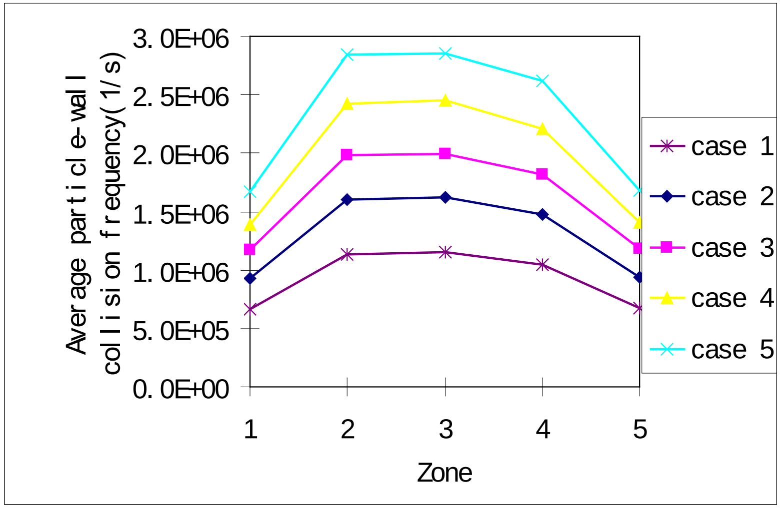
Five zones along the Z direction.

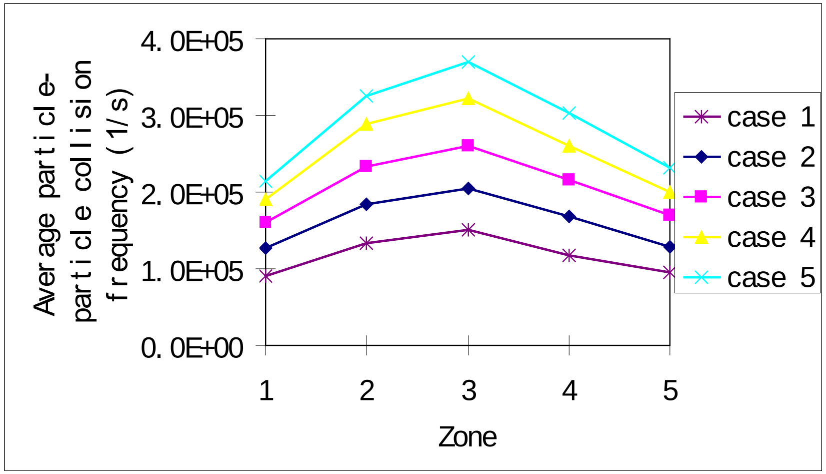


Average particle velocity magnitude in each zone under different cases. (“Average” means average in *both* number and time. And time average is taken from 0.2*s* to 0.45*s*.)

Simulation Results

- Particle Collisions
  - Zone 3 has the largest collision frequencies.

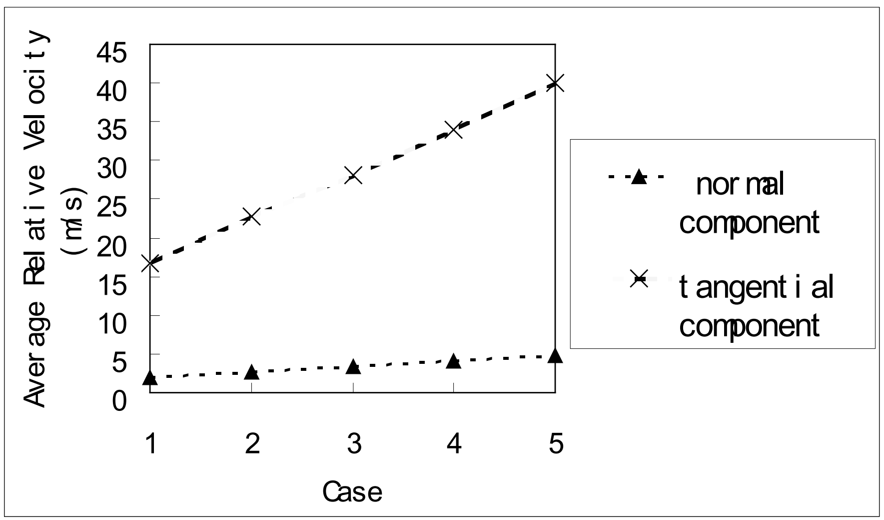




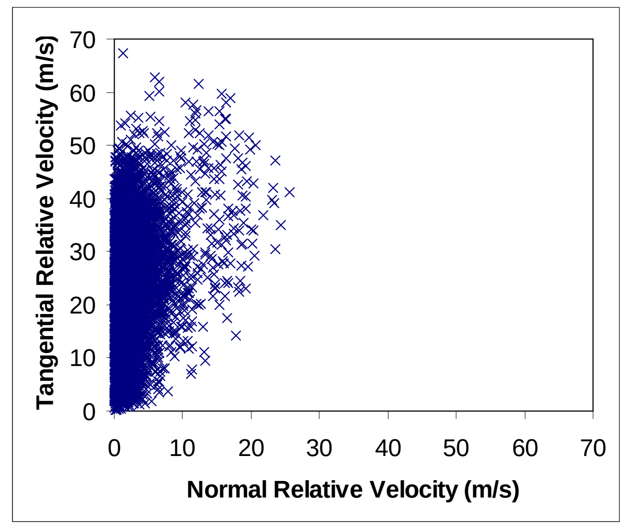
Average collision frequency between the particle and wall and average collision frequency between the particles ("Average" is the time average from 0.2*s* to 0.45*s*.).

Simulation Results

- The ratio of the normal to the tangential component of the relative velocity of particle-particle collisions is about 1:8.3.
- The collisions between the particles can be considered in the majority as "*sideswipe collisions*".



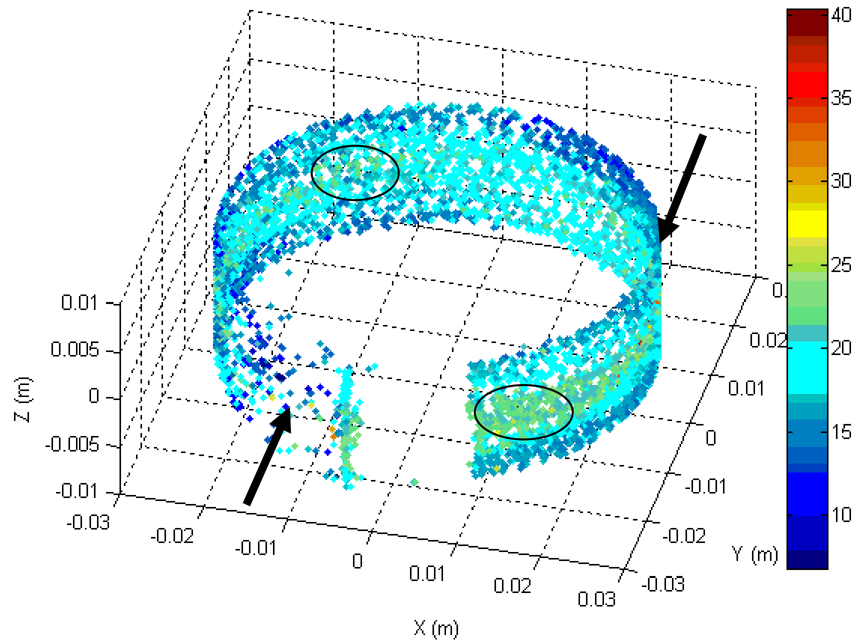
Comparison of the normal and tangential components of the average collision speed for particle-particle collision.



Scatter plot of the normal relative velocities vs. the tangential relative velocities of the collisions between the particles in the Case 2.

Simulation Results

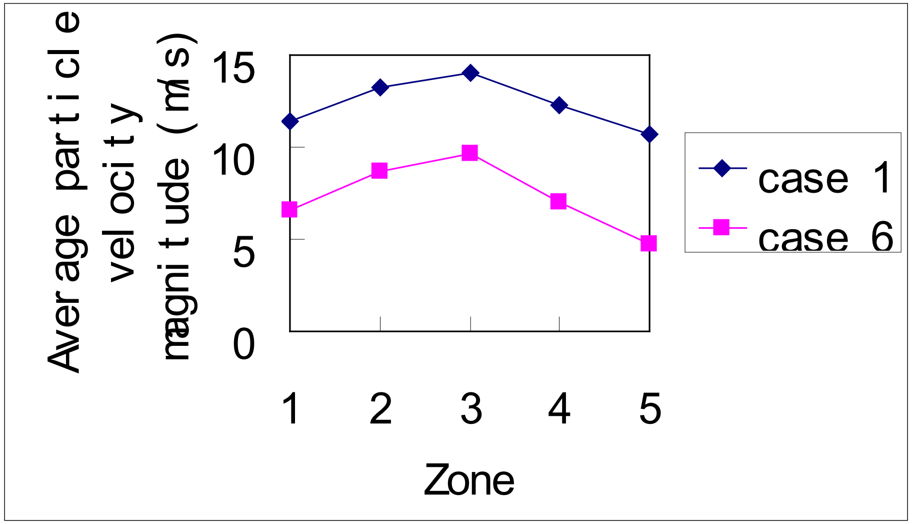
– The particle-wall collisions occur most intensively and frequently at the positions opposite to the two grinding nozzles (marked with circles in Figure).



3-D illustration of the particle-wall collisions in the Case 2. (Duration: 0.001*s*, from 0.44*s* to 0.441*s*).

Simulation Results

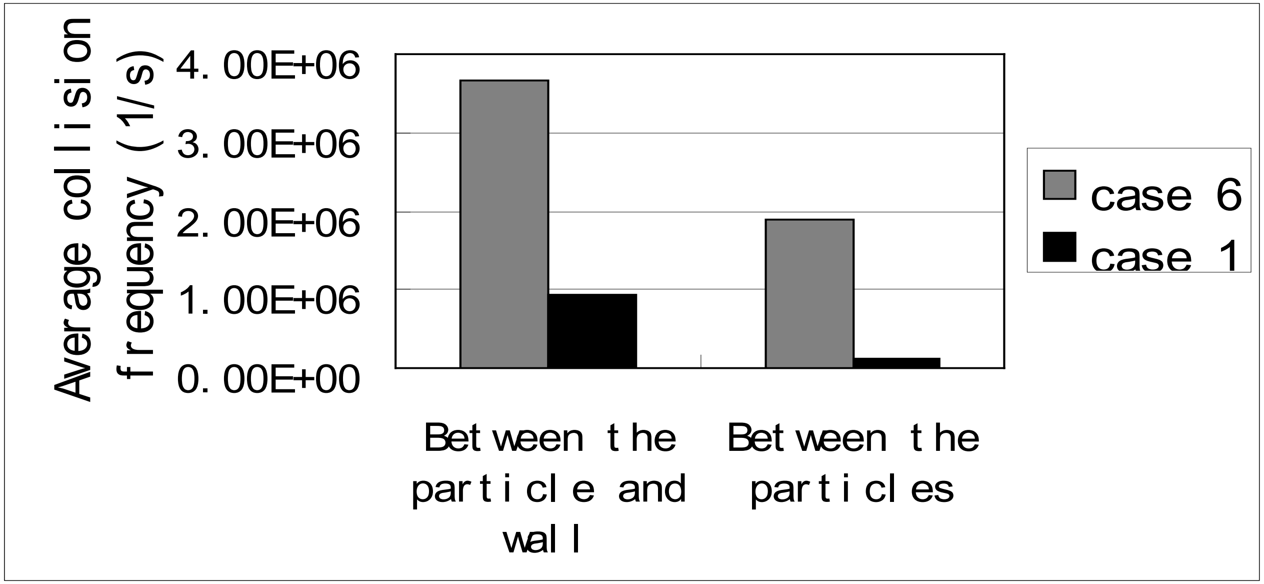
- The Effect of the Number of the Particles
  - 7000 particles were used in the simulation under the operating condition of the Case 1, which is referred as Case 6.
  - The average particle velocity in Case 6 is about one half of that in Case 1.



Comparison of the average particle velocity between Case 1 and Case 6.

Simulation Results

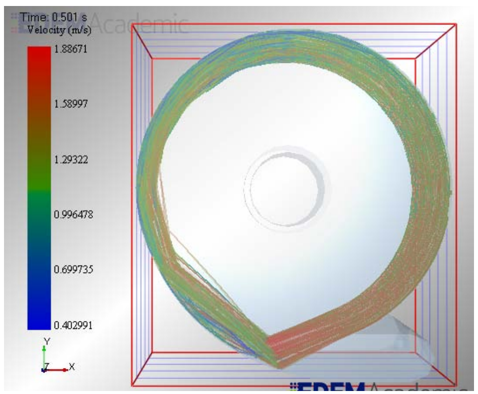
- The collision frequencies increase significantly for Case 6.
- The particle-particle collision frequency increases faster with the number of the particles than the particle-wall collision.
- The ratio of particle-particle collision to particle-wall collision is 1:3 and 1:8, respectively, for case 6 and case 1.



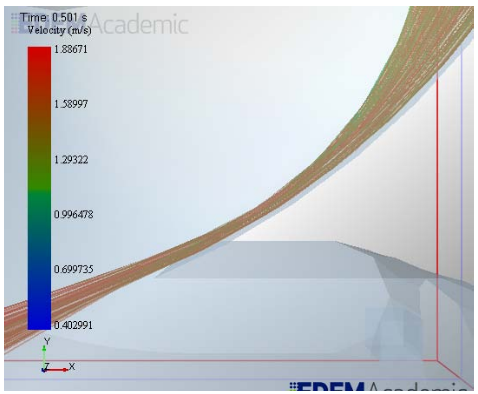
Comparison of average collision frequency between Case 1 and Case 6. (“Average” is the time average from 0.2*s* to 0.45*s*.)

Simulation Results

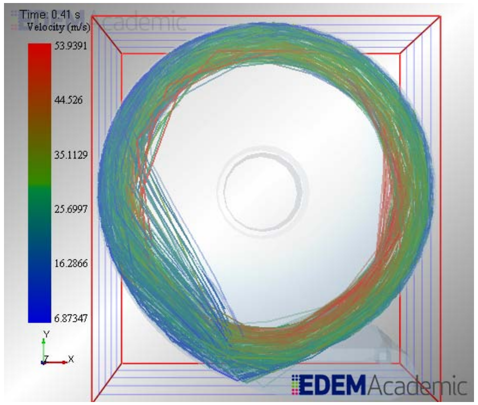
- Streamlines of the Particle Motions



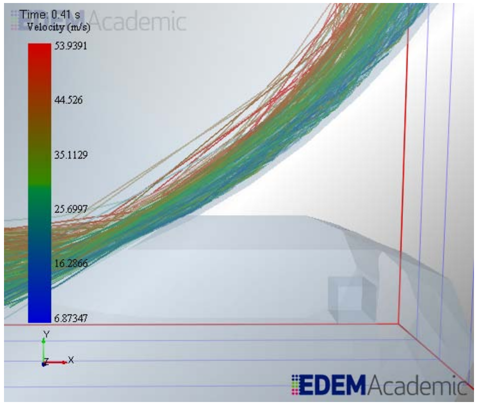
(a)



(b)



(c)



(d)

Comparison of the particle motions with grinding air and without grinding air (in (a) and (b), only FP=344.7*kPa*; in (c) and (d), FP=GP=344.7*kPa*.).

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Conclusion

- The particles are driven to the peripheral wall forming a circulating particle layer.
- Those particles located near the grinding air nozzles are accelerated to higher velocities by two grinding air streams compared to other particles. Those high-speed particles are more likely to hit the wall, or collide with other particles due to the velocity difference.
- The distribution of the particle velocities becomes broader with the increasing of the operating pressures, leading to a higher probability of the establishment of the relative velocities and higher relative velocities to some extent.
- Both the particle-particle collisions and the particle-wall collisions play an important role in the particle size reduction.
- Particle-particle collisions can be considered to be “sideswipe collisions” in majority, and mainly lead to particulate abrasion, instead of cleavage or fracture.
- The feed air stream is not as efficient and effective as the grinding air stream in terms of facilitating particle breakage.

Thank You!

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