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CFD–DEM simulation of material motion in air-and-screen cleaning device

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ABSTRACT

In this work, a numerical study of the gas–solid flow in an air-and-screen cleaning shoe is carried out by use of the combined Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD) model where the motion of discrete particles phase is obtained by DEM which applies EDEM software and the flow of continuum fluid by the traditional CFD which solves the Navier–Stokes equations at a computational cell scale. The effect of inlet airflow velocity is studied and analyzed in terms of grains and short straws' longitudinal velocity and vertical height, and cleaning loss. Simulation results showed that, in a certain range, different inlet airflow velocity only affects the magnitude of airflow velocity in the cleaning shoe, but does not affect the distribution regularity of flow field in the cleaning shoe. With the inlet airflow velocity increase, vibrating screen processing power improves, while grain losses increase. Grains mainly concentrate on 4–12 sections under the screen surface. Comparison of numerical simulation results with experiments has demonstrated adequate agreement. It showed that numerical simulation of material motion on vibrating screen of air-and-screen cleaning device based on CFD–DEM is feasible. The results provide a basis for improving the design on air-and-screen cleaning device of combine harvester.

1. Introduction

Cleaning device is an important part of combine harvesters, its superior or inferior performance directly affects the whole combine harvester performance. High efficiency, high performance combine harvester makes new demands for the cleaning device. Previous research investigated the influence of the different cleaning device settings like fan speed, screen lip angle, oscillation frequency and amplitude on the transportation of grain and chaff along with the cleaning screen by experiment on test bed (Simpson, 1966; German and Lee, 1967; Lee and Winfield, 1969; Bőttinger and Kutzbach, 1987; Cheng and Wang, 1999; Xu et al., 2007; Chen et al., 2009). But experiment on test bed is with high cost and strong seasonality.

With the development of Computational Fluid Dynamics (CFD) technology, it has been able to implement complex geometry area numerical simulation of fluid flows, quantitative description of temporal and spatial change characteristics of the flow field, more profoundly revealed the mechanism of fluid. CFD continues to expand the scope of application and offers new ways to solve practical engineering problems (Karim and Nolan, 2011; Ahuja and Patwardhan, 2008; Blocken et al., 2009; Hanna et al., 2009). Gebrehiwot et al. (2010) applied CFD to study the effect of the addition of a cross-flow opening on the performance of the fan using three fans of similar geometries but different in their cross-flow opening.

Numerical simulation based on the so-called Discrete Element Method (DEM) (Cundall and Strack, 1979) is an effective way to study on screening process. This method has been applied to the study of particle flow in various industrial processes and shown to be very useful in understanding the fundamentals (Yu, 2003). However, its application to screening operation is rather preliminary. Li et al. (2003) presented a mathematical investigation of particulate motion on an inclined screening chute using the Discrete Element Method (DEM). Cleary (2000) used the Discrete Element Method (DEM) to simulate a full industrial scale double deck banana screen for a range of accelerations. Hongguang et al. (2008) developed a two-dimensional DEM emulator named SieveDEM by a VC++.NET, and investigated three typical penetrating behaviors in screen process by the emulator. Zhao et al. (2010) simulated the screening process of particles flow on the vibrating plate based on the dry contact model of soft-ball, and analyzed the motion state and change of screening efficiency of coal particles flow, and discussed the effect of particles size distribution on screening efficiency.

On the other hand, in recent years, the so-called combined approach of Discrete Element Method (DEM) and CFD (CFD–DEM) has been developed (Tsuji et al., 1992; Xu and Yu, 1997; Zhou et al., 2010) and accounts for both particle–particle and particle–fluid interactions. The CFD–DEM approach has been proved to be effective in modeling various particle–fluid flow systems (Li et al., 1999; Xu et al., 2000; Rhodes et al., 2001; Kafui et al., 2002; Yu and Xu,

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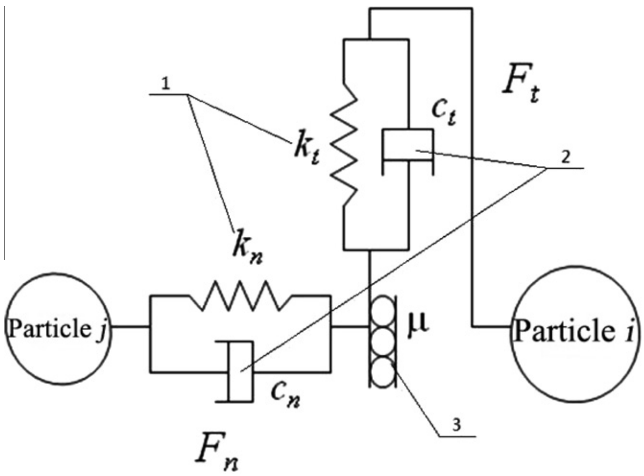

Fig. 1. Model of contact forces.

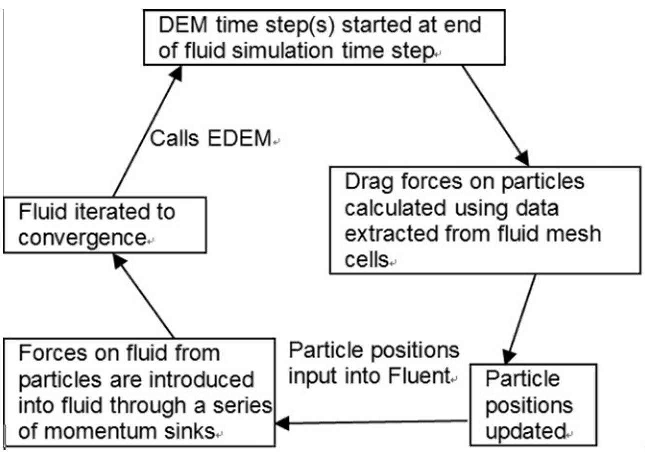

Fig. 2. The process flow for EDEM–CFD coupling.

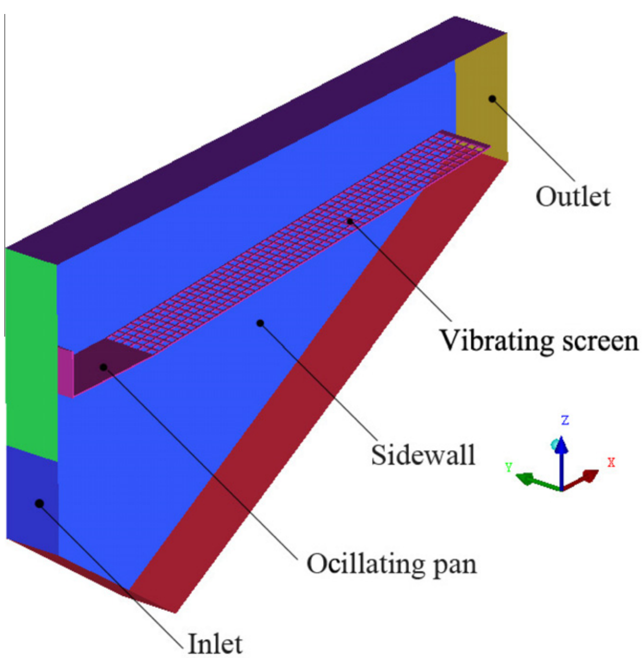

Fig. 3. Three-dimensional (3D) model of the cleaning device.

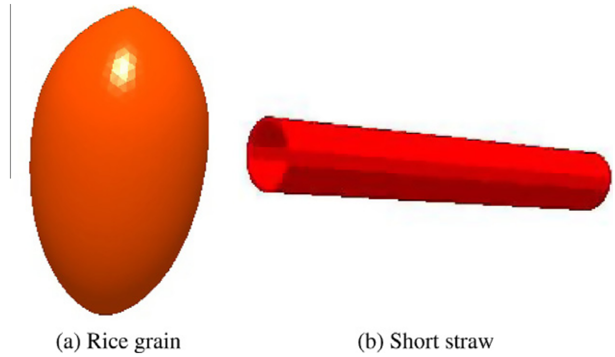

Fig. 4. 3D model of materials.

Table 1
Summary of modeling conditions.

Material properties	Grain	Short straw	Screen (wall)	
Density (kg/m^3)	1380	100	7800	
Poisson's ratio	0.3	0.4	0.3	
Shear modulus (MPa)	2.6	1	700	
Collision properties	Grain–grain	Grain–short straw	Grain–screen (wall)	Short straw–screen (wall)
Coefficient of restitutions	0.2	0.2	0.5	0.1
Coefficient of static friction	1	0.8	0.58	0.8
Coefficient of rolling friction	0.01	0.01	0.01	0.01
Vibrating screen	Motion form	Amplitude	Frequency	Vibrating direction angle
	Sinusoidal translation	20 mm	4.5 Hz	30°
Test case	Case 1	Case 2	Case 3	Case 4
Inlet airflow velocity (m/s)	5	7.5	10	12.5
Inlet direction angle (°)	20	20	20	20

2003; Limtrakul et al., 2004; Di Renzo and Di Maio, 2007; Tsuji, 2007; Kuang et al., 2008). In particular, efforts have been made to extend the CFD–DEM approach to study complex particle–fluid flow systems (Kawaguchi et al., 1998; Rong and Horio, 2001; Ibsen et al., 2004; Chu and Yu, 2008; Chu et al., 2009a,b). To date, to the authors' knowledge, few studies have been made on the gas–solid flow in air-and-screen cleaning device by means of CFD–DEM approach.

In the air-and-screen cleaning device, there are interactions of particle–particle and particle–fluid. So it is a complex gas–solid two-phase flow. Therefore, we use Computational Fluid Dynamics (CFD) and particle discrete element (DEM) to simulate the screening process of air-and-screen cleaning device. The effect of inlet airflow velocity is studied and analyzed in terms of grains and short straws' longitudinal velocity and vertical height, and cleaning loss. Theoretical basis for improving the design on air-and-screen cleaning device of combine harvester was proposed in this paper.

2. Mathematical model

2.1. Equations of gas phase

The CFD portion of the coupling model uses the existing Eulerian–Eulerian model in FLUENT. In the Eulerian model, an additional