Movement law of the threshing material in threshing and cleaning machine for plot-bred wheat

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Abstract: In order to clarify and enhance the work performance of the threshing and cleaning machine for plot-bred wheat and further reduce the grain retention in all working areas in the machine, in this study, a discrete element model for the threshing material of plot-bred wheat and a gas-solid coupling simulation model for the machine were established by ensuring all the harvesting criteria for the machine. Then numerical simulation was completed on the movement process of the threshing material in the threshing and cleaning machine for plot-bred wheat, the movement law and motion trajectory of all components of the threshing material were explored, and the impact forms of unreasonable work parameters on the separating and cleaning process were analyzed. First, four working areas were divided in the threshing and cleaning machine for plot-bred wheat. Under gas-solid flow coupling effect, the number variation of threshing material in each working area was analyzed under the effect of gas-solid coupling, and the operation characteristics of "no retained seeds and convenient cleaning" of the threshing machine for plot-bred wheat were further improved. The verification test results showed that, when the feeding amount of wheat was 0.30 kg/s, the rotation speed of the shaft of the tooth-type threshing cylinder was set to 1350 r/min, the rotation speed of the winnower was set to 500 r/min, the rotation speed of the residue absorption fan was set to 1000 r/min, the average total loss rate in threshing of the sample machine was 0.56%, and average impurity rate of the threshing material was 5.26%, average damage rate in threshing was 0.68%. In the test, the status of material discharged from the residue absorption fan outlet and bottom of the cyclone separator was similar to that of the simulation results, showing that it was feasible to use the method of gas-solid coupling to simulate the movement law of threshing material in the threshing and cleaning machine for plot-bred wheat.

Keywords: plot-bred wheat, threshing and cleaning machine, computational fluid mechanics, discrete element, numerical simulation, test

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1 Introduction

Field plot breeding is a systematic project in agriculture that demands huge labor and financial resources. It mainly includes field plot sowing, plot harvesting, plot seed processing and handling, and plot test data processing[1,2]. The agriculturally developed countries in the world (such as the USA, Austria, and Germany) attached great importance to the research and development of field plot breeding harvesting machinery, and have conducted in-depth researches on threshing and harvesting machinery and equipment and detection equipment related to field breeding, which improved breeding and harvesting effect and ensured the accuracy and reliability of breeding test data. Mechanized harvesting in field plot breeding can exponentially enhance the working efficiency of breeding and ensure the reliability of the test collected data. In recent years, the proposal of the sustainable development strategy of global eco-agriculture has raised higher demands (no retained seeds, convenient cleaning, and high level of automation) for the multi-stage harvesting of field plot (breeding harvesting, threshing, and cleaning) and work performance of supported equipment for combine harvesting machinery, to improve the working level of mechanized field plot breeding tests[3-5].

Studies in foreign countries in plot breeding harvesting machinery started relatively early, with no seed retention and mature technologies in cleaning. Foreign manufacturers are mainly represented by Wintersteiger in Austria and Hilge in Germany engaged in the design and manufacturing of field wheat breeding combine harvester[1,2]. The research on the plot wheat breeding harvesting machinery in China started late and developed only a few products. Due to immature technology, multi-stage harvesting is mainly adopted by using swather and fixed type threshing and cleaning machine for field wheat breeding[5-8]. In China, the movable type threshing and cleaning machine for plot-bred wheat designed by Hongxinglong Agriculture Science Research Institute of General Bureau of Land Reclamation, Heilongjiang, has an air flow throughout the whole separation and cleaning process in operation. The designed machine has a strong ability of anti-mixing, and demands no manual machine cleaning, hence, it is extensively applied in multi-stage harvesting in

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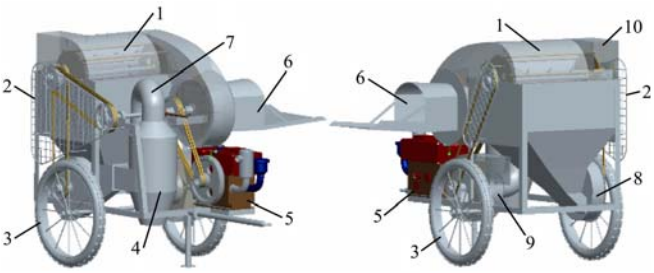
breeding in China[9,10]. Therefore, based on the structural design of the sample machine and the gas-solid two-phase flow theory, the movement law of threshing material in the threshing and cleaning machine for plot-bred wheat was studied, to further reveal the interaction mechanism for gas-solid two-phase flow of agricultural material in the threshing and cleaning device, and optimize the separating and threshing performance of the machine. The study is of great significance in elevating the mechanized operation level for plot-bred wheat in China.

2 Structure of the device and working principles

2.1 Structure

The structure of the threshing and cleaning machine for plot-bred wheat is shown in Figure 1. It is mainly composed of the threshing and separating mechanism (threshing drum and concave, cleaning device (winnower, cyclone separator, residue absorption fan and residue suction pipeline, feeding mouth, discharge outlet, diesel engine, walking wheel, and protective cover[9].



1. Threshing drum 2. Protective cover 3. Walking wheel 4. Cyclone separator 5. Diesel engine 6. Feeding mouth 7. Residue suction pipeline 8. Residue absorption fan 9. Winnower 10. Discharge outlet

Figure 1 Structure of the threshing and cleaning machine for plot-bred wheat

2.2 Working principle

In operation, breeding wheat is thrown tangentially into the threshing chamber under the fast rotating impellers at the feeding mouth. After entering the threshing chamber, the breeding wheat does circumferential and axial movement driven by the tooth-type drum, and in collision and beating, the wheat grains are threshed from the ear of wheat. Under the effect of the centrifugal force of the drum, wheat grains, short stems, glumes, and light impurities are separated by the grid type concave, and long wheat stems are discharged from the discharge outlet. Later, all the threshing material enters the winnower and is thrown into the cyclone separator. Due to different densities of the components of the threshing material, under the effect of negative pressure air flow generated by the residue absorption fan, glumes at low suspension speed and light impurities are first discharged through the suction pipeline with the air flow, and grains at high suspension speed fall down from the cyclone separator.

2.3 Main technical parameters

Based on the preliminary study of the research group, the main technological parameters of the threshing and cleaning machine for plot-bred wheat are shown in Table 1. The feeding amount can be adjusted manually at the feeding mouth, and the rotation speed of the drum, winnower, and residue absorption fan can be adjusted by changing belt wheels with different diameters[9].

Table 1 Main technological parameters of the machine

Parameters	Values
Size (Length×width×height)/mm× mm×mm	2240×1560×1705
Power/kW	11.0
Walking style	Movable type
Type of drum	Tooth-type
Machine weight/kg	391
Feeding type	Whole feeding type
Concave type	Grid type
Feeding amount/kg·s^{-1}	0.30-0.50
Rotation speed of the drum/r·min^{-1}	1350-1450
Rotation speed of the residue absorption fan/r·min^{-1}	900-1000
Rotation speed of the winnower/r·min^{-1}	500-600
Production rate/kg·h^{-1}	250-350

3 Simulation-based mathematical model

Gas phase control equation the simulation process in this study involves the periodic rotation of the threshing drum, winnower and residue absorption fan, hence, the RNG K-ε turbulence model was adopted in the numerical simulation. The equation for the RNG K-ε turbulence model is shown in Equations (1) and (2) in references [3, 11].

Particle contact model in this study, the threshing material flow was relatively sparsely distributed, thus the collision among different components and between material and boundary belong to non-viscous contact with relatively small time steps, therefore, hard-sphere Hertz-Mindlin non-slip contact model was adopted. In the simulation calculation, first, judge the contact condition among particles in the computational domain, then, the acting force among particles, counterforce, and displacements are determined based on newton's third law, and the new unbalanced force produced among adjacent particles are calculated based on newton's second law, till the force on each particle becomes balanced. The control equation is shown in Equations (3) and (4) in references [3,11].

4 Model establishment and parameter setting

4.1 Model establishment and mesh division in computational domain

Simplify the model for the threshing and cleaning machine for plot-bred wheat in Solidworks, eliminate the parts that have no effect on the simulation process, save it in the form of "x_t", and later import the Geometry module in ANSYS Workbench, and extract fluid domain on the model. Change the fan area into rotating fluid domain by Boolean operation, other parts belong to the static fluid domain[12-14]. Later, divide meshes on the cleaning device in the Mesh module, and get 726 602 unstructured tetrahedral meshes. The network of the cleaning device is shown in Figure 2.

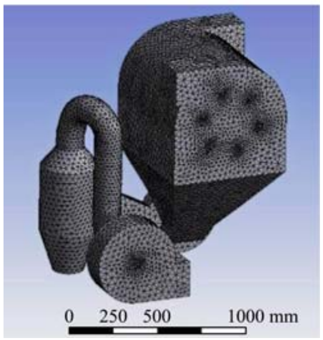
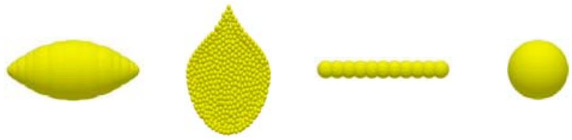


Figure 2 Mesh model for the cleaning device

4.2 Material model and parameter setting

The threshing material for the breeding wheat in the simulation mainly includes grains, glumes, short stems, and light impurities, the shapes of each kind of material are different. Multi-spherical particle filling method was adopted in EDEM to simulate the shapes of different types of material. In order to improve the fitting degree in shape and save the operation resources of the computer, 18, 6, and 19 non-equivalent spherical particles were used to simulate wheat grains, glumes, and short stems, and spherical particles with a radius of 1 mm were used to simulate light impurities. The discrete element model for the components of the breeding wheat is shown in Figure 3[3].



a. Wheat grain model b. Wheat glume model c. Short stem model d. Light impurity model

Figure 3 Discrete element model of the components of the breeding wheat as the threshing material

In the software EDEM, the setting of property parameters, recovery coefficients, static friction factors between materials, and dynamic friction factors between materials of breeding wheat are shown in reference [3]. In the simulation process, 1150 breeding wheat grains are produced per second at the feeding mouth, 2800 wheat glumes are produced per second, 2500 short stems are produced per second, and 300 light impurities are produced per second.

4.3 Coupling parameter setting

The Moving Reference Frame in FLUENT was adopted to simulate the rotation of the residue absorption fan. Set the rotation speed of the rotation area as 1000 r/min, and set the fan to “Moving Wall”, the relative rotation area is static, and the rotation speed is 0 r/min. In order to ensure the stable exchange of the flow field data in the rotation area and static area, the interface was set in Mesh Interfaces. At the same time, choose the area as the fluid medium, with a density of 1.2 kg/m^3, and viscosity of 1.8×10^{-5} Pa·s. The pipeline wall is a non-sliding wall, and the pressure-based SIMPLE algorithm was adopted to do coupling solution on the velocity field and pressure field, the second-order upwind was adopted for the item of momentum, first-order upwind was adopted for turbulent kinetic energy, and turbulent dissipation rate, with residue error precision of 10^{-3} s. In the calculation of gas-solid coupling, since the solid phase volume fraction is lower than 10% and belongs to the dilute phase pneumatic transmission system, therefore, the Euler-Lagrange coupling model was adopted.

5 Simulation process and result analysis

5.1 Movement law of threshing material in separating and cleaning

According to the work parameters of the threshing and cleaning machine for plot-bred wheat obtained in the preliminary test by the research group[9], combined with the existing optimization results, the rotation speed of the tooth-type threshing drum was set to 1350 r/min, 1400 r/min, and 1450 r/min, the rotation speed of the residue absorption fan was set to 900 r/min, 950 r/min, and 1000 r/min, and the simulation time step was 3×10^{-6} s, and simulation lasted for 4 s. The simulation process was shown in Figure 4.

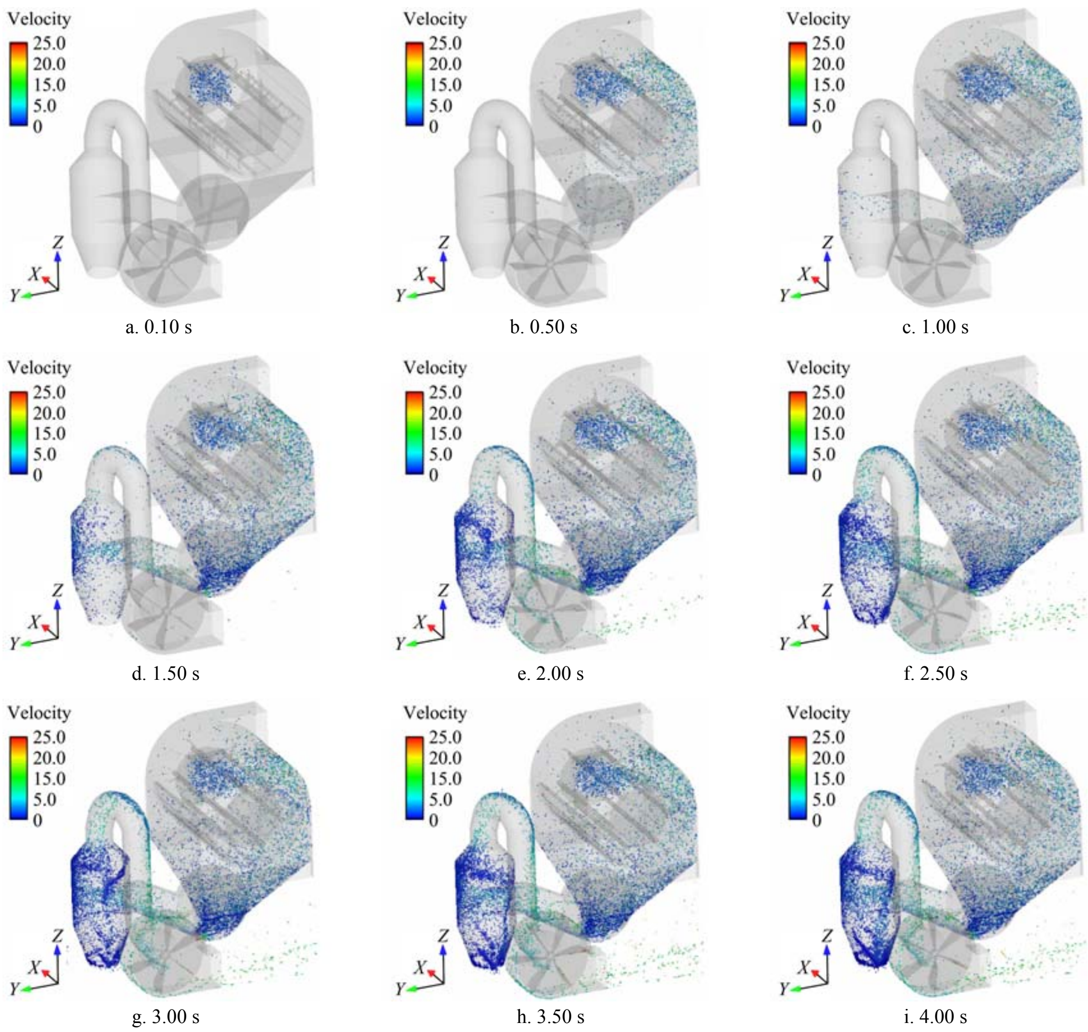


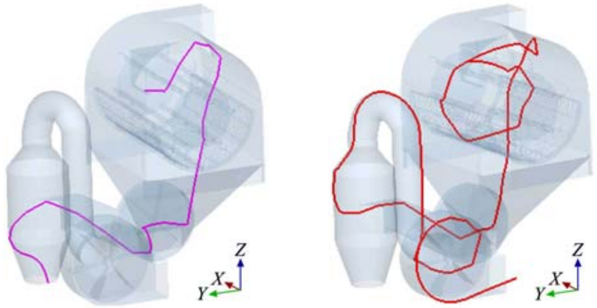
Figure 4 Working process of the threshing and cleaning machine for plot-bred wheat

The wheat threshing material was produced at an initial speed of 0 m/s, and the separating and threshing process of the threshing material in the machine was simulated, to explore the movement law and analyze its characteristics of “no retained seeds and convenient cleaning”. Figure 4 shows the simulation process when the flow field of the cleaning air flow becomes stable. The rotation speed of the tooth-type threshing drum was set to 1350 r/min, the rotation speed of the winnower was set to 500 r/min, the rotation speed of the residue absorption fan was set to 1000 r/min, and time t=0.10-4.00 s. From t=0 s, numerical simulation by EDEM is close to the working condition of the threshing and cleaning machine for plot-bred wheat[15-18]. When t=0.10 s, the threshing material produced by the material plant gradually entered the tooth-type threshing drum, as shown in Figure 4a. When t=0.50 s, the threshing material started to scatter along the enclosure under the beating of the nail teeth of the threshing unit in the drum, and accelerated its movement under the high-speed rotation of the drum (Figure 4b). As shown in Figure 4c, when t=1.00 s, under the effect of the gravity of the threshing material, and collision force between the drum and the enclosure, the threshing material gradually entered the winnower along the tapered plates at both sides of the bottom of the drum. When t=1.50 s, under the effect of high-speed air flow of throwing in the winnower, the material quickly entered the cyclone separator, then the amount of the material continued to increase (Figure 4d). As shown in Figure 4e, when t=2.00 s, the threshing material in the pressure gradient force was subject to gravity, pressure gradient force, drag force, spinning lift force, and collision force from the wall, a few grains fell down from the bottom outlet of the cyclone separator. When t=2.50 s, the light-weighted glumes, short stems and light impurities in the threshing material were discharged through the suction pipeline with the upward air flow under the effect of residue absorption fan (Figure 4f). As shown in Figures 4g and 4i, when t = 3.00-4.00 s, the threshing material was continuously affected by the rotating airflow and inertial force in the cyclone separator, and the “layering” between the components was constantly increasing. The heavier wheat grains gradually formed a continuous particle flow, which rotated downward along the wall of the drum and fell into the grain receiving box; the remaining material was quickly discharged through the suction pipe under the negative pressure of the suction fan. In this way, separating and cleaning of breeding wheat threshing materials was completed.

5.2 Movement trajectory of the threshing material

In the simulation, through adjusting and setting the rotation speed of the tooth-type threshing drum, the winnower, and the residue absorption fan, it was ensured that all the breeding wheat grains fell down from the bottom of the cyclone separator, and the short stems, glumes, and light impurities were discharged from the suction pipeline under the effect of the residue absorption fan. In order to further improve the cleaning capacity of the machine, then mark the movement trajectories of wheat grains and other threshing material (short stems, glumes, and light impurities) in the separating and cleaning process. The movement trajectory of wheat grains was marked in purple lines in Figure 5a, and the trajectories of short stems, glumes, and light impurities of the breeding wheat were marked in red lines in Figure 5b[19].

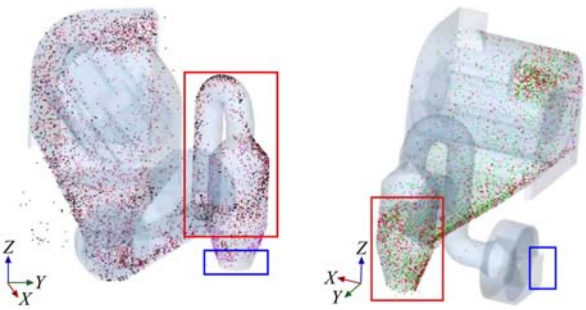
As shown in Figure 5, when the working parameters of the machine are relatively reasonable, the breeding wheat grains entered into the winnower through the threshing drum, and are thrown by the winnower, the grains entered into the cyclone separator through the pipeline, then under the effect of rotating air flow, the grains fell down along the drum wall to the grain receiving box. At the same time, the short stems, glumes, and light impurities which are lighter also entered the cyclone separator through the threshing drum and winnower, and under the negative suction effect of the residue absorption fan, they move upward along the drum wall, and were finally discharged out of the machine through the suction pipeline.



a. Movement trajectory of the wheat grains b. Movement trajectories of short stems, glumes, and light impurities

Figure 5 Movement trajectories of the components of threshing material

It can be known from Figure 6 that, when the working parameters of the sample machine were unreasonable (the rotation speed of the residue absorption fan was too high or too low), the separating and cleaning states for plot-bred wheat were different. When the rotation speed of the winnower was fixed, and the rotation speed of the residue absorption fan was too high (Figure 6a), the vertical movement range of short stems, glumes, and light impurities in the cyclone separator became larger, and the grains in them had irregular movement, then plenty of grains were discharged out of the machine, causing loss of grains. When the rotation speed of the winnower was fixed, and the rotation speed of the residue absorption fan was too low (Figure 6b), there was not enough pressure in the suction pipeline to absorb the threshing material, causing the grains to move quirking at the bottom of the cyclone separator and enter into the central high-speed area full of most short stems and glumes. The layering phenomenon between them disappeared, and the grains along with a lot of short stems and glumes fell down, causing lower cleaning rates.



a. Discharge of all impurities b. Discharge of all grains

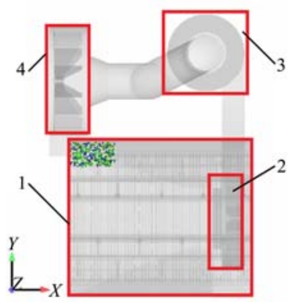
Note: The red boxes represent all discharge parts, and the blue boxes represent no discharge parts.

Figure 6 Two unreasonable separating and cleaning status

6 Amount variation characteristics of threshing material in the working area

6.1 Division of working areas

No grain retention within the machine is one of the most important performance indicators after harvesting plot-bred wheat. According to the working process of the machine and its functional area, it is necessary to divide the four working areas of the machine (threshing drum area, winnower area, cyclone separator area, residue absorption fan area), as shown in Figure 7[3]. Under gas-solid flow coupling effect, the number variation of threshing material in each working area was analyzed under the effect of gas-solid coupling, and the operation characteristics of "no retained seeds and convenient cleaning" of the threshing machine for plot-bred wheat were further improved.



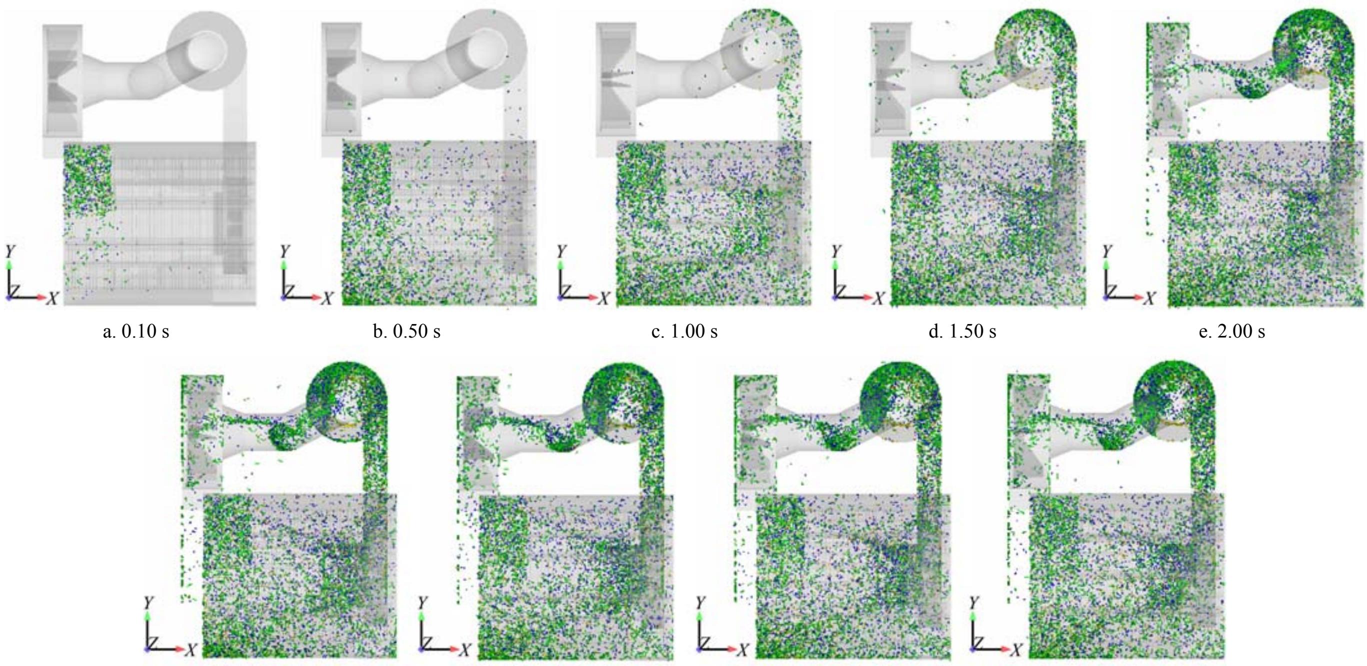
1. Threshing drum area 2. Winnower area 3. Cyclone separator area
4. Residue absorption fan area

Figure 7 Working areas of the threshing and cleaning machine for plot-bred wheat

6.2 Number characteristics of components of threshing material in the working areas

As shown in Figure 8, when simulation time was between 0.1-4.0 s, the working parameters of the sample machine were set as follows: the rotation speed of the tooth-type threshing drum was 1350 r/min, the rotation speed of winnower was 500 r/min, the rotation speed of the residue absorption fan was 1000 r/min. The software EDEM was used to analyze and measure the movement status and the number of the components of the threshing material in the four working areas to further explore the movement law of the components, enhance the grain cleaning rate, reduce loss rate and better improve the effect of "no seed retention" in the machine.

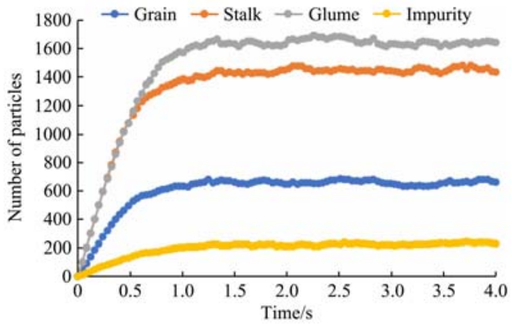
It can be seen from Figures 8a-8i that, by choosing reasonable working parameters for the sample machine, with the increase of the wind speed in the working areas, the threshing material had a high initial speed upon entering the cyclone separator, and the components of the material had consistent movement speed, with weaker blocking effect and stronger "layering effect" among them. The laminar condition of the threshing material was good, and conducive to the effective separation of grains from glumes and short stems[10,20], so improved the cleaning rate and lowered the rate of seed retention effectively. However, when the wind speed increased in the working area, the laminar condition of the threshing material gradually disappeared, the material flow became more and more steady, thus the cleaning rate reduced and the loss rate increased with the increase of the rotation speed of the fan. In the separating and cleaning process of the threshing material, the threshing wheat grains went through the three working areas of the threshing drum, the winnower, and the cyclone separator, and the rest threshing material (short stems, glumes, and light impurities) finally entered the fourth working area of the residue absorption fan through the pipeline and were discharged. Therefore, the layout of the working areas, and above shortened the movement path of the breeding wheat grains, reduced the number of seeds entering working areas, lowered the rate of seed retention, hence, the layout and order of the working areas are reasonable.



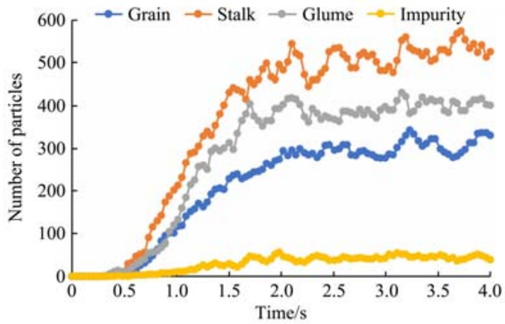
a. 0.10 s b. 0.50 s c. 1.00 s d. 1.50 s e. 2.00 s
f. 2.50 s g. 3.00 s h. 3.50 s i. 4.00 s

Figure 8 Movement characteristics of threshing material in the working areas

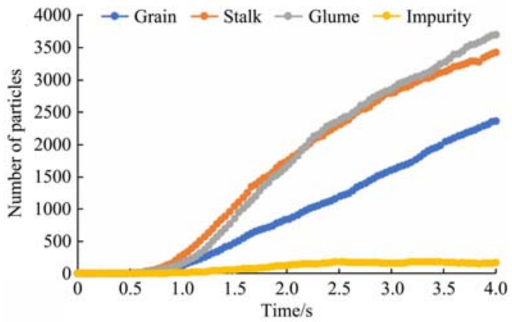
Figure 9 shows the number distribution of the components of the threshing material in a stable and convergent air flow field in the four working areas of the machine[16]. The number distribution of components of threshing material in the threshing drum area is shown in Figure 9a. Since the threshing material was directly generated at the feeding mouth, under the rotation of the drum, the number of components was different from that in the initial setting, but the proportion of the components kept basically consistent after the simulation started for 1.5 s. The number distribution of components of threshing material in the winnower area is shown in Figure 9b. In this area, the number of wheat grains and light impurities were less than that of short stems and glumes. However, compared with that in the threshing drum area, after the simulation started for 2.0 s, the number of glumes was about 300-400, while the number of short stems was about 430-560. The reason is that the weight of glumes is light, and after the components entered the winnower, the glumes would be first blown away by the high-speed air flow from the winnower, thus there were few glumes retained in winnower. The number distribution of components of threshing material in the cyclone separator area is shown in Figure 9c. After the light impurities entered the cyclone separator, they were discharged immediately by the residue absorption fan along the pipeline, so that the number of light impurities was kept at about 200, showing a stable tendency. Under the joint action of the fields of winnower and residue absorption fan, short stems and some glumes had irregular movement at the upright part of the cyclone separator, and the number of them was interactively increasing in this area (the number reached 3000-3800 during the simulation). The grains had helical movement in short stems, glumes and drum wall, thus the drum is the area with the highest number in the four areas (the number reached 2200-2300 during the simulation). As time went by, the number was in linear growth, however, since the cyclone separator was in upright arrangement, there was no seed retention in this area. The number distribution of the threshing material in the residue absorption fan area is shown in Figure 9d. There were no discharged grains in this area, showing that the adopted working parameters were reasonable and no loss occurred. Since short stems are heavier than glumes and light impurities, they were discharged more slowly under the suction by the negative air flow of the residue absorption fan, so the number of short stems was the highest in this area (as high as 200-350 during the simulation).



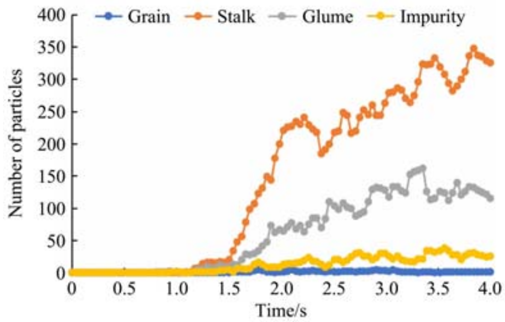
a. Distribution of components of the threshing material in the threshing drum area



b. Distribution of components of the threshing material in the winnower area



c. Distribution of components of the threshing material in the cyclone separator area



d. Distribution of components of the threshing material in the residue absorption fan area

Figure 9 Number distribution of components of threshing material in the working areas

From the overall distribution of the components of the threshing material in the four working areas, the areas where the number of particles of each component tended to be the same over time mainly appeared in the threshing drum area and the winnower area, which are the key areas that would easily retain grains. Therefore, there was no need to halt the operation after the threshing and cleaning of plot-bred wheat, but it was necessary to resume after the airflow cleaning machine for an interval of 20-30 s for the threshing and cleaning of the next variety.

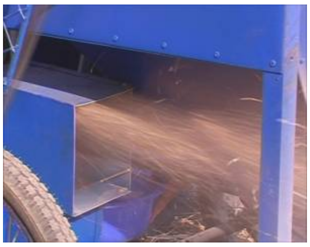
7 Test verification

The verification test for the work performance of the threshing and cleaning machine for plot-bred wheat is shown in Figure 10a. The test material was breeding wheat grains in the breeding plot of Gansu Academy of Agricultural Sciences. The variety was Longchun No. 27, with a thousand seed mass of 41.8 g and moisture content of 21.6%. During the test, the feeding amount of the wheat grains was 0.30 kg/s, the rotation speed of the tooth-type threshing drum was set to 1350 r/min, the rotation speed of the winnower was set to 500 r/min, the rotation speed of the residue absorption fan was set to 1000 r/min. In order to meet the operation requirements of high threshing rate, low impurity rate, and low loss rate for the threshing and cleaning machine for plot-bred wheat, by referring to the measurement indicators in General provisions of the methods for determining the test conditions of agricultural machinery (GB/T5982-2005), the total loss rate in threshing (loss rate before threshing and loss rate during threshing), content impurity rate in threshing material, and damage rate as the evaluation indicators for work performance.

At the same time, observe the status of short stems, glumes, and light impurities of the wheat at the outlet of the residue absorption fan (Figure 10b) and the status of the harvested grains at the bottom mouth of the cyclone separator (Figure 10c).

Test results showed that when the feeding amount of the wheat grains was 0.30 kg/s, and the rotation speed of the tooth-type threshing drum was set to 1350 r/min, the rotation speed of the winnower was set to 500 r/min, and the rotation speed of the residue absorption fan was set to 1000 r/min, the average total loss rate of the sample machine was 0.56%, average content impurity rate of the threshing material was 5.26%, and average damage rate in threshing was 0.68%. At the same time, the status of material discharged from the bottom of the residue absorption fan and cyclone separator was similar to that in the simulation process. After the threshing and cleaning test was completed and an interval of machine cleaning by air flow, there was no retained grain in all of the four working areas in the sample machine, showing that the test results were basically consistent with the simulation results. Hence, the movement law of the threshing material in the threshing and cleaning machine for plot-bred wheat based on gas-solid coupling theory was feasible and accurate.

a. Threshing and cleaning device for plot-bred wheat



b. Discharge process of short stems, glumes and light impurities

c. Harvested wheat grains

Figure 10 Test process of the threshing and cleaning machine for plot-bred wheat

8 Conclusions

1) In this study, a discrete element model of the threshing material of the plot-bred wheat was established, and a gas-solid coupling simulation model on the threshing and cleaning machine for plot-bred wheat was constructed. Then the CFD-DEM coupling method was adopted to do numerical simulation on the movement process of the threshing material in the machine, and the transfer law and trajectories of the components of the threshing material were explored, then the influence law of unreasonable working parameters on the separating and cleaning process was analyzed.

2) The four working areas of the threshing and cleaning machine for plot-bred wheat were divided, which are the threshing drum area, winnower area, cyclone separator area, and residue absorption fan area. Under gas-solid flow coupling effect, the number variation of threshing material in each working area was analyzed under the effect of gas-solid coupling, and the operation characteristics of “no retained seeds and convenient cleaning” of the threshing machine for plot-bred wheat were further improved.

3) The verification test was carried out on the work performance of the threshing and cleaning machine for plot-bred wheat. Test results showed that the average total loss rate in threshing of the sample machine was 0.56%, the average impurity rate of the threshing material was 5.26%, the average damage rate in threshing was 0.68%, and the test results met the requirements of relevant standards. In the test, the status of material discharged from the residue absorption fan outlet and bottom of the cyclone separator was basically consistent with that of the simulation results. It verified the feasibility and accuracy of the movement law of the threshing material in the threshing and cleaning machine for plot-bred wheat.

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[References]

[1] Zhu M, Chen H J, Li Y L. Investigation and development analysis of seed industry mechanization in China. Transactions of the CSAE, 2015; 31(14): 1–7. (in Chinese)

[2] Shang S Q, Yang R B, Yin Y Y, Guo P Y, Sun Q. Current situation and development trend of mechanization of field experiments. Transactions of the CSAE, 2010; 26(Supp.1): 5–8. (in Chinese)

[3] Dai F, Song X F, Zhao W Y, Han Z S, Zhang F W, Zhang S L. Motion simulation and test on threshed grains in tapered threshing and transmission device for plot wheat breeding based on CFD-DEM. Int J Agric & Biol Eng, 2019; 12(1): 66–73.

[4] Fu J, Chen Z, Tian L Q, Han L J, Ren L Q. Review of grain threshing theory and technology. Int J Agric & Biol Eng, 2018; 11(3): 12–20.

[5] Dai F, Zhao W Y, Han Z S, Li X K, Gao A M, Liu X L. Improvement and experiment on 4GX-100 type wheat harvester for breeding plots. Transactions of the CSAM, 2016; 47(S1): 196–202. (in Chinese)

[6] Chang J G, Liu X B, Ye T, Du M J. Agricultural plot field trial breeding status and development of machinery. Journal of Agricultural Mechanization Research, 2011; 33(2): 238–241. (in Chinese)

[7] Dai F, Zhang F W, Gao A M, Han Z S. Optimization of key operating parameters in 4GX-100 type cropland plot wheat seed combine harvester. Transactions of the CSAE, 2012; 28(Supp.2): 53–58.

[8] Bart L, Bart M, Josse D B, Wouter S. LiDaR sensing to monitor straw output quality of a combine harvester. Computers and Electronics in Agriculture, 2012; 85(1): 40–44.

[9] Wei L J. The design of plot wheat breeding threshing machine and research on it's low damage characteristics. Lanzhou: Gansu Agricultural University, 2016; 69p. (in Chinese)

[10] Jin X, Du X W, Gan BX, Ji J T, Dong X, Wang G X. Cleaning performance experiment of cyclone separating system in miniature combine harvester. Transactions of the Chinese Society for Agricultural Machinery, 2016; 47(5): 99–105. (in Chinese)

[11] Dai F, Song X F, Guo W J, Zhao W Y, Zhang F W, Zhang S L. Simulation and test on separating cleaning process of flax threshing material based on gas-solid coupling theory. Int J Agric & Biol Eng, 2020; 13(1): 73–81.

[12] Li H C, Li Y M, Gao F, Zhao Z, Xu Li Z. CFD-DEM simulation of material motion in air-and-screen cleaning device. Computers and Electronics in Agriculture, 2012; 88(6): 111–119.

[13] He Y, Bayly A E, Hassanpour A L. Coupling CFD-DEM with dynamic meshing: A new approach for fluid-structure interaction in particle-fluid flows. Powder Technology, 2018; 325: 620–631.

[14] Ma L C, Wei L B, Pei X Y, Zhu X S, Xu D R. CFD-DEM simulations of particle separation characteristic in centrifugal compounding force field. Powder Technology, 2019; 343: 11–18.

[15] Wang S Y, Li H L, Wang R C, Wang X, Tian R C, Sun Q J. Effect of the inlet angle on the performance of a cyclone separator using CFD-DEM. Advanced Powder Technology, 2019; 30(2): 227–239.

[16] Jiang E C, Sun Z F, Pan Z Y, Wang L J. Numerical simulation based on CFD-DEM and experiment of grain moving laws in inertia separation chamber. Transactions of the CSAM, 2014; 45(4): 117–122. (in Chinese)

[17] Liu L Y, Hao S Y, Zhang M, Liu D M, Jia F G, Quan L Z. Numerical simulation and experiment on paddy ventilation resistance based on CFD-DEM. Transactions of the CSAM, 2015; 46(8): 27–32. (in Chinese)

[18] Oldal I, Safranyik F. Extension of silo discharge model based on discrete element method. Journal of Mechanical Science & Technology, 2015; 29(9): 3789–3796.

[19] Dai F, Song X F, Shi R J, Zhao W Y, Guo W J, Zhang Y. Migration law of flax threshing materials in double channel air-and-screen separating cleaner. Int J Agric & Biol Eng, 2021; 14(3): 92–102.

[20] Tong S G, Shen Q, Tang N, Jia Y P, Cong F Y, Gu W. Numerical simulation and optimization experiment of mixed flow field on longitudinal axial flow cleaning device. Transactions of the CSAM, 2016; 47(7): 135–142. (in Chinese)