

# NUMERICAL SIMULATION AND EXPERIMENTAL STUDY ON PELLETING MOTION LAW OF AGROPYRON SEEDS UNDER VIBRATION FORCE FIELD

## 振动力场作用下冰草种子丸化运动规律数值模拟与试验研究

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### ABSTRACT

In order to improve the pelleting effect of Agropyron seeds, the pelleting experiment was conducted under different working parameters. In this paper, the discrete element simulation software EDEM was used to establish the simulation model, and the influence of the vibration frequency of coater, the tilt angle of coater, and the rotational speed of coater on the movement trajectory of the Agropyron population were analysed. The simulation results show that the rotational speed is 40r/min, the tilt angle is 35° and the vibration frequency is 20 Hz, and the amplitude is 2 mm, the optimal trajectory of Agropyron population is obtained. The orthogonal experiment of 3 factors (vibration frequency of coater, rotational speed of coater, tilt angle of coater) and 5 levels were designed. The working parameters of pelleting Agropyron seeds were optimized by investigating the 4 indexes of compressive strength, seed rate, single seed rate and pelleting qualified rate. The results show that the vibration is the main factor affecting the compressive strength and single seed rate, the rotational speed is the main factor affecting the seed rate, and the inclination angle is the main factor affecting the pelleting rate. The optimal parameters are as follows: the rotational speed is 40r/min, the tilt angle is 35° and the vibration frequency is 20Hz.

### 摘要

为了提高小粒冰草种子丸化包衣效果, 对不同工作参数下的冰草种子进行丸化处理。运用离散元仿真软件 EDEM 建立仿真模型, 分析了包衣锅振动频率、包衣锅倾角、转速对冰草种群运动轨迹的影响规律。仿真结果表明: 转速为 40r/min, 倾斜角为 35°, 振动频率为 20HZ, 振幅为 2mm 时, 冰草种群运动轨迹最佳。设计了 3 因素 (包衣锅振动频率、包衣锅转速、包衣锅倾斜角) 5 水平的正交试验, 通过考察抗压强度、有籽率、单籽率、丸化率 4 个指标, 对冰草种子丸化包衣的工作参数进行优选, 试验结果分析表明: 振动幅度是影响抗压强度、单籽率的主要因素, 转速是影响有籽率的主要因素, 倾斜角是影响丸化率的主要因素, 最优的参数水平为转速为 40r/min, 倾斜角为 35°, 振动频率为 20HZ。

### INTRODUCTION

The rapid growth of populations in pastoral areas, including Inner Mongolia, China, have caused intensive over utilization of grasslands. This represents approximately 40% of land area in China (Wu, 2013). Overgrazing and conversion of grassland to cropland has led to declines in overall agricultural productivity due to increased soil erosion, degraded soil structure and reduced soil fertility (Shen, 2016). Recently, China implemented vegetation restoration programmes to improve biodiversity in agriculture environments, soil health, and to reduce erosion and desertification (Qiu, 2017). Pelleting technology of Agropyron seeds are widely used as cover crops to reduce desertification and restore productivity on degraded grasslands.

In recent years, domestic and foreign scholars have made great progress in the research of seed pelleting technology. Qiu used biostimulant method to coat the covering crops to improve the germination rate, survival rate and seedling growth (Qiu, 2020). Pasha simulated the coating process of corn seeds in a rotary coating machine by using discrete element method (DEM), established a coating layer model to predict the coating uniformity of seeds, and studied the influence of different coating process parameters on the coating variability of batch seeds (Pasha, 2017). Amirkhani studied the formulation of broccoli seed coating agent based on plant protein hydrolysis, so as to enhance seedling and plant growth (Amirkhani, 2017).

*Tamilselvi* studied the physical properties of carrot seeds (particle size, shape, sphericity, 1000 grain weight), and carried out germination, hydration and crushing test on bare and pelleted carrot seeds (*Tamilselvi, 2016*).

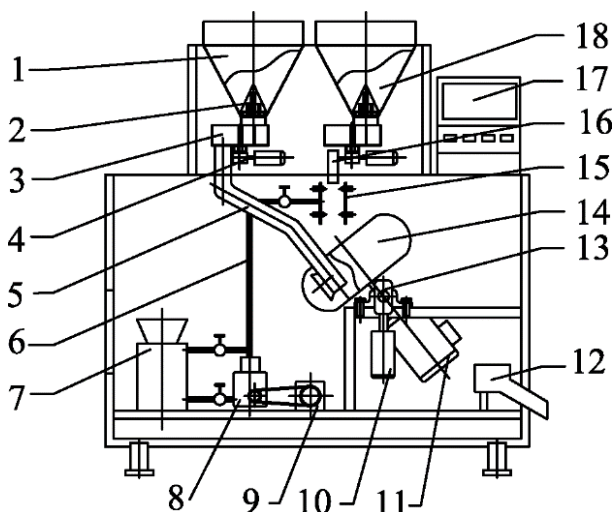
Although domestic and foreign scholars have made corresponding research achievements in pelleted coating technology and equipment, there are still many problems, such as insufficient theoretical research, insufficient mechanism exploration, and inconsistent pelleting process (*Hou, 2020*).

## MATERIALS AND METHODS

### TEST EQUIPMENT

#### Vibration pelletizer

Vibration pelletizer was used to coat seeds in all experiments (Fig. 1). Each seed coating treatment consisted of two components (powder and liquid). For each batch, the powder and liquid were applied to the surface of the seeds in incremental amounts as they were rotating and vibrating in the pelleting machine to achieve uniform results.



**Fig. 1 - Schematic diagram of overall structure of pelletizer for Agropyron seeds**

1. Powder feed inlet
2. Feed inlet valve
3. Weighing system
4. Step motor
5. Powder conveying pipeline
6. Liquid medicine pipe
7. Liquid medicine storage tank
8. High pressure pump
9. Motor
10. Rotary stepper motor
11. Coater motor
12. Outlet port
13. Electric vibration exciter
14. Coater
15. Nozzles
16. Seed diffuser plate
17. Controller
18. Seed feed inlet

#### Texture analyser

A texture analyser (TA-XTplusC, Texture Technologies Corp., Hamilton, MA) was used to test the compressive strength of coated seeds. The TA-XTplusC is a precision instrument used to measure the surface mechanical properties of coated seeds and the compressive strength of a single seed. The arm of the texture analyser containing a weighing sensor moves in a downward motion to compress the coated seed placed on the base of the analyser and then returns to its original position. Data are assessed as the peak load force (N). After the seed coat is completely broken, the force (N) increases until the seed inside the seed coat is crushed, and then the data is recorded.

#### Movement law of pelleting seeds

The seeds and powder move with the coater, and the movement state of the particles is different under different rotational speeds. Solid particles, like fluids, are called fluidization of particles (*Sun, 2008*). If the rotational speed of coater is too high, the pelleted seeds in the coater will move around the inner wall under the action of centrifugal force. At this time, there is no relative movement between the pelleting seeds and the inner wall of coater, which cannot play the role of rubbing and friction, thus losing the effect of pelleting, polishing and rounding. If the rotational speed of coater is too slow, it is difficult to drive the pelleted seeds to roll in the coater, and the pelleted seeds only slide and fall on the wall of the coater under the action of gravity. Therefore, the following assumptions are made:

1. The seeds are approximately ellipse with uniform mass distribution, and the powder is approximately spherical with uniform size and mass distribution.
2. Ignore air resistance.
3. Consider the seed as a particle.

The state of the seed in the coater is shown in Fig. 2. The distribution of seeds at different angles is shown in Fig. 3, where  $V_3$  is the speed of the coater and  $V_4$  is the speed of the seed.

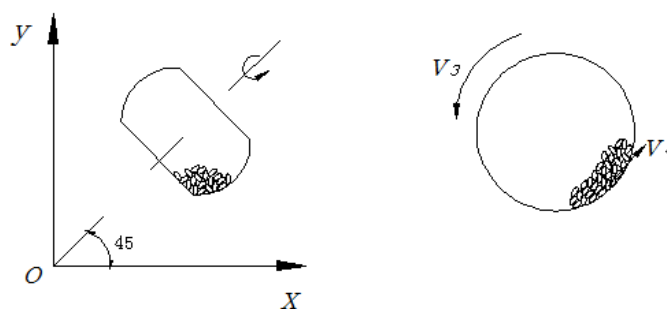


Fig. 2 - Movement diagram of Agropyron seed in coater

The tilt angle of the coater can be adjusted by the tilt angle adjusting mechanism. However, the tilt angle of the pot body shall not be less than the natural rest angle of the material, otherwise the material will stick to the surface of the pot and rotate with it and lose the function of rubbing and friction. Besides, the tilt angle affects the residence time of materials on the surface of coater. The longer the seed is placed on the coater, the denser the seed is. Therefore, on the premise of ensuring product quality and considering the improvement of production efficiency, the size of tilt angle should be reasonably selected to make the pelleted seeds mix evenly.

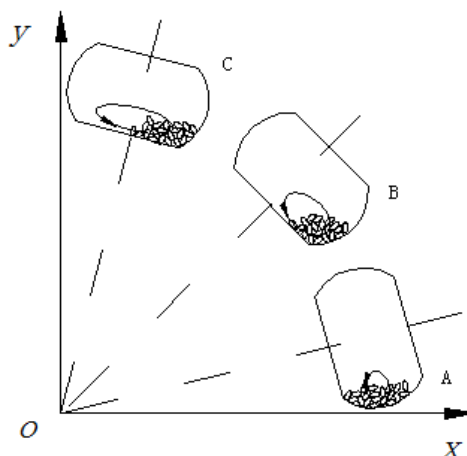


Fig. 3 - The distribution of seeds at different angles

As shown in Fig. 3, in state A, the particles fill the bottom of the coater, seeds and powder slide on the bottom of the pot, and there is no rolling phenomenon, so the coating effect is poor. In state B, the seeds rotate in the middle position, and the seeds and materials are sent to the bottom of the coater and then roll down. At this time, the materials do not move in a circle in the coater, but do similar elliptical movement, so the coating effect is better. However, in the C state, the pelleting effect became worse when the seeds rotated at the bottom of the coater.

#### Flow characteristics of powder

The solid powder in the coater presents a flow state, with the same properties as liquid, namely solid fluidized bed. Like liquid, the fluidization of solid has three flow states: laminar, turbulent and transitional flow. When the velocity is very small, the fluid flows in layers and does not mix with each other, which is called laminar flow. With the increase of flow velocity, the fluid begins to appear disordered, and some of the fluid begins to swing. This kind of flow condition is called transitional flow. When the velocity is large, the fluid oscillates violently, and in the flow field even appears vortex. The phenomenon of mixing occurs between the same layers of fluid, and each part shows irregular movement. Some move horizontally, others move vertically. This motion is called turbulence. The turbulent friction is mainly the momentum transport of fluid clusters (Qi, 2019).

Assuming that the powder particle is a sphere, the resultant force on a single powder particle can be obtained (Fig. 4).

$$\frac{1}{6} \pi \rho_s d_s^3 \frac{du_s}{dt} = \sum F \quad (1)$$

Where:  $\rho_s$ - Material density, [kg/m<sup>3</sup>];

$d_s$ - Powder radius, [mm]

$\frac{du_s}{dt}$  - Material acceleration, [m/s<sup>2</sup>];

$\sum F$  - Resultant force on materials, [N];

Due to this complex resultant movement, the kneading between powder and seed is realized, and the ideal pelleting state is achieved. Because the friction and collision between seeds and powders are caused by turbulent motion, it is necessary to analyse the flow characteristics of powder flow near the surface of seeds. It is assumed that the movement of material on the seed surface is an ideal smooth plane turbulence model. The fluid is divided into laminar and turbulent flow near the wall, in which the laminar flow derives the turbulence. From the microscopic point of view, the seed surface of Agropyron is actually uneven, and the turbulent boundary layer is divided into turbulent region, transition zone and viscous bottom zone in the direction perpendicular to the seed surface. In the process of turbulent motion, the closer to the seed surface, the smaller the velocity of solid particles and the corresponding shear stress generated by the velocity, but the velocity gradient is larger. Therefore, the viscous shear stress plays an important role. We define this region as laminar flow, that is, the turbulent region is not all turbulent layer, which is also called viscous bottom zone. Because the seed surface is affected by the thickness of viscous substrate, roughness height  $h$  and Reynolds number ( $Re$ ) (Fig. 5), it can be divided into three states.

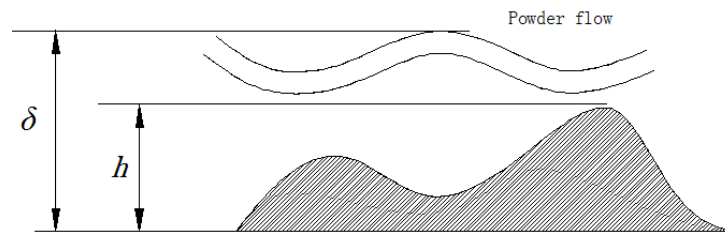


Fig. 4 - Viscous sublayer of material turbulence layer

When  $\delta > h$ , the Reynolds number ( $Re$ ) is small, and the thickness of viscous bottom layer is greater than that of rough layer. In this case, the turbulent boundary layer is called smooth region. When  $\delta < h$ , the thickness of viscous bottom layer is less than that of rough layer. At this time, the roughness height affects the movement of material flow and produces Eddy current, which increases the irregularity of material flow. The corresponding turbulent boundary layer is called turbulent rough region. When the turbulent resistance of material flow is caused by the interaction of viscosity and turbulence, the corresponding turbulent boundary layer is called turbulent transition zone.

According to the above analysis, only when the Reynolds number ( $Re$ ) is higher, the roughness height  $h$  is larger, and the thickness of viscous bottom layer is smaller, the material flow is easy to form turbulent flow. However, the turbulent friction is mainly the momentum transport of fluid micro clusters. So the viscous force between Reynolds numbers can't be dissipated by a larger inertia force. The introduction of vibration can increase the inertia force of powder and destroy the laminar flow state. The pelleting process of material flow is conducted in turbulent flow. In addition, through the irregular movement of solid materials, the surface of Agropyron seeds was repeatedly collided, and the high-quality pelleting effect was achieved.

## NUMERICAL SIMULATION

### Model parameters

Natural Agropyron seeds was selected as the research object. According to the physical characteristic parameters of Agropyron seed simulation (Table 1), the overlapping sphere model is adopted in the discrete element simulation software EDEM. It can effectively delay the occurrence of "self-locking" phenomenon, and has better fitting degree to the boundary. According to the actual measurement of the size of Agropyron seeds, its shape parameters can be defined as the long half axis  $a = 2.5$  mm and the short half axis  $b = 1.2$  mm. For such an axisymmetric ellipsoid element, multiple spheres are filled in EDEM (Fig. 5).

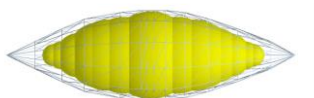


Fig. 5 - Simulation model of Agropyron seeds

Table 1

Physical characteristics and simulation parameters of Agropyron seeds

Object	Parameter	Value
Agropyron seeds	Density/(kg·m <sup>-3</sup> )	763
	shear modulus/Pa	1.08×10 <sup>7</sup>
	Poisson's ratio	0.28
Device model	Density/(kg·m <sup>-3</sup> )	7 890
	Shear modulus/Pa	1.1×10 <sup>7</sup>
	Poisson's ratio	0.269
Particle to particle interaction	Static friction factor	0.5
	Restitution coefficient	0.31
Particle to device interaction	Static friction factor	0.5
	Restitution coefficient	0.24

**RESULTS AND DISCUSSIONS**

The discrete element software EDEM was used to simulate and analyse the pelleting of seeds and nutrient soil particles under various motion modes of Agropyron seed pelleting machine under vibration. The actual trajectory of the pelleting of seeds and nutrient soil was studied intuitively, and the influence of different motion combinations on pelleting effect was analysed. There are three movements of seeds in the coater. One is that the seeds rise to a certain height with the rotation of the coater. The second is the rolling and falling of seeds on the bottom of the coater, and the third is the overturning and jumping of seeds themselves.

**Influence of vibration frequency on motion state**

The simulation experiment was conducted under the condition that the rotational speed of the coater was 40 r/min, the tilt angle of the coater was 35° and the amplitude of the coater was 2 mm. The simulation movement state of the population was shown in Fig.6.

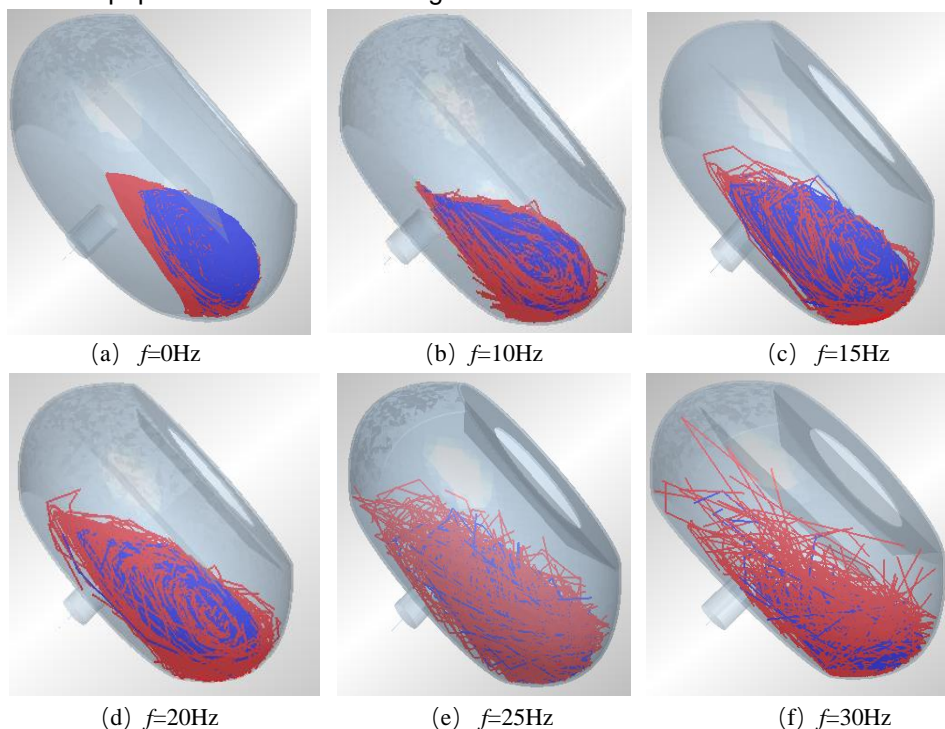


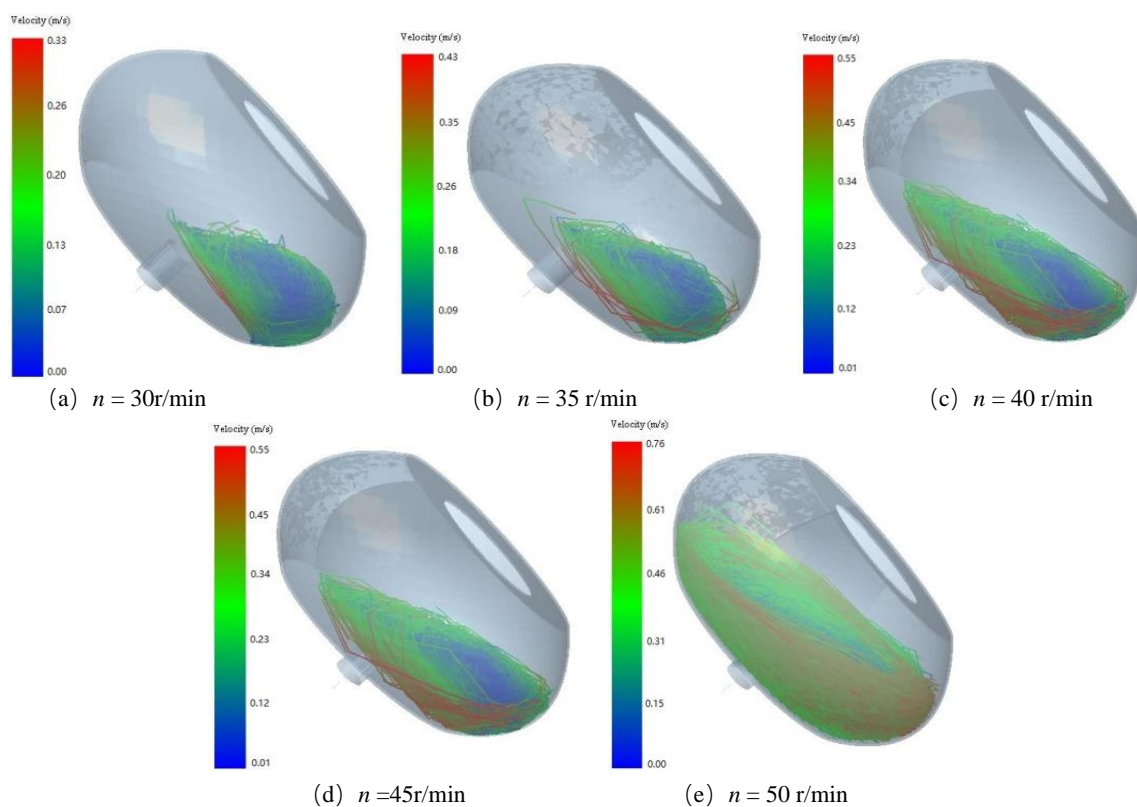
Fig. 6 - Motion trajectories at different frequencies

It can be seen from Fig. 6 that when the vibration frequency of the coater is 0 Hz (no vibration), the

Agropyron seeds and pelleting powder are at the bottom of the coater and separated from each other, resulting in poor pelleting quality. When the vibration frequency was 10 Hz and 15 Hz (with vibration), the interaction between Agropyron seed and pelleting powder began to occur, which accelerated the dispersion of seed and powder, and intensified the relative movement trend between the seed and pelleting powder, which was beneficial to the pelleting of Agropyron seeds. When the vibration frequency increased to 20 Hz and 25 Hz, the more intense the movement between the Agropyron seeds and the pelleting powder, the greater the chance of contact, collision and friction, the better the surface mechanical properties of the pelleted seeds. When the vibration frequency increases to 30 Hz, the movement trend of particle flow is obviously intensified. In the process of rapid vibration, some pelleting powder is vibrated to the top of the coater to separate from the Agropyron seeds due to its light weight, which reduces the pelleting effect. The simulation results show that when the vibration frequency is 20 Hz and 25 Hz, the mixing effect of Agropyron seeds and pelleting powder is better, and the quality of pelleting seed is better under this condition.

### Influence of rotational speed on motion state

The single factor simulation analysis method is used to determine the optimal speed range of the coater. When the vibration frequency of the coater is 20 Hz, the tilt angle of the coater is 35° and the amplitude of the coater is 2 mm, the single factor simulation experiment is conducted under the conditions of rotational speed of 30 r/min, 35 r/min, 40 r/min, 45 r/min and 50 r/min, respectively. The simulation process is shown in Fig. 7.



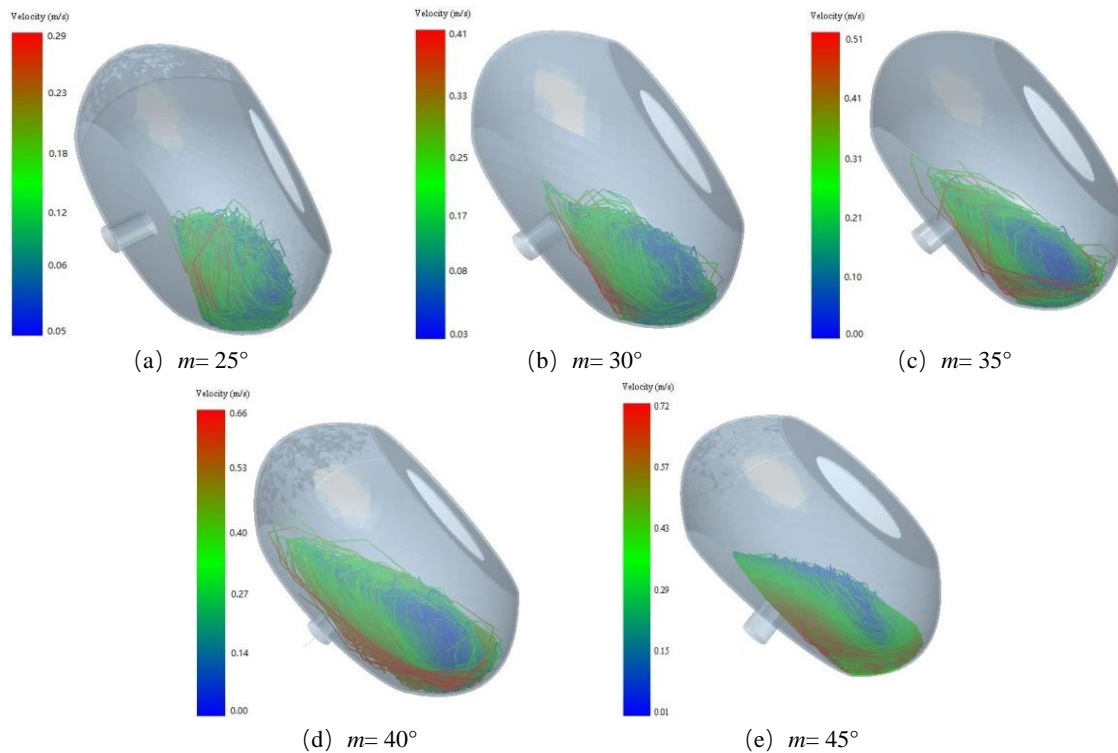
**Fig. 7 - Motion trajectories at different rotational speeds**

It can be seen from Fig. 7 that when the rotational speed of the coater is 30 r/min and 35 r/min, the seeds and powder are accumulated at the bottom of the coater, resulting in poor pelleting quality. When the speed of the coater is 40 r/min, the movement trend of the seeds and pelleting powder was intensified, which could achieve the purpose of rotating the seeds and pelleting powder with the coater. Besides, the distribution area of particles in the coater space increased, and the pelleting quality was better.

However, when the speed of the coater is 45 r/min and 50 r/min, the pelleting effect was weakened due to less chances of collision, rolling and friction between the particles. The simulation results show that when the speed of coater is 40 r/min, the mixing effect of seeds and pelleting powder is better, and the pelleting quality is higher.

### Influence of tilt angle on motion state

In order to achieve better rolling effect of Agropyron seeds and determine the influence of tilt angle of coater on the motion state, the discrete element simulation software EDEM was also used to analyse the population pelleting trajectory. The smaller the tilt angle is, the longer the retention time of Agropyron seeds on the surface of coater is, and the denser the Agropyron seeds are rolled out, but the multiple seed rate will increase. Therefore, when the speed of the coater is kept at 40 r/min, the vibration frequency is 20 Hz and the amplitude is 2 mm, the single factor simulation experiment is conducted under the conditions of tilt angle of 25°, 30°, 35°, 40° and 45° respectively. The simulation process is shown in Fig. 8.



**Fig. 9 - Motion trajectories at different tilt angles**

It can be seen from Fig. 9 that when the coater angle is 25° and 30° respectively, the Agropyron seeds and pelleting powder are almost static relative to the coater, which easily leads to the increase of multiple seed rate and seedless rate, and the decrease of single seed rate and pelleting qualified rate. When the tilt angle of coater was 35° and 40° respectively, the movement of Agropyron seeds and pelleting powder was more intense, which was conducive to the rapid contact pelleting of seed and powder, and improved the pelleting effect and quality. However, when the coater angle was 45°, with the gradual increase of the angle, the Agropyron seeds and powder could not cover the bottom of the pot, and there was a blank area of seeds on the coater, and the seeds began to slide with the whole pot body, the pelleting effect was poor. Therefore, when the tilt angle of the coater is 35° and 40° respectively, the pelleting effect is better and the pelleting quality is higher.

### EXPERIMENT VERIFICATION

50g Agropyron seeds with 99% purity were selected for each experiment. The pelleting powder was a mixture of 500 mesh diatomite, talc powder and bentonite, and the liquid agent of pelleting was an aqueous solution of carboxymethyl cellulose and polyvinyl alcohol with mass concentration of 1.5%. The ratio of seed, powder and liquid was 1:3:1.

#### Orthogonal test

In order to determine the optimal working parameters combination of the vibration pelletizer, the compressive strength, seed rate, single seed rate and pelleting qualified rate were used as performance evaluation indexes (Li, 2017). Taking the vibration frequency, rotational speed and tilt angle of coater as experimental factors, L25 (53) orthogonal test table was selected.

The experimental factors and levels are shown in Table 2, and the orthogonal test scheme and test results are shown in Table 3.

Table 2

Factors and levels encoding table

Level	A Rotational speed of coater (r/min)	B Tilt angle of coater (°)	C Vibration frequency of coater (Hz)
1	25	40	10
2	30	35	15
3	35	30	20
4	40	25	25
5	45	20	30

Table 3

Orthogonal test scheme and test results

Test number	Test conditions			Test index			
	A Rotational speed (r/min)	B Tilt angle (°)	C Vibration frequency (Hz)	Compressive strength (N)	Seed rate (%)	Single seed rate (%)	Pelleting qualified rate (%)
1	25	40	10	46.12	88.6	78.2	66.2
2	25	35	15	64.28	90.4	85.0	82.7
3	25	30	20	100.36	91.2	84.0	70.2
4	25	25	25	67.04	90.2	85.4	58.1
5	25	20	30	116.52	87.1	76.8	74.7
6	30	40	15	62.44	91.4	93.0	82.7
7	30	35	20	102.16	88.0	85.4	72.4
8	30	30	25	115.44	92.0	80.8	71.2
9	30	25	30	103.20	91.0	74.8	68.4
10	30	20	10	38.08	89.4	80.8	69.4
11	35	40	20	88.84	92.8	92.4	84.8
12	35	35	25	118.24	92.2	80.0	75.7
13	35	30	30	147.12	94.2	83.6	73.1
14	35	25	10	64.12	90.2	83.2	72.6
15	35	20	15	92.52	87.8	81.2	59.8
16	40	40	25	147.04	90.8	78.4	75.9
17	40	35	30	91.12	94.8	85.5	79.9
18	40	30	10	48.12	91.0	86.4	80.3
19	40	25	15	95.56	95.0	82.4	72.8
20	40	20	20	97.40	94.8	87.8	60.9
21	45	40	30	93.24	88.8	75.6	60.6
22	45	35	10	97.68	93.0	87.4	68.8
23	45	30	15	78.64	90.8	83.8	71.5
24	45	25	20	110.52	90.0	82.9	85.1
25	45	20	25	65.96	91.2	82.8	79.2

### Analysis of experiment results

#### Range analysis of compressive strength

The range analysis of compressive strength, seed rate, single seed rate and pelleting qualified rate which mainly affect the coating quality was conducted. The range analysis of orthogonal test with compressive strength as index is shown in Table 4. The results of range analysis show that the order of primary and secondary factors affecting compressive strength is vibration frequency C, rotational speed A and tilt angle B. The best combination factor and level of compressive strength is A3B3C5.

Table 4

#### Analysis of extreme difference in compressive strength

K value	A	B	C
K1	78.86	87.54	58.82
K2	84.26	94.70	78.69
K3	102.17	97.94	99.86
K4	95.85	88.09	102.74
K5	89.21	82.10	110.24
R	23.30	15.84	51.42



### Range analysis of seed rate

The range analysis of orthogonal test with seed rate as index is shown in Table 5. The results of range analysis show that the order of primary and secondary factors affecting seed rate is rotational speed A, tilt angle B and vibration frequency C. The result shows that the combination factor and level with the highest seed rate was A4B3C3.

Table 5

K value	A	B	C
K1	89.50	90.48	90.44
K2	90.36	91.68	91.08
K3	91.44	91.84	91.36
K4	93.28	91.28	91.28
K5	90.76	90.06	91.18
R	3.78	1.78	0.92

### Range analysis of single seed rate

The range analysis of orthogonal test with single seed rate as index is shown in Table 6. The results of range analysis show that the order of primary and secondary factors affecting the single seed rate is vibration frequency of coater C, tilt angle of coater B and rotational speed of coater A. The result shows that the combination factor and level of the highest single seed rate was A3B2C3.

Table 6

K value	A	B	C
K1	81.88	83.52	83.20
K2	82.96	84.66	85.08
K3	84.08	83.72	86.50
K4	84.10	81.74	81.48
K5	82.50	81.88	79.26
R	2.22	2.92	7.24

### Range analysis of pelleting qualified rate

The range analysis of orthogonal test with pelleting qualified rate as index is shown in Table 7. The results of range analysis show that the order of primary and secondary factors affecting pelleting rate is tilt angle of coater B, rotational speed of coater A and vibration frequency of coater C. The result shows that the combination factor and level with the highest pelleting qualified rate was A4B2C3.

Table 7

K value	A	B	C
K1	70.38	74.04	71.46
K2	72.82	75.90	73.90
K3	73.20	73.26	74.68
K4	73.96	71.40	72.02
K5	73.04	68.80	71.34
R	3.58	7.1	3.34

### Determination of optimal level combination

The comprehensive balance method is obtained to select the optimal level combination. For factor A, the seed rate is the main factor, and A4 is the best. For factor B, the pelleting qualified rate is the main factor, and B2 is the best. For factor C, the compressive strength is the main factor, and C5 is the best. For the single seed rate, it is the main factor, and C3 is the best. As for the seed rate and pelleting rate, C3 is the most important factor. According to the above comprehensive balance, A4B2C3 is the best level combination for pelleting Agropyron seeds, that is, the rotational speed is 40 r/min, the tilt angle is 35° and the vibration frequency is 20Hz.

## CONCLUSIONS

1) Through the discrete element simulation (EDEM) analysis, the particle motion state under different working parameters was determined, and the pelletizing mechanism was revealed. In addition, it can be seen that the introduction of vibration force field can change the movement state of materials and improve the quality of pelleting.

2) The main factors affecting the compressive strength, seed rate, single seed rate and pelleting qualified rate were analysed by orthogonal test. The results showed that the main factor affecting the compressive strength was vibration frequency C, the main factor affecting seed rate was rotational speed A, the main factor influencing single seed rate was vibration frequency C, and the main factor influencing pelleting rate was tilt angle B. The optimum combination of pelleting was determined as A4B2C3, which was rotational speed of 40 r/min, tilt angle of 35° and vibration frequency of 20Hz.

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