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Study on the Principle and Influencing Factors of Rice Pot Experiment

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Abstract: *In this paper, we first completed the discrete element model of the lifting of the rice pot, and then made detailed theoretical calculation and derivation for the perspectives of continuum and explored various influencing factors in many aspects. Finally, mechanical structure stress simulation and physical experiment are conducted to verify the theoretical results.*

Keywords: *Discrete element; continuum; influencing factors*

1. Introduction

We can find a common life phenomenon: we can put a pair of chopsticks into the rice pot to lift the rice pot. Similarly, insert a spoon into the rice pot. However, compared to the former, the mechanical system analysis of the latter is more complex. It involves the relevant physics knowledge of discrete element and continuum.In this paper, we complete the discrete element modeling of the rice pot mechanical system, and analyze the force situation of the spoon in the rice pot and its influencing factors. Relevant simulation validation was also completed in ANSYS simulation software.Finally, we conducted a physical experiment to verify the conclusion[1-2].

2. Model building

2.1 Discrete element selection

The EDEM discrete element simulation software is used to model the discrete discontinuum and complete the rice spoon. The filling effect is shown in Fig.1 (a) (b) (c):

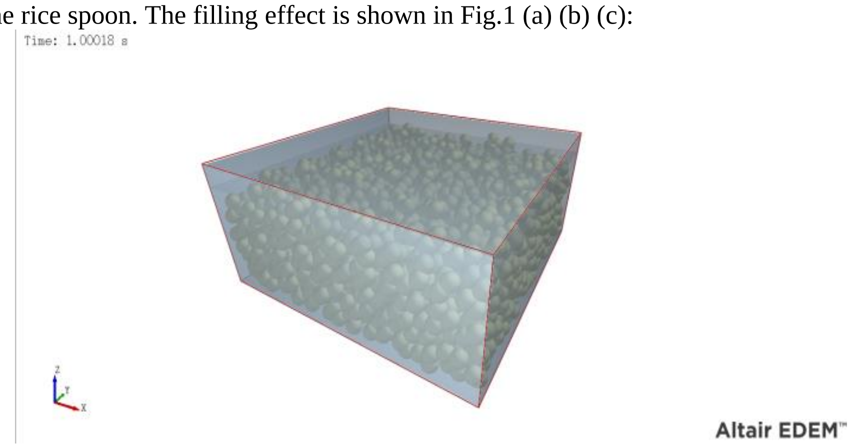

Figure 1 (a): Overall schematic diagram of the modeling of rice pot and rice spoon

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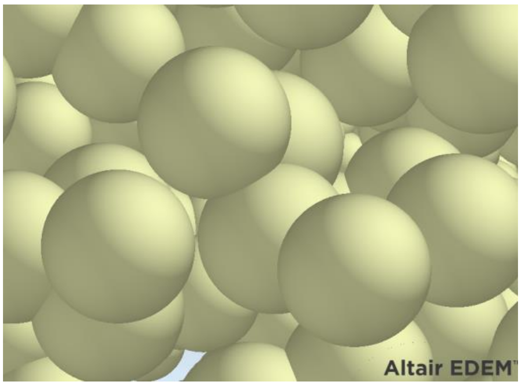

Figure 1 (b): Internal schematic of rice modeling

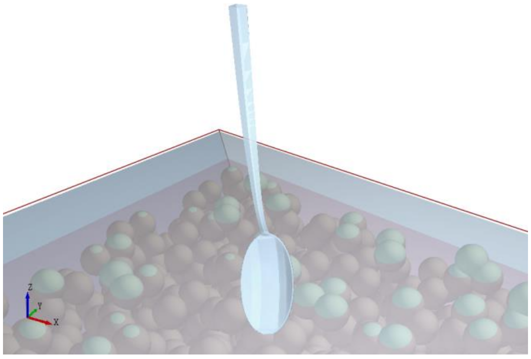

Figure 1 (c): Schematic illustration of the modeling spoon insertion

2.2 Theoretical derivation

2.2.1 The relationship between the internal pressure and the depth of the rice pot

S is the area of the upper surface (lower surface) of the kettlebell, the unit gravity of the rice grain, and C is the circumference of the upper surface or lower surface of the kettle.$S(p + dp)$ is the pressure formed by the pressure, γSdz is gravity, $fCdz$ is the friction force of the side to the unit element, the force analysis diagram is shown in Fig. 2.

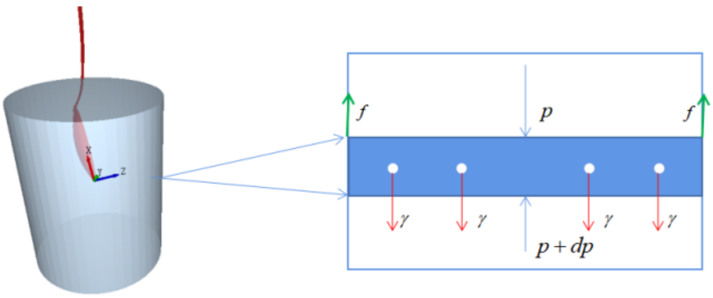

Figure 2: Schematic diagram of the lateral wall force analysis

[1] deduces the relationship between the internal depth and the pressure of the rice pot in detail[3-5].

$$S(p + dp - p) = \gamma Sdz - fCdz \tag{1}$$

$f = N\mu,\mu$ is the friction coefficient, according to the geophysics, the normal stress and tangential stress on the wall are proportional, then $N = kp,k$ is the stress ratio coefficient.The formula (1) can be reduced to

$$dp = \gamma dz - \frac{CKp\mu dz}{S} \tag{2}$$

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At the same time divided by $(\gamma - \frac{Ckp\mu}{S})$, (2)can be reduced to $\frac{dp}{(1-\frac{Ckp\mu}{S})} = dz$

Solve the differential equations ,we obtain $\gamma - \frac{Ckp\mu}{S} = e^{-\frac{Ck\mu}{S}z}$

In a cylindrical container,CD = 4S, Set K = kμ.then

$$p = \frac{D\gamma}{4k}(1 - e^{-\frac{4kz}{D}}) \quad (3)$$

2.2.2 Maximum friction force of the vessel wall

The spoon model is shown in Fig. 3.

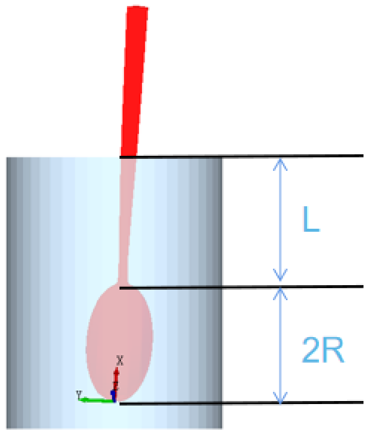

Figure 3: Schematic diagram of some variable definition of spoon handle and spoon

Set the length of the handle of the spoon to L and the radius of the spoon is R. Set the maximum friction of the side wall to $f_{sidemax}$According to the deduced formula of z deep pressure, we can get the formula of the maximum side wall friction of the spoon. H is the accumulation height of meters.

$$df_{sidemax} = \frac{\pi D^2\gamma}{4k}(1 - e^{-\frac{4kz}{D}})dz$$

$$f_{sidemax} = \int_0^H df_{sidemax}$$

Finally, it is found that

$$f_{sidemax} = \frac{\pi D^2\gamma}{4k}(L + 2R + \frac{D}{4k}e^{-\frac{4kH}{D}} - 1) \quad (4)$$

3. Analysis of the mechanical properties of the spoons in the continuum

3.1 Analysis of spoon handle

Microelement and force analysis of spoon handle is shown in Fig. 4:

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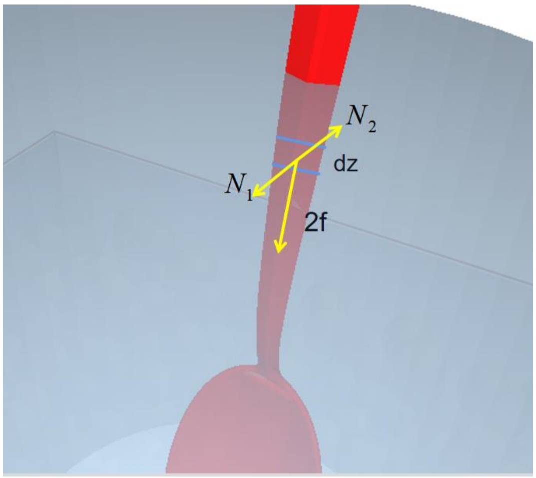

Figure 4: Schematic diagram of the microelement and force analysis of the spoon handle

Set the maximum friction force at the handle to f_{1max}.Each integrated area microelement of length dz is subjected to the friction and positive pressure given by the meters on the front and back sides, and the positive pressure is equal in the opposite direction [6-9].

$$df_{1max} = 2\frac{D\gamma}{4k}(1 - e^{-\frac{4kz}{D}})b\mu_0 dz$$

$$f_{1max} = \int_0^L df_{1max}$$

Then

$$f_{1max} = b\mu_0 \frac{D\gamma}{2k}(L + \frac{D\gamma}{4k}e^{-\frac{4kL}{D}} - \frac{D}{4k}) \quad (5)$$

3.2 Force analysis of the spoon head part

3.2.1 Squeeze pressure analysis

The diagram of force analysis of spoon head is shown in Fig. 5:

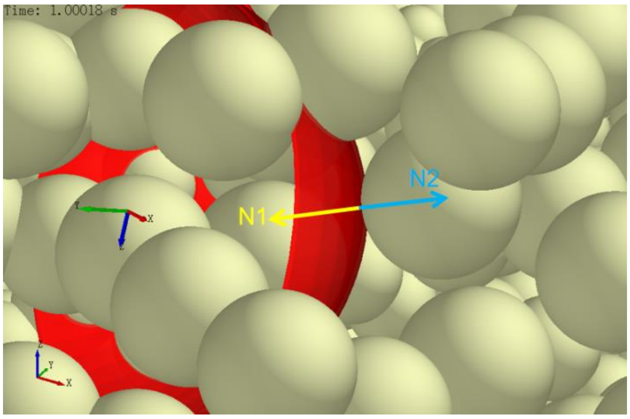

Figure 5: Force analysis of spoon head

3.2.2 Friction force analysis

Since the spoon has an upward movement trend when lifting the jug, the direction of the friction force at each point of the spoon is the tangent direction at the point in the vertical plane. As shown in the figure 6 below, the points in the horizontal semicircle are uniformly affected by the friction force f, points A and B are the points on the central symmetry of the horizontal semicircle, the two forces and the y direction angle are set to θ.

$$f = pds$$

$$f_A sin\theta = f_B sin\theta$$

The schematic diagram of force analysis of spoon head friction is shown in Fig. 6:

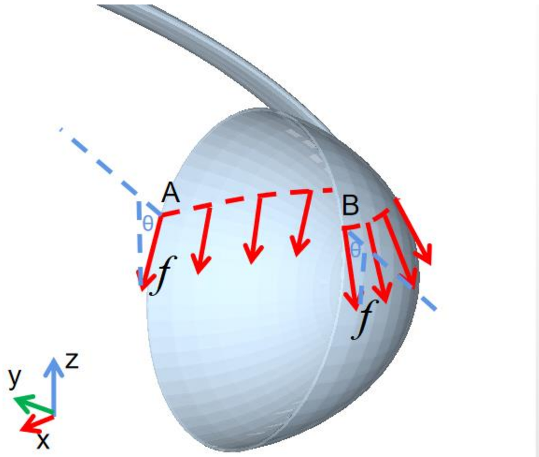

Figure 6: Schematic diagram of force analysis of spoon head

The components of each force in the other direction except the z axis cancel each other, so the effective component of the frictional force is f_z.

The schematic diagram of the head of the spoon θ is shown in Fig.7. Set the maximum friction on the head of the spoon to df_{2max}.Taking each horizontal half circle as the integral area, the friction force of the whole spoon along the z axis of the area is C, and the Angle of the circle between the connection with the center of the circle and the positive direction of the z axis is θ, we can conclude[10-11]:

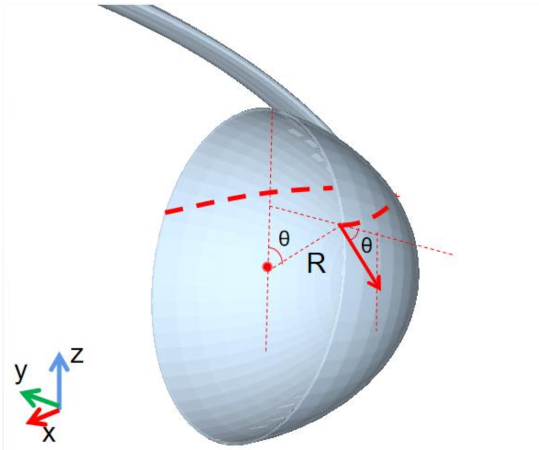

Figure 7: Schematic diagram of spoon head

$$C = \pi\sqrt{R^2 - L^2}$$

$$df_{2max} = C\frac{D\gamma}{4k}(1 - e^{-\frac{4k(L+R+l)}{D}})\mu_0 sin\theta dl$$

$$f_{2max} = \int_{-R}^{R} 2df_{2max}$$

Then

$$f_{2max} = \frac{\pi\mu_0}{R}\frac{D\gamma}{2k}\int_{-R}^{R} l\sqrt{R^2 - l^2}(1 - e^{-\frac{4k(L+R+l)}{D}})dl) \tag{6}$$

Given the friction inside and outside the head of the spoon, the final result is 2 times the integral.

4. Analysis of the continuum simulation

The force of the spoon is very similar to the force model of the continuum, so the idea of equivalent

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conversion can be used to abstract the meter into a continuous fluid, and design the hydrodynamic simulation of the "inverse relative motion direction" to analyze the force characteristics of the spoon.

The model established by EDEM is imported into ANSYS, and the workbench mechanical simulation module (Fluent with Fluent meshing function) module is selected. The simulation domain made in the space claim module is shown in Fig 8.

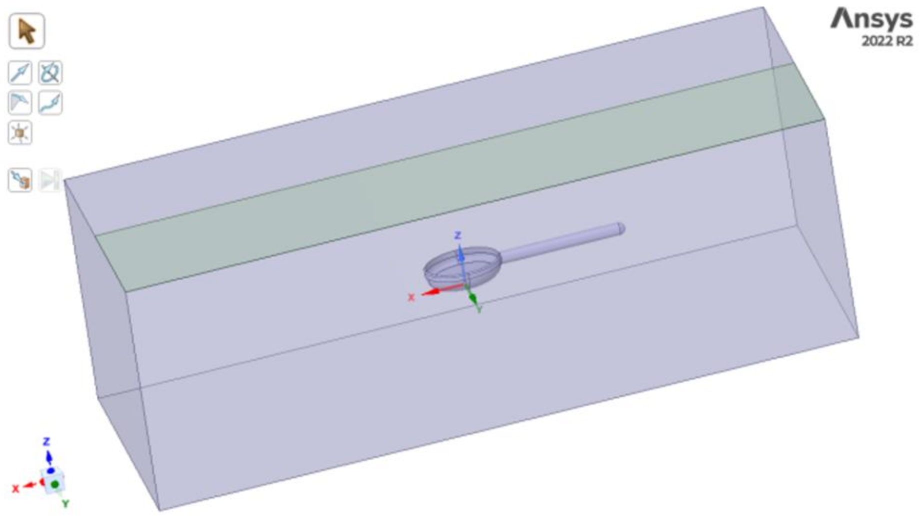

Figure 8: Sets up the simulation domain in ANSYS

4.1 Simulation grid and calculation settings

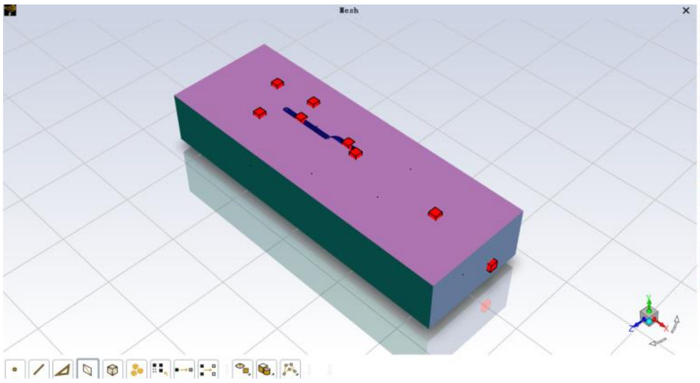

Figure 9 (a): Setting the boundary in ANSYS

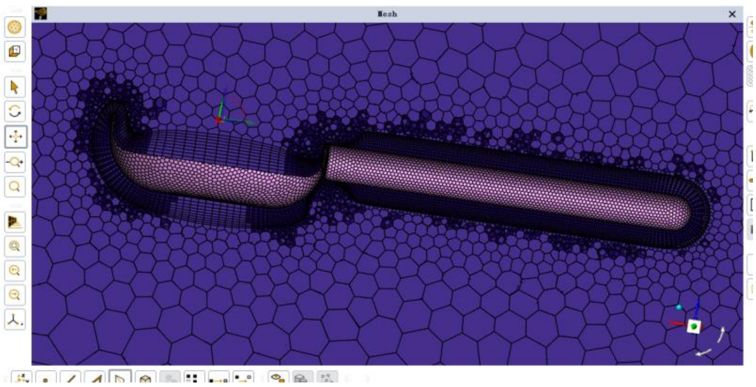

Figure 9 (b): sets up the grid in ANSYS

Set simulation conditions (grain fluid density conditions, surface friction coefficient, viscosity coefficient, etc.) as shown in Fig.9 (a) (b). In the simulation domain of the model, let the rice fluid through the spoon, the distribution of the spoon in the continuum as shown in Fig. 10(a), the residual analysis is shown in Fig. 10 (b), the spoon head force analysis diagram is shown in Fig. 10 (c).

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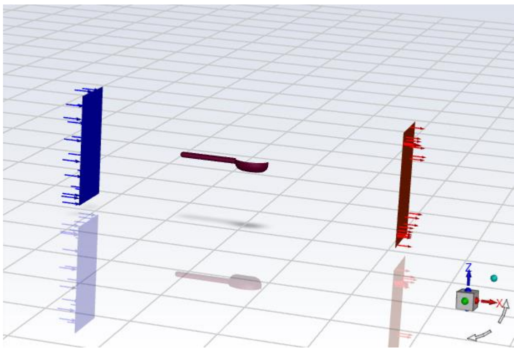

Figure 10 (a): Apply an airflow source in the ANSYS

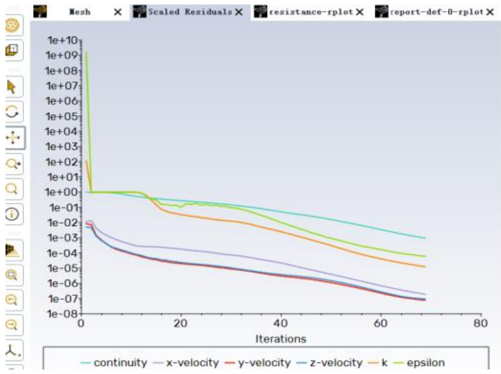

Figure 10 (b): correlation image of residual convergence

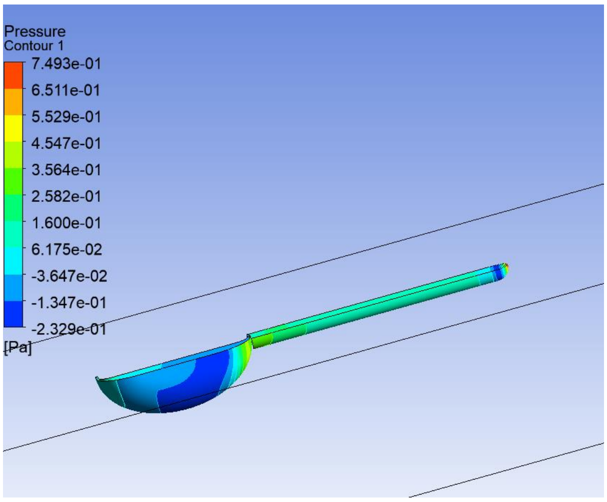

Figure 10 (c): Spoon force distribution diagram

Check the validity of the mechanical distribution of the spoon handle and the head.

5. Analysis of influencing factors

According to the above formula, we roughly get the friction between the wall of the container and the spoon and the particulate matter, and the subsequent force analysis for the whole. When all the influencing factors reach any of the following formula, the experiment can be completed.

$$f_{sidemax} = G_0 + \gamma SH$$
$$f_{1max} + f_{2max} = G_0 + \gamma SH \quad (7)$$

5.1 Divide conditions

When the maximum friction is greater than gravity, the spoon can lift the container (regardless of the

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spoon head). If satisfied:

$$\frac{D^2\pi}{8k}e^{-\frac{4kH}{D}} < \left(b\mu_0 - \frac{D\pi}{2}\right)L + \frac{\mu_0 bD}{4k}e^{-\frac{4kL}{D}} - \frac{D}{2}\left(\frac{\mu_0}{2k} - \pi\right) \tag{8}$$

The friction force between the particulate matter and the spoon reaches the maximum friction required for lifting. L is the total height of the spoon insertion, and H is the total height of the particulate matter. If satisfied:

$$\frac{D^2\pi}{8k}e^{-\frac{4kH}{D}} > \left(b\mu_0 - \frac{D\pi}{2}\right)L + \frac{\mu_0 bD}{4k}e^{-\frac{4kL}{D}} - \frac{D}{2}\left(\frac{\mu_0}{2k} - \pi\right) \tag{9}$$

The friction between particulate matter and the wall of the container provides the maximum friction required for lifting, L is the total height of the spoon insertion, and H is the total height of particulate matter.

5.2 Influencing factors

Here, the analysis discusses the conditions that the remaining parameters should meet under the influence of a single variable.

5.2.1 Bottom diameter

$$H = -\frac{D}{k}\ln\left(\frac{4k}{D}\left(\frac{4Gk}{D^2\pi\gamma} - L - 2R + 1\right)\right) \tag{10}$$

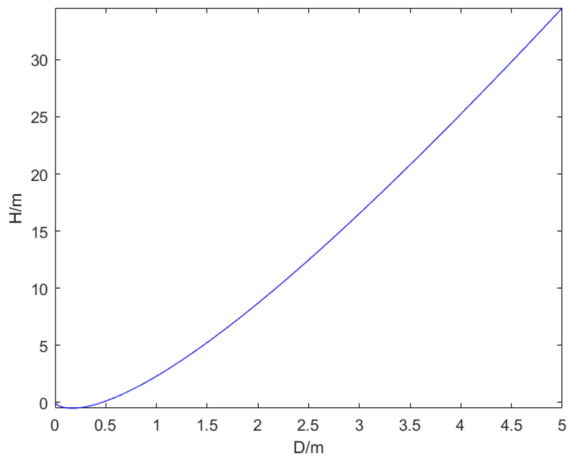

Figure 11: H and the correlation parameter function relationship

It can be seen that when removing H is very small, D shows a monotonic increase as the radius of the bottom surface increases as shown in Fig. 11. When the friction between the particles and the spoon is maximal, the relevant parameters except L remain unchanged. Because the height of the particulate matter is constant, and the right side of the equation is a fixed value, so the $f_{1max} + f_{2max}$ is also constant. At this point, when D increases, the effect of $\frac{D}{4k}e^{-\frac{4kL}{D}}$ in the equation is greater, so to ensure that the provided friction provided can support the experiment, the insertion depth L will also increase.

5.2.2 Particulate matter material difference

The change of particle material affects the friction coefficient, where $K = k_0\mu_0$, K is proportional to μ_0.It is obvious that when k increases, $\frac{D^2\pi\gamma}{4k}$,$\frac{D}{4k}$and $e^{-\frac{4kH}{D}}$ will decrease.Then when other variables remain unchanged, it is inversely proportional to the friction coefficient. If the rice grain is replaced with glass beads, the friction coefficient is reduced, so if other variables are consistent, the unit gravity G_0 and height of the particle need to satisfy $\gamma H = \frac{f_{sidemax}G_0}{S}$ to maintain balance. Because the unit gravity of the glass bead is greater than the rice grain, the height should be appropriately reduced only to meet the conditions.

5.2.3 The degree of moisture

For glass beads, the surface is smooth enough that the original dry friction coefficient is changed to

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the wet friction coefficient after adding water, so that the friction coefficient decreases, and because when other constants are constant,$f_{sidemax}$is inversely proportional to the friction coefficient, so if water is added without affecting the change of other variables,The balance can not be maintained until it needs to satisfy

$$G_{water} = f_{sidemax} G_0 \gamma HS \quad (11)$$

For the rice grains, they will swell with water, causing the rice grains to squeeze against each other, and the friction coefficient increases. Unlike glass beads, the water consumption is significantly less than the glass beads for the same volume.

6. Experimental analysis

The iron spoon insertion depth of 8cm meters container, measuring the overall system gravity of 2.2N can lift meters container, that in most cases, the maximum static friction container wall is greater than the spoon and meters maximum static friction, in this case system total weight is less than the spoon and meters between maximum static friction, thus can lift the rice pot.

6.1 The relationship between the spoon material and the maximum measured tension and depth

In the experiment, the rice pot was fixed, and the spoon of different materials was used to measure the critical friction value of the spoon pulled out at different depths of the rice pot , as shown in Table 1.

Table 1: Insertion depth and maximum friction force data

Plastic spoon		Stainless steel spoon	
Depth of penetration /cm	Maximal friction /N	Depth of penetration /cm	Maximal friction /N
0.60	0.20	0.60	0.10
0.80	0.30	0.80	0.11
1.10	0.50	1.10	0.14
3.11	1.00	3.11	0.18
5.50	2.10	5.50	0.30
6.90	3.00	6.90	0.50
8.80	4.30	8.80	0.90
10.00	5.40	10.00	1.30
12.50	6.80	12.50	1.85
14.50	9.60	14.50	2.60

From Fig.12 and Fig.13, the curve trend of the exponential relationship curve, indirectly verified the pressure and depth of the exponential relationship, second, the maximum friction in the same depth is caused by the friction coefficient between the two material surface and meters, by the experimental phenomenon observation, compared with plastic stainless steel material and meters friction coefficient is bigger , as shown in Table 2.

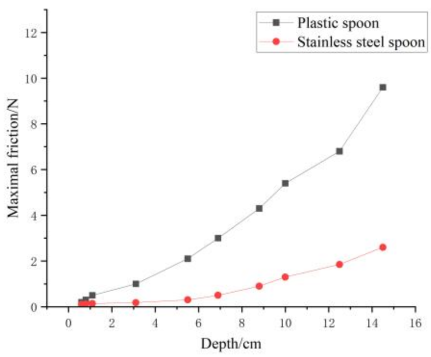

Figure 12: The friction curve diagram of spoons of different materials

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6.2 The relationship between the material humidity degree and the tensile force

Table 2: Insertion depth and maximum friction data in dry and wet rice

Dry material		Wet material	
Depth of penetration /cm	Maximal friction /N	Depth of penetration /cm	Maximal friction /N
0.60	0.10	0.60	0.30
0.80	0.11	0.80	0.50
1.10	0.14	1.10	0.80
3.11	0.18	3.11	2.00
5.50	0.30	5.50	3.20
6.90	0.50	6.90	4.00
8.80	0.90	8.80	5.70
10.00	1.30	10.00	7.40
12.50	1.85	12.50	10.8
14.50	2.60	14.50	15.3

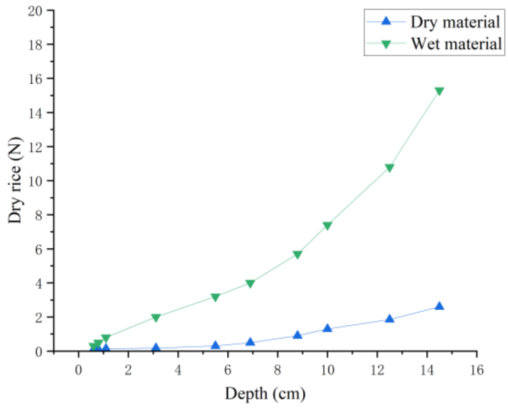

Figure 13: Contrast curve of moisture to the maximum friction

7. Summary

This paper shows the modeling results of dispersion element in EDEM and ANSYS, obtains the pressure formula of different depths and analyzes the effective friction force on the surface of the spoon, and calculates the maximum friction force formula. The influence of the bottom diameter of the container, the particle material, the lifting material and the moisture of the discrete particles were analyzed and verified by the physical experiment, and the experimental phenomenon of rice pot was completely analyzed.

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