Analysis on Simulated Test of Large-scale Efficient Roto-screen Separator

Weiiwei Wu¹, Jinglan Ruan²³*, Panpan Zhang² and Fulin Yuan⁴
¹Guangdong Science & Technology Cooperation Center, Guangzhou, Guangdong, 510033
²School of Mechanical Engineering, Henan University of Technology, Zhengzhou, Henan, 450001
³National Engineering Research Center for Grain Processing Equipment, Kaifeng, Henan, 475000
⁴Kaifeng Maosheng Machinery Manufacturing Co., Ltd., Kaifeng, Henan, 475000
*Corresponding author’s e-mail:ruanjl@126.com

Abstract. With the help of the software EDEM, this paper analyzes the influence of kinematic parameters of large-scale efficient roto-screen separator on the average advance speed of the materials and the screening efficiency through simulation experiment. The results indicate that the influence levels of the kinematic parameters are: turning radius > rotation speed > screen leaning angle; to achieve better screening effect, the turning radius, rotation speed and screen leaning angle should be set at 20mm, 450r/min and 6°~8° separately.

1. Introduction

It is inevitable that various kinds of impurity will be mixed with the grain during the processes of seed selection, cultivation, reaping, desiccation and storage, and detrimentally affects the product quality and its processing. Therefore, the cleaning of grain and the removal of impurities are the essential procedures in the processing phase in order to improve the purity of the products and the performance of the processing machinery, and ensure the people’s health and the production safety. One of the most frequently used method for cereal impurities removal is screening, i.e. choose specific screen according to the difference of the particle size and sort them in order to remove the impurities. There are some ubiquitous problems existed with the traditional cleaning machines, such as the low handling capacity, high energy dissipation, large floor space. To solve these problems, the large-scale efficient roto-screen separator, which is of high productivity, low dynamic energy dissipation, and good performance of cleaning and grading, is meticulously designed and produced with digestively absorption of the internationally advanced technologies based on the actual situation of food production in China. [1]

EDEM is a kind of mechanical simulation analysis software based on discrete element technology, especially used to deal with the particle system in the engineering field. In the processing process, the cereal is existed in particle groups, a kind of typical granular material. As the theory of discrete element technology matured over the years, the application scope of EDEM is expanding too. With EDEM, it is easy to probe into the mechanical properties [1] of the particle groups. This paper employs the discrete element method to simulate [3] the sieving process of large-scale efficient roto-
screen separator in order to analysis the influence of the movement of screen surface on the average advance speed and screen efficiency.

![Figure 1. Rotary cleaning sieve.](image)

![Figure 2. Model of sieve in EDEM.](image)

2. Create the geometric model for analyzing the sieve
The structure of the sieve is simplified for the convenience of simulation and the 3D solid modeling method is used to create the geometric model for EDEM numerical simulation analysis, as showed in Figure 2.

3. Simulation test analyses

3.1 Simulation Settings

3.1.1 Simulation Settings of Sieve. If the sieve is set to rotate planarly with the turning radius of 15mm, rotate speed of 300rpm, and the kinematic equation is:

\[ s_x = 15 \cdot \sin(10 \cdot \pi \cdot t) \]  
\[ s_y = -15 \cdot \sin(10 \cdot \pi \cdot t + \pi/2) \]

Since the motion form of the 8 sieves of the large-scale efficient roto-screen separator is the same, a single layer sieve screening model is built in order to simplify the calculation.

3.1.2 Simulation Settings of Particles. In this paper, wheat is chosen as research object. The parameters of wheat particles for DEM modeling are showed in Table 1.

| Ball No. | Radius/mm | X/mm   | Y/mm   | Z/mm   |
|---------|-----------|--------|--------|--------|
| 1       | 1.8       | 0.000367 | -0.00027 | 0.000451 |
| 2       | 1.7       | 0.000349 | -0.80027 | 0.000699 |
| 3       | 1.7       | 0.000385 | 0.79973  | 0.000203 |
| 4       | 1.5       | 0.000334 | -1.50027 | 0.000916 |
| 5       | 1.5       | 0.000401 | 1.49973  | -1.3e-05 |
| 6       | 1.2       | 0.000322 | -2.00027 | 0.001071 |
| 7       | 1.2       | 0.000412 | 1.99973  | -0.000168 |

The shape of wheat particles is similar to an oval with an average long axis of 6.8mm and short axis of 3.4mm, which can be stacked by multi-spheres with EDEM when doing the parametric modeling in the process of simulation analysis. Beside wheat particles, clastic particles, stone pieces...
and triangle stones are modeled too, as the lower sieve for impurities is chosen as the analytic target this time. The particle size is set smaller than the size of screen holes to ensure the small impurities can pass through the sieve. In the analysis, the simulated particle number is 5000, and the formation rate is showed in Table 2 and Figure 3.

Table 2. Initial parameters setting of particles.

| Property | Particle Type | Factory Type | Particle No. | Formation Rate (particles/s) | Largest Attempts (times) | Start Time (s) |
|----------|---------------|--------------|--------------|-------------------------------|--------------------------|---------------|
| Value    | Wheat Particles | dynamic      | 4000         | 5000                          | 20                       | 1e-12         |
| Value    | Clastic Particles | dynamic      | 400          | 5000                          | 20                       | 1e-12         |
| Value    | Stone Pieces   | dynamic      | 400          | 5000                          | 20                       | 1e-12         |
| Value    | Triangle Stones | dynamic      | 200          | 5000                          | 20                       | 1e-12         |

Figure 3. The model of sieving particles.

3.2 Simulation test analysis

Single factor method is employed to analyze the influence of sieve turning radius, rotate speed and leaning angel on the average advance speed and screening efficiency of the particle group. The motion parameters of the rotary cleaning sieve are chosen according to the actual conditions. A 4-level simulation test is set on each single factor for each of the 3 motion parameters. The test data are showed in Table 3.

Table 3. Table of numerical test design during sifting and sieving.

| Factor                        | Level |
|-------------------------------|-------|
| sieve leaning angle (°)      | 2     | 4     | 6     | 8     |
| turning radius r(mm)         | 10    | 15    | 20    | 25    |
| rotate speed (rpm)           | 200   | 300   | 450   | 600   |

3.2.1 Analysis of Particle Advance. The EDEM simulation analysis is conducted through the parameter change of the numerical test, then the fitted equation of the relation between the sieve leaning angle, turning radius, rotate speed of the screening machine and the average advance speed of the particle group during the steady state sieving is generated as:

\[ v = 0.009476 + 0.11528 \]  
\[ v = 0.01933A - 0.13346 \]  
\[ v = -7.16082E-7a^2 + 0.00134n - 0.17835 \]

Results of the variance analysis of the fitted equation are showed in Table 4, 5, 6:
Table 4. Variance analysis table of the influence of sieve leaning angle on average particle advance speed.

| Variation Source    | DOF | Quadratic Sum | Mean Square | F          | Significance |
|---------------------|-----|---------------|-------------|------------|--------------|
| Regression analysis | 1   | 0.00359       | 0.00359     | 446.84056  | 2.314608E-4  |
| Residual error      | 2   | 2.4084E-5     | 8.028E-6    | R^2=0.99111 |
| Total               | 3   | 0.00361       |             |            |              |

Table 5. Variance analysis table of the influence of turning radius on average particle advance speed.

| Variation Source    | DOF | Quadratic Sum | Mean Square | F          | Significance |
|---------------------|-----|---------------|-------------|------------|--------------|
| Regression analysis | 1   | 0.04672       | 0.04672     | 544.18118  | 0.00183      |
| Residual error      | 2   | 1.71692E-4    | 8.5846E-4   | R^2=0.99451 |
| Total               | 3   | 0.04689       |             |            |              |

Table 6. Variance analysis table of the influence of rotate speed on average particle advance speed.

| Variation Source    | DOF | Quadratic Sum | Mean Square | F          | Significance |
|---------------------|-----|---------------|-------------|------------|--------------|
| Regression analysis | 1   | 0.04782       | 0.02391     | 41311.92612| 0.00348      |
| Residual error      | 2   | 5.7874E-7     | 5.7874E-7   | R^2=0.99996 |
| Total               | 3   | 0.04782       |             |            |              |

Through the significance analysis of the fitted equations, the inspection results show that when the determination coefficient R^2 > 0.99, the regression effect is significant.

From the numerical analysis results, it can be deduced that the change of the sieve turning radius has the most significant influence on the average advance speed of the materials. The influence level of the 3 parameters from high to low are: turning radius > rotate speed > leaning angle. The larger the leaning angle is, the higher the average advance speed is; the influence of the turning radius on the average advance speed approximately keeps a linear relationship, which is more significant than the one of the leaning angle. The relation between the average advance speed and the sieve rotate speed is non-linear. The results show that the average advance speed increases with the rotate speed within certain limits, when the rotate speed > 450rpm, the change of the average advance speed changes decelerates with the increase of the rotate speed.

3.2.2 Screening efficiency analysis. Screening efficiency is an important indicator comprehensively reflecting the screening quality. It refers to the specific value between the weight of the sifted content after sieving and the weight of the sifted content in the raw materials that can pass through the sieve before sieving.

If the number of the impurities in the overtails and the total number of the impurities in the screening materials are counted respectively when it reaches the steady sieving condition, the screening rate in the steady sieving condition can be calculated through the equation:

\[\eta_{sum} = \frac{n_{sifted}}{n_{sum}} = 1 - \frac{n_{overtails}}{n_{sum}} \quad (6)\]

In the equation, \(\eta_{sum}\) refers to the screening efficiency in the steady screening condition, \(n_{sifted}\) refers to the total number of the impurities contained in the materials, \(n_{overtails}\) refers to the number of the sifted content. The dynamic screening efficiency is calculated through the number of overtails (except wheat particles) on the screen and the sifted material particles (except wheat particles) passed through the screen, as showed in Figure 4-6.

Figure 4 shows that if the screen leaning angle is changed at the initial phase, its influence on the dynamic screening efficiency is slight and most materials are gathered in the blanking box, not yet to disperse on the sieve; as the process of screening goes on, the material particle group is scattered and layering on the sieve, the dynamic screening efficiency becomes stable, and the synchronized dynamic screening efficiency improves with the increase of the screen leaning angle; the time of the increase of the dynamic screening efficiency will be shorten with the increase of the screen leaning angle, when
the angle is 6° and 8°, the change rules of the dynamic screening efficiency are basically the same, and the dynamic screening efficiency is higher compared to that at 2° and 4°. At the initial phase, the dynamic screening efficiency is higher when the screen leaning angle is 10°; at the stable screening phase and the subsequent discharging phase, its value is lower than that at 6° and 8°.

Figure 5 shows that when the turning radius is set at 20-25mm, the dynamic screening efficiency is significantly higher than that at 10-15mm. Besides, when the turning radius is set at 20 and 25mm, the change rules of the dynamic screening efficiency are basically the same; but from the perspective of the average value, when the turning radius is set at 20mm, the dynamic screening efficiency is higher.

Figure 4. The influence of screen leaning angle on dynamic screening efficiency.

Figure 5. The effect of radius of gyration on dynamic screening efficiency.

The value analyses of the 3 conditions mentioned above indicate the changes of the effect of the 3 screen kinematic parameters on dynamic screening efficiency: turning radius > rotation speed > screen leaning angle.

4. Conclusions
(1) The effect of the roto-screen separator screen kinematic parameters on the average advance speed is: turning radius > rotation speed > screen leaning angle. The average advance speed will be faster with the larger screen leaning angle. The influence of the turning radius is larger than that of the screen leaning angle on the average advance speed. In a certain scope, the average advance speed is increasing as the rotation speed of the screen is increasing, but when the rotation speed is over 450 rpm, the changing rate will slow down.

(2) The turning radius, rotation speed and screen leaning angle will have great influence on the steady screening efficiency, as turning radius > rotation speed > screen leaning angle. When the screen kinematic parameter is set at turning radius 20mm, rotation speed 450r/min, screen leaning angle 6°~8°, the dynamic screening efficiency will reach a favourable screening effect.

Acknowledgment
Foundation Program: National Key Technology R&D Program for the 13th Five-year Plan (Project Number: 2017YFD0401101-01); Key Science & Technology Research Project of Kaifeng City, Henan Province (No. ZD16010).

References
[1] Ruan, J.L., Wu, W.B. (2017) Principles and Applications of Grain Processing Machine, China Machine Press. Beijing.
[2] Liu, F.Y., Zhang, J., Li, B., Chen, J. (2016) Calibration of Parameters of Wheat Required in Discrete Element Method Simulation Based on Repose Angle of Particle Heap. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE) [J], 32(12): 247-253.
[3] Zhao, L.L. (2013) 3D DEM Simulation Research of Vibratory Screening Process, China University of Mining and Technology Press. Xuzhou.
[4] Favier, J.F., Abbaspour-Fard, M.H., Kremmer, M. (1999) Shape Representation of Axially-symmetric, Non-spherical Particles in Discrete Element Simulation Using Multi-element Model Particles. Engineering Computations International Journal for Computer-aided Engineering and Software [J], 16:467-480.

[5] Jiao, H.G. (2006) Computer Emulation of Particle Motion on the Screen Plate and Its Validation by Test. Mining & Metallurgy [J], 15(1):63-67.