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# The Proposal of the New Drum and the Analysis of Two-Component Particles Movement Characteristics

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***Abstract*** **– A new types drum cooler is presented, which has heat exchange tubes on the inner wall surface, thus improving the waste heat utilization efficiency from the metallized pellets and the multi-component particles movement characteristics. The discrete element method are employed to investigate the axial and total velocity, also the number of particles in contact with the wall. Moreover, high consistency between experimental results and simulation results. Compared with traditional drum cooler, two-component particles total velocity in new types drum cooler is increased 174%.**

***Keywords*** **– Metallized Pellets, Discrete Element Method, Heat Exchange Tube, Multi-Component Particle, Drum Cooler.**

## I. Introduction

The waste heat materials from the metallurgy industry and building industry are about 4.29 billion tons, and the heat is about 5.1×1012 MJ, if this part of the heat is used, about 170 million tons of coal can be saved [1]. The waste heat generated accounts for about 17% -67% of the total heat [2]. So, waste heat recovery is also a way of cleaner production [3].

China has used metalized particles as early as the last century [4], and it was widely used in the steel industry and metallurgy industry [5]. Therefore, it is extremely curial to study the utilization of waste heat from metallized pellets [6]. Nowadays, many factories using traditional cooler drum to recover the waste heat, Fig. 1 elucidates the traditional drum cooler's sketch map. By spraying water or water mist directly on the outer wall of the cylinder to cool the metallized pellets. But it has many disadvantages: Large volume; easy to deform; poor heat transfer efficiency, and also can pollutes water and air. This does not meet the purpose of cleaner production.

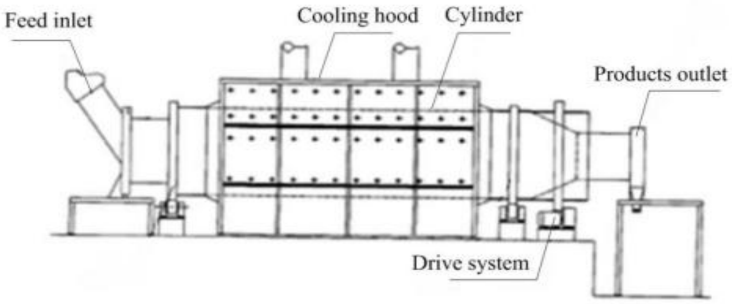


Fig. 1 Sketch map of the drum cooler structure.

Many relevant pieces of research elucidated that the heat transfer characteristics of the particles largely determined by the particles' flow characteristics [7-9]. Chen et al. [10] elucidated the mechanism of heat transfer that the filling rate and average residence time of the particle have a great influence on heat transfer efficiency. Ngako et al. [11] found the average residence time is inversely proportional to the rotating velocity by the simulation. Chen et al. [12] analyzed the dispersion performance of the particles that was improved with the increases of rotating velocity. The discrete element method (DEM) has good accuracy in simulating particle flow [13-15].

The particles' movement has been studied by many researchers, but they are mainly focused on single size particle or multi-component particles in the traditional drum cooler. There are few studies on the new types drum cooler with heat exchange tubes, especially for multi-component particles. Due to the actual production which the particle size can not be the same, so the flow characteristics of two-component particles and three-component particles are studied. Using the Hertz-Mindlin no sliding contact model and the discrete element method focus on how the dip angle, rotating velocity, and filling rate affect the particles flow characteristics. Further contrast the difference between traditional and new types drum cooler.

## II. Physical and Mathematical Description

The discrete element method in simulating the particles' flow has great advantages, so used it to simulate the flow characteristics of the two-component and three-component particles. The discrete element method divides the element into many small rigid parts, in this way, each rigid part can be solved by the motion formula, then utilize iterative method to solve, obtain the discontinuous overall movement formula. EDEM, a kind of DEM software, the required storage space is small and the calculation speed is fast, has an irreplaceable advantage for large displacement and nonlinear problems. The model that a part of the drum is established using EDEM is shown in Fig. 2. The simulation model of new types drum cooler has 36 heat exchange tubes on the inner wall. And the model parameters are showed in Table 1.


Fig. 2. The model of new type drum.

Table 1. Model parameters.

| Projects | Parameters |
|---|---|
| Length | 300 |
| Diameter | 3200 |
| Thickness | 33 |

The axis direction is consistent with the z axis, and the drum' cross-section is in the xy plane. Because the simulate parameters have an important influence on the result, so the selection of parameters should be suitable for actual production. The actual production parameters of dip angle, rotation velocity, and filling rate are 5°, 2.2 r/min, and 12% separately. Therefore, the selection of parameters should include the actual production parameters. Table 2 shows the simulate parameters.

According to the above conditions, the motion characteristics of the particles were analyzed, which is how the parameters of the new drum cooler affect the multi-component particles. The axial velocity, total velocity, and the rate of axial velocity to total velocity (RAT) and contact number between the particles and the inner wall surface (contact number) are used to describe the particle movement characteristics.

Table 2. Simulation parameters.

| Projects | Parameters |
|---|---|
| Dip angle (°) | 1, 2, 3, 4, 5 |
| Rotating velocity (r/min) | 1.2, 1.7, 2.2, 2.7, 3.2 |
| Filling rate (%) | 1.5, 5, 8.5, 12, 15.5 |
| Number of heat exchanger tubes | 24, 30, 36, 42, 48 |

## III. Experiment and Model Validation

Before starting the formal simulation, the model needs to be tested and verified, so the experimental system was established at the Shandong University of Technology. The experimental system elucidates in Fig. 3, it consists of a motor system, drum and measuring system, fixed system, and different size ball.

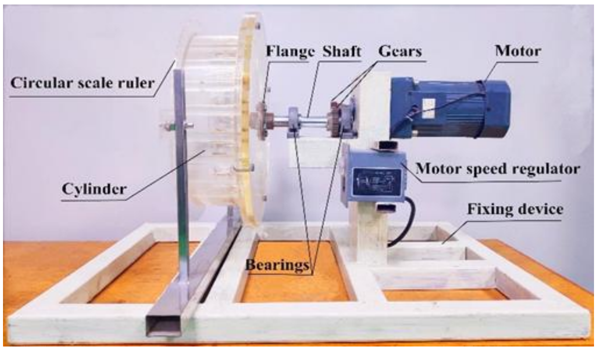


Fig. 3. Experimental system.

The particle bed morphology of experiment and simulation are shown in Fig. 4. The maximum relative errors of the maximum and minimum angle of repose are 1.7%, 3.4%, the thickness of the active layer is 2.1%. The maximum relative error occurs at a higher velocity because when the velocity is high, the particles move violently, and measurement errors will inevitably occur in the experimental test. The maximum relative error is less than 5%, indicating that the model built is reasonable and feasible, then subsequent calculations can be performed based on this model.

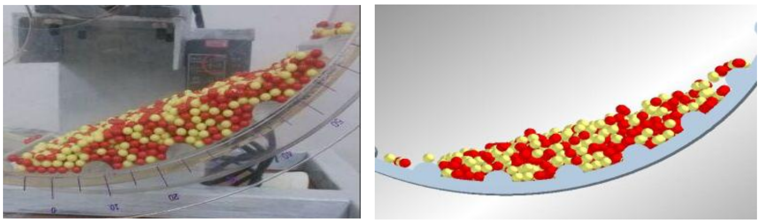

Fig. 4. Experiment and simulation of particle bed morphology.

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## IV. Result and Discussion

### A. *Shape of two Component Particles Motion in New Drum*

Fig. 5 elucidates the shape of the bed morphology and velocity vector cloud image in the drum cooler, As shown in Fig. 5, the first figure that the red particles with d = 25 mm were surrounding by the blue particles with d = 30 mm. The passive layer particles are sandwiched between the heat exchange tubes and its relative position is almost unchanged, so the mixing and separation of particles occur mainly in the active layer. The mobility of small particles is better and the inertia of larger particles is greater, when particles in the active layer, small particles are more likely to settle to the bottom of the active layer. In this way, after many cycles, a bed shape in which small particles are surrounded by large particles are formed. The process of particles which in the upper active layer rolling to the bottom of the active layer actually is a process of separating different size particles. At this time, the active and passive layer are mainly composed of particles with d = 30 mm, and the particles with d = 25 mm are mainly located in the core areas.

Form the velocity vector cloud image, the blue part of the image is core areas and the velocity of particles in this position is almost 0, upper on the core areas is the active layer and below the core areas is the passive layer, and the total velocity of particles with d = 30mm is greater than the total velocity of particles with d = 25mm.

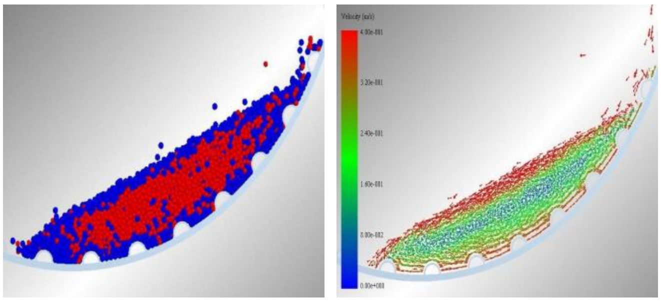

Fig. 5. Two-component particles bed morphology and velocity vector cloud image.

### B. *Two-component Particles Flow Characteristics in the Two Different Drums*

In this chapter, the two-component particles with d = 25 mm and d = 30 mm are selected as the research object and analyzes how the parameters of the new drum cooler affect the two-component particles and single size particles.

### C. *Effect of Dip angle on Two-Component Particle*

As shown in Fig. 6(a), the mixed particles axial velocity increased with the increase of dip angle, which increased from 18 mm/s to 103 mm/s. For the single size particles, the axial velocity of particles with d = 25 mm and d = 30 mm is almost the same. Because as the dip angle increasing, the component force of the particle gravity in the axial direction of the drum becomes larger, and the particles start to move after breaking the self-lock, the particles start to roll from the front side to the back side of the drum, so the axial velocity of the particles are kept increasing, which further promotes the increase of the total velocity.

The mixed particles' total velocity increased with the increase of dip angle, which increased from 260 mm/s to 281 mm/s in Fig. 6(b). For the single size particles, the total velocity of d = 25 mm and d = 30 mm particles increased slightly, because the existence of the heat exchange tube promotes the radial velocity of the particles

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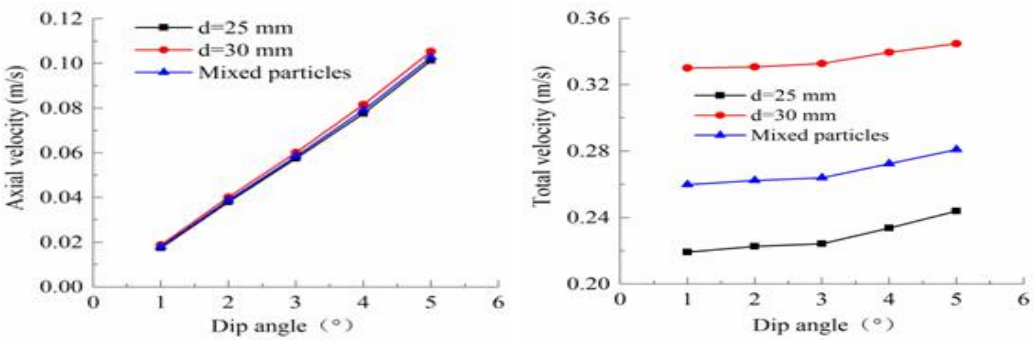
by enhancing the carrying effect of the drum on the particles, also the axial velocity of the particles are kept increasing, which further promotes the increase of the total velocity. So, the total velocity is increasingly large.




(a) Axial Velocity (b) Total Velocity

Fig. 6. Dip angle affect the two-component particles axial and total velocity.

As shown in Fig. 7, the dip angle increased from 1° to 5°, the RAT of mixed particles increased from 0.069 to 0.366. Because as the dip angle increasing, the dip angle mainly promoted the particles' axial velocity. The greater the dip angle, the greater the axial velocity, also the increased rate of the particles' axial velocity is greater than the increased rate of the total velocity, so the rate of axial velocity to total velocity increases continuously.

For the single size particles, the change rule of large size particle with d = 30 mm and small size particle with d = 25 mm is as same as mixed particles. Because the axial velocity of d = 25 mm and d = 30 mm particles in the new cooler is almost the same. According to Fig. 5 particle bed morphology and velocity vector cloud image, the total velocity of particles with d = 30 mm which mainly accumulated at active and passive layer is larger than the particle with d = 25 mm which mainly accumulated at core areas, and the axial velocity of particles with d = 30 mm and d = 25 mm are almost in same, so the rate of particles with d = 25 mm is larger than the particles with d = 30 mm.

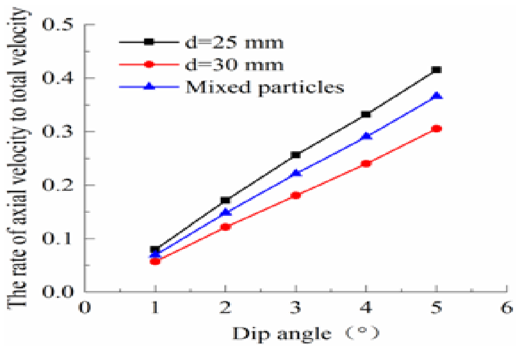



Fig. 7. Dip angle affect the two-component particles RAT.

As shown in Fig. 8, the contact number of particles in the new drum cooler fluctuates slightly between 540 and 560 with the increase of dip angle. Because the increase of the dip angle does not have a substantial effect on the contact number, particles just roll from the front side to the back side of the drum, so the contact number almost unchanged. For the single size particles, particles with d=30 mm are larger than particles with d = 25 mm in the contact number. Because according to Fig. 5 particle bed morphology, the bed morphology appears a phenomenon that small size particles were surrounding by large size particles in new type drum.

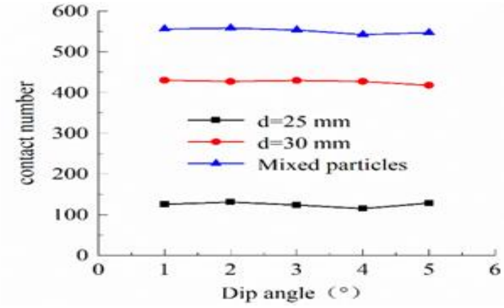
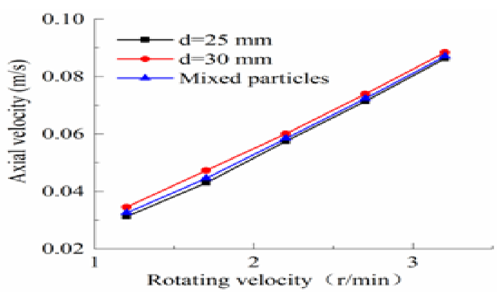



Fig. 8. Dip angle affect the number of two-component particles in contact with the wall.

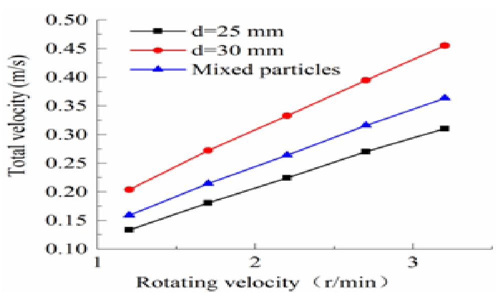
D. *Effect of Rotating Velocity on Two-Component Particle*

As shown in Fig. 9(a), the axial velocity increased with the increase of rotating velocity, which increased from 32 mm/s to 87 mm/s. Because the rotating velocity is increasingly fast, thus enhancing the stirring effect of the drum cooler. The thickness of the active layer is increased causing the improvement of the particle's fluidity. So, the axial velocity of the particles is increased. The heat exchange tubes prevent the axial speed from increasing too fast due to the hindrance effect of the heat exchange tube, so the axial velocity just changed a little. For the single size particles, different size particle on the axial velocity is in same, because the string effect and hindrance effect works on both size particles.

The total velocity increased with the increase of rotating velocity, which increased from 159 mm/s to 364 mm/s in Fig. 9(b). For the single size particles, the change rule is as same as mixed particles, because the rotating velocity is increasingly fast, thus enhancing carrying effect of the heat exchange tube, particles move with the heat exchange tubes of the drum. So, the total velocity of the particles is increased. For the single size particles and according to the Fig. 5, the particles bed morphology appears a phenomenon that the small particles are surrounded by large particles in the new cooler and the active and passive layer are mainly composed of particles with d = 30 mm, and the particles with d = 25 mm are mainly located in the core areas, so the particles with d = 30 mm in passive layer can move with the heat exchange tube. According to the speed low of the particle bed, the total velocity of d = 25 mm particles is smaller than the total velocity of d = 30 mm particles.




(a) Axial Velocity




(b) Total Velocity

Fig. 9. Rotating velocity affect the two-component particles axial and total velocity.

As shown in Fig. 10, the RAT increased with an increase of the rotating velocity, which increased from 0.204 to 0.240. Because the increased rate of axial velocity is faster than total velocity, so the RAT is increased gradually. For the single size particles, the change rule of large size particle with d = 30 mm and small size particle with d = 25 mm is as same as mixed particles and the RAT of d = 30 mm is smaller than that of d =

25mm. Because the total velocity of particle size with d = 25 mm is smaller than the total velocity of particle size with d = 30 mm, and according to Fig. 5 the particles bed morphology appears a phenomenon that the small particles are surrounded by large particles. Particles with d = 30 mm are mainly in the active and passive layer and the particles with d = 25 mm are mainly located in the core areas, the large particles in passive layer can carry by the heat exchanger tube, so the total velocity of particle with d = 30 mm is large. According to Fig. 9(a) and (b) that the axial velocity of d = 30 mm and d = 25 mm is almost in same but the increases rate of axial velocity is faster than the change rate of total velocity, so the RAT is increased, and RAT of the particle with d = 25 mm is large than that with d = 30 mm.

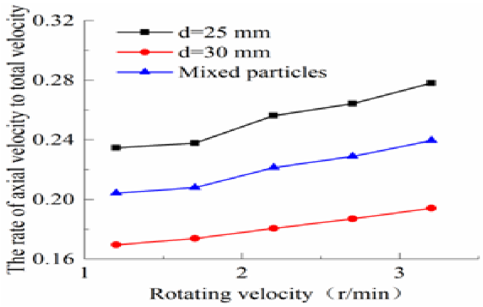



Fig. 10. Rotating velocity affect the two-component particles' rate of axial velocity to total velocity.

Fig.11 elucidates the influence of the rotating velocity on the contact number. As shown in Fig. 11, the contact number reduced with the increase of rotating velocity, which decreased from 620 to 496. Because the rotating velocity is increasingly fast, enhancing the stirring effect to the particles, the radial movement of the particles became violent. Finally, the particles separated from the wall surface, thus reducing the contact number.

For the single size particles, the contact number of d = 25 mm particles and wall surface increases slightly. Because the particles with d = 25 mm are mainly accumulated at core areas, and the stirring effect makes the particles with d = 25 mm can through the d = 30 mm particle layer and contact with the drum wall. The contact number of particles with d = 30 mm are reduced gradually, because the area between heat exchange tube composed with particles with d = 30 mm and d = 25 mm, the number of particles with d = 25 is increased slightly, thus causing the number of particles with d = 30 mm decreased gradually. With the increases of rotating velocity, the stirring effect enhances the particle movement in passive layer, more and more particles start to separate from the wall surface. The number of mixed particles is mainly composed of particles with d = 30 mm, so the changing trend of mixed particles is similar to the particles with d = 30 mm.

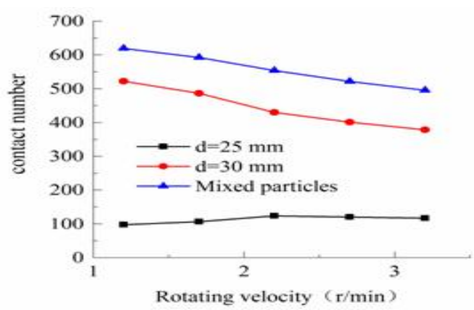
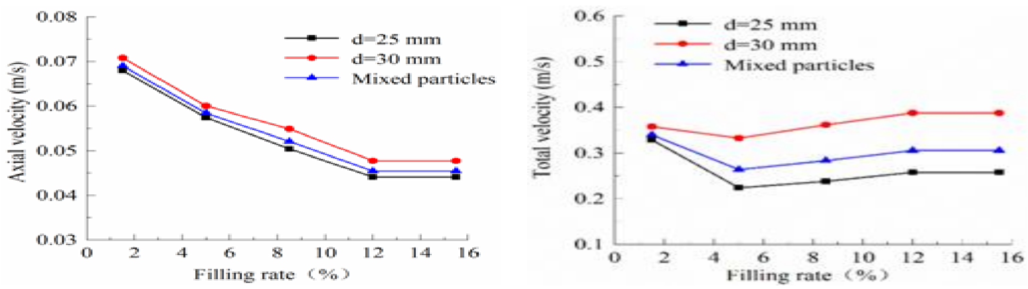



Fig. 11. Rotating velocity affect the number of two-component particles in contact with the wall.

E. *Effect of Filling Rate on Two-Component Particle*

As shown in Fig. 12(a), the axial velocity of particles reduced with the increase of the filling rate, which reduced from 69 mm/s to 45 mm/s. For the single size particles, different size particles have the same change trend. Because with filling rate increasing, the number of particles is increased and the pressure of particles in the bottom of the drum is increased, so the friction between particles and wall is increased, but the component of gravity in the axial direction of the drum remains unchanged, also the hindrance of the heat exchange tube to the axial velocity was enhanced, most of the particles were hindered, so the axial velocity was decreased.

The total velocity, which decreased from 340 mm/s to 264 mm/s then increased to 306 mm/s with the increase of filling rate in Fig. 12(b). Because when the filling rate is 1.5%, the number of particles is small and both particles are sandwiched between the heat exchange tubes then moving with the drum. In this case, the total velocity is very close to rotating velocity, so the total velocity is higher. When the filling rate is increased to 5% gradually, some particles can not sandwich by the heat exchange tube, so the total velocity is decreased gradually. When the filling rate is greater than 5%, the total velocity is increasingly large, because with the increase of filling rate, the bed becomes thicker and the particle fluidity becomes better, resulting in a gradual increase in the total velocity.




(a) Axial Velocity (b) Total Velocity

Fig. 12. Filling rate affect the two-component particles axial velocity and total velocity.

As shown in Fig. 13, the RAT of mixed particles increased from 0.203 to 0.221 then decreased to 0.149 with the increase of filling rate. Because with the filling rate increases, the total velocity decreased and then increased, the axial velocity is decreased continuously. For the single size particle, the RAT of particles with d = 25 mm larger than that with d = 30 mm. When the filling rate is increased from 1.5% to 15%, according to Fig. 12(a) and (b) that the total velocity of the particle is first decreased and then increased, but for the axial velocity is decreased gradually. Due to the small particles are surrounding by large particles, the particles of d = 30 mm are mainly located in the passive and active layer, the particles with d = 25 mm are mainly located in core areas, The total velocity of d = 30 mm is bigger than d = 25mm, but the axial velocity is almost in same, thus causing the RAT of particles with d = 25 mm is larger than that with d = 30 mm.

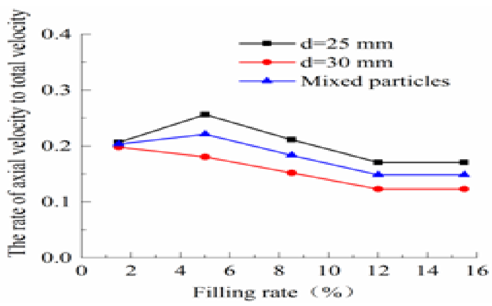



Fig. 13. Filling rate affect the two-component particles' rate of axial velocity to total velocity.

As shown in Fig. 14, the contact number increased with the increase of filling rate, which increased from 351 to 784. Because with the increases of filling rate, the number of particles in drum cooler is increased, under these circumstances, the chance of particle contacts the inner wall surface has increased. When the filling rate is larger than 12%, the contact number can not increase anymore, because the area between heat exchange tubes has already been filled with particles, so the contact number keeps unchanged. For the single size particles, with the increase of filling rate and according to Fig. 5 particles bed morphology that the bed morphology appears a phenomenon the small particles are surrounding by large particles, and the passive layer becomes thicker, small particles pass through the passive later become harder, so the contact number of particles with d = 25 mm decrease gradually, the contact number of particles with d = 30 mm are increased. With the increases of filling rate, the contact number of mixed particles is almost as same as the particles with d = 30 mm, because the area between heat exchange tubes is mainly composed of the particles with d = 30 mm.

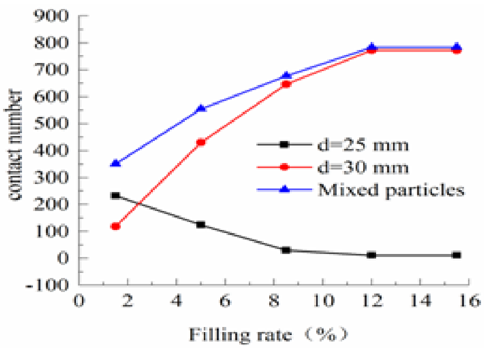



Fig. 14. Filling rate affect the number of two-component particles in contact with the wall.

## V. Conclusion

A new types drum cooler with heat exchange tube was proposed and the motion characteristics of multi-component particles were studied, the following conclusions were drawn from this research:

1. For the two-component particles, when the dip angle and rotating velocity are increasingly large, the particle's axial and total velocity and the rate are increased, but the contact number is changed a little and decreased respectively.
2. For the two-component particles, with the filling rate increasing, particles' axial velocity is decreasing continuously while the contact number is increasing. The rate of axial velocity to total velocity increases first and then decreases but the change rule of total velocity is opposite to the change rule of the rate.
3. For two-component particles, the contact number of particles with d = 30 mm is greater than the contact number of particles with d = 25 mm. But in the new drum cooler, the contact number of particles with d = 20 mm and d = 30mm are almost in the same and both are larger than the contact number of particles with d = 25 mm.
4. The new drum has better advantages in particle flow characteristics, so it provides a new method for particle cooling and waste heat utilization.

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