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Improvement in the feeding method to an inclined conveyor designed for the recycling of foundry sand

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Abstract The goal of the inclined conveyor method for particle shape separation is to process a large amount of feed material for recycling technology. The high feed rate has been achieved because the movement of particles is faster than for other previously introduced equipment. The separation performance of the apparatus was tested with foundry sand. A large amount of sand was treated, and various processing capacities were studied experimentally. The feed method was improved from point to line with wide troughs to process the higher feed rate. We succeeded in attaining a feed rate of 1.49×10^{-3} kg/s with a 0.3-m trough. The space filling, which was an important factor in deciding the capacity of the feed rate, was defined. This method is useful for any kind of line-feed method.

Key words Separation by shape · Inclined conveyor · Recovery of foundry sand · High feed rate

Introduction

The separation of solid materials based on particle shape has been carried out to remove foreign substances from such materials as grains and seeds. An improvement in the functional characteristics and ease of handling is urgently required in recent advanced technologies in the chemical, mineral processing, and manufacturing industries, and point separation by shape can be an effective way to control raw materials.[1]

Shape separation can be applied not only to the purification of particulate materials, but also to the recycling of solid waste. We have developed several types of shape separation technique for particulate materials, including an inclined conveyor,[2] an inclined vibration plate,[3] and a horizontal circular motion plate,[4] and we have ascertained that the recovery of materials from electric scraps could be performed with these shape separation techniques.[5] In this work, we studied the applicability of shape separation to the treatment of reclaimed foundry sand. Sand discharged from the casting process is reclaimed at disposal sites, and it has become difficult to secure enough sites. The reclaimed foundry sand contains a lot of spherical ceramic beads. Therefore, these have to be recovered for economic and environmental reasons. Shape separation may provide the potential to recover ceramic beads from waste sand because both materials are the same size and density. The most important point in this application is to process large amounts of particles, which is necessary for all recycling technologies.

The feed rate of the shape separator based on the sliding and/or rolling motion of differently shaped particles is influenced by the retention of nonspherical particles on the separation field, as reported previously,[6,7] and therefore it is not enough to process the reclaimed foundry sand. It is of interest to increase the feed rate of the waste sand in the inclined conveyor, and we have examined increments of the amount of processed materials to improve the feeding method.

Experimental

Apparatus

An inclined conveyor was developed as a sliding- and/or rolling-type shape separator.[2] According to the results of the point feeding method shown in Fig. 1, it was found that nonspherical particles spread over the entire surface of the belt were effective in processing a large amount of feed material.

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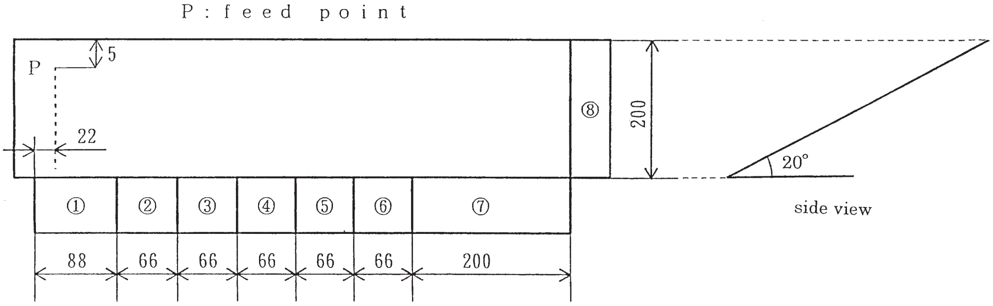

Fig. 1. Positions of the feed point on the belt and vessels (dimensions in mm)

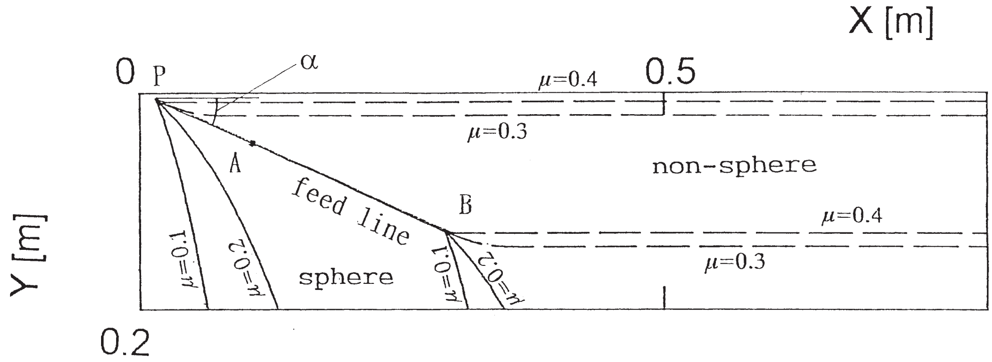

Fig. 2. Position of the feed line and trajectories of the particles

The line feed instead of the point feed seems to be very effective for processing large amounts of material. However, some types of line feed were not very effective, such as the horizontal line feed. Therefore, a vibrating feeder with two different trough widths (0.1 m and 0.3 m) was used. This fed the sand in a line at an inclination with respect to the direction of belt transportation. The angle of the line feed from the direction of the convey or belt, α, was fixed at 24° because then there was no interaction between the spherical and nonspherical particles, as shown in Fig. 2. The angle should be determined carefully in order to avoid the crossing of the trajectories.

The relation between the particle shape and the friction coefficient was studied by Yamamoto et al.[8] As the shapes of foundry sand were similar to those of a mixture of glass beads and silica sand, spherical particles were considered to have a friction coefficient of 0.1–0.2 in dynamic friction, while the friction coefficient of nonspherical particles was 0.3–0.4.[2] The tangent of the inclination to the horizontal must be fixed between the two particle friction coefficients. Reclaimed foundry sand was fed on line P–A or P–B in Fig. 2 through the trough.

Procedures

Reclaimed foundry sand, as shown in Fig. 3, was used as the experimental material. This material was irregular silica sand mixed with an artificial spherical sand called Cerabeads (Naigai Cerabeads by Naigai Ceramics, Tokyo, Japan). These Cerabeads were newly developed ceramic beads to be used as foundry sand. Their properties are shown in Table 1. The mass fraction of Cerabeads was 0.527 based on measurements using an image analyzer (LA-555 by Pias, Tokyo, Japan). For this experiment, the belt speed and the angle of inclination were fixed at 0.50 m/s and 20°, respectively, based on the results of a theoretical analysis.[4] Reclaimed foundry sand was fed to the conveyor with a vibrating feeder, and was collected in vessels 1–8 located at the positions illustrated in Fig. 1. The particles collected in each vessel were weighed, and their mass fractions in each of the collected fractions were measured by a photographic survey.

Table 1. Properties of reclaimed foundry sand

	Shape	Size range (mm)	Mean diameter (mm)	Density (kg/m^3)
Silica sands	Irregular	0.1–0.5	0.207	2.65×10^3
Cerabeads	Spherical	0.3–0.5	0.362	2.89×10^3

In order to study the feeding process the sand was fed by two kinds of feeding systems, (1) a point-feed system which feeds particles to point P with a V-shaped trough, as shown in Fig. 1, and (2) a line-feed system which feeds at the line PA (0.1 m) or PB (0.3 m) with a wide trough, as shown in Fig. 2.

Results and discussion

Recovery of cerabeads from reclaimed foundry sands

The angle of inclined, θ, and the belt speed, U, were important operating parameters, and were fixed at 20° and 0.50 m/s, respectively. However, the separation efficiency decreased as the feed-rate increased. This is considered to be caused by an interaction between the Cerabeads and silica sand.

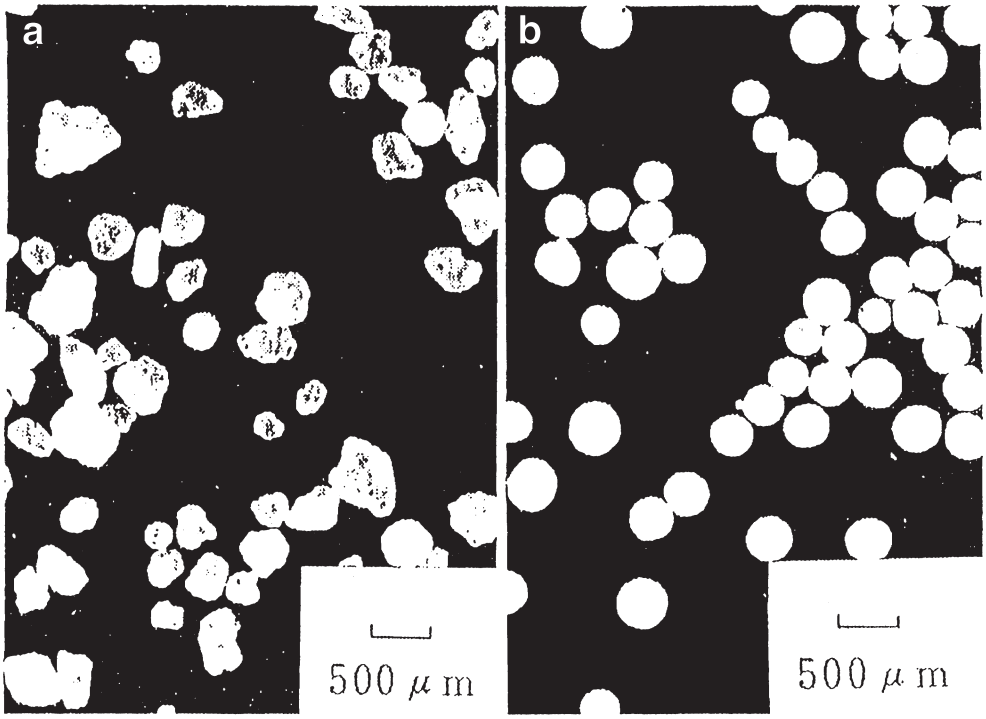

Fig. 3. Photograph of reclaimed foundry sands (a mixture of silica sands and Cerabeads). **a** Silica sand. **b** Cerabeads

Figure 4 shows the distribution of the recovery of the spherical and nonspherical particles with the positions of the vessels at five different feed rates using the point-feeding method. The position of the vessels, X_i, was defined as the displacement in x-direction from the feed point. The recovery of spherical, r_{Si}, and nonspherical, r_{Ni}, particles in each vessel was calculated using the following equations:

$$r_{Si} = x_i W_i/(x_F W_F) \tag{1}$$
$$r_{Ni} = (1 - x_i)W_i/\{(1 - x_F)W_F\} \tag{2}$$

where x_F is the mass fraction of spherical particles in the feed, x_i, is the mass fraction of spherical particles in vessel i, W_F is the mass of feed per unit time, and W_i is the mass of particles recovered in vessel i per unit time.

Particles which did not roll down into vessels 1–7 were conveyed to the end of the belt and dropped into vessel 8. These recoveries, r_{S8} and r_{N8}, are shown on the right-hand side of this figure as reference data.

As shown in this figure, the recovery distribution of nonspherical particles was almost independent of the feed rate. When the feed rate was increased, the recovery distribution of spherical particles shifted in the direction of belt transportation because the retention of nonspherical particles affected the motion of spherical particles. In other words, the movement of spherical particles was affected by the movement of nonspherical particles, and spheres tended to be transferred in the x-direction along with the many nonspheres retained on the belt.

Table 2 shows the performance of the separation at two different feed rates, W_F. The recovery of spherical particles (Cerabeads) in the product, r_{SP}, the recovery of nonspherical particles (silica sands) in the residue, r_{NR}, and Newton's

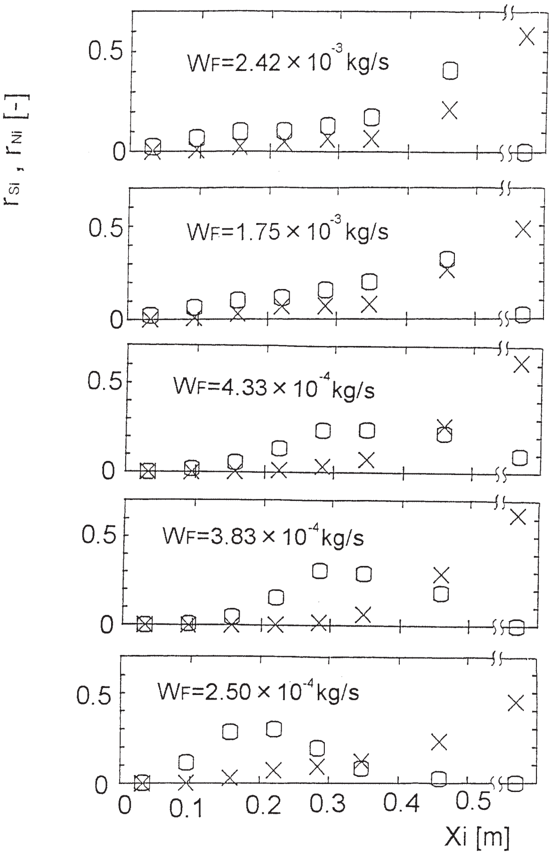

Fig. 4. Effect of the positions of the collection vessels on spherical and nonspherical particle recoveries in the vessel (*circles*, spheres; *crosses*, nonspheres)

Table 2. Recovery and separation efficiency of reclaimed foundry sand ($U = 0.50\,\text{m/s}$, $\theta = 20°$, V-shaped trough)

W_F	r_{SP}	r_{NR}	η
2.50×10^{-4} kg/s	0.849	0.803	0.652
2.42×10^{-3} kg/s	0.999	0.579	0.578

separation efficiency, η, were calculated using the following equations:

$$r_{SP} = \Sigma r_{Si} = x_P W_P / (x_F W_F) \quad (3)$$

$$r_{NR} = \Sigma r_{Ni} = (1 - x_R) W_R / \{(1 - x_F) W_F\} \quad (4)$$

$$\eta = r_{SP} - (1 - r_{NR}) \quad (5)$$

where x_P is the mass fraction of spherical particles in products, x_R is the mass fraction of spherical particles in residues, W_P is the mass of products per unit time, and W_R is the mass of residues per unit time.

The maximum values of η when the dividing point between the product and the residue had been determined are shown in Table 2. The dividing point was fixed between vessels 5 and 6 for $W_F = 2.50 \times 10^{-4}$ kg/s, and between vessels 7 and 8 for $W_F = 2.42 \times 10^{-3}$ kg/s.

The results using the line feed are shown in Figs. 5 and 6 under the operating conditions $U = 0.33$ m/s and $\theta = 15°$. The abscissa, X_i, was the distance in the x-direction from the middle point of the feed line to each vessel. The ordinate was the recovery of the spherical or nonspherical particles. When a line feed with a 0.1- or 0.3-m trough was used, the same trends as with a point feed with a V-type trough were obtained.

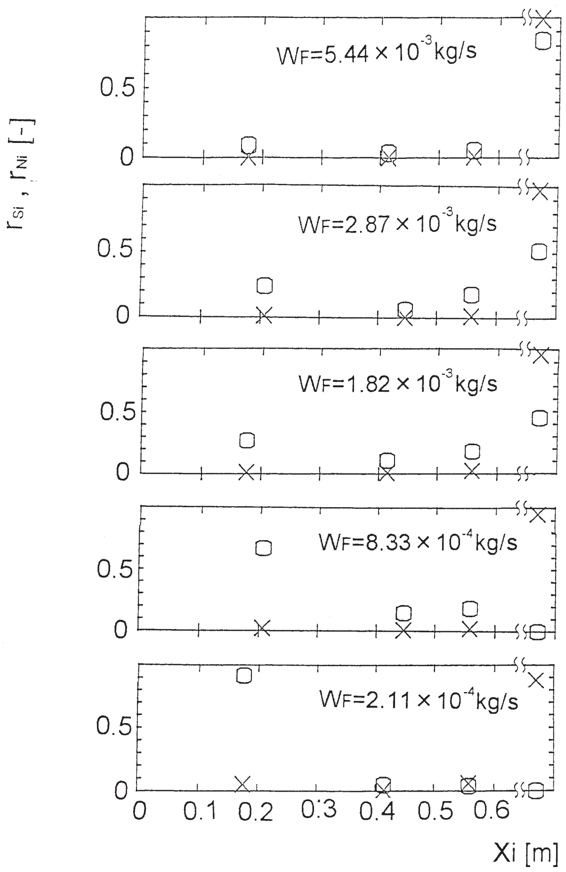

Fig. 5. Effect of the positions of the collection vessels on spherical and nonspherical particle recoveries in the vessel (*circles*, spheres; *crosses*, nonspheres; feed line 0.1 m)

Treatment capacity

In order to understand the capacity of this method, the quantity of nonspherical particles being transported on the belt was calculated, and the degree of its interceptive effect on the movement of spherical particles was taken into consideration. Nonspherical particles on the feed line moved with the belt speed. As shown in Fig. 7, the whole area of movement of the particles in unit time is $Ul \sin\alpha$, where l is the width of the feed and α is the angle between the feed line and the direction of belt movement. The total number of nonspherical particles with a diameter d_N and a density ρ_N fed to the conveyor in unit time is $(1 - x_F)\, W_F / (\rho_N\, \pi d_N^3/6)$. A nonspherical particle occupies an area πd_N^2. Therefore, the space filled by nonspherical particles, η_N, is defined as

$$\phi_N = 6(1 - x_F) W_F / (\rho_N d_N U l \sin\alpha) \quad (6)$$

where ρ_N is the density of nonspherical particles, d_N is the mean diameter of nonspherical particles, and l is the length of a feed line. We assumed that the thickness of the nonspherical-particle layer was the same as the diameter of the nonspherical particles.

This value denotes the number of nonspherical particles per unit area on the belt. When this is in unity, the nonspherical particles are tightly packed on the belt with no voids. On the other hand, when ϕ_N is 0, there is nothing on the belt.

Figure 8 shows the relation between X_i and the recovery when the number of nonspherical particles is almost the same, but different trough widths are used. The upper graph is for a 0.1-m trough, and the lower graph is for a 0.3-m trough. The recovery distributions of spherical particles were similar when the abundance of nonspherical particles remaining was the same. This is the reason why the interaction was determined by the space filled by nonspherical particles on the belt. This space is important for determining the capacity of this method.

Conclusion

The performance of an inclined conveyor method was developed as a new type of particle shape separator. It is very simple in structure and low in cost.

This method is characterized by the possibility of processing a large amount of feed material. The performance was experimentally investigated, and it became clear that the interaction between spherical and nonspherical particles was the main factor affecting the feed rate, and that this

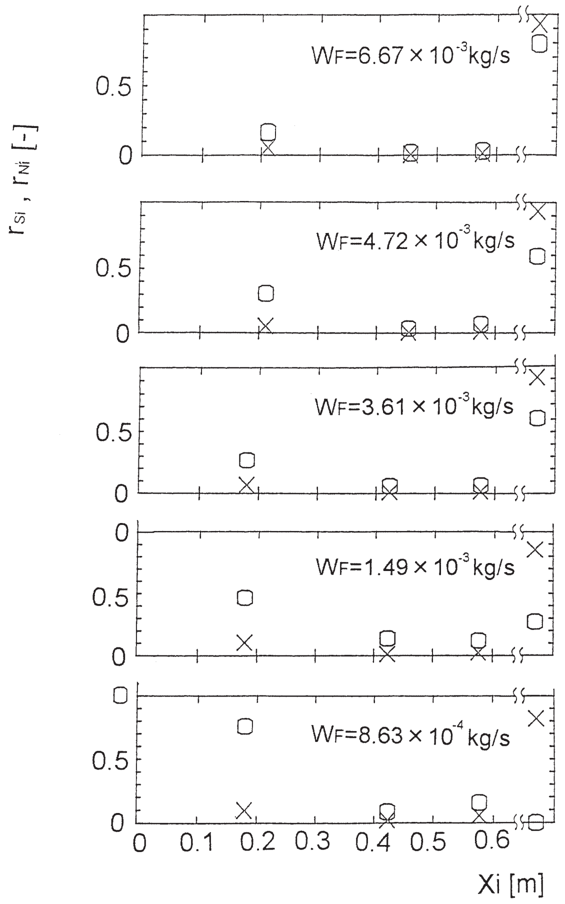

Fig. 6. Effect of the positions of the collection vessels on spherical and nonspherical particle recoveries in the vessel (*circles*, spheres; *crosses*, nonspheres; feed line 0.3 m)

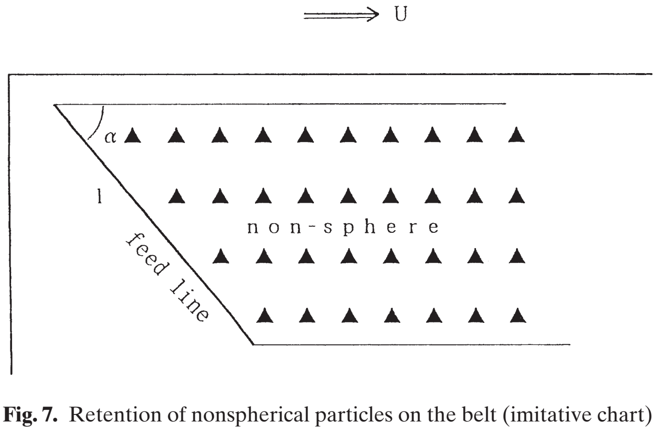

Fig. 7. Retention of nonspherical particles on the belt (imitative chart)

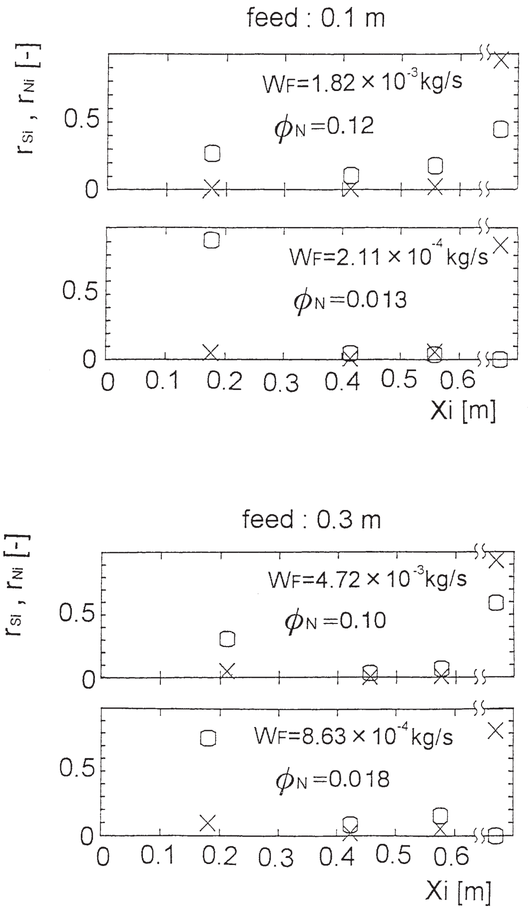

Fig. 8. Effect of space filled by nonspherical particles on spherical and nonspherical particle recoveries (*circles*, spheres; *crosses*, nonspheres)

interaction was determined by the proportion of nonspherical particles on the belt.

When the feed rate was 0.433×10^{-3} kg/s with a V-shaped trough, the movement of spherical particles was blocked by the nonspherical particles. As the feed method to the line feed was improved, it was possible to increase the quantity of material processed. As a result, good separation efficiency was maintained because the trajectories of spherical particles were not affected by the nonspherical particles. This can be seen by comparing Fig. 6 with Fig. 4, when the feed rate was 1.49×10^{-3} kg/s with a 0.3-m trough. The best conditions for separation should be determined after actual recovery performance has been ascertained.

We decided the space filling and the capacity of the treatment using a line-feed method. It was clear from our results that the improvement in the feed method was effective for large amounts of processed material.

Abbreviations

d_N	mean diameter of nonspherical particles (m)
l	length of feed line (m)
r_{Si}	recovery of spherical particles in vessel *i*
r_{Ni}	recovery of nonspherical particles in vessel *i*
r_{SP}	recovery of spherical particles in product
r_{NR}	recovery of nonspherical particles in residue
U	belt transportation velocity (m/s)
W_F	mass of feed per unit time (kg/s)
W_i	mass of particles recovered in vessel *i* per unit time (kg/s)
W_P	mass of products per unit time (kg/s)

W_R	mass of residues per unit time (kg/s)
x_F	mass fraction of spherical particles in feed
x_i	mass fraction of spherical particles in vessel *i*
x_P	mass fraction of spherical particles in products
x_R	mass fraction of spherical particles in residues
X_i	distance of vessel *i* in the *x*-direction from the feed point on the belt
α	angle between the feed line and the direction of belt movement
ϕ_N	space filled by nonspherical particles on the belt
η	Newton's separation efficiency
μ	friction coefficient
θ	angle of inclination of conveyer
ρ_N	density of nonspherical particles (kg/m^3)

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