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Establishment of a prediction model for the cut size of turbo air classifiers

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ABSTRACT

Cut size is one of the core indices for the classification performance of turbo air classifiers. It is directly affected by operation parameters, such as feeding speed, rotor cage rotary speed, and air inlet velocity. Under these considerations, this study presents a method for establishing a prediction model for the cut size of turbo air classifiers. The method is developed on the basis of a dimensionless equation to obtain an empirical formula for cut size. The calcium carbonate and talc powder classification experiments on a turbo air classifier are carried out to obtain training samples and testing samples. Then the prediction model is calculated by multiple-variable nonlinear regression based on training samples. The verification tests for both calcium carbonate and talc powder testing samples indicate that the predicted cut sizes are closer to the experimental results than the findings calculated according to the theoretical formula in other references. The influence of operation parameters on cut size is also determined using the prediction model. Cut size decreases with increasing rotor cage rotary speed and increases with increasing air inlet velocity. At a high feeding speed, the probability of particle aggregation increases with increasing solid concentration, thereby decreasing cut size. As indicated by the indices of the cut size prediction model, the air inlet velocity and rotor cage rotary speed distinctly influence cut size, whereas feeding speed exerts a negligible effect. The proposed modeling method can be used to establish prediction models for the cut sizes of the turbo air classifier, serving as foundation for regulating the operation parameters for classification.

1. Introduction

A turbo air classifier is the important equipment in powder preparation systems, finding extensive application in building materials, medicine, metallurgy, electronic materials, chemicals, and agriculture. The indices for the classification performance of turbo air classifiers include cut size, classification precision, Newton classification efficiency, and fine powder yield. Classified fine particles should satisfy the particle fineness and narrow particle size distribution necessary in modern engineering technology [1,2]. Thus, regulating the operation parameters for classification is crucial to producing powder that conforms to special customer requirements.

In ideal classification, particles with sizes less than d_{50} are collected by a classifier together with fine powders, whereas particles with sizes greater than d_{50} are collected together with coarse powders. Particles with sizes equal to d_{50} have a 50% probability of being collected together with either fine or coarse powders. In actual production and classification, d_{50} is often regarded as the standard particle size [3]. A cut size model can be obtained in two ways. One is by inferring a theoretical formula for cut size on the basis of aerodynamics [4–7]. That is, when the centrifugal force and radial air resistance applied to particles are balanced, the particles revolve along the cylindrical surface of a turbo air classifier. The particle size determined during this process is regarded as the cut size (d_{50}). To obtain the theoretical formula of cut size, researchers often assume minimal solid concentration and synergy among particles in the annular classification region. On the basis of these assumptions, the forces applied to a single particle in the annular classification region are then analyzed. Guo et al. [8] deduced the theoretical model of cut size in accordance with the analysis of the inner flow field of a turbo air classifier:

$$d_{50} = 3C_D\rho_a R v_r^2 / 4v_\theta^2 \rho_P \quad (1)$$

where C_D is the drag coefficient, R is the outer radius of the rotor cage, v_r is the radial velocity of air flow at the outer cylindrical periphery of the rotor cage, v_θ denotes the tangential velocity of air flow at the outer cylindrical periphery of the rotor cage, ρ_a represents air flow density, and ρ_P denotes particle density.

During actual classification, particle motion in the annular classification region is complicated. Particle collision, agglomeration, and other interactions among particles influence cut size. Researchers typically disregard these factors or fail to simplify them as coefficients in

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theoretical functions. Such neglect causes large discrepancies between theoretical and experimental results. Aimed at calculating actual cut size (in this study, “cut size” refers to the particle size at the point at which partial classification efficiency is 50%), multiple-variable nonlinear regression can be carried out to determine the empirical formula of cut size as another method. For example, as early as the 1990s, Onoda Cement Co., Ltd. in Japan obtained the empirical formula of O-Sepa on the basis of mass experimental data [9].

In fact, some disputes have occurred regarding the definition for “cut size”; thus, an accepted theoretical idea is that this unit of measurement should be the particle diameter calculated on the basis of aerodynamics. Some scholars attach importance to actual cut size, which is usually indicated as a 50% separating size in a fractional recovery ratio curve; this definition indicates that theoretically calculated cut sizes do not necessarily coincide with actual cut sizes, but that these values must exhibit a unified trend [10]. Therefore, the theoretical and experimental formulas of cut size can serve as theoretical bases for regulating and optimizing the operation parameters for particle classification. Several factors affect the classification performance of turbo air classifiers. Cut size changes with variations in the structural and operation parameters of a turbo air classifier. These parameters are interrelated. Although Onoda Cement Co., Ltd. developed the experimental formula of cut size by multiple-variable nonlinear regression, using this method to clearly identify the influence of operation parameters on cut size is difficult because of the complex coefficient in the experimental formula [11].

To model the relationship between cut size and the operation parameters of turbo air classifiers, a method for establishing a prediction model for the cut size of turbo air classifiers is developed. The method is developed on the basis of a dimensionless equation. The operation parameters are subjected to dimensional analysis and the structural parameters of a turbo air classifier, as well as the characteristic parameters of a representative raw material and fluid medium, are used to determine similarity parameters. In identifying such parameters, Buckingham's theorem is used as basis. Then, the dimensionless equation is subjected to multiple-variable nonlinear regression, with calcium carbonate and talc powder as the sample materials used in classification experiments. Then the cut size prediction model of turbo air classifiers for different materials can be constructed. The verification tests indicate that the predicted cut sizes are closer to the experimental results than the values calculated according to the theoretical formula. Moreover, there are goodness of fit of the prediction model for both calcium carbonate and talc powder testing samples. Finally, the influence of operation parameters on cut size is discussed according to the prediction model.

Table 1
Symbols and dimensions of the factors effecting classification via the turbo air classifier.

No.	Factor and index	Symbol	Dimension
1	Gravity acceleration	g	$[LT^{-2}]$
2	Cross-sectional area of air inlet	A_e	$[L^2]$
3	Cross-sectional area of fine powder outlet	A_f	$[L^2]$
4	Cross-sectional area of feeding inlet	A_g	$[L^2]$
5	Volute height	H	$[L]$
6	Inner radius of rotor cage	R_{zn}	$[L]$
7	Outer radius of rotor cage	R_{zw}	$[L]$
8	Outer radius of guide blades	R_{dw}	$[L]$
9	Inner radius of guide blades	R_{dn}	$[L]$
10	Installation angle of the guide blades	β	
11	Air density	ρ_a	$[ML^{-3}]$
12	Raw material density	ρ	$[ML^{-3}]$
13	Air viscosity	μ	$[ML^{-1}T^{-1}]$
14	Air inlet velocity	v	$[LT^{-1}]$
15	Rotor cage rotary speed	n	$[T^{-1}]$
16	Feeding speed	Q	$[MT^{-1}]$
17	Cut size	d_{50}	$[L]$
18	Pressure difference	$\triangle P$	$[ML^{-1}T^{-2}]$

2. Dimensionless equation

2.1. Factors that affect classification via turbo air classifier

The factors that affect classification via turbo air classifiers are the operation parameters, the structural parameters of turbo air classifiers, and the characteristic parameters of raw materials and fluid media (Table 1). Operation parameters include feeding speed, rotor cage rotary speed, and air inlet velocity. Structural parameters include the cross-sectional areas of feeding inlets, fine powder outlets, and air inlets, as well as volute height, the outer and inner radii of rotor cage, the outer and inner radii of guide blades, and the installation angles of guide blades. Guide blades are uniformly distributed along the circumference of a given circle (Fig. 1). The characteristic parameters of raw materials and fluid media are the density of raw materials, air density, and air viscosity. All these parameters are independent variables.

In Table 1, M, T, and L denote mass, time, and length, respectively; these parameters are called basic dimensions. Because some of the parameters in Table 1 are dimensionless, they are excluded from dimensional analysis and regarded as the similarity parameters of classification using turbo air classifiers. For convenience, the outer diameters of rotor cage R_{zw} and cut size d_{50} are used to represent length [L] and the cross-sectional area of the air inlet A_e is considered the dimension of the area $[L^2]$.

2.2. Similarity parameters of a turbo air classifier

The dimensionless parameters of a turbo air classifier can be simplified as

$$\pi = g^a {A_e}^b {d_{50}}^c \rho^d \mu^e v^f \Delta P^l Q^h {R_{zw}}^i n^j. \tag{2}$$

Among the 10 parameters, 7 similarity parameters $(10-3=7)$ are determined in accordance with Buckingham's theorem as follows [12]:

$$\pi = \left[LT^{-2}\right]^a \left[L^2\right]^b [L]^c \left[ML^{-3}\right]^d \left[ML^{-1}T^{-1}\right]^e \left[LT^{-1}\right]^f \left[ML^{-1}T^{-2}\right]^l \left[MT^{-1}\right]^h [L]^i \left[T^{-1}\right]^j. \tag{3}$$

The dimension matrix is shown in Table 2.

Given that the dimension of the π equation is 1, the following equations can be derived:

$$\begin{aligned} &d+e+l+h=0\\ &a+2b+c-3d-e+f-l+i=0\\ &-2a-e-f-2l-h-j=0. \end{aligned} \tag{4}$$

The indices h, i, and j of equation set (4) are expressed by other indices, thus:

$$\begin{aligned} &h=-d-e-l\\ &i=-a-2b-c+3d+e-f+l\\ &j=-2a+d-f-l. \end{aligned} \tag{5}$$

The coefficients of equation set (5) are taken as the items of the corresponding row in the π equation, and the other items are regarded as unit items (Table 3).