BEHAVIOR OF JET SUCKING CYCLONIC ULTRAMICRON CLASSIFIER①

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ABSTRACT

The jet sucking cyclonic ultramicron classifier is a new type ultramicron classification device with parallel nozzles and series diffusers. It has the advantages of forced dispersing particles and precise changeable cut-size classification. The experimental results showed that a minimum average classification size of 0.15 μm was obtained. The velocity field of the jet sucking cyclone was analysed and the theoretical equation for the cut-size was derived.

Key words: jet sucking cyclone classification

1 INTRODUCTION

Recently, the three developing tendencies of the classification technology have been ultramicronic classification, precise classification and energy-saving classification, of which the ultramicronic classification is one of the important subjects studied by the modern powder metallurgic processing. The ultramicron classifier has three types of structure, of which the cyclonic ultramicron classifiers have the common defect of small handling amount[1-5].

Being aimed at eliminating this defect, the authors developed a type of jet sucking cyclonic ultramicron classifier in 1991 by making full use of the characteristics of the aggregate flow of vortex and ring sink from the jet cyclone and suction, and the combination of parallel and series. Its performances of average classification size, cut-size adjustment and handling amount have been improved significantly compared with those in refs. [1—5]. An average size of 0.15 μm was obtained, and the handling amount was raised to 0.22～1.4 kg/h. To some extent, it can be put into practical use for ultramicronic classification with a cyclone.

2 STRUCTURE DESIGN OF SUCKING CYCLONIC ULTRAMICRON CLASSIFIER AND ITS WORKING PRINCIPLE

2.1 *Structure Design of Jet Sucking Cyclone*

A separator structure is adopted for each stage cyclone in the existing cyclonic classification devices. Just because of this the largest weakness of an existing classification device as a classifier is its difficulty in size adjustment. This structure also limits the increase of the cut-size and handling amount. Furthermore, no rapid forced dispersing measures in the existing cyclonic classification devices also influence the improve-

① Chinese manuscriupt received April 17, 1993; translated by Peng, Chaoqun and Wen, Qing

ment of classification rates.

The jet sucking cyclone is designed based on the principle that the aggregate flow of vortex and ring sink from the jet cyclone and suction leads to the rapid dispersing and forced classification of the powders. It is mainly composed of 1—sucking nozzle, 2—diffuser, 3—central exhauster, 4—cyclone and 5—collecting chamber (Fig. 1).

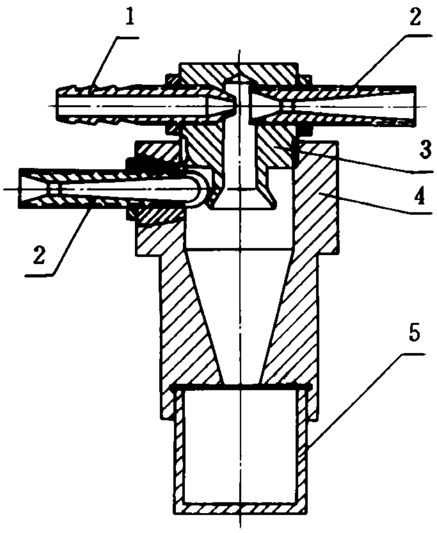

Fig. 1 A schematic diagram of a jet sucking cyclone

2. 2 *Working Principle of Jet Sucking Cyclone*

The ultramicrons were jetted into the diffusers by high-speed gas flow from the sucking nozzle, and were accelerated, mixed, diffused and dispersed there before being brought into the cyclone. The powder was classified by the aggregate field of forced vortex and ring sink from the sucking jet cyclone and suction in the cyclone. Coarse powder, in the presence of the gravity , falls into the collecting chamber along with the downward gas flow. Ultramicrons were exhausted from the central exhauster under the suction of the jet sucking gas flow.

The installment of the sucking nozzle, diffusers and central flared exhauster not only strengthens the accelerating, mixing and dispersing effects of the powder, but also increases the sucking force of the gas in the exha ster and makes the equilibrium point of the axial carring force capable of being adjusted in a larger range as well as intensifies the centrifugal force field thus improves the classification effect.

2. 3 *Structure Design and Working Principle of Jet Sucking Cyclonic Ultramicron Classifier*

Fig. 2 is a schematic diagram of the jet sucking cyclonic ultramicron classifier. It consists of 4 stages of jet sucking cyclones in series, and its main components are : 1—air compressor, 2—throttle valve, 3—filtration and decompression valve, 4—distributor, 5—rotor flowmeter, 6— regulator, 7— charging hopper, 8—electric vibrating feeder, 9—sucking feeder, 10—jet sucking cyclone group, 11— voltage modulation duster. The cyclone group are connected in diameter order from large to small, the sucking nozzles of each stage cyclone are connected in parallel with the corresponding regulators of the flowmeters; the diffusers of each stage cyclone are connected in series with the diffusers of its former stage. Thus the jet sucking cyclone group is made up by the way of the sucking nozzles in parallel and the diffusers in series.

In processing, the powder was added to the feeder; with the electric vibrating feeder for feeding speed control, the powder was jetted into the first stage cyclone by the sucking feeder and classified there, grade— 1 (coarse) micron powder was obtained in the collecting chamber; the micronic powder exhausted by the exit diffuser of the first stage cyclone were jetted into the second stage cyclone, and classified there, grade —

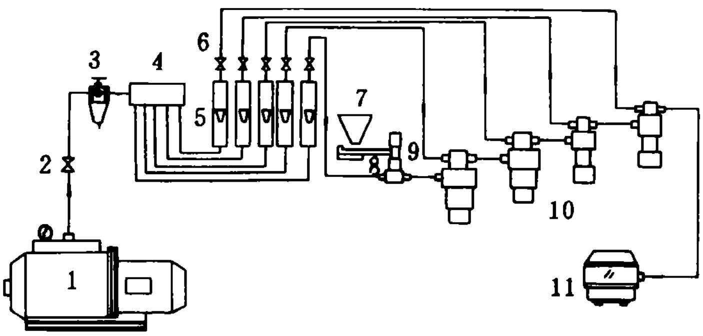

Fig. 2 A schematic diagram of jet sucking cyclonic ultramicron classifier

2 (relatively fine) micronic powder was obtained in the corresponding chamber; on the analogy of this, grade—3 (fine) and grade—4 (finer) ultramicrons were obtained.

In the voltage-modulation duster, grade—5 (finest) ultramicrons were collected from the ultramicrons exhausted by the exit diffuser of the 4th cyclone.

Due to the adoption of the structure of series diffusers and parallel sucking nozzles in the jet sucking cyclonic group, the cut-size of each stage can be regulated by changing jetting pressure of each stage cyclone and the sucking force of the duster.

3 ANALYSES OF THEORETIC CUT-SIZE OF JET SUCKING CYCLONE

3.1 *Analysis of Velocity Field*

With regard to the classification theory of the cyclone, the cut-size equation is generally established based on the method for the study of cyclonic separator, i. e. on the consideration of the equilibrium between the centrifugal force in the vortex field and the centripetal carrying force. But in our study, according to the flow characteristics of the jet sucking cyclone, the influences of the jet and suction on the classification flow field are further considered from the analysis of the flow relationship, the equations for calculating the pressures at the jet sucking nozzle exit and the central flared exhauster can be obtained as follows:

$$p_a = p_2 - \frac{8}{\pi^2}\rho Q_2^2\left(\frac{1}{d_a^4} - \frac{1}{d_2^4}\right) \qquad (1)$$

$$p_k = p_1 + \rho\left(\frac{\Gamma}{2\pi}\right)^2\left(\frac{2}{D^2} - \frac{2}{D_k^2}\right) \qquad (2)$$

where $\Gamma = 8Q_1R_pd_1^2$, then the flow rate at the flared exhauster is:

$$u_k = \left\{\frac{2}{\rho}(p_1 - p_2) + \left(\frac{\Gamma}{\pi}\right)^2 \times \left(\frac{1}{D_k^2} - \frac{1}{D^2}\right) + \left(\frac{4}{\pi}\right)^2\left(\frac{Q_2^2}{d_a^4} + \frac{Q_1^2}{d_0^4} - \frac{Q_2^2}{d_2^4}\right)\right\}^{1/2} \qquad (3)$$

and the radial velocity u_{kr} at the flared exhauster is in direct proportion to u_k, i. e. $u_{kr} = \lambda u_k$.

According to its flow characteristics, the central exhauster can be taken as a ring sink with a height of h, thus the radial velocity of the jet sucking cyclone can be derived as:

$$u_r = \frac{\lambda D_k}{2r} \times \left[\frac{2}{\rho}(p_2 - p_1) + \left(\frac{2Q_1R_p}{\pi d_1^2}\right)^2\left(\frac{1}{D_k^2} - \frac{1}{D^2}\right) + \left(\frac{4}{\pi}\right)^2 \times \left(\frac{Q_2^2}{d_k^4} + \frac{Q_1^2}{D_0^4} - \frac{Q_2^2}{d_2^4}\right)\right\}^{1/2} \qquad (4)$$

According to the flow characteristics of the tangential jet from the diffusers in the cyclone, it can be taken as a planar vortex, thus the tangential velocity of the jet sucking cyclone can be derived as:

$$u_\theta = \frac{4Q_1R_p}{\pi d_1^2}\frac{1}{r} \qquad (5)$$

3.2 *Theoretical Cut-size*

In consideration of the above flow characteristics, according to the equilibrium of the centrifugal force and radial carrying force of the gas flow, exerted on the particles, the equation of the theoretical cut-size of the jet sucking cyclone can be established as:

$$d_k = K(ud_1^4D_kD^2)^{1/2} \times [\frac{2}{\rho}(p_1 - p_2) + (\frac{2Q_1R_p}{\pi d_1^2})^2(\frac{1}{D_r^2} - \frac{1}{D^2})(\frac{1}{D_k^2} - \frac{1}{D^2}) \times (\frac{4}{\pi})^2(\frac{Q^2}{d_2^4} + \frac{Q^2}{D_2^4} - \frac{Q_2^2}{d_2^4})]^{1/4} \div [(\rho_p - \rho)Q_1^2R_p^2]^{1/2} \qquad (6)$$

where $K = 3\pi m\sqrt{\lambda}/8$; m is the cut-size coefficient connected with cut-size passing ratio $(0.5 \leqslant m < 1)$; λ is a velocity coefficient connected with the jet rate and flow capacity of the diffusers $(0 < \lambda < 1)$.

When the cut-size of any stage jet sucking cyclone is calculated, Q_1 in equation (1) is the total jet flow capacity of the former stages.

4 TESTS AND ANALYSES OF JET SUCKING CYCLONIC ULTRAMICRON CLASSIFIER

4.1 *Experimental Equipment and Conditions*

A cyclone group with cyclones of four diameter specifications of d50, 44, 40, 36 mm, was studied. The experimental conditions were as follows: pressure = 0.14 ~ 0.45 MPa, flow capacity = 0.113 ~ 0.4 Nm^3/min, and handling amount = 0.22 ~ 1.4 kg/h. The jet pressure is controlled by the pressure regulator the jet flow capacity of each stage by the rotor flowmeter; the system sucking force by the voltage-modulation duster, and the handling amount by the electric vibrating feeder. The equipment is shown in Fig. 2.

Five kinds of ultramicrons were selected for test and their parameters are listed in Table 1.

Table 1 Experimental ultramicrons

powder	density /g. cm^{-3}	size range /μm	d_{50} /μm	viscosity
graphite	2.2	0.1~15.0	1.50	relatively weak
light calcium carbonate	2.6	0.1~8.0	0.88	strong
siliceous rock	2.65	0.08~8.0	1.19	relatively strong
quartz	2.66	0.05~5.0	0.54	ordinary
alumina	3.95	0.1~10.0	5.44	weak

4.2 *Experimental Results*

The above powder having been classified, 4 or 5 grades of ultramicrons were obtained and the size distribution determined by a MICRON SIZER are shown in Figs. 3 ~ 6.

4.3 *Interrelation Analysis*

(1) The classification results of the graphite (handling amount = 0.38 kg/h) showed: for stage A cyclone, d_{50} = 0.31 μm and 60% of the particles have size of 0.25 ~ 0.8 μm; for stage B, d_{50} = 0.49um, and 80.1% of 0.4 ~ 1.0 μm; for stage C, d_{50} = 0.81 μm, and 77.8% of 0.7 ~ 1.5 μm; for level D, d_{50} = 1.7 μm, and 65.1% of 1.0 ~ 6.0 μm. The reason for the wider size distribution range of stage D, i.e. the first stage, is that the first stage plays the role of primary selection and classifies most of the particles larger than 1 μm, then sup-

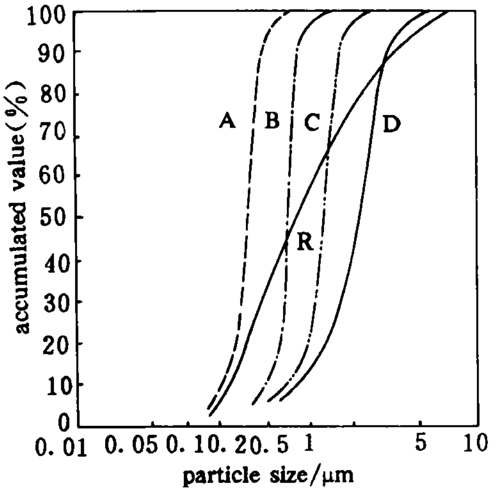

Fig. 3 **Classification size distribution of graphite**

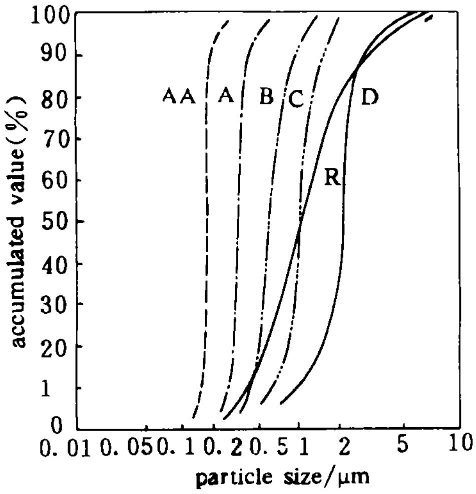

Fig. 5 **Classification size distribution of siliceous rock**

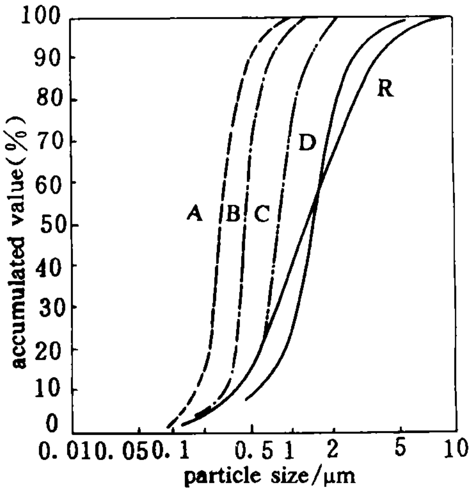

Fig. 4 **Classification size distribution of light calcium carbonate**

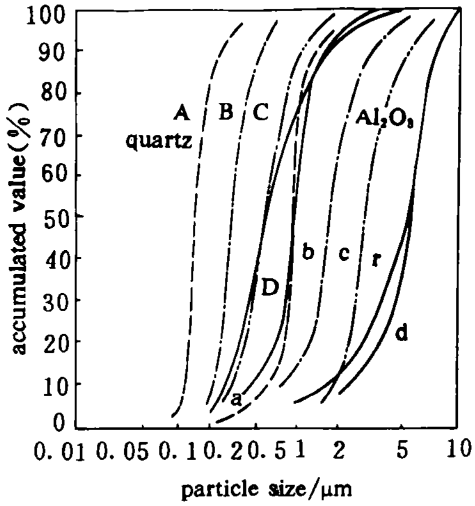

Fig. 6 **Classification size distribution of quartz and alumina**

plies the later stages with ultramicrons for precise classification.

(2) The classfication results of the light calcium carbonate (handling amount $=0.22$ kg/h) showed: for stage A cyclone, $d_{50}=0.39$ μm, and 87.8% of 0.25~0.8 μm; for stage B, $d_{50}=0.73$ μm, and 85.0% of 0.6~1.4 μm; for stage C, $d_{50}=1.44$ μm, and 83.6% of 1.0~3.0 μm; for stage D, $d_{50}=2.23$ μm, and 53.9% of 2.0~6.0 μm.

(3) The classification results of the siliceous rock (handling amount $=0.35$ kg/h) showed: for stage AA duster, $d_{50}=0.19$ μm, and 87.8% of 0.15~0.2 μm; for stage A duster, $d_{50}=0.65$ μm, 64.2% of 0.6~1.1 μm; for stage C duster, $d_{50}=1.06$ μm, and 68.3% of 1.0~1.8 μm; for stage D duster, $d_{50}=2.18$ μm, and 86.6% of 1.5~5.0 μm.

(4) The classification results of the quartz (handling amount = 0.48 kg/h) showed: for stage A cyclone, d_{50}= 0.15 μm, and 74.1% of 0.12 ~ 0.2 μm; for stage B, d_{50} = 0.3 μm, and 82.4% of 0.2 ~ 0.6 μm; for stage C, d_{50} = 0.56 μm, and 72.1% of 0.4 ~ 1.0 μm; for stage D, d_{50} = 0.77 μm, and 54.8% of 0.8 ~ 3 μm.

(5) The classification results of the aluminga (handling amount = 1.4 kg/h) showed: for stage A cyclone, d_{50} = 0.92 μm, and 70 of 0.6 ~ 1.0 μm; for stage B, d_{50} = 1.79 μm, and 82.0% of 1.0 ~ 3.0 μm; for stage C, d_{50} = 3.68 μm, and 73.8% of 3.0 ~ 6.0 μm; for level D, d_{50} = 6.02 μm, and 67.5% of 4.0 ~ 8.0 μm.

(6) The designed and experimental parameters being substituted into equation (6), the theoretical cut-size for each stage cyclone was obtained, and their comparison with the experimental data was shown in Fig. 7. From Fig. 7, it is evident that the theoretical values are constantly smaller than the experimental ones. This is caused by the negligence in the theoretical analysis of the obstruction effect of the powder concentration and the cyclonic wall surface on the gas and solid flow, and the adherence of the powders.

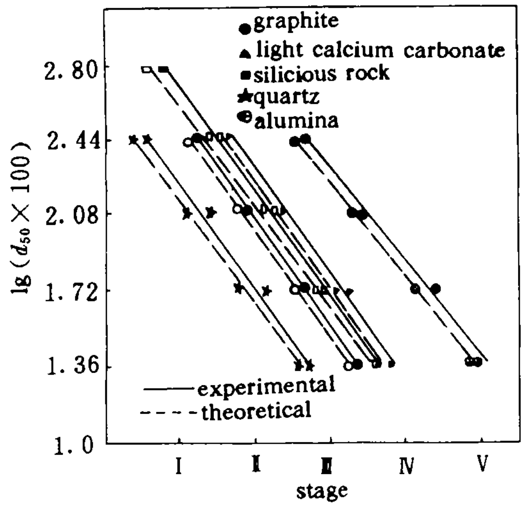

Fig. 7 Comparison between theoretical classification cut-sizes and experimental data

(7) The comparisons of the classification effects were shown in Fig. 8 between the jet sucking cyclonic ultramicron classifier and the multi-stage cyclone developed by Southern Institute of the Enviromental Protection Bureau of America, the multi-stage cyclone by ToKyo University of Japan, and the multi-segment classifier by Northeastern University of China.

It is evident that the minimum classification size of the jet sucking cyclonic ultramicron classifier for the classification of ultramicrons is decreased by more than 67.6%.

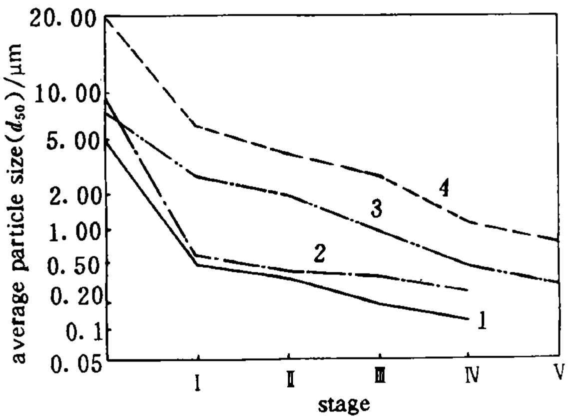

Fig. 8 Comparision of classification effects between several cyclonic classifier

1—The jet sucking cyclonic ultramicron classifier developed by the authors; 2—The multi-stage cyclone developed by Tokyo University of Japan; 3— The multi-stage cyclone develoved by the Southern Institute of the Enviromental Protection Bureau of America; 4— The multi-segment classifier developed by Northeastern University of China

5 CONCLUSIONS

(1) The jet sucking cyclone, designed by making full use of the characteristics of the aggregate flow of vortex and ring sink from the jet cyclone and the suction , and

the adoption of parallel nozzles and series diffusers, can significantly improve the performances of the multi-stage cyclone group in cut-size, size adjustment and handling amount, and reach practical effects of precise classification for ultromicrons to some extent.

(2)An equation for calculating theoretical cut-size of the jet sucking cyclone was established.

(3) 4-or 5-stage classifications with a handling capacity of 0.22～1.4 kg/h can be made simultaneously for the ultramicrons (0.15～5 μm) by the jet sucking cyclonic classifier.

(4) The jet sucking cyclonic ultramicron classifier can decrease the minimum average size to 0.15 μm from 0.34 μm which has been reached by the existing multi-segment type cyclones. Therefore, it is of obvious effect and considerable significance.

Symbols

d_1, d_2, d_3—the cross-section diameters of the diffuser exit, the nozzle entrance and exit;

D_1, D_k, D_0—the diameters of the cyclone the flared exit and shaft of the exhauster;

K, m—the cut-size coefficient and cut value coefficient;

P_1, P_2—the pressures at the extrances of the diffuser and the nozzle P_a;

P_a, P_k—the pressures at the nozzle exit and the flared exit of the exhauster, Pa;

Q_1, Q_2—the volumetric flow capacity of the diffuser and the nozzle, m^3/min;

u_k—the velocity at the flared exit of the exhauster;

U_r, U_Q—the radial and tangential velocities of the cyclonic flow field, m/s;

Γ—the velocity circulation of the cyclonic vortex field;

λ—the velocity efficiency of the gas force radius;

μ—the dyamic gas viscosity;

ρ, ρ_p—the densities of the gas and the particles.

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