SEPARATION CHARACTERISTICS OF THE HYDROCYCLONE WITH A CENTRAL CONE AND ANNULAR TEETH[①]

Chu Liangyin, Chen Wenmei
Department of Chemical Processing Machinery, Sichuan Union University, Chengdu 610065
Luo Qian
Department of Mineral Engineering, Northeastern University, Shenyang 110006

ABSTRACT A new hydrocyclone with a central cone and a vortex finder attachment has been developed by the authors recently, and it is shown that the sharpness of separation of this new hydrocyclone is higher than that of the conventional one. In this paper, a series of experiments were carried out to further investigate the performance of this new hydrocyclone. The results showed that in all cases the sharpness of separation, flowrate ratio of underflow to feed, cut size and overall separation efficiency of the new hydrocyclone were larger than those of the conventional one. The effects of geometric parameters and position of the central cone on the hydrocyclone performance were also reported.

Key words hydrocyclone central cone annular teeth separation sharpness classification efficiency separation characteristics

1 INTRODUCTION

Hydrocyclones are finding more and more applications in industry because of their obvious advantages such as simple structure, large capacity and small volume. However, the sharpness of separation of a hydrocyclone is not high even under the best circumstances because of the mixing of coarse particles with fine particles in the products. This is due to the flow characteristics in hydrocyclones. In a hydrocyclone, there mainly exist outer helical flow, inner helical flow, circulation flow and short circuit flow. It is well known that the short circuit flow brings some coarse particles directly into overflow without any separation, indicating that cutting down or even dispelling the short circuit flow is beneficial to improve the sharpness of separation of a hydrocyclone. And, because of the existence of the turbulence and the boundary layer flow on the wall inside a hydrocyclone, some fine particles discharge with underflow, resulting in the drop of the separation sharpness.

Based on the above thinking, many efforts were made to develop efficient hydrocyclones with some new structures in order to change the flow characteristics of the conventional ones, e.g. water-injected[1] and air-sparged hydrocyclones[2] were developed to interrupt the boundary layer flow in order to diminish the fine particle content in underflow, and a hydrocyclone with a solid core[3] and a thick-wall vortex finder[4] was developed to stabilize the tangential flow and to cut down the short circuit flow in order to diminish the mixed extent of coarse particles with fine particles in products, etc. Although more efficient than conventional hydrocyclones in the experimental studies, these hydrocyclones have not yet been widely used in full plant-scale industries because of a variety of rea-

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sons. Thus it is necessary to further develop new hydrocyclones with simple structure and high efficiency that can be easily popularized in industry.

Recent experimental research on the motion of the solid particles in a hydrocyclone[5-7] showed that some particles in the inner helical flow moved towards the wall in the cylindrical section, indicating that some coarser particles in the inner helical flow can still be separated in the cylindrical section before they enter the vortex finder. Therefore expediting the centrifugal settlement of the particles in the inner helical flow in cylindrical section is beneficial to improve the sharpness of separation of a hydrocyclone. Based on this thought, a new hydrocyclone with a central cone and vortex finder attachment was developed by the authors[8], and preliminary investigation showed that the sharpness of separation of the new hydrocyclone is higher than that of the conventional one[9].

In this paper, a series of experiments were carried out to further investigate the performance of this new hydrocyclone, and the effects of geometric parameters and position of the central cone on the performance were also reported.

2 EXPERIMENTAL

2.1 Experimental program

Both the conventional and the new hydrocyclones were employed in the experiment in order to compare their different separation performances. The experiments of the new hydrocyclones with different central cones were arranged according to the orthogonal design.

The solid particles used in the experiments were made of quartz with density of 2 650 kg/m^3. The particle size distribution is given in Table 1. The liquid phase was water. The concentration of the feed slurry was 10 percent by weight. And, the inlet pressure was selected as 80kPa. In all the experiments, the operation parameters and the feed characteristics were kept constant.

Table 1 Size distribution of the particles in feed

Particle size/ μm	Percentage/ %
- 5	1.71
+ 5- 10	0.84
+ 10- 20	2.55
+ 20- 30	3.86
+ 30- 40	3.56
+ 40- 50	4.26
+ 50- 60	6.15
+ 60- 80	6.51
+ 80- 100	6.95
+ 100- 125	14.73
+ 125- 154	23.11
+ 154- 180	11.94
+ 180- 250	12.16
+ 250	1.67
Total	100.00

2.2 Apparatus

The geometry of the hydrocyclone employed in the experiment is shown in Fig. 1. The vortex finder attachment was designed with several annular teeth fixed outside the vortex finder wall, whose geometry is shown in Fig. 2. The central cone, whose axis was the same as that of the hydrocyclone, was a solid cone with two opposite cones, and was located near the interface of the conical and the cylindrical sections of the hydrocyclone. Both the shape and the axial location of the central cone were changed in the experiment, as shown in Fig. 3 and Table 2, in order to investigate the influence of central cones of various dimensions and positions on the hydrocyclone performance.

3 RESULTS AND DISCUSSION

3.1 Flowrate ratio of underflow to feed

The influences of the vortex finder attachment and the dimension of the central cone on the flowrate ratio of underflow to feed(U/F) are shown in Fig. 4. It is obvious that the flowrate ratio of U/F in the new hydrocyclone is larger than that in the conventional one. Firstly, the vortex finder attachment makes the flowrate ratio of U/F increase, because the annular teeth prevent the short circuit flow forming on the outside wall of the vortex finder, which indicates that the annular teeth are effective on cutting down the short circuit flow. Secondly, the larger the diameter of the central cone, the larger the flowrate ratio of U/F. The reason is that, the larger the diameter of the central cone, the more the part of inner helical flow forced into circulation flow, which shows that the diameter of the central cone should not be too large.

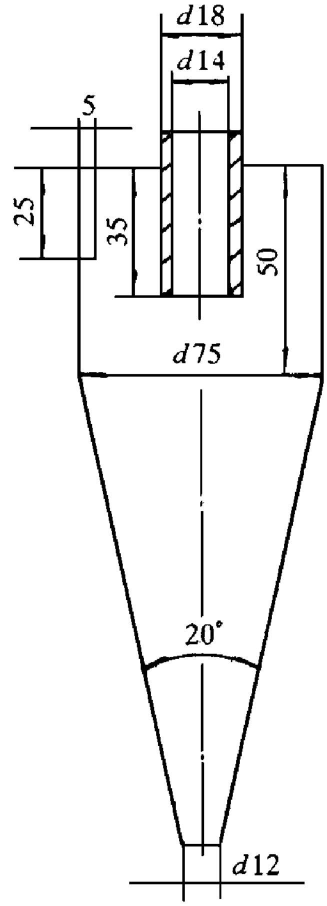

Fig.1 Geometry of the hydrocyclone

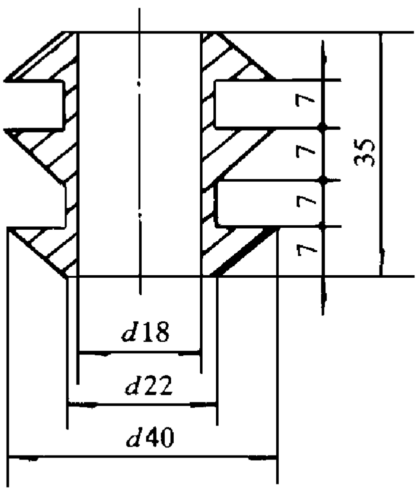

Fig. 2 Geometry of the vortex finder attachment

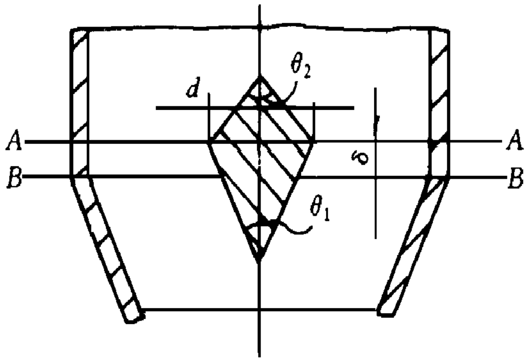

Fig.3 Parameters of the central cone

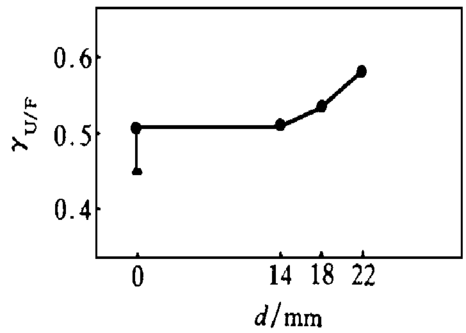

Fig. 4 Effects of the vortex finder attachment and the diameter of the central cone on the flowrate ratio of U/F($r_{U/F}$)

(d = 0 stands for no central cone)

▲ —without vortex finder attachment;

● —with vortex finder attachment

Table 2 Geometry and location parameters of the central cones

No.	Diameter d/mm	Lower angle θ_1/(°)	Upper angle θ_2/(°)	Axial position δ/mm
1	14	30	60	-5
2	14	60	120	0
3	14	90	180	5
4	18	30	120	5
5	18	60	180	-5
6	18	90	60	0
7	22	30	180	0
8	22	60	60	5
9	22	90	120	-5

Note: Axial position $\delta > 0$ indicates that the line *A*-*A* is located above the line *B*-*B* in Fig. 3, while $\delta < 0$ indicates that the line *A*-*A* is located below the line *B*-*B*.

3.2 Cut size

The grade efficiency curves of separation of the conventional and the new hydrocyclones are shown in Fig. 5. It can be found that the cut size of the new hydrocyclone is larger than that of the conventional one due to the decrease of the content of fine particles in underflow, indicating that, to get the same cut size, the diameter of the new hydrocyclone should be smaller than that of the conventional one.

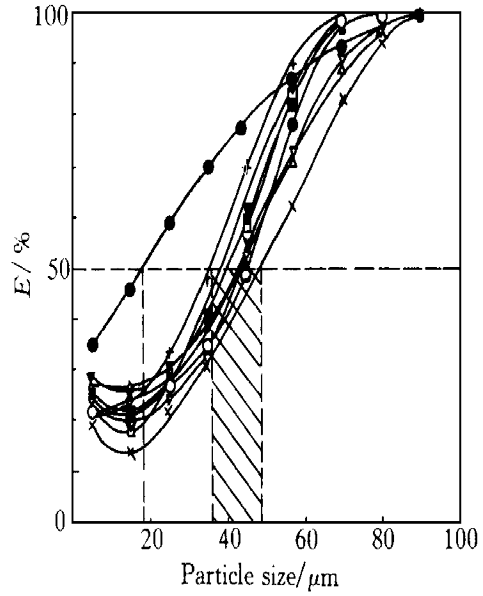

Fig. 5 Grade efficiency(*E*) curves of separation of the conventional and the new hydrocyclones

● —conventional hydrocyclone;
○, ▲, △, ▼, ▽, + , ×, ■, □ —new hydrocyclones with central cones No. 1~ No. 9

3.3 Sharpness of separation

The sharpness of separation is defined as the ratio of two particle diameters corresponding to 35% and 65% on the grade efficiency curve[9], i. e.

$$K = d_{35}/d_{65} \tag{1}$$

From Fig. 5 we can draw a conclusion that the sharpnesses of separation of all the new hydrocyclones are higher than that of the conventional one.

Fig. 6 shows the grade efficiency vs d/d_{50} for the conventional and the new hydrocyclones, from which the above conclusion can be seen more obviously.

The effects of the dimensions and positions of central cones on the sharpness of separation are shown in Fig. 7, from which some conclusions can be drawn as the following: (1) the diameter of the central cone affects the sharpness of separation lightly; (2) the four parameters can be arranged in the following order according to the degree to which they affect the sharpness of separation: $\theta_1 > \delta > \theta_2 > d$; (3) the optimum lower angle is 60°, and the optimum upper angle is 120°; and (4) the lower the axial position of the central cone, the higher the sharpness of separation. It is necessary to carry out more experiments to determine the optimum axial position of the central cone.

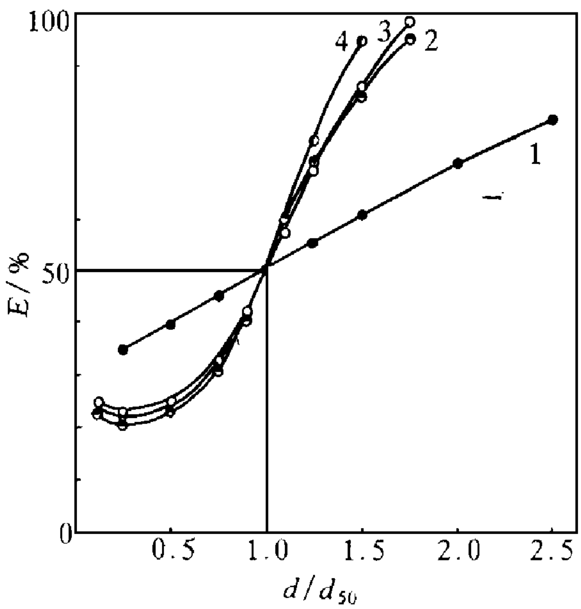

Fig. 6 Grade efficiency vs d/d_{50} for the conventional and the new hydrocyclones

1 —conventional hydrocyclone;
2, 3, 4 —new hydrocyclones with central cones No. 5, No. 8 and No. 2

3.4 Separation efficiency

The overall separation efficiency of the new hydrocyclone is always higher than that of the conventional one, as shown in Fig. 8. This is due to the enlargement of the flowrate ratio of U/F within the new hydrocyclone. From Fig. 8 it can also be found that central cones No. 5 and No. 8 correspond to two highest overall efficiencies, which indicates that the optimum lower angle of central cone of the new hydrocyclone for solid-liquid separation is 60°.

4 CONCLUSION

The new hydrocyclone with a central cone and annular teeth has been demonstrated to be

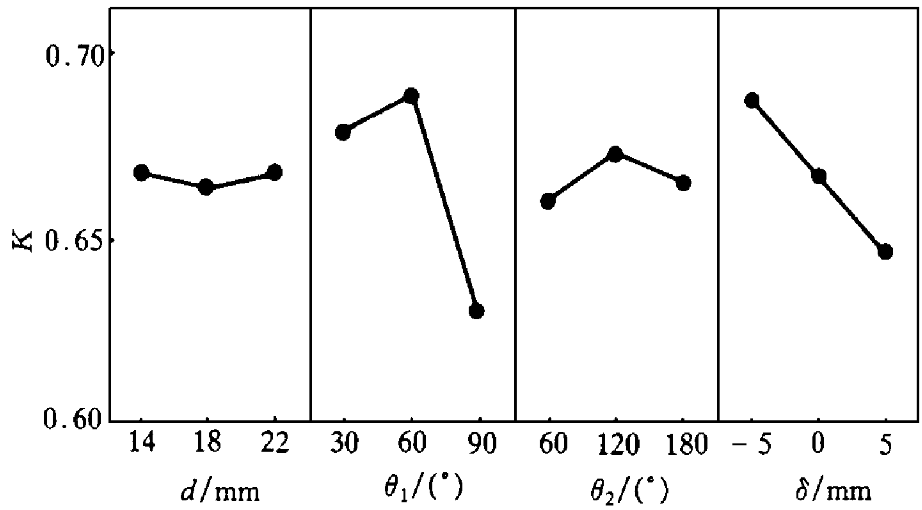

Fig. 7 Effects of dimensions and positions of central cones on the sharpness of separation(K)

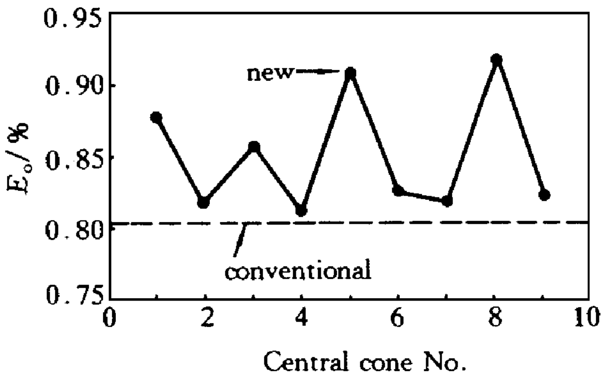

Fig. 8 Overall separation efficiencies(E_o) of the conventional and the new hydrocyclones

efficient to improve the particle separation. The annular teeth outside the vortex finder wall can effectively cut down the short circuit flow, and the central cone can obviously increase the sharpness of separation. The flowrate ratio of underflow to feed, sharpness of separation, cut size and overall separation efficiency of the new hydrocyclone are all larger than that of the conventional one. This new hydrocyclone with simple structure can be applied to improve both classification and solid-liquid separation.

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