Memoirs of the Faculty of Engineering, Okayama University, Vol. 33, No.2, pp. 19-24, March 1999

Small Type Hydrocyclone with a Perforated Inner Cylinder

Kyoji YAMAMOTO*, Xuecheng JIAO** and Xuezhen JIAO***

(Received March 1 , 1999)

A new type of hydrocyclone with a perforated inner cylinder is tested experimentally to study its performance for liquid-solid separation. The size of the cyclone is small so that it may be effective for small particle separation. Two types of the inner cylinder were made : the one has 39.5% void fraction of the perforated surface and the other has 73.5%. The mean particle diameter is 4.5 μ m.

It is found that the pressure loss of the cyclone with the inner cylinder is reduced by about 25% compared with that of the ordinary type. The new type cyclone has better separation efficiency.

1. INTRODUCTION

The hydrocyclone is one of the simplest devices to separate materials contained in the liquid. The materials may be particles of solid, bubbles of gas or an immiscible liquid. The size of solid particles to be separated is usually larger than several tens micro meter for a medium size of the cyclone, and is smaller for very small cyclone. The cyclone will find a lot of applicability in various fields of industry if it separates solid particles whose size is of several microns or even of sub microns. The wast water treatment contaminated by small particles is one of the important applications of such cyclone to keep the natural environment clean. The improvement of efficiency of the cyclone in pressure loss as well as in separation efficiency is also important to reduce the energy consumption. In this respect, it is useful and necessary to construct a hydrocyclone which has good separation efficiency and less pressure loss for small particles.

In previous studies [(1)～(4)] , we proposed a new type of cyclone with a perforated inner cylinder and tested its performance. We found that this shows a good performance. The separation efficiency is improved andthe pressure loss is greatly decreased compared with an ordinary cyclone without an inner cylinder. The hydrocyclone examined [(4)] was of medium size and considered for a medium particle size ; actually it was tested for particle of 45 μ m average size. In the present study, we make a small size hydrocyclone with a perforated inner cylinder. The small size cyclone is generally efficient for small particles. We shall examine the performance of the cyclone for particle of

---

* Department of Mechanical Engineering
** The Graduate School of Natural Science and Technology
*** Institute of Harbin Architectural and Civil Engineering

4.5 μ m average diameter.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows a schematic diagram of the experimental apparatus. The water containing small solid particles is mixed uniformly by a mixer ⑦ in a tank ①, and is fed into the hydrocyclone ③ by a pump ② through the float type area flow meter ⑧ and the pressure gauge ⑩. The overflow discharge from the cyclone flows into a tank ⑤ and the underflow discharge is led to a tank ④. The flow rate is adjusted by the valve ⑨. The pressure difference before and after the cyclone (points A and B) is measured by the pressure gauge ⑩ and the manometer ⑪. Here, the length La is 120 mm and Lb is 100 mm. The flow meter ⑧ was used as a reference and actually the flow rate through the cyclone was obtained by measuring the flow rates of the underflow and overflow discharges.

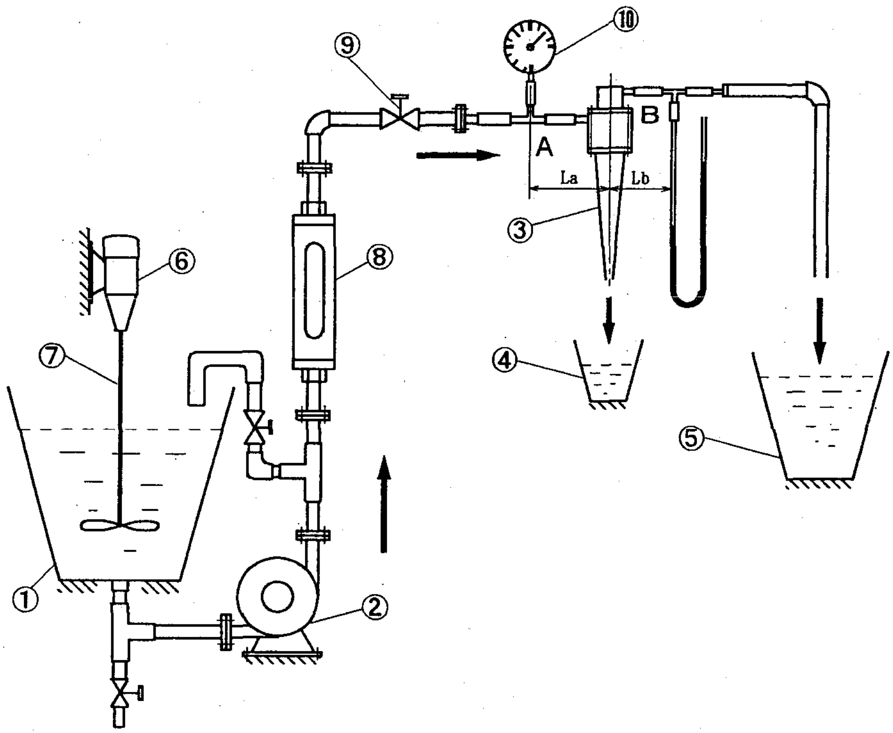
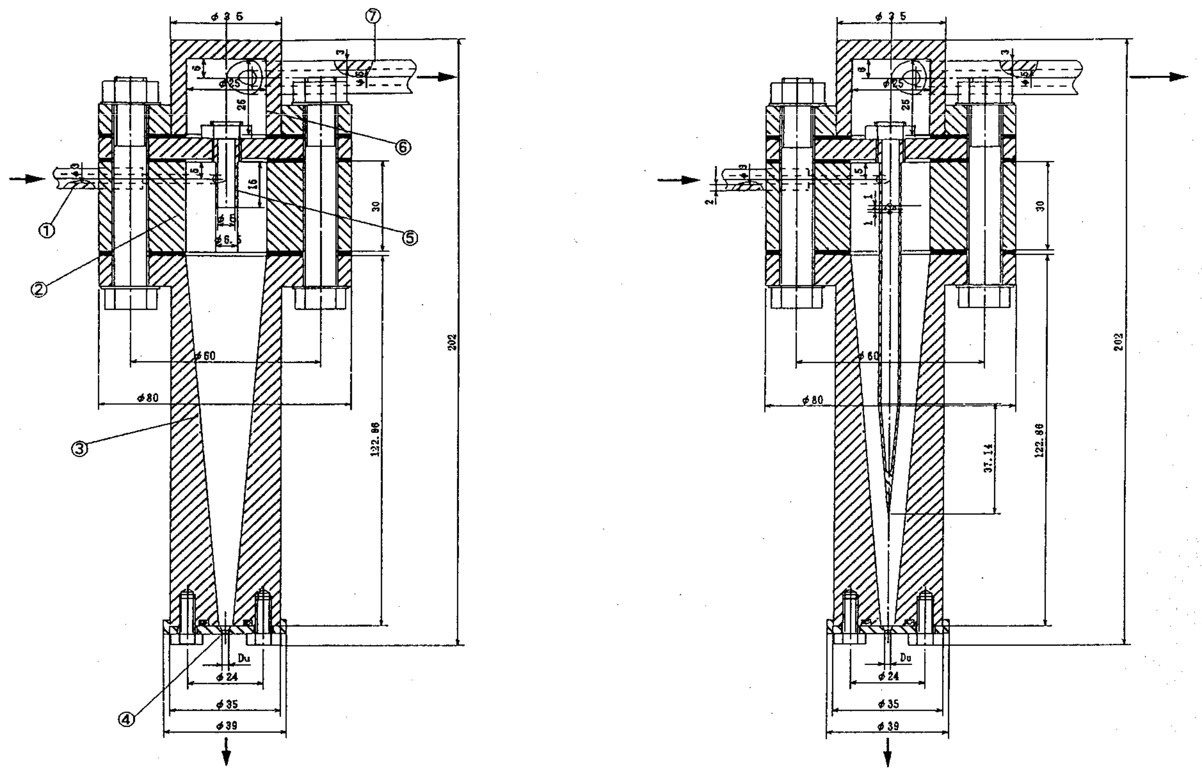


Fig. 1 Experimental apparatus

Figure 2 shows the hydrocyclone used in the present study. Figure 2 (a) is an ordinary type and 2 (b) shows the new cyclone which has a perforated inner cylinder within the ordinary type cyclone. The diameter of the inner cylinder is the same as that of the overflow pipe ⑤ in Fig.2 (a). We made two types of the inner cylinder. The type I has 39.5% void fraction of the perforated surface, while type II has 73.5% void fraction. Three different diameter of the underflow exit were used , i.e. Du=1.5, 2.5 and 3.5 mm..

3. PARTICLE SIZE DISTRIBUTION

The particle used in the present experiment is kaolin. The mean diameter is 4.5 μ m and the density of a particle is 2.5×10^3 [kg/m^3]. The weight distribution versus particle diameter is shown in Fig.3. The water is used as an operating liquid. The weight concentration of solid in water is 0.4%.



① Feed inlet ② Cylinder section ③ Conical section ④ Underflow orifice ⑤ overflow pipe
⑥ Overflow chamber ⑦ Overflow exit

(a) Ordinary cyclone (b) Cyclone with inner cylinder

Fig.2 Structure of hydrocyclone

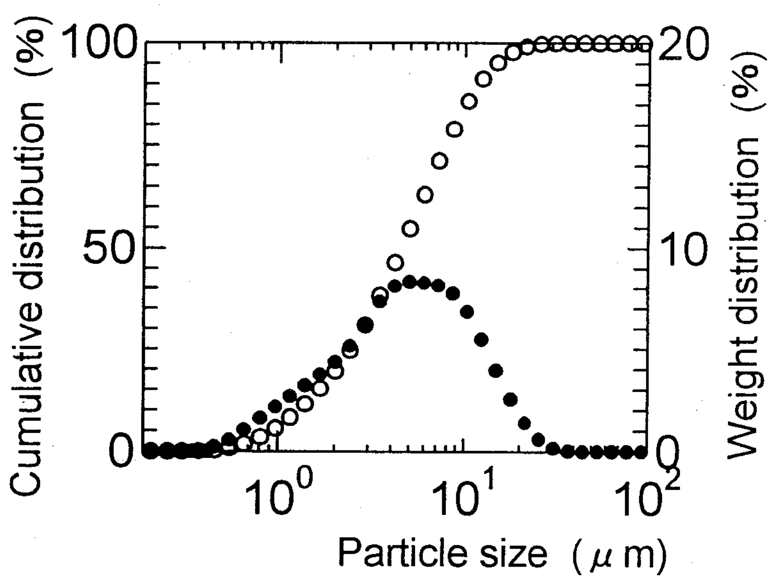


Fig. 3 Weight distribution of feed particle

Table 1 Symbols

type	D_u(mm)	symbol
O	1.5	○
	2.5	□
	3.5	△
I	1.5	●
	2.5	■
	3.5	▲
II	1.5	*
	2.5	×
	3.5	+

4. RESULTS OF EXPERIMENT

We obtained the pressure loss between A and B in Fig.1, i.e. before and after the cyclone. The separation efficiency of the solid particle is also obtained. We first define the Reynolds number Re as

$$Re = D_i V_i / \nu , \tag{1}$$

where V_i is the velocity at the inlet of the cyclone, D_i is the diameter of the inlet pipe and is 3mm in the present experiment, and ν is the kinematic viscosity of water. The Reynolds number in the present experiment was $0.3 \sim 0.7 \times 10^5$. The coefficient of pressure loss ξ in the cyclone is defined by

$$\xi = 2(P_0 - P_2)/(\rho V_i^2), \tag{2}$$

where P_0 and P_2 are the pressures at A and B in Fig.1, respectively, and ρ is the density of water. Further, we define the separation efficiency η :

$$\eta = G_1/G_0, \tag{3}$$

where G_0 is the feed solid rate in the upstream flow and G_1 is the solid rate in the underflow. The centrifugal efficiency η_c defined by [5]

$$\eta_c = \frac{G_1/G_0 - H_1/H_0}{1 - H_1/H_0} \tag{4}$$

is also used. Here, H_0 is the flow rate to the cyclone and H_1 is the flow rate of the underflow, i.e. H_1/H_0 is the flux ratio of the underflow. The centrifugal efficiency indicates the cyclone effect on separation mechanism. Table 1 shows the symbols expressing the data in Figs.5 and 6 to follow. The blank mark is for the ordinary cyclone, the filled mark is for type I, and other mark is for type II.

4.1 Flow Pattern

The most striking difference of the flow between new and ordinary cyclones is near the center of the cyclone. The ordinary cyclone generally has an air core which is connected with the atmosphere through the downflow exit and continues to the overflow pipe. The new cyclone with an inner cylinder, on the other hand, has no air core. Partly because of removal of air core, the flux ratio H_1/H_0 of new type is larger than that of the ordinary cyclone.

4.2 Pressure Loss

Figure 4 shows the pressure loss coefficient ξ versus the inlet velocity V_i. It will be seen that ξ is almost constant over V_i for the new type cyclone. This means that the pressure loss is proportional to V_i^2. The pressure loss of type II is the least of three, and the second one is type I. The ordinary type has the worst pressure loss. This is almost 1.5 times as large as type II. The inner cylinder seems to hinder the smooth flow to the overflow pipe and hence it would induce a large pressure loss. However, actually this is not so. The inner cylinder removes the inner air core which usually appears in an ordinary hydrocyclone. This core is caused by the low pressure at the center of the cyclone where otherwise the forced vortex prevails. Therefore, the inner air core is accompanied with the low pressure in the cyclone and produces the high pressure loss.

4.3 Separation Efficiency

The separation efficiency η of solid particles is shown in Fig.5. It will be seen that type II

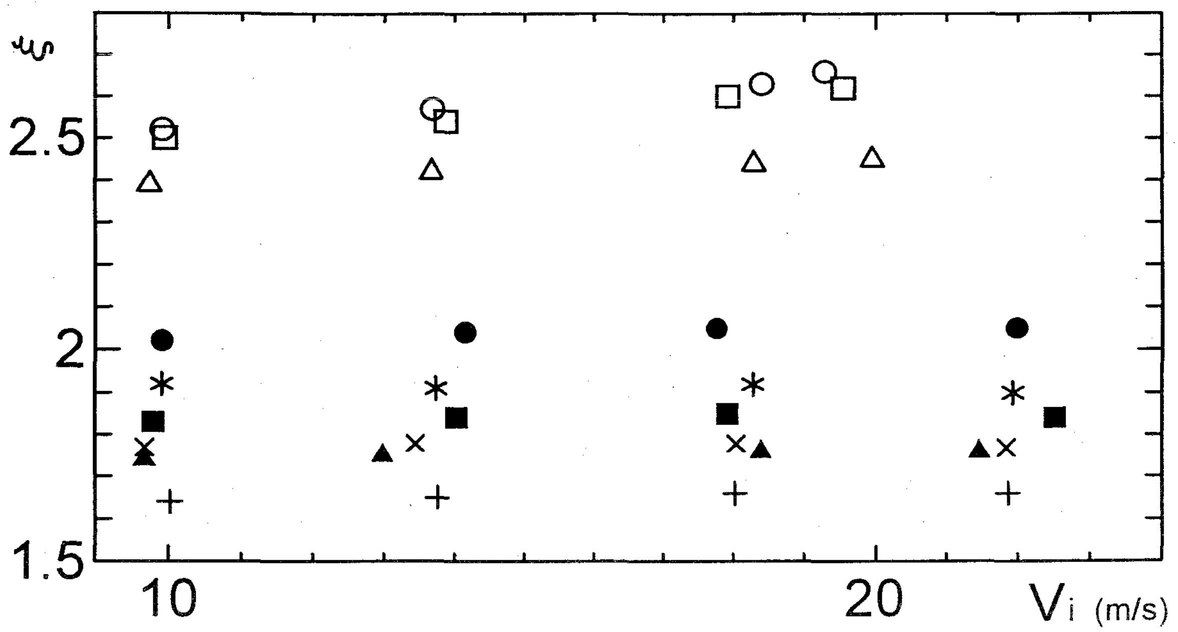


Fig. 4 Pressure loss coefficient versus feed velocity

cyclone is the most efficient for separation among three types. The next one is type I. The ordinary type takes rank third. Since the air core blocks the downflow to the exit, the flux ratio H_1/H_0 is small. Therefore, the ordinary type cyclone has low capacity in operation. The separation efficiency η depends on the underflow rate. Figure 6 shows the variation of η with H_1/H_0. The meaning of symbols in this figure is different from previous symbols in Table 1 and is cited in this figure. It will be seen that the efficiency of type II is better than that of the ordinary cyclone at large flux ratio and is about the same at low flux ratio.

Figure 7 shows the centrifugal separation efficiency η_c. It will be seen that type II have good efficiency for the centrifugal separation among three types.

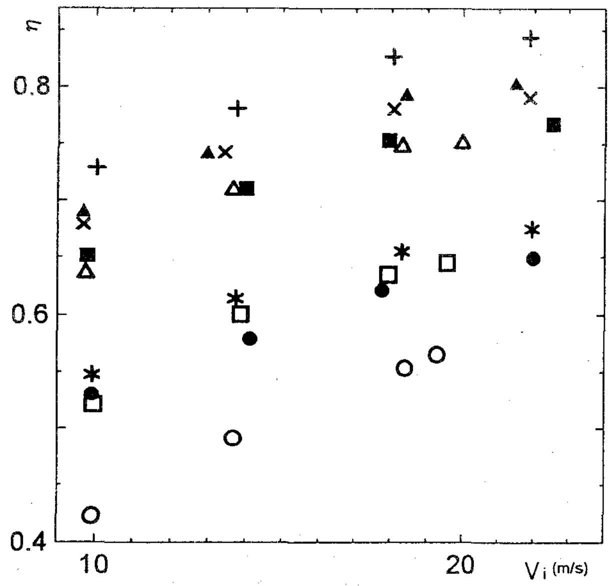


Fig. 5 Separation efficiency

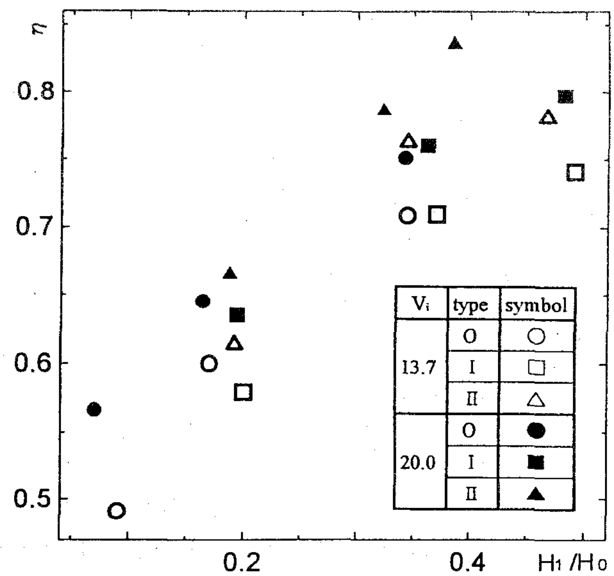


Fig. 6 Separation efficiency versus flux ratio

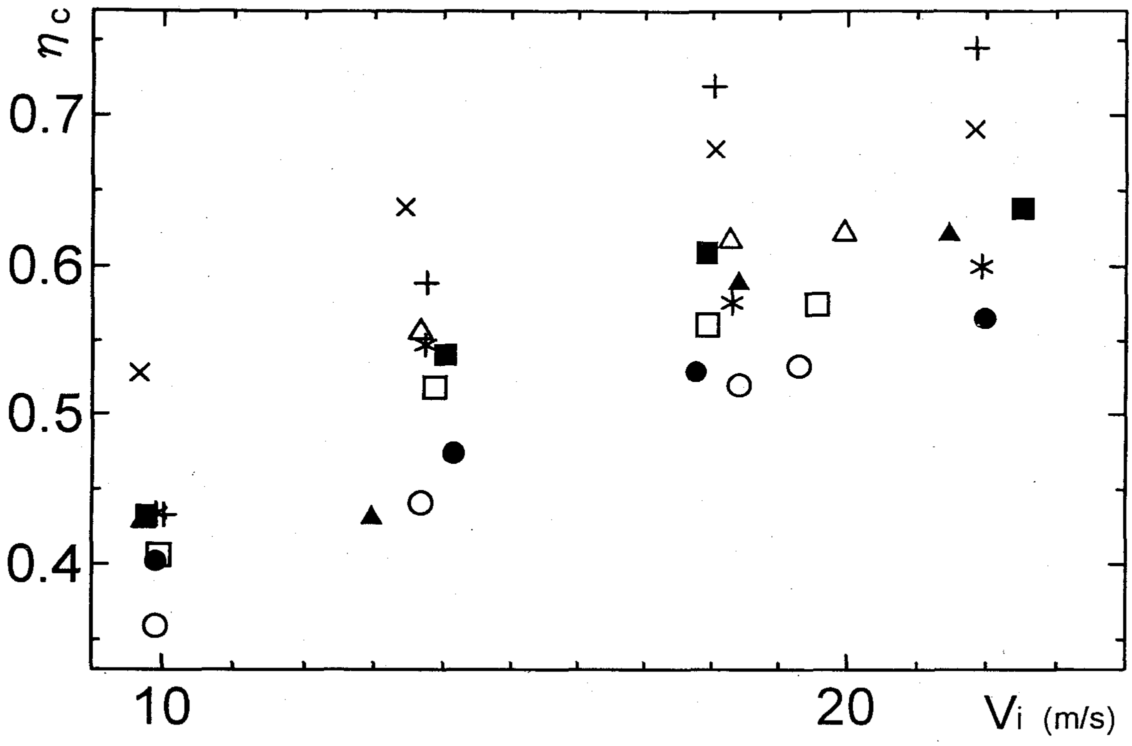


Fig. 7 Centrifugal separation efficiency

5. CONCLUSION

We constructed new small hydrocyclone which has a perforated inner cylinder. Two types of inner cylinder were made, i.e. the one has 39.5% void fraction of the perforated surface (type I) and the other has 73.5% void fraction (type II). We tested their performance together with the conventional cyclone, and obtained the following results :

(1) The air core which appears at the center of the conventional cyclone disappears in both type I and II. Consequently, the flow rate at the downstream exit increases for type I and II compared with the conventional cyclone.

(2) The pressure loss decreases about 30% for type I and 33% for type II compared with the conventional one.

(3) The new cyclone with inner cylinder have better separation efficiency compared with the conventional one.

ACKNOWLEDGEMENT

The authors would like to express their cordial thanks to Mr. T. Koizumi and Mr. T. Miura for their help in the experiment.

REFERENCES

(1) Xuezhen Jiao and Kyoji Yamamoto : Tarns. JSME, **59** (1993),3153.
(2) Kyoji Yamamoto, Xuezhen Jiao and Toshiyuki Nishitani : Trans. JSME, **60** (1994),1257.
(3) Kyoji Yamamoto and Xuezhen Jiao : Memoirs Faculty Eng., Okayama Univ., **28** (1994),159.
(4) Kyoji Yamamoto and Xuecheng Jiao : Trans. JSME, **63** (1997),3623.
(5) D. Bradley : " The Hydrocyclone ", Pergamon Press (1965),64.