Cyclone Dust Collector with a Perforated Internal Rotating Cylinder

Kyoji YAMAMOTO* and Xuezhen JIAO**

(Received January 11 , 1994)

SYNOPSIS

An experimental investigation has been made of the cyclone dust collector with a perforated internal rotating cylinder. The size of the rotating cylinder is of $0.5D$, where D is the diameter of the cyclone body, and is the same size as the outlet tube. The dust collection efficiency as well as the pressure loss has been measured when the inlet flow speed is $9 \sim 21\ m/s$ and the rotating speed of the cylinder is $37 \sim 63\ m/s$. The velocity and pressure distributions were also measured.

It is found that the collection efficiency decreases and the pressure loss increases as the rotating speed increases. It is also shown that both the inward radial velocity and the upward vertical velocity become large as the rotating cylinder increases its speed. As a whole, the rotation of the internal cylinder makes worse performance of the cyclone dust collector.

1. INTRODUCTION

The cyclone dust collector has been playing an important and indispensable role in environmental protection, in industrial production processes, etc.. This type of dust collector are widely used as a purifier at moderate level because of its simple structure, no moving parts and easy maintenance. There has been a lot of work on the cyclone. However, since the flow inside the cyclone is very complicated and is not well understood in details, we must make more studies theoretically and experimentally in order to improve the collection efficiency, cut size and pressure loss.(1) Recently, a numerical work(2) has been made using a turbulent model equation to predict the flow inside the cyclone. A new type of cyclone with internal perforated cylinders(3),(4) is proposed and is shown to be very efficient for dust collection and pressure loss.

It is essential to increase the rotational velocity in the cyclone for getting good collection efficiency and small cut size. The high rotational velocity can be obtained using a rotary.(5),(6),(7) It may be claimed that the simple structure and easy maintenance of the conventional cyclone dust collector would be impaired by introducing mechanical rotating parts. However, the highly reliable rotary machine in modern technology would bring out little trouble in operation. We should use

*Department of Mechanical Engineering
**The Graduate School of Natural Science and Technology

rotary machines positively if they may improve efficiency of dust collector. More studies should be made of the rotary dust collector. In a previous work,(8) we proposed a new type of the rotary dust collector, which provides rotating two concentric perforated cylinders in the conventional cyclone dust collector. This was shown to improve considerably the dust collection efficiency.

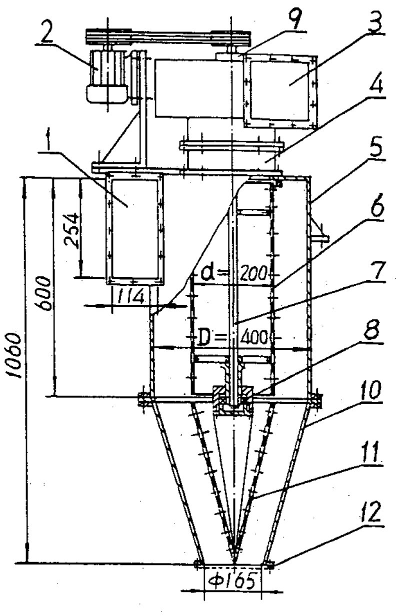
The rotary cyclone dust collector proposed by Matsuyama *et al*(6) consist of a single rotary cylinder whose diameter is much smaller than the cyclone diameter and which is made of a wire gauge or bars. In order to compare these types of rotary cyclones(6),(7) with the one of two-concentric perforated rotating cylinders,(8) we remove the outer rotating cylinder from the latter and make a single rotating perforated cylinder cyclone. We measure the dust collection efficiency, the pressure loss, and the velocity and pressure distributions in this type of cyclone.

2. EXPERIMENTAL APPARATUS AND EXPERIMENTAL METHOD

Figure 1 shows the cyclone dust collector with a perforated rotating cylinder. This is composed of the inlet (1), motor (2), spiral outlet (3), exhaust pipe (4), main body (5), perforated rotary cylinder (6), shaft (7), bearings (8), (9), conical section (10), inner perforated conical section (11), and dust hopper (12). The perforated rotary cylinder (6) has a diameter of $0.5D$, where D is the body diameter, and can be rotated by the motor (2). The hole diameter of the perforated cylinder is 3.45 *mm* and its porosity is about 0.4. The perforated conical section also has the same hole as on the cylinder, but it does not rotate. At the top of the inner conical section, the supporter with eight spokes is connected with the main body. The whole view of the experimental setup, which is designed on the basis of JIS(9),(10), is shown in Fig.2. The flow rate through the cyclone was measured at the inlet nozzle and is calculated by the following equation

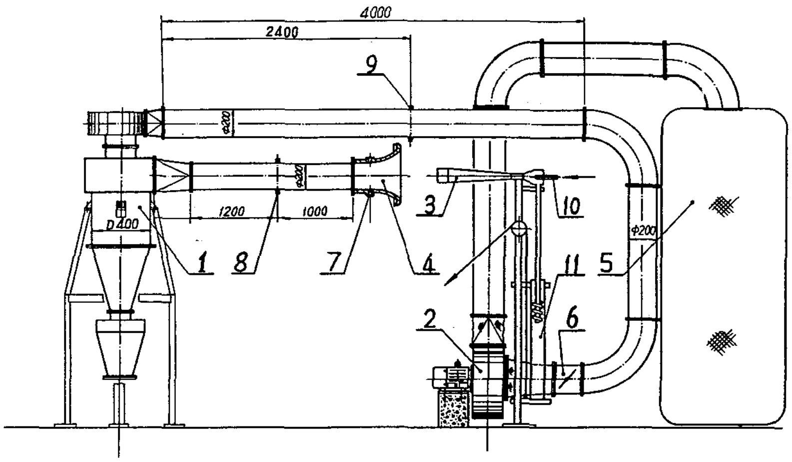
$$Q = A\Phi\sqrt{2P_r/\rho}, \qquad [m^3/s] \tag{1}$$

where A is the area of the cross section (7) at which the static pressure is measured, P_r is the pressure difference between (7) and the atmosphere, ρ the density of the air, and Φ is the nozzle discharge coefficient and taken to be 0.99.(10)



1-Inlet 2-Motor 3-Spiral outlet
4-Exhaust pipe 5-Main body
6-Perforated rotary cylinder 7-Shaft
8, 9-Bearings 10-Conical section
11-Inner perforated conical section
12-Dust hopper

Fig. 1 Cyclone with a perforated rotating cylinder



1-Cyclone 2-Fan 3-Scattering device of dust
4-Inlet nozzle 5-Outlet bag filter 6-Valve
7, 8, 9-Measuring points of pressure
10-Compressed air 11-Container of dust

Fig. 2 Experimental setup

The coefficient of pressure loss is defined by

$$\xi = \Delta P_t/(V_i^2\rho/2), \quad (2)$$

where V_i is the inlet velocity, ΔP_t the total pressure loss through the dust collector, which is given by

$$\Delta P_t = \Delta P_s' + \Delta P_k - \sum \Delta P_a, \quad (3)$$

Here, $\Delta P_s'$ is the static pressure difference between ⑧ and ⑨,ΔP_k the corresponding dynamic pressure difference, and $\sum \Delta P_a$ is the pressure loss in the tubes before and after the cyclone and is calculated by

$$\sum \Delta P_a = \sum \xi V_i^2 \rho/2, \quad (4)$$

where $\sum \xi$ is the friction factor of the duct and taken to be 0.3.(11)

The dust used in the present experiment is talc.(12) The talc density is 2700 kg/m^3. The residue distribution of the talc is shown in Fig.3. The talc was fed by means of suction jet and dispersed through an air ejector into inlet nozzle area.

The measurment of velocity and pressure distribution was made using five-holes Pitot-static tube. The details of measurement is given in section 4.

3. TOTAL DUST COLLECTION EFFICIENCY AND PRESSURE LOSS

Measurements have been done when the inlet flow velocities are 9.0, 12.0, 15.0, 18.0 and 21.0 m/s and the numbers of rotation of the perforated cylinder are (I) 3580, (II) 3900, (III) 4720, (IV) 5330, (V) 6050 rpm, and (VI) 0. The dust concentration in the flow was 6 g/m^3.

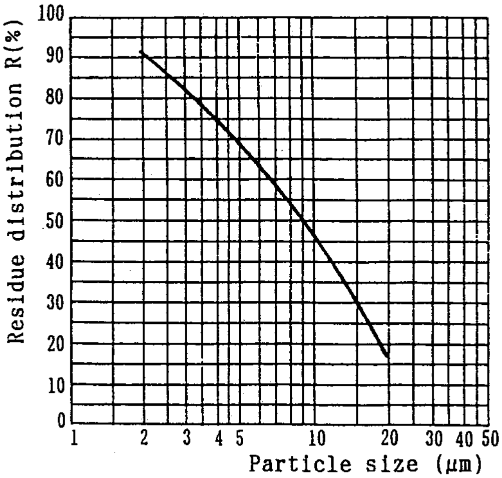


Fig. 3 Residue distribution of the talc

The results are shown in Tables 1 and 2, and Fig.4. The results for a conventional type of cyclone(4) in which the perforated inner cylinder and cone are removed are shown in the same figure. In boxes in Table 2, the upper numeral indicates the total pressure loss, while the lower one means its coefficient. It will be seen in Fig.4 that the dust collection efficiency is extremely bad when the rotating speed is high and the inlet flow speed is small. This is improved as the inlet flow speed increases. However, the efficiency even at 18 m/s inlet speed is still fairly lower than that of the conventional cyclone.

The total pressure loss increases with rotating speed of the cylinder. Especially, its loss is relatively large for high rotating cylinder when the inlet flow speed is small.

We may conclude that the present type rotary cyclone with a single perforated cylinder is not efficient in both dust collection and pressure loss.

4. METHOD FOR MEASURING THE VELOCITY FIELDS

We used a five-holes Pitot-tube for velocity measurement (Fig.5). The diameter of head is 5 mm and that of hole is 0.5mm. The holes are connected to the manometer as shown in Fig.6. The Pitot-tube was calibrated in a wind tunnel with a uniform speed V_∞. The Pitot-tube was set in the wind tunnel so that the pressure at holes [4] and [5] are the same. Then, we turn the Pitot-tube around the axis C-C so that the line A-A through hole [2] makes an angle α with the uniform flow. Let the pressure at each hole be $P_1, P_2 \cdots, P_5$, and the difference of water level of the manometer i and j be Δh_{i-j}. We define the following equations:

$$K_\alpha = \frac{P_1 - P_3}{P_2 - P_4} = \frac{\Delta h_{1-3}}{\Delta h_{2-4}} = f_\alpha(\alpha), \tag{5}$$

$$K_{1-3} = \frac{P_1 - P_3}{P_0} = \frac{\Delta h_{1-3}}{\Delta h_0} = f_{1-3}(\alpha), \tag{6}$$

$$K_{2-4} = \frac{P_2 - P_4}{P_0} = \frac{\Delta h_{2-4}}{\Delta h_0} = f_{2-4}(\alpha), \tag{7}$$

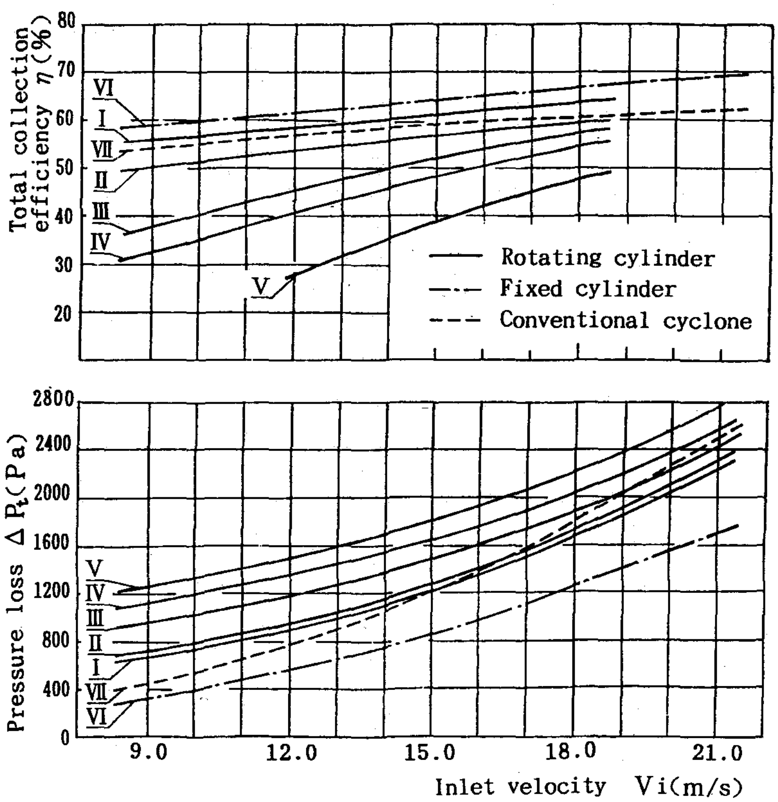
$$K_2 = \frac{P_2}{P_0} = \frac{\Delta h_2}{\Delta h_0} = f_2(\alpha), \tag{8}$$

Table 1 Total collection efficiency η (%) of the cyclone dust collector with a perforated rotating cylinder

Inlet velocity V_i (m/s)		9.0	12.0	15.0	18.0	21.0	Number of rotation n (rpm)	Rotating velocity V_c (m/s)
Flow rate Q (m^3/s)		0.261	0.348	0.434	0.521	0.608		
I	Pulley: d_1/d_2=6.0/6.0	55.8	58.4	60.9	63.6		3580	37.4
II	Pulley: d_1/d_2=6.0/5.5	50.2	53.1	56.2	59.5		3900	40.9
III	Pulley: d_1/d_2=6.0/4.5	38.7	42.9	51.5	57.9		4720	49.4
IV	Pulley: d_1/d_2=6.0/4.0	32.6	39.4	47.1	55.5		5330	55.8
V	Pulley: d_1/d_2=6.0/3.5		27.5	39.7	46.3		6050	63.3
VI	Cyclone with an internal perforated cylinder	58.3	61.7	64.0	66.1	68.7	0	0
VII	Conventional reverse-flow cyclone	54.1	56.9	59.0	60.6	62.5		

Table 2 Pressure loss ΔP_t (Pa) and its coefficient ξ of the cyclone dust collector with a perforated rotating cylinder

Inlet velocity V_i (m/s)		9.0	12.0	15.0	18.0	21.0	Number of rotation n (rpm)	Rotating velocity V_c (m/s)
Flow rate Q (m^3/s)		0.261	0.348	0.434	0.521	0.608		
I	ΔP_t (Pa)	678	915	1265	1705	2242	3580	37.4
	ξ	14.0	10.6	9.37	8.77	8.47		
II	ΔP_t (Pa)	735	970	1329	1778	2324	3900	40.9
	ξ	15.1	11.2	9.84	9.15	8.78		
III	ΔP_t (Pa)	958	1187	1516	1938	2444	4720	49.4
	ξ	19.7	13.7	11.2	9.97	9.24		
IV	ΔP_t (Pa)	1135	1373	1665	2053	2557	5330	55.8
	ξ	23.4	15.9	12.3	10.6	9.66		
V	ΔP_t (Pa)	1258	1512	1825	2243	2790	6050	63.3
	ξ	25.9	17.5	13.5	11.5	10.5		
VI	ΔP_t (Pa)	306	550	872	1256	1715	0	0
	ξ	6.30	6.36	6.46	6.46	6.48		
VII	ΔP_t (Pa)	444	791	1258	1824	2503		
	ξ	9.14	9.15	9.32	9.38	9.46		



I : V_c=37.4 II : V_c=40.9 III : V_c=49.4
IV : V_c=55.8 V : V_c=63.3 VI : V_c= 0

V_c --Rotating velocity of a perforated rotating cylinder(m /s)

Fig. 4 Total collection efficiency η (%) and Pressure loss ΔP_t (P a)

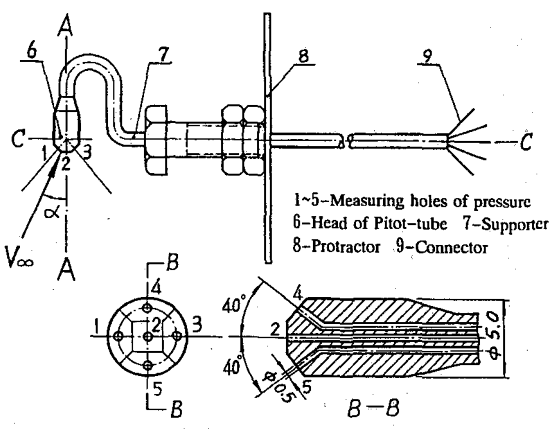


Fig. 5 Five-holes Pitot-tube

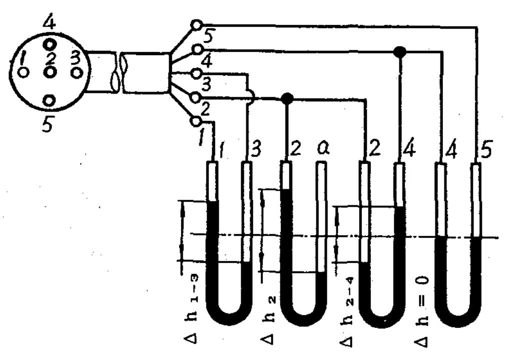


Fig. 6 Five-holes Pitot-tube and manometer

where P_0 is the dynamic pressure of uniform flow V_∞ and h_0 is the corresponding water level. These are related by

$$P_0 = \rho V_\infty^2/2 = h_0 \rho_1 g, \tag{9}$$

where ρ_1 and ρ are densities of water and air, respectively. The value of Δh_2 is the water level of manometer [2] for which one end is open to air. Figure 7 shows the calibration curves obtained.

5. CALCULATION OF THE VELOCITY AND PRESSURE FIELDS FROM MEASUREMENT

We put the Pitot-tube into the cyclone dust collector in such a way that the axis C-C of the Pitot-tube is on the radial line of the cyclone cylinder and rotate it so that Δh_{4-5} may be zero. We read the rotational angle β, and the water level difference Δh_{1-3},Δh_{2-4}, and Δh_2, and then calculate K_α from eq.(5). We read the corresponding values of K_{1-3}, K_{2-4}, and K_2 with K_α from curves in Fig.7. Then, we can calculate the velocity V from the following equation.(13)

$$V = \sqrt{2\rho_1 g \Delta h_{1-3}/\rho K_{1-3}} = \sqrt{2\rho_1 g \Delta h_{2-4}/\rho K_{2-4}}. \tag{10}$$

The static and total pressures, P_s and P_t, are calculated by

$$P_s = \rho_1 g \Delta h_2 - K_2 \rho_1 g \Delta h_{2-4}/K_{2-4}, \tag{11}$$
$$P_t = \rho_1 g \Delta h_2 - (1 - K_2)\rho_1 g \Delta h_{2-4}/K_{2-4}. \tag{12}$$

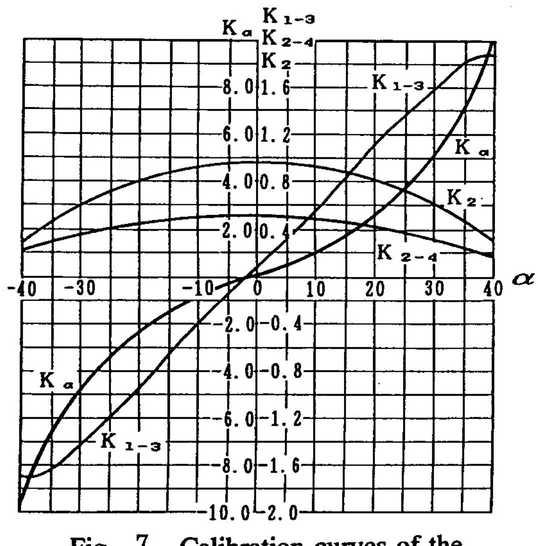


Fig. 7 Calibration curves of the Five-holes Pitot-tube

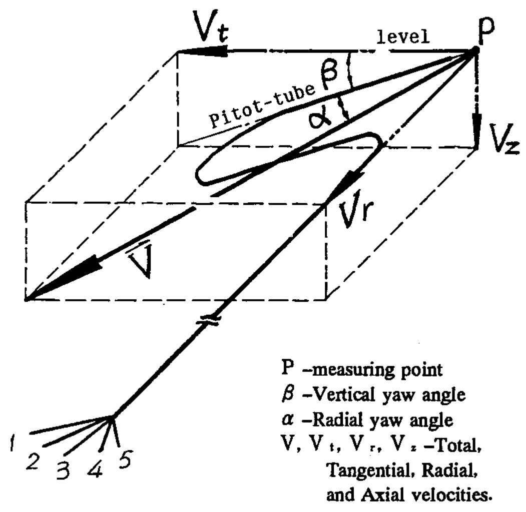


Fig. 8 Velocity decomposition

Referring to Fig.8, we can calculated the tangential velocity V_t, the radial velocity V_r, and the axial velocity V_z by the following equation:

$$\begin{aligned} V_t &= V\cos\alpha\cos\beta, \\ V_r &= V\sin\alpha, \\ V_z &= V\cos\alpha\sin\beta. \end{aligned} \tag{13}$$

6. RESULTS FOR THE VELOCITY AND PRESSURE DISTRIBUTIONS

Figures 9 and 10 show the velocity and pressure distributions between inner and outer cylinders. The inlet flow velocity was 18 m/s in all cases. The numbers of rotation of the inner perforated cylinder were (I) 3580, (Ⅲ) 4720, and (Ⅴ) 6050 rpm. The scale attached to each figure shows the magnitude of velocity or pressure.

7. DISCUSSIONS OF THE RESULTS

7.1 Tangential Velocity V_t

The tangential velocity between the cylindrical section increases with the rotation of the inner cylinder, and accordingly, in the conical sections, too. In this respect, as far as the tangential velocity, the rotation would produce a favorable behavior to separation of the dust. However, the rate of increase of the tangential velocity is not high. The ratio of average tangential velocity in cases of (I), (Ⅲ) and (Ⅴ) is seen to be 1 : 1.1 : 1.3, while the corresponding ratio of rotational velocity of cylinder is 1 : 1.3 : 1.7. The tangential velocity caused by the rotating cylinder does not spread into fluid, but is confined in a narrow boundary layer adjacent to the inner cylinder. This is due to a large inward radial velocity.

7.2 Radial Velocity V_r

The inward radial velocity in the cylindrical section increases with number of rotation of the inner cylinder. The increase of inward radial velocity without increasing the tangential velocity causes drift of dusts toward the center of the cyclone and eventually let them out of the cyclone. The rotation of the inner cylinder plays an adverse role for dust collection. The large radial flow accompanies large pressure gradient and large pressure loss.

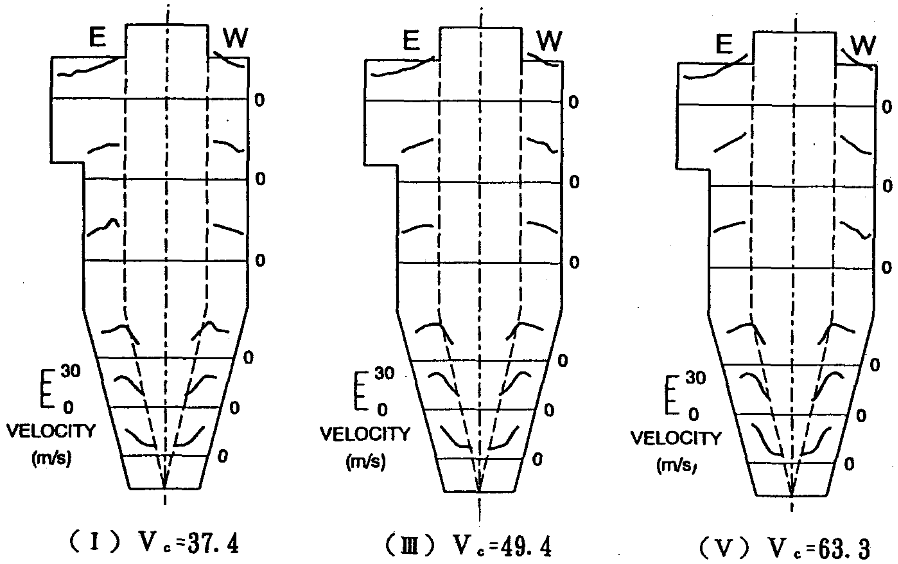
7.3 Axial Velocity V_z

It will be seen in Fig.9(c) that there appears an oscillation of tangential velocity. This seems to be related with the secondary flow. The oscillating flow promotes mixing of the suspended dust and prevents separation.

The upward axial velocity at the conical section increases with rotation of the cylinder, and this causes the upward drift of dust, otherwise it falls into the dust hopper. The upward flow is considered to be produced by the large suction pressure inside the rotating cylinder. Here, again, the rotation of the cylinder plays an adverse action to the dust separation.

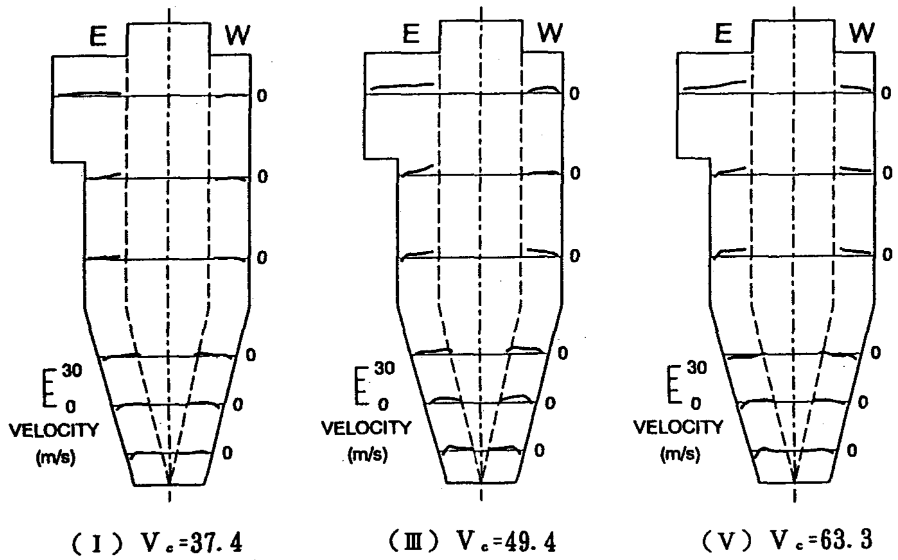
7.4 Pressure Distributions

The solid line in Fig.10 shows the total pressure and the dotted line the static pressure. The pressure drop toward the center of the cylinder will be seen to become large as the rotational velocity of the cylinder increases. The pressure drop is dominant at conical section and is responsible for the upward drift of dust mentioned above.



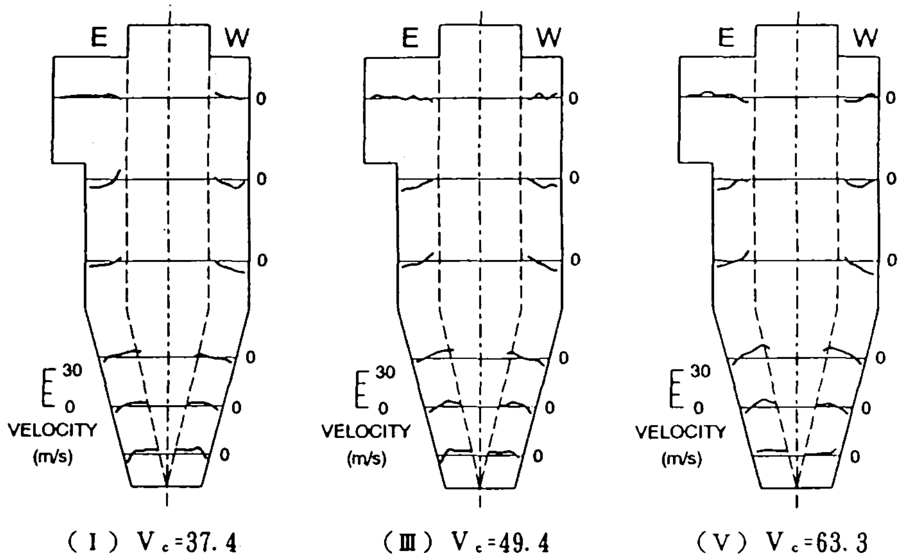
V_c --Rotating velocity of a perforated rotating cylinder(m /s)

Fig. 9 (a) Tangential velocity V_t



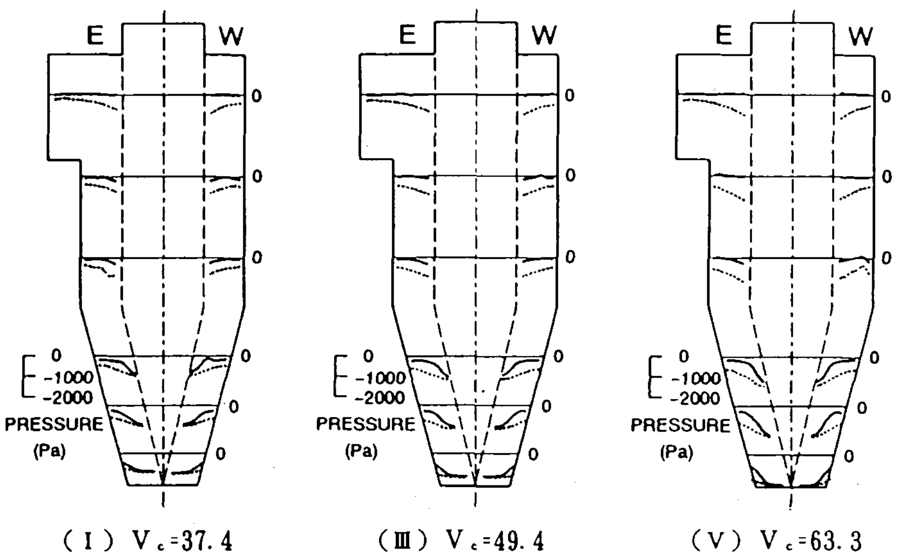
V_c --Rotating velocity of a perforated rotating cylinder(m /s)

Fig. 9 (b) Radial velocity V_r



V_c --Rotating velocity of a perforated rotating cylinder(m /s)

Fig. 9 (c) Axial velocity V_z



V_c --Rotating velocity of a perforated rotating cylinder(m /s)

Fig. 10 Pressure distributions

P_s : Static pressure (dotted line), P_t : Total pressure (solid line)

8. CONCLUSION

We made the experiment of the cyclone dust collector which has a rotating internal perforated cylinder and obtained the following results:
(1)The rotation of the internal cylinder reduces the collection efficiency of the cyclone.
(2)The pressure loss through the cyclone increases with the rotational speed of the cylinder.
(3)The average tangential velocity does not increase with proportion to the rotational speed.
(4)The inward radial velocity increases with increase of the rotational velocity. This causes confinement of the tangential velocity in a boundary layer near the inner cylinder.
(5)The upward axial velocity at the conical section increases with rotation of the cylinder and causes drift of dust upward.
(6)In conclusion, the rotation of the internal perforated cylinder is never useful for dust collection.

Acknowlegement

The authors would like to express their cordial thanks to T. Nishitani for preparing the manuscript.

References

[1] A. Ogawa: "Cyclone Separator (Saikuron Bunriki in Japanese)", Earth Pr. (1980), 21.

[2] O. Kitagawa, M. Yamamoto, C. Arakawa and H. Kawata: Trans. Japan Soc. Mech. Eng., **59** (1993), 1959.

[3] X. Jiao and K. Yamamoto: Trans. Jpn. Soc. Mech. Eng.,**59** (1993), 3153

[4] K. Yamamoto and X. Jiao: Prepr. of Jpn. Soc. Mech. Eng., No.938-3 (1993), 343.

[5] K. Iinoya: "Dust Collector (Shujin Sochi in Japanese)", Japan Industrial News Pr. (1980), 128.

[6] T. Matsuyama, I. Umehara, and K. Yoshida: Chem. Eng.,**18** (1954), 187.

[7] Y. Tanaka, H. Shinohara, M. Hongo, T. Adachi and T. Ishida: Chem. Eng. **27** (1963), 85.

[8] K. Yamamoto and X. Jiao: Prepr. of Jpn. Soc. Mech. Eng., (1994).

[9] JIS B9910 (1977).

[10] JIS B8330 (1981).

[11] "Flow resistance in pipes and ducts (in Japanese)", Jpn. Soc. Mech. Eng., (1976), 6.

[12] JIS Z8901 (1984).

[13] И. Л. Поьх:"Experimental method of aerodynamics in mechanical engineering (trans. Murata, Ogawa and Miyake, in Japanese)", Asakura Pr. (1969), 144.