Collection Efficiency of Cylindrical and Elliptic Cyclone Dust Collectors with Vortex Breaker

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The cyclone dust collector is applied to many kinds of industries and also there are many types of cyclones which are selected for the application and the placement of the establishment. However the cross section of these cyclones is the circular cylindrical section for the optimum condition of the turbulent rotational flow. However from the energy consumption and the collection efficiency points of view, the circular cross section of the cyclone is not always recommended but the elliptic cross section is recommended. Therefore in this paper, the detailed experimental results of the collection efficiency for the circular cross section and for the elliptic cross sections of the eccentricity ε=0.5,0.6and 0.7 are reported . The test dust for these experiments is fly-ash of the mean diameter Xpm=18.0 μm and 18.3 μm. The feed particle concentration is Co=1.0~50 g/m^3.

Keywords: elliptic cyclone, eccentricity, collection efficiency, fly-ash, feed particle concentration, pressure drop.

Introduction

Until now there are many papers concerning the collection efficiency and the cut-size Xc for the returned type, axial type and also rotary flow types of the cyclone dust collectors[1,2,3,4]. The cross section of these cyclones is the circular cylindrical body. One of the main reasons for the circular section is that the flow control on the three dimensional turbulent rotational flow becomes easy and also the movement of the solid particles along the concave wall surface becomes smooth. So the collection efficiency ηc(%) of the cyclone shows very stable state. However from energy consumption point of view, the circular cross section is not always the optimal shape but the elliptic cross section is the optimal one, which depends on the eccentricity ε. According to the above stated description, the comparison of the experimental results of the collection efficiency of the cyclone of the circular cross section with the vortex breaker with that of the elliptic cross section of ε=0.5,0.6 and 0.7 with the vortex breaker is shown in detail[5-12].

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Test Dust

The test dust for the experiment of the collection efficiency is fly-ash which is two kinds of dust, one of these has the mean size Xpm=18.0μm and its density ρp=2120 kg/m^3, and the other is Xpm=18.3μm and ρp=2310 kg/m^3.

Performance of Cyclones

Test 1

In order to recognize the performances of the cylindrical and elliptic (ε=0.6) cyclones of the tangential inlet pipe of the diameter Do=50 mm without the vortex breaker in the bottom surface of these cyclones as shown in Fig.1, the pressure drop ΔPc(Pa) of the pure air flow and also the collection efficiency ηc(%) are examined by using the test dust of Xpm=18.0μm. Fig.2 shows the relationship between the pressure drop of pure air flow and the mean inlet velocity in the tangential inlet pipe.From this result, it is found that the pressure drop of the cylindrical cyclone is higher than that of the elliptic cyclone of ε=0.6 due to the difference of the distribution of the tangential velocity of gas flow in these two cyclones.

Nomenclature

a	major length of ellipse (m)
b	minor length of ellipse (m)
be	length of the minor axis of the elliptic exit pipe(m)
C	gap distance between the cyclone body and the outer edge of the vortex bunker(m)
Co	feed particle concentration (g/m^3)
D1	diameter of the cylindrical cyclone body (m)
Hi	imaginary length in the cyclone construction (m)
h	vertical height of elliptic cone of the vortex breaker (m)
ΔPc	pressure drop of the cyclone (Pa)
Qo	flow rate of gas into the cyclone (m^3/s)
RC	dimensionless parameter defined by eq.(1)
RE	dimensionless parameter defined by eq.(2)
Rec	cyclone Reynolds number (1) Defined as $Rec(1) = Qo / Hi \cdot v$
Vo	mean inlet velocity in the inlet pipe (m)
Vc	volume of the cylindrical cyclone (m^3)
Ve	volume of the elliptic cyclone (m^3)
Vθm	maximum tangential velocity of gas flow (m/s)
Xpm	mean particle size (μm)
ε	eccentricity defined as $\varepsilon = \sqrt{1-(b/a)^2}$
ζc	coefficient of the pressure drop (1)
ηc	collection efficiency (%)
ρp	density of the solid particle (kg/m^3)
ρ	density of gas (kg/m^3)
ν	kinematic viscosity of gas (kg/m^3)

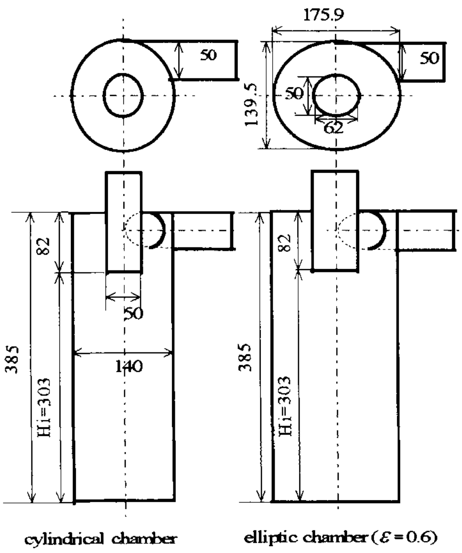


Fig.1 Schematic illustration of two types of the cyclones without the vortex breaker which are made by the transparent acrylic resin

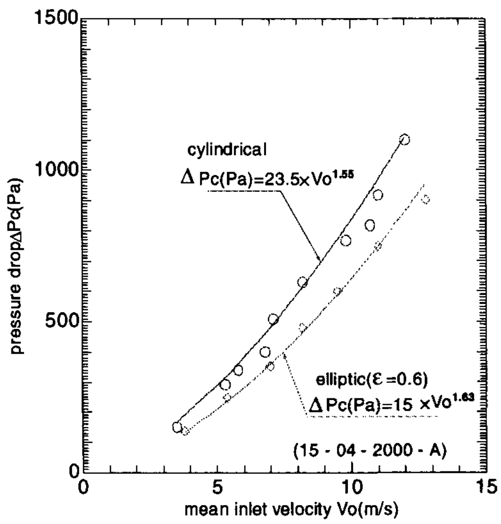


Fig.2 Correlation between the pressure drop and the mean inlet velocity for the cylindrical and elliptic cyclones of Do=50 mm without the vortex breaker

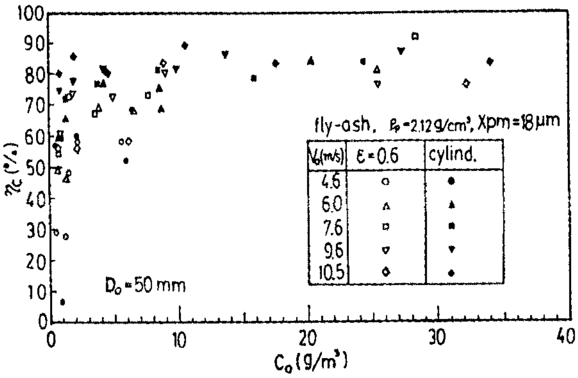
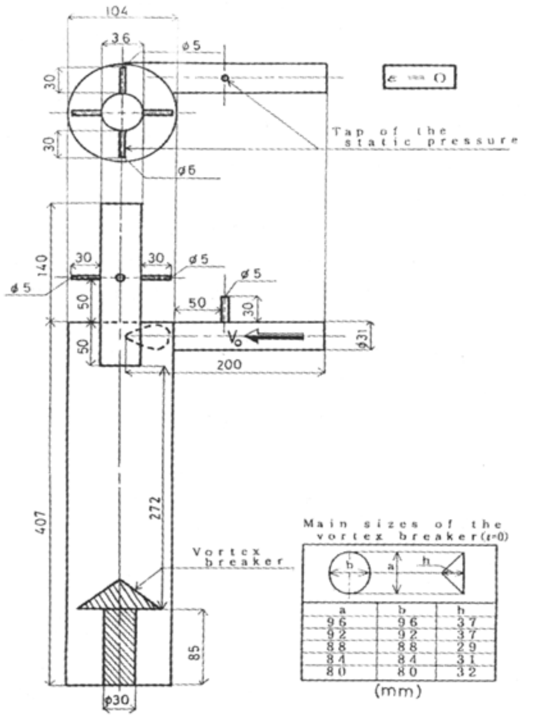


Fig.3 Correlation between the collection efficiency and the mean inlet dust concentration for the cylindrical and elliptic cyclones without the vortex breaker

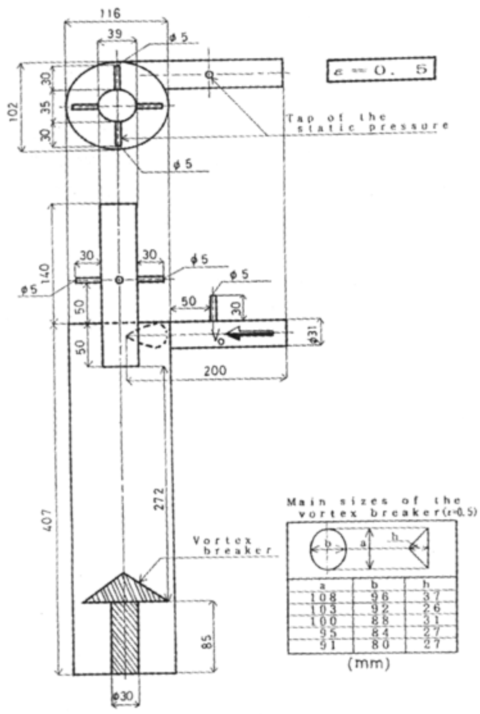
Test 2

In order to make a confirmation of the effect of the eccentricity and the size of the vortex breaker on the collection efficiency, the schematic illustrations of the construction of these cyclones are shown in Fig.4 (cylindrical cyclone), Fig.5 (eccentricity ε=0.5), Fig.6 (eccentricity ε=0.6) and Fig.7 (eccentricity ε=0.7) in detail. These cyclones are made by the transparent acrylic resin. The test dust is fly-ash of the mean diameter Xpm=18.3μm and its density ρp=2310 kg/m^3. The diameter of the tangential inlet pipe is Do=30 mm and also the detailed size of the vortex breaker is shown in these figures. The feed particle concentration for these experiments is defined as Co=1~5 g/m^3 and Co=14 ~ 50g/m^3.



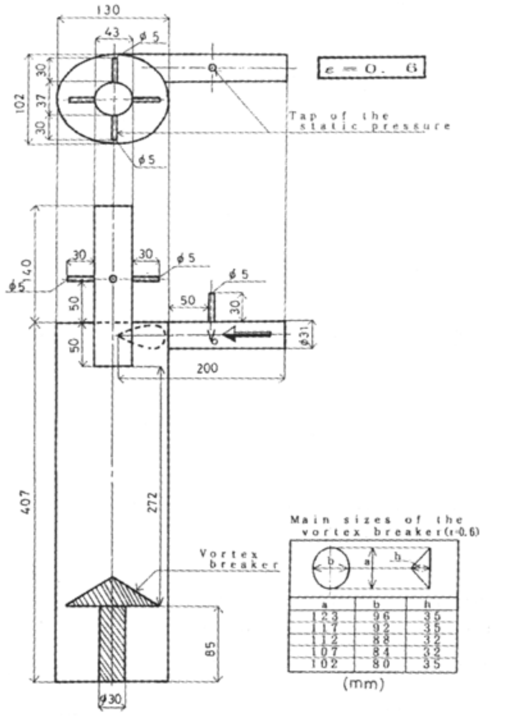
a	b	h
96	96	37
92	92	37
88	88	29
84	84	31
80	80	32

Fig.4 Construction and main sizes of the cylindrical cyclone of the diameter of the inlet pipe Do=30 mm with the vortex breaker.



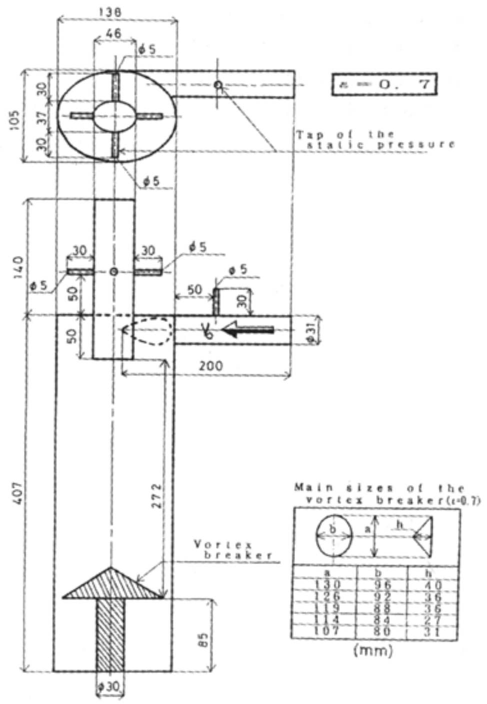
a	b	h
108	96	37
103	92	26
100	88	31
95	84	27
91	80	27

Fig.5 Construction and main sizes of the elliptic cyclone(ε=0.5) of the diameter of the tangential inlet pipe Do=30 mm with the vortex breaker.



a	b	h
123	96	35
117	92	35
112	88	32
107	84	32
102	80	35

Fig.6 Construction and main sizes of the elliptic cyclone(ε=0.6) of the diameter of the tangential inlet pipe Do=30 mm with the vortex breaker.



a	b	h
130	96	40
126	92	36
119	88	36
114	84	27
107	80	31

Fig.7 Construction and main sizes of the elliptic cyclone(ε=0.7) of the diameter of the tangential inlet pipe Do=30 mm with the vortex breaker.

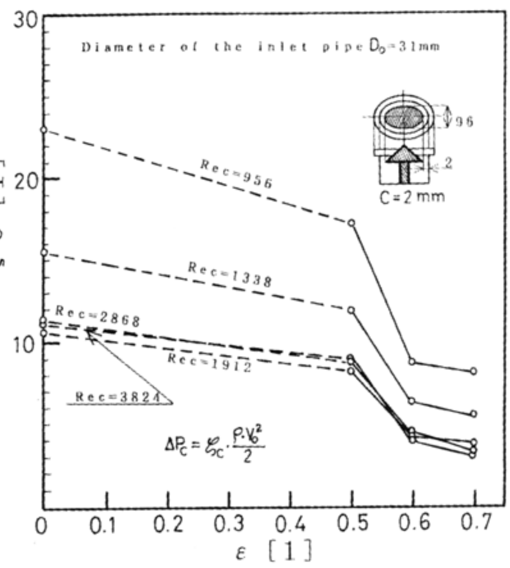


Fig.8 Correlation between the coefficient of the pressure drop and the eccentricity for the gap length C=2mm of the vortex breaker

Fig.8 shows the correlation between the coefficient of the pressure drop and the eccentricity (cylindrical cyclone ε=0) for the gap distance between the cyclone outer body and the vortex breaker C=2 mm

From these experimental results, the pressure drop of the cyclones ε=0.6 and 0.7 becomes smaller in comparison with that of cyclones ε=0 and 0.5. Then the correlation between the collection efficiency for C-2mm and the mean inlet velocity for the two kinds of the feed particle concentration is shown in Fig.9.

The size of the vortex breaker is shown in these figures in detail. In general, the collection efficiency is promoted with increasing the feed particle concentration from Co=1.45~to Co=17.32~48.83 g/m^3. Then the collection efficiency of ε=0 and 0.5 clearly shows the better characteristics in comparison with that of ε=0.6 and 0.7. The main reason is based upon the experimental results of the pressure drop as shown in Fig.8. Next, making a confirmation of these experimental results, in Fig.10 the correlation between the collection efficiency for C=2mm and the energy dissipation which is defined as W=ΔPc×Qo is shown for two kinds of the feed particle concentration.

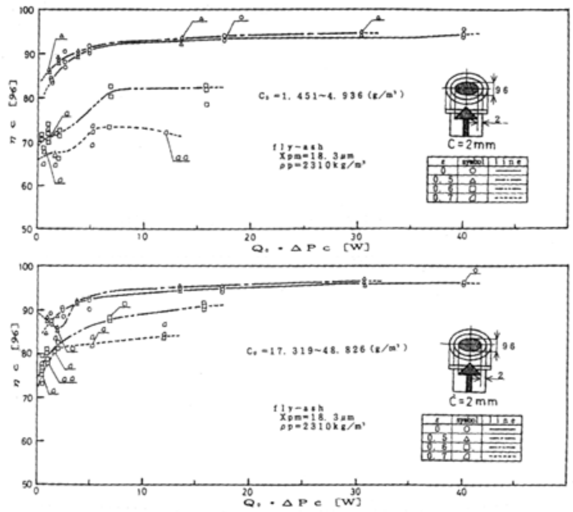


Fig.10 Correlation between the collection efficiency for C=2mm and the energy dissipation W(Watt) for two kinds of the feed particle concentration.

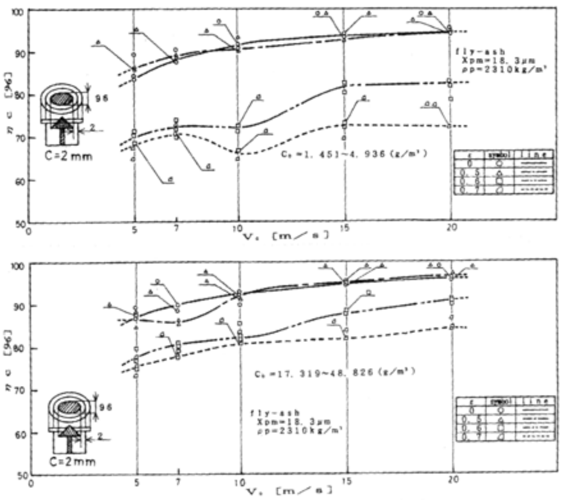


Fig.9 Correlation between the collection efficiency for C=2mm and The mean inlet velocity for two kinds of the feed particle concentration.

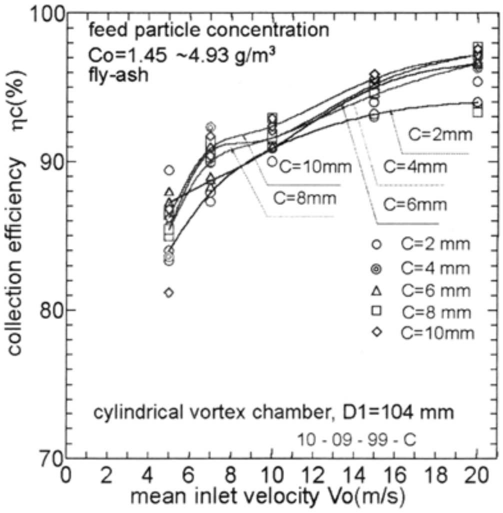


Fig.11 Correlation between the collection efficiency of the cylindrical cyclone(ε=0) depended on the gap distance C(mm) and the mean inlet velocity for Co=1.45~4.93g/m^3.

From these results, the mechanical separation process for ε=0 and 0.5 is similar in comparison with that of ε=0.6 and 0.7. Therefore from practical point of view, the elliptic cyclone of ε=0.5 can be applied to the industry with high reliability.

On the other hand, the collection efficiency(Co=1.45~4.93 g/m^3) which is depended on the gap distance C(mm) and the mean inlet velocity for the cylindrical cyclone is shown in Fig.11.

From these results, for the cylindrical cyclone, the collection efficiency does not change remarkably with increasing the gap distance C.

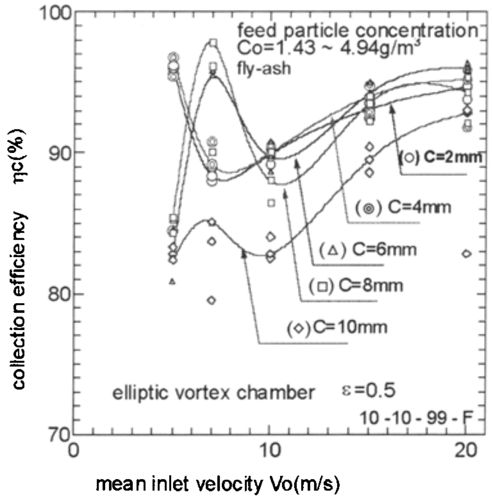


Fig.12 Correlation between the collection efficiency of the cyclone with ε=0.5 depended on the gap distance C(mm) and the mean inlet velocity for Co=1.43~4.94 g/m^3.

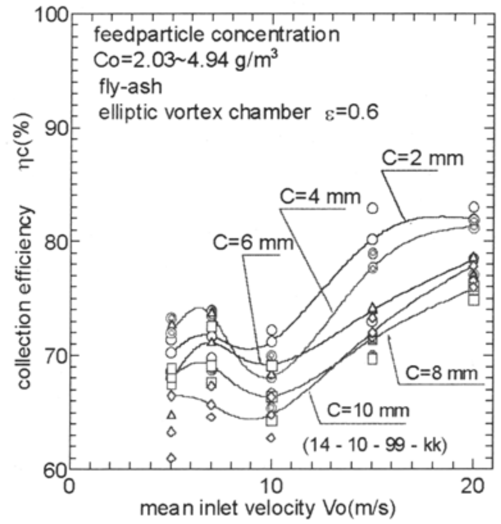


Fig.13 Correlation between the collection efficiency of the cyclone with ε=0.6 depended on the gap distance C(mm) and the mean inlet velocity for Co=2.03-4.94 g/m^3

However as shown in Fig.12 for ε=0.5, The collection efficiency is depended not only on the mean inlet velocity but also on the gap distance C(mm). Especially the collection efficiency shows the lower value on C=10mm .

Fig.13 shows the correlation between the collection efficiency of the cyclone with ε=0.6 depended on the gap distance C(mm) and the mean inlet velocity for Co=2.03~4.94 g/m^3. The collection efficiency becomes to decrease with increasing the eccentricity ε. Fig.14 shows the correlation between the collection efficiency depended on the gap distance C(mm) and the mean inlet velocity for Co=2.26 ~ 4.96 g/m^3. The collection efficiency becomes more decreasing. The main reasons are based upon the radial distribution of the tangential velocity of gas flow and the pressure drop of these cyclones which are depended on the eccentricity ε.

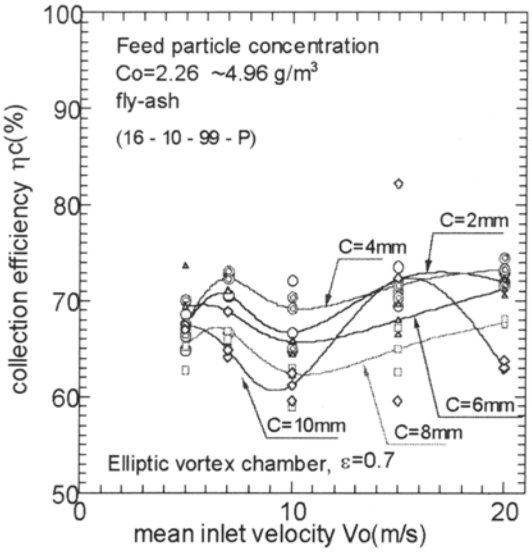


Fig.14 Correlation between collection efficiency of the cyclone with ε=0.7 depended on the gap distance C(mm) and the mean inlet velocity for Co=2.2—4.90 g/m^3.

The Maximum Tangential Velocity of Gas Flow

In order to explain the physical meaning of the collection efficiency which depended on the eccentricity ε, the experimental results of the maximum tangential velocity VθM (m/s) which depended on the eccentricity ε are shown in Fig.15. The construction and the main sizes of these cyclones with Do=30 and 50 mm without the vortex breaker are shown in Fig.1. The ordinate is the dimensionless maximum tangential velocity VθM/Vo(1) and the abscissa is the dimensionless equations of RC for the cylindrical cyclone and RE for the elliptic cyclone defined as follows;

$$RC = \frac{4 \cdot D_0^2 \cdot D_2}{\pi \cdot D_1^2 \cdot H_T} \cdot \mathrm{Re}\, c \tag{1}$$

$$RE = \frac{8 \cdot b_e \cdot D_0^2 \sqrt{1-\varepsilon^2}}{\pi \cdot D_1^2 \cdot H_T} \cdot \mathrm{Re}\, c \tag{2}$$

Where, b_e is the length of the minor axis of the elliptic exit pipe In this figure, it will be found that the empirical equation for Do=50 mm cyclones can be represented as

$$\frac{V_{\theta \cdot M}}{Vo} = 0.23 \times (RC\ or\ \ RE)^{0.55} \tag{3}$$

On the other hand, the empirical correlation between RC or RE of the cyclones for Do=30 mm and Vθm/Vo could not be obtained. however the maximum tangential velocity clearly shows the dependence on the eccentricity. Then increasing the eccentricity, the maximum tangential velocity becomes decreasing. This phenomenon is the main reason of why the collection efficiency becomes decrease with increasing the eccentricity.

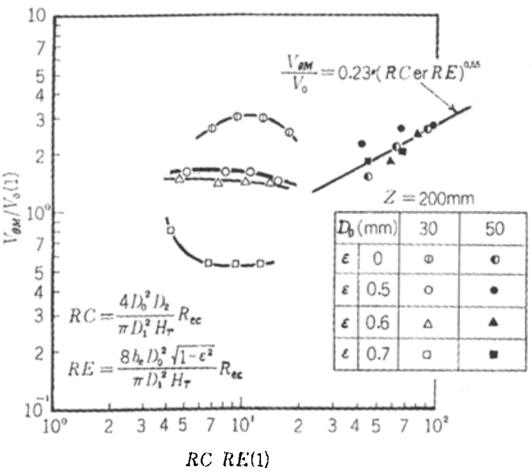


Fig.15 Correlation between the maximum tangential velocity and the dimensionless parameters RC and RE defined by Eqs.(1) and (2) for the cyclones of Do=30 and 50 mm without the vortex breaker.

Radial Distributions of Tangential Velocity at Z=50 and 200 mm in Cylindrical and ε=0.5, 0.6 and 0.7 Cyclones with Do=30mm Without Vortex Breaker

Fig.16 shows radial distributions of the tangential velocity which is measured by the cylindrical Pitot-tube at Z=50 and 200 mm in the cylindrical(ε=0) and ε=0.5,0.6 and 0.7 cyclones with the diameter Do=30mm of the inlet pipe without the vortex breaker for the inlet velocity Vo=5,8,11and 15 m/s. From these figures, it will be found out that the radial distributions of the tangential velocity become to change so sharply with increasing the eccentricity. This is a main reason for explaining the physical meanings of the pressure drop and the collection efficiency which depended on the eccentricity ε.

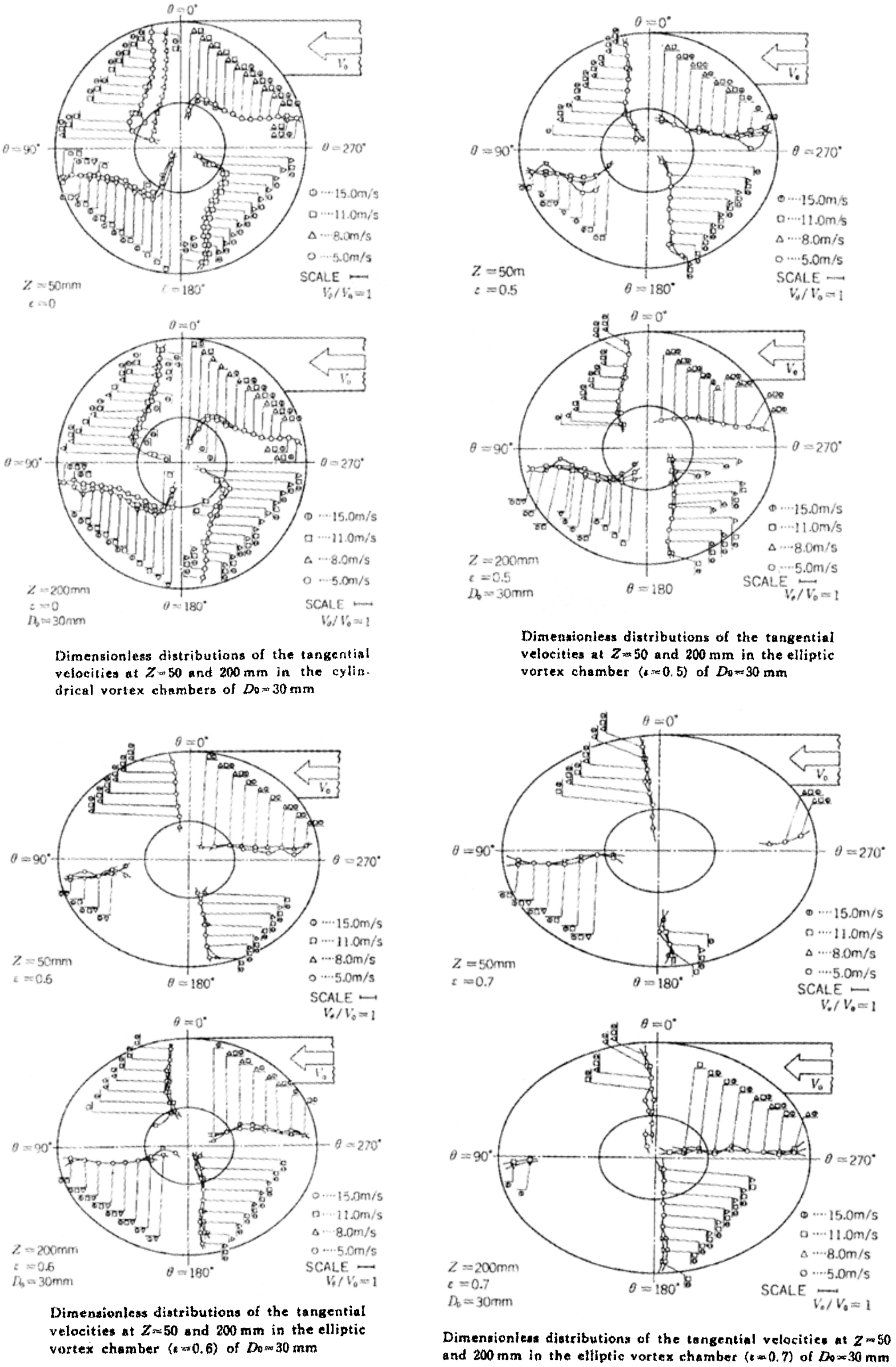
Conclusions

(1) As shown in Fig.3, The collection efficiency of the cylindrical cyclone without the vortex breaker shows better than that of the elliptic cyclone of ε=0.6 without the vortex breaker. Also the pressure drop of the cylindrical cyclone gives higher value than that of the elliptic cyclone. Even if the volume ratio of the cylindrical Vc(m^3) to elliptic Ve(m^3) cyclones is Vc/Ve=0.795, the measured tangential velocity of gas flow in the cylindrical cyclone was higher than that in the elliptic cyclone. Also, in the elliptic cyclone, the tangential velocity along the same elliptical circuit showed the accelerating and decelerating flow patterns. These flow phenomena give the physical explanation of the cause and effect for the collection efficiency and for the pressure drop. The construction of these cyclones was shown in Fig.1.

(2) The main constructions of the cyclones of Do=31mm with the vortex breaker as shown in Figs.4 (cylindrical, ε=0), 5 (ε=0.5), 6 (ε=0.6) and 7 (ε=0.7), the pressure drop of the cyclone with C=2mm becomes to decrease with increasing the eccentricity ε. This result relates to the collection efficiency. Even if the volume ratio of the cylindrical cyclone Vc to the elliptic cyclone Ve is Vc/Ve=0.914 for ε=0.5, Vc/Ve=0.816 for ε=0.6 and Vc/Ve=0.746 for ε=0.7, it is very clear that the cyclone shape depended on the eccentricity shows how it influence the rotational flow patterns in the cyclones. In Fig.16, the detailed radial distributions of the tangential velocity are shown.

(3) Fig.9 shows the correlation between the collection efficiency and the mean inlet velocity for C=2mm under the conditions of Co≈1-5 g/m^3 and Co≈17-49 g/m^3. In general, the collection efficiency is increased with increasing the feed particle concentration,

however the collection efficiency deeply depends on the eccentricity. In practical point of view, the collection efficiency of the elliptic cyclone with ε≤0.5 is kept on the stable high performance.



Dimensionless distributions of the tangential velocities at Z=50 and 200 mm in the cylindrical vortex chambers of Do=30 mm

Dimensionless distributions of the tangential velocities at Z=50 and 200 mm in the elliptic vortex chamber (ε=0.5) of Do=30 mm

Dimensionless distributions of the tangential velocities at Z=50 and 200 mm in the elliptic vortex chamber (ε=0.6) of Do=30 mm

Dimensionless distributions of the tangential velocities at Z=50 and 200 mm in the elliptic vortex chamber (ε=0.7) of Do=30 mm

Fig.16 Radial distributions of the tangentiall velocity measured at Z=50 and 200 mm in the cylindrical (ε=0) and ε=0.5,0.6 and 0.7 cyclones with Do=30 mm without vortex breaker for Vo= 5,8,11 and 15 m/s.

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