The Pressure Loss in Cyclone Dust Separator

Sachio HARADA
Susumu ICHIGE

1 Introduction

This article is the report of our experiments and theories concerned with how much the pressure loss in cyclone dust separator may be changed by different proportions of the construction. Many studies to calculate the pressure loss in cyclone have been done by number of students.(1)(2)(3)(4) C. J. Stairmand's research,(3) among them, seems to be particully excellent. But his required equation is too complicated to apply to predict the pressure loss of cyclone and does not always corespond with the experimental equations. This is the primary object to improve his required figure and to obtain a more satisfactory method in predicting the pressure loss of cyclone.

The standard type of cyclone has been published as illustrated as in Fig 1 (5),(6), the diameter of cylindrical portion of cyclone body being exprssed with D, width of inlet slot $b={}^{D}/_{4}$; length of inlet slot, $h={}^{D}/_{2}$; inside diameter of exit pipe $d={}^{D}/_{2}$; length of exit pipe $l=5{}^{D}/_{8}$; length of cylindrical portion of cyclone body $H=2D$; length of conical portion of cyclone body $H'=2D$; dia of pipe by which passed to dust pot $d'={}^{D}/_{4}$.

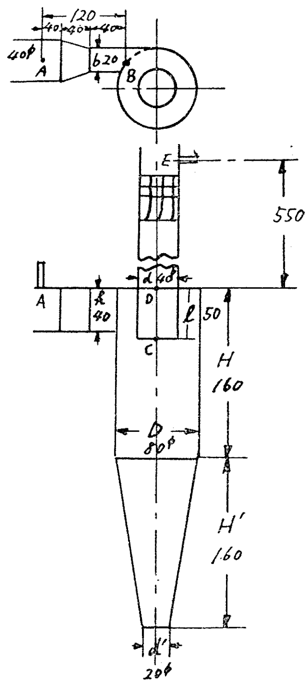

Fig. 1

In these experiments we have obserbed the enfluence in pressure losses by the different proportions of the main parts in the standard type of cyclone; *i. e.*,(1) by the different length of l, (2) by the different length of H, (3) by the different diameter of d, and (4) by the different cross-sectional area of inlet slot.

In this paper, the pressure loss in cyclone was measured with the pure air which did not contain solid particles, for the purpose of being easy in the analysis of the flow in cyclone.

The total pressure loss in cyclone is represented as in the following expression;

$$\triangle P=(P_i-P_e)+\frac{\gamma(V_i^2-V_e^2)}{2g} \quad \cdots\cdots (1)$$

where P_i=static pressure in inlet slot A

P_e=static pressure in exit pipe D

=(static pressure in E)−(pressure loss in pipe between D and E)

V_i=linear speed in inlet slot A

V^e=linear speed in exit pipe D

γ =specific weight

g =acceleration of gravity

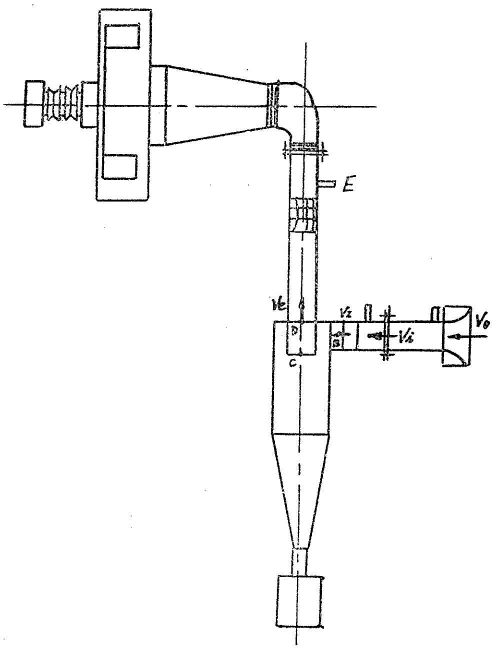

Fig 2

When a comparison of the performance in different volume of fluid through cyclone per unit time is to be made, a graph plotted on actual measured units of pressure loss is of relatively little utility, because the pressure loss $\triangle P$ be changed by the volume of the fluid flow in cyclone. While $\triangle P$ is directly proportional to the specific weight γ and to the square of the velocity V of fluid through the cyclone.

A graph plotted performance on ${}^{\triangle P}/v^2(\gamma/2g)$, instead of $\triangle P$, is generally constant in different volumes through the cyclone.

Therefore we have plotted the performance on f instead of $\triangle P$; where

$$f=\frac{\triangle P}{\gamma v_1^2/2g} \quad \cdots\cdots\cdots (2)$$

v_1 = linear speed in inlet slot B

Of course the value of f be changed in different proportions of the cyclone construction. Actually f has been often represented as follows.

$$f=\zeta\frac{b\,h}{d^2} \quad \cdots\cdots\cdots (3)$$

And ζ has been considered to be approximately constant. In this paper, the research as to ζ, simultaneously, has been done.

2 Experiments

2-1 The effect of the length of exit pipe

Several cyclones, similar in all respects except as to the length l of the exit pipe, have been tested for comparative performance. The characteristics given in Fig 3, are given for f and ζ. The graph (represented in solid lines) shows little effects of these variation. f and ζ are both almost constant except as to the values at the point of $l \doteqdot 1.25$ in which are both somewhat higher.

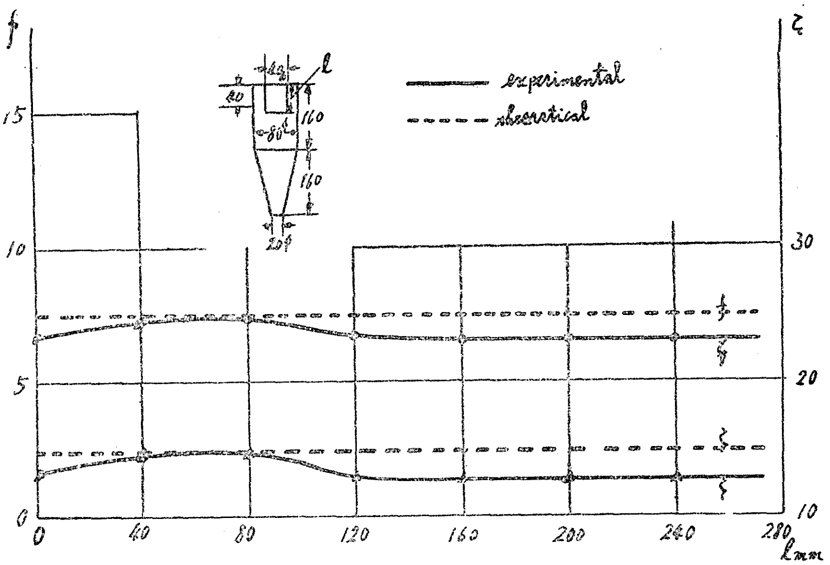

Fig 3

2-2 The effect of the length of the cylindrical portion.

Several cyclones, similar in all respects except as to the length H of cylindrical portion have been tested for comparative performance. The graph given in Fig 4, shows little effects of the variation on f and ζ.

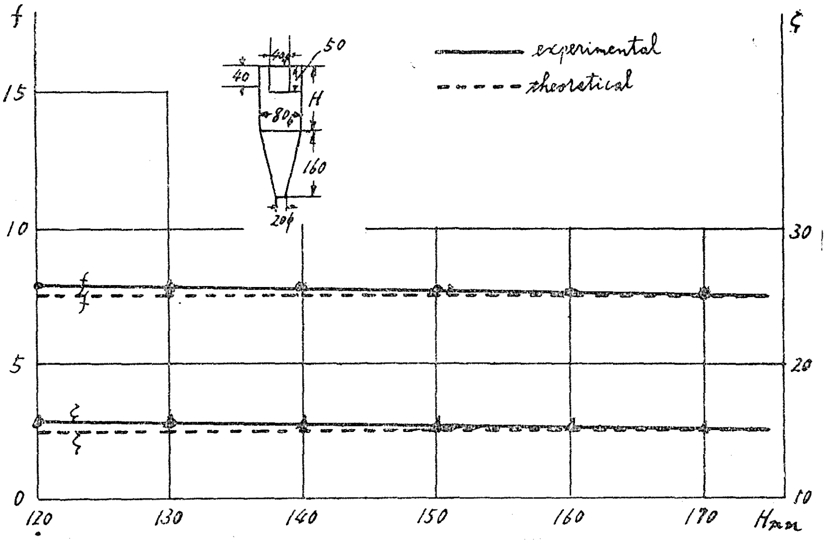

Fig 4

2-3 The effect of the diameter of exit pipe.

Several cyclones, similar in all respects except as to the diameter d of exit pipe, have been tested for comparative performance. The data given in Fig 5, have shown these features distinctly. The characteristics offers as much diversity with downward as $f \sim d$ curve and with upward as $\zeta \sim d$ curve in increasing the length of d. Now the value of ζ cannot be considered being constant.

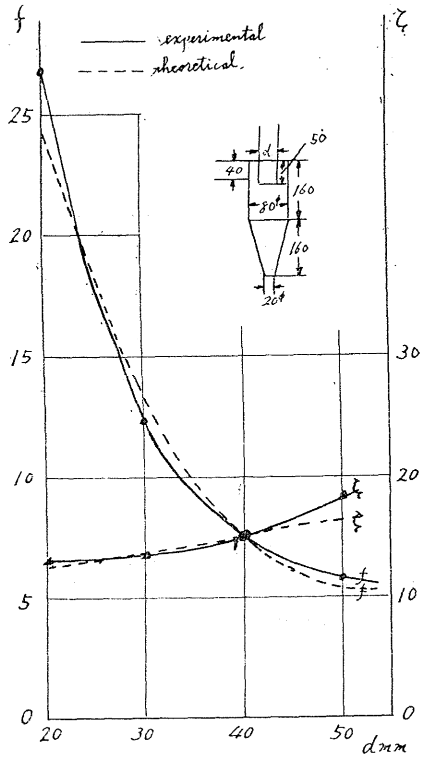

Fig. 5

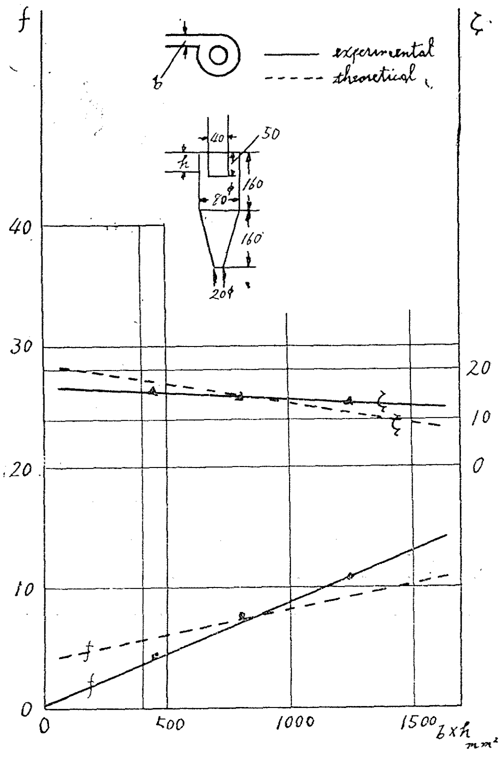

Fig. 6

2-4 The effect of the cross-sectionl area of the inlet slot.

Several cyclons, similar in all respects except as to the cross-sectional area $(b \times h)$ of the inlet, have been tested for comparative performance. Fig. 6 shows the relation for this experiment. The increase in the area of $(b \times h)$ has been reducted to increase the value of f and to decrease the value of ζ.

3 Theoretical research

3-1 The condition of flow in the cyclone

It has been shown that the spinning speed be inversely proportional to the n power of radius, i, e, that $UR^n = \text{const}$, where U is spinning speed at radius R. A theoretical analysis, confirmed by experimental, has shown that the spinning speed increases as the inverse square root of the radius up to half the radius of the exit pipe[3]; i. e.;

$$U^2R=K=\text{const} \quad \cdots\cdots (4)$$

By assessing in this article that the relation be held right, it is therefore possible to determine the flow conditions in the cyclone, as set out felow. The momentum of the gas entering the cyclone is equall to $Q\gamma V_I$, where Q is the volume of the fluid through the cyclone per unit time and it can be shown that $Q=V_I(bh)$.

Thus the moment of momentum of the fluid at the inlet can be expressed as

$$Q\gamma V_I R_I = V_I^2 R_I (bh)\gamma \quad \cdots\cdots (5)$$

In this expression R_I=the mean inlet radius of the vortex.

The gas enters the tangential inlet, whirls through several revolutions in the body and cone, and departs still whirling, through the axial cylindrical air out let. Two distinct vortics are present in the cyclone. One is the large-diameter descending helical current in the body and cone, and the other an ascending helix of smaller diameter. It can be considered that the friction loss, generated allong the contacting lager between the two vortics, takes the place of the bulk of the momentum of the fluid. If the frictional loss be defined as $G\gamma U^2_a$ per unit area, the total loss of the moment of momentum per unit time by this friction becomes

$$G\gamma U^2_a(d/2)\pi dH'' \quad \cdots\cdots (6)$$

In this expression, G is the non-dimensional frictional constant, U_a is the spinning speed at the exit radius $d/2$, and H'' is the hypothetical height of the cylinder which is the contacting lager between the two vortics. The total loss of momentum of is equal to the momentum supplied, so that (6)=(5)

i.e., $$G\gamma U_a^2(d/2)\pi dH''=V_I^2R_I(bh)\gamma \quad \cdots\cdots (7)$$

In this expression, the moment of momentum remaining in the fluid at exit is neglected in this page, which is but little as compared with the moment at inlet

$$U^2R=K=\text{const} \quad \cdots\cdots \text{from } (4)$$

$$\therefore \quad U_a^2(d/2)=U_I^2R_I$$

Substituting this value in (7), we have

$$G\gamma U_I^2R_I\pi dH''=V_I^2R_I(bh)\gamma$$

$$\therefore U_I^2=\frac{b\,h}{G\pi dH''}\,V_I^2 \quad \cdots\cdots (8)$$

Thus, from (8) we can determine the relation between the vortex spinning speed U_I and the velocity V_I in the inlet pipe, in terms of the physical proportions of the cyclone.

3-2 The pressure loss

The total pressure loss ΔP can be divided as follows;

ΔP= [centrifugal head in cyclone vortex]+ [loss at inlet]

−[(kinetic head recoverable at exit)−(loss at exit)] $\cdots\cdots$ (9)

The various losses are deduced as follows;

(1) Centrifugal head in cyclone vortex:—

we consider the spin of an elementary ring of fluid of radius R and width dR, and of unit depth. If U be the speed of spin, centrifugal acceleration is equall to U^2/R. Now the weiget of fluid involved is equall to $2\pi RdR\gamma$, so that the difference of pressure dP due to the rotation of the elementary ring is given $dp\times 2\pi R\times 1=U^2/Rg\ 2\pi RdR\gamma$

$$\therefore\ dp=\frac{U^2\gamma}{Rg}\ dR \qquad (10)$$

Substituting (4), *i. e.,* $U^2R=K$, in (10), we have

$$dp=\frac{\gamma K}{g}\frac{dR}{R^2} \qquad (11)$$

Then , [centrifugal head in cyclone vortex]

$$=\int_{R_e}^{R_I} dp=\frac{\gamma K}{g}\int_{R_e}^{R_I}\frac{dR}{R^2}=\frac{\gamma K}{g}\left[-\frac{1}{R}\right]_{R_e}^{R_I}$$

$$=\frac{\gamma K}{g}\left(\frac{1}{R_e}-\frac{1}{R_I}\right)$$

$$=\frac{\gamma}{g}U_I^2\left(\frac{R_I}{R_e}-1\right) \qquad (12)$$

since $K=U^2R=U_I^2R_I$

In this expression R_I, *i. e.*, mean inlet radius of the vortex, is equal to $(D/2-b/2)$, and R_e, *i. e.*, effective exit radius of vortex, is equall to $d/4$, as quoted by C, J, stairmand[3]. Thus we have

$$\frac{R_I}{R_e}=\frac{(D-b)/2}{d/4}=\frac{2D-2b}{d} \qquad (13)$$

Substituting the values of (13) and (8) in (12), we have

[Centrifugal head in cyclone vortex]

$$=\frac{\gamma}{2g}V_I^2\frac{bh}{d^2}\frac{2(2D-2b-d)}{\pi\ G\ H''} \qquad (14)$$

(2) Loss at inlet ; —

The kinetic head at inlet is $\frac{\gamma}{2g}V_I^2$, accordingly it can be considerable as follows;

$$[\text{loss at inlet}]=C_1\frac{\gamma}{2g}V_I^2 \qquad (15)$$

where C_1 the fraction of the loss at inlet, depends on the conditions at inlet, and can be determined by experiment.

(3) kinetic head recoverable and loss at exit ;—

It can be considerable that the kinetic head recoverable and the loss at exit are each proportional to the kienetic head at exit, *i. e.*, $\frac{\gamma}{2g}V_e^2$. Thus we have

$$[(\text{kinetic head recoverable at exit}) - (\text{loss at exit})] = C_2 \frac{\gamma}{2g} V_e^2$$

where C_2, the factor of the kinetic head recoverable and the loss at exit, depends on the conditions in the exit pipe, and can be determined by experiments.

Substituting the value of (14), (15) and (16) in (9), the total pressure loss $\varDelta P$ can be obtained from the next figure, *i. e.* ;

$$\varDelta P = \frac{\gamma}{2g} V_I^2 \frac{bh}{d^2} \frac{2(2D-2b-d)}{\pi \quad GH''} + C_1 \frac{\gamma}{2g} V_{I2}^2 - C \frac{\gamma}{2g} V_e^2$$
$$= \frac{\gamma}{2g} V_1^2 \frac{bh}{d^2} \left[\frac{2(2D-2b-d)}{\pi \; G \; H''} + C_1 \frac{d^2}{bh} - C_2 \frac{16\,bh}{{}^2\pi d^2} \right] \quad \cdots\cdots \quad (17)$$

Thus the value f of (2), *i. e.*, $\dfrac{\varDelta P}{\gamma V_I^2/2g}$ can be given by the relation:

$$f = \frac{bh}{d^2} \left[\frac{2(2D-2b-d)}{\pi \; G \; H''} + C_1 \frac{d^2}{bh} - C^2 \frac{16\,bh}{\pi^2 d^2} \right] \quad \cdots\cdots\cdots\cdots \quad (18)$$

The value of ζ, is $f = \zeta \dfrac{bh}{d^2}$, is given in the same manner with f as follows:

$$\zeta = \left[\frac{2(2D-2b-d)}{\pi \; G \; H''} + C_1 \frac{d^2}{bh} - C_2 \frac{16\,bh}{\pi^2 d^2} \right] \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (19)$$

The values of G, H'', C_1 and C_2 are determined by our experiments as follows:

$$\left.\begin{array}{l} G = \dfrac{1}{50} \\ H'' = 2D \\ C_1 = 0.5 \\ C_2 = 2.5 \end{array}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (20)$$

Substituting these values of (20) in (18) and (19), we have obtained the theoretical curves for f and ζ against our experiments as plotted in Fig 3~6.

All these thearetical curves have approximately coresponded with the experimental curves.

4 Conclusion

The conclusions obtained from our experimental and theoretical researches are as follows.

(1) In our experiments, the total pressure loss $\varDelta P$ or the non-dimensional factor f has had big different values due to alternating the sectional area of inlet or exit. and the value of ζ in the relation *i. e.*, $\varDelta P = \dfrac{\gamma V_I^2}{2g} \zeta \dfrac{bh}{d^2}$, has not been always constant, against as considered.

(2) The theoretical values for pressure loss become as follows.

$$\varDelta P = \frac{\gamma V_I^2}{2g} \frac{bh}{d^2} \left[\frac{2(2D-2b-d)}{\pi \; G \; H''} + C_1 \frac{d^2}{bh} - C_2 \frac{16\,bh}{\pi^2 d^2} \right]$$
$$f = \frac{bh}{d^2} \left[\frac{2(2D-2b-d)}{\pi \; G \; H''} + C_1 \frac{d^2}{bh} - C_2 \frac{16\,bh}{\pi^2 d^2} \right]$$

$$\zeta = \left[\frac{2(2D-2b-d)}{\pi\ G\ H''} + C_1 \frac{d^2}{bh} - C_2 \frac{16\,bh}{\pi^2 d^2} \right]$$

These theoretical values approximately corespond with our experimented data.

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