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Experiments on the Pressure Drop in the Hydrocyclone*

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The pressure drop in the hydrocyclone is an important factor along with its performance, since the pump used for the cyclone must be selected according to the pressure drop and also because the amount of necessary energy is dependent upon the pressure drop and the quantity of liquid.

The author has measured the differences in pressure between the inlet and the overflow pipes under various operating conditions.

The influences of the following factors on the pressure drop were investigated: (1) Feed inlet velocity v_i , (2) Diameters of vortex finder D_o , underflow nozzle D_u and cylindrical portion D , (3) Dimension of inlet nozzle $\sqrt{bh}$, (4) Height of cyclone H , (5) Inserted length of vortex finder S , (6) Types of feeding and (7) Pulp density of feed slurries δ_f .

From the results of his experiments, the author has shown that the pressure drop through the cyclone may be represented by the Eq. (4.2).

1. Introduction

In order to determine the head of the pump when constructing a plant, it is necessary to know the pressure drop of the hydrocyclone. Although a number of reports on research in this subject have already been published in connection with the gascyclone^{(1)~(10)}, only two or three dealing with the hydrocyclone have been published so far by Dahlstrom and others⁽¹¹⁾⁽¹²⁾. While these reports serve to explain the characteristics of the resistance of the hydrocyclone to a certain extent, they nevertheless do not always concur with experimental results. This is due to the fact that because part of the slurry is constantly being discharged from the underflow nozzle during operations, it is extremely difficult to establish a formula which will accurately express the pressure drop during the process of operation.

In this paper, the author has sought to describe the various dimensions of each part of the cyclone and their influences on pressure drop, along with some experimental formulas based on the results of his tests. By comparing these with the already known Dahlstrom's formula and First's formula of the gascyclone, he has attempted to prove that the former possesses a slightly higher generality than the latter.

2. Experimenting apparatus and measuring methods

The apparatus and test material employed in these tests were identical with those described in a previous report⁽¹³⁾. The apparatus was a closed circuit type consisting of a tank, pump and cyclone, an experimental plant with a treating capacity of approx. 20 m³/hr. The hydrocyclone was similar to the one shown in Fig. 1, with each part exchangeable in different dimensions. To be more specific, D is available in four sizes, 3~6 inches; $\sqrt{bh}$ in six sizes, 6.89~25.4 mm; D_o in five, 12~50 mm; D_u in five, 8~22 mm; S in eight, 0~290 mm; H in six, 347~2027 mm; H_1 in two, 105 and 185 mm; H_2 in six, 242~1922 mm and θ in six, 2.6~20.3°. For feeding purposes, two types, the tangential and the volute were adopted.

In conducting the afore-mentioned experiments, various combinations of different sized parts were employed, the pressure drop within the feed inlet velocity ranges of $v_i=3\sim 20$ m/s being measured. In this case, discharging from the underflow nozzle was limited to the spray form, while pure water was chiefly employed as the fluid.

For the purpose of measuring a pressure drop Δp kg/cm², i.e. a pressure difference equal to Δh mmHg, a differential manometer was installed between the feed inlet portion of the cyclone and the discharging pipe connected with the vortex finder. The readings of a pressure gauge installed

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Fig. 1 Experimental hydrocyclone employed

Fig. 2 Relationship between pressure drop and feed inlet velocity

Fig. 3 Relationship between coefficient of pressure loss and Reynolds' number

Fig. 4 (A) Relationship between coefficient of pressure loss and vortex finder opening

(B) Relationship between coefficient of pressure loss and underflow nozzle opening

directly in front of the feed inlet nozzle were recorded for determining the feed pressure p_i kg/cm². In this case, a comparison of the respective values of the Δh and p_i revealed that while the former possessed a maximum 5 % pressure head as against the latter, this difference was greatly reduced once the p_i was increased. On the assumption that this 5 % represents the resistance in the discharging pipe, it has been included from a practical point of view in the "resistance of the cyclone" within this report.

3. Experimental results

3.1 Influence of feed inlet velocity v_i

Fig. 2 shows one example of the results of this experiment, in which the diameter of the vortex finder D_o acts as a parameter. The tangential type of feeding was adopted, this type being consistently employed throughout all the following tests, except where otherwise stated.

As Fig. 2 indicates, it is possible to establish the following relationship between the pressure drop Δp and the v_i within the limits of these testing conditions.

$$\Delta p \propto v_i^n \quad (3.1)$$

In the above formula, the index n ranges between the limits of $n=1.8\sim 2.1$. It is presumed that any increase in n is caused by a turbulence in the flow, in other words, an increase in the Reynolds' number R_e . Generally speaking, however, $n \approx 2.0$ may be regarded as an appropriate standard. Fig. 3 is an example of the influence of the R_e on the dimensionless number of the coefficient of pressure loss ζ , in other words the ratio of the head loss $\Delta p/\gamma$ against the velocity head at the inlet nozzle $v_i^2/2g$. Here too, the D_o is employed as a parameter, γ represents the specific weight of the fluid, g the gravitational acceleration and ν_{20} the coefficient of the kinematic viscosity of the fluid at 20°C.

From the figure, it can be seen that the ζ remains at a constant once the R_e exceeds a certain value. For this reason, in consolidating the values of the experiment, the R_e was restricted to the limits of a constant ζ in order to avoid any influences of viscosity.

3.2 Influence of vortex finder opening D_o

From Fig. 4 [A] it can be seen that the relationship between the ζ and the D_o is $0.4 \leq D_u/D_o \leq 1$, i.e., in a normal cyclone where $D_o > D_u$, this influence is represented by the equation

$$\zeta \propto D_o^{-m} \quad (3.2)$$

within the limits of $\sqrt{bh} = 6.89 \sim 25.4$ mm, the

index m being a function of the $\sqrt{bh}$. This value ranges between $1.80 \sim 0.28$, showing a gradual decrease as the $\sqrt{bh}$ becomes smaller.

3.3 Influence of underflow nozzle opening D_u

It can be seen from Fig. 4 that in a normal cyclone where $D_u < D_o$, the influence of the D_u is less than that of the D_o . However, in the case of a special exception such as $D_u > D_o$, the D_u takes the place of the D_o in imposing a great influence on the ζ . For example, the relationship of the ζ and D_u when $D_o = 12$ mm (constant) takes the form of Fig. 4 [B], i.e.

$$\zeta \propto D_u^{-m'} \quad (3.3)$$

while the index m' likewise forms a function of the $\sqrt{bh}$.

Fig. 5 is an example of the influence of D_u/D_o on the ζ . Here too, when the D_u/D_o is as in the above case, i.e., when $D_u/D_o < 1$, the dimension of the D_u has practically no effect on the ζ . This tendency becomes greater the larger the D_o or the smaller the $\sqrt{bh}$ is. A further study will reveal, however, that the maximum value of the ζ exists around the region of $D_u/D_o \approx 0.4 \sim 0.5$.

3.4 Influence of inlet nozzle $\sqrt{bh}$

Fig. 6 shows that the relationship between the ζ and the $\sqrt{bh}$ can be formulated as

$$\zeta \propto (\sqrt{bh})^l \quad (3.4)$$

within the limits of $0.4 \leq D_u/D_o \leq 1$ and $\sqrt{bh} = 10 \sim 25.4$ mm against any D_u/D_o . Index l is a function of the D_o , its value changing within the range of $1.3 \sim 2.5$ and becoming larger with a decrease in

Fig. 5 Relationship between coefficient of pressure loss and ratio of underflow nozzle and vortex finder openings

the D_o .

3.5 Influence of cylindrical portion D

The influence of the D on the ζ as indicated in Fig. 7 is represented by the equation

$$\zeta \propto D^p \dots \dots \dots (3.5)$$

against any D_o , the index $p \approx 0.5$. This means that the influence of the D as compared with the $\sqrt{bh}$ and the D_o is rather less.

Fig. 6 Relationship between coefficient of pressure loss and inlet nozzle opening

Fig. 7 Relationship between coefficient of pressure loss and diameter of cylindrical portion

Fig. 8 Relationship between coefficient of pressure loss and height of cyclone

Fig. 9 Relationship between coefficient of pressure loss and inserted length of vortex finder

Fig. 10 Influence of type of feeding on pressure drop

3.6 Influence of height of cyclone H

Fig. 8 shows that the influence of the H on the ζ takes the form of

$$\zeta \propto H^{-q} \dots (3.6)$$

within the limits of $\sqrt{bh} > 12.75$ mm and $H/D_0 < 40$ against any D_0 , with the index $q \approx 0.95$.

3.7 Influence of inserted length of vortex finder S

As Fig. 9 demonstrates, the ζ is but slightly influenced by the S . This is due to the fact that the flow in the discharging nozzle is constantly circuiting, and it was anticipated that no such influence was involved in this test.

3.8 Influence of type of feeding

A study of Fig. 10 reveals that the tendencies in both diagrams are completely identical, except that the Δp for the same v_i is slightly smaller in the case of the volute type. Consequently it can be said that the tangential type is more advantageous for hydrocyclone designing purposes.

4. Experimental equations for pressure drop

4.1 Experimental equations

The influences of the dimensions of the various parts of the cyclone on the pressure drop have been revealed through the results of the aforementioned tests. In a consolidated form, the coefficient of the total pressure loss may be expressed as

$$\zeta = f \frac{(\sqrt{bh})^l}{D_0^m} \frac{D^p}{H^q} \dots (4.1)$$

Here f represents the coefficient of resistance, with each term expressed in gravitational units. The respective indices are constants capable of being obtained experimentally, and as indicated before, $l=1.3 \sim 2.5$, $m=1.80 \sim 0.28$, $p \approx 0.5$, and $q=0.9$.

Furthermore, for the purpose of consolidating l and m , the influence of the D_0 on the ζ can be converted into terms of a dimensionless number $\sqrt{bh}/D_0$, and by plotting the values of each $\sqrt{bh}$ the results become as indicated in Fig. 11. In a cyclone of $\sqrt{bh} \geq 12.75$ mm but of $\sqrt{bh}/D_0 \geq 0.4$, it can be assumed that m appears as a constant of $m=1.72$. In the same way, by translating the influence of the $\sqrt{bh}$ on the ζ into a dimensionless number of $\sqrt{bh}/D_0$, and plotting the respective values of D_u/D_0 , Fig. 12 is obtained. From this result, it can be assumed that a cyclone of $D_u/D_0 \leq 1$ with $\sqrt{bh}/D_0 \geq 0.4$ takes a constant value of $l=2.09$.

As a result, in a cyclone of $D \geq 125$ mm and $H \geq 366.5$ mm, the experimental equation of the

coefficient of the total pressure loss in the case of $v_i=10$ m/s under a normal dimension ratio of $\sqrt{bh}/D_0 \geq 0.4$, $\sqrt{bh} \geq 13$ mm and $D_u/D_0 \leq 1$ would be

$$\zeta = f \frac{(bh)^{1.05}}{D_0^{1.7}} \times \frac{D^{0.5}}{H^{0.9}} \dots (4.2)$$

From Fig. 13, which represents Eq. (4.2), the

Fig. 11 Relationship between coefficient of pressure loss and ratio of inlet nozzle and vortex finder openings

Fig. 12 Relationship between coefficient of pressure loss and ratio of inlet nozzle and vortex finder openings

Fig. 13 Diagram of total pressure loss

coefficient of resistance f is obtainable as $f \approx 113$.

A further study of Fig. 13 will reveal that a transitional point exists around $\zeta = 5$. For this reason, Eq. (4.2) is applicable in the case where $\zeta > 5$, while when $\zeta < 5$, the incline of the straight line becomes $1/2$ as indicated by the dotted line, while $f = 25$, $\zeta < 5$ is applicable to special cyclones which are beyond the applicable ranges of Eq. (4.2).

4.2 Comparison with other formulas

In the following, the author has attempted a comparison and examination of Dahlstrom's and others' formulas⁽¹¹⁾⁽¹²⁾ and also First's formula⁽²⁾ in gascyclones with his own experimental Eq.(4.2).

In the first place, by denoting that $\Delta p/\gamma = \Delta h[\text{m}]$, feed liquid volume Q [l/s], $b \times h$ [m^2] and D_o [m], Eq. (4.2) can be re-written as follows:

$$\Delta h = 6.12 \times 10^{-6} \cdot Q^2 / (bh)^{0.95} D_o^{1.7} D^{-0.5} H^{0.9} \dots (4.3)$$

It will be seen from the above that there is actually very little difference between this equation and Dahlstrom's formula $\Delta h = 6.4 \times 10^{-6} \cdot Q^2 / (D_i \cdot D_o)^{1.8}$ in which the dimension of the inlet nozzle opening is represented as D_i . However, inasmuch as Dahlstrom's formula ignores the influences of the D and H , it is clear that some handicap will inevitably arise when considering the pressure drop in connection with such performances as the collection of minute particles, etc. Again, Yoshioka's formula indicates $\zeta = 54.3 \times D_i^{2.8} / D_o^{1.9} D^{0.9}$, with the influence of the D being the opposite of the author's. In connection with this point, and judging from the fact that the pressure drop arising from the helical flow is hardly ever recovered, it can be assumed that even theoretically speaking, the ζ is in proportion with the D .

A comparison of First's formula with Eq.(4.2) revealed that the indices were more or less identi-

cal. The author's experimental values were accordingly applied to First's formula $\zeta = 24 \times (bh/D_o^2) \times (D/H)^{2/3}$, where it was found that owing to the wide margin of error, it would consequently be impossible to apply this formula in the form as it is to hydrocyclones. It is presumed that this large margin of error is caused by the difference in the R_e of the two formulas during operations. In order to apply gascyclone formulas to hydrocyclones, it is therefore necessary to convert the coefficient of resistance f so that it correlates with the R_e . For example, if the coefficient of resistance in First's formula is fixed at 49, it may be applied to hydrocyclones within the margin of error range of 20~30%.

5. Summary

1) Commencing with a description of the influences of the various factors upon the pressure drop of the hydrocyclone, several experimental equations were formulated on the basis of these results, and a comparison of these equations with Dahlstrom's formula and First's formula in the field of the gascyclone given, along with some observations.

2) As a result, it was revealed that the influences of the various parts of the hydrocyclone were similar to those of the gascyclone. This fact was already anticipated from the results of experiments conducted in connection with the velocity distribution within the cyclone.

3) The experimental equations of the author turned out to be very similar in form to Dahlstrom's formula. However, inasmuch as the latter ignores the influences of the cylindrical portion opening as well as the height of the cyclone, this presents a handicap when considering pressure drop in connection with other performances.

4) When applied in the original form to hydrocyclones, First's formula in the field of gascyclones yields a wide margin of error. It is presumed that this is caused by the differences in the R_e , and even if the coefficient of resistance in this formula were converted into values applicable to the hydrocyclone, an error of 20~30% would be unavoidable.

5) The main fluid employed was pure water, and also fine pulverized coal and powdered lime slurries. Within the limits of these experiments, the latter yielded a slightly lower Δp value as compared with the former, but with no other appreciable difference. However, the median particle size of the test material was approx. 40 μ ,

while the pulp density was kept within the limits of $\delta_f=1.5\%$ by weight. If the density is increased further, however, it is presumed that its influence on the Δp will become greater by reason of the presence of solid minute particles, and the value will accordingly decrease.

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