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by

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Pressure Drop in The Hydrocyclone*

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The success of removal of suspended solid from suspending liquid by a hydrocyclone is a function of the dimensions of the hydrocyclone, operation variables, and physical properties of the liquid and particles. Hydrocyclone develops separational power through the use of fluid pressure energy. There is thus a loss in pressure or a pressure drop, across the unit which is an important operating variable.

In this article the pressure drop in the hydrocyclone is given by an equation which depends on the velocity head, Reynolds number, and shape factors of the hydrocyclone. A summary of the utility of the equations presented by earlier authors is also given.
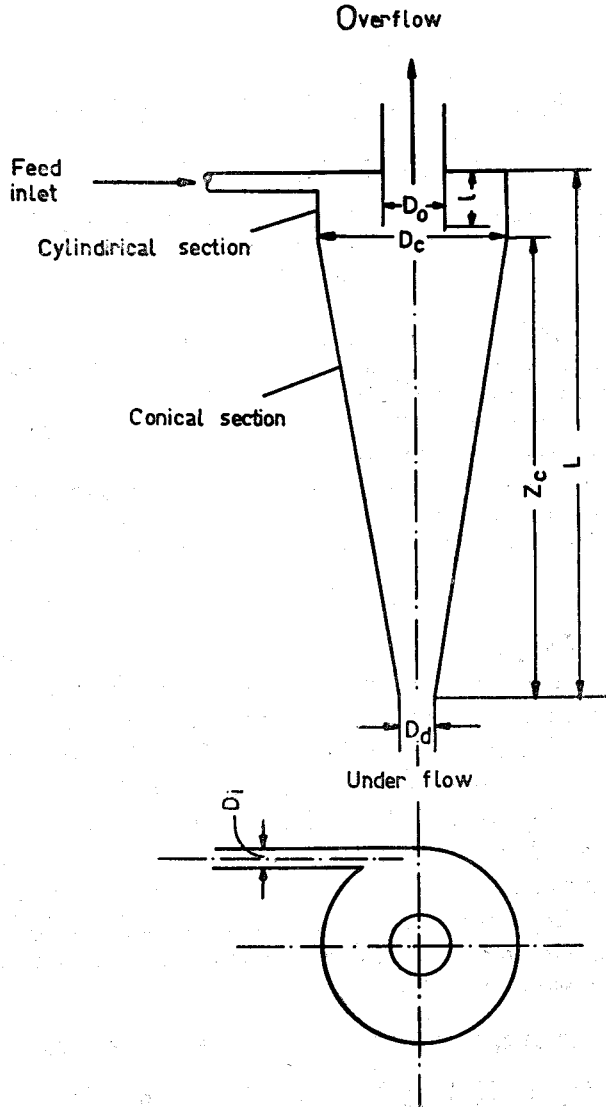
INTRODUCTION

The hydrocyclone is a piece of equipment which utilizes fluid pressure energy to create rotational fluid motion. This rotational motion causes relative movement of materials suspended in the fluid thus permitting separation of these materials one from another or from the liquid. The rotation is produced by tangential injection of the fluid into a vessel. At the point of entry the vessel is usually cylindrical. It can remain cylindrical over its entire length though it is more usual for it to become conical. The important criterion which distinguishes a hydrocyclone is not, however, the shape of the vessel but the use of fluid pressure to cause rotation.

DERIVATION OF THE EQUATION AND PHENOMENOLOGY

Operating a hydrocyclone requires a certain pressure drop which increases with the throughput and further depends

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* The data recorded are taken from a part of the dissertation of T. Özdamar submitted to the Faculty of Science in partical fulfilment of the requirments for the Master Degree.

Overflow

Feed
inlet

Cylindrical section

Conical section

D_o

D_c

Z_c

L

D_d

Under flow

D_i

Cross - sections of a hydrocyclone

on the construction of the hydrocyclone. Inside the hydrocyclone there exists a pressure gradient. In nearly all practical cases a gas core develops. The absence of a gas core generally results in an increase of the total pressure drop at the same throughput and a lovering of the efficiency.

The pressure drop in a hydrocyclone depends on the diameter (D_c), inlet velocity (U_i), liquid density (d_l), liquid viscosity (n), conical length (Z_c), and the shape factors (S).

$$(-\triangle P)\, g_c = f\, (D_c,\, U_i,\, d_l,\, n,\, Z_c,\, S_1,\, S_2,\, S_3,\, \ldots,\, S_n)$$

The shape factors are: $S_1 = \dfrac{D_i}{D_c}$

$$S_2 = \dfrac{D_o}{D_c}$$

$$S_3 = \dfrac{D_u}{D_c}$$

$$S_4 = \dfrac{L}{D_c}$$

$$S_5 = \dfrac{1}{D_c}$$

Ignoring temporarily the shape factors,

$$(-\triangle P)\, g_c = f\, (D_c,\, U_i,\, d_l,\, n,\, Z_c)$$

Application of the method of dimensional analysis:

$$(-\triangle P)\, g_c = C_1\, (D_c^{\,a}\, U_i^{\,b}\, d_l^{\,c}\, n^d\, Z_c^{\,e})$$
$$+ C_2\, (D_c^{\,a'}\, U_i^{\,b'}\, d_l^{\,c'}\, n^{d'}\, Z_c^{\,e'}) + \cdots$$

where a, b, c, d, and e are constant exponents and C_1, and C_2 are constants. Since the dimensions of each term in the series are identical, only the dimensions of the first term of equation need be considered for dimensional homogenity

$$(-\triangle P)\, g_c = C_1\, (D_c^{\,a}\, U_i^{\,b}\, d_l^{\,c}\, n^d\, Z_c^{\,e})$$

For each variable in the equation, substitution of the appropriate dimensions gives

$$\frac{\bar{F}}{\bar{L}^2} \; \frac{\overline{M}\,\bar{L}}{\bar{t}^2\,\bar{F}} = \frac{M}{\bar{L}\;\bar{t}^2}$$

$$= C_1 \, (\bar{L})a \, \left(\frac{\bar{L}}{t}\right)^b \, \left(\frac{\overline{M}}{\bar{L}^3}\right)^c \, \left(\frac{\overline{M}}{\bar{L}\,t}\right)^d \, (\bar{L})^e$$

Sum of the exponents for $\overline{M}$: $1 = c + d$

Sum of the exponents for $\bar{L}$: $-1 = a + b - 3c - d - e$

Sum of the exponents for $\bar{t}$: $-2 = -b - d$

Solving for a, b, and c in terms of d and e gives

$$c = 1 - d$$
$$b = 2 - d$$
$$a = -d - e$$

Equation than may be written

$$(-\triangle P)\; g_c = C_1 \, (D_c)^{-d-e} \, (U_i)^{2-d} \, (d_1)^{1-d} \, (n)^d \, (Z_c)^e$$

$$(-\triangle P)\; g_c = C_1 \, (U_i^2 \, d_1) \, \left(\frac{n}{D_c \, U_i \, d_1}\right)^d \, \left(\frac{Z_c}{D_c}\right)^e$$

$$\frac{(-\triangle P)\, g_c}{U_i^2 \, d_1} = C \, \left(\frac{D_c \, U_i \, d_1}{n}\right)^{-d} \, \left(\frac{Z_c}{D_c}\right)^e$$

By taking account of the shape factors,

$$\frac{(-\triangle P)\, g_c}{\dfrac{1}{2}\, U_i^2 \, d_1} = \left(\frac{D_c \, U_i \, d_1}{n}\right)^{-d}$$

$$\left(\frac{Z_c}{D_c}\right)^e \, \left(\frac{D_i}{D_c}\right) \, \left(\frac{D_o}{D_c}\right) \, \left(\frac{D_u}{D_c}\right) \, \left(\frac{L}{D_c}\right) \, \left(\frac{1}{D_c}\right)$$

SIGNIFICANCE OF DIMENSIONLESS GROUPS AND VALUES OF COEFFICIENTS

The pressure drop in hydrocyclones is in a form made up of several groups of variables, each of which is in itself dimensionless.

$N_{Re} = \dfrac{D_c \, U_i \, d_1}{n}$ is the Reynolds number. The coefficient of the Reynolds number determined by experiments, varying from $- 0.1$ to -0.5, but constant for every liquid. Therefore, the constant can be given as,

$$d = - 0.1 \text{ to } - 0.5$$

To avoid turbulence, $e = 0.7$.

$\dfrac{1}{2} d_1 U_i^2$ is the inlet velocity head. This is the dynamic pressure which pump should produce to accelerate the feed liquid from the position of rest to the inlet velocity U_i,

$$\frac{(-\triangle P) \, g_c}{\dfrac{1}{2} \, U_i^2 \, d_1} = \left(\frac{D_c \, U_1 \, d_1}{n} \right)^{-d}$$

$$\left(\frac{Z_c}{D_c} \right)^{0.7} \left(\frac{D_i}{D_c} \right) \left(\frac{D_o}{D_c} \right) \left(\frac{D_u}{D_c} \right) \left(\frac{L}{D_c} \right) \left(\frac{1}{D_c} \right)$$

It should be pointed out that this pressure drop correlation is valid only for hydrocyclones operating with an air core. When no air core is present this has in general the effect of increasing the pressure drop by a factor of two.

A SUMMARY OF THE UTILITY OF THE EUQTIONS PRESENTED

Bradley   [1]   : $\dfrac{(-\triangle P) \, g_c}{\dfrac{1}{2} \, U_i^2 \, d_1} = \dfrac{a^2}{m} \left[\left(\dfrac{D_c}{D_o} \right)^{2m} - 1 \right]$

Dimensionless, applicable to any size of cyclone and any proportions provided that the flow pattern constants m and a are known and the relationship between a and Q is known. Is an approximation to simplify the mathematical form of the equation. The approximation is likely to cause error in the case of large overflow diameters. Use of a slightly different diameter ratio as suggested by Tarjan could be more correct. a and m are factors dependent on cyclone design and fluid properties. a is also dependent on flowrate.

De Gelder [2]   : $Q = b \, A_i \left(\dfrac{2 \, (-\triangle P)}{d_1} \right)^{0.5}$

where $b = \dfrac{b\infty}{1 - \dfrac{j \, A_c}{6 \, A_i} \left(\dfrac{2}{N_{Re} \, \mathrm{Sin} \, \dfrac{\theta}{2}} \right)^{0.5}}$

b and j are factors dependent on cyclone design. The formula is dimensionless, applicable to any size of hydrocyclone. Probably limited to involute entry types though this should not be a severe limitation. Mathematically inconvenient in use.

Trawinski [3]   : $Q = K \, D_i \, D_o \left(\dfrac{(-\triangle P) \, g_c}{d_1} \right)^{0.5}$

where K is a factor which contains diameter ratios, friction loss and cone angle variables. Applicable to any size of hydrocyclone. Limited in use through insufficient published data on the constant K. Appears in the comparasion of this table to predict a low pressure drop for large angle cones.

Chaston   [4]   : $Q = 10\ A_i\ (-\triangle P)^{0.5} \pm 20\ \%$

Q (gal /min), A_i (in²), (– $\triangle$ P) (psi)

Empirical, applicable to a wide range of sizes of production hydrocyclones, preferably of wide cone angle, (20 or more). Likely to predict high due to the use of plant feed pressure data. Ignores the effects of change in overflow diameter and should, therefore, be used with caution in cases where overflow diameter proportions differ markedly from normal.

Dahlstrom [5]   : $Q/H^{0.5} = 6.38\ (D_o.D_i)^{0.9}$

Q (U. S. gal /min), H (ft of liquid), D_o and D_i (in) Constant later given as varying from 5.5 to 6.5, being higher with smaller cone angles or longer cylinder lenghts. Original equation determined empirically for a range of variations in D_o/D_u of 0.6 to 2.0. Widely and successfully applied.

Elcox   [6]   : : $Q = 24.7\ K\ D_i^2\ ((-\triangle P)/d_1)^{0.5}$

where K the discharge coefficient is 0.35. Q (gal /min), D_i (in), (– $\triangle$ P) (psi), d_1 (g /cc). Empirical, applicable to a wide range of sizes of production hydrocyclones, preferably of wide cone angle. Ignores the effects of change in overflow diameter and should therefore, be used with caution in cases where overflow diameter proportions differ markedly from normal.

Haas   [7]   : H = $\dfrac{0.07\ Q^{2.27}}{D_c^{0.8}\ D_i^{1.3}\ D_o^{2.0}}$

Q (U.S. gal /min), H(ft of liquid), D(in). Possibly limited to small diameter hydro-

cyclones, but may be of wider application. Takes no account of lenght or angle effects.

Yoshioka and Hotta [8] :
$$\frac{(-\triangle P)\ g_c}{\dfrac{1}{2}\ U_i^2\ d_1} = \frac{54.3\ (D_i/D_c)^{2.8}}{(D_o/D_c)^{1.9}}$$

Dimensionless, applicable to medium diameter hydrocyclones though possibly of wider application particularly since aperture effects are introduced with a relative size term rather than an absolute size term. Takes no account of length or angle effects.

Rietema [9, 10] :
$$\frac{(-\triangle P)}{\dfrac{1}{2}\ d_1\ U_i^2} = k_1\ (D_i/D_o)^{k_2}\ (D_c/L)^{0.7}\ (1 - R_f)^{0.8}$$

at N_{Re} inlet = 25000 . Dimensionless ; correlation developed from data on a single diameter of hydrocyclone though this should not be restrictive. Appears to be accurate, but accuracy is limited by necessity to interpolate values for constants, given graphically. The effects of alteration in hydrocyclone lenght are covered more adequately than by any of the other empirical equations.

The equation given in this article applicable to any size of hydrocyclone and any design, accurately.

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ÖZET

Sıvıda dağılmış olarak bulunan katının hidrosiklonla ayrılması hidrosiklonun boyutlarına, operasyon değişkenlerine, sıvının ve katı parçacıklarının fiziksel özelliklerine bağlıdır. Hidrosiklonun verimi, önemli bir operasyon-değişkeni olan hidrosiklondaki basınç-düşmesine bağlıdır. Bu makalede hidrosiklonlarda basınç düşmesi, hız yüksekliğine, Reynolds-sayısına, ve hidrosiklonun şekil-faktörlerine bağlı bir denklemle verilmiştir.