The Effect of Feed Concentration on the Performance of Hydrocyclones

by

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Abstract : Hydrocyclones have found wide application in many areas such as solid/liquid separation, powder classification and purification of minerals. The effect of solids concentration on separation performance of hydrocyclone is well recognised in practice but very little quantitative information exists in the literature. A brief review of the current knowledge in the area is followed by a proposal of a semi-empirical dimensionless correlation which relates the reduced cut size to the operating variables including the solids concentration. The validity of correlation is shown by comparison with the results of tests performed with 125 mm and 50mm diameter hydrocyclones at varying feed concentrations.

The equation proposed here allows scale-up and predicting of performance in application with feed concentration higher than 8% by volume when available theories cannot be applied.

1. Hydrocyclones :

Hydrocyclones have found wide application in various fields of technology, such as solid-liquid separation and powder classification. The basic principle employed in hydrocyclone is centrifugal sedimentation. Although centrifuges too use the same principle, unlike hydrocyclone, they have moving parts. In the case of hydrocyclones the necessary vortex motion is performed by the fluid itself.

2. Objectives of this work :

Theories and semi-empirical equations exist in the literature for predictions of grade efficiencies and pressure drops for hydrocyclones of a given design, operated under given flow rates with given solid and suspending liquid. Whilst these theories give reasonable predictions at very low feed concentration of solids they cannot be used at higher concentrations, which occur in most industrial applications. This paper consists of a proposal of a semi-empirical dimensionless correlation which relates the reduced cut size ($x'50$) to the operating variables including the solids concentration and the underflow-to-through put ratio.

3. Prediction of cut size :

Despite the difference in the assumptions made by different authors, most of the theoretical correlations in the literature can be shown to lead to the form

$$\frac{X'_{50}}{D_c} = K \left[\frac{\mu Dc}{Q \Delta P}\right]^{0.5} \qquad \text{..................(1)}$$

Where K is a constant for a given hydrocyclone design and it varies from 1.7×10^{-2} to 2.3×10^{-2}.

This equation and all other correlations hold good only when the feed concentration is low.

High solid concentrations have the following effects on the performance of hydrocyclones.

(*i*) hindered settling and thereby departure from Stoke's law;

(*ii*) an increase in the effective pulp viscosity.

(*iii*) even higher concentrations in the apex of the cone with resultant alteration of the character of the underflow stream.

(*iv*) change in pressure drop or capacity.

(*v*) change in flow pattern.

Most of the available equations are based on Stoke's law. This law refers to streamline flow conditions and also is a relationship for the unhindered movement of single particles. These conditions do not prevail at higher feed concentrations. Consequently, those equations fail when the solids concentration of the feed is high.

The solid content of the feed was found to be the variable which influenced the X'_{50} size the most. Since the settling velocity is a function of the size of a particle, the exponential form of the relationship between the cut size and the concentration is a possibility. The equation suggested by Plitt relating cut size to the hydrocyclone variable is :

$$X_{50} = \frac{35_{Dc}^{6.46} \quad D_i^{0.6} \quad Do^{2.21} \quad \exp^{(.0636c)}}{D_c^{6.71} \quad h^{0.38} \quad Q^{0.45} \quad (P_s - P_f)^{0.5}} \qquad \text{..................(2)}$$

When the concentration of feed is the only operating variable for a given hydrocyclone, this equation reduces to

$$X_{50} \sim \exp \; KC \qquad \text{..................(3)}$$

Where K is a constant

C is the concentration of the feed.

Bradley had obtained the following relationship between the cut size and the operating variables.

$$X_{50} = 3(0.38)^n \; D_i^2 \; \frac{\tan\frac{\theta}{2} \; \mu(1-R_f f)^{\frac{1}{2}}}{D_c \; Q\Delta P} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Which for a fixed design and size of cyclone and constant flow rate becomes

$$X_{50} \sim (1-R_f)^{\frac{1}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Combining equations (1), (3) and (5) we get :

$$\frac{X_{50}}{D_c} = K_1 \left[\frac{\mu D_c}{Q\Delta P}\right]^{\frac{1}{2}} (1\text{-}R_f)^{\frac{1}{2}} \exp K_2C \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Equation (6) could be a useful one for design purposes because at present there are no adequate means to predict the performance of hydrocyclones at higher concentrations. A series of test runs were carried out using a test rig installed at the University.

4.0 Description of the test apparatus :

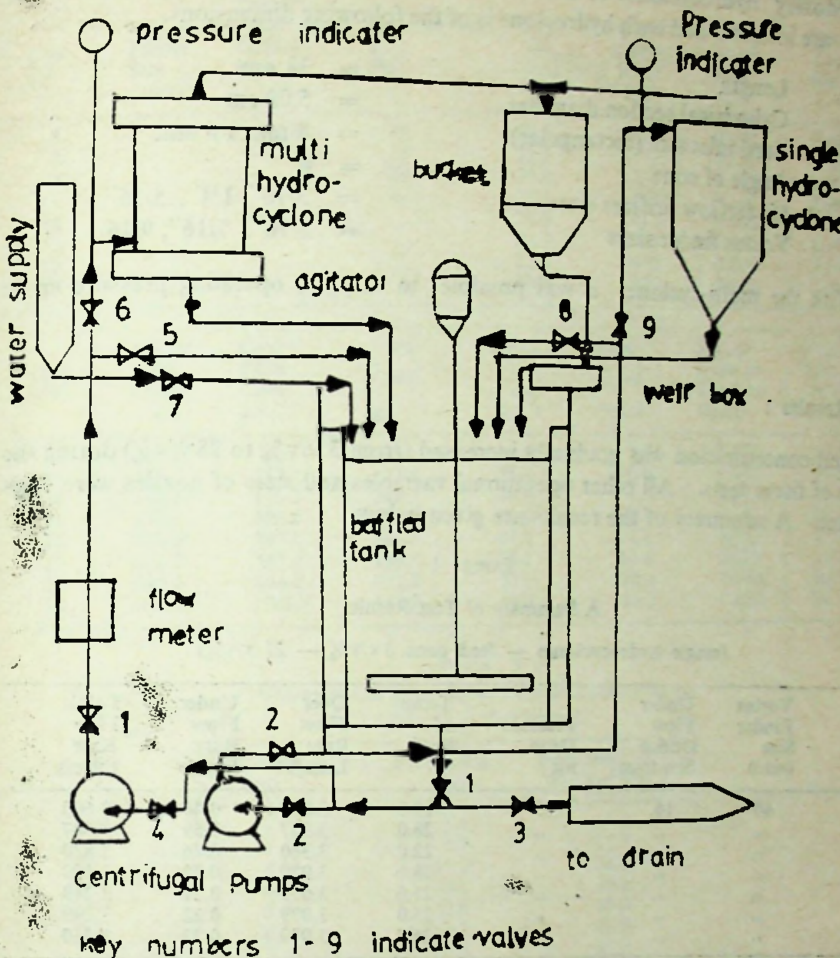
Figure 1 shows the flow diagram of the test rig. It consists of a 300 litre baffled tank and a weir box which collects overflow from the two hydrocyclones (single and multiple), and overflows into the tank. The tank is kept about 2/3 full with a slurry of calcium carbonate. An agitator is used to keep the fine solids in suspension. The agitation created by re-circulation of the slurry also helps the conditions within the tank to be nearly homogeneous. The feed is pumped through the hydrocyclones using centrifugal pumps. The particle size distribution of the feed is shown in Figure 2.

4.1 Single Hydrocyclone :

This hydrocyclone, model RW 2515, is manufactured by AKW of West Germany. The whole cyclone is made from vulkolan (a polymer based on polyurethane), the underflow nozzle is simply pushed to the cyclone apex and secured by a cap. The dimensions of the hydrocyclone are :

Length	=	78 cm
Cylindrical section length	=	28 cm
Underflow diameter	=	1.6 cm
Cylindrical section diameter	=	12.5 cm
Vortex finder diameter	=	4 cm
Feed inlet diameter	=	2.52 cm
Angle of cone	=	15°

The maximum feed pressure employed was 15 psi because the bucket collecting the overflow stream from the hydrocyclone would otherwise overflow at higher feed pressures.



A FLOW DIAGRAM OF THE TEST RIG

FIG. 1

4.2 Multi-hydrocyclone :

The multi-hydrocyclone is that of Mozley 2'' assembly. The assembly consists of 4 Mozley hydrocyclones of diameter 2'', placed in parallel. All the hydrocyclones are identical and each hydroclone is of the following dimensions.

Length	=	38 cm
Cylindrical section diameter	=	5.08 cm
Feed inlet size (rectangular)	=	8 mm x 6 mm
Angle of cone	=	6'
Underflow orifices sizes	=	3/16'', 1/4'', 5/16''
Vortex finder sizes	=	5/16'', 7/16'', 9/16''

With the multi-cyclone, it was possible to vary the operating pressure up to 30 psi.

5.1 Results :

The feed concentration was gradually increased (from 3 v/v% to 28 v/v%) during the course of these tests. All other operational variables and sizes of nozzles were kept constant. A summary of the results are given below.

TABLE 1

A Summary of Test Results

(single hydrocyclones — feed conc. 3 v/v% — 27 v/v%)

Exp. No.	Vortex Finder Size (mm)	Under Flow Orifice Size (mm)	Pressure Drop psi	Temp of Feed °C	Over Flow Rate Litre/s	Under Flow Rate Litre/s	Total Flow Rate Litre/s
1	40	16	15	19.0	3.140	0.46	3.600
2	,,	,,	,,	28.0	3.357	0.59	3.947
3	,,	,,	,,	22.0	3.360	0.46	3.820
4	,,	,,	,,	28.0	3.079	0.22	3.299
5	,,	,,	,,	25.0	3.079	0.21	3.289
6	,,	,,	,,	25.0	3.079	0.22	3.299
7	,,	,,	,,	26.0	3.079	0.23	3.310

Exp No.	Under Flow Conc. g/l	Overflow Conc. g/l	Feed Conc. g/l	Under Flow Conc. v/v%	Feed Conc. v/v%	Under Flow to Thruput Ratio Rf	Total Efficiency %
1	105.9	78.0	81.5	4.1	3.1	0.166	12.8
2	165.9	83.4	95.8	6.5	3.7	0.260	15.1
3	441.0	262.9	316.0	19.4	13.2	0.168	12.0
4	712.9	398.1	418.2	35.5	18.2	0.064	10.8
5	746.5	475.8	492.7	37.6	22.0	0.064	9.6
6	753.0	520.7	536.2	38.5	24.6	0.067	9.4
7	761.6	573.3	586.5	39.0	27.5	0.069	9.1

TABLE 2

A Summary of Test Results

(multihydrocyclone - feed conc. 3 v/v% — 27 v/v %)

Exp No.	Vortex Finder Size (in)	Under Flow Orifice Size (in)	Pressure drop Psi	Temp of Feed °C	Over Flow Rate L/S	Under Flow Rate L/S	Total Flow Rate L/S
8	9/16	3/16	28	20.0	2.351	0.140	2.491
9	,,	,,	28	25.5	2.473	0.130	2.603
10	,,	,,	29	24.0	3.210	0.143	3.353
11	,,	,,	30	24.0	2.412	0.140	2.552
12	,,	,,	,,	23.0	2.412	0.140	2.552
13	,,	,,	,,	20.0	2.455	0.200	2.745
14	,,	,,	,,	22.0	3.445	0.200	3.644
15	,,	,,	,,	24.0	2.070	0.184	2.254

Exp. No	Under Flow Conc. g/l	Over Flow Conc. g/l	Feed Conc. g/l	Under Flow Conc. %v/v	Feed Conc. %v/v	Under Flow to Thruput Ratio	Total Eff. & %
8	386.6	75.6	93.1	16.6	3.7	0.056	23.3
9	556.7	132.8	153.1	25.8	6.0	0.048	17.5
10	832.1	176.3	204.3	44.3	8.2	0.043	17.4
11	826.9	182.6	218.0	43.9	8.8	0.055	20.8
12	871.5	247.8	282.0	47.5	11.6	0.055	17.0
13	886.3	347.7	386.9	48.1	16.6	0.073	16.7
14	949.2	464.2	491.2	53.9	22.1	0.054	10.6
15	1010.0	528.9	568.2	59.3	26.5	0.082	14.5

TABLE 3

Values of Cut Size Against Feed Concentration

(*Single hydrocyclone*)

Experimental No.	Feed Conc. v/v %	Reduced Cut Size X_{50} μm
1	3.1	11.2
2	3.7	15.7
3	13.2	28.8
4	18.2	36.5
5	22.0	39.0
6	24.7	42.0
7	27.5	47.0

TABLE 4

Values of Cut Size Against Feed Concentration

(*multi hydrocyclone*)

Experimental No.	Feed Conc. v/v %	Reduced Cut Size X_{50} μm
8	3.7	10.4
9	6.0	14.4
10	8.2	17.9
11	8.8	18.5
12	11.6	20.0
13	16.6	20.5
14	22.1	23.0
15	26.5	29.5

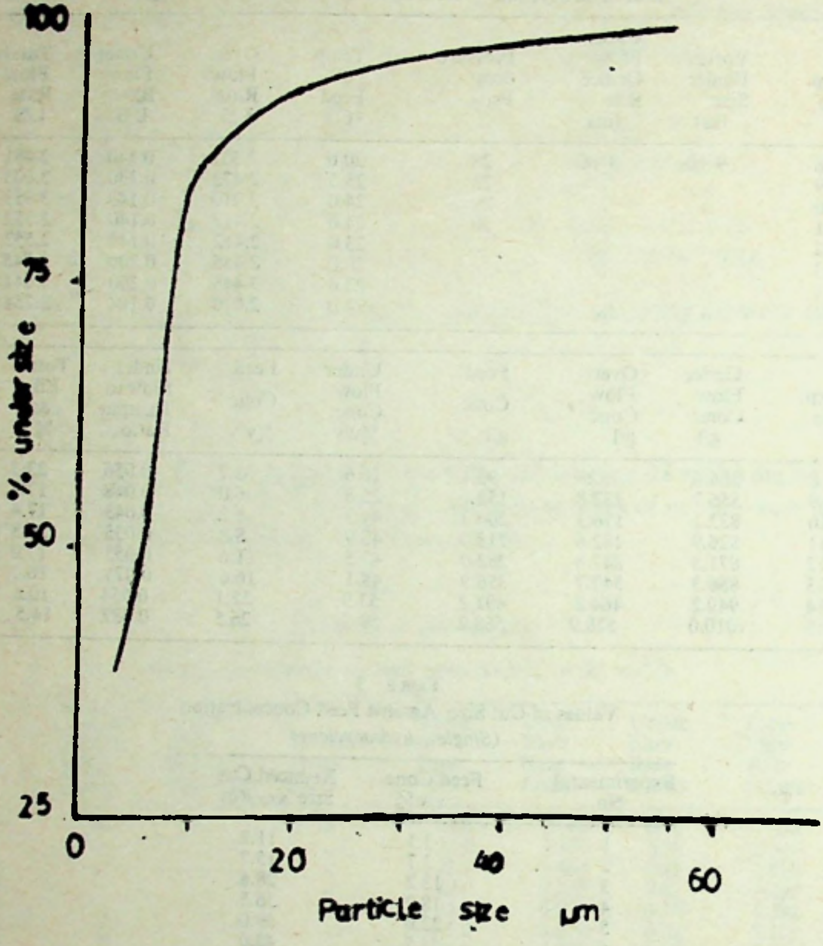


FIG-2. Particle size distribution of the feed

Table 5

Type of Hydrocyclone	k_2	k_1
Single D_c = 12.5cm	3.2307	0.03578
Multiple (set of 4) D_c = 5 cm	2.304	0.046

5.2 Discussion :

Comparison of experimental data with Equation 6 (fig. 3 and 4) shows that at higher feed concentration (>8v/v %), there is a good agreement between the experimental values and those predicted by the Equation. The maximum differences are 4.53% and 7.19% for single and multi hydrocyclones respectively.

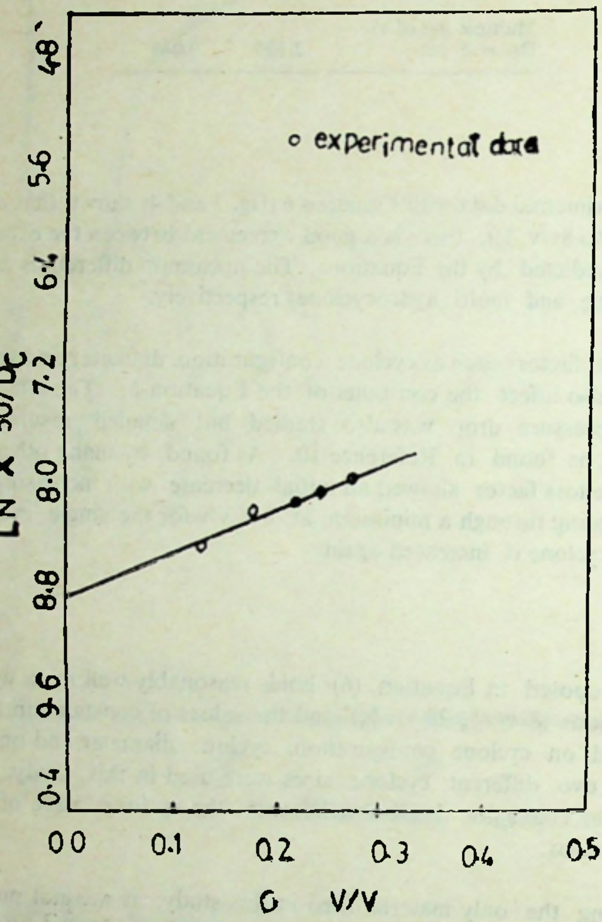
It is thought that factors such as cyclone configuration, diameter and the materials of feed may also affect the constants of the Equation 6. The effect of feed concentration on pressure drop was also studied but detailed results are not given here and can be found in Reference 10. As found by many other workers before, the pressure loss factor showed an initial decrease with increasing concentration and after going through a minimum at 8% v/v for the single cyclone and 12% for the multi-cyclone it increased again.

6. Conclusions :

The correlation proposed in Equation (6) holds reasonably well for a wide range of feed concentrations (8 v/v% 28 v/v%) and the values of constants in the correlation may depend on cyclone configuration, cyclone diameter and on the feed solids. Although two different cyclone sizes were used in this study, the effect of cyclone diameter could not be shown because the cyclones were of different geometric proportions.

Limestone being the only material used in this study, it was not possible to examine the effect of feed material and its properties but, in analogy with hindered settling under gravity, it is very likely that this effect is appreciable. Further work is now necessary to establish the above mentioned relationships so that the proposed equation can be used in scale-up.

The pressure loss of hydrocyclones is influenced by the concentration of feed. Although initially there is a decrease in pressure loss along with the increase in feed concentration which is due to suppression of turbulence and changes in flow profiles by the presence of particles, at higher concentrations pressure loss increases with increase in feed concentration when the effect due to the increase in effective viscosity becomes predominant.



FIG·3 comparison of data obtained using single-hydrocyclone with equation 6

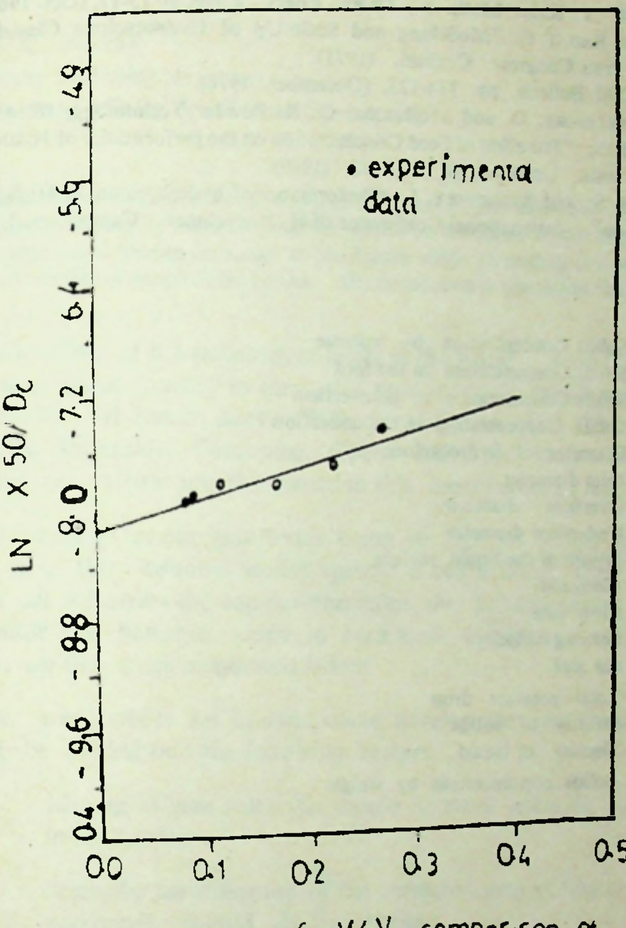


FIG. 4 : comparison of equation 6 with experimental data obtained using multi hydrocyclone

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Nomenclature :

C	Solids Concentration by volume
C_f	Solids Concentration in the feed
C_o	Solids Concentration in the overflow
C_u	Solids Concentration in the underflow
D_c	Diameter of hydrocyclone
D_i	Inlet diameter
D_o	Overflow diameter
D_u	Underflow diameter
H	Height of the liquid surface
$K_1 K_2 K$	Constants
Q	Flow rate
V	Settling velocity
X_{50}	cut size
Δ_p	Total pressure drop
P_s	Density of solids
P_f	Density of liquid
ϕ	Solids concentration by weight