Design and Fabrication of Hydrocyclones Using Krebs Mathematical Model

Hettiarachchi RNDS, Liyanaarachchi KR, Lokubalasooriya LBAM, Merza AAMIMA, Thinesh S and *Fernando WLW
Department of Earth Resources Engineering, University of Moratuwa
*Corresponding author - wlwf2002@yahoo.com

Abstract: Hydrocyclone is one of the most important devices used in mineral processing industry. It is a continuously operating classifying device that utilizes centrifugal, gravitational and inertial forces to classify particles. The cut point (d_{50}) of a Hydrocyclone is the particle size at which 50% of particles in the feed of that size report to the underflow. There are a number of empirical relationships which are used for designing Hydrocyclones and in this research a parallel circuit of four Hydrocyclones were designed and fabricated by using Mular and Jull's Krebs mathematical model. In practice, the cut point is mainly controlled by Hydrocyclone design variables such as cyclone diameter, inlet diameter, vortex finder diameter and apex diameter. Krebs model provides relationships among these design variables. Disordered Kaolinite (Ball Clay) suspensions of 7% and 5% solids concentration were prepared and subjected to classification in the fabricated battery of Hydrocyclones. The resulting Hydrocyclone overflows were evaluated by Andreasen Pipette Method against predetermined d_{50} values, which were calculated by using the Krebs equation for d_{50}. The average recovery of less than 14 and 13 micron fractions were 98.96% and 94.28% respectively for the ball clay suspensions of 7% and 5% solid concentrations.

Keywords: Classification, cut point, hydrocyclone, prototype

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1. Introduction

In Sri Lanka, the ceramic industry is experiencing a shortage of china clay and ball clay and as a result these vital raw materials have to be imported at exorbitant prices draining country's valuable foreign exchange.

However, there are deposits available in the country which are owned by private parties. Due to the lack of knowledgeof processing, most of the deposits are under-utilized causing an immense loss of this valuable mineral. By water dispersion and size separation clay can be up-graded and the resulting value added clay can be sold and even exported at a higher price. The most important stage in the clay processing is a particle size control. This can be achieved through hydrocyclones.

Fernando WLW, B.Sc.(Cey), M.Phil.(Leeds), Ph.D.(Leeds), A.I.Ceram(UK), M.I.Ref.Eng.(UK), MIMM(UK), C.Eng.(UK), F.I.ChemC, C.Chem.(Cey), Senior Professor in Department of Earth Resources Engineering, University of Moratuwa.
***Hettiarachchi RNDS, Liyanaarachchi KR, Lokubalasooriya LBAM, Merza AAMIMA, Thinesh S,** Final year Undergraduate students in the Department of Earth Resources Engineering, University of Moratuwa.*

The hydrocyclones are devices which can be properly designed and fabricated to obtain particles of any size range at micron size levels including kaolin or ball clay. As there are no sieves to operate effectively at these size ranges, the best solution is to design pilot plant with cyclones using the Krebs model. In this research a parallel circuit of hydrocyclones was designed using this model and tested so that the final products conforming to particle sizes less than 15 microns were obtained, which can be utilized in industries such as ceramics, rubber, paper, plastics and pharmaceuticals.

2. Methodology

Four cyclones and a suitable rig were designed and fabricated. Dimensions of cyclones were calculated by the mathematical model of Mular and Jull (B A Willis 1985), with the data feeding into a computer program (Cyclone), developed by ourselves. The design diagram was drawn (Figure 3) and hydrocyclones were fabricated (Figure 4). The following relationships were taken in to consideration to determine the dimensions of hydrocyclone.

$$Di = \sqrt{0.05}\,Dc \quad \text{... (1)}$$

$$Do = 35\%\,Dc \quad \text{... (2)}$$

$$Du = 25\%\,Dc \quad \text{... (3)}$$

$$\frac{l}{Dc} = 0.4 \quad \text{... (4)}$$

$$h = \frac{Dc}{2} \quad \text{... (5)}$$

$$L = \frac{Dc\left(1 - \tan\frac{\theta}{2}\right) - Du}{2\tan\frac{\theta}{2}} \quad \text{....(6)}$$

$$\theta = 20^0 \quad \text{... (7)}$$

Where, Dc, Di, Do, Du are diameters of cyclone body, inlet, vortex and underflow respectively, L- height of the cyclone, h- height of the cylindrical portion, θ-included angle of the conical portion and l- height of the vortex finder.

The four cyclones were assembled symmetrically in parallel so as to have the same feed and slurry pressure getting equally distributed to all the cyclones. Initially, the unit (Figure 1) was tested with water for any leaks. This step is vital before conducting the trial with the slurry. As there was no slurry pump available to feed the clay slurry in to the cyclones under pressure, a 200 litre plastic tank was modified with the usual fittings to store the slurry and was kept at a higher elevation so as to provide the required pressure drop and the feed rate when in operation.

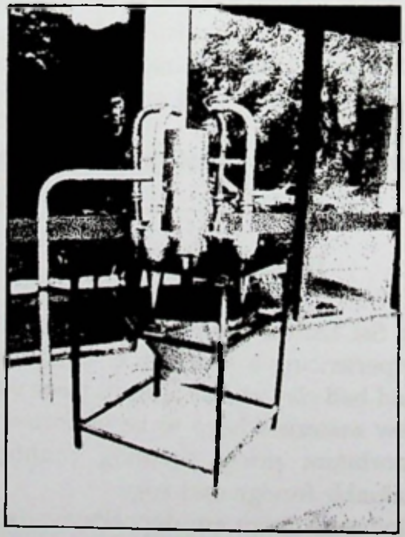

Figure 1 – Battery of Four Cyclones

Suspension of ball clay was made by sieving ball clay slurry through 250 micron mesh and the underflow was taken to fill the 200 litre tank. After assembling the pilot plant (Figure 2) and having checked for no leaks, the suspension was fed in to the battery of cyclones.

During the first few seconds of operation, attempt was made not to sample the product as the system was allowed to come in to equilibrium and thereafter slurry from the overflow was recovered, sampled and tested for particle size.

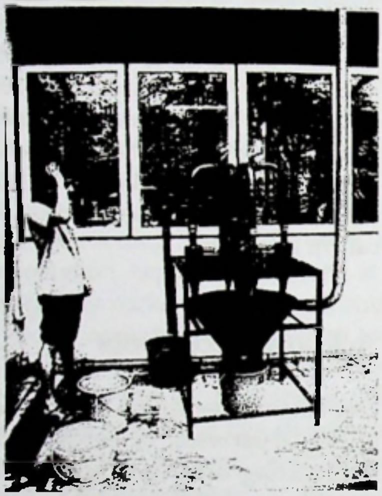

Figure 2 – Conducting the Test

Particle size determination was made by using the sedimentation technique in line with Andreasen pipette method as shown already (Grimshaw 1971). In the particle size analysis by Andreasen Pipette Method, time taken to settle (t) a specific particle size (d) was calculated by Stokes' law.

$$t = \frac{18\eta x}{d^2(\rho - \sigma)g} \quad \ldots (8)$$

$\eta = 0.01$poise, $x = 20$cm, $\rho = 2.4$g/cm^3,

$\sigma = 1.0$ g/cm^3 and $g = 981$cm/s^{-2}

On substituting the above, we have:

$$t = \frac{2.6212 \times 10^{-3}}{d^2} \quad \ldots (9)$$

Table 1 – Settling Time for Cut Point

Slurry	Cut Point (micron)	Settling Time
7%	14	22m 17s
5%	13	25m 51s

3. Results

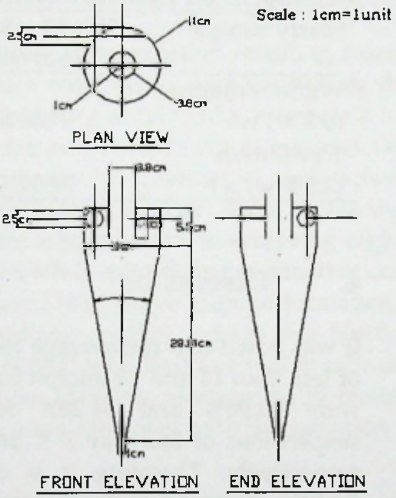

Figure 3 – Design Diagram for Hydrocyclone

Figure 4 – Designed Hydrocyclone

Table 2 - Andreasen Test Results for 7% Suspension Cyclone Overflow

Slurry Sample	% < 14 micron Recovery
Without dilution (7% w/w)	99.24%
1:1 dilution (3.5% w/w)	98.68%

Table 3 - Andreasen Test Results for 5% Suspension Cyclone Overflow

Slurry Sample	% < 13 micron Recovery
Without dilution (5% w/w)	94.44%
1:1 dilution (2.5% w/w)	94.12%

4. Discussion

It was noted that the average recovery of less than 14 and 13 micron fractions were 98.96% and 94.28% for the suspensions of ball clay 7 % and 5 % respectively. Therefore it is evident that the designed hydrocyclones have attained the desired cut points as anticipated. This can be considered as a very good achievement.

There can be some fraction of particles less than the cut point reporting to the underflow. Therefore, the underflow from this battery of hydrocyclones can be fed in to a secondary circuit of hydrocyclones in order to enhance the recovery when implemented in the industrial scale.

However, the focus of the research was to provide a basis to specify a Hydrocyclone to achieve a particular 'cut point' with the aid of Krebs mathematical model. The evaluation of hydrocyclones by Andreasen Pipette Technique has proved that the objectives of the research were successfully accomplished.

5. Conclusions

It has been shown that by using the Krebs mathematical model hydrocyclones can be fabricated and used in industry. They are most suitable devices for the industry in a developing country like Sri Lanka, mainly because they are simple and inexpensive to manufacture. Though the product that is subjected to classification is clay, it can be utilized for mineral particles such as calcite, soapstone and others which are having very wide industrial applications as fillers a coating pigments and in pharmaceuticals as carrier minerals.

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