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Modified hydrocycloning for effective elimination of stubborn slimes

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ABSTRACT

The present paper deals with the skillful exploitation of the extremely high shear-fields inside a hydrocyclone to effectively eliminate a sticky slime from a phosphate ore before beneficiating the coarser fraction using conventional mineral processing techniques. Earlier studies on samples of the same ore at NML and abroad established that it was necessary to pass the ore through a series of three stages of desliming, each consisting of a step of rigorous attrition scrubbing followed by hydrocycloning, for effective elimination of the slime. With the new approach,by innovative modifications on the standard hydrocyclone design, it was possible to eliminate all the stages of attrition scrubbing while minimising the stages of hydrocycloning. It could be established that the modified technique not only yielded concentrate of grade comparable to that obtained by employing the earlier more complex flowsheet, it also improved the P_2O_5 recovery.

INTRODUCTION

The simple device, hydrocyclone, puts the slurry in it through very complex multidirectional force fields. A number of different theoretical approaches to predict the resulting hydrocyclone performance have been surveyed by Bradley [1] and Svarovsky [2]. However, because of insufficient knowledge of the basic flowfields all of them are approximate and / or empirical in approach. In fact, the use of hydrocyclone has grown steadily during the past years without corresponding increase in the understanding of the fundamental principles of its operation. Therefore, investigators try to encompass and define all the parameters influencing the performance of a hydrocyclone. The aim of these studies has been to create appropriate mathematical models through which the function of hydrocyclone in different processes and with different raw materials could be simulated. Actually, proper understanding of the influence of the force fields on the solid particles and the liquid inside the hydrocyclone may lead to innovative modifications on the basic system to achieve specific results.

Hydrocyclone, in its conventional form, has got some limitations in performance. Deviations from conventional design have also been reported to overcome these limitation and to achieve desirable results for different types of applications viz., lighter dispersions from heavy continuous medium [3,4], the twin vortex cyclone (TC cyclone) for classification [5,6], wide range of variations in the ratio of cylindrical to conical sections for classification, thickening and preconcentration [7] etc., to mention a few. In case of lighter dispersions, a swirl chamber and very small included angle for the conical (taper) section followed by very long cylindrical (downstream) section was used for oil separation (< 1%) from water. For TC - cyclone, cylindrical upper body and a lower wash water section together with a secondary cyclone were used to control the high by-pass of conventional hydrocyclone. While considering the ratio of cylindrical to conical section, effects of very small to very large ratios were examined for different types of applications.

In a recent study at NML on a phosphatic ore of very poor grade (assaying about 10 % P_2O_5), it was observed that getting rid of the slime was as important for adequate beneficiation of the ore, as it was difficult. The ore occured as a naturally degraded soil deposit and the slime contained earthy lateritic minerals which made it extremely sticky. Earlier studies on samples of the same ore at NML and abroad established that it was necessary to pass the ore through a series of three stages of desliming, each consisting of a step of rigorous attrition scrubbing followed by hydrocycloning, for effective elimination of the slime.

In the present study, attempts were made to use hydrocyclone for dual purposes, attrition scrubbing and desliming simultaneously. The high shear-field created inside the hydrocyclone was utilised for attrition scrubbing by providing a sufficiently large space at the cyclone's cylindrical portion, which was specially modified for this purpose. The conventional lower part (conical section) was, of course, there for desliming after attrition scrubbing. The modified hydrocyclone design when operated with higher inlet pressure, in comparison to earlier studies, was found to improve the performance of the flow sheet to a great extent.

SAMPLE

The sample came from a lateritic soil-type phosphate deposit derived from carbonatite complexes. Such deposits occur at Araxa, Catalao-1 and Tapira in Brazil, Sokil in Finland, Cargill and Martison in Canada and Sukulu in Uganda [8]. These are residual soils developed by weathering of carbonatities and other magmatic and metasomatic rocks of alkaline, intermediate and ultramafic composition [8].

During weathering a large amount of calcium, magnesium, sodium, potassium and a fair amount of silica, that are released from these rocks, are removed by carbonated water [9]. The major part of iron and aluminium remains as colloidal precipitates of ferrous oxides, hydroxides, hydrous aluminium silicates (clay) and aluminium hydroxides [9,10]. These insoluble residues along with the enriched primary/secondary phosphates, quartz and other minerals form the deposits [9,10].

Intimate association of the lateritic material (iron and aluminium oxides and hydroxides) with the other minerals results in the reddish brown appearence of these deposits. The lateritic scales, stains or encrustations are often so firmly attached to the other mineral grains that they could be released only by resorting to grinding as is reportedly the practisce at the Araxa plant in Brazil [11].

Microscopic examination revealed the presence of limonite, magnetite (martitised), hematite, and goethite as major minerals along with apatite and quartz. Presence of clay was indicated by earthy smell on moistioning the sample. The chemical analysis of the sample is shown in Table 1 and the sieve analysis of the ROM ore sample is given in Table 2 [12].

Earlier Studies

To develope a flowsheet for the beneficiation of the phosphatic soil, studies were carried out at NML in two phases. In the first phase, the reproducibility of the results obtained by employing a flowsheet developed abroad was confirmed along with suggesting some modifications of the flowsheet. Then 200 kg of concentrate was produced following the recommended flowsheet for evaluation of its suitability for production of fertilisers.

Table 1 : Chemical Analysis of the as-received sample

Constituent	Wt(%)
P_2O_5	10.33
Fe(T)	22.32
Fe_2O_3	31.90
SiO_2	19.60
Al_2O_3	15.40
CaO	11.01
MgO	0.50
BaO	0.20
LOI	8.15

Table 2 : Size analysis of the as-received sample

Size, micron	Wt(%)
+ 840	4.6
– 840 + 590	4.9
– 590 + 420	5.7
– 420 + 300	5.1
– 300 + 210	6.5
– 210 + 151	16.9
– 151 + 100	8.3
– 100 + 74	10.6
– 74 + 44	10.0
– 44	27.4
Total	100.0

To remove the limonitic slimy coating, which stubbornly adhere to the other mineral grains, it was necessary to subject the ROM ore, after screening out the +840 micron size fraction, to three stages of hydrocycloning (50 mm size) each preceded by attrition scrubbing. Then only conventional beneficiation techniques could be effectively employed to upgrade the ore. The cyclone was operated at about 5 psig pressure in all the three stages. After desliming, 43.26 % of ROM ore was obtained as cyclone underflow assaying 13.87% P_2O_5 with recovery of 59.47% P_2O_5 in it [12].

Desliming with Modified hydrocyclone

Observations during the campaign to produce the 200-kg concentrate for evaluation indicated that bigger cyclones could be more useful for desliming the -840 micron size fraction of the ore. At the same time, the possibility of using the higher shear-force for scrubbing inside the hydrocyclone was also considered. Consequently, attempts were made to study the efficacy of a bigger cyclone with extended cylindrical portion to serve the dual purposes of attrition scrubbing (to dislodge the slimy coating) and desliming simultaneously. Inlet pressure was maintained at around 2.5 times that of earlier studies to create the high shear fields for proper attrition scrubbing as well as to attain a lower cut to minimise loss of value. Both, one stage and two stage hydrocycloning were done to compare the extent of desliming achieved at different stages.

RESULTS AND DISCUSSION

The -840 micron size fraction of the ROM ore was deslimed using a 75-mm hydrocyclone with an extended cylindrical section (nearly four times the conventional design), keeping the feed pressure at 12 psig. It was observed that an underflow (64.5% of the feed by weight) assaying 12.83% P_2O_5 with recovery of 80.2 % P_2O_5 in it could be produced, while the overflow assayed 6.22% P_2O_5. This result was better than that obtained after two stages of attrition scrubbing, each followed by hydrocycloning in the earlier studies (Table 3). From the particle size distribution of the products after single stage modified hydrocycloning (Table 4) it was observed that the slime contained more than 80% –10 micron size particles in it. Using the same cyclone design parameters but with slightly higher operating pressure, the second stage hydrocycloning produced an underflow weighing 90.23% of the stage-feed, assaying 13.3% P_2O_5 with a recovery of 93.5% P_2O_5 with respect to the stage-feed, i.e., 75% with respect to the ROM ore (Table 3). Particle size distribution of the products and the cyclone partition curve for the second stage of hydrocycloning are given in (Table 4) and Fig. 1 respectively. The data indicated that the system could effect a sharp cut at about 10 micron size, and that the final slime contained over 87% particles finer than this size.

Table - 3. Comparison of performance of earlier and modified circuits

Circuit	Stage	Product	% Wt (wrt.O)	Assay % P_2O_5	Distribution % P_2O_5 (wrt.O)
Earlier	I	O F	22.90	7.33	16.64
		U F	73.76	11.32	82.75
	II	O F	17.5	7.17	12.44
		U F	56.26	12.61	70.31
	III	O F	13.0	8.4	10.82
		U F	43.26	13.87	59.47
Modified	I	O F	32.2	6.22	19.4
		U F	64.5	12.83	80.2
	II	O F	6.3	8.46	5.17
		U F	58.2	13.3	75.0

Comparing the particle size distributions of the cyclone products obtained by employing the earlier flowsheet (Table 5) [12] and the modified circuit (Table 4) it was observed that more fines were rejected in the overflow and less retained in

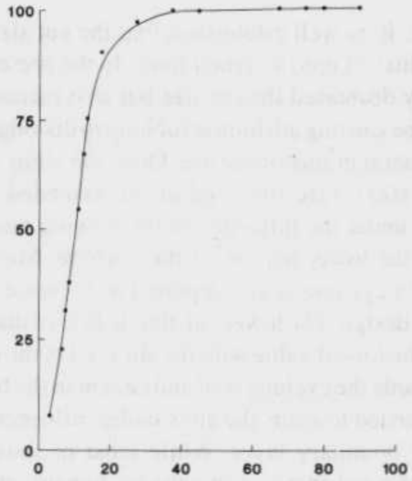

Fig. 1 : Cyclone partition curve (modified desliming –2nd stage).

the underflow of the modified circuit. Similarly, a comparison of performance of the earlier and the modified circuits (Table 3), indicated that the latter was more efficient of the two, since it yielded concentrates with higher P_2O_5 recoveries at comparable grades.

Table 4 : Size analyses of cyclone products of modified design

Size, microns	Products			
	Cy. U/F (1st stage)	Cy. O/F (1st stage)	Cy. U/F (2nd stage)	Cy. O/F (2nd stage)
+590	0.5		1.0	
+420	11.5		17.0	
+300	13.5		18.0	
+224	12.5		13.0	
+151	8.5		10.0	
+101	13.5		11.5	
+75	10.39		6.0	
+46	5.49		6.84	
+31	5.94	0.3	7.1	0.3
+21	6.93	1.9	5.4	1.8
+9.5	4.89	16.2	1.97	10.8
9.5	6.36	81.6	2.19	87.1
Total	100.00	100.0	100.00	100.0

In a hydrocyclone, it is well established that the cut size decreases with increase in feed rate (Plitt [13]) upto a certain limit. In the present study, increase in feed pressure not only decreased the cut size but also increased the shear forces inside the hydrocyclone causing attrition scrubbing to dislodge the limonitic slimy coatings from the mineral grains of the ore. Once the slimy coatings (more than 80% <10 micron in size) were liberated at the extended cylindrical portion, desliming took place under the influence of the varying tangential, vertical and radial force fields at the lower portion of the cyclone. Moreover, the extended cylindrical section of a cyclone is also reported to decrease the cut size as compared to conventional design. The lower cut, thus achieved due to modified design, helped in restricting the loss of value with the slimes. On the otherhand, the larger particles, thrown towards the cyclone wall and caught in the boundary layer inside the conical part are carried towards the apex under influence of the pressure distribution outside the boundary layer. While most of those particles join the underflow, because of rapid increase in velocity towards the apex, few get deflected and join the overflow depending on cut size [14].

Table 5 : Size analyses of cyclone products in earlier studies

Size, microns	Products					
	Cy. U/F	Cy. O/F	Cy. U/F	Cy. O/F	Cy. U/F	Cy.U/F
	(1st stage)		(2nd stage)		(3rd stage)	
+590	3.3		4.28		4.73	
+420	5.55		7.27		7.38	
+300	5.18		4.69		5.29	
+224	8.26		8.22		7.30	
+151	13.56		11.83		8.28	
+101	11.10		9.42		10.46	
+75	8.38		8.70		10.81	
+46	1.83	2.40	2.76	3.20	4.19	3.10
+31	3.62	4.00	3.37	5.30	5.11	6.20
+21	4.46	10.60	4.29	6.80	5.25	7.70
+9.5	9.20	12.90	10.53	10.00	8.27	12.00
−9.5	25.53	70.10	24.64	74.70	22.93	71.00
Total	100.00	100.00	100.00	100.00	100.00	100.00

Further, with increasing feed rate the Reynolds number of the feed slurry also increases and more and more larger particles report to the underflow. But at considerably high Re, no further improvement in efficiency can be attained because increasing amount of coarser particles are deflected towards the overflow. This happens because the boundary layer attains a constant minimum boundary layer thickness near the apex-end of the cyclone [15]. Any coarse particle which, during its downward journey near the apex, comes out of this boundary layer is trapped in the inner spiral (solid body rotating liquid column) and is transported towards the overflow. Thus, very high Re leads to lower efficiency of separation in a cyclone. The inlet pressure was, therefore, controlled carefully to enhance the performance of modified hydrocyclone circuit when operated with the phosphatic soil sample. To choose the proper inlet pressure, a critical balance had to be struck between the beneficial and detrimental effects of increasing Re on the efficiency of separation.

CONCLUSIONS

In the above study it has been established that hydrocyclone can be used successfully to serve the dual purposes of attrition scrubbing and desliming simultaneously, for effective elimination of stubborn slimes.

Two innovative modifications led to efficient attrition scrubbing – (i) increased feed pressure and (ii) use of an extended cylindrical portion of the cyclone. The desliming that took place in the lower conical portion of the cyclone was also improved due to the combined effect of the above two innovations. The net result was a 25% higher P_2O_5–recovery (at similar grades) as compared to the earlier circuits.

Achieving attrition scrubbing and desliming simultaneously in a hydrocyclone is a novel development established through the present studies.

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