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Processing of chromite ultra-fines in a water only cyclone

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ABSTRACT

In the present investigation, an attempt is made to examine the interdependencies among the operating parameters and their interactional effect on the separation performance of a water-only cyclone for treating ferruginous chromite fines. Statistically designed experiments are carried out, and empirical models are developed for the critical response parameters, i.e., yield (%) to underflow, grade (%Cr_2O_3 and%SiO_2) and Cr:Fe ratio of the underflow stream. Further, using these empirical models, operating regime of the process parameters is optimized to obtain the peak performance of water-only cyclone. Also, efforts are made to validate the prediction models with the experimental results.

1. Introduction

In water-only cyclone (WOC), a medium is created autogenously in the conventional cyclone to separate the particle based on the density along with size and shape. The WOC uses water as a medium for separation, and the operating principle of a WOC differs from a conventional cyclone due to its modified geometry [1,2]. It has a wide angle conical bottom, a long cylindrical portion and a long vortex finder extending along the length of the cylindrical portion. The wide cone angle builds up an autogenous bed of particles along the conical section of the cyclone. This autogenous bed to prevents particles from moving unimpeded and hindered settling principle dominates. The long cylindrical portion increases the average retention time of particles inside the cyclone to enable better separation [3–8]. Traditionally, the water-only cyclone is being used in coal preparation to clean the coal of size less than 0.5 mm and there are some literature which narrates the application on water-only cyclone to separate different minerals [1,2,9–12]. The main advantages of water-only cyclones are the simplicity and economic aspects in installation and operation. High separation efficiencies are not as common as competing processes, so they are best used as a pre-cleaning stage for subsequent separation process based on the liberation characteristics of the treating material.

Chromite ore beneficiation is majorly dominated by gravity concentration techniques. In India, about 50% (by weight) of the feed is discarded into the tailing stream during beneficiation process which consists of a huge quantity of the chromite values in fine and ultra-fine sizes. Being strategically important and from the mineral conservation perspective, the chromite resources and its sustainability for future use, recovery of chromite from tailings has become inevitable. Extensive work has been carried out at R&D, Tata Steel in the past for the beneficiation of tailings by adopting different methods of beneficiation techniques [13–20]. In addition, conventional hydro cyclone has been extensively used at different stages which include de-sliming, pre-concentrating, etc. However, there was no report in the literature regarding the use of WOC for the recovery of the chromite fines which could be substituted with the conventional one. It is also essential to systematically analyze the effect of different process parameters on the efficient separation in WOC. So, it is realized that a scientific study is required in this direction to evaluate the application of WOC in the mineral industry.

Generally in mineral processing, rigorous and costly experimental evaluations of laboratory and pilot-scale equipment trials are conducted for assessing the performance of any unit operation. So, developing a low cost, time-saving tool (model), with the ability to accurately predict the beneficiation results of the unit operation would be very helpful. The success of separation with water-only cyclone depends on the selection of suitable process variables at which the response reaches its optimum. One of the methodologies for obtaining the optimum results is statistical analysis [21–25]. Different statistical experimental designs are used for different objectives, such as randomized block designs can be utilized for screening the relevant factors [22–25]. Some

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literature reports on modelling using these methods in mineral and coal processing operations were also available. Using different statistical design method, models were developed for chromite and celestite concentrates by varying the process variables of multi gravity separator [26–28]. Another model was developed for Turkish coals using the Response Surface Methodology and Box-Behnken design [29]. Optimization and modelling studies of the hydro cyclone for treating Indian iron ore slime, as well as low-grade bentonite were reported [25,30]. Response surface methodology was used to evaluate the performance of the froth floatation on coal fines, as well as for the establishing the optimum conditions to separate ultrafine coal by spiral concentrator [31,32]. Second order quadratic model was developed by using response surface methodology for separation of titanium bearing minerals from Indian beach sand minerals for separation of ferruginous chromite by using spiral concentrator [16,17,33]. By using similar statistical method, another study was reported on dry high-intensity roll magnetic separator for separating hematite fines [34]. In addition to these, several full factorial statistical studies were carried out to understand the effect of variables on the separation performance of different mineral processing unit operations [9,11,35–36].

In the present study, an experimental detailed program was considered based on a three-level full factorial design to evaluate the individual parameters and their interactional effects on the overall separation performance of a WOC. A software on statistical package was used to analyze the experimental results and identify the suitable operating range for these operating parameters to achieve the optimum separation performance of this equipment while treating ferruginous chromite fines.

2. Experimental studies

2.1. Material

Ferruginous chromite fines sample was collected from the tailing stream of the fine and ultrafine circuit of chromite beneficiation plant, Sukinda for the present test work. The entire sample was first dried and sampled for detailed characterization (size analysis, size-wise chemical analysis and XRD analysis) and test work. The sample contained 22.5% Cr_2O_3, 23.1% $Fe_{(T)}$, 18.0% SiO_2 and 7.7% Loss on Ignition (LOI). Particle size distribution of the feed is given in Fig. 1 and it can be found that 80% (by weight) of the mass is of particle size below 45 μm. The particle size analysis along with chemical analysis of each fraction was analyzed and tabulated in Table 1. Further, the distribution of different elements/compounds in different size fractions are calculated and given in Fig. 2. It is observed from the Fig. 2 that 45.1% of the Cr_2O_3 is distributed at ultrafine particle size range i.e. below 25 μm. Similarly, 70.1% of the $Fe_{(T)}$ and 49.6% of the SiO_2 are distributed in that ultrafine size range. The XRD study was carried out using PaNalytical X'pert PRO X-ray diffractometer to identify

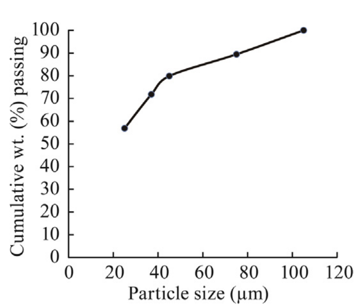

Fig. 1. Particle size distribution of chromite sample.

Table 1
Particle size distribution with size wise chemical analysis.

Particle size (μm)	Weight (%)	Assay value (%)		
		Cr_2O_3	$Fe_{(T)}$	SiO_2
+75	10.5	25.2	15.8	20.7
−75+45	9.6	25.3	15.3	23.3
−45+37	8.1	26.7	14.4	23.7
−37+25	14.9	28.9	17.4	18.5
−25	56.9	16.7	28.4	15.7
Feed		22.5	23.1	18.0

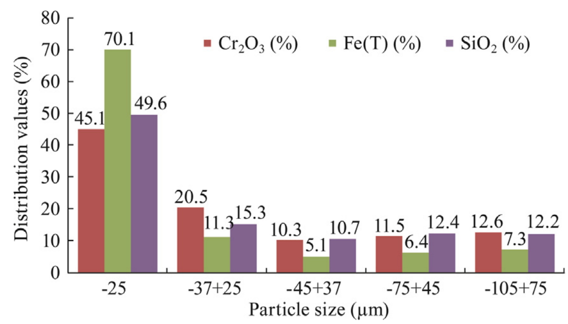

Fig. 2. Size-wise distribution of different elements/compounds in the chromite sample.

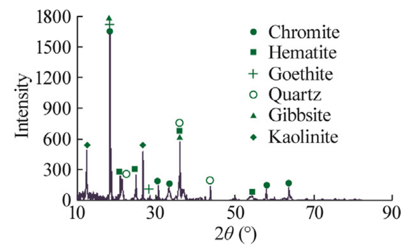

Fig. 3. XRD pattern of ultrafine chromite sample used in the present investigation.

the mineral phases in the tailing sample. The XRD pattern is shown in Fig. 3, where it can be noticed that the chromite is the major phase with hematite and goethite being the other iron-bearing mineral phases. Gibbsite, kaolinite, and quartz are the major gangue mineral phases occurring with chromite phases.

2.2. Experimental setup and procedure

A 50 mm cylindrical diameter stub cyclone made by Richard Mozley Ltd. was used for the test work. A closed circuit test rig consisting of a slurry pump and a bypass line was used to conduct the experiments (Fig. 4). Slurry feed rate to the separator and the pressure at the inlet was adjusted using the by-pass valve. Before carrying out the experiment, pre-determined quantities of feed sample and water were thoroughly mixed in the slurry tank to maintain the desired feed slurry concentration (pulp density). Initially, the slurry was pumped through the separator by keeping the by-pass valve fully open, and subsequently, the opening of the valve was adjusted to the desired feed inlet pressure. The system was then allowed to run for a few minutes to attain a steady state. The steady state condition was believed to be achieved as soon as the slurry flow rates through the overflow and underflow were found to be consistent. The overflow and underflow streams were then collected for a known period, and the respective slurry weights were recorded. The slurry samples were dried and