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ULTRA FINE CHROMITE CONCENTRATION USING SPIRAL CONCENTRATOR

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ABSTRACT

The conventional chromite beneficiation circuit utilises spiral concentrator for recovering chromite fines and as its efficiency decreases with respect to the decrease in particle size. Pilot scale studies have been performed to understand the effect of different process parameters which influence the separation of ultra fine chromite fines from a typical plant tailing. The process parameters of spiral concentrator such as feed rate (m^3/hr), feed pulp density (% solids by weight) and splitter position (cm) are considered for the study. Splitter position has major influence on both grade and recovery of the concentrate fraction of spiral concentrator. Maximum grade of 48.54% Cr_2O_3 can be achieved in the concentrate fraction of spiral concentrator with 20.41% Cr_2O_3 recovery. Performance of spiral concentrator at different combination of process parameters was analysed with 3D surface plots.

Keywords: *Ultra fine chromite, Beneficiation, Spiral concentrator, Performance, Modelling.*

INTRODUCTION

Chromite ore is the main source of chromium metal, chemical and refractory. Based on certain physical and chemical properties, the ore is classified for different user industries.[1] During the beneficiation of chromite ore, about 50% (by weight) of the total feed is discarded into tailings which consist of huge quantity of the chromite values. From the mineral conservation point of view, the chromite resources and its sustainability for future use, beneficiation of tailings is imperative. Significant research effort has focused on recovery of chromite values from the plant tailings which need to be focused on point of mineral conservation, utilisation and environment protection.[2] The tailing generated from the Turkish chromite beneficiation plant was treated in the multy gravity separator for producing the desirable grade.[3–6] Low grade chromite sample from Karaburhan was treated with a combination of wet shaking table and multigravity separator for obtaining marketable grade.[6] A combination of multi gravity separator and column flotation has been studied for the upgradation of the plant tailing.[2] Most of the heavy minerals including chromite are treated in gravity concentration at different stages of upgradation.[7, 8] The popularity of gravity concentration is due to their simplicity, low operating cost and ease of operation. Spiral concentrator is one of the key unit operation which is widely used for concentrating different minerals/coal.

Spiral separators are used globally in the mineral/coal industry; it consists of an open trough that twists downward in helix configuration about a central axis. It is essentially a flowing film gravity concentrator, where the action of gravity and hydrodynamic forces due to the circulating flowing film are combined to separate gangue mineral from pure mineral.[13] The detailed separation principle of spiral concentrator has been discussed in the literature.[9–11] The main process variables of a typical spiral concentrator are the feed flow rate, feed pulp density and the splitter position.[9, 11–13]

In the present investigation, the experiments were carried out with an objective to develop the quadratic models which can be used for accessing the performance (grade and recovery of concentrate fraction) of spiral concentrator. In addition to these, performance of the spiral separator at different combination of process variables has been evaluated with 3D surface plots.

MATERIALS AND METHOD

Sample

The sample as received for the present investigation, was from the tailing fraction of fine circuit of chromite beneficiation plant of Sukinda region, India which analysed 21.96% Cr_2O_3, 20.7% $Fe_{(T)}$, 14.68% of Al_2O_3, 19.59% SiO_2, 4.52% MgO and 7.9% LOI (Loss on Ignition) with Cr : Fe ratio of 0.72. The material is ferruginous in nature due to its high iron content. As received sample has been subjected to particle size analysis, size wise chemical analysis and XRD (X-Ray Diffraction) studies. Particle-size measurement of the chromite sample was performed using the standard laboratory Sieve Shaker and the size distribution of the sample is shown in Fig. 1.

Sizewise chemical analysis was carried out by ICP analyser and the result is given in Table 1. The feed sample has been subjected to the X-Ray Diffraction study for the identification of the mineral phases which has been shown in Fig. 2. From Fig. 2, it is revealed that the sample contains chromite along with hematite, goethite, gibbsite, quartz and kaolinite.

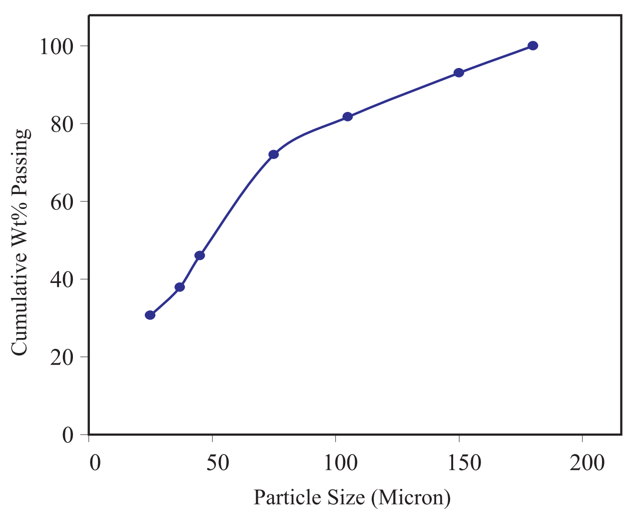

Fig. 1: Particle size distribution of chromite sample.

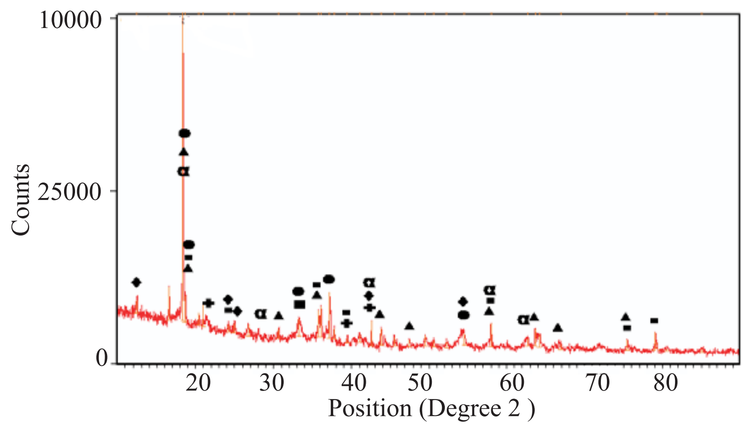

Fig. 2: XRD pattern of chromite sample with identified phases
(▲: chromite, ■: hematite, ◆: kaolinite, ●: gibbsite, ✚: quartz, α: goethite).

Table 1: Sizewise chemical analysis of chromite sample

Size (Micron)	(%) Assay Value			
	Cr_2O_3	$Fe_{(T)}$	Al_2O_3	SiO_2
+150	10.07	21.38	18.99	25.89
–150 + 105	15.8	18.03	18.4	25.31
–105 + 75	17.06	16.99	17.2	27.28
–75 + 45	22.6	19.41	14.02	21.62
–45 + 37	28.54	19.21	13.01	17.1
–37 + 25	32.13	17.45	12.62	15.69
–25	23.81	24.94	13.02	13.47

Methods

In the present study, statistically designed experiments were carried out to find out the relationship between the response functions (grade and recovery of the concentrate fraction) and three variables of the spiral concentrator. All the experiments were conducted using a single-start Carpco Humphrey (supplied by Carpco, Inc, USA) which was having a pitch of 16 inches and 5 turns, in which the effect of three process variables at three levels was studied. The variables and their levels are given in Table 2. All the designed experiments were conducted and the results of these experiments were used for the computer simulation programming applying the least square method using the mathematical software package (Matlab 7.1).

The model for the responses is of the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3$$

where β_0 is the model constant; x_1, x_2, x_3 are independent variables; β_1, β_2, β_3, are linear coefficients; β_{12}, β_{13}, β_{23} are cross product coefficients and β_{11}, β_{22}, β_{33} are the quadratic coefficients.[15]

Table 2: List of variables and their levels

Sl. No.	Variables	Levels		
		Low (–1)	Center (0)	High (+1)
1.	Feed rate in m^3/hr (x_1)	1.2	2.1	3
2.	Feed pulp density in % solids by wt. (x_2)	10	20	30
3.	Splitter position in cm (x_3)	12	14	16

RESULTS AND DISCUSSION

The experiments were carried out using the spiral concentrator to concentrate the chromite values from plant tailings. It has been observed that splitter position has influence on quality of the concentrate fraction. It was possible to achieve the concentrate grade of 48.54% Cr_2O_3 at 12 cm of splitter position. By increasing the splitter position to 16 cm from 12 cm, the grade was decreased to 30.41% Cr_2O_3. Similarly there is also influence of feed rate which showed that the concentrate fraction of spiral concentrate has enriched to 37.74% Cr_2O_3 at feed rate of 1.2 m^3/hr, whereas by increasing the feed rate to 3 m^3/hr, the quality of the concentrate fraction was drastically decreased to 26.57% Cr_2O_3. There is no significant change in the quality of the concentrate fraction of spiral concentrator, by changing the pulp density of the feed. It is also observed that as the splitter position increased from 12 to 16 cm, Cr_2O_3 recovery of concentrate fraction has enriched from 20.41% to 28.6%. Similarly the recovery has decreased drastically from 38.46% to 21.72% as the pulp density of the feed changed from 10% to 30% solids by weight.

From the experimental results, the second order response functions representing the grade (%Cr_2O_3), recovery (%Cr_2O_3) of the concentrate fraction could be expressed as function of the feed rate, pulp density and splitter position. The estimated coefficient for different responses along with the Analysis of Variance (ANOVA) is presented in Table 3.

The ANOVA for both the response models are given in Table 3. The F-value of grade and recovery is 12.05 and 10.77 respectively at higher than 99.99% confidence level. The Prob>F for both the model is acceptable (less than 0.05) which indicates the developed models are significant. The relationship between the predicted and observed value of the responses is quite good as the R^2 value for grade and recovery of the concentrate fraction of the spiral concentrator is 0.94 and 0.93 respectively.

From Table 3, it is observed that the main effects, splitter position, feed rate as well as the square of splitter position, pulp density and interaction between pulp density and splitter position have significant effect on grade (%Cr_2O_3) of the concentrate fraction of the spiral concentrator whereas the sources (such as pulp density, square of feed rate and interaction between feed rate and pulp density, between feed rate and splitter position) have negligible effect. It is also noted that as there is an increase in three process parameters, the grade of the concentrate fraction of spiral concentrate decreases due to the negative sign of the estimated coefficients. Similarly the model for estimating the recovery (%Cr_2O_3) of the concentrate fraction of the spiral concentrate illustrates that among the main effects splitter position, pulp density as well as the square of feed rate, pulp density and interaction between feed rate and splitter position have considerable effects on recovery (%Cr_2O_3) of the concentrate fraction of spiral concentrator. It may be noted that feed rate, square of splitter position and interaction between feed rate and pulp density, pulp density and splitter position were less significant. It is observed that both feed rate (A) and feed soild concentration

(B) are inversely proportional to the recovery of concentrate fraction due to the negative sign of the estimated coefficient where as splitter position is directly proportional to the recovery. As there is an increase in the splitter position, the recovery of concentrate fraction increases.

Table 3: ANOVA and estimated coefficients for grade and recovery of concentrate fraction.
[SS: Sum of Square, MS: Mean Sum of Square, F-Value: Fissure test Value,
x_1: Feed rate, x_2: Feed Pulp density, x_3: Splitter Position]

Statistics	Grade (%Cr_2O_3)	Recovery (%Cr_2O_3)
SS	691.55	1036.45
MS	76.84	115.16
F-Value	12.05	10.77
Prob>F	0.0017	0.0024
R^2	0.94	0.93
Parameters	Estimated Coefficients	
x_1	–2.8	–4.15
x_2	–0.98	–5.47
x_3	–7.36	7.31
x_1^2	–1.44	4.45
x_2^2	–2.97	–3.15
x_3^2	5.69	–2.82
$x_1 x_2$	0.39	2
$x_1 x_3$	0.12	–3.99
$x_2 x_3$	1.72	0.58

For better understanding, the predicted models are described in terms of three dimensional (3D) response surface plots which show the effect of process variables of spiral concentrator on different responses and are plotted in Figs. 3 and 4. Each figure shows the 3D response surface plots between two variables of spiral concentrator and the response at centre level of the third variable. This will give the idea of the interactional effects of different variables on responses.

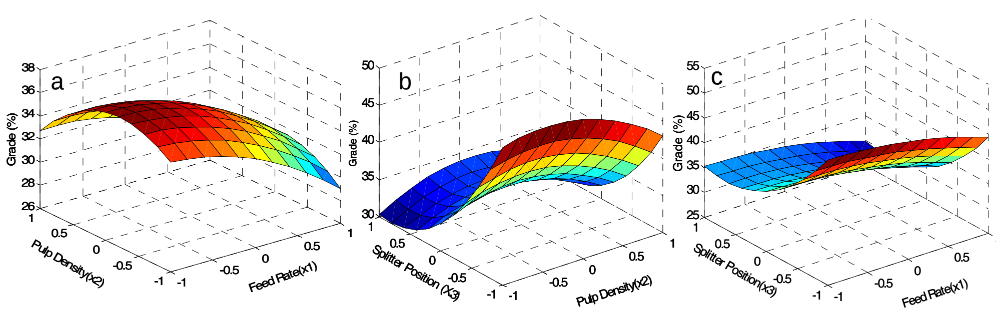

Fig. 3: Response surface plots showing the effects on grade (%) of concentrate fraction: (a) between feed rate (x_1) and pulp density (x_2), (b) between feed rate (x_1) and splitter position (x_3), and (c) between pulp density (x_2) and splitter position (x_3).

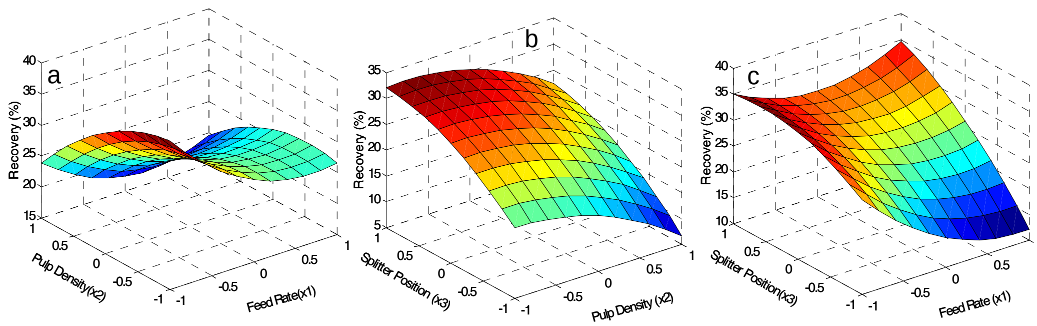

Fig. 4: Response surface plots showing the effects on recovery (%Cr_2O_3) of concentrate fraction:(a) between feed rate (x_1) and pulp density (x_2), (b) between feed rate (x_1) and splitter position (x_3), and (c) between pulp density (x_2) and splitter position (x_3).

CONCLUSION

Chromite values from ultra fine tailings of chrome ore beneficiation plant can be recovered by right combination of process parameters of spiral concentrator. The three process parameters considered in this study were feed rate, feed pulp density and splitter position. The mathematical models were developed for both grade and recovery of Cr_2O_3 in the concentrate fraction by using sets of experimental data and mathematical software package Matlab 7.1. The predicted values obtained using the models were in very good agreement with the observed values (R^2 value of 0.94 for the grade and 0.93 for the recovery of %Cr_2O_3 in the concentrate fraction). Splitter position has major influence on both grade and recovery of the concentrate fraction of spiral concentrator. In order to accomplish a better understanding of the process parameters of the spiral concentrator on grade and recovery of Cr_2O_3 in the concentrate fraction, the predicted model values were presented as 3D response surface graphs.

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