Journal of Mining and Metallurgy, 48 A (1) (2012) 39 - 49

Journal of Mining and Metallurgy

EFFICACY OF MULTI GRAVITY SEPARATOR FOR CONCENTRATING FERRUGINOUS CHROMITE FINES

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(Received 20 December 2011; Accepted 10 July 2012)

Abstract

The Multi-Gravity Separator (MGS) is novel enhanced gravity equipment for the separation ultra-fine minerals. The present investigation studied on the effects of different process variables on the performance of a multi-gravity separator for concentration of ultra-fine ferruginous chromite. The results revealed that, shake amplitude and wash water flow rate play a dominant role in controlling the grade (%Cr_2O_3) of the concentrate fraction whereas tilt angle and drum speed influence much on the recovery (%Cr_2O_3) of the concentrate fraction. It was found that the MGS could produce a concentrate of 45.69% Cr_2O_3 with 56.41% recovery from a feed assaying 21.06% Cr_2O_3 and 23.02% of $Fe_{(T)}$. In addition to this, optimized conditions were determined for producing metallurgical grade chromite concentrate (>40% Cr_2O_3) with 60% recovery. Different correlations were made for predicting the silica and iron content of the concentrate fraction.

Key words: *Multy gravity separator, enhanced gravity separation, chromite, ultrafine processing, plant tailing.*

1. Introduction

About 98% of the total proved Indian chromite reserves are located at the Sukinda valley in Odisha. Depletion of high grade reserves and increased consumption of ore concentrate necessitates the beneficiation of low grade ore and also recovery of chromite values from plant tailings. Extensive work has been carried out by numerous researchers for the beneficiation of tailings by adopting different methods of beneficiation techniques exploiting the difference of physical properties [1-2]. As a general rule, the separation efficiency decreases when the particle size becomes finer. Therefore an enhanced gravity method utilizes centrifugal force to accentuate the density separation. Descriptions of these process developments and devices are given in literature [3-4]. The minimum particle size that can be effectively processed depends on the settling force applied.

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Fine chromite particle beneficiation has been advanced by the introduction of new generation techniques such as column flotation, enhanced-gravity separators like Multi-Gravity Separator, Altair jig, Kelsey jig, Knelson concentrator and Falcon Concentrator etc. during the last two decades [5-7]. An upsurge of interest in such equipment was realized after successful commissioning of Turkish chromite beneficiation plant [8-9]. Similarly various researchers have explored the application of Multi Gravity Separator (MGS) for fine chromite beneficiation [10-13]. The chromite beneficiation plants of Sukinda region, India generates huge quantities of rejects which contains enormous amount of ultra-fine chromite particles, could not be recoverable by the conventional circuits [14].

The objective of this study was to determine the feasibility of enhanced gravity separation for the recovery of ultra-fine chromite particles from the tailings generated from the beneficiation plant of Sukinda region, India which is very rich in iron minerals (near gravity minerals). Further it was aimed to understand the effect of the process variables such as shake amplitude, drum speed, tilt angle and wash water flow rate on performance (grade and recovery of % Cr_2O_3 in concentrate fraction) of MGS for recovering ultra-fine chromite.

2. The Multi Gravity Separator – Background

The multi gravity separator is a unique enhanced gravity separator for the separation of fine and ultra-fine minerals. The principle of the multi gravity separator may be the combination of principle of conventional shaking table and spiral concentration. Feed slurry is introduced continuously midway into the internal surface of the drum via an accelerator launder, which is to reduce turbulence caused by the introduction of the feed. Wash water is introduced via a similar accelerator launder close to the outer end of the drum. Studies indicate that the slurry follows a spiraling pattern on the revolving drum surface. Heavier particles or particles of higher specific gravity penetrate the slurry and are pinned to the surface of the drum as a result of the centrifugal forces to form a semi-solid base layer. An intermediate layer consisting of a relatively dilute suspension of lower specific gravity particles, and slime particles forms above this. The top layer consists of relatively clear water. The shake provides an additional shearing force on the particles in the flowing film, resulting in improved separation, whilst the specially designed scrapers moving across the drum surface continually re-grade the settled particles, thus minimizing entrainment of gangue. Thus the high density particles pinned to the surface of the drum are continuously swept up the slope by the scrapers, during which time they are subjected to counter current washing before discharging at the open, front end as concentrate. The lower density minerals along with the majority of the wash water flow down-stream to discharge as tailings via slots at the inner end of each drum. Several literatures were found on the detail of operational mechanism of MGS [15-18]. The schematic diagram of multi-gravity separator and its separation mechanism has shown in Figure 1. The parameters affecting the efficiency of separation on the MGS are reported as the drum speed (100 to 300 rpm), tilt angle (0° to 9°), shake amplitude (10 to 20 mm), shake frequency (4.0-5.7 cps), wash water (0 to 10 l/min) and pulp density of the feed slurry (10% to 50% by mass) [19].

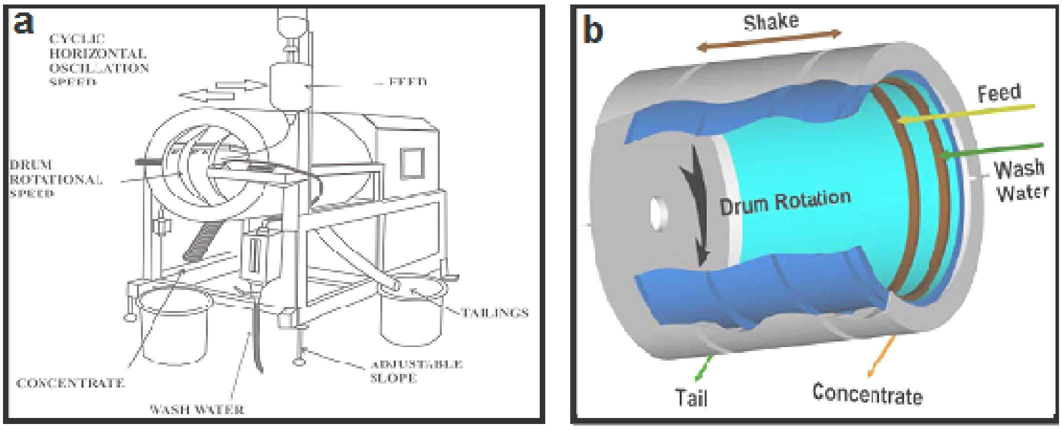

Figure 1. *(a) Schematic diagram of Multi Gravity Separator, (b) Particle separation mechanism of MGS*

3. Experimental

3.1. Material Characterisation

The plant tailings were collected from a chromite beneficiation plant at Sukinda, Odisha. The representative sample was subjected to characterization in terms of particle size distribution, size wise chemical analysis, X-Ray Diffraction (XRD) study. The particle size analysis was carried out and the results are presented in Table 1.

Table 1. *Particle size distribution of the ultra-fine chromite sample*

Particle Size (μm)	Cumulative wt. % Passing
-150	100.00
-100	95.07
-75	89.45
-45	79.85
-37	71.77
-25	56.88

From Table 1, it was observed that about 80% of the sample is having size below 45 microns whereas ~57% by weight is below 25 micron. The sample contained 21.06% Cr_2O_3, 23.02% $Fe_{(T)}$, 18.01% SiO_2 and 7.76% of Loss on Ignition (LOI). The size wise chemical analysis is given in Table 2 which shows that the Cr_2O_3 content increases as particle size decreases up to 25 microns but below 25 micron there is a sudden decrease. Whereas, the iron and silica contents are more or less evenly distributed up to 25 microns but below 25 micron $Fe_{(T)}$ and silica content is 70 and 49% respectively.

The XRD study was carried out using PaNalytical X'pert PRO X-ray diffractometer for identifying the mineral phases in the head sample [20-21]. The XRD pattern is shown in Figure 2, where chromite is the major phase along with hematite and goethite being the other iron-bearing mineral phases.

Table 2. *Size wise chemical analysis and their distribution*

Particle Size (μm)	Weight (%)	Assay Value (%)			Distribution Value (%)		
		Cr_2O_3	$Fe_{(T)}$	SiO_2	Cr_2O_3	$Fe_{(T)}$	SiO_2
+75	10.55	25.21	15.86	20.77	12.63	7.27	12.17
-75+45	9.59	25.34	15.29	23.24	11.54	6.37	12.37
-45+37	8.09	26.76	14.39	23.7	10.28	5.06	10.65
-37+25	14.89	28.95	17.43	18.45	20.47	11.27	15.25
-25	56.88	16.7	28.35	15.7	45.10	70.05	49.58

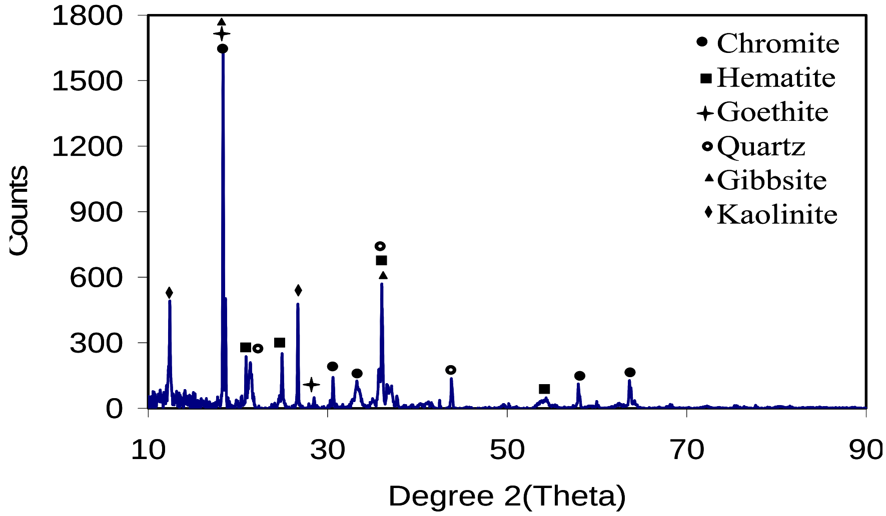

Figure 2. *XRD pattern of chromite tailing head sample*

Gibbsite, kaolinite and quartz are also the major gangue mineral phases along with chromite phases.

3.2. Methods

All the experiments were conducted using a laboratory/pilot scale multi-gravity separator (Richard Mozley Ltd, model no: C-900). The setup (Figure 3) consists of a feed slurry tank, peristaltic pump for supplying feed at desired rate and sample container for collecting the products.

The feed slurry tank (50 liters capacity) was fitted with a stirrer to keep the solids in suspension throughout the feeding time. Samples from concentrate and tailings streams were collected at steady state condition. Initially predetermined quantity of feed sample and water were mixed in the slurry tank with the help of the stirrer to maintain the desired feed pulp density (25% solids by weight). Randomly test conditions were selected to screen the important process variables and their levels for further experimentation with statistical designed experiments. The process variables and their levels studied are listed in Table 3. For each experiment after attaining steady state, both the products were collected, dried, weighed and analyzed for different radicals.

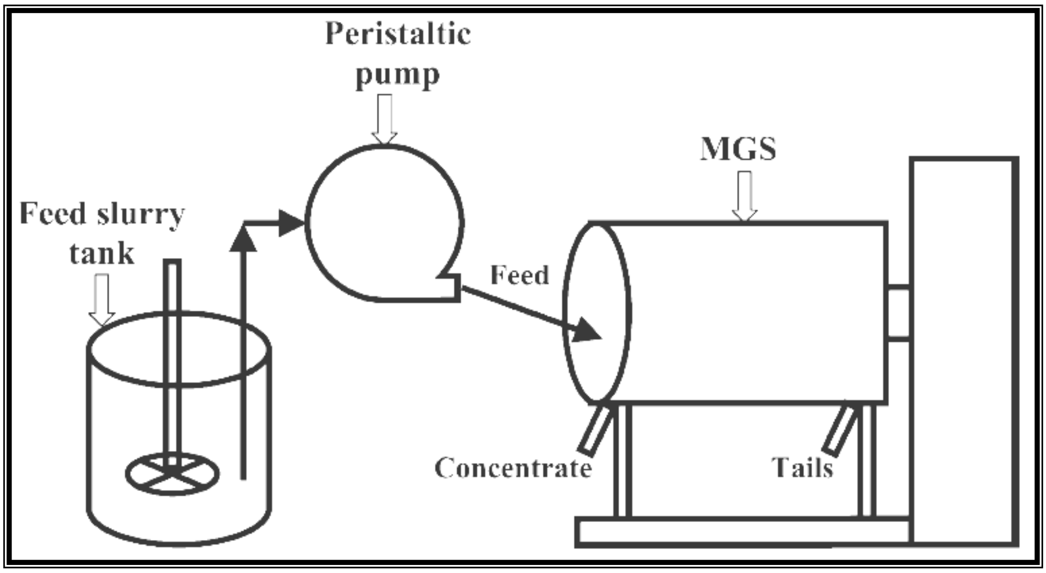

Figure 3. *Experimental set up of multi gravity separator*

Table 3. *List of variables and levels studied on MGS*

Sl.No.	Variables	Levels
1	Shake Amplitude in cm. (SA)	15-25
2	Drum Speed in rpm (DS)	150-250
3	Tilt Angle in degree (TA)	2-6
4	Wash Water Flow Rate in lpm (WW)	3-9
5	Shake Frequency in cps (SF)	4.8
6	Solid Feed Rate in tph (SFR)	0.1
7	Feed Pulp Density in %solids by wt.(FPD)	25

4. Result and Discussion

The grade and recovery (%Cr_2O_3) of concentrate fraction of each test has given in Table 4. From Table 4, it is observed that maximum grade of 45.69% Cr_2O_3 with 56.41% recovery was achieved at higher levels of shake amplitude and wash water flow rate, intermediate levels of drum speed and deck tilt angle. This can be attributed as at higher shake amplitude, the agitation required is high which facilitate to separate the entrapped /misplaced light particles and higher wash water flow rate helped to prevent entrapment of low density particles (gangue minerals) [21]. The silica content was lowering minimum to 3.84% from 18.01% at the same condition.

Experimental results of the present studies indicate that, the silica rejection to the tailing fraction was more than 70% at all the tests. So it is an effective tool for rejecting the silicate gangue minerals from the concentrate fraction.

Table 4. *Results of the MGS test work*

Test No.	S.A (mm)	D.S (rpm)	T.A (deg.)	W.W (lpm)	Grade (%) of Concentrate Cr_2O_3	$Fe_{(T)}$	SiO_2	Recovery ($\%Cr_2O_3$)
1	20	150	6	6	28.61	19.29	16.49	18.3
2	20	250	6	6	22.43	25.09	16.81	72.6
3	15	150	4	6	26.75	23.95	12.54	15.4
4	15	250	4	6	26.03	21.30	16.54	82.44
5	15	150	6	9	22.18	26.01	15.43	16.0
6	15	250	6	9	35.04	19.96	9.61	69.21
7	15	200	4	3	34.39	19.92	11.28	73.16
8	15	200	4	9	39.85	19.28	7.45	72.66
9	20	200	4	3	32.43	20.19	14.24	81.00
10	20	200	4	9	45.69	19.11	3.84	56.41
11	15	250	4	6	26.03	21.30	16.54	82.44
12	15	250	2	6	23.67	24.38	15.23	84.07
13	10	200	4	6	34.12	17.46	14.06	71.61
14	20	200	4	6	44.36	15.31	7.14	65.93

(SA: Shake Amplitude, DS: Drum Speed, TA: Tilt Angle, WW: Wash Water Flow Rate)

Similarly the maximum recovery ($\%Cr_2O_3$) of 84.07% was achieved with 23.67% of grade ($\%Cr_2O_3$) was achieved at lower levels of tilt angle, higher level of drum speed and intermediate levels of shake amplitude as well as wash water flow rate. This can be ascribed as the drum rotation increases, the gravitational force acted upon the particle increases which assist in particle size recovery as well as density of the fraction reporting to concentrate fraction increases [22]. Effect of processes on the performance of the MGS is discussed below.

4.1. Effect of drum speed

The drum revolutions generate centrifugal forces on particles which not only allow the heavier particles of chromite minerals to reach the compact solids bed, but also allow some portion of lighter minerals to penetrate the heavies bed. The effect of drum rotation on recovery and grade at different rpm was studied while keeping other variables constant (Test 1-6 of Table 4).

It was found that the Cr_2O_3 recovery in concentrate fraction increases with increase in drum rotation whereas the grade decreases (on each set). This can be explained as increased drum revolutions generate higher centrifugal forces on particles which not only allow the heavier coarse locked chromite particles reach the compact solids bed, but also allows some portion of lighter silica minerals thus decreasing the overall grade and increase-ing the recovery [22]. But in Test no. 5 and 6, there is an exception due to the higher level of wash water flow rate which dominate the influence on grade of the concentrate fraction. In this case the grade of the concentrate has upgraded from 22.18% to 35.04% Cr_2O_3 at higher level of wash water flow rate.

4.2. Effect of wash water flow rate

Wash water enhances the washing effect due to which, the lighter gangue particles migrate towards the tailing end of the MGS. When wash water flows on the drum surface, the particle motion through water and separation between particles of different sizes and densities take place as a result of the interplay of body forces (gravitational or centrifugal), drag forces and particle inertia. The experimental results, at different wash water flow rate with different shake amplitude are shown in Table 4 (Test no.7-10). It can be observed that there is an increase in the concentrate grade with an increase in the wash water rate. Keeping other variables constant at i.e., shake amplitude (15mm), an increase in wash water from 3 to 9 lpm(Test. No.7 and 8) has increased the concentrate grade from 34.39% to 39.85% Cr_2O_3. Similarly, with an increase in wash water flow rate from 3 to 9 lpm (Test. No.9 and 10), the grade (%Cr_2O_3 content) has increased from 32.43% to 45.69% at constant shake amplitude of 20mm. Improvement in the concentrate (%Cr_2O_3) with an increase in wash water rate can be explained, as the washing effects on the upper layers of the settled bed as due to rise in water velocity inside the drum. In addition to this there is a transportation of concentrate along with the rejects which ultimately decreases the recovery (%Cr_2O_3) of the concentrate fraction [16]. It is noted that, at lower shake amplitude i.e. 15mm, there is a trivial effect on recovery compared to the higher shake amplitude (20mm). The combined effect of shake amplitude and wash water flow rate provides the agitation by which the low density gangue minerals free from the drum surface and wash away to the tailing end.

4.3. Effect of Tilt Angle (Drum Inclination)

The drum inclination controls the movement of particle and fluid on the drum surface by which the residence time of the particle depends. It may be observed that (Test no 11 and 12) (Table: 4), the recovery of Cr_2O_3 decreases with an increase in drum inclination where as there is an increase in grade (%Cr_2O_3) of concentrate fraction with increase in the drum inclination. This effect can be explained by the fact that, with an increase in drum inclination, the downward flow velocity of the wash water increases [23]. As a result, the residence time of the particles inside the drum decreases, which eventually reduces the separation time between the heavies and lights inside the drum. Due to less residence time, the probability of heavies i.e. free chromite particles have a greater chance of being carried away with the excess wash water flowing over the particle bed and report into the tailings fraction, which ultimately decrease in the recovery.

4.4. Effect of Shake Amplitude

The shake amplitude is to assist in dilation of the feed material and stratifies based on their mass on the surface of the drum. It is observed that there is increases in the concentrate grade from 34.12% to 44.36% Cr_2O_3 with the increase in shake amplitude from 10 to 20 mm (Test no 13 and 14) whereas the Cr_2O_3 recovery to concentrate fraction reduced to 65.93% from 71.61%. This can be explained as; enhanced shearing force created by the strong shake disrupts the layer of low density mineral particles stratified on to the drum surface. Therefore, only the coarsest and the heaviest particles are expected to be dragged to the concentrate fraction by the scrappers whereas the fine heavier chromite particles are washed away with the flowing film of wash water at higher shake amplitude which resulted with poor recovery.

5. Optimisation Studies

Multi gravity separator is an effective tool for the beneficiation of ultra-fine concentration. In mineral processing, grade and recovery are the important and widely used parameter for accessing the efficiency of any unit operation. Grade and recovery are always inversely proportional to each other. The relationship between grade and recovery of concentrate fraction of MGS has shown in Figure 4 which resembles with the theory.

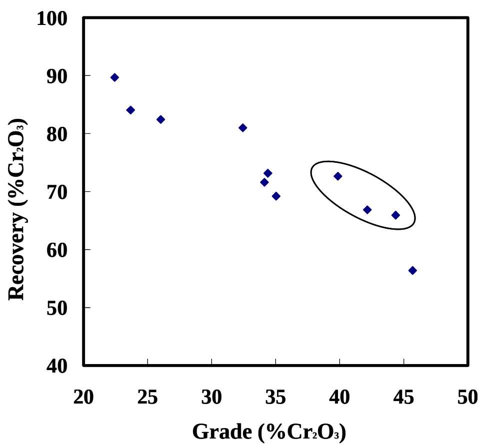

Figure 4. Relation between grade and recovery (%Cr_2O_3) of concentrate fraction

From Figure 4, it is clear that the metallurgical grade (>40% Cr_2O_3) of chromite can be produce from the ultra-fine plant tailing with recovery (% Cr_2O_3) higher than 60%. The recovery value of the selected compound (Cr_2O_3) was fixed for optimisation based on the concentration of chromite in the feed sample which is analysed mineralogically [24]. The marked test conditions (Test no. 8, 10 and 14) can be used for the production of ultra-fine metallurgical grade concentrate from the plant tailing. It is also evident that, better recovery with the marketable grade product can be achieved at intermediate levels of drum revolution speed and drum tilt angle.

In the chromite plant tailing, silicate and iron bearing minerals are the major gangue minerals. The relation between the Cr_2O_3 and the silica content of the concentrate fraction of MGS is shown in Figure 5 which demonstrates, that as there is an increase in the Cr_2O_3 content in the concentrate fraction, while the silica content decreases.

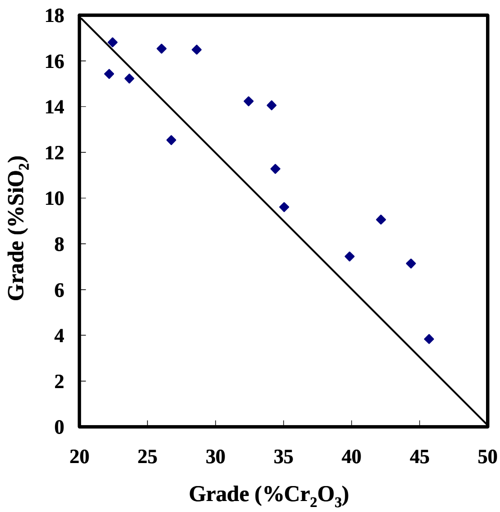

Figure 5. Relation between % Cr_2O_3 and % silica content of concentrate fraction

Similar trend is also observed for the iron content in the concentrate fraction and shown in Figure 6.

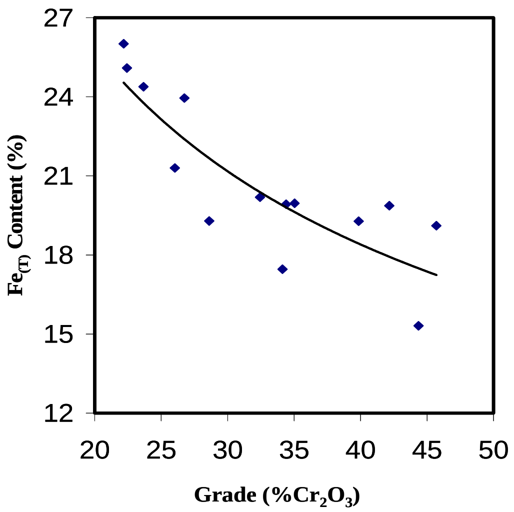

Figure 6. *Relation between %Cr_2O_3 and % Fe(T) content of concentrate fraction*

For predicting the silica and iron content in the concentrate fraction of MGS, regression equations were developed and expressed as:

$$\%Silica\ in\ Con Fraction = 27.27 - 0.46 * Cr_2O_3\ in\ Con$$

$$\%\ Fe_{(T)}\ in\ Con.\ Fraction = 111.45 * Cr_2O_3\ in\ Con.^{(-0.4883)}$$

The correlation coefficient (R^2) between the actual and predicted values for both the silica and $Fe_{(T)}$ content in the concentrate fraction of MGS are 0.83 and 0.69 respectively.

6. Conclusion

Ultra-fine chromite can be successfully concentrated from the chromite plant tailings by using multi gravity separator. Chromite, hematite, goethite, gibbsite, kaolinite, quartz were the major mineral phases present in the feed sample. A maximum grade of 45.69% Cr_2O_3 can be achieved with 56.41% recovery from a feed assaying 21.03% of Cr_2O_3. It was found that, shake amplitude and wash water flow rate have a major influence on grade (%Cr_2O_3) whereas drum tilt angle and drum speed influences the recovery (%Cr_2O_3) of concentrate fraction. In addition, optimized conditions were determined for producing metallurgical grade chromite concentrate. Intermediate levels of drum revolution speed (200 rpm) and drum tilt angle (4 degree) are the conditions essential for the metallurgical grade chromite concentrate production. Regression equations with significant correlation were developed for predicting the silica and iron content of the concentrate fraction. Further statistically designed experiments can be planned to understand as well as to establish the effect of the studied variables on particle separation of ultrafine ferruginous chromite particle.

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