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GRAVITY CONCENTRATION OF SUDANESE CHROMITE ORE USING LABORATORY SHAKING TABLE

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Abstract. The main raw materials for chromium metal is chromite. Geologically, chromite deposits are associated, by their nature of formation, with specific gangue minerals such as serpentine, olivine, and chlorite. These associated minerals are of lower densities than chromite. This criterion of density difference between chromite and the associated minerals suggests the use of gravity separation techniques for concentrating the low-grade chromite ores. This paper presents the results of an investigation on the concentration of a low-grade (30% to 35% Cr_2O_3) chromite ore from Chickay Mine, East of Sudan, using a shaking table. The studied parameters were the table tilt angle and the feed size distribution. The optimum table tilt angle was 6o, and the best performance of the table was obtained when the feed was split into two size fractions, -1.168 + 0.18 mm and – 0.18 mm, without desliming. The concentrate assay, under these conditions, was 47.2% Cr_2O_3 at a recovery of 75 percent.

keywords: concentration of low-grade chromite ores, gravity separation, shaking tables, table tilt angle, feed size distribution

1. Introduction

Chromium is one of the most important industrial elements nowadays. The chromium metal is used in metallurgical, and chemical, industries, whereas in refractory, chromite, the main mineral of chromium, is a main constituent in the refractory bricks for lining of high temperature furnace. In metallurgy, chromium is used in stainless steels, tool and alloy steels, nickel-chromium heating elements, in metal plating, manufacture of ferro-chrome alloys, and in the manufacture of grinding media, balls and rods, and mill liners in grinding plants. In chemical industry, it is used in the manufacture of paint pigments and chemical compounds, as an oxidizing agent in organic syntheses, as an electrolyte in chromium plating baths, and as an agent for tanning and dyeing of leather (USBM, 1992).

Chromite can be classified on the basis of the Cr/Fe ratio. The highest grade chromites are those having the Cr/Fe ratio of more than 2.0, and containing a minimum of 46% - 48% Cr_2O_3 (Hundhausen, 1947; Habashi and Bassyouni, 1982; Maliotis, 1996). Chemical and refractory grade chromites typically have Cr/Fe ratios ranging from 1.4 to 2.0. Low-grade chromites are those which have low Cr/Fe ratios and contain relatively small amounts of chromium.

Chromite occurs as a primary mineral of ultra-basic igneous rocks, peridotites, and their modifications, serpentine, talc carbonate, and chlorite. It also occurs in basic gabbros under suitable conditions. Usually the chromite deposits occur as small grains, but by the segregation of these grains, ore-bodies rich in Cr_2O_3 may be formed (Read, 1957).

2. Background

Although flotation offers an attractive technique for the separation of fine materials with minimum chromium losses, earlier flotation results of low-grade chromite ores were inferior to those obtained by tabling (Nafziger et al., 1979; Nafziger, 1982). Flotation requires fine grinding, which necessitates high slime losses and creates the slime coating problems, which needs careful reagent control and additional depressing and dispersing reagents. For this reason, fine-grained disseminated chromite ores do not respond well to this technique. Also the complicated aqueous chemistry due to dissociation of ions such as iron and lead require makes the system control extremely difficult. Chromite flotation could not be floated using anionic collectors below pH 6. The important phenomena like dimerization, miscellization, and precipitation are all involved and controlled by the system pH (Klassen and Krokhin, 1963). Knowledge of the PZC's of the constituting minerals in ore under investigation must be known. The following PZC values have been reported for the most common minerals in the chromite ores: chromite, pH of 5.6-7.2 (Palmer et al., 1975; Guney and Atak, 1997); serpentine, pH of 5.2 (Yerel, 2005); magnetite, pH of 4-6.5; talc, pH of 2.1; and quartz, pH of 2.8 (Branko et al., 1992).

Chromite ores are usually concentrated by gravity concentration techniques based on differences in specific gravity between chromite and the common associating gangue minerals and rocks such as serpentine and olivine. Jigging has been used to upgrade a California chromite ore containing 18.1% Cr_2O_3 to produce a concentrate assaying 43.5% Cr_2O_3 at a recovery of 77% with Cr/Fe ratio of 2.38 Batty et al., 1947). However, jigging failed to enrich the Topraktepe chromite ore due to inadequate liberation of the ore in the appropriate jigging size fraction (Tevfik, 2007). However, Humphrey spiral technique was successful in concentrating the Topraktepe chromite ore at a suitable size fraction, -0.3 + 0.212 mm. The concentrate obtained under these conditions assayed 54.6% Cr_2O_3 at a recovery of 94.9% (Topraktepe, 2007). Heavy media separation was attempted to concentrate the Seiad Lake chromite ore at a feed size fraction +100 mesh (+150 µm) materials (Hunter and Sullivan, 1960). Considerable amount of coarse gangue minerals was rejected and a sink product assaying 35.0% Cr_2O_3 at a recovery of 86% was obtained. Concentrating the Elazig-Kefdag chromite ore in Turkey using a Multi-Gravity Separator, MGS, was reported by Gence in 1999. The obtained concentrate assayed 52.1% Cr_2O_3 at a recovery of 69.6% at the optimum operating conditions. The Multi-gravity Separator was also used for concentration of the Topraktepe chromite ore, and a concentrate assaying 57.5% Cr_2O_3 from an ore assaying 46.2% Cr_2O_3 was obtained. Shaking tables were used for concentration of the Stillwater chromite ore (Sullivan and Worktine, 1964). Although significant amount of the chromium content remained in the middling fraction, the chromite recovery was reasonable. Treating the middling fraction of this process by tabling in a second stage increased the chromium recovery. Using the shaking table for enriching an Egyptian chromite ore containing serpentine as the major gangue mineral was found to be effective in concentrating the ore under consideration (Yousef et al., 1970). In a second stage, they used a magnetic separator to further remove most of the iron minerals from the table concentrate. The final concentrate assayed 68% Cr_2O_3 at a recovery of 80 % with the Cr/Fe ratio of 3.7.

Magnetic separation was not effective in enriching the California chromite ore (Hunter and Sullivan, 1960). The grade of the concentrate did not exceed 42% Cr_2O_3 at a recovery of 62%. The limited chromite recovery may be due to coating of chromite particles with magnetite which removed part of the chromite to the waste product. The Kempersayi chromite ore was concentrated by two-stage magnetic separation; 5000 Oersted and 11000 Oersted ($4{\cdot}10^4$ A/m and $8.8{\cdot}10^4$ A/m) (Starun et al., 1960). The concentrate obtained assayed 55.6% Cr_2O_3 at a recovery of 82.8%.

Electrostatic separation at 15 to 20 kV produced a high grade concentrate assaying 54% Cr_2O_3 at a recovery of 58% and the Cr/Fe ratio of 2.42 from the California chromite ore (Hunter and Sullivan, 1960). The low recovery in this case was due to the high percentage of fines which was partially untreated and partially masked the particles and hence precluded selective separation. High-tension electrostatic separation of a table concentrate from the Montana chromite ore resulted in a final concentrate assaying 42% Cr_2O_3 at a recovery of 86%.

In Sudan, chromite ore deposits occur mainly in the Ingassana Hills in the Blue Nile region. Other occurrences have been reported at Hammissana, Sol Hamid in the Northern Red Sea Hills, the Nuba Mountains in Southern Kordofan, Jabal Rahib Northwest Sudan, and Jabal El-Tawil in Central Butana in Southern Sudan. The Ingassana chromite ore is considered as one of the largest chromite ore deposits in Sudan. Its chromite reserves was estimated to be 2 teragrams (Tg or million tons), with chromium oxide assay in the range from 20% to 51% Cr_2O_3 (Habashi and Bassyouni, 1982; Ahmed, 1998). The mining area at Ingessana Hills is connected to Khartoum, Port-Sudan and other important parts of Sudan with fairly maintained motor roads and railways through Damazine city, the capital of Blue Nile Governorate.

Chickay Chromite Mine in the Ingassana area is about 80 km from Damazine city. The chromite ore in the Chickay Mine is in the form of a vein of complicated shape. Due to depletion of high grade chromite ore, and the presence of a large amount of low-grade ore in the area, it was necessary to come up with a suitable mineral processing technique to upgrade these low-grade ores together with the leftover fines from the previous chromite mining operations. The flotation technique was attempted for enriching the Chickay chromite ore. The assay of the feed to the flotation cell was 20.3% Cr_2O_3. Under optimum conditions, the chromite concentrate assayed 28.7% Cr_2O_3 at a recovery of 94.5%. Of course, the assay of the obtained concentrate is not satisfactory, which indicates that the flotation is not the right technique to concentrate this type of ore (Tammam, 2010; Seifelnasr and Tammam, 2011). The main objective of the present work is to investigate the amenability of the Chikay low-grade chromite ore to be concentrated by gravity methods, utilizing the relatively large difference in the specific gravity of the main constituting minerals, chromite and serpentine, in particular by using the shaking table.

3. Material, equipment, and procedure

3.1. Material

A low grade chromite sample of about 250 kg was collected from Chikay Mine, at the Ingassana Hills, Blue Nile Governorate, Eastern Sudan. The chromium oxide (Cr_2O_3) content in the sample under investigation was, on the average, 34.2% Cr_2O_3. The major associated gangue mineral was serpentine (density 2.6 g/cm^3) together with little olivine mineral (3.3 g/cm^3). The density of the chromite mineral is about 4.6 g/cm^3. This significant difference in specific gravities between the constituting minerals gives a *concentration criterion* of more than 2.0 and suggests using one of the gravity separation techniques for upgrading the chromite ore.

3.2. Equipment

One of the effective gravity techniques in this case is tabling. Shaking Table is a highly selective gravity separator. A laboratory shaking table of 50 cm x 90 cm was used for the concentration of the chromite sample. Figure 1 shows a schematic drawing for the used shaking table. The fixed operating parameters were: 300 stroke/min, 11 mm stroke length, 50 g/min dry solids feed rate fed at a solid/liquid ratio of 1:4, 9 dm^3/min wash water flow rate. The positions of the products (tailings, middlings, and concentrate) splitters were fixed during the whole investigation. The studied variables were: the tilt angle of the table and the feed size.

3.3. Procedure

The table was set at the pre-assigned operating conditions, and the material was continuously fed into the feed box of the table at a constant feed rate until the system attains a steady state. The products (tailings, middlings, and concentrate) were collected in their respective collecting pans, filtered, dried, weighed and analyzed for Cr_2O_3.

4. Results and discussion

The chromite ore was ground to pass 1.2 mm which was a suitable size for tabling with minimum amount of fines. The study of the degree of liberation was performed for various size fractions of the ground ore by counting the free chromite particles in each fraction under the microscope. It was found that the highest counts for the free chromite particles, 56.7 %, were in the size range -200+100 microns.

Two series of separation experiments were carried out; one for different tilt angles of the table, and the other for different particle size ranges of the feed material to the table. In some experiments the ore sample was deslimed at 75 micrometers. The feed size fractions were prepared using a hydrocyclone to obtain equal settling particles.

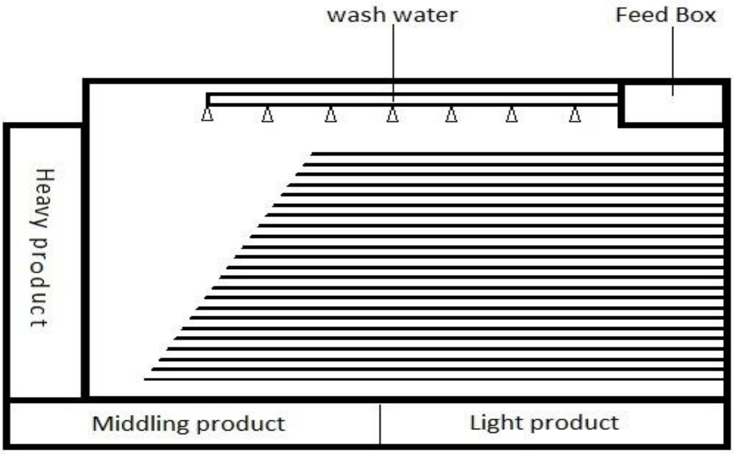

Fig. 1. A schematic layout of the shaking table

4.1. Effect of tilt angle

The table was tilted at three different tilt angles: 4^o, 6^o, and 8^o. The feed to the table was a deslimed material whose size fraction was -1.168·0.075 mm. The -0.075 mm contains about 9.0% of the chromite contained in the feed sample. Figure 2 shows the grade and recovery of the concentrate fractions obtained at each tilt angle. The grade of the concentrate at 4^o and 6^o tilt angles was very close, 49.9% and 48.8.0% Cr_2O_3, respectively, whereas at a tilt angle of 8^o the grade of the concentrate was 54.2% Cr_2O_3. The best recovery, 63.19%, was obtained at a table tilt angle of 6^o, whereas the worst recovery, 13.6%, was obtained at a tilt angle of 8^o. The reason for the deterioration of the recovery at the high table tilt angle is probably due to the higher downward pushing force of the particulate system flowing on the table surface by the washing water flowing downward. The washing action, under these conditions, pushes the material more towards the middlings and the tailings sections. This is confirmed by a high yield of the chromite, 73.5%, in the middling fraction when the table tilt angle was 8^o, whereas the chromite yield in the middlings was 38.4% and 27.1% at tilt angles of 4^o and 6^o, respectively (Fig. 3). The higher assay of both the concentrate and middlings at table tilt angle of 8^o is again due to the enhanced gravitational force of the wash water by the increased tilt angle, which was able to push down larger amount of the rich chromite ore particles before it reaches the concentrate collection area. Based on the above discussion, a tilt angle of 6^o was chosen for the second series of experiments. Table 1 summarizes the effect of the tilt angle of the table on the concentrate parameters, grade and recovery.

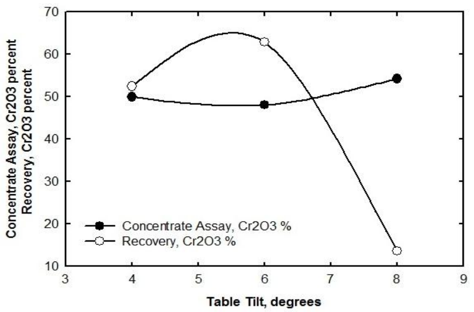

Fig. 2. The trend of Cr_2O_3 assay and recovery of the concentrate as a function of the table tilt angle in degrees

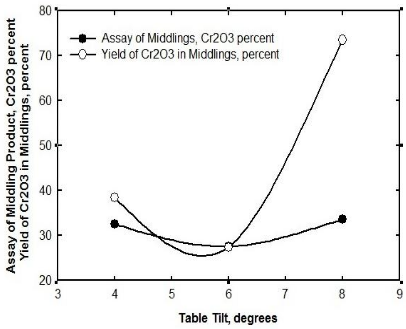

Fig. 3. The trend of the Cr_2O_3 assay and yield in the middling fraction at different table tilt angles in degrees

4.2. Effect of feed size fraction

To study the effect of the feed size fraction on the grade and recovery of the chromite concentrate four alternatives were attempted.

1) The deslimed ore (-1.168 + 0.075 mm) was used as the table feed and the slimes, -0.075 mm, was excluded. This alternative was discussed in the above section, Table 1. The grade and recovery of the concentrate were 48.8% Cr_2O_3 and 63.2% Cr_2O_3, respectively.
2) In this alternative, an attempt was made to split the deslimed feed into two fractions -1.168 + 0.25 and -0.25 +0.075 mm. Table 2 presents the results obtained in this series of experiments. The combined concentrate assays 48.1% Cr_2O_3 at a recovery of 66.6% Cr_2O_3.
3) The table feed in this case was a whole feed, i.e., -1.68 mm without desliming or fractionation. The concentrate assays 47.35% Cr_2O_3% at a recovery of 68.2%. Table 3 presents the results obtained in this case. The tailings contain only about 6% of the valuable constituent.

4) The fourth series of experiments was designed to use the whole sample without desliming, but it was split into two fractions; -1.68 +0.180 and -0.180 mm, and each fraction was used as a separate feed to the table. Table 4 presents the grades and chromite distributions in the various products of the feed fractions and the combined concentrate in this series of experiments. The combined concentrate assays 47.22% Cr_2O_3 at a recovery of 74.9%.

Table 1. Effect of the tilt angle of the shaking table on the concentration of the Sudanese chromite ore. The feed to the table is a deslimed ore of -1.168 + 0.75 mm

Tilt Angle, degrees	Product	Weight, %	Assay, Cr_2O_3, %	Cr_2O_3 Distribution, %
4^o	Concentrate	37.4	49.9	52.3
	Middlings	42.1	32.5	38.36
	Tailings	2.1	10.4	0.61
	Total	81.6		91.27
6^o	Concentrate	45.0	48.8	63.19
	Middlings	34.2	27.5	27.08
	Tailings	2.3	12.3	0.8
	Total	81.5		91.07
8^o	Concentrate	7.9	54.2	13.54
	Middlings	69.4	33.5	73.51
	Tailings	4.8	20.5	3.1
	Total	82.1		90.22

Table 2. Effect of the feed size fraction of the deslimed ore on the shaking table performance for concentrating of the chromite ore. The tilt angle of the table is 6 degrees.

Prticle size, mm.	Product	Product, Wt. %	Assay, $Cr_2 O_3$, %	$Cr_2 O_3$ Distribution, %
-1.68 + 0.25	Concentrate (1)	37.1	49.2	52.80
	Middlings	18.6	27.0	14.34
	Tailings	0.20	12.1	0.05
	Subtotal	55.9	41.68	67.19
-0.25 + 0.075	Concentrate (2)	11.0	44.47	14.0
	Middlings	15.6	24.33	10.92
	Tailings	2.4	11.34	0.80
	Subtotal	29.0	30.89	25.72
Combined Concentrate (1+2)		48.1	48.12	66.61

Table 3. Effect of the whole feed size fraction without desliming (-1.168 mm) on the shaking table performance for concentrating of the chromite ore. The tilt angle of the table is 6 degrees

Product	Product, Wt. %	Assay, Cr_2O_3 %	Cr_2O_3 Distribution, %
Concentrare	48.8	47.35	68.16
Middlings	34.0	28.85	25.92
Tailings	16.6	12.01	5.93
Total Feed	100.0	33.91	100.1

Table 4. Effect of the feed size fractions of the non- deslimed ore on the shaking table performance for concentrating of the chromite ore. The tilt angle of the table is 6 degrees

Prticle size, mm	Product	Product, Wt. %	Assay, Cr_2O_3, %	Cr_2O_3 Distribution, %
-1.168+0.180	Concentrate (1)	40.2	48.88	60.32
	Middlings	23.8	24.59	17.9
	Tailings	0.4	5.5	0.06
-0.180	Concentrate (2)	11.5	41.35	14.63
	Middlings	7.9	16.19	3.92
	Tailings	16.1	6.39	3.17
Total	Feed	99.9	32.60	100.0
Combined Concentrate (1+2)		51.7	47.22	74.9

These four alternatives can be grouped into two sets; tabling of a deslimed feed and tabling of non-deslimed feed. The deslimed feed was treated once as a whole deslimed feed and the other series of experiments was carried out by splitting the deslimed feed into two size fractions, alternatives 1 and 2. The non-deslimed feed was also treated once as a whole feed and in the other series the sample was split into two fractions, alternatives 3 and 4. In both groups, the assay of the concentrate was almost the same whether the feed to the table was one fraction or two fractions, whereas the recovery was higher when the feed was split into two fractions than the case of one fraction. This trend is probably due to the way the particulates rearrange themselves during stratification on the table surface, where the heavy species gets better chance to segregate to the table surface, travelling towards the concentrate end, leaving the light species on the top to be washed off by the wash water. Also, it can be noticed that the chromite recovery is considerable higher in alternative 4 than in alternative 2, while the assay of the final concentrate is almost the same for both alternatives. This is possibly because the feed in alternative 4 was not deslimed, and hence the losses in the fine fraction was less and most of the chromite particles were recovered.

5. Summary and conclusions

The chromite reserves in Sudan are mostly of low-grade. The chromite content ranges from 20% to 35% Cr_2O_3. This grade is too low for industrial uses. The froth flotation technique failed to upgrade this type of ore to the marketable grade. As a result of the reasonable difference in specific gravity between the chromite mineral and the main associated ingredients, gravity separation was a possible solution for concentrating such ore. In the present work, a laboratory shaking table has been used for upgrading this type of low-grade chromite ore. Several series of experiments were carried out to investigate the effect of the table tilt angle and the feed size range on the table performance, grade and recovery. The assay of the feed ranged from 30% to 35% Cr_2O_3. The optimum mesh of grind, liberation, was in the size fraction of 200 μm to 100 μm. Encouraging results were obtained. The table tilt was varied from 4 degrees to 8 degrees. A table tilt of 6 degrees gave the best results as compared with the other tilt angles, where the concentrate assays 49% Cr_2O_3 at a recovery of 63%. With respect to the table feed size distribution, it was found that closer feed size range is better than wider size range, which is logical for the table performance. Another conclusion was that splitting the feed into size fractions without desliming is more advantageous than desliming the feed. This latter finding is logical because the fine chromite fraction would have been lost if the feed is deslimed. The final concentrate which was obtained at tilt angle of 6 degrees and the feed was split into two fractions without desliming, -1.168 + 0.18 mm and -0.18 mm, assayed 47.2% Cr_2O_3 at a recovery of 75%.

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