Journal of Environmental Analytical Chemistry

Al-Tigani et al., J Environ Anal Chem 2019, 6:4

Research Article Open Access

Beneficiation of Disseminated Low-Grade Sudanese Chromite Ore in Gedarif State at Umm Saqata-Qala Elnahal

Mahmoud Motasim Hassan Al-Tigani[1*], Abdelshakour Awdekarim Mohamed[2] and Ahmed Abdullah Sadeek Seifelnasr[3]

[1]*Department of Mining Engineering, Faculty of Engineering Sciences, Omdurman Islamic University, Khartoum, Sudan*

[2]*Department of Chemical Engineering, Faculty of Engineering, University of Khartoum, Khartoum, Sudan*

[3]*Department of Mining Engineering, Faculty of Petroleum and Mining, Suez Canal University, Suez, Egypt*

[*]**Corresponding author:** Mahmoud Motasim Hassan Al-Tigani, Department of Mining Engineering, Faculty of Engineering Sciences, Omdurman Islamic University, Khartoum, Sudan, Tel: 00249960579034; E-mail: Mahmoudmotasim2018@hotmail.com

Rec date: October 07, 2019; **Acc date:** November 01, 2019; **Pub date:** November 09, 2019

Abstract

This study was performed on disseminated low-grade chromite ore, Gedarif State, Umm Saqata-Qala Elnahal, to treatment the ore by Heavy media separation (HMS) with low intensity magnetic separation (LIMS) for course fraction size (-212+75) µm and selective flocculation for chromite slimes (-75) µm. The ore of the study area is low grade contains 21.5% Cr_2O_3 with the liberation size of chromite mineral in the range (0.30-0.05) mm. The main gangue of the ore is mineral silicates as the Antigorite mineral. The ore was crushed, ground, and then classified to tow fraction size (-212+75) µm and slimes (-75) µm. Fractions size (-212+75) µm contained 25.58% Cr_2O_3 was treated by HMS via Bromofrom mixed with carbon tetrachloride flowed by low intensity magnetic separator. HMS with LIMS obtained the highest recovery 82.52% and grade 46.62% Cr_2O_3 for chromite concentrate with 2.54 Cr/Fe. The slimes (-75) µm contained 22.17% Cr_2O_3 was treated by selective flocculation method. Optimum grade 42.71% Cr_2O_3 and recovery 37.10% for chromite concentrate, were achieved at sodium silicate concentration 100 mg/l, starch concentration 45 mg/l, pH=9, and solid percentage 5%.

Keywords: Beneficiation; Low-grade chromite ore; HMS; LIMS; Slimes; Selective flocculation

Introduction

Chromite is an oxide mineral composed of chromium, iron, and oxygen ($FeCr_2O_4$). An important mineral used in metallurgy, chemistry, and refractory industries. Chromite ores contain a variety of gangue minerals such as serpentines and olivine. Low-grade deposits and the fines resulting in the mining operations cannot be economically used. Therefore, beneficiation of low grade and finely disseminated chromite ores is becoming important, due to the shortage of high grade ore reserves [1,2].

High grade chromite ore commonly was mined from Ingassana hills deposits in the Blue Nile region. Also form Jabal El-Tawil in Central Butana in Southern Sudan in Umm Saqta-Qala Elnahal. The reserve of the study area was estimated and it has more than 600000 tons of chromite deposit, some occurrences are not determined [3-5].

Beneficiation of a low grade chromite ores is an essential step towards optimum utilization of natural resources. Some of the old practices like hand-picking, size reduction and screening are still in use to upgrade and prepare chromite ore for use in the industry. During mining, ferruginous and siliceous chromite ore fines are created as rejects and have no market value. These low grade rejects can be utilized after suitable beneficiation which helps in conservation of high grade ore where resources are limited in the country. Simple gravity separation by tabling is very commonly used when the gangue is siliceous in the form of serpentine and talc. However Heavy media separators and Jigging are employed to recover coarse chromite [1,6]. Fine chromite (slimes) is recovered via centrifugal force technique by using falcon separator or nelson separator [7].

Heavy media separation method (HMS)

Heavy media separation or dense medium separation is commonly used to treatment the industrial minerals such as coal, black sand, chromite, etc. HMS is applicable to any ore of mineral, after the optimum degree of liberation by crushing and grinding. Bromoform (S.G. 2.89) mixing with carbon tetrachloride to give densities in the range (1.58-2.89) g/cm^3 widely was used as dense media in industrial mineral processing. Moreover, Ferrosilicon (S.G. 6.7- 6.9) is an alloy of iron and silicon which should contain not less than 82% Fe and 15-16% Si was also used for industrial mineral treatment [8].

Massive low grade chromite ore (21.56% Cr_2O_3) of the Ingassana Hills was treated by HMS using Ferrosilicon as the dense media. The results obtained high recovery 85.8 with optimum grade 46.5% Cr_2O_3 [9].

Magnetic separation method

This method uses to improve grade of Cr_2O_3 chromite when the chromite mineral located with ferrous mineral such as magnetite and hematite. As well as it uses to remove free iron oxides and Cr/Fe [1]. Sunil Kumar applied low intensity magnetic separation on concentrate of shaking table (48% Cr_2O_3) to improve Cr/Fe via roll magnetic separator. The results achieved optimize recovery (43.3%) and grade (52.3% Cr_2O_3) with Cr/Fe 3.35 at current 2.5 ampere [10].

Selective flocculation method

Use of selective flocculation is almost an indispensable practice for the treatment of mineral industry effluent which contains large proportion of fine solids [11]. In flocculation, the fine particulates suspended in liquid, interact with the flocculating agent and consequently aggregate to form flocs which settle rapidly under the influence of gravity [8].

Starch molecular and polyacrylamide are used to recover chromite mineral from slimes. Starch molecular with sodium silicate achieved efficiency [12]. Both ionic and cationic flocculants are suitable for the sedimentation of chromite tailings. However, the non-ionic polyacrylamide was not found ecient for the tailings flocculation [13].

Materials and Methods

Materials

Chromite ore samples: Low grade disseminated chromite ore was collected from different interval locations through the lenses body in Umm Saqata (sample A: N 13°20`04.3`` E 35°04`07.5``/sample B: N 13°20`4.4`` E 35°4 7.4``/sample C: N13°, 20`, 4.6`` E 35°, 4`, 7.4``). The samples were lumpy with a total collection weight about 100 kg, then were thoroughly mixed to be homogenous.

Heavy media separation regents: Promoform ($CHBr_3$) was used as the heavy media (purity 98%, wt. per ml. at 20°C 2.88-2.910 g, refractive index 1.596-1.598, and non-volatile matter >0.1%).

Carbon tetra-chloride was used for adjustment the specific gravity of the media by mixing with a promoform which has specific gravity 1.58 g/ml at 20°C.

Selective flocculation regents: Potato starch and sodium silicate were used as the flocculant and dispersant respectively.

HCL and NaOH were used as the modifiers to adjustment the pH of the pulp. Distilled water was used in all experiments tests.

Methods

Samples preparation: A representative sample of the lumpy samples was taken (about 30 kg) with particle size of 10 cm. The sample was crushed by jaw crusher to -2 cm then by roll crusher to - 2 mm in a closed circuit after that a representative sample was taken for sieve and chemical analysis. The sample -2 mm was ground for 20 minutes in close circuit rod mill with (212 micron) fraction to avoid the over grinding and decreasing slimes. Finally, the grinding product was dis-limed by using wet screening via screen 75 micron. Figure 1 shows the flow sheet of the sample preparation and equipment.

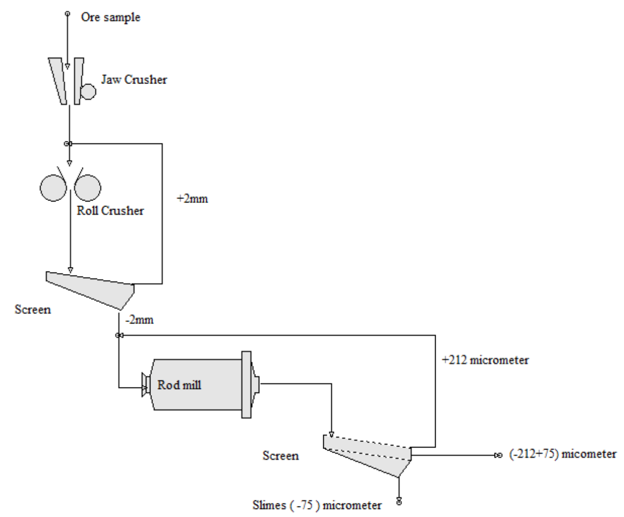

Figure 1: Sample preparation flow sheet.

Heavy media separation procedure: Carbon tetra-chloride was mixed with a promoform to generate liquids with different densities 2.5, 2.6, 2.7, 2.8 and 2.9 g/cm^3, which were saved in bottles for next experiments. Forty mills of each heavy media liquid were added to separating funnels. To each funnel the feed of low grade chromite mineral (-212+75) micron are added so that the solid constitute 35% of the total mixture (pulp). Each mixture thoroughly mixed for two minutes and then allowed to stay for 30 minutes, after which two layers will appear. The upper layer (tailing) and lower (concentrate) (Figure 2). The concentrate is removed from the bottom of the separating funnel, filtrated to recycle the Heavy media and dried. Low intensity magnetic separator is then used to remove the magnetite from the concentrate. The concentrate is subjected to the XRF instrument to determine Cr_2O_3 (%).

The above procedure was repeated using pulps containing 25% and 45% solid by weight of the total pulp using 2.9 g/cm^3 of the heavy media. The density 2.9 g/cm^3 was used because it gave the highest grade and recovery. Formula (1) using to determine the Recovery.

$$Re=[C.c/F.f] \times 100 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where Re=Recovery percentage, C=Weight of concentrate, c=concentrate assay, F=Weight of feed, f=feed assay.

Figure 2: Heavy media separation.

Selective flocculation procedure: Starch was dissolved by cooking in distilled water for 60 min in boiler at 140°C. The cooked starch was homogenized and then stored in concentration 0.5 g/l and it was freshly prepared daily to avoid degradation. Sodium silicate was also dissolved in distilled water by magnetic stirrer for 30 min and then stored 1 g/l concentration. Selective flocculation for chromite slimes was performed in single stage in 1000 ml graduate beaker.

All the tests were carried out in pulp density 5% solid by weight. Firstly, the influence of pH was studied at pH 3, pH 6, pH 9, and pH 12. After adjusting the desired pH of the pulp, the solution of the sodium silicate was added prior starch solution about 10% from volume of pulp with concentration 100 mg/l and then the pulp is mixed fully for 2 minute to insure the activity of the sodium silicate and the slimes of silicates be dispersed.

Starch solution was also added about 10% with concentration 10 mg/l from the volume of pulp and then the pulp is agitated fully for 1 min and allowed to settle for 30 second (Figure 3). The supernatant of the upper 80% part of the beaker was siphoned off and then the settled product was collected, weighted and analyzed for Cr_2O_3.

The above procedure was repeated to study the effect of starch solution concentration at 25 and 45 mg/l. The concentration of the sodium silicate solution was 100 mg/l and using pH 9 of pulp. The pH 9 was used because it obtained the highest grade and recovery. Finally, the parameter of the sodium silicate solution concentration was studied at 150 and 200 mg/l by application of the same procedure at starch solution concentration 45 mg/l and pH 9 of the pulp which was achieved highest results.

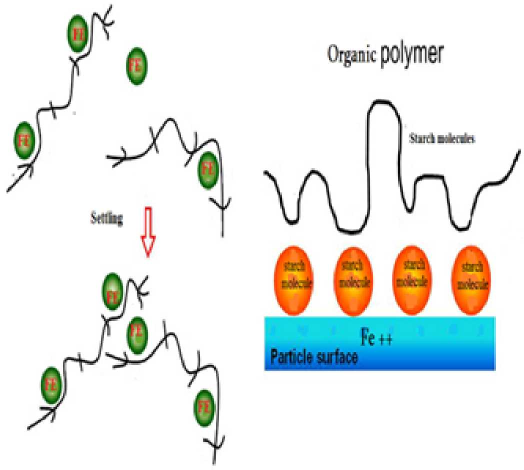

Figure 3: Selective flocculation mechanism.

Results and Discussion

Mineralogical analysis

Microscopic studies, X-ray diffraction, and scanning electron microscope revealed that the most of gangue mineral associated with tested chromite ore are silicates as the Antigorite Mineral (Figure 4). However, this ore was a low grade disseminated chromite ore and the liberation size in the range of (0.3-0.05 mm).

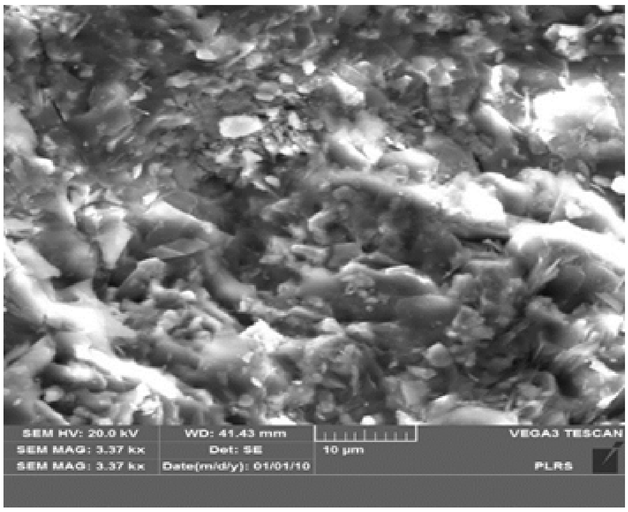

Figure 4: Scanning electron image.

As well as the chromium element was located in spinel composition (AB_2O_4) with Ca and Fe (chromtite ($CaCrO_4$), chromite ($FeCr_2O_4$)). Moreover, the sample contained Antigorite ($MgO.SiO_2.H_2O$), Magnetite (Fe_3O_4), and Chabazite ($Ca_{1.85}$ ($Al_{3.7}Si_{8.3}O_{24}$)) (Figure 5).

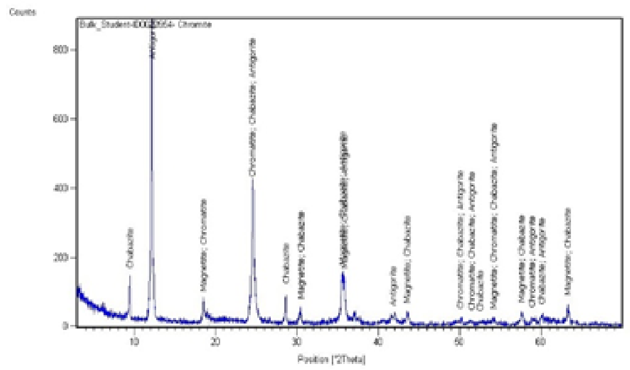

Figure 5: Pattern of the mineral phases.

Size distribution and chemical analysis: Figure 6 shows the cumulative passing weight curve of ground sample. Table 1 shows the chemical analysis of the head sample (-2 mm) via XRF and it revealed that the silicate mineral is mainly gangue in the ore.

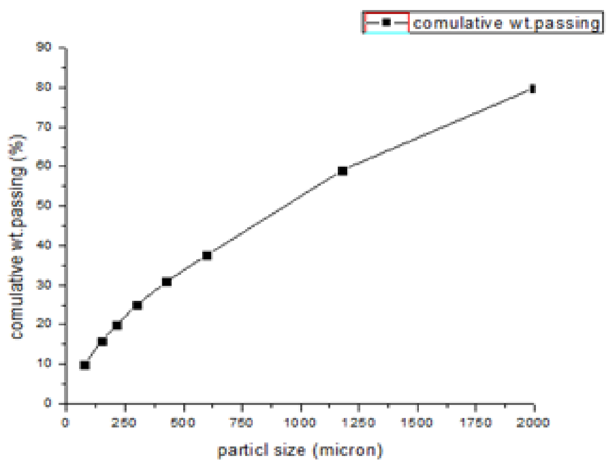

Figure 6: The size distributions of ground sample.

Oxide	Cr_2O_3	Fe_2O_3	SiO_2	Al_2O_3	MgO
%	21.5	11.8	32.61	4.608	28.09

Table 1: Chemical analysis of the head sample.

Table 2 shows the chemical analysis of wet screening products and it demonstrated that the 89% of the material by weight was in size (-212+75) µm and containing 25.58% Cr_2O_3 and 11% of the material by weight was in size fraction -75 µm and containing 22% Cr_2O_3. The chromite mineral upgraded from 21.58% to 25.58% in wet screening stage witch is attributed to different grind ability of chromite and gangue minerals.

Sieve size (micrometer)	Wt (%)	Cr_2O_3 (%)	Content (unit)
-212+75	89	25.58	22.76
-75	11	22.168	2.438
Head sample	100	21.58	21.58

Table 2: Chemical analysis of wet screening products.

Heavy media with low intensity magnetic separation

The effect of specific gravity: Table 3 shows that the chromite recoveries and grade as function of various densities at solid percentage 35% and it's revealed that the increasing the density of media causes de-creasing in recovery. The recovery of chromite concentrate increased at densities 2.6 g/cm^3, 2.7 g/cm^3 and 2.9 g/cm^3 whereas the low recovery was obtained at density 2.9 g/cm^3.

S.G. g/cm^3	Grade Cr_2O_3 (%)	Recovery Cr_2O_3 (%)	Cr/Fe Ratio	Yield Ferromagnetic
2.9	45.8	80.93	2.54	15.35
2.8	42.6	84.57	2.59	11.08
2.7	42.1	89.22	2.53	12.5
2.6	41.8	90.78	2.55	11.73
2.5	30.7	85.48	2.45	10.74

Table 3: The recoveries and grades at various heavy media densities and solid percentage 35%.

The grade was increased in high densities 2.8 g/cm^3 and 2.9 g/cm^3. Even though the highest recovery was obtained at density 2.6 g/cm^3 but it has low grade. The reason for the decreasing of the recovery at the high density media is commonly return to the resistance Heavy media or the drak force [8]. Highest grade and good recovery were achieved at density 2.9 g/cm^3. Figure 7 shows the recovery and grade curves in Heavy media separation tests.

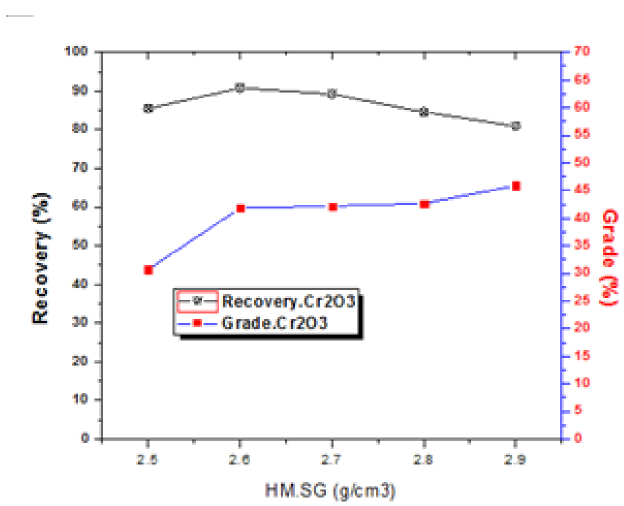

Figure 7: Recovery and grade of chromite concentrate curves obtained by heavy media separation tests.

Effect of pulp density: Table 4 shows the chromite recoveries and grades as the function of various solid percentage of the pulp at heavy media density 2.9 g/cm^3 and its revealed that the increasing of solid percentage causes decreasing in the recoveries.

Solid	Grade Cr_2O_3	Recovery	Cr/Fe	Yield Ferro-Mag
%	%	%	%	%
25	46.624	82.52	2.54	15.78
35	45.879	80.93	2.54	15.35
45	35.321	75.95	2.5	10.52

Table 4: Recoveries and grades at various solid percentage and heavy media density 2.9 g/cm^3.

High recovery was attended at solid percentage 25%. Moreover, the grade of chromite concentrate decreased in high solid percentage and this may be due to the free settling witch is obtaining in low solid percentage so that the particles precipitate without any hindrances. Highest grade with good recovery was obtained at solid percentage 25% of the pulp. Figure 8 shows the recoveries and Grades of chromite as function of various solid percentages at heavy media density 2.9 g/cm^3.

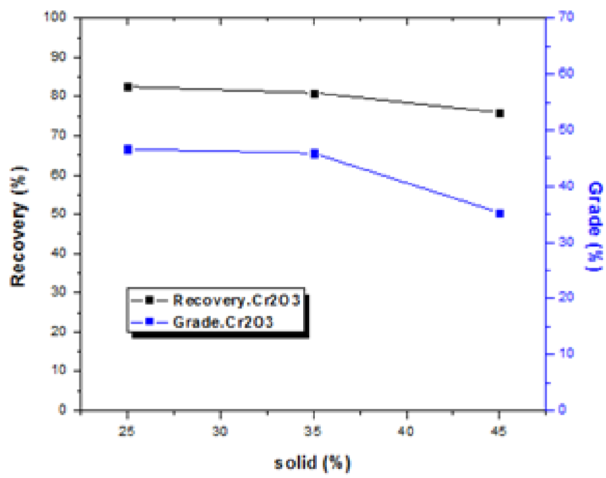

Figure 8: Recoveries and grades of chromite as function of various pulp densities at heavy media density 2.9 g/cm^3.

The effect of low intensity magnetic separation on heavy media separation product: Through the results which are given in Tables 3 and 4 revealed that the yield of ferromagnetic product is very low and that is mean the iron is found as the spinel in chromite composition greater than free magnetite.

Selective flocculation of the chromite slimes

Influence of pH: As seen Table 5 the recovery of chromite concentrate in acidic pH is higher than recovery in alkaline pH. High grade chromite concentrate was attended at pH 9, this can be partly attributed to the zeta potential charge between chromite and silicates also to the electrostatic between positively charged mineral (chromite slimes) and negatively charged starch molecules slimes [12,14]. However, at pH 12 the grade of the chromite concentrate was decreased which is attributed to the increase of the adsorption of sodium silicate on chromite mineral at rang of pH so that the adsorption of starch molecules decreased on chromite [2].

Test No	pH	Grade	Recovery
		%	%
1	3	34.398	44.9
2	6	36.152	43.9
3	9	36.675	39.1
4	12	35.468	42.4

Table 5: The recoveries and grade as function of various pH at sodium silicate concentration 100 ml/l, concentration starch 10 mg/l, and solid 5%.

The selective flocculation of a high grade and recovery was obtained at pH 9. Figure 9 shows the recovery and grade as function of various pH at starch concentration 10 mg/l starch and sodium silicate concentration 100 mg/l.

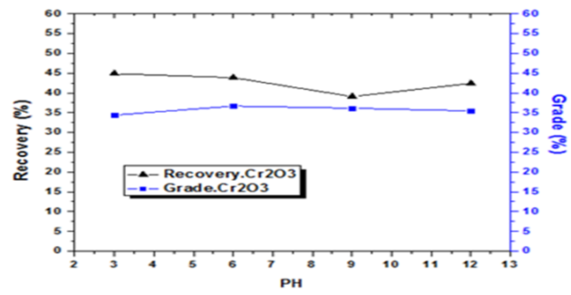

Figure 9: The recoveries and grade curves as function of various pH at sodium silicate concentration 100 ml/l, starch concentration 10 mg/l, and solid 5%.

Effect of the starch concentration: Table 6 shows that the increasing of the starch concentration causes increasing the grade of the chromite concentrate. The highest grade of chromite was obtained at starch concentration 45 mg/l witch is attributed to the selectivity of the starch molecules to adsorb on chromite surface particles and this causes increasing in rate of settling of the chromite slimes [12].

Test No	Starch	yield	Grade Cr_2O_3	Recovery Cr_2O_3
	mg/l	%	%	%
1	10	23.6	36.675	39.1
2	25	21.7	36.88	36.1
3	45	19.28	42.71	37.6

Table 6: The recoveries and grade as function of various starch concentration at pH 9, sodium silicate concentration 100 ml/l, and solid 5%.

The selective flocculation of a high grade and recovery was obtained at starch concentration 45 g/l. Figure 10 shows the recoveries and grade curves as function of various starch concentration at pH 9, sodium silicate concentration 100 ml/l, and solid 5%.

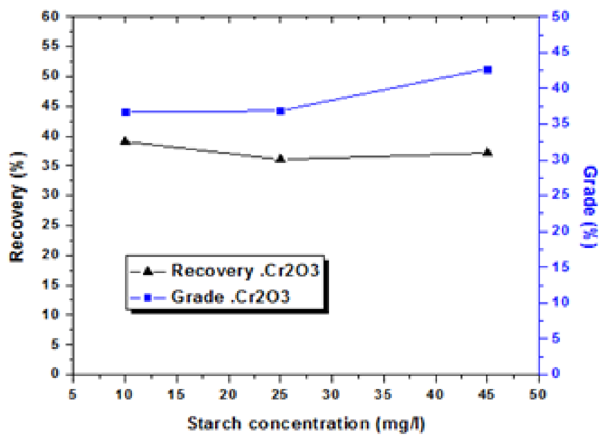

Figure 10: The recoveries and grade curves as function of various starch concentration at pH 9, sodium silicate concentration 100 ml/l, and solid 5%.

Effect of the sodium silicate concentration: Table 7 reveals that the increasing sodium silicate causes increasing the grade of the concentrate and decreasing the recovery. The highest grade of chromite concentrate was obtained at sodium silicate concentration 200 mg/l but it has the lowest recovery which is attributed to dispersant force on the slimes of mineral silicate, because increasing the sodium silicate concentration increasing the negative charge on the slimes of mineral silicate and that is increasing the selectivity of the starch molecules on chromite slimes, also it is decreasing the settling of slimes silicate (gangue).

Test No	Sodium Silicate	pH	Grade Cr_2O_3	Recovery Cr_2O_3
	mg/l	OH-	%	%
1	100	9	42.71	37.1
2	150	9	42.98	35.04
3	200	9	43.27	33.7

Table 7: The recoveries and grade as function of various sodium silicate at pH 9, starch concentration 45 mg/l, and solid 5%.

The selective flocculation of the optimum grade and recovery was achieved at sodium silicate concentration 150 mg/l. Figure 11 shows the recoveries and grade curves as the recoveries and grade as function of various sodium silicate at pH 9, starch concentration 45 mg/l, and solid 5%.

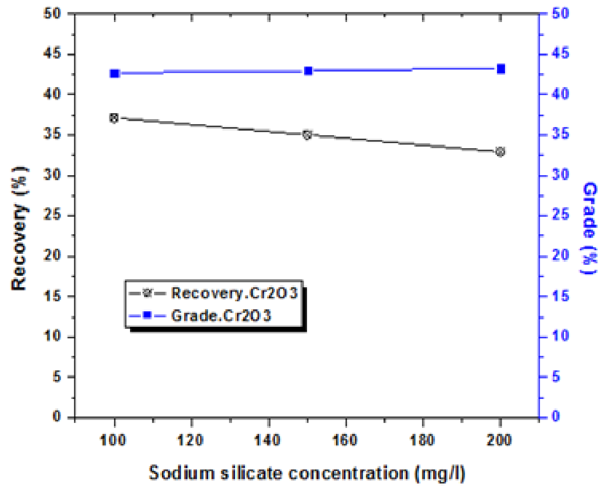

Figure 11: The recoveries and grade as function of various sodium silicate at pH 9, starch concentration 45 mg/l, and solid 5%.

Conclusion

Low grade chromite ore of the study area is disseminated and the most of gangue mineral associated with tested chromite ore are silicates as the Antigorite. In addition to, the ore a liberation size in the range of (0.3-0.05) mm. Heavy media separation followed by low intensity magnetic separation test at pulp density of 25% and heavy medium density 2.9 g/cm^3 produced a concentrate with highest grade of 46.687% Cr_2O_3 and optimum recovery of 82.52%, while Heavy media separation followed by low intensity magnetic separation test at pulp density of 35% and heavy medium density 2.5 g/cm^3 obtained a concentrate with lowest grade 30.74 Cr_2O_3 and high recovery 85.48%. This attributed to the hindrance settling which obtains in high pulp density. Also attributed the decreasing of the drak force and resistant force of media separation, these obtains in lowest heavy media densities. Selective flocculation for chromite slime revealed that increasing the pH greater than pH 9 caused decreasing the grade of the concentrate that is attributed to the increase of the adsorption of sodium silicate on chromite mineral. Low recovery of 37.1% with grade of 42.71% Cr_2O_3 at pH 9 and starch concentration of 45 mg/l, and sodium silicate concentration 100 mg/l.

Acknowledgement

The authors thank General of Geological Research Authority of Sudan (GRAS) in Gadaref State, for logistic support during the fieldwork. Also the acknowledgment is going deeply to Eng. W. Osaman, Quality Control Department in Kush for Mining Co-ltd for financial support. Moreover, the authors thank Eng. I. Mubarak, University of Khartoum, Faculty of Engineering, Chemical Engineering Department for supporting in samples analysis.

References

1. Gundewar BPS (2013) Monograph on Chromite. Government of India, Ministry of Mines, Indian Bureau of Mines, pp: 94-97.

2. Seifelnasr AA, Tammam T (2011) FLotation Behavior of Sudanese Chromite Ores. Journal of Engineering Sciences, Assiut University, pp: 649-661.
3. Suleiman Y (1994) Economic potentiality of mineral and rocks in Gala Enhal&umm saqata. MSc Thesis, Khartoum University, Sudan.
4. Ahmed AAM (1998) Sudan Industrial Mineral & Rocks. Center for Strategic Studied, Khartuom, Sudan, pp: 76-106.
5. Republic CP (1979) Summary of talks on the project of chromite prospecting and exploration in the Sudan. Ministery Indust. Mining, Khartoum.
6. Seifelnasr AA, Tammam T, Abouzeid AZM (2012) Gravity Concentration of Sudanes Chromite Ore using Labrotaroy Shaking Table. Physicochemical Problems of Mineral Processing.
7. Singh KKBSCM (2004) Gravity concentration of fines and ultrafines. National Metallurgical Laboraton, pp: 40-56.
8. Wills BA, Finch J (2015) Wills' mineral processing technology: an introduction to the practical aspects of ore treatment and mineral recovery. Butterworth-Heinemann.
9. Magboul EMM (2014) Effective Processing of Low Grade Chromite Ore by Heavy Medium Separation Process. University Of Khartoum Engineering Journal.
10. Tripathy SK, Singh V, Ramamurthy Y (2012) Improvement in Cr: Fe ratio of Indian chromite ore for ferro chrome production. International Journal of Mining Engineering and Mineral Processing 1: 101-106.
11. Bulatovic SM (2007) Handbook of Flotation Reagents. Elsevier Science & Technology Books 1: 229-230.
12. Beklioglu B, Arol AI (2004) Selective flocculation behavior of chromite and serpentine. Fizykochemiczne Problemy Mineralurgii/ Physicochemical Problems of Mineral Processing, 38: 103-112.
13. Karmakar NC, Sastry BS, Singh RP (2002) Flocculation of chromite ore fines suspension using polysaccharide based graft copolymers. Bulletin of Materials Science 25: 477-478.
14. Souza RF, Brandão PR, Paulo JB (2012) Effect of chemical composition on the ζ-potential of chromite. Minerals Engineering 36: 65-74.