Asian Journal of Chemistry Vol. 22, No. 3 (2010), 2417-2426

Use of Gravimetric Separators for the Beneficiation of Gunduzler Chromite Ore

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This study involves gravity processing of chromite samples taken from Eskisehir/Gunduzler ore deposit. Several gravity concentration tests including jig, shaking table and MGS concentration with different flowsheet options were performed for this purpose. The study revealed that a Cr_2O_3 rich concentrate high recovery values can be obtained by the application of gravity concentration techniques from this ore.

Key Words: Chromite ores, Shaking table, MGS.

INTRODUCTION

Eskisehir/Gunduzler chromite ore deposit is located at east of Eskisehir. The ore is mostly disseminated type but also vein formations can be seen in the cracks. Chromite is found in severely mashed serpentine[1].

The ore is very friable and can easily be comminuted by crushing and grinding operations. Chromite minerals are observed as mainly disseminated into serpentine and serpentinized dunite matrix and have a particle liberation size of about 300 μm.

In general, particle liberation size and the type of gangue mineral determine the beneficiation method of the chromite ore. If the ore contains significant amount of olivine, the separation is harder by gravity processing due to the high specific gravity of the olivine. Magnetic separation is needed for this type of ores. In case of the presence of the serpentine as gangue mineral, gravity concentrators such as jigs, shaking tables, spirals and multi gravity separators are the most commercially used devices. These devices separate the minerals from each other based on the differences between their specific gravities. It is a low cost and environmentally friendly operation[2,3]. Flotation is another method to be used for the concentration of chromite ores, but it is rather difficult to separate chromite from serpentine because of the similar surface properties of both minerals[4].

Conventional flotation, column flotation and multi gravity separators are usually preferred for the treatment of the chromite ores having fine particle liberation size (below 100 μm). Shaking table, spirals and jigs are more appropriate for the coarser particles[2-8].

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In this study, different techniques of gravity concentration were applied to recover chromite from Eskisehir/Gunduzler chromite ore. For this purpose, a laboratory scale mineral jig, shaking table and a pilot scale MGS (Mozley multi-gravity separator) were employed in concentrations tests.

EXPERIMENTAL

The main ore mineral in the investigated sample (chromitite) is chromite (chromian spinel). Chromite mineral is found as massive and disseminated assemblages. Massive ore includes *ca.* 90-95 vol. % chromite with closely packed < 0.02-3 mm large chromite grains. Interstitial silicates between the grains are mainly olivine and serpentine group minerals. Disseminated ore includes *ca.* 65-70 vol. % chromite with 0.02-2 mm large chromite in a matrix made of serpentinized olivine (Fig. 1a). Both massive and disseminated ore are characterized by cataclastic texture with fissures, cracks and breccia. However the latter is much more affected (Fig. 1a). Chromite in massive ore is generally fresh with only ferrite-chromite and magnetite alterations along its borders, fissures and cracks (Fig. 1b). There alterations are more abundant in more severely brecciated disseminated ore.

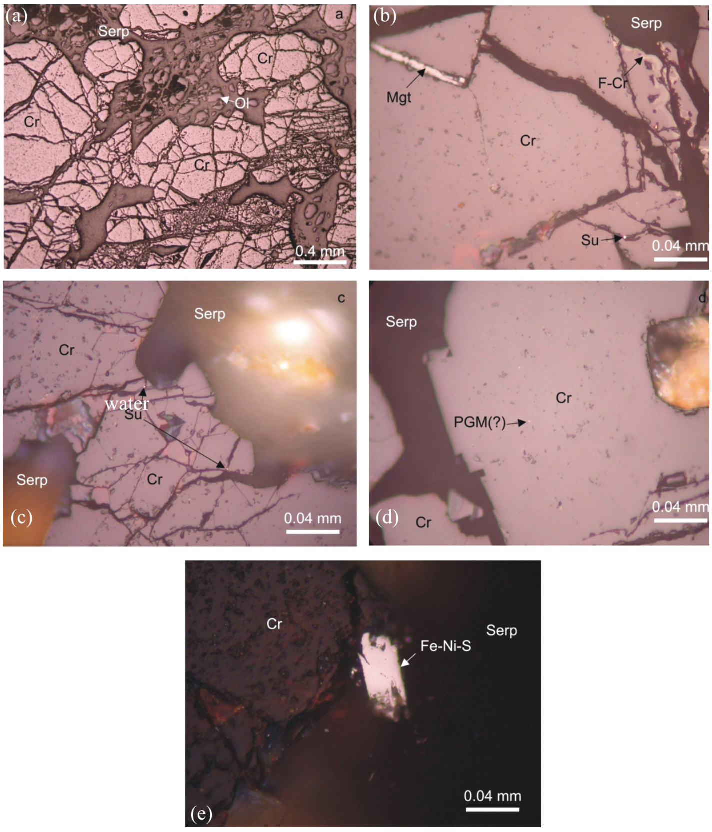

Fig. 1. Microscopic examination of the ore

Very small (*ca.* 2 μ) sulfide grains are located in cracks of the chromite crystals (Figs. 1b and c). These grains are usually too small to determine *via* conventional reflected light microscopy. However, this kind of occurrences are generally ubiquitous in chromitites and might be base-metal (Fe-Ni-Cu) sulfides and/or alloys. A very small (*ca.* 2 μ) isolated and discrete sulfide inclusion (Fig. 1d) observed in the massive ore is suspected to be a platinum-group phase (a member of laurite-erlichmanite series), however, dimensions of the grain did not allow us to make an exact determination. In addition, a relatively larger sulfide (*ca.* 60 μ) is found located in contact of the chromite crystal and silicate mineral. This phase is isotropic, presents rather high reflectivity and a light yellow color with a whitish tint. This phase may be interpreted as a Fe-Ni-S bearing phase (Ni-pyrite, pentlandite, *etc.*) (Fig. 1e).

The effect of size reduction on the liberation of particles was investigated by means of microscopic examinations. The study showed that whether in its pure or partially separated form, chromite and gangue minerals mingled in different size fractions. As can be seen from the Fig. 2, chromite is distributed almost evenly in all particle size classes, but the number of the liberated chromite particles increases below 0.5 mm particle size. Liberation ratio rises to about 80 % below 0.3 mm particle size and reaches almost 100 % below 0.1 mm. The pictures of the particles representing different size fractions are given in Fig. 2.

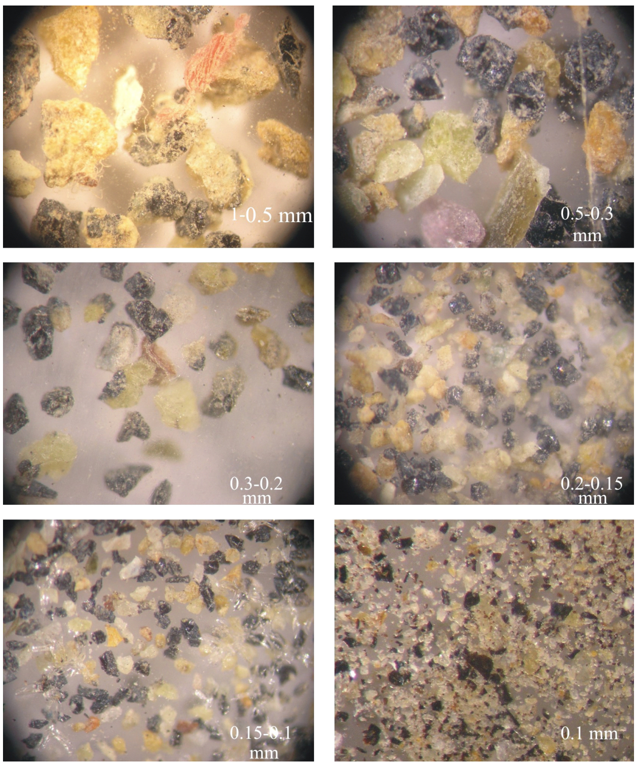

Fig. 2. Microscopic images of the particles classified in different size ranges

General procedure: The whole sample was crushed below 15 mm using a jaw crusher. The crushed ore was split to 3 sub-samples by using a sample splitter. The first sample was classified into different size fractions by screening to use in the first group of concentration tests. The second sample was crushed below 5 mm using a roll crusher and ground below 0.5 mm using a rod mill and used in shaking table tests. The third sample was crushed below 5 mm using a roll crusher and ground below 0.1 mm using a rod mill and used in MGS concentration tests. The flow sheet of the experiments was given in Fig. 3.

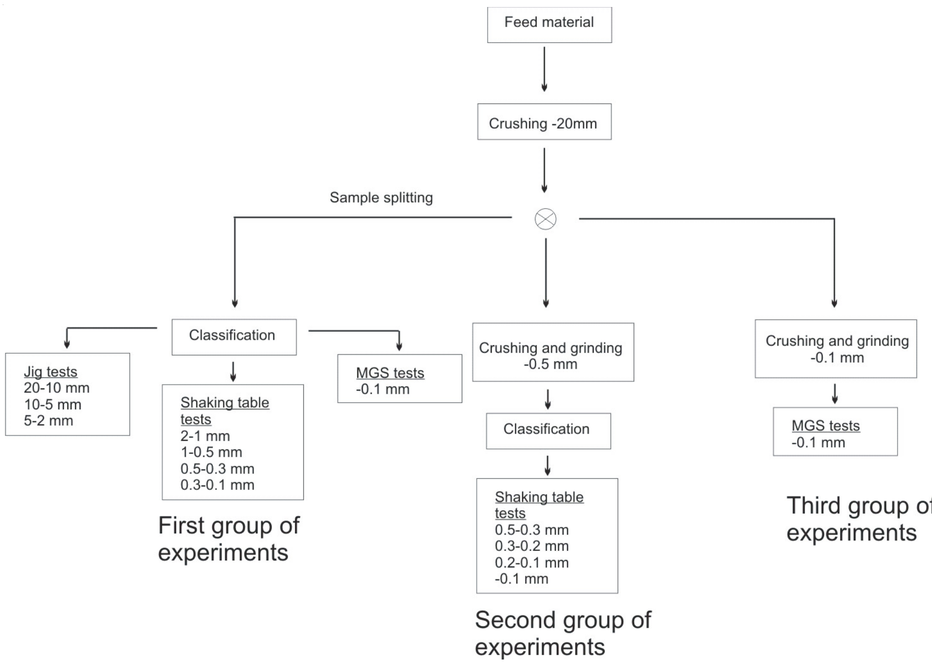

Fig. 3. Flowsheet of the experiments

Detection method: Mineralogical characterization of the ore was carried out using an optical microscope. Elemental composition of the samples was determined by using wet chemical analysis technique and an Analytic JenaAG novAA 330 atomic absorption spectrometer.

RESULTS AND DISCUSSION

First group of concentration tests (the tests on 15 mm crushed material): 15 mm crushed ore sample was classified into different size fractions by screening before using in the experiments. 15-2 mm size fraction was employed in the jigging tests, 2-0.1 mm size fraction was used in the shaking table tests and 0.1 mm size fraction was subjected to MGS separation.

Jigging tests of 15-2 mm size fraction: Mineralogical analysis studies showed that sufficient liberation for an effective separation can not be sustained at coarse particle sizes. For this reason, the jigging tests were performed to find out whether a large portion of the chromite can at least be pre-concentrated effectively. The tests were conducted by using a one-compartment mineral jig. The results were presented in Table-1.

TABLE-1
RESULTS OF THE JIGGING TESTS OF THE 15-2 mm PARTICLE SIZE FRACTION

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
15-10	Concentrate	69.85	16.55	5.97	23.98	79.85	74.90	65.74
	Tailing	30.15	9.68	4.64	28.96	20.15	25.10	34.26
	Feed	100.00	14.48	5.57	25.48	100.00	100.00	100.00
10-5	Concentrate	76.92	25.89	6.25	22.51	89.96	80.70	70.77
	Tailing	23.08	9.63	4.98	30.97	10.04	19.30	29.23
	Feed	100.00	22.14	5.95	24.46	100.00	100.00	100.00
5-2	Concentrate	76.57	31.02	6.39	25.27	91.11	86.26	72.18
	Tailing	23.43	9.90	3.33	31.83	8.89	13.74	27.82
	Feed	100.00	26.07	5.67	26.80	100.00	100.00	100.00

As it can be seen from the Table-1, the clearest separation was obtained by using 5-2 mm particle size fraction. This test showed that it is possible to remove 23-43 % of the total material by using a mineral jig before feeding to the shaking tables with 91.11 % chromite recovery. The grade of this pre-concentrate was about 31 % Cr_2O_3. However, a techno-economical evaluation should be done before the implementation of this option in the processing flowsheet.

Shaking table tests of 2-0.1 mm size fraction: These tests were realized using a 1270 mm × 480 mm Wilfley type shaking table by applying the following operational parameters; stroke: 10 mm, tilt angle: 4º, water: 11 L/min, speed: 500 rpm. A single-stage cleaning was applied after rougher concentration. The results were given in Table-2.

The best result was achieved for 0.3-0.1 mm size fraction in this group of experiments. A concentrate containing 56.00 % Cr_2O_3 and a middling assaying 44.01 % Cr_2O_3 was produced. The middling grade was considerably high and thus can be joined to the concentrate. The overall Cr_2O_3 recovery can be increased to 64.28 % by combining these two products, however, the grade of the new concentrate decreases to 45.35 % Cr_2O_3.

MGS tests of 0.1 mm size fraction: 0.1 mm particle size fraction of the 15 mm crushed ore was subjected to MGS concentration tests by using a pilot scale MGS separator. Some of the operational parameters such as pulp density (25 %), wash water rate (5 L/min), shaking amplitude (15 mm), shaking frequency (4.8 cycles/s) and feeding rate (2.5 L/min) were kept constant in all the tests. The results obtained by changing rotational speed and tilt angle of the drum are presented in Table-3.

TABLE-2
RESULTS OF THE SHAKING TABLE TESTS OF THE 2-0.1 mm PARTICLE SIZE FRACTION

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
2-1	Concentrate	49.04	30.80	7.87	20.57	58.22	59.11	40.59
	Middling	17.37	25.83	6.29	24.98	17.29	16.73	17.45
	Tailing	33.59	18.91	4.69	31.04	24.49	24.16	41.96
1-0.5	Feed	100.00	25.94	6.53	24.85	100.00	100.00	100.00
	Concentrate	24.06	38.93	7.86	18.12	40.05	32.48	17.28
	Middling	24.41	25.45	6.51	23.27	26.56	27.28	22.51
0.5-0.3	Tailing	51.53	15.15	4.55	29.49	33.39	40.24	60.21
	Feed	100.00	23.39	5.82	25.24	100.00	100.00	100.00
	Concentrate	16.15	57.44	10.41	15.41	31.21	23.52	10.45
	Middling	38.62	37.18	8.53	18.18	48.28	46.11	29.47
	Tailing	45.22	13.49	4.80	31.65	20.51	30.36	60.08
	Feed	100.00	29.74	7.15	23.82	100.00	100.00	100.00
0.3-0.1	Concentrate	8.93	56.00	12.64	10.41	13.52	11.73	4.28
	Middling	70.92	44.01	10.66	18.54	84.40	78.56	60.60
	Tailing	20.15	3.82	4.64	37.82	2.08	9.71	35.12
	Feed	100.00	36.98	9.62	21.70	100.00	100.00	100.00

TABLE-3
MGS TEST RESULTS OF 0.1 mm PARTICLE SIZE FRACTION (TILT ANGLE: 4º)

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
220	Concentrate	78.13	29.61	11.38	19.70	93.09	83.42	68.18
	Tailing	21.87	7.85	8.08	32.84	6.91	16.58	31.82
	Feed	100.00	24.85	10.66	22.57	100.00	100.00	100.00
200	Concentrate	66.34	30.51	11.28	19.06	90.38	76.58	52.91
	Tailing	33.66	6.40	6.80	33.44	9.62	23.42	47.09
	Feed	100.00	22.40	9.77	23.90	100.00	100.00	100.00
180	Concentrate	48.46	44.17	14.54	18.02	88.59	65.53	32.47
	Tailing	51.54	5.35	7.19	35.23	11.41	34.47	67.53
	Feed	100.00	24.16	10.75	26.89	100.00	100.00	100.00

In general, increasing the tilt angle and decreasing the rotational speed of the drum led to higher concentrate grades but lower recovery values. The optimum conditions for the recovery of chromite from 0.1 mm particle size fraction was provided by applying 6º tilt angle and 180 rpm rotational speed. A concentrate assaying 46.49 % Cr_2O_3 with 85.77 % recovery and 47 % yield was obtained by the use of these operational parameters.

Second group of concentration tests (the tests with 0.5 mm ground material): The material ground below 0.5 mm was classified into particular size fractions and has been subjected to the shaking table and MGS concentration tests.

TABLE-4
MGS TEST RESULTS OF 0.1 mm PARTICLE SIZE FRACTION (TILT ANGLE: 6º)

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
220	Concentrate	71.16	33.84	12.02	20.73	91.99	80.84	60.83
	Tailing	28.84	7.27	7.03	32.94	8.01	19.16	39.17
	Feed	100.00	26.18	10.58	24.25	100.00	100.00	100.00
200	Concentrate	60.21	37.15	10.84	18.73	89.63	70.88	45.28
	Tailing	39.79	6.50	6.74	34.25	10.37	29.12	54.72
	Feed	100.00	24.95	9.21	24.91	100.00	100.00	100.00
180	Concentrate	46.35	46.49	13.88	16.10	85.77	65.88	29.00
	Tailing	53.65	6.66	6.21	34.05	14.23	34.12	71.00
	Feed	100.00	25.12	9.76	25.73	100.00	100.00	100.00

Shaking table tests of 0.5 mm size fraction: The material was screened to prepare different particle size fractions for using in the shaking table tests. The tests were done using different table tilt angles, the other operational parameters were kept constant.

0.5-0.3 mm particle size fraction was treated by applying 4º, 3º and 2º tilt angles. However, the tests conducted by the application of 3º and 2º tilt angles were unsuccessful. The results obtained by the use of 4º tilt angle were given in Table-5.

TABLE-5
RESULTS OF THE SHAKING TABLE TESTS OF 0.5-0.3 mm SIZE FRACTION

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
0.5-0.3	Concentrate	49.04	42.19	10.87	15.63	32.48	24.04	9.08
	Middling	17.37	31.02	9.43	20.86	40.40	35.31	20.52
	Tailing	33.59	11.18	5.83	38.44	27.12	40.64	70.40
	Feed	100.00	26.73	7.89	21.39	100.00	100.00	100.00

The liberation degree of the chromite particles was still not enough for a successful separation at this particle size. A concentrate containing 42.19 % Cr_2O_3 and a middling assaying 31.02 % Cr_2O_3 were obtained in this experiment. Concentrate and middling chromite recoveries were 32.48-40.40 %, respectively.

Shaking table tests of the 0.3 mm size fractions were performed by applying the same operational parameters. The tests conducted by the application of 4º and 3º tilt angles were failed at this time. The results obtained by the use of 2º tilt angle were presented in Table-6.

As it is a well known fact that table concentration gives better results for the materials classified into narrow particle size ranges, concordantly, better results were obtained from the concentration tests with the narrowly classified samples above.

TABLE-6
RESULTS OF THE SHAKING TABLE TESTS OF 0.3 mm SIZE FRACTION

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
0.3-0.2	Concentrate	34.55	53.50	11.10	15.38	60.36	48.37	22.11
	Middling	35.64	29.51	8.12	24.55	34.35	36.52	36.42
	Tailing	29.81	5.44	4.02	33.41	5.30	15.11	41.46
	Feed	100.00	30.63	7.93	24.02	100.00	100.00	100.00
0.2-0.1	Concentrate	35.20	42.14	14.11	10.70	57.27	46.75	21.47
	Middling	42.90	24.12	10.78	17.99	39.95	43.51	44.00
	Tailing	21.91	3.29	4.72	27.65	2.79	9.74	34.53
	Feed	100.00	25.90	10.63	17.54	100.00	100.00	100.00
-0.1	Concentrate	19.16	44.99	14.75	12.10	51.00	34.03	9.67
	Middling	32.54	15.69	8.32	22.30	30.22	32.62	30.28
	Tailing	48.30	6.57	5.73	29.79	18.78	33.35	60.05
	Feed	100.00	16.90	8.30	23.96	100.00	100.00	100.00

Third group of concentration tests (the tests with 0.1 mm ground material): MGS tests: In this test, the feed material was ground below 0.1 mm and subjected to MGS concentration using the optimum parameters found in the first group of tests. The results are given in Table-7.

TABLE-7
RESULTS OF THE MGS-ONLY CONCENTRATION TEST

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
180	Concentrate	56.37	34.85	12.99	17.41	93.30	80.31	39.84
	Tailing	43.63	3.23	4.11	33.98	6.70	19.69	60.16
	Feed	100,00	21.06	9.12	24.64	100,00	100,00	100,00

MGS separator achieved a chromite recovery of 93.30 % at a yield of 56.37 %. The grade of the concentrate was found to be as 34.85 % Cr_2O_3.

Conclusion

An overall evaluation of the first group of experiments was summarized in Table-8. The data represent the evaluation of a flowsheet option assuming the processing of 15-2 mm size fraction for the production of a pre-concentrate using the jig units. The remaining equipments (shaking table and MGS) operate for the beneficiation of 2 mm material according to this assumption. The grade of the concentrate produced by the concentration of 2 mm material using shaking table and MGS will be about 39.09 % Cr_2O_3. Re-processing of the pre-concentrate and middlings are not involved in the calculations.

An overall evaluation of the second group of tests was summarized in Table-9. This flowsheet considers grinding of ore below 0.5 mm and concentrating using shaking tables. The assay of the concentrate was found as 45.56 % Cr_2O_3 and overall

TABLE-8
OVERALL EVALUATION OF THE FLOWSHEET OPTION INCLUDING JIGS AS THE PRE-CONCENTRATORS AND SHAKING TABLE AND MGS UNITS AS THE MAIN CONCENTRATORS

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
15-2	Concentrate	61.08	26.89	6.28	23.26	69.54	61.37	58.30
	Tailing	18.68	9.70	4.55	31.10	7.67	13.59	23.84
	Feed	79.76	22.86	5.87	20.02	77.21	74.96	82.14
-2	Concentrate	6.35	39.09	9.87	18.12	43.63	40.18	5.43
	Middling	6.02	36.88	8.93	20.40	38.99	34.46	3.63
	Tailing	7.87	12.57	5.03	27.31	17.37	25.37	8.80
	Feed	20.24	28.12	7.71	4.53	100.00	100.00	17.86

TABLE-9
OVERALL EVALUATION OF THE SHAKING TABLE-ONLY FLOWSHEET OPTION OF 0.5 mm GROUND MATERIAL

Size fraction (mm)	Products	Weight (%)	Grade (%)			Fractional recovery (%)		
			Cr_2O_3	Fe	MgO	Cr_2O_3	Fe	MgO
0.5	Concentrate	31.64	45.56	13.00	12.82	58.22	44.87	20.16
	Middling	35.94	23.47	9.46	20.77	34.07	37.08	37.10
	Tailing	32.42	5.89	5.10	26.52	7.71	18.05	42.73
	Feed	100.00	24.76	9.17	20.12	100.00	100.00	100.00

recovery of the concentrate was calculated as 58.22 % according to this flowsheet option. About 32 % of the total feed is obtained as a saleable product.

It is important to note that both of the flowsheet options mentioned above produce high-grade middling products. These middlings can be re-ground and fed to the circuit to increase the overall efficiency.

The last flowsheet option considers grinding of the feed material below 0.1 mm and the use of a MGS separator for the concentration (Table-7). By implementing this option, a concentrate assaying 34.85 % Cr_2O_3 can be obtained with 93.30 % chromite recovery. This result imply that MGS device is very effective for recovering fine chromite particles, but it can not produce high grade concentrates with high recoveries from this ore.

As a conclusion, it can be said that concentration of Gunduzler chromite ore by gravity processing devices is possible and different flowsheet options can be implemented for this purpose. The best available option seem to be grinding of the ore below 0.5 mm and concentrating it by using shaking tables. After grinding of the ore below 0.5 mm, 0.1 mm fraction can be separated from the rest of the material and treated using MGS concentrator.

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(*Received*: 1 October 2009; *Accepted*: 3 December 2009) AJC-8138