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Original Research

Recovery of chromite from concentrator plant tailings

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A B S T R A C T

In this study, experimental studies have performed to recover chromite from Eskiköy-Sivas chromite concentrator which is owned Bilfer Madencilik ve Turizm A.Ş. Mineralogical and liberation measurement studies were performed, and it was decided to grind the feed to 100% finer than 300 µm.

Gravity concentration and wet high intensity magnetic separation (WHIMS) tests were performed. After grinding to -300 µm, -38 µm fraction which cannot be recovered efficiently was removed. The studies were conducted on 300+100 µm and -100+38 µm fractions. After the beneficiation tests, it was determined a circuit consists of spiral concentrator and shaking tables could produce a concentrate containing 48% Cr_2O_3 from the tailings having 6.54 % Cr_2O_3, with a 56% recovery.

Keywords: *Tailings, Particle Size Distribution, Spiral, Shaking Table, Magnetic Separation.*

Introduction

Chromite ($(Mg,Fe^{+2})(Cr,Al,Fe^{+3})_2O_4$), which has been used metallurgy, chemical, refractory and foundry industries, is an irreplaceable mineral.

Türkiye is the fourth in the chromite reserves and second in the production (USGS, 2022). Chromite deposits are distributed to all regions. Since the beneficiation plants have been in operation since the beginning of the 20th century, there are large amount of tailings accumulated containing varying amount of chromite, and the depletion of high grade deposits have been motivated the researchers for the recovery of chromite from old tailings (Acar, et al.,2018, Güney, et al., 2016, Güney, et al., 2001 and Çiçek, et al. 2002).

Currently, there are two operating plants in Türkiye processing tailings.

In countries such as South Africa, Iran, and India, which have a significant share in chromite production, there are studies to obtain concentrate from tailings. (Tripathy et al, 2011, Khakmardan et al, 2020, Feng and Aldrich, 2003, Tripathy et al, 2013 and Kumar et al, 2009).

It is possible to enrich the chromite ore by different methods. However, it is necessary to choose the most appropriate and economical management. In the selection of the most suitable method, mineralogical, physical, and chemical properties of the ore have an important place. (Deniz et al., 2001)

Gravity concentration has been the main method used in chromite beneficiation. Dense medium separation, jigging, spiral concentrators, shaking tables and Multi-Gravity Separator are used in operating plants (Burt, 1984).

Magnetic separation and flotation have also found application in a few cases (Nafziger, 1975). As the chemical composition and attenuation grain size of chromite, which has a spinel structure, are very variable, enrichment methods naturally also contain differences. For example, increased the Fe^{+2} ratio in the chromite content increases its magnetic susceptibility. Therefore, it can be enriched by high-intensity magnetic separation. (URL-1)

Beneficiation of chromite from tailings is more difficult and complex since free liberated chromite particles were already recovered in the original process.

This paper was extracted from MSc thesis of Mehmet Özyurt at Sivas Cumhuriyet University and presents beneficiation studies have been performed for the recovery of chromite from the tailings of a chromite beneficiation plant operating since 1987 in Eskiköy- Sivas.

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1. Materials and methods

1.1. Sampling

Samples were taken from the tailing storage facility of the mine by trenching and shaft samples in both vertical and horizontal axes. Main sample was then divided to sub sample of 500 kg by coning-quartering.

1.2. Characterization of the sample

1.2.1. Chemical composition of the sample

XRF method was used for chemical analyses. The chemical composition of the sample is given in Table 1.

Table 1. *Chemical composition of the tailings*

% Amount							
Cr_2O_3	Fe_2O_3	Al_2O_3	MgO	SiO_2	CaO	Ni	Co
6.54	6.34	2.12	35.05	28.13	1.12	0.28	0.02

1.2.2. Size distribution of the tailings and Cr_2O_3 distribution of the fractions

The size distribution of the tailings after wet sieving and Cr_2O_3 content of the size fractions are given in Table 2.

Table 2. *Size distribution and Cr_2O_3 content of the size fractions.*

Sieve Size (mm)	Weight (%)	Cr_2O_3 %	Distribution (%)
-9.50+1.18	4.85	2.65	2.01
-1.18+0.6	14.71	4.33	9.95
-0.6+0.3	21.42	5.25	17.57
-0.3+0.106	25.08	6.36	24.91
-0.106+0.038	14.06	10.04	22.06
-0.038+0.025	3.24	16.65	8.41
-0.025	16.64	5.81	15.10
Total	100.00	6.40	100.00
Assay	-	6.54	-

As can be seen from the Table 2, chromite content of the size fractions increases as the size decreases down to 25µm. About 23 % of Cr_2O_3 is in the -38 µm, while 30% of it is in +300µm.

1.2.3. Determination of Mineral Composition and Liberation

1.2.3.1. Quantitative XRD Analysis

XRD pattern of the sample were obtained by using Rigaku-Miniflex 600 equipment. XRD pattern of the tailing sample is given in Figure 1 and its mineral composition is given in Table 3.

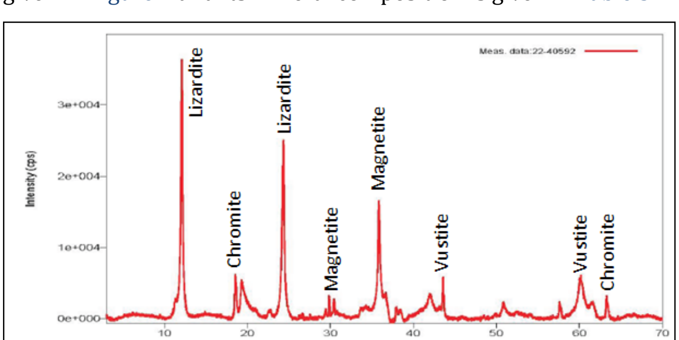

Figure 1. *X-ray diffraction pattern of the tailing*

Table 3. *Mineral composition of tailing as measured by quantitative XRD*

Mineral	Mineral Formula	Weight (%)
Lizardite	$Mg_3\,(Si\,O_5)\,(O\,H)_4$	84.5
Magnetite	$Fe_3\,O_4$	2.2
Wustite	$Fe_{.9712}\,O$	3.6
Chromite	$FeO\,Cr_2\,O_3$	4.7
Amorphous solid	-	5.0
Total	-	100.0

1.2.3.2. Determination of liberation

Grain counting using an optical microscope is one of the methods that can be applied to determine the degree of attenuation. It is based on the principle of examining the product remaining on each sieve in the sieve series with a microscope after the sieve analysis is done as a result of the size reduction processes.

Easily identifiable grains can be counted in “Stereo (Binocular) Microscopes” up to 75 µm. The method is based on counting the precious and non-precious free particles and the combined particles under the microscope.

For the determination of liberation degree of the tailings particle counting under binocular microscope. For this purpose, -300+212 µm, -212+150 µm, -150+106 µm and -106+75 µm, size fractions were prepared by wet sieving.

Liberation degrees of the size fractions are given in Figure 2. As expected, the liberation increases as the size decreases. The liberation of the finest fraction studied, -106+75 µm, was found to be 76.52% which denotes grinding would be required before beneficiation. Fherefore, the sample was ground to 100% finer than -300 µm.

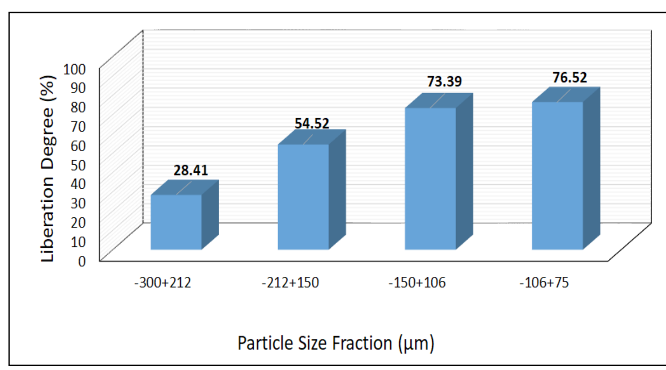

Figure 2. *Liberation degree of size fractions*

1.3. Mineralogy and liberation of ore produced from quarries

The bright sections of the hand samples taken from the quarries that provide raw materials to the ore beneficiation plant, prepared by embedding in araldite, were examined by ore microscope. Serpentine mineral containing euhedral and semi-euhedral chromite crystals and olivine residues filling them were observed in these sections. Most of the chromite crystals had dimensions of 0.25-0.3 mm. Chromite texture is generally in cataclastic structure and not strictly angular. Cataclastic tissue is a structure prone to slime production. It is possible to release the chromite to a large extent as a result of grinding the ore below 300 microns.

It was determined that the data obtained from the determination of the degree of attenuation of the waste and the data of the attenuation dimension obtained from the microscopic analysis of the run-of-the-mill ore were consistent.

1.4. Beneficiation Studies

Since the amount of tailings is about 500 kg, it was logical to build the tailing recovery circuit in the existing concentrator building. Therefore, to reduce the footprint of the circuit, spiral concentrator was thought to be the most convenient alternative as a pre-concentration step. On the other hand, the efficiency of gravity concentration drops sharply for the particles smaller than 40µm. Multi Gravity Separator has higher efficiency than shaking tables for this size range was not considered due to the very high investment cost of the equipment. Instead, -38 µm was removed from the feed by wet screening. The fractions prepared and their Cr_2O_3 contents are given in Table 4.

Table 4. *Cr_2O_3 contents of size fractions used in tests*

Size (micron)	Weight %	Cr_2O_3 %	Distribution (%)
-300+100	65.28	6.46	63.99
-100+38	20.14	8.12	24.81
-38	14.58	5.06	11.20
Total	100.00	6.59	100.00
Analysis		6.54	

The simplified flowsheet for the beneficiation studies is given in Figure 3.

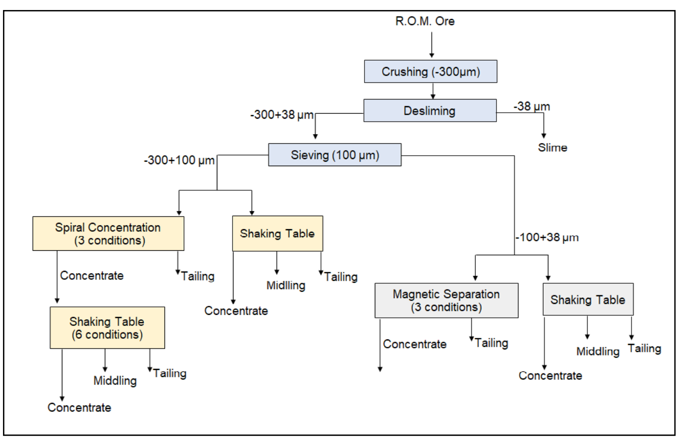

Figure 3. Simplified flowsheet of beneficiation studies

1.4.1. Spiral Beneficiation Studies for -300+100 µm Fractions

The spiral concentrator used in the tests has 600mm diameter, seven turns (Mineral Deposit A87D). The test conditions are given in Table 5.

Table 5. *Spiral test conditions*

Parameter	Value
Feed Size (µm)	-300+100
Solid Content (%)	30
Flowrate (m^3/s)	2
Product Splitter Position	
S1	High grade
S2	Concentrate + Middling
S3	High Yield (Pre-concentrate)

1.4.2. Shaking Table Tests for -300+100 µm Fraction

The dimension of the shaking table test is 500x1.200 mm (Wilfey). The shaking table was fed with the help of a vibrating feeder placed under a 5 kg capacity bunker. Then, the tests were carried out by adjusting the washing water and the table at optimum values. The test conditions are given in Table 6.

Table 6. *Shaking table test conditions*

Variable	Value
Feed Size (µm)	-300+100
Solid Content (%)	30
Feed Flowrate (m^3/h)	0.05
Wash Water (l/min.)	10
Table Tilt (degrees)	4

1.4.3. Shaking Table Test for -100+38 µm Fraction

The test conditions for -100+38 fraction shaking table test are given in Table 7.

Table 7. *Shaking table test conditions*

Variable	Value
Feed Size (µm)	-100+38
Solid Content (%)	25
Feed Flowrate (m^3/h)	0.04
Wash Water (l/min.)	6
Table Tilt (degrees)	3

1.4.4. WHIMS Tests

These tests were performed with -100+38 µm.

Chromite displays paramagnetic properties, and its susceptibility varies according to the substituting elements in the crystal structure (Svoboda, 1987).

Matrix type WHIMS (Carpco) was used in the tests as described in the literature (Carpenter, 1964 and Svoboda, 1987).

After the pulp having 25% solids onto the matrix, the feeding was stopped 5 litres of wash water was used to wash out non-magnetics. Steel balls was used as matrix material. The tests were performed at 0.49, 0.86 and 1.10 Tesla magnetic field intensity.

2. Results and discussion

2.1. Spiral Tests

The test results for three different product splitter positions, S1, S2 and S3, are given in Table 8, 9 and 10, respectively. The effect of splitter position on the weight recovery, the grade and the recovery are shown in Figure 4.

Table 8. *Spiral concentration test results (splitter position S1)*

	S1		
	Weight %	Cr_2O_3 %	Recovery %
Concentrate	6.16	24.90	22.70
Tailing	93.84	5.57	77.30
Feed	100.00	6.76	100.00

Table 9. *Spiral concentration test results (splitter position S2)*

	S2		
	Weight %	Cr_2O_3 %	Recovery %
Concentrate	12.03	21.33	36.79
Tailing	87.97	5.01	63.21
Feed	100.00	6.97	100.00

Table 10. *Spiral concentration test results (splitter position S3)*

	S3		
	Weight %	Cr_2O_3 %	Recovery %
Concentrate	25.11	14.20	56.21
Tailing	74.89	3.71	43.79
Feed	100.00	6.34	100.00

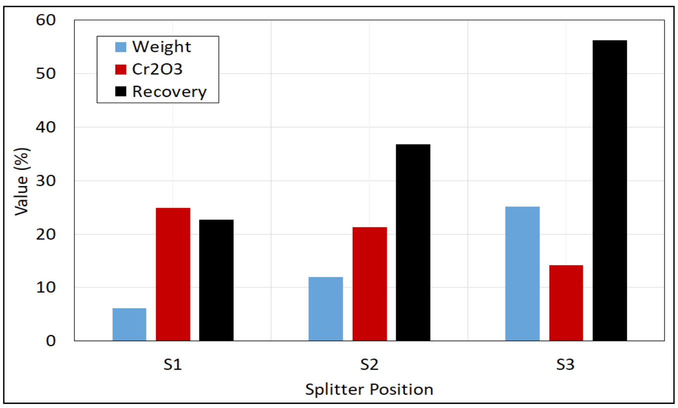

Figure 4. *Effect of splitter position on concentrate weight, Cr_2O_3 grade and recovery*

As can be seen from Table 10, even for the largest splitter position, the recovery was 56.2%. However, 75% of the feed was removed as tailings. Pre-concentration with spiral concentration would reduce the number of shaking tables required significantly and allows to fit in existing concentrator building.

2.1.1. Shaking Table Test with Spiral Concentrate

Using the spiral concentrate taken at the largest splitter position (S3), a shaking table test was performed, and the results are presented in Table 11.

Table 11. *Shaking table test results with spiral pre-concentrate*

	Weight %	Cr_2O_3 %	Recovery %
Concentrate	25.55	47.51	77.89
Middling	30.17	7.88	15.26
Tailing	44.28	2.41	6.85
Feed	100.00	15.58	100.00

The results showed that a concentrate having 47.51% Cr_2O_3 with a stage recovery of 77.89 % could be obtained. Middling taken at this stage could be recycled to the feed to increase the recovery.

2.2. Shaking Table Test Results

2.2.1. -300+100 µm Size Fraction

Shaking table test for -300+100 µm fraction is given in Table 12.

Table 12. *Shaking table test results with R.O.M. ore*

	Weight %	Cr_2O_3 %	Recovery %
Concentrate	7.82	50.83	57.62
Middling	1.70	37.28	9.18
Tailing	90.49	2.53	33.20
Feed	100.00	6.90	100.00

Shaking table enables the production of concentrate having over 48% Cr_2O_3 with a higher recovery than spiral concentrator.

In a plant application, a scavenger stage must be added to the spiral concentration to increase the recovery. Then rougher-scavenger concentrate can be fed the shaking tables for final upgrading. Otherwise, the performance of shaking table is superior comparing the spiral concentrator in single stage.

2.2.2. -100+38 µm Size Fraction

The test results are given in Table 13.

Table 13. *Shaking Table Test Results with -100+38 µm size fraction*

	Weight %	Cr_2O_3 %	Recovery %
Concentrate	1.73	42.34	8.72
Middling	14.03	25.76	43.02
Tailing	84.24	4.81	48.26
Feed (Analysis)	100.00	8.40	100.00

As it can be seen from Table 13, both the grade and the recovery are low in single stage beneficiation. Since 25% of the chromite is in -100+38 µm fraction, it must be processed. To increase the performance of the shaking table, two stage separation may be used. In the first stage, a combined product of concentrate and middling can take while 80-85% of the material could be removed as tailings. In the second stage, a concentrate can be taken and middling could be recycled back to the feed of the second stage. Such an arrangement would improve both the recovery and the grade.

2.3. WHIMS Results

The results of the WHIMS test at 0.49, 0.86 and 1.10 Tesla are given in Table 14, 15 and 16, respectively. The results are also presented for different field intensities in Figure 5.

Table 14. *H.I.W.M.S test results with -100+38 µm fraction (0.49 Tesla)*

	0,49 Tesla		
	Weight %	Cr_2O_3 %	Recovery %
Concentrate	60.90	12.27	91.92
Tailing	39.10	1.68	8.08
Feed	100.00	8.13	100.00

Table 15. *H.I.W.M.S test results with -100+38 µm fraction (0.86 Tesla)*

	0,86 Tesla		
	Weight %	Cr_2O_3 %	Recovery %
Concentrate	78.13	10.14	97.16
Tailing	21.87	1.06	2.84
Feed	100.00	8.15	100.00

Table 16. *H.I.W.M.S test results with -100+38 µm fraction (1,10 Tesla)*

	1,10 Tesla		
	Weight %	Cr_2O_3 %	Recovery %
Concentrate	89.46	9.03	99.25
Tailing	10.54	0.58	0.75
Feed	100.00	8.14	100.00

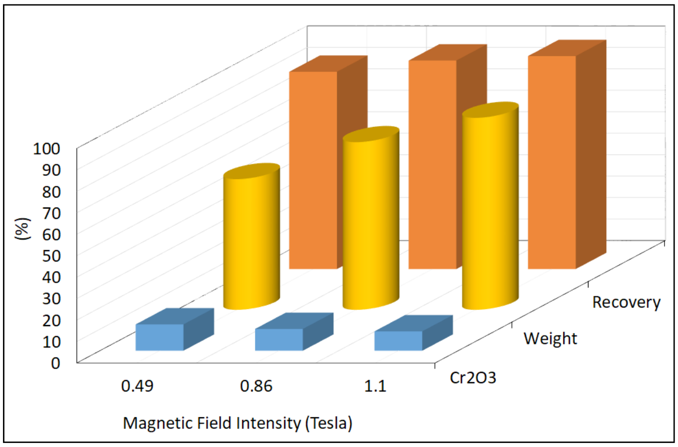

Figure 5. *Effect of magnetic field intensity on concentrate weight, grade, and recovery*

The best result was obtained at 0.49 Tesla field intensity. The tailing grade was 1,68% Cr_2O_3 and 40% of the material could be with 8% metal loss.

In larger plants, WHIMS could be used an efficient pre-concentration step for this fraction since single WHIMS equipment could process 300 tph. This could reduce the number of equipment used in downstream processing.

The chromite recovery in conventional plants is higher at the medium size range and deteriorates both at the coarser and the fine size range. The losses at the coarser range are usually result from poor liberation, the efficiency of shaking tables and spirals are lower for the finer size range.

There is an operating plant processing Üçköprü- Fethiye chromite concentrator tailings. The plant uses shaking tables and MGS for chromite recovery. MGS is particularly useful for the recovery of fines (-100µm) fraction which consists of 80% of the Cr_2O_3. Over 2 million tons of tailings was processed (Uysal, 2022).

As the high grade and easy to process ores were almost depleted, the lower grade ores are now being processed. This requires increase in plant capacities to keep the operation profitable. With this respect, spiral concentrators have been found applications in high-capacity plants (Burt, 1984). Modern spirals can process 12-18 tph feed in a 1 m^2 footprint. Such a capacity can be processed 4-6 triple-deck shaking tables each requires ~10 m^2. Although the efficiency of shaking tables is higher than spiral concentrator in single stage separation, the investment, operating costs, control, and water consumption would be in favour of spiral concentrator.

The best arrangement for a general flowsheet may be removal of barren oversize, grinding, pre-concentration by spirals, final concentration by shaking tables and MGS for fine fraction.

Considering the limited amount of tailings in Eskiköy plant, two stage spiral concentration (rougher-scavenger) and the shaking tables for final concentration was found to be feasible and could be installed in the existing concentrator building.

Conclusions

Since the chromite are locked with gangue minerals at the sizes coarser than 300 µm, the tailings should be ground to 100% finer than 300 µm before beneficiation.

Spiral concentration tests showed that 75% of the feed could be removed with a 43,79 % Cr_2O_3 loss. To increase the recovery, a scavenger stage is recommended.

WHIMS could be used as an efficient pre-concentration step for -100+38 µm fraction.

Feasibility studies showed that the tailings of Eskiköy plant can be processed economically with a minimum investment by using two stage spirals and shaking tables.

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