Benefication of low-grade chromite ores of abandoned mine at Topraktepe, Beyşehir, SW Turkey

Tevfik Agacayak*[1], *Veysel Zedef* a *Salih Aydogan

Úprava málohodnotnej chrómovej rudy z opustenej bane Topraktepe, Beyşehir, SW Turkey

Optimum enriching possibilities of chromite ores from the abandoned Topraktepe mine were investigated. To obtain the best enriching method(s), shaking table, multi gravity separator, humprey spiral and jigging tests were tested. The best grades for Cr_2O_3 are 55.65% by shaking table, 57.52% by multigravity separator, 54.58 % by humprey spiral test and 50.68 % by jigging. To provide these results, the particle sizes of the ore are -0.3 to 0.212 mm for shaking table, -0.106 to 0.075 mm for multi gravity separator, -0.3 to 0.212 mm for humprey spiral and -2 to 1 mm for jigging. Regarding the best grades obtained, the recoveries for shaking table, multi gravity separator, humprey spiral and jigging methods are 85.38 %, 79.83 %, 94.89 % and 87.58 % respectively. The results of these tests show that a further recovery of remaining 500 000 tons of ore could be possible from the abandoned Topraktepe chromite deposit.

***Key Words**: Chromite, recovery, enriching methods, Topraktepe, Turkey*

Introduction

Turkey is the sixth largest chromite ores exporter in the world. These ores have been mined from mostly serpentinized ultramafic bodies, discontinuously spreaded all over the country. With the exception of chromite deposits at Bursa, NW Turkey, the majority of the Turkish chromite deposits are of 'Alpine type' which is usually regarded as a high grade-good quality ore. One of the main disadvantages of the Alpine type chromite deposits are its low (usually not more than a few hundred thousand tons) reserves as compared to the 'stratiform type' chromite deposits. In Turkey, many deposits were abandoned as they were regarded as low grade chromite ores, although there have been some successful applications for recoverying fine chromite tailings (Bayat et al., 1999; Cicek and Cocen, 2002). The important abandoned mines were spreaded all over the country, namely the Bursa, Kutahya and Eskisehir district in NW Turkey, the Burdur, Mugla, Antalya, Konya district in SW Turkey; the Kastamonu, Cankırı district in Northern Turkey; the Sivas, Erzincan, Erzurum district in Eastern Turkey; the Icel, Hatay, Gaziantep district in Southern Turkey and many more. The ores mined at the deposits found in the districts mentioned above were usually >55 % Cr_2O_3 grade, and generally sold as such, although there have been some chromite concentrator plants (for example Karagedik, Fethiye, SW Turkey) working with a 30-35 % Cr_2O_3 grade (Guney et al, 2001). Unfortunately, when the ore grade limit below this, the mine was virtually abandoned since the profit-rate gets lowered.

The chromite ore at Topraktepe was mined between 1986 and 1991 with the Cr_2O_3 grade of approximately 55 %. The ore was classified as 'Podiform type Al-chromite' (Zedef et al., 1994). During the mining period, about 200 000 tons of ore were recovered from the central part of the chromite body where the Cr_2O_3 grade is the highest. When the Cr_2O_3 grade lowered to <50 %, the mine was abandoned, in October 1991. Our investigations reveal that the foundation of very basic enrichment methods (for example crushing and shaking table) could easily upgrade the chromium contents.

The aim of this paper is to show that many abandoned chromite mines in Turkey could be re-mined economically. To prove this, we examined the low grade ores of the Topraktepe mine and investigated the enrichment possibilities using the gravity separation methods, namely the Willfley type shaking table, jigging (Harz Mineral Jig), MGS (C900 type) and the Humprey spiral (HG-7 type).

Location and geologic settings

The Topraktepe chromite mine is located at the Konya district and the mine is approximately 150 km away from the port city of Antalya (Fig. 1). The chromitiferous ore body is situated between the transition zone of dunite and harzburgite which belong to the Yesildag ultramafic rock units. The Yesildag ultramafics have been classed as a member of Camlık Group, which consists mainly of dunite, and lesser amounts of harzburgite, dolerite dikes and certain chromitiferous ores (Sen, 1996). According to Sen (1996), however,

[1] *Tevfik Agacayak, Veysel Zedef, Salih Aydogan,* Selçuk University Engineering and Architecture Faculty, Mining Engineering Department 42075 Konya/Turkey, Phone: +90 332 223 20 46, Fax: +90 332 241 06 35, vzedef@selcuk.edu.tr
(Recenzovaná a revidovaná verzia dodaná 21. 12. 2007)

the group is a part of the alloktonous Bozkir Unit, which presumably over trusted on Mesozoic carbonates during the Upper Cretaceous. These ultramafics cover an area of approximately 6 km^2 in the study area and the ore body is situated at the central part of the ultramafics. The chromitiferous body is 500 m long, 300 m width and about 50 m thick. The ore body is cross-cut by an oblique fault roughly oriented NE to SW. As indicated above, the high grade central part of the ore body was mined with the low grade part of the remaining ore left. The low grade ore consists of 32 % Cr_2O_3 on average (Zedef et al. 1994), the remaining gangues are wall-rock particles namely dunite and harzburgite. Our assessments display that approximately half a million tons of an ore could still be recovered from the mine.

Material and method

To undertake the necessary enrichment tests, as a first step, we collected random samples from the abandoned mine. The total weight of the samples was about 500 kg. This sample was made homogenous by mixing properly and then reduced to approximately 150 kg by a hand-selection from the relatively high grade ore. At this stage, the particle size of the ore was between 75 and 100 mm. By using a laboratory type jaw crusher, the particle size reduced to <10 mm. During the crushing, a considerably fine product occurred.

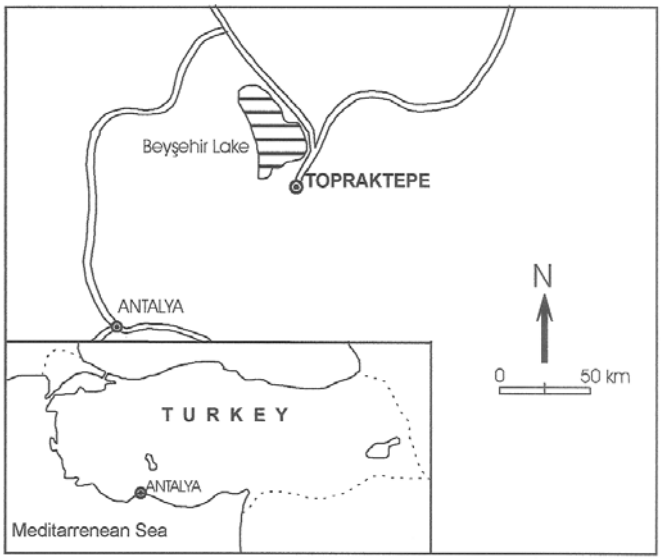

Fig. 1. Location of the Topraktepe chromite mine.

In this work –1 + 0.5, -0.5 + 0.3, -0.3 + 0.212, -0.212 + 0.106, -0.075 + 0.053, -0.053 + 0.038 mm particle classes were used for the shaking table tests, and -3.35 + 2, -2+1 mm particle sizes were used for the jigging tests. For the humprey spiral tests, -0.3 + 0.212, -0.212 + 0.106 mm particle classes and for the multi gravity separator tests -0.106+0.075 mm particle classes were used.

Results and discusion

We randomly collected 20 samples from the 500 kg of the stock to asses the Cr_2O_3 content, and the grade of 20 % was found on average. The samples at this step include gangue, wall-rock particles dunite and harzburgite as well as the choromitiferous ore. The average composition of the particle classes obtained by crushing is given in Tab. 1.

Tab. 1. Chemical composition of Topraktepe chromite ores related to particle classes.

Particle Size [mm]	**Weight** [g]	**Weight** [%]	**Cr_2O_3** [%]	**MgO** [%]	**SiO_2** [%]	**Al_2O_3** [%]	**Fe_2O_3** [%]	**CaO** [%]	[%]
-10 +7	39900	26.50	47.53	18.73	6.49	7.26	15.58	0.69	3.72
-7 +4.75	12900	8.57	47.9	18.77	6.01	8.64	15.42	0.7	2.56
-4.75 +3.35	19450	12.92	47.81	17.56	6.15	9.18	15.48	0.82	3.00
-3.35 +2	20150	13.38	48.54	15.83	5.67	13.25	13.18	0.76	2.77
-2 +1	15850	10.53	50.35	16.25	8.28	9.03	15.81	1.00	2.31
-1 +0.5	12200	8.10	48.3	14.29	5.94	12.24	15.54	0.81	2.88
-0.5 +0.3	10500	6.97	46.51	18.95	7.1	6.96	16.3	0.73	3.45
-0.3 +0.212	5100	3.39	47.55	17.42	7.83	9.18	15.23	0.76	2.03
-0.212+0.106	6750	4.48	48.35	17.48	6.25	9.24	15.28	0.81	2.59
-0.106+0.075	2500	1.66	46.22	19.4	8.17	6.87	14.79	0.95	3.60
-0.075+0.053	2800	1.86	40.87	17.46	10.3	9.22	15.27	0.79	6.09
-0.053+0.038	1100	0.73	39.33	17.44	15.1	9.20	15.24	0.77	2.92
-0.038	1350	0.90	28.38	17.48	17.5	9.24	15.28	0.82	11.30
TOTAL	150550	100.00	-	-	-	-	-	-	-
AVERAGE	-	-	47.68	17.45	6.78	9.21	15.25	0.78	2.85

As can be seen from Tab. 1, the Cr_2O_3 grade is up to 50.35 %, depending on the particle sizes. The particle size (the grinding time), the leaching time, temperature and the oxygen partial pressure are the main factors of the chromium extraction for other (Amer and Ibrahim, 1996; Amer, 1992). The pH is also a very important player during the extraction processes (Weng et al, 1994). The reduction is generally favored with fine particles of the ore during the enrichment processes (Chakraborty et al, 2003).

Shaking Table Tests

The shaking table tests were carried out with -1+0.5, -0.5+0.3, -0.3+0.212, -0.075+0.053, -0.053+0.038 mm particle fractions using approximately 1 kg of samples. The experimental conditions applied for each fraction are given in Tab. 2. The results obtained from these tests are displayed in Tab. 3.

Tab. 2. Experiment conditions for the shaking table tests.

Particle fraction [mm]	**Shaking Stroke** [mm]	**Table slope** [°]	**Solid Ratio** [%]	**Shaking frequency** [rpm]
-1 +0.5	12	6	25	300
-0.5 +0.3	12	6	25	300
-0.3 +0.212	12	6	25	300
-0.212+0.106	12	6	25	300
-0.075+0.053	12	4	20	300
-0.053+0.038	12	4	20	300

Tab. 3. Results of the shaking table tests with the -1+0.038 mm particle fractions.

Particle size [mm]	**Products**	**Amount** [%]	**Cr_2O_3** [%]	**Recovery** [%]
-1 +0.5	Concentrate	80.97	51.17	85.78
	Tailing	19.03	36.09	14.22
	Feed	100.00	48.30	100.00
-0.5 +0.3	Concentrate	83.18	51.62	92.30
	Tailing	16.82	21.24	7.68
	Feed	100.00	46.51	100.00
-0.3 +0.212	Concentrate	72.95	55.65	85.38
	Tailing	27.05	24.65	14.02
	Feed	100.00	47.55	100.00
-0.075+0.053	Concentrate	72.71	42.76	76.07
	Tailing	27.29	35.84	23.93
	Feed	100.00	40.87	100.00
-0.053+0.038	Concentrate	46.12	43.81	51.37
	Tailing	53.88	30.50	48.63
	Feed	100.00	39.33	100.00

As seen from Tab. 3, the Thopraktepe (Yeşildağ-Beyşehir-Konya) chromite ores are suitable to be enriched by shaking table. The Marketable concentrate grade was reached for the first 4 particle fractions and the concentrate was produced with a high recovery. The best results were obtained with the recovery of 85.38 % and the grade of 55.65 % Cr_2O_3 using the -0.3+0.212 mm particle fraction.

Multi Gravity Separator (MGS) tests

In this test, the technical parameters of multi gravity separator were as follows:

the drum rotation speed:	100-200 rpm	the drum slope angle:	0-9°
the shaking frequency:	4/4. 8/5.7 cycles/s.	the wash water:	0-10 l/min.
the shaking amplitude:	10/15/20 mm	the feed:	max. 200 kg/h.

The multi gravity separator tests were carried out with the -0.106+0.075 mm particle fraction using approximately 2.5 kg of samples.

The experiment conditions for the multi gravity separator with the -0.106+0.075 mm particle fraction are as follows:

the drum slope angle	: 4°	the shaking amplitude	: 10 mm
the shaking frequency	: 5.7 cycles/s.	the drum rotation speed	: 150/175 rpm
the wash water	: 2 l/min.	the flow	: 1.4/1.2 l/min.
the solid ratio	: 30 %	the water	: 5.5/5 l.

The results obtained from these tests are given in Tab. 4.

Tab. 4. Experimental results of Topraktepe (Yeşildağ-Beyşehir-Konya) chromite ores separated by the multi gravity separator.

Drum rotation speed [rpm]	**Products**	**Amount** [%]	**Cr_2O_3** [%]	**Recovery** [%]
150	Concentrate	64.15	57.52	79.83
	Tailing	35.85	26.00	20.17
	Feed	100.00	46.22	100.00
175	Concentrate	88.98	51.06	98.18
	Tailing	11.02	7.63	1.82
	Feed	100.00	46.22	100.00

In the light of data shown in Tab. 4, the Topraktepe chromite ores could be enriched by the multi gravity separator. The best result was obtained at 150 rpm of drum rotation speed. A concentrate of 57.52 % Cr_2O_3 grade was produced with a recovery of 79.83 %. As a result, the concentrate grade and recovery decrease while the drum rotation speed increases.

Humprey spiral tests

The Humprey spiral tests were carried out with -0.3+0.212, -0.212+0.106 mm particle fractions and 25 % solid ratio using approximately 3 kg of samples. The results obtained from these tests are given in Tab. 5.

Tab. 5. Experimental results of Topraktepe chromite ores separated by the humprey spiral.

Particle fraction [mm]	**Products**	**Amount** [%]	**Cr_2O_3** [%]	**Recovery** [%]
-0.300+0.212	Concentrate	82.67	54.58	94.89
	Tailing	17.33	14.02	5.11
	Feed	100.00	47.55	100.00
-0.212+0.106	Concentrate	86.07	53.42	95.10
	Tailing	13.93	17.02	4.90
	Feed	100.00	48.35	100.00

As seen in Table 5, The Humprey spiral tests were carried out with two different fractions. The best results were obtained with a recovery of 94.89 % and grade of 54.58 % Cr_2O_3 using the -0.3+0.212 mm particle fraction. The data show that there is a negative correlation between the particle size and recovery, and the particle size and Cr_2O_3 grade as well.

Jigging tests

The jigging tests were carried out with -3.35+2,-2+1 mm particle fractions using approximately 1 kg of samples. The results obtained from these tests are shown in Table 6.

Tab. 6. Experimental results of Topraktepe (Yeşildağ-Beyşehir-Konya) chromite ores separated by jigging.

Particle size [mm]	**Products**	**Amount** [%]	**Cr_2O_3** [%]	**Recovery** [%]
-3.35+2	Concentrate	76.19	48.75	76.52
	Tailing	23.81	47.87	23.48
	Feed	100.00	48.54	100.00
-2+1	Concentrate	87.01	50.68	87.58
	Tailing	12.99	48.14	12.42
	Feed	100.00	50.35	100.00

As can be seen from Table 6, the jigging tests were carried out with two different fractions. There was no change in the grade for both particle fraction.

Conclusion

This work shows that the low grade Cr_2O_3 ores of abandoned mines in Turkey could easily be mined with very little investment. A proper crushing and devices (separators) can increase the Cr_2O_3 grade in these mines. And thus, the ores of Cr_2O_3 could be regained and added to the economic advancement in such developing countries. In the Topraktepe mine case, approximately 400 000 tons of ore with about 20 % grade worth about 3.2 million US dollars. As indicated before, there are many such deposits in Turkey.

Specifically, the following conclusions can be made regarding the results obtained from different enrichment tests.

1. Simply by crushing of the ore, the average Cr_2O_3 grade can be up to 20 % (from 20 % to 40 %).
2. By shaking table, the grade would be as high as 55. 65 % (from 47.55 % to 55.65 %) in between the particle sizes of -0.3 and +0.212.
3. The MGS test result show that the Cr_2O_3 grade could be from 46.22 % to 57.52 % at the drum speed 150 rpm.
4. The ore at Topraktepe could also be enriched by the Humprey spiral. The Humprey spiral tests revealed that the Cr_2O_3 grade would be increased up to 7 % (from 47.55 % to 55.58 % in -0.3+0.212 mm particle fraction).
5. Only the jigging failed to enrich the ore as there was an inadequate liberation of the ore after crushing.

Acknowledgements: *This work was reproduced from the MSc thesis of Tevfik Agacayak and supported by the BAP of the University of Selcuk (Bu calısma Selcuk Universitesi Bilimsel Araştirmalar Coordinatorlugu-eski adıyla SUAF- tarafından desteklenmiştir). The shaking table and jigging tests were performed in the Cumhuriyet University Mining engineering laboratories*.

References

Agacayak, T.: 2004, Topraktepe (Yesildag, Beysehir, Konya) kromitlerinin zenginlestirme yontemlerinin arastırılması: MSc Thesis (Unpublished), *Selcuk University, Konya, Turkey, 2004*.

Amer, A. M., Ibrahim, I. A.: Leaching of a low grade Egyptian chromite ore, *Hydrometallurgy, 43, 1996, 307-316*.

Amer, A. M.: Processing of Ras-Shait chromite deposits, *Hydrometallurgy, 28, 1992, 29-43*.

Bayat, O., Cocen, I., Cicek, T., Ozsever, V., Vapur, H., Inan, S.: Concentration of Aladag-Adana chromite tailings by gravitational methods, in: 8th Balkan Mineral Processing Conference, *September 13-18, 1999*.

Chakraborty, D., Ranganathan, S., Sinha, S. N.: Kinetics of reduction of chromium in chromite ore, Transactions of the Indian Institute of Metals, 56, 2003, 335-339.

Cicek, T., Cocen, I.: Applicability of Mozley gravity separator (MGS) to fine chromite tailings of Turkish chromite concentrating plants, *Minerals Engineering, 15, 2002, 91-93*.

Guney, A., Onal, G. And Atmaca, T.: New aspect of chromite gravity tailings re-processing, *Minerals Engineering, 14, 2001, 1527-1530*.

Sen, O.: Üzümlü (Beyşehir güneyi-Konya) ve Bademli (Akseki kuzeyi-Antalya) arasında kalan Toroslar'ın stratigrafisi ve tektonik özellikleri. Doktora Tezi (yayınlanmamış), Selçuk Üniv. Fen Bilimleri Enstitüsü, Konya, 186 p (in Turkish with English abstract) 1996.

Weng, C. H., Huang, C. P., Herbert, E., Allen, A. H., Cheng, D., Sanders, P. F.: Chromium leaching behavior in soil derived from chromite ore processing waste, The Science of The Total Environment 154, 1994, 71-86.

Zedef, V., Öncel, M. S., Arslan, M., Döyen, A. Ve Söğüt, A. R.: Alpin Tipi Kromit Yataklarına Jeokimyasal Açıdan Farklı Bir Örnek;Yeşildağ (Beyşehir-Konya) Kromit Yatağı, Selçuk Üniv. Müh. Mim. Fak. Derg., 9, 28 – 35, 1994, (in Turkish with English abstract).