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Study on the Gravity Processing of Manganese Ores

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Manganese ores from Sindirgi Balikesir region, Kinik district, Turkey are low grade types and need beneficiation to utilize them in ferromanganese and chemical industry. Mineralogical and chemical characterization of ores from this region indicated their susceptibility to manganese enrichment. In this study, the optimum gravity beneficiation method parameters for the production of marketable concentrates from Sindirgi, Balikesir, Turkey manganese ore were investigated. A final concentrate containing 47 % Mn and 20 % SiO_2 was produced by the application of the most appropriate beneficiation conditions with *ca.* 64 % metal recovery. Furthermore, it was found that the concentrates containing 52.62 % Mn, with lower silicate ratio for chemical purposes can also be recovered.

Key Words: Manganese ores, Gravity separation.

INTRODUCTION

Manganese is a little-known element other than to a small circle of technical specialists who are predominantly metallurgists and chemists. Yet, it is the fourth most used metal in terms of tonnage, being ranked behind iron, aluminum and copper.

The history of manganese in the 20th century has been a stream of new processes and metallurgical/chemical applications developed with a significant impact on markets as diverse as beverage cans, agricultural pesticides and fungicides and electronic circuitry used in consumer products[1].

The different needs of manganese have therefore caused a great deal of attention to be devoted to improve recovery from its ore. Approximately 94 % of all manganese ore is consumed in the manufacture of steel, primarily as ferromanganese and silicomanganese and other minor alloy-related industries. The other 6 % is used by the non-alloying industries, including the chemical, paint, fertilizer and battery industries[2,3]. There are numerous other applications of manganese oxide and manganese salts for this purpose can come from ore, oxides, carbonates and even metallic manganese. The economically important manganese minerals include: the oxides pyrolusite, psilomelane, braunite and manganite; the silicate piemontite and the carbonate rhodochrosite. The most important ores consist of manganese dioxide in the form of pyrolusite, psilomelane and wad, usually with variable amounts of iron oxides. Ores containing 5-10 % Mn are called manganiferous iron ores, those containing 10-35 % Mn are ferruginous manganese ores, whereas those with more than 35 % Mn are manganese ores. Manganiferous iron ores and ferruginous manganese ores are also referred to as manganiferous ores. The major production is[4,5] from sources with *ca.* 15 % Mn to more than 50 % Mn.

The various end-uses of manganese have different ore requirements giving rise to the classification of manganese ore into metallurgical, chemical and battery grades. Metallurgical grade material has about 38-55 % Mn and may differ from chemical grade ore only in physical form. Chemical and battery grade ores are often categorized by their MnO_2 content, which is typically in the range of 70-85 % (44-54 % Mn).

Although many manganese occurrences are known in which the limited size of these deposits make them marginal to sub marginal. Other large deposits are not economically exploitable due to the low concentration of manganese. The third consideration and of prime importance, are the impurities associated with the manganese mineralization. Due to the diversity and complexity of manganese formations, the impurities are many in number and complex in nature. Following is a broad generalization of types of impurities: (a) Metallic impurities: *e.g.*, iron, lead, zinc, copper, arsenic and silver minerals. (b) Non-metallic impurities such as sulfur and phosphorous mineral. (c) Volatiles, *i.e.*, water, carbon dioxide and organic matters.

Primary factors in the evaluation of deposits manganese are the amenability of material to beneficiation and the price projection over the life of the necessary capital investment. Raw manganese ore may be upgraded by flotation, heavy medium or high-intensity magnetic separation. Manganese ores and concentrates are purified by several methods[6].

Now a days, few manganese operations in some milling plants are more complicated than washing, screening, jigs, tables and in a few instances, flotation. Now it is not only necessary to increase the manganese content, but also to decrease the percentage of impurities. Because each deposit is distinctly different from most other deposits, no single process is applicable to all of the ores.

EXPERIMENTAL

The low grade manganese ore from Sindirgi/Balikesir/Turkey was used in the study. The samples were taken from different locations of the ore deposit and the storage area containing the previous productions. Mineralogical microscopically studies were carried out in Dokuz Eylul University in the Ore Dressing Division showed that manganese is present as pyrolusite, psilomelane and manganite. The main iron minerals present are hematite and limonite. The samples are intimately associated with gangue minerals that include chromites, calcite and quartz materials. The mean values of the wet chemical analysis showed that the sample had the following composition: 18.58 % Mn, 0.82 % Fe, 1.02 % Al_2O_3 and 62.85 % SiO_2 in addition to sulphides and moisture.

General procedure: The sample was crushed below 15 mm size using a jaw crusher. The crushed ore was subjected to screen/metal analysis. The results of the screen/metal analysis showed that about 88 % of the Mn content is above 1 mm particle size. For this reason, it was decided to classify the material as the coarse (+1 mm) and fine (-1 mm) ore samples before using in the concentration tests. The coarse material was subjected to jigging experiments and the material below 1 mm was treated with shaking table.

Detection method: Elemental composition of the samples was determined by using wet chemical analysis technique and an AnayltikJenaAG novAA 330 atomic absorption spectrometer.

RESULTS AND DISCUSSION

The material was subjected to screen/metal analysis to determine MnO, Al_2O_3, Fe_2O_3 and SiO_2 contents of the each particle size fraction. The results were presented in Table-1. As can be seen from the Table-1, 88 % of the Mn content is above 1 mm particle size. The coarse material (more than 1 mm size) was used in the jigging experiments. The remaining less than 1 mm size material was later used in shaking table tests.

TABLE-1
RESULTS OF THE SCREEN/METAL ANALYSIS

Particle size (mm)	Weight (%)	%				Distribution (%)			
		Mn	Al_2O_3	Fe	SiO_2	Mn	Al_2O_3	Fe_2O_3	SiO_2
+12.5	7.62	26.16	0.69	0.65	52.26	10.73	5.14	6.02	6.34
12.50 -9.500	16.07	19.54	0.86	0.75	62.95	16.90	13.50	14.64	16.10
9.500-4.750	35.91	17.83	0.88	0.56	64.43	34.47	30.86	24.60	36.81
4.760-3.350	11.26	17.34	1.37	0.81	63.90	10.51	15.07	11.07	11.45
3.350-2.000	9.08	15.14	0.96	0.80	65.16	7.40	8.51	8.86	9.41
2.000-1.000	8.68	17.33	1.18	1.04	66.17	8.10	10.00	11.00	9.14
1.000-0.500	4.65	17.15	1.33	1.42	63.02	4.29	6.04	8.03	4.66
0.500-0.315	1.89	18.88	1.35	1.79	61.84	1.92	2.49	4.13	1.86
0.315-0.212	1.21	19.06	1.63	1.88	59.98	1.24	1.93	2.76	1.15
0.212-0.106	1.36	21.02	1.75	1.96	58.02	1.54	2.32	3.25	1.26
0.106-0.075	1.46	21.47	1.85	1.95	55.54	1.69	2.64	3.47	1.29
0.075-0.063	0.35	24.31	1.85	2.35	37.37	0.46	0.63	1.00	0.21
0.063	0.46	29.90	1.93	2.09	43.69	0.74	0.87	1.17	0.32
Total	100	18.58	1.02	0.82	62.85	–	–	–	–

Jig concentration: The tests were conducted by using a mineral jig. The material was classified into narrow size fractions before using in the experiments to minimize the effect of particle size.

In the first experiment, +10 mm particle size fraction was used. The results were presented in Table-2. As can be seen from the Table-1, a concentrate assaying about 32 % Mn was obtained with 48.83 % yield and about 75 % recovery. The middling grade was 15.12 % and the recovery of the middling was about 16 %. The tailing is mostly consisted of SiO_2 %.

TABLE-2
RESULTS OF THE JIG CONCENTRATION TEST
OF THE +10 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	48.83	32.59	0.61	5.14	43.11	74.75	47.88	65.11	34.02
Middling	23.10	15.19	0.65	3.32	71.42	16.48	24.14	19.89	26.66
Tailing	28.07	6.65	0.62	2.06	86.66	8.77	27.98	15.00	39.31
Feed	100	21.29	0.62	3.86	61.87	–	–	–	–

The second experiment was performed using 0.8-1.0 mm particle size fraction. The products were analyzed again and the results were given in Table-3.

TABLE-3
RESULTS OF THE JIG CONCENTRATION TEST
OF THE 10-8 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	24.53	50.11	0.65	4.29	11.51	37.53	22.83	26.35	6.80
Middling	25.42	42.17	0.86	4.58	25.46	32.73	31.30	29.15	15.58
Tailing	50.05	19.47	0.64	3.55	64.41	29.75	45.87	44.49	77.62
Feed	100	32.76	0.70	3.99	41.53	–	–	–	–

The concentrate Mn grade was increased to 50.11 % in this experiment. The yield percentage was decreased to 24.53, whereas the recovery of Mn was achieved as 37.53 %. The middling grade was determined as 42.17 %, the Mn recovery of this product was found as 32.73 %.

5-8 mm particle size fraction was also subjected to jigging experiments. The results were included in Table-4.

TABLE-4
RESULTS OF THE JIG CONCENTRATION TEST
OF THE 8-5 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	28.84	40.45	1.25	7.43	28.53	59.23	13.69	34.33	13.30
Middling	22.84	18.85	4.13	3.43	64.32	21.86	35.83	12.55	23.75
Tailing	48.32	7.71	2.75	6.86	80.59	18.91	50.47	53.11	62.95
Feed	100	19.70	2.63	6.24	61.86	–	–	–	–

The Mn grade of the feed material was 19.70 % for this experiment and it was increased to 40.45 % after the jig separation. The weight percentage of the concentrate was 28.84, Mn recovery was found as 59.23 %. A middling assaying 18.85 % Mn was obtained with 21.86 % recovery.

The fourth experiment was done by using 3-5 mm particle size fraction. A high grade concentrate was obtained in this experiment (Table-5).

TABLE-5
RESULTS OF THE JIG CONCENTRATION TEST
OF THE 5-3 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	25.01	52.62	2.77	3.46	7.18	45.05	30.78	18.33	3.96
Middling	21.28	45.11	4.14	5.14	15.58	32.86	39.15	23.17	7.31
Tailing	53.71	12.02	1.26	5.14	74.93	22.10	30.07	58.49	88.73
Feed	100	29.22	2.25	4.72	45.36	–	–	–	–

A concentrate containing 52.62 % Mn was produced with 45.05 % Mn recovery in this experiment. Middling grade was found to be quite high (45.11 %). Total recovery of the concentrate and middling was reached to 77 %.

The last group of jigging tests was performed using 1-3 mm particle size fraction and the results were presented in Table-6.

TABLE-6
RESULTS OF THE JIG CONCENTRATION TEST
OF THE 3-1 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	35.27	39.53	1.22	5.91	31.23	69.51	40.66	18.70	17.64
Tailing	64.73	9.45	0.97	2.89	79.43	30.49	59.34	81.30	82.36
Feed	100	20.06	1.06	2.30	62.43	–	–	–	–

A concentrate containing 39.53 % Mn was produced in the experiment. The concentrate recovery was achieved as 69.51 %. Concentrate yield percentage was found as 35.27 %.

Shaking table concentration: A laboratory scale Wilfley shaking table was used in the shaking table concentration tests. The material was classified into narrow size fractions before using in the experiments to minimize the effect of particle size.

In the first experiment, 0.5-1.0 mm particle size fraction was used. The results were presented in Table-7. The Mn grade of the feed material was very low (13.53 %). A concentrate assaying 34.47 % Mn was obtained from this material with 55.73 % Mn recovery. The middlings except the first middling can be considered as tailing due to their low Mn content.

0.3-0.5 mm particle size fraction was used in the second shaking table concentration test. The results were given in Table-8.

TABLE-7
RESULTS OF THE SHAKING TABLE CONCENTRATION TEST
OF THE 1-0.5 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	21.87	34.47	1.84	5.72	35.16	55.73	33.56	19.23	10.63
Middling 1	7.49	15.35	1.50	5.37	68.67	8.50	9.37	6.18	7.11
Middling 2	28.65	7.65	0.93	9.49	83.19	16.20	22.22	41.81	32.93
Middling 3	27.43	6.68	1.21	6.63	84.56	13.55	27.68	27.96	32.05
Tailing	14.56	5.59	0.59	2.15	85.92	6.02	7.16	4.81	17.29
Feed	100	13.53	1.20	6.50	72.37	–	–	–	–

TABLE-8
RESULTS OF THE SHAKING TABLE CONCENTRATION TEST
OF THE 0.5-0.3 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	16.90	46.53	2.55	5.57	23.94	30.17	24.99	15.67	7.80
Middling 1	7.13	42.55	1.00	6.63	22.57	11.64	4.13	7.87	3.10
Middling 2	24.88	27.65	1.87	6.63	52.36	26.39	26.98	27.46	25.12
Middling 3	23.14	22.78	1.20	5.41	53.97	24.55	25.09	25.54	23.36
Tailing	27.95	6.77	1.16	5.04	75.34	7.26	18.80	23.45	40.61
Feed	100	26.07	1.72	6.01	51.86	–	–	–	–

The results showed that it is possible to obtain a concentrate containing 46.53 % Mn with 30.17 % recovery. Middling grades were higher for this experiment, especially the first middling grade was very high (42.55 %).

The last experiment was carried out by using less than 0.3 mm particle size fraction. Table-9 presents the results of this experiment.

TABLE-9
RESULTS OF THE SHAKING TABLE CONCENTRATION TEST
OF THE -0.3 mm PARTICLE SIZE FRACTION

Products	Weight (%)	Grade				Fractional recovery			
		Mn %	Al_2O_3 %	Fe %	SiO_2 %	Mn %	Al_2O_3 %	Fe %	SiO_2 %
Concentrate	12.45	43.54	2.61	5.03	20.71	28.36	23.01	10.85	4.13
Middling 1	10.92	22.35	1.32	5.51	55.46	12.77	10.21	10.42	9.71
Middling 2	24.36	17.93	0.75	6.75	66.94	22.85	12.94	28.48	26.15
Middling 3	20.62	16.26	1.17	3.54	68.41	17.54	17.08	12.64	22.62
Tailing	31.65	11.17	1.64	6.86	73.65	18.49	36.76	37.61	37.38
Feed	100	19.12	1.41	5.77	62.36	–	–	–	–

A concentrate containing 43.54 % Mn with 28.36 % recovery was produced in this experiment. The middling grades were close to the feed grade. The first middling grade was the highest; however it was still very low (22.35 % Mn).

Conclusion

The increases in the demand and marketing prices of the manganese concentrates are promoting the production of manganese from ore deposits today. There is no high-grade manganese ore deposit in Turkey. Turkey is manganese importer for now. The plants which produces manganese alloys needs high grade Mn and there is no such producer which can meet this demand. Iron and steel plants require manganese ores containing 28-35 % Mn. The presented study can provide an alternative for these plants to meet their Mn need. Lack of a stable vein mineralization may cause changes in grade and quality of the produced raw ore. This may require using specific mining and mineral processing operations. According to the results of the jig separation tests; the use of 3-8 mm particle size fraction produced the highest-quality concentrates. The use of selective crushing and the application of hand picking for the coarse gangue particle removal would be useful. Jig concentration can be applied after the secondary crushing operation. It is recommended to store -3 mm particle size fraction for the later concentration in shaking tables. 64 % of the fed material was obtained as a concentrate assaying 45-47 % Mn in this study.

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