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EVALUATION OF LOW GRADE IRON ORE DEPOSIT IN ERZINCAN-TURKEY FOR IRON ORE PELLET CONCENTRATE PRODUCTION

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Abstract. In this study the separation possibility of gangue minerals from a low grade magnetite ore with 45% Fe from an iron ore deposit located near Erzincan-Turkey was investigated. The iron ore deposit consists of mainly magnetite mineral. Hematite is the second iron oxide found in the deposit. The gangue minerals contain mainly SiO_2 and Al_2O_3 impurities. The main object of the research is to investigate the production of a concentrate suitable for iron ore pellet production. The concentrate for pellet production should have at least 65% Fe with reasonable gangue contents (SiO_2 <6.0% and Al_2O_3 <1.0%). The Davis tube and low intensity drum type wet magnetic separators were used for upgrading the Fe content and separation of gangue impurities from the iron ore. The results showed that, in order to produce a concentrate with sufficient Fe grade (>65% Fe), the iron ore should be ground to get 45% of material by weight to be finer than 45 μm. The concentrate with over 65% Fe and 90% Fe recovery could be produced with 45% Fe content from the feed material by crushing, grinding and magnetic separation operations.

keywords: iron ore, magnetite, magnetic separation, iron ore pellet

1. Introduction

The main raw material for iron production in the iron-steel industry is iron oxide ore. Natural iron oxide ores can be typically classified as high grade (>65% Fe), medium grade (<65 and >62% Fe) and low grade (<62% Fe) in terms of their Fe contents. The high grade iron ores, which can be used directly in the blast furnace to produce metallic iron, are not abundant in earth's crust to supply the need of iron-steel industry. The exploitation of low grade iron ores is possible after enrichment. The low grade iron ores with considerable amount of gangue minerals, e.g. silica, alumina, calcium and magnesium compounds, require concentration. For concentration, iron ore is crushed and ground for liberation before the implementation of separation techniques. Liberation can mostly be achieved at a very fine particle size and, hence, the concentrate obtained is not suitable to be charged directly into the blast furnace or the DR-plant without converting it into suitably sized agglomerates. The most

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commonly employed agglomeration technique is pelletizing. In pelletizing, a mixture of finely ground iron ore, water and binder is rolled in a mechanical disc or drum to produce agglomerates (green balls or wet pellets). Green pellets then undergo a thermal process, which consists of three stages, namely drying (250 – 400^oC), preheating (900 – 1100^oC) and firing (1200 – 1300^oC) (Sivrikaya and Arol, 2010). Pellets can be charged to reduction furnaces to produce metallic iron.

In previous exploration studies conducted by MTA (General Directorate of Mineral Research and Exploration of Turkey) revealed the existence of four main formations; Kızılkaya, South Kızılkaya, Taştepe and Dönentaş (Yaman, 1985; Yıldırım, 1985). It was also reported that the iron ore deposit consists of mainly magnetite. Hematite is the second iron oxide found in the deposit. The reserve (proven plus possible) of the deposit determined by 95 drilling (12 km in total) done by MTA is given in Table 1.

Table 1. Proven plus possible reserves and average iron grade of Bizmişen iron ore deposit - Kızılkaya, Taştepe and Dönentaş formations (Yaman, 1985; Yıldırım, 1985)

Formation	Reserve, ton	Fe %	SiO_2%	Al_2O_3%	S %
Kızılkaya	10.652.230	54.44	8.23	2.04	1.45
Kızılkaya (South*)	456.700	58.30	-	-	-
Taştepe	2.240.170	43.24	16.29	3.14	0.51
Dönentaş	9.817.789	43.94	12.05	3.52	1.99

* no detailed data for this formation is avaible

The iron ores have been mined from the Taştepe and Kızılkaya formations. No production was carried out from Dönentaş formation. A possible and efficient production method is necessary to exploit iron ore found in this formation since it has remarkable reserve and Fe grade.

In previous concentration investigation conducted by MTA (Yaman, 1985) the iron ore from Taştepe formation was tried to be enriched by magnetic methods. The iron ore was crushed to -1 cm and concentrated by magnetic separation. A concentrate was produced with 54.51% Fe which is suitable for sinter feed. The tailing of this concentration stage was ground to 150 μm (100 mesh) and concentrated by magnetic separator. An upgraded concentrate with 61.99% Fe which was intended to be used for pellet feed, was obtained. However, both products were considered to be not suitable since the first one has a high S content and the second one has a low Fe content. Investigators concluded that a concentration method in which magnetic separation after grinding 80% of the ore to -45 μm should be suitable for this iron ore.

In another study conducted with the iron ore from the Dönentaş formation by MTA (Yıldırım, 1985) the production of lump ore, sinter feed and pellet feed was investigated. It was reported that in the study, lump ore (-22.6+8.0 mm), sinter feed (-8.0 +0.106 mm) and pellet feed (-0.074 mm) concentrates were produced after crushing and grinding by successive stage magnetic separation tests.

In this study in the light of the previous works, the evaluation of the low grade iron ore deposit was performed. Production of concentrates was investigated for iron ore pellet formation by magnetic separation concentration.

2. Material and methods

A 100 kg of the Taştepe formation was obtained. Samples of the Kızılkaya and Dönentaş formations cannot be taken representatively from the mine field. Therefore, these samples were taken from the core samples obtained by drilling done by MTA. Representative samples were taken from the magnetic part of the whole core samples. Seven different core samples (B5, B52, B73, B81, B97, B27 and B31) were divided by sawing and put in separate plastic bags.

The core samples were separately crushed to -10 mm with a jaw crusher and half of samples were split and sealed in labeled plastic bags and saved. The other half was stored as stock material after crushing with a roller crusher to -500 µm. Magnetic enrichment test samples used in concentration experiments were ground up to desired fineness with a centrifuge ball mill. The Fe content of the core representative samples are given in Table 2.

Table 2. Fe content of the core samples used in enrichment tests

Sample Name	Formation	Fe %	
		METU(1)	MTA(2)
Taştepe	Taştepe	50.27	-
B5	Taştepe	43.00	39.20
B52	Dönentaş	43.98	44.79
B73	Dönentaş	49.85	53.42
B81	Dönentaş	45.10	51.80
B97	Dönentaş	50.82	57.14
B27	Kızılkaya	59.34	60.49
B31	Kızılkaya	42.59	53.78

(1)Average Fe content of the representative blended core sample determined at METU (Middle East Technical University)
(2)Average Fe content of the formation written in MTA reports (Yaman, 1985; Yıldırım, 1985)

Magnetic separation technique was preferred due to its suitability for magnetic ore and simplicity. The magnetic separation was performed in two stages. At the first stage 8 different samples were ground to different fineness in centrifuge ball mill and concentrated by the Davis tube (Fig. 1). The applied magnetic field of the Davis tube was 0.1 T. About 15-20 g of ground sample was fed to the Davis tube and a concentrate was taken. The liberation of the ore particles is the main parameter affects the concentration efficiency. Therefore, different feeds with different sizes were fed to the Davis tube. The Fe content of the concentrates was determined by the titration method to see the effect of particle size on the Fe content and recovery. The suitable particle size, which provides 65% Fe grade, was considered as the liberation size for individual test samples.

At the second stage of the investigations, laboratory size low intensity drum type wet magnetic separator (Fig. 2) was used to produce in larger quantities concentrates and to see the suitability of the magnetic drum separator regarding the liberation size determined at the first stage. Representative samples weighing 2 kg were separately taken from Taştepe (B5 and B52 samples) and ground in a ball mill. In addition, a mixed (Mix1) sample was prepared by blending all samples, excluding B27, in equal amount. Since B27 consists of hematite, it cannot be concentrated with the low intensity magnetic separator efficiently. The B27 sample has also relatively high Fe content, so it was thought that it can be used as direct lump feed for metal iron production in reduction operations (blast furnace or DRI furnace). Another mixed sample (Mix2) was prepared by blending all samples to see the effect of the B27 sample on efficiency of separation.

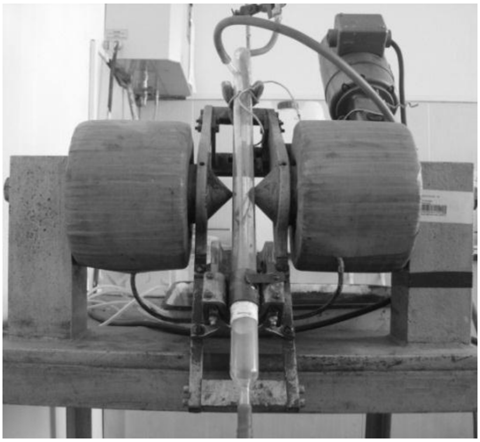

Fig. 1. Laboratory Davis tube magnetic separator

Fig. 2. Laboratory size low intensity drum type wet magnetic separator

The Taştepe, B5, B52, Mix1 and Mix2 samples in 2 kg batch were ground in ball a mill and concentrated in a laboratory size low intensity drum type wet magnetic separator and the concentrates were analyzed. All concentrates, excluding Mix2, were used in pelletizing tests.

A 50^{o} inclined laboratory-scale balling disc (Fig. 3) (390 mm diameter, 100 mm depth, 11 rpm) was used for the pelletizing experiments. A laboratory muffle furnace was used to fire the pellets. Each dry 1 kg concentrate sample was mixed with 0.8% bentonite and 10% water before pelletizing.

The detailed pelletizing procedure was explained in our previous publication (Sivrikaya and Arol, 2011). The green pellets were air-dried overnight and then fired at 1200°C for 2 hours in a muffle furnace at a heating rate of 5°C/min.

Fig. 3. Laboratory size pelletizing disc to produce iron ore pellets

3. Results and discussion

3.1. Magnetic separation test with the Davis Tube

The production of a concentrate with 65% Fe was aimed during the magnetic separation experiments. In the light of the previous results, the liberation was assumed to be at finer particle sizes. In addition, the reference particle size (80% -45 μm) for industrial pellet feed was accepted. Therefore, the enrichment possibility of samples was investigated according to their fineness (-45 μm). The results are given in Figs. 4-6. The results are grouped according to their formation taken from.

The Davis tube enrichment results for the Taştepe and B5 core samples which represent the Taştepe formation are given in Fig. 4. As can be seen from Fig. 4, when the sample is ground to 45%, by weight of -45 μm particles, the Fe grade of concentrate is over 65% Fe.

The B52, B73, B81 and B97 core samples represent the Dönentaş formation. The Davis tube enrichment results for these samples are given in Fig. 5. The results showed that a concentrate with over 65% Fe can be produced if the feed is ground 38-53% by weight -45 μm.

Different results were obtained with B27 and B31 core samples representing the Kızılkaya formation (Fig. 6). A concentrate with over 65% Fe can be produced when the B27 core sample feed is ground to 25% by weight of the -45 μm size fraction. A further grinding (60% -45 μm) increased the grade of the concentrate up to around 68.5% Fe. The B27 core sample consists of hematite and due to oxidation of hematite, this sample gets loose structure and could be ground easily. A direct use of the lump ore is more appropriate since the grade of the B27 sample feed is high (59.34% Fe) and the loses (Table 5) would occur during low intensity magnetic separation for this type of hematite ores. Therefore the B27 core sample were not used in pelletizing experiments. Davis tube enrichment results for the B31 core sample showed that a concentrate with about 65% Fe can be produced if the feed is ground 90% by weight -45 μm.

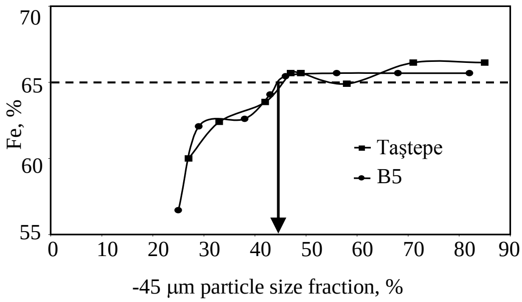

Fig. 4. Davis tube separation results of Taştepe formation according to the content of the -45 μm particle size fraction in the feed sample

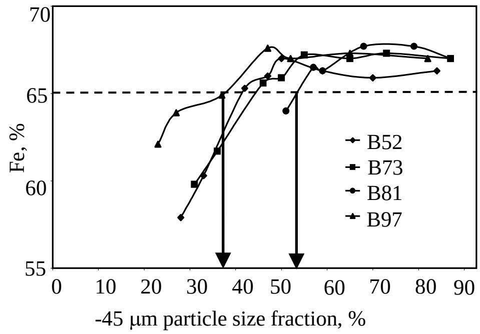

Fig. 5. Davis tube separation results of Dönentaş formation according to the content of the -45 μm particle size fraction in the feed sample

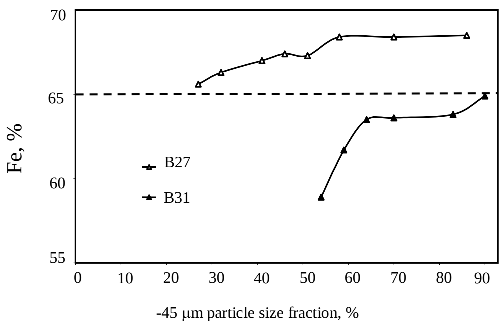

Fig. 6. Davis tube separation results of Kızılkaya formation according to the content of the -45 μm particle size fraction in the feed sample

The results given above show the necessity of fine grinding for the Bizmişen iron ore for enrichment. In order to produce concentrates with sufficient Fe content, the iron ore should be ground to 45-80% by weight of the -45 μm size fraction in the feed. The required particle size for pellets production is assumed to be 80% -45μm. Therefore, two different ground samples about this particle size (80% by weight -45 μm) were analyzed and recoveries as well as efficiency of separation were calculated. The results are given in Table 3.

As can be seen in Table 3, the concentrates with over 65% Fe and 90% Fe recovery could be produced using the Taştepe, B5, B52, B81, B97 and B31 core samples, by magnetic separation. It is a well-known that the recovery should be over 90%. Hence, these results and findings are satisfying. Although the Fe content for the B27 and B73 core samples were found to be high enough, their recovery were not sufficient. The reason of this is believed to be due to a low magnetic susceptibility of the minerals (hematite and pyrite) present in the two samples. The relatively lower magnetic susceptibility of these minerals leads to loses during low intensity magnetic separation.

Table 3. Grade and recoveries of concentrates produced with Davis tube according to the particle size of feed sample

Formation	Sample name	Particle Size (-45 μm), %	Grade of Fe, %			Recovery by weight, %		Recovery of Fe, %	
			Feed	Concentrate	Tailing	Concentrate	Tailing	Concentrate	Tailing
Taştepe	Taştepe	71.0	50.3	66.3	10.5	71.3	28.7	94.0	6.0
		85.0	50.3	66.3	11.0	71.0	29.0	93.6	6.4
	B5	68.0	43.0	65.6	7.5	61.1	38.9	93.2	6.8
		82.0	43.0	65.6	8.7	60.3	39.7	92.0	8.0
Dönentaş	B52	70.0	44.0	65.9	7.8	62.3	37.7	93.3	6.7
		84.0	44.0	66.3	8.5	61.4	38.6	92.5	7.5
	B73	73.0	49.8	67.3	16.1	65.9	34.1	89.0	11.0
		87.0	49.9	67.0	17.5	65.4	34.6	87.9	12.1
	B81	79.0	45.1	67.7	7.7	62.3	37.7	93.6	6.4
		87.0	45.1	67.0	10.9	61.0	39.0	90.6	9.4
	B97	65.0	50.8	67.3	9.5	71.5	28.5	94.7	5.3
		82.0	50.8	67.0	10.1	71.6	28.4	94.4	5.6
Kızılkaya	B27	70.0	59.3	68.4	39.1	69.1	30.9	79.6	20.4
		86.0	59.3	68.5	44.7	61.5	38.5	71.0	29.0
	B31	83.0	42.6	63.8	7.7	62.2	37.8	93.2	6.8
		90.0	42.6	64.9	10.9	58.7	41.3	89.4	10.6

3.2. Magnetic separation tests with magnetic drum concentrator and pelletizing experiments

The Davis tube experiments showed that the enrichment of the Bizmişen iron ore is possible and the produced concentrates with a sufficient amount of Fe (over 65% Fe). In order to achieve this target the ore should be ground to finer sizes. Since the desired particle size for pellet production is minimum 80% -45 μm, the feed was ground to this fineness and fed to the laboratory size low intensity drum type wet magnetic separator. Different particle sizes were not using the drum separator due to a lack of enough samples.

Five different samples namely Taştepe, B5, B52, Mix1 and Mix2, were used during the drum separator tests. The first three samples were ground and concentrated separately. The latter two were formed by blending all samples Taştepe, B5, B52, B73, B81, B97 and B27 and B31 (14.29% from each samples excluding B27 for Mix1, 12.5% from each for Mix2). All five samples were concentrated separately with the low intensity magnetic separator. Different concentrates and tailings were analyzed and recoveries as well as efficiency of the separation were calculated. The results are given in Table 4.

Table 4. Grade and recoveries of concentrates produced with magnetic drum separator

Sample Name	Grade of Fe%			Recovery by weight, %		Recovery of Fe, %	
	Feed	Concentrate	Tailing	Concentrate	Tailing	Concentrate	Tailing
Taştepe	50.3	65.3	10.9	72.4	27.6	94.0	6.0
B5	43.0	65.5	7.0	61.6	38.4	93.8	6.2
B52	44.0	65.6	7.2	63.0	37.0	94.0	6.0
Mix 1(1)	46.5	64.6	11.0	66.2	33.8	92.0	8.0
Mix 2(2)	48.1	66.3	14.0	65.2	34.8	89.9	10.1

(1) Taştepe, B5, B52, B73, B81, B97 and B31 core samples were blended in equal amount (14.29%)
(2) All core samples were blended in equal amount (12.50%)

Considering the Fe content of all test samples (excluding Mix2), the concentration using the magnetic drum separator was found to give sufficient Fe grade and recovery in the products. The Mix2 sample including the B27 core sample, resulted in low Fe recovery because of the reasons mentioned previously.

The pelletizing experiments with addition of 0.8% bentonite (Meyer, 1980) were carried out with all concentrates excluding Mix2. The green pellets were formed in a laboratory pelletizing disc 9 -16 mm in diameter. The green pellets were fired at 1200^{o}C in a muffle furnace after drying. Detailed elemental analyses were carried out on the products pellets. Elemental analyses with XRF (X-Ray Fluorescence spectrometer analyzer) were done in İSDEMİR (Iskenderun Iron and Steel Co.) and ERDEMİR (Eregli Iron and Steel Co.) and are given in Table 5.

Required limits by a pellet buyer, İSDEMİR, are given in Table 5. According to these results, all components excluding Al_2O_3 of concentrates produced by magnetic separation are suitable to produce blast furnace quality pellets. The reason of relatively high SiO_2 and Al_2O_3 in pellets than in the concentrates is due to the addition of bentonite binder. The high Al_2O_3 problem can be overcome in two ways. In one, the magnetic concentration can be tested with finer particle size to remove the Al_2O_3. In the second method, this type of concentrates can be blended with concentrates containing less of Al_2O_3.

When finer particles are used during concentration, the Fe recovery will decrease (this can be seen in Table 3). Furthermore, concentrates containing very fine particles in the feed for pellet production lead to some operational difficulties and losses. A cost analysis should be done to consider the cost of further grinding, the losses caused by finer particles and low concentration recovery.

In order to determine the presence of valuable component in the tailing of Mix 1, the tailing after magnetic separation was examined by semi-quantitative spectral analysis. The result was given in Table 6. No significant valuable components were found in the tailing according to this result.

Table 5. Chemical analyses of concentrates produced with magnetic drum separator and pellets produced from these concentrates

Components	Products						
	B5 Concentrate (İsdemir)	B52 Concentrate (İsdemir)	Taştepe Concentrate (İsdemir)	Mix 1 Concentrate (İsdemir)	Mix 1 Concentrate (Erdemir)	Mix 1 Pellet (Erdemir)	Required limits by pellet buyer(2)
Total Fe	65.01	65.94	65.16	65.54	65.62	64.06	>65.50
SiO_2	3.41	2.47	2.99	2.75	2.85	3.33	<6.00
Al_2O_3	2.37(1)	2.32(1)	2.35(1)	2.12(1)	2.34(1)	2.50(1)	<1.00
CaO	1.33	1.22	1.35	1.15	1.04	1.03	<3.00
MgO	1.26	1.21	1.25	1.20	1.06	1.07	<1.50
Na_2O	0.079	0.079	0.078	0.076	0.037	0.035	<0.05
K_2O	0.026	0.012	0.029	0.015	0.087	0.047	<0.05
TiO_2	0.064	0.042	0.027	0.038	0.061	0.064	<0.50
Mn	0.11	0.16	0.13	0.15	0.13	0.13	<3.00
P	0.016	0.017	0.016	0.017	0.013	0.012	<0.06
S	0.029	0.10	0.108	0.166	0.095	0.003	<0.01
As	0.0001	0.001	0.0001	0.0001	0.002	0.002	<0.005
Cr	0.0053	0.0046	0.0049	0.005	0.002	0.007	<0.05
Ni	-(3)	-	-	-	0.004	0.004	<0.01
Zn	0.0269	0.0475	0.0299	0.0347	0.032	0.043	<0.01
Pb	0.0001	0.001	0.001	0.001	0.001	0.001	<0.01
Cu	0.001	0.0019	0.0039	0.0032	0.006	0.006	<0.01
Sn	-	-	-	-	0.00	0.00	<0.005
Mo	-	-	-	-	0.00	0.00	<0.005
V	-	-	-	-	0.006	0.006	<0.02
LOI	+1.83	+2.01		+1.48	+1.66	+0.06	-

(1) Considered high for iron ore pellet production; (2) Limits applied by İSDEMİR (Iskenderun Iron and Steel Co.) for acid iron ore pellets (http://www.isdemir.com.tr); (3) Under detection limit

Table 6. Result of semi-quantitative spectral analysis of tailing of Mix 1 sample

Components	Fe	SiO_2	Al_2O_3	Ca	Mn	Cu	Ti	Co
%	>10.0	>10.0	>10.0	>1.0	0.4	0.3	0.1	0.04

4. Conclusion

A large part of the Bizmişen iron ore deposit consists of low grade iron ore (mainly magnetite) with high content of impurities (SiO_2 and Al_2O_3). Therefore the direct use of iron ore from this deposit is impossible. The results drawn from study are as follows.

- The liberation size of this low grade iron ore was found to be about 45 µm for the production of concentrates with over 65% Fe content by magnetic separation.
- The concentrates produced cannot be used directly due to their fine particles. Agglomeration process is necessary to produce reduction furnace feed. The concentrate meets the requirements for iron ore pellet production.
- The pelletizing results showed that all components excluding Al_2O_3 of concentrate produced by magnetic separation are suitable to produce blast furnace quality pellets.
- The problem of high content of Al_2O_3 can be overcome by either further grinding applied to achieve better liberation and thus to produce a concentrate with acceptable Al_2O_3 content, or blending with low Al_2O_3 concentrates.

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