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Conference Paper · November 2017

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BMPC 2017

XVII. Balkan Mineral Processing Congress

Proceedings

November 1-3, 2017

Antalya,Turkey

Turkish Mining Development Foundation

INVESTIGATION OF BENEFICIATION OF A MANGANESE ORE BY JIG

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ABSTRACT

Beneficiation of a manganese ore with a grade of 33.00% Mn from Suşehri, Sivas, Turkey was investigated via jigging. The purpose of the study was to produce a concentrate with a minimum grade of 46% Mn and a particle size over 10 mm. The ore was crushed under 20mm and classified into seven size fractions (-20+15,-15+9.53, -9.53+6.35, -6.35+3.18, -3.18+1.40, -1.40+0.589 and -0.589mm). Excluding the coarsest and finest fractions, the other fractions were concentrated with a laboratory scale mineral jig. The highest grades of the concentrates, %44.32 and %44.54 Mn were obtained with -3.18+1.40mm and -1.40+0.589mm fractions, respectively. It was determined that jigging alone is not sufficient to produce a concentrate with 46% Mn over 10 mm particle size from Suşehri manganese ore.

Key words; Manganese ore, Beneficiation, Jig, Gravity based separation,

1. INTRODUCTION

Manganese is a metal found in the chemical formula of different minerals together with iron and many other minerals in nature. There are more than 300 minerals containing manganese in different grades. The most important minerals of manganese are manganosite, pyrolusite psilomelane, manganite, vernadite, braunite, hausmannite, rhodochrosite, rhodonite, and bustamite. The most important manganese bearing minerals are given in Table 1. Iron bearing minerals are always associated with manganese ores. Manganese ore deposits may be of four different types: hydrothermal manganese deposits, sedimentary manganese deposits, residual manganese deposits, and metamorphic manganese deposits.

Table 1. The most important minerals of manganese

Mineral name	Theoretical Empirical Formula	Mn%
Manganosite	$Mn^{2+}O$	77.45
Pyrolusite	$Mn^{4+}O_2$	63.19
Psilomelane	$Ba(H_2O)Mn^{3+}{}_5O_{10}$	46.56
Manganite	$Mn^{3+}O(OH)$	62.47
Vernadite	$Mn^{4+}{}_{0.6}Fe^{3+}{}_{0.2}Ca_{0.1}Na_{0.1}O_{1.5}(OH)_{0.5}1.4(H_2O)$	30.48
Braunite	$Mn^{2+}Mn^{3+}{}_6SiO_{12}$	63.60
Hausmannite	$Mn^{3+}{}_3O_4$	72.03
Rhodochrosite	$Mn^{2+}(CO_3)$	47.79
Rhodonite	$Mn^{2+}{}_{0.9}Fe^{2+}{}_{0.02}Mg_{0.02}Ca_{0.05}SiO_3$	38.29
Bustamite	$Mn^{2+}{}_{2.25}Ca_{0.75}Si_3O_9$	32.37

Manganese metal is used in different industries especially in metal alloying processes. The mining and mineral processing industries extract the manganese from those manganese minerals and use the manganese alloyed steels themselves due to wear-resistant property. The grizzly screens, feeders, surfaces of jaw, gyratory, roll, hammer crushers and balls, rods and liners of grinding mills are made from manganese alloyed steels to protect the equipment from wear (Wills and Napier-Munn, 2006). Manganese is essential to iron and steel production due to its sulfur-fixing, deoxidizing, and alloying characteristics. The largest usage area, with almost 90% of the production, of manganese is iron and steel industry since manganese imparts malleability, tenacity and hardness to steel. Manganese is also used in aluminum alloying processes, in battery, paint, fertilizer and chemistry industries.

Manganese ores contain different manganese grades. The process of high grade manganese ores to produce ore concentrates to be used as raw materials in above mentioned industries is relatively easy and includes mining, crushing and classification. However, the increasing demand for the metal encouraged the mining industry to exploit all manganese bearing resources recently. Even, the seabed may become a viable source of minerals in the future since manganese nodules have been known since the beginning of the nineteenth century (Mukherjee et al., 2004; Wills and Napier-Munn 2006)

Turkey has some manganese ore deposits; however, they are small in terms of quantity and of lower quality when compared to the world reserves. Only 0.11% of the world manganese reserves are found in Turkey (Development Plan 2001–2005). Iron bearing manganese ores are commonly used in sintering process in iron-steel facilities to decrease manganese ore use. The production of manganese ores in Turkey is not sufficient to meet the domestic demand and Turkey is very much dependent on the import manganese ore (Development Plan 2001–2005). Therefore, the evaluation of domestic manganese ores for concentration is rather important.

The conventional methods to concentrate the manganese ores are gravity separation, magnetic separation, flotation (Fuerstenau et al. 1986), pyrometallurgical and hydrometallurgical leaching processes (EI-Hazek et al., 2006; Jiang et al., 2004; Bafghi et al., 2007; Hariprasad et al., 2007; Senanayake, 2004), reduction roasting followed by magnetic separation, and manganese recovery by acid leaching (Sharma 1992). Low-grade manganese ores usually contain multiple elements such as iron (hematite, goethite, etc.), aluminum (aluminosilicate, bauxite, etc.), silicon (quartz, etc.). Zhixiong et al (2015) investigated the feasibility of selectively sulfating manganese dioxide with SO_2 as reductant followed by water leaching for extraction of manganese from iron rich low-grade manganese ores. Some studies were carried out for reducing the ore at elevated temperature by various reducing agents such as natural gas, coal, graphite, sulfur dioxide, hydrogen, and then leaching the reduced product with hot dilute sulfuric acid (Misra and Khangaonkar, 1975; Guven and Hurman, 1995). Other studies depended on roasting of manganese ore in the presence of sulfatising agent such as SO_2, FeS_2, Na_2SO_3 and then leaching the roasted product with hot water (Masayasu et al., 1991; Jana et al.1999). The main drawbacks of these studies and methods were high-energy consumption, environmental restrictions, and high costs (Adel et al. 2004). Other concentration studies, including shaking table, Mozley spiral concentrator, dry belt type magnetic separation, high intensity magnetic separation and flotation, were carried out by several researchers (Riaz et al, 2010; Mishra 2009; Hassan 2013). In this study, the possibility of beneficiation of a manganese ore with 33% Mn grade ore was investigated to produce a commercially sellable manganese concentrate with a minimum of 46% Mn grade and a particle size over 10 mm using jig alone.

2. MATERIALS AND METHODS

The manganese ore used in the experimental laboratory tests was taken from a manganese ore deposit from Suşehri region in Sivas, Turkey. The hand-picked pieces from different parts of the ore field and open cuts were collected to take a representative sample. The ore taken from the field was first reduced to approximately 200 kg representative sample. The ore was crushed to -20mm in stages using a lab scale jaw crusher. The concentration tests were carried out using this crushed sample.

A laboratory scale, mechanical diaphragm and fixed bed screen, Denver mineral jig with 13*18*20cm (L*D*H) dimensions of jig compartment (Figure 1). Batch type jigging was applied at constant operational parameters for all the tests. After jigging three different layers of jig bed were collected manually and analyzed for Mn content.

3. RESULTS AND DISCUSSIONS

Some ores are crushed selectively during comminution due to differences in hardness and breakage characteristics of minerals in the ore. In order to see if any selective breakage, thus concentration of Mn, occurred in any given size fraction, the crushed ore was classified into different size fractions and each fraction was analyzed for Mn. The results of Mn grade and Mn distribution of all the fractions are given in Table 2.

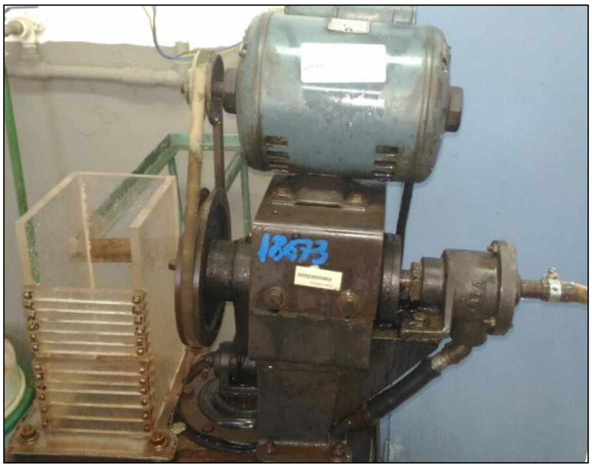

Figure 1. Photo of the jig used in the experiments

Table 2. Mn grade and distribution of different fractions of the crushed ore

Size fractions (mm)	Amount (%)	Mn grade (%)	Mn distribution (%)
-20+15	39.30	35.20	41.92
-15+9.53	16.40	34.39	17.09
-9.53+6.35	11.70	29.44	10.44
-6.35+3.18	11.60	28.41	9.99
-3.18+1.40	9.20	30.47	8.50
-1.40+0.589	5.20	31.82	5.01
-0.589	6.60	35.23	7.05
Feed	100.00	33.00	100.00

As seen in Table 2, the tested manganese ore has 33.00% Mn feed grade. When the ore is crushed to -20mm, more than half of it (55.70% by weight) remained coarser than 9.53mm which is about target concentrate particle size. All of the fractions had more or less similar Mn grades, ranging from 28.41 to 35.23% Mn. Therefore, it was seen that upgrading the ore grade to 46% Mn was not possible only by crushing and classification. As a result, jigging, a well-known gravity separation technique was considered a viable alternative for the concentration of this ore to produce the target commercial product. Since, the jig used in the tests was a lab scale one, only -15+9.53mm, -9.53+6.5mm, -6.35+3.18mm, -3.18+1.40mm and -140+0.589mm fractions were subjected to concentration. Since -20+15mm size fraction was too large and -0.589mm was too fine for the jig at hand, these fractions were not tested with the jig. The results of jigging experiments are given in Table 3. -0.589mm fraction was cleaned by decantation method to wash the slime and lightest particles. However, Mn increase could not be obtained by decantation.

It can be concluded that a concentration can be achieved when -15.00+9.53mm size fraction is concentrated with jigging process. However, the Mn grade of the concentrate was 40.70% with 49.80% weight recovery which still lower than the target Mn grade limit due to insufficient liberation and separation efficiency.

According to jig results of -9.53+6.35mm fraction, a concentrate with 38.60% Mn with 53.30% weight recovery was obtained. This Mn grade is still lower than the target Mn grade limit.

Table 3. The results of concentration of different size fractions of the ore

Size fraction (mm)	Product	Mass (%)	Mn grade (%)	Mn recovery (%)	Overall Mn recovery (%)
-15+9.53	Heavy	49.80	40.70	67.1	11.5
	Middling	25.60	23.40	19.9	3.4
	Light	24.60	15.90	13.0	2.2
	Feed	100.00	30.17	100.0	17.1
-9.53+6.35	Heavy	53.30	38.60	75.6	7.9
	Middling	27.50	13.60	13.7	1.4
	Light	19.20	15.20	10.7	1.1
	Feed	100.00	27.20	100.0	10.4
-6.35+3.18	Heavy	43.61	39.22	67.1	6.7
	Middling	24.38	17.45	16.7	1.7
	Light	32.01	12.92	16.2	1.6
	Feed	100.00	25.50	100.0	10.0
-3.18+1.40	Heavy	44.00	44.32	73.8	6.3
	Middling	27.20	15.54	16.0	1.4
	Light	28.80	9.32	10.2	0.9
	Feed	100.00	26.40	100.0	8.5
-1.40+0.589	Heavy	57.20	44.54	80.4	4.0
	Light	42.80	14.53	19.6	1.0
	Feed	100.00	31.63	100.0	5.0

After jigging of -6.35+3.18mm, -3.18+1.40mm and -140+0.589 mm fractions, concentrate products with relatively upgraded Mn grades can be obtained, however, those Mn grades are still lower than the target Mn grade. When examining the concentration results of last two finer size fractions with the jig, it can be seen that the grades of the concentrates were increased with decreasing particle size. The reason of the increase of grades was due to liberation. Concentrates with about 44.50%Mn grade could be produced from two last finer fractions of -3.18+1.40mm, and -1.40+0.589mm with 44.00 and 57.20% weight recoveries, respectively. Overall Mn recoveries of the fractions are shown in Table 3 as well.

These results showed that the desired concentrate with 46% Mn grade from Suşehri manganese ore could not be produced over 10mm particle size with gravity concentration technique. The desired Mn grade can only be obtained at finer particle size. For instance, the ore should be ground under about 1mm. Such crushed ore can be concentrated with shaking table or spiral techniques. In this case the desired Mn grade can be obtained over 46% Mn grade. However, this was not tried since the target of the study was to produce a concentrate at coarser particle size. When the ore ground and concentrated with shaking table or spiral, the concentrate can be used after an agglomeration process like briquetting.

4. CONCLUSION

The purpose of the study was to determine the applicability of the simple and cheap conventional separation techniques to produce a sellable manganese ore concentrate with a minimum 46% Mn grade and a particle size over 10 mm from Suşehri manganese ore. For this aim, a laboratory scale jig was used and the following are the results of the present experimental study:

- It was determined that through chemical analysis that the tested ore has 33.00% Mn grade.
- A concentrate with 40.50% Mn grade with 49.80% weight recovery from -15+9.53mm fraction and a concentrate with 44.54% Mn grade with 57.20% weight recovery from -1.40+0.589mm fraction could be obtained.
- The jig results showed that Suşehri manganese ore cannot be concentrated effectively by gravity technique to produce a sellable concentrate with a minimum 46% Mn grade and a particle size over 10 mm due to low liberation at desired coarser size fractions.
- It was suggested that the ore should be ground to finer particle size and can be concentrated by shaking table, spiral and MGS techniques or other beneficiation techniques. Laboratory investigations should be done to determine the concentration parameters.
- So produced fine manganese ore concentrate can be used after briquetting process.

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