Pak. J. Sci. Ind. Res. 2010 **53** (6) 298-302

Beneficiation Studies of Bajaur Manganese Ore by Different Processing Techniques

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(received September 28, 2009; revised August 20, 2010; accepted August 25, 2010)

Abstract. The manganese ore of Bajaur Agency of Pakistan was subjected to flotation, heavy medium separation, gravity concentration and magnetic separation techniques for beneficiation. The original composition of the manganese ore was 45.56% Mn , 4% Fe_2O_3, 40% SiO_2. The Mn content was raised to a maximum ~ 48.76 % in the concentrate with the recovery of ~ 67.78 % through flotation technique. Other techniques rendered marginal increase in Mn concentration against the theoretical possibility of substantial enrichment by rejecting the ~ 20 % gangue minerals. The separation of manganese minerals from associated gangue was difficult, due to mineralogical complexity of the ore, extreme fineness of the particle size, texture and minerals intergrowth. High Mn/Fe ratio, phosphorus, and silica contents were within tolerable limits for utilisation of the ore in ferro-manganese production.

Keywords: manganese, Bajaur agency, magnetic separation, flotation, beneficiation

Introduction

Manganese, a grey metal resembling iron, is hard and brittle and of little use alone. It constitutes about 0.1 % of the earth crust and is the twelfth most abundant element (JCPDS, 1979; Fraser and Belcher, 1975; Kostov, 1968; Palache *et al.,* 1944). Manganese is essential for the steel industry where it is used mostly as a ferroalloy. Chief minerals of manganese are pyrulosite, romanechite, manganite, hausmannite and rhodochrosite (Rao *et al.,* 1998; Craig and Vaughan, 1994; Roberts *et al.*, 1990; Jacoby, 1975). Pyrolusite is a black, opaque mineral with a metallic luster and is commonly soft enough to soil the fingers. It is usually a secondary mineral formed by the oxidation of other manganese minerals. Romanechite, formerly known as psilomelane (Brandes and Flint, 1980) is a hard, black amorphous material with a dull luster and is commonly found in massive form. When free of other oxide minerals, romanechite can be identified readily by its superior hardness and lack of crystallinity. Manganite is an opaque mineral of medium hardness, ranging in colour from steel grey to iron black, with a dark, reddish brown streak. It has also a sub metallic luster. Hausmannite is a black opaque mineral, usually crystalline having a sub metallic luster and specific gravity of 4.73 to 4.86. It has a hardness of 5.5 and a brownish black streak. Rhodochrosite is the most common carbonate mineral of manganese and usually occurs with rhodonite. It is light rose in colour, although other shades are not uncommon. None of the natural sulphides of manganese are of any commercial importance. Some silicates have been mined. Rhodonite and braunite are of interest because these are frequently associated with the oxides and carbonate minerals (Schouten, 1962).

In general, only the ores containing at least 35 % manganese are classified as manganese ores. Those having 10-35 % manganese are known as ferruginous manganese ores, and ores containing 5-10 % manganese are known as manganiferrous ores (Kirk Othmer, 2004.). Ores containing less than 5% manganese with the balance of mostly iron are classified as iron ores.

Pakistan, during 1989-90, imported manganese ore and concentrate, manganese dioxide, ferromanganese and manganese metal and articles, worth Rs. 293,486 thousand (Ahmed and Siddiqui, 1993). All of the ferromanganese is consumed by iron and steel industries. Most of the oxides, whether ores or others, are probably used in the manufacture of dry cells, with the remainder for other uses.

Different workers like (Master, 1960; Master and Qureshi, 1958; Rizvi, 1951) have described in detail some manganese deposits of Las Bela District in southern Balochistan. Las Bela deposits include those of Siro, Khabri, Dhora, Haji Mohammad Khan Bent and Kohan Jhal. In Khyber Pakhtunkhwa province, manganese deposits are located in Galdanian, Tarnawai, Abbottabad, and Chura Gali, about 19 km northeast of Abbottabad; a small lode manganese oxide

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minerals is exposed near Thal, about 112 km West of Kohat and Bajaur Agency.

FATA Development Authority (FDA) has newly explored manganese prospects in Bajaur Agency at Takht area. The exploratory activities have so for revealed occurrence of reserves of an estimated 0.12 million tons manganese ore, having MnO_2 content ~ 45.56% on an average, in association with meta-sedimentary rocks of Island Arc sequence (Haqqani and Din, 2006). Bajaur Agency of Pakistan covers an area of 1354 km^2 out of which 1250 km^2 area has been previously explored geologically on reconnaissance scale which indicated favourable geological environment for occurrence of metallic minerals like manganese and chromite in the Agency. Keeping in view the geological environments, as the extension of Takht Manganese project, exploratory activities were also extended to Sagi area, Mohmand Agency which indicated encouraging manganese occurrences on the ground.

The present work was undertaken to test the susceptibility of the manganese ore of Bajaur Agency to beneficiation through subjecting it to techniques of flotation, heavy medium separation, gravity concentration and magnetic separation as well as chemical analysis.

Materials and Methods

The manganese ore sample, supplied by FDA from Bajuar Agency region was crushed in a jaw and role crusher up to ~20 mm size. The roll crushed representative sample was drawn for sieving and heavy medium studies. This roll-crushed material was ground to 100 mesh size in a laboratory disk mill (pullverissette 13). All the flotation and magnetic separation tests were carried out on this ground product, containing 45.56% Mn.

Sieve analysis was accomplished by passing a known weight of roll crushed material successively through finer sieves to determine the percentage weight in each fraction. All the sieve fractions were analyzed chemically (Si, Mg, Al) on atomic absorption Model Z-8000, Hitachi Japan (Mn, Fe), Flame photometer Model PFP 7 JENWAY UK (Ca, Na, K) and UV double beam spectrophotometer Model Hitachi Japan (P) to determine the metal distribution pattern. The metal distribution pattern is shown in Table 1.

Heavy medium separation and gravity concentration. Various size fractions of the roll crushed material were subjected to sink and float tests, using an organic liquid, tetrabromoethane of specific gravity 2.96. The material was stirred with the heavy liquid, and then set aside to stand until complete separation of float and sink took place. The sink was drawn off through the bottom, and the float was separated in a separating funnel. Both the products were washed with acetone and water to remove adhering liquid and then dried. Distribution of heavy and light components in each fraction is given in Table 2.

Magnetic separation. Magnetic separation studies were carried out using drum type magnetic separator with drum dimensions as 200 mm dia X 200 mm width and magnetic intensity of about 7000 Gauss. The magnetic product of each test was repeatedly passed thrice through the separator for accuracy and for sharp separation. The non-magnetic fraction was processed once again and the magnetic fraction thus obtained was considered as middling. The three products obtained on magnetic drum separator were analyzed for Mn, Fe and Si; results are given in Table 3.

Flotation studies. Flotation tests of manganese ore sample were carried out in Denver flotation machine. The disk mill ground material was screened on 100 mesh size Tyler standard screen. The over size material carrying visible mineral grains was reground to pass 100 mesh size screen and combined with the undersign fraction. The flotation cell was filled with water. Water from local source with temperature variation from 20 °C to 25 °C was employed for the pulp formation and for addition to maintain the cell level during flotation. Manganese ore mesh 300 g was weighed to give predetermined pulp density of 30% ore weight. Concentrated

Table 1. Major and minor compound distribution in bulk and sieve fractions of manganese ore of Bajaur Agency

Size (μm)	MnO_2	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	L.O.I.	P_2O_5	Na_2O	K_2O	Total
Bulk	72.09	1.09	9.37	0.78	5.85	0.04	10.01	0.02	0.21	0.19	99.58
+ 500	74.61	1.51	9.36	0.95	5.02	0.01	7.48	0.01	0.20	0.16	99.31
-500 +180	72.20	1.80	9.56	0.77	5.62	0.05	8.70	0.02	0.21	0.18	99.11
-180 +105	71.72	1.12	9.43	0.65	6.22	0.03	10.13	0.02	0.22	0.19	99.73
-105 + 75	69.74	1.08	9.66	0.62	7.50	0.04	10.50	0.02	0.20	0.19	99.55
-75 + 63	72.24	0.89	9.31	0.69	5.96	0.06	9.90	0.01	0.17	0.19	99.42
-63	72.24	0.86	9.08	0.80	6.02	0.06	10.02	0.06	0.27	0.22	99.63

Table 2. Distribution of heavy and light components in various sieve fractions of roll crushed material

Size (µm)	Wt (%)	Float (%)	Sink (%)
+ 500	9.61	1.54	98.46
-500 +180	29.33	2.18	97.82
-180 +105	15.71	4.31	95.69
-105 + 75	5.13	10.50	89.50
-75 + 63	3.36	15.36	84.64
-63	36.86	5.05	94.95

Table 3. Magnetic separation studies of manganese ore on drum magnetic separator

Product	Wt.	Wt. (%)	Mn (%)	SiO_2 (%)	Fe_2O_3 (%)	Distribution of Mn (%)
Magnetic-I	176.4	75.06	46.30	8.18	1.25	76.28
Magnetic-II	34.2	14.52	42.50	9.82	0.63	13.54
Non-magnetic	25.0	10.61	43.96	8.34	0.81	10.24

sulphuric acid of specific gravity 1.84 was added drop wise to adjust the pH of the pulp (~ 6.5). Oleic acid, anionic petroleum sulphonate (Aero 801) and anionic alkyl succinamate (Aero 830, 845) promoter were used as principal collector in the present studies (American Cyanamide Co., 1989). Areo-830 and 830 were also used in the secondary collector with oleic acid and petroleum sulphonate, 20 % of the total collectors doses. acid and fatty acid soap collectors (0.2 g/L of slurry). The frother, 2-3 drops mixed glycol and alcoholic combination (Aero 65 and Aero 70) were added to the pulp and mixed maintaining a definite mixing time (5 minutes). The speed of impeller kept constant at 1500 rpm. Flotation was carried out until the froth was completely exhausted. Concentrate and tailing were allowed to settle down, decanted, dried, weighed and analyzed for Mn. Data is given in Table 4.

Results and Discussion

Heavy media technique was used to know the potential of separation by this technique. Distribution of heavy and light components in each fraction, are given in Table 2 but not analyzed, because on an average the light fraction is 4.39 % in this roll-crushed material. Thus, there was not significant gravity differential to effect a gravity based separation.

Using the guidelines offered by the concentration criterion, one can speculate about the possibility of successful gravity concentration on any ore. The criterion is

Cc = (Dh–Df) (Dl-Df) where:

Cc = concentration criterion

Dh = specific gravity of heavy minerals

Dl = specific gravity of light minerals

Df = specific gravity of fluid medium used

The value of Cc should be greater than 2.5 for effective separation; separation efficiency decreases as the value of Cc decreases and when value of Cc becomes less than 1.25, gravity concentration becomes almost impossible. The Bajaur manganese ore has quartz and calcite as the associated major

Table 4. Flotation tests results of manganese ore

Collector	Product (%)	weight (%)	Mn (%)	Distribution of Mn (%)
Oleic acid	Concentrate	90.0	45.91	90.69
	Tailing	10.0	42.50	9.33
Aero – 801	Concentrate	61.67	48.29	65.36
	Tailing	38.33	41.15	34.62
Aero – 830	Concentrate	67.0	46.86	68.57
	Tailing	33.0	42.91	31.08
Aero – 845	Concentrate	75.0	46.20	78.05
	Tailing	25.0	43.65	23.95
Oleic acid + Aero – 830	Concentrate	67.67	47.37	79.71
0.16 + 0.04	Tailing	23.33	39.60	20.28
Oleic acid + Aero – 845	Concentrate	71.67	47.29	74.38
0.16 + 0.04	Tailing	28.33	41.20	25.62
Aero – 801+ Aero – 830	Concentrate	63.33	48.76	67.78
0.16 + 0.04	Tailing	36.67	40.05	32.23
Aero – 801+ Aero – 845	Concentrate	67.0	48.51	71.34
0.16 + 0.04	Tailing	33.0	39.67	28.73

gangue minerals. Specific gravity of manganese ore is in the range of 3.5 to 4.8 and that of the gangue between 2.65 to 2.7. Applying the concentration criterion equation, the Cc value was less than 2.5,which indicates that it is likely that gravity concentration of manganese ore deposits from Bajuar Agency may be virtually difficult. This was confirmed by gravity separation tests using both shaking and mozley tables. On shaking table, almost all the feed sample flew away and the analysis of mozley table test products, i.e., heavy and light fractions, showed almost no difference in their grade.

The laboratory sink and float tests data on various size fractions of the disk ground feed sample of manganese ore reveal that only 5 to 6 % of the unwanted gangue minerals associated with manganese can be rejected by heavy medium separation. By gravity concentration, grade of manganese ore can be raised marginally and insignificantly. It can be, therefore, concluded that gravity concentration and heavy medium separation techniques are not the pragmatic approach to achieve the desired manganese enrichment of Bajaur Agency deposits.

The mineralogical composition and distribution of elements in various size fractions of Bajuar Agency manganese ore samples indicate that the gangue minerals occur in close association with manganese minerals. Minute grains of manganese minerals are intergrown in gangue minerals and similarly gangue grains exist within the manganese phase which pose problems in their liberation. Incomplete liberation resulted in poor enrichment and poor recovery of the manganese content in magnetic separation tests carried out on drum magnetic separator. The results of magnetic separation studies on drum magnetic separator (Table 3) revealed the possibility of enriching the manganese content to maximum 46.83% with very poor recovery of 28.26%. It can be seen from the results that the manganese minerals are not prone to enrichment by low intensity magnetic separation. High intensity magnetic separator may give some better result.

The manganese minerals of Bajaur Agency deposits are oxides containing hausmannite as major mineral and psilomelane and brunite as minor. These minerals occur in complex association with each other. These are black in bulk and are very fine grained and inter-grown with each other as well as with fine gangue minerals. The separation of these oxides from gangue through flotation is more difficult due to the mineralogical complexity of the ore, fine particle size, texture and mineral inter growth. The results, show that manganese content increased marginally when oleic acid, petroleum sulphonate and alkyl succinmate were used as principal collectors. An improved enrichment of manganese content was obtained when Aero 830 and 845 were used as secondary collector with oleic acid and petroleum sulphonate. The manganese content in concentrate was raised to the maximum of ~ 48.76 % with the recovery of ~ 67.78 %.

Acknowledgement

We gratefully acknowledge the financial assistance provided by FDA for carrying out these studies. We are really indebted to Mr. Yaqoob Shah, D.G. Minerals, FDA for his keen interest and all-time support in this work. We are thankful to all the persons at PCSIR Laboratories, Peshawar who put their hard work in carrying out this project.

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