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# Utilisation potential of Low-Grade Siliceous Manganese ore from Balangir district, Odisha, India

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**Abstract:** The low-grade siliceous manganese ores from different Mn-ore mines of Balangir district, Odisha, India were studied with respect to their mineralogy which revealed the presence of two distinct phases pyrolusite, cryptomelane, and goethite as ore minerals and quartz as the gangue mineral. Different physical beneficiation techniques like gravity and magnetic separation were employed for the possible separation of the ore-gangue phases for their utilization and the results reported. The results reveal that a feed having 23% Mn could be upgraded to more than 39.3% Mn by using a dry belt-type magnetic separator with 69% recovery at 1.00 Tesla magnetic intensity.
**Keywords:** Manganese ore, Size classification, Magnetic separation.

## Introduction

The state of Odisha occupies a significant position in the mineral map of India in general, and manganese ores in particular. Large-scale Mn-mineralization is associated with three distinct geological formations viz., the Iron Ore Group (IOG), the Gangpur Group, and the Eastern Ghats Group (EGG). The Mn-deposits of the IOG rocks are usually of medium grade and free from phosphorus whereas the ores of the other two manganese provinces have high P content and therefore do not find much use in industry. In the present study area, manganese ore deposits associated with the Precambrian meta-sedimentary and meta-igneous rocks like khondalite, calc-granulite, charnockite and quartzite occur as discontinuous bodies around Larambha and Kaneital in the Balangir district of Odisha. While some of the deposits occur in concentrations amenable for economic exploitation others have remained unutilized due to their low grade and high silica content.

Several workers (Mishra et al., 2009, 2015; Mohapatra et al., 2009) have attempted to upgrade the low-grade Mn-ores from the Bonai-Keonjhar belt belonging to the Iron Ore Group through physical beneficiation techniques like gravity and magnetic separation methods. The influence of fabric or microstructure on the beneficiation potential of the low-grade Mn-ores has also been discussed by many workers (Mishra et al., 2011, 2013). The utilization potential of the low-grade siliceous Mn-ores from the Gangpur Group has been studied by Rao et al. (1988) and Mohapatra et al. (1995). Several other workers (Mpho et al., 2013; Mehdilo and Irranajad, 2014; Wu et al., 2015) have also attempted to upgrade the manganese values or enhance the Mn/Fe ratio through physical beneficiation methods. Mishra et al. (2019) have undertaken the detailed characterization of Mn-ore deposits of the Eastern Ghats province around Ambadola with respect to their mineralogical and microstructural attributes to determine their amenability to beneficiation. The present work focuses on the amenability of low-grade siliceous Mn-ores from the Balangir district to physical beneficiation techniques.

## Methodology

Around 10kg of representative low-grade siliceous manganese ore samples was collected from Larambha-Kanaital area, Balangir district, Odisha. All the samples were crushed to below 2mm size by roll crusher at different gap settings and classified into different size fractions using standard test sieves viz. 2mm, 1mm, 0.5mm, 0.25mm, 0.15mm and 0.075mm.

The mineralogical characterization was carried out using an optical microscope DM2500P (Leica make) and an X-ray diffractometer (Rigaku, Ultima IV). High-intensity dry belt magnetic separator of type LOG 1.4 SEP operated at 50 DC Volt and 4.17 DC amp. current, suitable for fine particle separation, (supplied by Box Mag Rapid Ltd., Birmingham, England) was employed. The magnetic intensity was varied between 0.73 and 1.23 Tesla. Dry samples of closed-size fractions were continuously fed to the belt magnetic separator by vibrating feeder at a controlled rate (6 rpm). For wet magnetic separation, wet high-intensity magnetic separator (WHIMS) supplied by M/s Box Mag Rapid, England was used. The magnetic intensity of the instrument was varied by varying the grid gaps and applied current. The Mn-containing slurry (with 25% solid concentration) was first conditioned for 10 minutes and then passed through the magnetic separator in several batches. The magnetic fraction was retained in the grid and the non-magnetic fraction was collected at the bottom. All the products obtained from each experiment were collected separately, dried, weighed and analyzed for Mn, Fe and selected samples for $SiO_2$.

## Results and interpretation

### Mode of occurrence of the Mn-ore

The Balangir district in Odisha hosts a large number of small Mn-ore pockets in khondalite and contact of calc-granulite and quartzite. The ores of usually low-grade type contain silica as the major gangue constituent. The low-grade siliceous Mn-ores usually occur as lenticular pockets containing large saccharoidal quartz grains embedded in an Mn-matrix (Fig. 1a). Large-scale brecciation and subsequent secondary silicification (Fig. 1b) also enhance the silica content in the ore.

**Fig. 1.** Field photographs of low-grade siliceous Mn-ore from Balangir. **a.** Manganese containing large pieces of saccharoidal quartz, Larambha, **b.** Highly brecciated Mn-ore with secondary silicification, Kanaital.

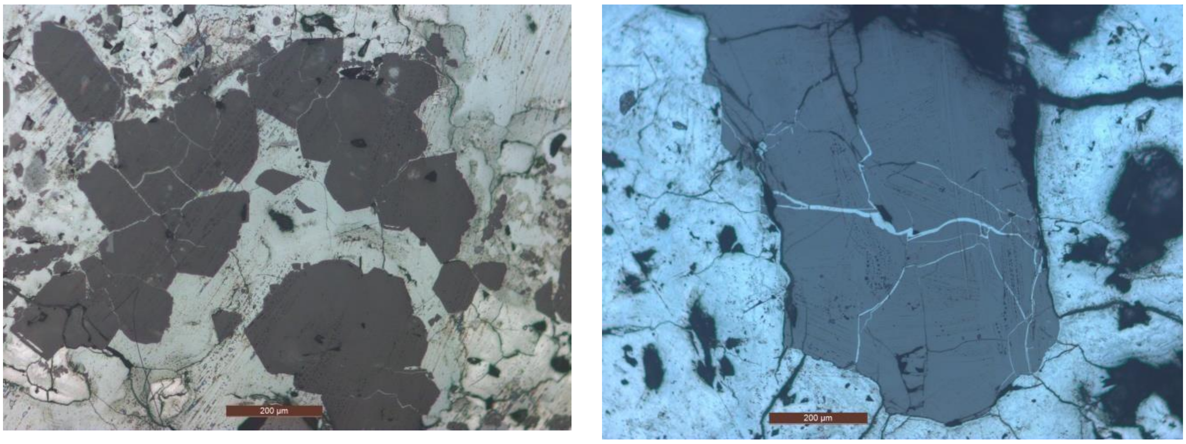


**Fig. 2.** Photomicrographs of Mn-ores showing different micro-texture. **a.** Silicate grains embedded within a matrix of cryptomelane and romanechite, 10X, **b.** A large irregular silicate grain present within cryptomelane, 10X.

### Mineralogical Characteristics

Optical microscope and X-ray diffraction studies were extensively undertaken for the mineralogical characterization of low-grade siliceous Mn-ore. The ore exhibits two distinct textural patterns; a) clusters of silicate (quartz) within the Mn matrix (Fig. 2a) and b) silicate grain surrounded by cryptomelane (Fig. 2b). The X-ray diffraction pattern of the bulk sample (Fig. 3a) exhibits the presence of quartz as the most dominant mineral followed by pyrolusite and minor kaolinite, which could have been derived from the alteration of feldspars.

 

**Physical and chemical characteristics**

The Mn content in Mn-ores of this area varies between 19.6 % to nearly 26.6 % with an average of 24.6 % which is categorized under marginal to low-grade type of Indian Mn-ores. Iron and alumina having average values of 11.5% and 9.0% respectively are considered high and usually contributed by goethite and aluminum silicate minerals like garnet, feldspar, and kaolinite. The maximum silica content reported from the samples is 37 % with an average of 31.2 % which is due to the presence of quartz. Other oxides like $K_2O$, $Na_2O$, CaO, MgO, BaO, $P_2O_5$, and $TiO_2$ occur in minor quantities.

**Beneficiation characteristics**

**Size classification**

The representative ROM sample from the study area was crushed in a jaw crusher and classified into different closed-size fractions using standard sieves of 2000, 1000, 500, 250, 150, and 75 µm. Each of the size fractions were analyzed for Mn, Fe, $Al_2O_3$, and $SiO_2$ by XRF. The results of the size classification and their chemical analyses are presented in Table 1. The results showed that the bulk Mn-ore is having a Mn content of ~23 % while silica assayed 31 %. The iron and alumina contents are 11.5% and 9.0 % respectively in the bulk sample. The Mn-minerals are mostly confined to the coarser fractions above 500 µm having Mn content of 26 %. The Fe and alumina contents remained almost uniform throughout the size fractions whereas silica content increased in size fractions below 500 µm size.

**Table 1.** Size classification and partial chemical analysis of Mn-ore.

| | Wt. % | Mn | Fe | $SiO_2$ | $Al_2O_3$ | Mn% distribution |
|---|---|---|---|---|---|---|
| Bulk | | 24.6 | 11.5 | 31.2 | 9.0 | 100 |
| -2000+1000µm | 43.9 | 27.6 | 13.9 | 28.4 | 7.2 | 49.7 |
| -1000+500 µm | 21.5 | 24.5 | 12.3 | 29.2 | 7.8 | 21.6 |
| -500+250 µm | 12.1 | 22.2 | 11.6 | 30.5 | 9.5 | 11.0 |
| -250+150 µm | 11.8 | 21.6 | 10.8 | 38.7 | 10.6 | 10.5 |
| -150 µm | 10.7 | 16.4 | 4.3 | 40.4 | 15.5 | 7.2 |
| Head | 100 | 24.4 | 11.9 | 31.3 | 8.9 | 100 |

**Heavy media separation**

The closed-size samples were subjected to sink and float studies using bromoform (specific gravity 2.86) as medium. The results of the studies are presented in Table 2. Float and sink products in each case were analysed for both Mn and Fe and only the sink products for alumina and silica. It may be seen from the table that Mn content in sink is almost uniformly distributed in all the size fractions. Further, the alumina and silica content of the sink products of all the size fractions are also nearly uniform varying between close ranges 4.0 to 5.5% and 27 to 31% respectively. This clearly indicates that no significant separation is achievable by the gravity method.

**Table 2**. Results of sink and float studies.

| Size in micron | Nature | Wt % | Mn % | Fe % | Mn % Dist. |
|---|---|---|---|---|---|
| -1000+500 µm | Float | 21.4 | 2.51 | 5.69 | 3.6 |
| | Sink | 78.6 | 29.0 | 15.9 | 96.4 |
| -500+250 µm | Float | 26.2 | 2.20 | 5.11 | 2.9 |
| | Sink | 77.8 | 29.2 | 15.2 | 97.1 |
| -250+150 µm | Float | 28.4 | 1.25 | 4.67 | 1.60 |
| | Sink | 71.6 | 27.6 | 14.7 | 98.4 |
| -150+75 µm | Float | 28.9 | 2.67 | 3.39 | 3.0 |
| | Sink | 71.1 | 29.1 | 12.6 | 97.0 |

**Magnetic separation**

The coarser size fractions i.e. -2000+1000 µm, -1000+500 µm, -500+250 µm and -250+150 µm were subjected to dry magnetic separation while the finer fraction -150 µm was processed through wet high-intensity magnetic separator. All the closed-size fractions of manganese ore from the study area were subjected to magnetic separation at different intensities (0.73 T, 1.00 T, and 1.23 T). The chemical analyses of magnetic and non-magnetic products are obtained at 1.00 T, which gives the best separation as given in Table 3. The results reveal that the upgradation of Mn values is uniform throughout the classes except for the –75 fraction, the maximum Mn content of ~42% being at a coarser fraction -2000+1000 µm size fraction. It is observed from the table that on average a product having 39.3 % Mn at ~69 % recovery can be obtained at 1.00 Tesla for all the size fractions.

**Table 3.** Results of dry and wet magnetic separation (-150 µm).

| Size, in µm | Wt. % | Mn % | Fe% | $SiO_2$ | $Al_2O_3$ | Mn % recovery |
|---|---|---|---|---|---|---|
| -1000 | 25.2 | 42.4 | 13.8 | 10.3 | 4.2 | 24 |
| -500 | 7.9 | 40.1 | 11 | 10.2 | 4.5 | 21 |
| -250 | 9.9 | 39.5 | 8.4 | 13.8 | 5.1 | 8.7 |
| -100 | 8.5 | 37.6 | 5.5 | 14 | 6.1 | 10.3 |
| -150 | 4.9 | 36.8 | 10.1 | 13.5 | 7.2 | 5.6 |
| Head | 56.4 | 39.3 | 9.6 | 12.2 | 5.4 | 69.6 |

## Discussion

Mineralogical characterization of low-grade siliceous manganese ores from Larambha-Kanaital area Balangir district, Odisha indicated the presence of two dominating but contrasting mineral phases. Pyrolusite with minor cryptomelane and goethite occur as the chief ore mineral and quartz with little kaolinite as gangue constituent. These two major phases, pyrolusite, and quartz differ significantly in respect of their specific gravities; 4.7 and 2.65 respectively. So conventionally, they should have been separated well by the heavy liquid separation method using bromoform (2.86) as the separating media. But the results of the chemical analysis of the Mn content in the sink product do not show any significant difference. Thus, it can be inferred that the upgradation of low-grade siliceous Mn-ores based on differences in density values is not possible. As an alternative, a magnetic separation technique was employed to find out the possibility of separating these two phases. Manganese minerals are para-magnetic while the siliceous gangue is non-magnetic. So, magnetic Mn-minerals can easily be separated from silica. Keeping this in view, all the coarse-size fractions were subjected to both dry and finer fraction (-150 µm) to wet high-intensity magnetic separation processes at different magnetic intensities (0.73 Tesla, 1.00 Tesla and 1.23 Tesla). The results reveal that better separation is achieved at coarser fraction and the Mn content gradually decreases towards the finer fraction. This observation is in commensurate with the results obtained from the size classification study which shows the concentration of Mn minerals in the coarser fraction. Among the different intensities studied the result at 1.00 Tesla gives the best separation. Thus, a final magnetic product with >39.3% Mn can be obtained with > 69% recovery through continuous dry and wet magnetic separation techniques from a bulk feed of 24.6% Mn and 31% $SiO_2$ with > 69% overall recovery by dry magnetic separation method at 1.00 Tesla magnetic intensity.

## Conclusions

The response of the magnetic separation process to the upgradation of low-grade siliceous manganese ores of the Larambha-Kanaital area, Balangir district, Orissa, India has opened up new vistas for utilising such ores otherwise rejected and dumped at mine sites causing both disposal and environmental hazards. Sincere efforts are required to recover this metal leading to value addition and zero waste mining.

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