भारत सरकार
GOVERNMENT OF INDIA
खान मंत्रालय
MINISTRY OF MINES

Manganese Ore

Vision 2020 and Beyond

सतत कार्यरत
ON WITH THE JOB

भारतीय खान ब्यूरो
INDIAN BUREAU OF MINES

INDIAN BUREAU OF MINES
GOVERNMENT OF INDIA
MINISTRY OF MINES

ORE DRESSING DIVISION
JANUARY, 2014

MANGANESE ORE: VISION-2020 AND BEYOND

ISSUED BY
CONTROLLER GENERAL
INDIAN BUREAU OF MINES
NAGPUR

PREFACE

Manganese ore is the basic source to provide manganese as indispensable input in making of iron & all types of steels. The Ministry of Steel has projected steel production of the country to touch 180 million tonnes by the year 2019-20 amid high growth rate of iron and steel industry. In view of this, the demand for manganese-based alloys requirement is bound to increase.

The reserves of high-grade manganese ore are limited (<10%), and the overall production is very low (around 2.5 million tonnes) and highly inadequate, considering the demand of the manganese-based alloy industry. Needing thereby, a major boost in exploitation activity to enhance overall productivity after revamping the entire mining sectorin the country. Presently, 90% of the country's production is utilised for making of manganese alloy (ferro-manganese & silicomanganese) after blending it with imported medium-high grade ore.

By 2020, the constraints of availability of high-grade manganese ore coupled with the anticipated demand of 8.33 million tonnes of r.o.m. based on metallurgical calculations for steel making would put a tremendous pressure on the consumer sector i.e., manganese alloy industry to provide better and consistent quality products which are not expensive.

Global markets are open to Indian end users with a wide variety of ore choice. The prices may not be very economic but availability and consistent supply are of prime importance which brings solace and consolation to manganese alloy units at present. The prevailing situation may not sustain for its perpetuity.

Taking cognisance of these issues, the Ministry of Mines, Govt. of India, entrusted Indian Bureau of Mines to conduct a re-look on policy orientation on the basis of techno-economical parameters. Born out of such imperatives is this comprehensive book entitled, "Manganese Ore:Vision 2020 & Beyond" that aims at revisiting a whole gamut of interconnected issues that exists and confronts the Indian manganese ore Industry in all its strata from Mines to Metals. This publication endeavours to cover the status of each specific type of industrial units of manganese ore in the country in detail, covering all aspects, viz. manganese ore resources & exploitation, beneficiation & agglomeration and manganese-based alloy making processes. Further, the publication identifies the gap areas in all the concerned units in the Sector i.e., exploitation in particular, so as to devise modus operandi to achieve optimum utilisation of available manganese ore reserves in order to meet the set national goal in steel production.

Centered on a gamut of technical insights, especially on the need for enhancement in manganese ore reserves; value addition/beneficiation of low-grade ores&fines; development of agglomeration activities especially sintering of beneficiated fines; conservation of limited high-grade manganese ore lumps; etc., this book attempts to steer a pathway to the future which could lead the country's manganese ore prospects into a realistic dimension of growth.

It has been our persistent effort over the years to evolve, moderate and implement strategies for development of Mineral & Mines Sector and this publication is one small step in that direction. It is believed that this publication will find interest and acceptance among all those Policymakers, Regulatory Agencies & Consultants who are associated and connected to this discipline of study and are concerned with the development of the country's Mines & Mineral Sector.

Nagpur
January 2014

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Printed at IBM Press, 61/250/August 2014

CONTENTS

Executive Summary

Manganese is an essential constituent of majority of steels. So far there is no technology which can substitute Manganese in steel making. Manganese combines the twin benefits of relatively low price with outstanding technical usage. It imparts numerous beneficial mechanical properties viz., hardness, toughness and workability to steel in addition to improving its strength, making it irreplaceable in steel making. Manganese input is provided in the form of raw ore, manganese-based alloys (ferromanganese or silicomanganese) and in rare cases manganese metal. It acts as a de-sulphuriser in iron making and used in the form of Blast Furnace (BF) grade manganese ore (28-30% Mn), whereas the manganese-based alloys (+65% Mn) are used primarily in steel making as deoxidizer, de-sulphuriser and as an alloying element. Manganese ores form the basic raw materials for manganese-based alloys. In India, about 90% of manganese ore is converted into manganese alloys partly of which is consumed in domestic steel production, while remaining are exported. Manganese requirement for non-metallurgical uses do not represent a quantity large enough to significantly affect the creation of the total demand for Manganese. Therefore, the iron and steel industry is the main consumer of manganese ore in the country.

The production of manganese ore and its alloys are in tandem with that of steel production for the last several years. However, the demand for manganese alloy would grow higher than the demand for steel due to high growth rate of manganese intensive steel like HSLA, 200 S and SS alloy in particular, wherein, manganese is replacing nickel and the consumption is about 110 kg/tonne.

1. The projected target of domestic steel production reflected in the National Steel Policy (NSP 2008) is 180 MTPA by 2020. In view of this, the demand for manganese-based alloys vis-à-vis manganese ore requirement is also bound to increase proportionally.

2. Of the envisaged total steel production, around 60% is expected through Blast Furnace Route i.e., around 110 million tonnes. About 10 kilograms of BF-grade manganese ore (28-30% Mn) is required for per tonne of iron produced in Blast furnace. Thus, the iron making through BF route will require BF-grade manganese ore (25-30% Mn) to the tune of 1.1 million tonnes per year.

3. Whereas, around 15 kilograms of manganese-based alloys (Grade-65-72% Mn) is required for per tonne of steel production. Thus, for the anticipated steel production of 180 MTPA by 2020, the requirement of manganese alloys would be around 2.7 MTPA.

4. The requirement of manganese alloy varies widely depending upon the process of steel making and the product quality envisaged. The consumption pattern of ferro-manganese (high carbon and refined together) and silicomanganese for the above purpose in Indian steel sector would be in the ratio of 2:3, indicating thereby the requirement of ferromanganese as 1.1 million tonnes and that of silicomanganese as 1.6 million tonnes.

5. Due to limited availability of high grade (+44% Mn) manganese ore reserves in the country, BF-grade (30-35% Mn) manganese ore have to be upgraded to produce high grade concentrate for ferromanganese making. However, feed to the silicomanganese making necessitates manganese ore assaying around 35% Mn only. Thus, about 4.2 and 3.7 MTPA manganese ore (30-35% Mn) will be required to produce 1.1 and 1.6 MTPA of ferromanganese and silicomanganese, respectively. Besides, 1.1 MTPA of BF-grade (25-30% Mn) ore is required for iron making (BF) totaling the Manganese ore requirement to 9 MTPA of ROM manganese ore for the Indian iron & steel industry by 2020.

6. India is bestowed with large resource of manganese ore that occurs in different geological formations across the peninsular area. The total resources of manganese ores in the country as per the UNFC system as on 01.04.2010 (NMI) are placed at 430 million tonnes. Out of these, 142 million tonnes are categorized as reserves and balance belongs to resources category. The overall grade of the manganese ore reserve in the country is in the range of 30-35% Mn (NMI 1.4.2010).

7. The total State-wise distribution of the resources in the country indicates that Odisha tops with 44% share followed by Karnataka 22%, Madhya Pradesh 13%, Maharashtra 8%, Andhra Pradesh 4% and Jharkhand & Goa 3% each. Remaining resources occur in Rajasthan, Gujarat and West Bengal.

8. Most of the exploration was carried out at a cut-off of 20% Mn as against the present threshold of 10% Mn. The exploration agencies lay emphasis on establishing the resource of manganese ores to over 25% Mn grade (BF grade) for its use in iron industry. This resulted in reporting/accounting of very meager (around 2%) reserve and resources of low-grade manganese ore (18-25% Mn) in the country. Therefore, after preliminary classification of the various ore types in particular deposit, zones of lower grades were totally overlooked. Low-grade manganese ore deposits are generally found associated with high-grade types. However, in some cases exclusive low-grade manganese ore deposits also come across which were totally ignored during exploration.

9. As on the year 2012-13, the manganese ore production of all grade in India is around 2.5 million tonnes (30-35% Mn). The entire production was from the major producers like MOIL, TATA, OMC, Sandur etc. and their future expansion plan envisaged a total production of around 5 million tonnes as against envisaged requirement of 9 million tonnes (30-35% Mn) by 2020.

Thus, a huge gap will persist in demand and supply position by 2020, which is matter of grave concern, and in the existing situation needs immediate attention to revamp the entire mining activity on a large scale by the companies.

10. With the consumption rate of 9 MTPA of ROM manganese ore, the estimated reserves (142 million tonnes) would last for 10-15 years maximum beyond 2020. Unlike other metals recycling of manganese i.e. extracting manganese from steel scrap is not possible. This has made manganese a consumable commodity in steel making, which is entirely dependent on fresh resources. Hence, necessary steps should be initiated to convert the resources to reserves.

11. With the depleting high-grade manganese ore reserves and revision of threshold value of manganese ores to 10% Mn, it is obligatory on the part of mining industry to exploit low/lean grade manganese ores, which are hitherto considered a waste. The fresh exploration strategy is to be drawn with the cut-off /threshold grade ores as a target.

12. The beneficiation of ROM ore at a cut-off of 10% Mn should aim to explore the possibility of obtaining concentrate in the range of over 35% Mn suitable for silicomanganese production, particularly which would reduce the load on imports and makes the country self-reliant in manganese ore supply.

13. At present, only processed manganese ores are used in industry. However, the manganese ore processing in the country is restricted to meet the physical and chemical standards. Therefore, the entire winning of ROM manganese ore across the country is carried out by selective mining followed by multi-stage crushing, dry screening and manual sorting of the sized fraction. In this process, around 50% by weight of the valuable manganese

is recovered and rests are lost in fines. This practice generates large amount of fines left unused at the mine site.

14. These stacked fines and the category of available low-grade resources falling in between threshold value and saleable grade on account of selective mining past all these years constitute the potential source for producing usable grade manganese concentrate after beneficiation. This will not only utilise existing discard material for recovery of valuable content, but also conserve limited high grade lumpy manganese reserves in the country.

15. Extensive R&D work has been carried out at various laboratories in India and at IBM's Ore Dressing Laboratory in particular on manganese ores of various gangue impurities across the country. The flow-sheets have been developed on almost all types of ore, producing concentrate suitable for sinter making. By and large these flow-sheets may offer a road map for likely process route of beneficiation. By taking advantage of the same, beneficiation work can be commenced by existing operators without any delay and is the need of the hour.

16. The manganese ore mining industry currently is being run in fragmented lease holds and operated by large number of small and medium enterprises. As creation of a beneficiation facility is capital intensive, it is not possible for small to medium-sized entrepreneurs in the non-captive sector to venture for it. However, a large number of small mines located nearby can go for some sort of consortium to have their beneficiation facility erected. This is possible because of similar characteristics of ore. A concept of custom mill for beneficiation needs to be introduced; whereby the fines from small mines in vicinity will be received and after blending, processed in a centralised processing unit, and the concentrate so produced would be sintered or sold to appropriate market of sintering unit. Such consortium will work on certain defined objectives for which they must sign an MOU amongst themselves.

17. The potential areas for such activity would be entire manganese mining belt in the country where a large chunk of mineralized reject has been stacked / dumped all these years.

18. The beneficiated / value added fines need to be agglomerated i.e., sintered in particular before its use. Beneficiation and agglomeration of these materials for manganese alloy making is the call of the day as India has a very high capacity of manganese alloy making facility.

19. Thus, the process of beneficiation followed by agglomeration will not only conserve the limited high-grade lumpy manganese ore, but also make it possible for optimum utilisation of the available valuables from mine/process rejects. This will reduce burden of stacking of tails/rejects for their disposal and resulted control over environmental degradation.

20. Small mine owners may also be encouraged for venturing into beneficiation and business considering its demand. Government of India may consider offering some additional incentives such as cheaper power and water tariff, reducing the royalty to sinter making industry and waiving of import duty on imported technology and equipment for setting up beneficiation and sintering facilities. Small mine owners should have a joint venture for beneficiation cum sintering plant in order to have sufficient feed material and affordable capital investment.

21. Manganese alloy industry will have to play a key role in immediate future in the development of steel sector as per National Steel Policy i.e., Steel industry has to depend a great deal on manganese alloy industry for the supply of ferromanganese and silicomanganese in future. Therefore, thrust should be given to beneficiation and sinter making which will in turn replace use of imported medium-high grade lumpy manganese ore in manganese alloy units in the country.

22. In spite of sizeable manganese ore under reserves category, inadequate production coupled with incomplete processing of exploited material in the country, it is interesting to note that the Indian manganese-based alloy industry at present is producing sufficient quantity of manganese alloys to meet the domestic and export demand. This is because of the fact that in the present scenario Indian manganese alloy industries import substantial quantities of medium and high-grade manganese ore and produce manganese alloy after

blending it with indigenous ores to a limited extent.

23. During the year 2011-12, the manganese ore produced in the country is around 2.35 million tonnes while its consumption is reported to be 4 million tonnes across all industries after necessary import of medium-high grade ore. Indian manganese alloy industry in the year 2011-12 has produced 1.9 million tonnes of manganese alloy using around 1.6 million tonne of imported medium and high grade manganese ore and sweetened with indigenous ores. The industry produced 25% of the manganese alloys in the form of ferromanganese and 75% in the form of silicomanganese, majority of which was exported.

24. The manganese alloy industry is highly fragmented with top seven companies sharing 30% of the production and rest 70% production is contributed by large number of small players. The present installed capacity of manganese alloy in the country is 3.16 million tonnes and is likely to be enhanced by 50% in immediate future. The augmented capacity of the manganese-based alloy plant will be quite high and would fulfill the requirement of envisaged steel production by 2020 apart from catering to the export commitment. The manganese alloy units are concentrated in Andhra Pradesh, Arunachal Pradesh, Chhattisgarh, Jammu, Jharkhand, Kerala, Maharashtra, Meghalaya and West Bengal. These units are basically producing manganese alloys for the purpose of export after meeting the meager domestic needs.

25. Nevertheless the situation of producing manganese alloy based on imported ore cannot go on perpetuity as the availability of high grade manganese ore in the world is limited and there is no guarantee of uninterrupted supply of manganese ore in the context of global scenario coupled with unpredictable exchange rate (Rupee-Dollar conversion). The largest manganese deposits, particularly for high grade ore are with the Kalahari region in South Africa. The production is also restricted because of the weak logistical network in the country. Even the low-grade ores cannot be beneficiated because of weak in land network and scarcity of electricity. Therefore, manganese ore availability will remain a major challenge in long run.

26. The total global resources of manganese ore are in billions of tonnes, including sea beds (nodules). But the proven reserves stand at 540 million tonnes only. Besides, as on date there is no technology available to extract sea bed reserves. Thus, the global ore availability would also be a matter of grave concern in near future. However, total dependence on imported ore for country's need is highly risky and should not be allowed to sustain for long and warrants immediate exploitation of indigenous resources for value addition.

27. High-grade lumpy manganese ore is the basic raw material for ferromanganese production. High manganese content (42 to 46% Mn), high Mn/Fe ratio (5 to 7) and low deleterious phosphorous (< 0.15% P) content are the specifications of manganese ore for ferromanganese production. Limited availability of high-grade manganese ore in the country coupled with the limitations of the domestic manganese ore supplying companies has resulted in sharp rise in the manganese ore prices due to large demand supply gap. In addition, there is global manganese ore grade deterioration with the decrease in manganese content and increase in phosphorous and silica content. All these factors compel us on priority to adopt beneficiation of low-grade manganese ores, mines and process rejects for recovery of high-grade concentrates in the required format.

28. To process the anticipated 4.2 million tonnes of BF-medium-grade (30-35% Mn) ore to generate concentrate for ferromanganese alloys production (1.1 MTPA), the present sporadic beneficiation facilities in the country comprising of dry screening, manual sorting, jigging etc as adopted in most of the mines barring few are highly inadequate. There are no immediate plans of major manganese mining companies to go in for beneficiation in a big way. However, deployment of (i) technologically more effective and high capacity beneficiation schemes in the existing plants; and (ii) setting up of new beneficiation plants have to be given top priority agenda for smooth supply of the raw material for manganese alloy making in the country.

29. Manganese ore characteristics of Indian deposits vary widely. The deposits in Maharashtra, Andhra Pradesh and Madhya Pradesh are mostly siliceous in nature with

medium to high phosphorus content, while deposits in Odisha, Karnataka and Goa are ferruginous in nature with low phosphorus and high alumina content. Geologically, the pattern of mineralization varies drastically from massive and compact ore bodies in Maharashtra and Madhya Pradesh to lean mineralization occurring as lenses and pockets in Odisha.

30. Exhaustive studies on BF-medium-grade manganese ore from different parts of the country at IBM's Ore Dressing lab with varying mineralogical nature and physical characteristics have been conducted and reported over the years. The metallurgical results are also well documented. The weight percent recovery of the concentrate in beneficiating various types of BF-medium-grade manganese ores on an average are around 60% only.

31. Characterisation of manganese ore in Indian context can broadly be classified as siliceous, ferruginous and high phosphorus ore. IBM has carried out beneficiation of manganese ore in respect of all the types of impurity successfully.

32. Siliceous ores contains major gangue of quartz, clay and other silicate minerals. The separation of such minerals can be affected after exploiting physical properties of density or magnetic susceptibility or electrical conductivity at its liberation mesh. The process of gravity concentration (HMS, HMC, Jig, Spiral and Table etc.), Magnetic Separation (DHIMS/WHIMS) and Electrostatic Separation (HTS) are generally deployed.

33. Ferruginous manganese ore resources predominate in Indian context. In such type of ore main gangue is of iron oxide minerals viz., limonite/goethite, hematite etc. As both the manganese and iron minerals have similar physical properties like specific gravity and magnetic susceptibility even after liberation, their separation is in difficult proposition deploying conventional physical beneficiation techniques. Separation of such gangue impurities can only be obtained after conversion of hematite/goethite to magnetite by reduction roasting, which can then be separated by low intensity magnetic separation (1200 gauss) at which the manganese minerals are non-magnetic.

34. High phosphorous manganese ores renders medium and high-grade manganese ore unsuitable for metallurgical use. The phosphorus is mainly contributed by apatite or at times present in the form of solid solution. The latter impurity cannot be reduced by any mineral beneficiation technique and can be used only after suitable blending with low phosphorus ores.

The apatite impurity can be reduced substantially deploying (i) Wet High Intensity Magnetic Separation (WHIMS) rejecting apatite and silicate minerals in non-magnetic fraction; and (ii) flotation of apatite followed by manganese leaving behind silica in the tails.

35. The beneficiation processes deployed on the majority of the Indian manganese ores generate concentrates in the fine size range that cannot be used as such for manganese alloy production without agglomeration. At present, large number of less than 9 MVA manganese-based alloy furnaces use fines with all the great risks of explosion, gas eruption and slag boil. This type of charging fines in the furnace is highly hazardous and must be discouraged and the fines should be used in the form of agglomerates only.

36. Of the three agglomeration techniques available, briquetting is not adopted because of phase change during metallurgical operations. Pelletisation is ruled out because of quantum and cost involved. Thus, sintering is the most appropriate and acceptable technology for manganese ore fines because of its flexibility and strength of the sinters.

37. The sintering units deployed in iron ore industry are too big for manganese industry. An attempt to scale down the sintering unit to suit the large 33 MVA manganese-based alloy Submerged Arc Furnace (SAF) of 500 tpd could not be commercialized because of high specific investment and high cost of production. As against this a few small alloy units, however, use pot sintering on batch scale.

Nevertheless, a new concept of mini sinter plant (MSP) called CAROUSAL has been conceived and established by MINITEC, Brazil and marketed in India. This should well be accepted and adopted by Indian manganese industry as their capacities match well with those of SAF from 9 MVA to 33 MVA.

38. In general, the cost of beneficiation manganese ores followed by sintering of the concentrate so produced compares well with that of lumpy manganese ores of the same grade.

39. Finally, it may be emphasized that, anticipated steel requirement by 2020 has necessitated the whole gamut of activities for manganese ore right from its mining at the threshold value of 10% Mn to value addition/ beneficiation and sintering followed by manganese alloy making.
It can therefore be concluded that the production and consumption pattern of manganese ore can be considered as a yardstick to measure the industrial development of any country based on steel production. As mining fraternity, it is our responsibility to see that the requirement of manganese ore input is comprehensively met in quantity as well as quality.

For a long term business, the manganese ore resources are to be planned at least for a period of fifty years with similar growth rates. As we look into our strength regarding availability of manganese ore reserves, the present level and anticipated manganese ore production by the major mining companies are not at all encouraging for the projected demand of the ore by 2020.

To keep pace with the likely growth of the manganese ore industry by 2020, the supply of quality raw material is the need of hour. Therefore, it is imperative to address timely execution of the following aspects:

(i) Enhancement in exploitation quantum either in the existing mines or opening new mines.

(ii) Preparation of feasibility of mining of several small/low grade deposits/old mine dumps already identified and proved earlier.

(iii) Introduction of total beneficiation by big manganese ore mines for value addition across all sizes of lumps and fines.

(iv) Development and Deployment of common beneficiation facility like custom mill for small and medium size entrepreneurs since individual small mine cannot afford a mechanized beneficiation plant.

(v) Recovery of ferromanganese from the huge quantities of ferromanganese slag accumulated at various ferromanganese plants in the country deploying gravity methods.

(vi) Exploration within existing lease/mine area.

(vii) Conversion of existing manganese ore resources into reserves at the current threshold of 10% Mn, on priority by detailed exploration followed by feasibility with proper state-of-the-art beneficiation facility.

(viii) Exploration in freehold area within known manganese belts.

(ix) Use of advanced and integrated exploration techniques for thoroughly exploring deeper deposits or deposits in complex geological environment, as most of the present exploration efforts are restricted to area near ancient mine workings or near surface deposits by conventional exploration techniques.

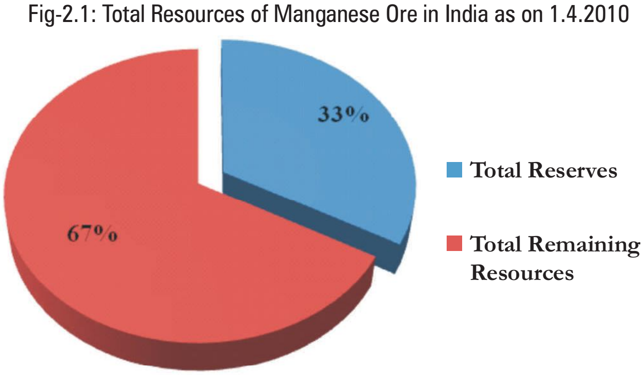
(x) Adoption of state-of-the-art drilling techniques with sophisticated rigs (such as RC) for three-dimensional sub-surface delineation of ore body as well as for directional drilling and underground exploratory drilling.

Indian manganese industry has to go for massive expansion of mining, beneficiation and agglomeration facilities in the country. In the national interest, a statutory regulation should be brought to ensure full utilization of the mined manganese ore to meet the requirement of 9 MTPA of ROM for Indian Iron and Steel industry by 2020.

Indian Mn Ore Resources & Exploitation

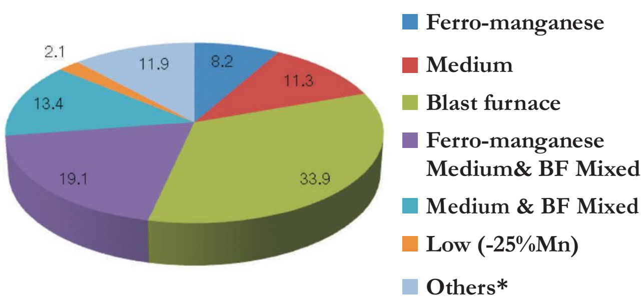
India is comfortably placed with regard to resources of manganese ore. As per UNFC system the total resources of manganese ore as on 1.04.2010 are placed at 430 million tonnes. Of these, 142 million tonnes (33%) are categorized as reserves and the balance 288 million tonnes (67%) are in the remaining resources category (Fig-1)

Fig-2.1: Total Resources of Manganese Ore in India as on 1.4.2010



These manganese resources are of assorted grade and accounts for ferromanganese grade (>44%Mn) 8%, medium grade (>35<44%Mn) 11%, BF grade (>25<35%Mn) 34% and the remaining 47% are of mixed, low (<25%Mn), others, unclassified, and not-known grades, including 0.35 million tonnes of battery/chemical grade. The broad grade-wise total manganese resources, are presented in Fig-2.

Fig-2.2: Grade-wise Resources of Manganese Ore as on 1.4.2010



The 'reserves' of manganese ore have been placed under proved (111) and probable (121) & (122) categories. The grade-wise manganese reserve as per NMI (1.4.2010) is presented in Fig.-3.

The 'remaining resources' of 288 million tonnes have been placed under feasibility (211), pre-feasibility (221) & (222), measured (331), indicated (332), inferred (333) and reconnaissance (334) categories. A sizeable quantity of the total resources of manganese ore constituting about 156 million tonnes (36%) has been estimated under inferred (333) and reconnaissance (334) categories. The present grade-wise total remaining resources of manganese as per NMI (1.4.2010) is presented in Fig.-4.

Fig-2.3: Grade-wise Reserves of Manganese Ore as on 1.4.2010

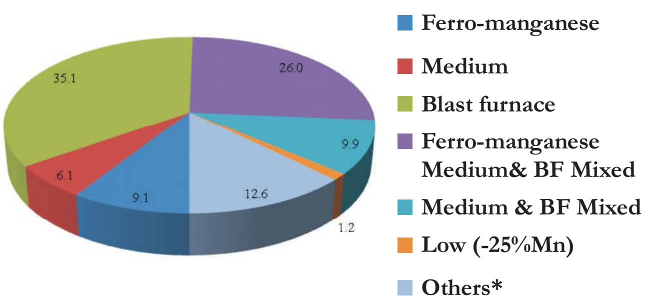
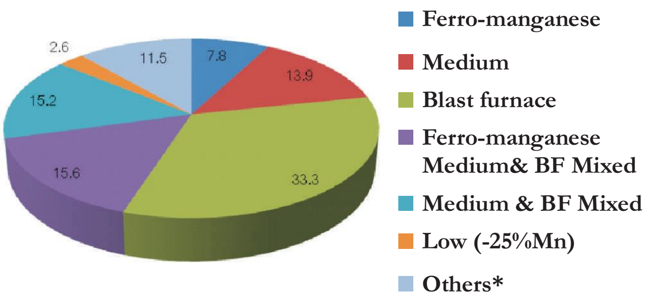
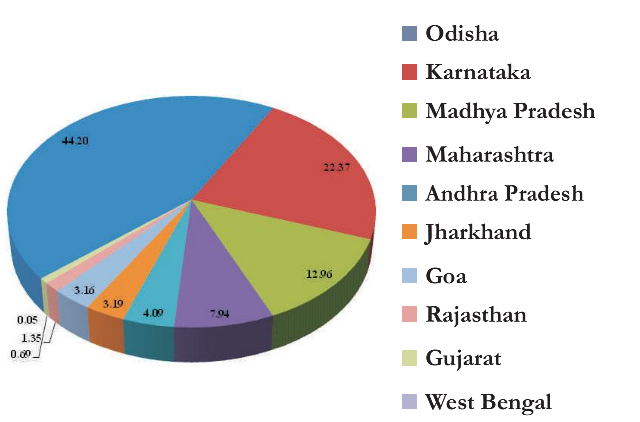


Fig-2.4: Grade-wise Total Remaining Resources of Manganese Ore as on 1.4.2010



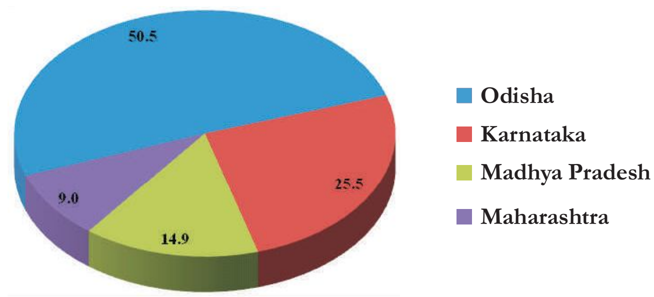
State-wise, Odisha tops the total resources with 44% share followed by Karnataka 22%, Madhya Pradesh 13%, Maharashtra 8%, Andhra Pradesh 4% and Jharkhand & Goa 3% each. Rajasthan, Gujarat and West Bengal together shared the remaining about 3% resources. The state-wise total resources of manganese ore as per NMI as on 1.4.2010 are presented in Fig.-5.

Fig-2.5: State-wise Resources of Manganese Ore Resources as on 1.4.2010



Manganese reserves are confined in the states of Odisha, Karnataka, Madhya Pradesh and Maharashtra.The state-wise total reserves of manganese ore as per NMI as on 1.4.2010 are presented in Fig. -6.

Fig-2.6: State-wise Reserves of Manganese Ore Reserves as on 1.4.2010



2.1 GENERAL GEOLOGY

Manganese ore in India occurs in diverse geological environment and geographic locations and is formed by a number of geological processes like hydrothermal, sedimentary and surficial.

Sedimentary deposits are the most abundant types. In this type both metamorphosed and un-metamorphosed sedimentary deposits are in place. The host rocks for un-metamorphosed sedimentary deposits are shale, sandstone, conglomerates, tuff, basalt, ortho-quartzite-clay association, limestone-jasper association and limestone-dolomite association. The variation in mineralogy in un-metamorphosed suit dominates rhodochrosite, pyrolusite, cryptomelane and psilomelane, etc. In metamorphosed sedimentary deposits, it occurs in regionally metamorphosed manganiferous sediments with association of sericite schist, pelitic rock/volcanic rock, quartzite, marble, BHQ, slates, dolomites etc. The variation in mineralogy in metamorphosed suit dominates braunite, bixybite-hollandite-hausmanite-jacobsite.

2.1.1 Genesis of Manganese-ore in India

In India the highest concentration of manganese is found in the Dharwar system of rocks. The richly manganiferous faces of this system contain enormous ag¬gregates of manganese ores such as psilomelane, braunite, pyrolusite, hollandite, etc.

Based on geological relations, the mode of origin and genesis, the manganese ore deposit of India has been classified in to the following four major groups:

2.1.1.1 Syngenetic gonditic deposits (spessartite -

rhodonite -quartz): These mainly belong to the syngenetic type of ore bodies, i.e. those which were formed contemporaneously with the enclosing rock. Manganese deposits are connected with the elastic sediments of the Gondite rocks. Ore with Archean rocks and condition occur in Dharwar rocks either as consolidated beds of chemically deposited manganese oxide or associated with the 'gondite' of highly metamorphosed Sausar series of rocks in Balaghat, Chhindwara, Jabalpur, and Jhabua districts of Madhya Pradesh, Bhandara and Nagpur districts of Maharashtra and its extensions and equivalents in Panchamahal, Sabarkhantha and Banaskantha districts of Gujarat and Banswara and Sawai Madhopur districts of Rajasthan.

2.1.1.2 Syngenetic reef deposits: These too belong to the syngenetic type of ore bodies. Manganese deposits are connected with the intrusive rock, Kodurite (a basic plutonic rock); Ores of hybrid origin associated with highly metamorphosed Kodurite suite of rocks (orthoclase-feldspar-garnet/spessartite-apatite in varying proportions) in Visakhapatnam, Srikakulam, Adilabad & Hyderabad districts of Andhra Pradesh and Koraput & Bolangir districts of Odisha.

2.1.1.3 Replacement deposits: These belong to the epigenetic class of ores, i.e., those formed by a process of concentration at a later date. Lateritoid ores, occurring in places on the outcrop of the Precambrian rocks formed by the surface replacement of the constituents of these rocks by percolating waters, sometimes with subsequent segregation. Such deposits occur in Iron ore series in Jamda-Koira valley of Singhbhum and Odisha and Dharwars in Karnataka and Goa. Deposits of Keonjharand Sundargarh districts of Odisha, North Canara, Bellary, Hospet, Tumkur, Chitradurga and Ratnagiri districts and those of Goa belong to this group.

2.1.1.4 Laterite deposits and supergene enrichments: These too belong to the epigenetic class of ores associated with all the above deposits. Manganese deposits are connected with the lateritic deposits due to metasomatic surface replacement of Dharwar slates and schist's.

Psilomelane(MnO_2 + MnO + BaO + K_3O + H_2O) and braunite (Mn_2O_3 + SiO_2) ores account for over 90 per cent of the total reserves of manganese in the country, while Pyrolusite (MnO_2) and cryptomelane ($KMn_8O_{16}Mn$) are other important ores.

Manganese ores are termed differently depending upon the percentage of manganese content. Ores with 40 to 60 per cent of manganese are classed as manganese ore; with 10 to 30 per cent of iron and 10 to 40 per cent of manganese as ferruginous manganese; with iron 40 per cent and manganese from 5 to 10 per cent as manganiferous iron; and iron more than 50 per cent but manganese less than 5 per cent as iron ore.

2.1.2 Mineralogy

There are over 100 minerals known to contain manganese. The most important manganese ore minerals identified are psilomelane (massive hard manganese oxides), hausmannite (Mn_2+Mn_{23}+O_4), pyrolusite (Mn_4+O_2), wad (soft, massive manganese oxides) and braunite (Mn_2+Mn_{63}+SiO_{12}). Other minerals such as manganite (Mn_3+O (OH)), bementite (Mn_{82}+$Si_6O_{15}(OH)_{10}$), and rhodochrosite (Mn_2+CO_3) have also been noted.

Manganese ores occur in almost all rocks such as granite, limestone and clay. The minerals containing manganese in commercially important quantity include the oxides (hydrous and anhydrous), the manganates, the carbonates and the silicates, other sources of the metal being manganiferous iron ores, manganiferous zinc ores, and manganiferous silver ores. Of the true manganese ores, the most important for metallurgical purposes are the oxides. The silicate and carbonate are comparatively unimportant.

The important manganese minerals, its composition, specific gravity, hardness and manganese content are presented in Table-1.

Pyrolusite (MnO2): This peroxide, otherwise known as "black manganese," crystallizes in the orthorhombic system, but the common form is a pseudo morph after manganite. The ore usually occurs massive or reniform,

Table-2.1: Common Manganese Minerals & its properties

Mineral	Color	Specific Gravity	Hardness (Mohs' Scale)	Composition	Mn Content
Pyrolusite	Black	4.8 – 5.6	2.0 – 2.5	MnO_2	63.2%
Manganite	Steel-gray	4.2 – 4.4	3-4	$Mn_2O_3.3H_2O$	60.4%
Braunite	Brownishblack	4.7 – 4.9	6 – 6.5	$Mn_2O_3 + SiO_2$	69.6%
Psillomelane	Steel-gray	3.7 -4.7	5-6	$MnO_2 + MnO + BaO + K_3O+$ ^H_2O	45-60%
Rhodochrosite	Pink	3.3 – 3.6	3.5 – 4.5	$MnCO_3$	47.8%
Rhodonite	Pink	3.5 – 3.7	5.5-6.5	$MnO\text{-}SiO_2$	41.9%
Hausmannite	Brownish black	4.7 – 4.8	5 – 5.5	Mn_3O_4	72.0%
Manganese glance		3.9 - 4.1	3.5 - 4	MnS	63.2%
Wad **or** "bog manganese"		3.0 - 4.3	1-6	Impure earthy mixture of hydrous manganese oxide	5.5%

sometimes with a fibrous and radiate structure. It is often impure, containing iron, silica, lime, barite, etc., with in many cases a little water. It is very soft, soiling the fingers. The mineral varies in colour from black to steel-grey and bluish-grey, and has a black streak. The hard and coarsely crystalline variety termed as 'Polianite' occurs in groups of needle-like crystals. It is steel grey or iron-grey in colour with metallic lusture. It is very brittle and has hardness between 6-6.5.

Psilomelane $Ba,Mn,Mn_8O_{16}(OH)_4$: This is a hydrous oxide of manganese, with or without varying amounts of barites and potash. Depending on the quantity of admixture its manganese content varies within broad limits of 45-60% Mn. It is amorphous, the common form being rounded or botryoidal masses, usually with a smooth surface. It also occurs reniform and stalactitic. Its colour is iron-black, passing into dark -steel-grey and sometimes, as in India, to an almost bluish-grey. Its streak is often brownish-black, owing to a proportion of the lower oxide being present, and shining; but in India, it is black. At times, the variety of this hydrated oxide containing some potash or soda is termed 'cryptomelane' (KMn8O16Mn). Psilomelane is the most abundant of all the manganese ores found in India.

Manganite $Mn_2O_3.H_2O$: This is a hydrous sesquioxide of manganese, otherwise known as "grey manganese ore". It is generally brittle and occurs in prismatic crystals or in columnar or fibrous masses, having uneven fractures. It crystallizes in the orthorhombic system, the crystals being often of many times greater length than breadth, assuming a needle-like form. Its colour is steel-grey to iron-black, with sub-metallic lusture, and its streak reddish-brown to nearly black. When pure, it contains 10-23% of water. On being exposed to oxidation, it turns into sooty pyrolusite.

Hausmannite Mn_3O_4: This is a mineral, very low in oxygen, crystallizing in tetragonal prisms, frequently twinned, and also occurring massive and granular. Its colour is brownish-black; streak chestnut-brown. In the oxidized zone, it decomposes turning into pyrolusite and psilomelane. It generally occurs in association with braunite. In the oxidized zone, it decomposes more rapidly than braunite, turning into pyrolusite and psilomelane.

Braunite ($3Mn_2O_3.MnSiO_3$): This is an anhydrous sesquioxide of manganese, invariably associated with silica, whether mechanically mixed or chemically combined, the proportion of silica being some-times as high as 8 or 10 percent. It crystallizes in the tetragonal system, occurring in pyramids resembling regular octahedra, and also occurs massive. It occurs as impregnations and massive bodies and characterized by black to brownish black colour streak. In the oxidized zone, it decomposes into pyrolusite and psilomelane.

Rhodochrosite or Dialogite $MnCO_3$: This is a carbonate of manganese, often with carbonates of iron, calcium and magnesium in varying quantities. Rhombohedral crystals occur rarely, the mineral being more commonly found massive, globular, botryoidal, or encrusting. It is brittle having uneven to conchoidal fracture. Its colour is white, pink, brownish, or yellowish-grey, with a rather pearly lusture; streak white. Effervescencing in acid serves as a characteristic feature of this mineral. It contains about 47.8% Mn when pure but the metal content can considerably enriched by roasting. It must be roasted forremoval of carbon dioxide before being charged into smelting furnaces; this leaves an oxidized product considerably higher in metallic manganese.

Rhodonite $MnSiO_3$: This is a pyroxene belonging to the triclinic system. It occurs either in crystals or massive, or as imbedded grains. The manganese may be in part replaced by iron, calcium, or zinc, and compact forms of the mineral sometimes contain an admixture of manganese carbonate. It is flesh-red, light brownish-red, greenish or yellowish (when impure), and often black on exposed surfaces owing to oxidation. It is one of the less important ores. Though, it is relatively common, it is not regarded as an ore of manganese.

Wad, or " bog manganese' (Hydrous Manganese Oxide): In general, this cannot be considered as a true manganese-ore. It is a mixture of oxides of manganese (MnO2 and MnO), with oxides of cobalt and copper, and sometimes of silver, giving certain varieties a special value. Iron is also present, and the ore contains from 10 to 20 per cent, of water. It results from the decomposition of other manganese minerals, and occurs generally in damp, low-lying places. It is amorphous, earthy, soft and friable, and resembles psilomelane except as regards hardness. It is not so valuable as pyrolusite or psilomelane, but is sometimes used in the manufacture of chlorine and of the pigment umber, and possesses value when used as a flux.

Apart from these important ores/minerals of manganese, there are several other minerals of manganese. They are:Albandite [MnS], Bixybite [$(Mn.Fe)_2O_3$], Coronadite [$PbMn_8O_{16}Mn$], Cryptomelane [$KMn_8O_{16}Mn$], Franklinite $(FeZnMn)O.(FeMn)_2O_3$, Jacobsite [$MnFe_2O_4$], Polianite [MnO_2], Vredenburgite [$3Mn_3O_4.{}_2H_2O$] etc.

2.2 MANGANESE ORE GRADE CLASSIFICATION (USES)

Classification of manganese ores is primarily based on the manganese content, besides, the tolerance limits for the various deleterious constituents.

2.2.1 The Bureau of Indian Standards (BIS) has classified the manganese ores as per IS: 11895 (reaffirmed in 2006) depending on Mn, Fe, SiO_2 and MnO_2 contents of the ores.

2.2.2 End use classification of resources: Specifications of manganese ore for different consuming industries vary considerably from dioxide to low grade ore. Manganese specifications primarily take into account the maximum or minimum limits for manganese, phosphorus, Mn/Fe ratio, silica, alumina and permissible limits for fines. End Use Grade Classification of Manganese Ore as per Expert Group Recommendation is as below:

1) Battery/Chemical grade MnO_2-72% (min.), Cu, Pb, Cr & Ni in traces.
2) Blast furnace (BF) Mn-25-35% P-0.2% (max), Al_2O_3 -7.5% (max), SiO_2-13% (max).
3) Ferromanganese Mn -38% (min), P – 0.2% (max), Mn: Fe – 2.5:1 (min.), 7.1 (max).
4) Medium grade Mn–35-37%.
5) Low grade Mn +18-25%.

The steel plants generally consume manganese ore with 25

Table-2.2:Classification of Manganese Ore (IS: 11895-2006)

Type of Ore	Constituents (%)				
	Mn	Fe	SiO_2	MnO_2	Fe+Mn
Manganese ore	35 & above	-	-	-	-
Ferruginous Manganese ore	< 35 & Up to 25	< 23 & Up to 13	-	-	48 (min.)
Siliceous Manganese ore	< 30 & Up to 25	-	15 (min.)	-	-
Manganiferous iron ore	< 25 & Up to 10	< 48 & Up to 30	-	-	55 (min)
Manganese ore (chemical grade)	-	5 (max)	-	>78	-

Source: Bureau of Indian Standards, (BIS)

Table-2.3: Specifications of Manganese Ore for the Production of Ferromanganese (IS: 4763-2006)

Sl No.	Grade (Mn %)	Constituents (%)				
		Fe (max)	SiO_2 (max)	Al_2O_3 (max)	SiO_2+ Al_2O_3 (max)	Mn/Fe Ratio (min)
1.	48 and over	7	7.5	2	8	7
2.	Below 48 upto 46	8	9	3	10	6
3.	Below 46 upto 44	10	10	3.5	10	4.5
4.	Below 44 upto 42	11	11	4	12	3.5
5.	Below 42 upto 40	13	12	5	13	3
6.	Below 40 upto 38	15	13	6	15	2.5

to 30% Mn, 5.0 to 15% SiO_2, 5 to 8% Al_2O_3, 14 to 26% Fe and 0.074 to 0.34% P. As per IS specifications (IS: 11281-2005), manganese ore for use in blast furnace should contain a minimum of 25% Mn and a maximum of 0.35%, P which fairly conform to the user industry specifications.

The physical requirements for Blast Furnace grade ore stipulate that it should be lumpy, hard, dense and no friable material with the size range of 25 to 85 mm, (+ 85 mm: 10% max.) and minus 10 mm: 10% (max).

2.3 DISTRIBUTION OF MANGANESE ORE IN INDIA

Indian manganese ore occurs throughout the peninsular region, in well-defined belts/zones located in Madhya Pradesh, Maharashtra, Odisha, Karnataka, Andhra Pradesh, Goa, Gujarat, Rajasthan etc. Some manganese occurrences are also in Bihar and Jharkhand, mostly associated with iron ore. Approximately, 5500 sq. km area is the potential geological environment of which 211 sq. km are under lease hold.

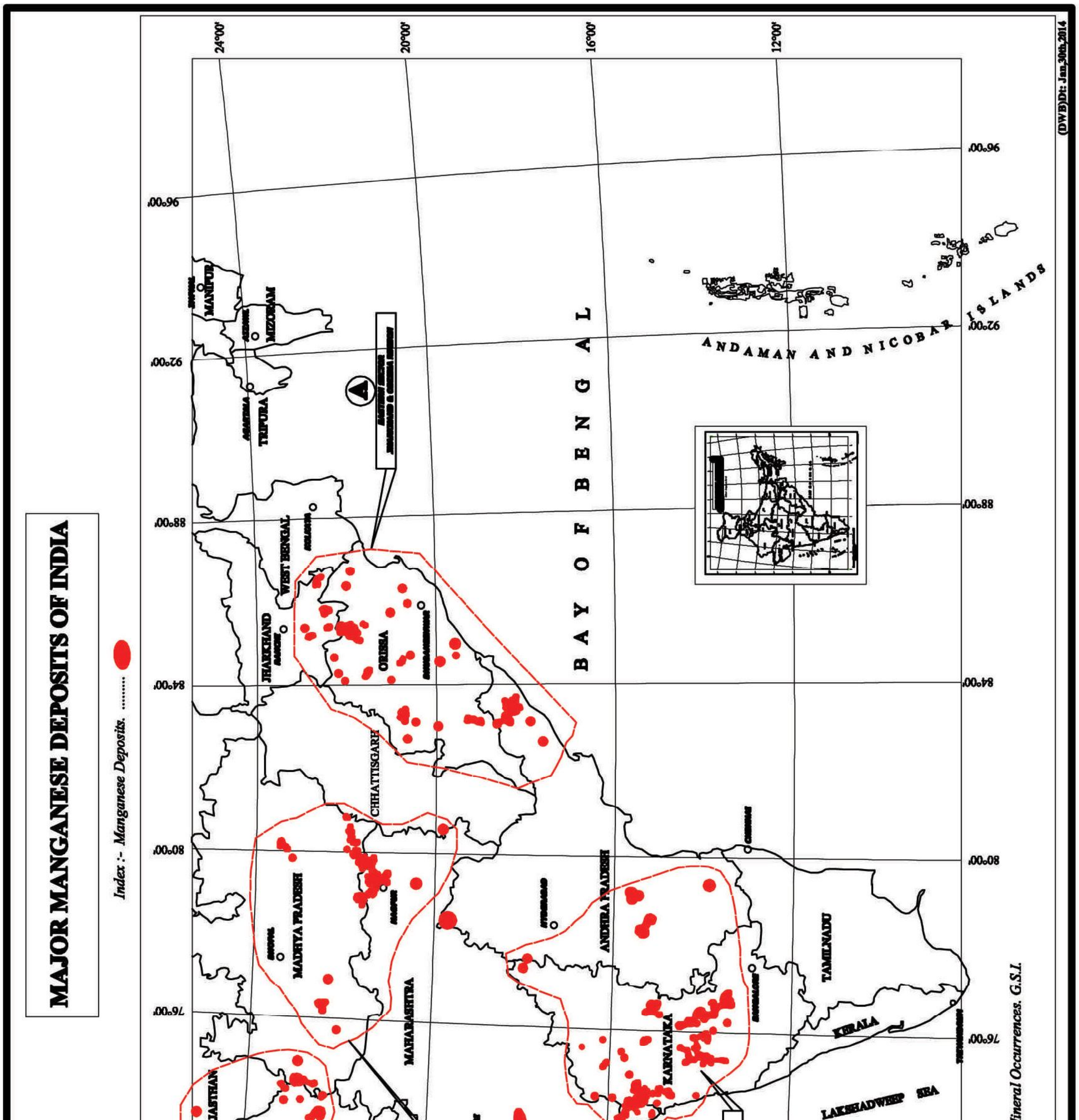
The various deposits based on their mode of occurrence and origin can be broadly classified into two groups: (1) The bedded and conformable deposits in the Pre-Cambrian meta-sedimentary rocks formed by metamorphic reconstitution of manganiferrous strata to primary oxide ores and silicates and (2) Surficial and supergene deposits derived by the concentration of manganese during the weathering of manganiferrous rocks or deposits.

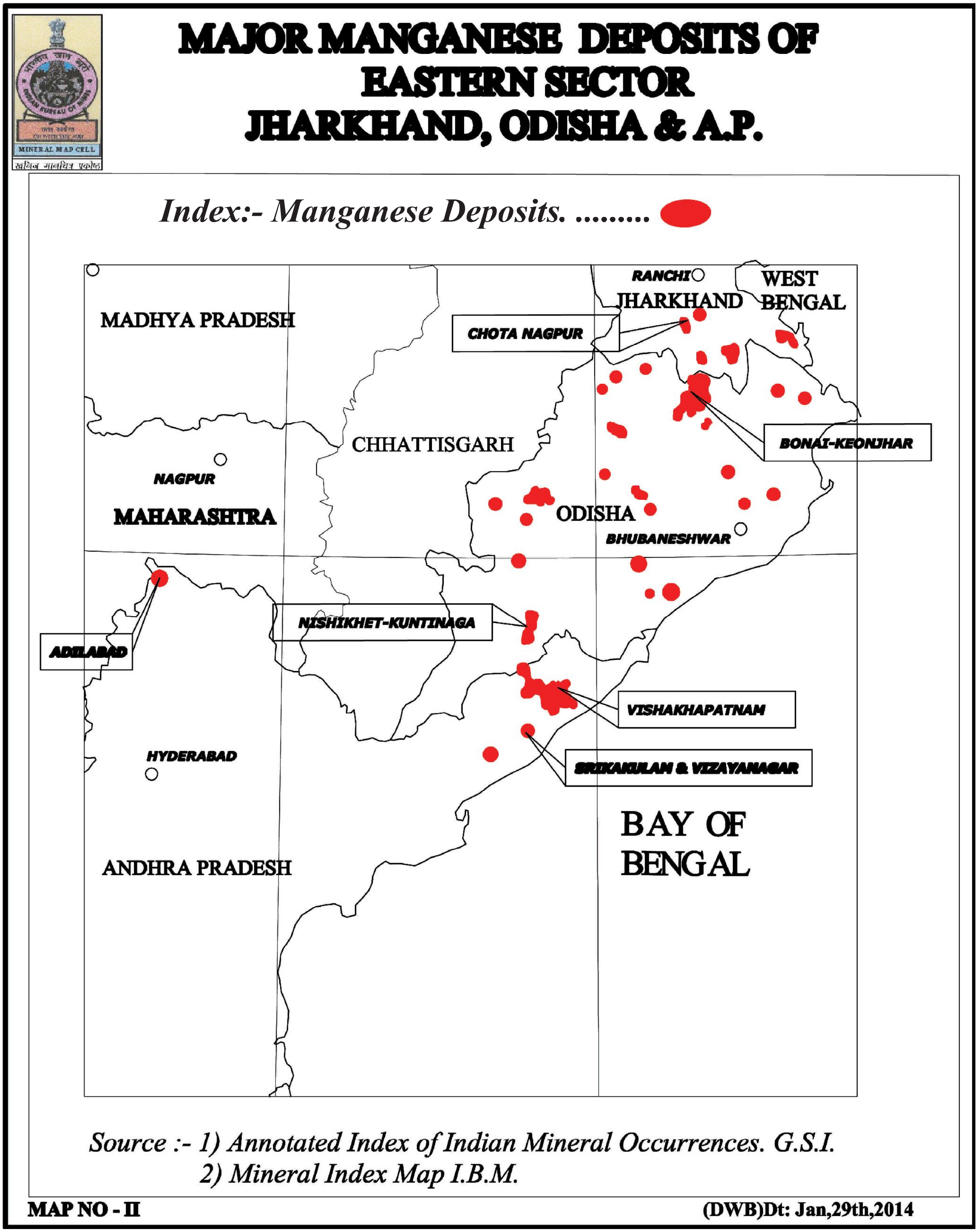
In India, major economic deposits of manganese ore occurrence, geographical location-wise can broadly be categorized to following four sectors: (A) Eastern Sector covering State of Jharkhand and Odisha; (B) Central Sector covering State of Madhya Pradesh and Maharashtra; (C) Western Sector covering State of Rajasthan and Gujarat; and (D) Southern Sector covering State of Goa, Karnataka and Andhra Pradesh. The Sector wise manganese ore belts/blocks, their geological set-up and ore characteristics are discussed herewith. Geographical location-wise as well as individual sector-wise occurrence of manganese ore in the country is presented in Map-I-V.

2.3.1 Eastern Sector (Jharkhand & Odisha)

In Odisha and Jharkhand, the manganese ore deposits have been mainly derived from secondary enrichment of the original manganiferrous shales and phyllites associated with the banded iron ore formations (BIF) of the Pre-Cambrian and Khondalite group of rocks. The ores of this region are characterized by low phosphorous and high iron contents. They also occur as lateroid capping's.

2.3.1.1 Manganese Ores of Jharkhand: Lateritoid deposits of manganese ore of small size consisting of psilomelane and pyrolusite occur in several parts of southern Chota Nagpur, particularly near Chaibasa in south Singhbhum district. Mode of occurrences of the deposits is in Kolhans overlying the iron ore series. South of Chaibasa, close to the iron ore deposits of Noamundi and Gua and west of Jamda, occur lenticular and irregular deposits of manganese ore. These deposits from the northern fringe of the Bonai-Keonjhar belt. There exists about 13.7 million tonnes of total Resources of manganese ore accounting to about 3.2% of the country's share (NMI 01.04.2010).


MAJOR MANGANESE DEPOSITS OF INDIA
Index :- Manganese Deposits. ....
BAY OF BENGAL
ARABIAN SEA
LAKSHADWEEP SEA
ANDAMAN AND NICOBAR ISLANDS
RAJASTHAN
GUJARAT
MADHYA PRADESH
MAHARASHTRA
CHHATTISGARH
JHARKHAND
WEST BENGAL
ORISSA
ANDHRA PRADESH
KARNATAKA
KERALA
TAMILNADU
TRIPURA
MIZORAM
MANIPUR
CENTRAL SECTOR MP & MAHARASHTRA REGION
Source :- 1) Annotated Index of Indian Mineral Occurrences. G.S.I.
2) Mineral Index Map I.B.M.
MAP NO-1
(DWB)Dt: Jan.30th,2014


MAJOR MANGANESE DEPOSITS OF EASTERN SECTOR JHARKHAND, ODISHA & A.P.
MINERAL MAP CELL
Index:- Manganese Deposits. ....
RANCHI
JHARKHAND
WEST BENGAL
MADHYA PRADESH
CHOTA NAGPUR
CHHATTISGARH
BONAI-KEONJHAR
NAGPUR
MAHARASHTRA
ODISHA
BHUBANESHWAR
NISHIKHET-KUNTINAGA
ADILABAD
VISHAKHAPATNAM
HYDERABAD
SRIKAKULAM & VIZAYANAGAR
BAY OF BENGAL
ANDHRA PRADESH
Source :- 1) Annotated Index of Indian Mineral Occurrences. G.S.I.
2) Mineral Index Map I.B.M.
MAP NO - II
(DWB)Dt: Jan,29th,2014

2.3.1.2 Manganese Ores of Odisha: Odisha is the largest producers of manganese ores in India and stands second to Karnataka in its reserve estimate. However, its major share comes from Bonai-Keonjhar manganese belt of North Odisha. Bonai-Keonjhar belt of North Odisha contributes 80% of the production of manganese ore of the State whose share comes to 36% of the country's total production. This belt is one of the most important manganese ore producing regions of India because of its low phosphorus content in the ore. Other manganese belts of Odisha are Nishikhal-Kutinga of south Odisha and gonditic deposits of Gangpur belt.

The state of Odisha has been endowed with the largest share of total resources of manganese ore in the country at 190 million tonnes accounting to about 44.2% of the country's share (NMI 01.04.2010). These resources have mainly been distributed in three districts, namely Keonjhar (129 million tonnes), Sundergarh (58 million tonnes) and Bolangir (2 million tonnes).

2.3.2 Central Sector (Madhya Pradesh & Maharashtra)

The manganese ore deposits of Madhya Pradesh-Maharashtra belt are bedded type and stretches over about 200 km length from Balaghat district, M.P. in the east to Nagpur district, Maharashtra in the west with a width of 25 km at its central part. The Precambrian Sausar Group meta-sediments host the manganese ore horizons. The manganese ore deposits occur in the lower part of Sausar sequence at three horizons, viz., (i) at the contact of Mansar Formation and overlying Chorbaoli Formation (Horizon -1), (ii) within Mansar Formation (Horizon - II) and (iii) at the contact of Mansar Formation and the underlying Lohangi/Sitasaongi Formation (Horizon - III). This belt accounts for about 35 million tonnes of manganese ore reserve. The main ore minerals are pyrolusite, psilomelane and braunite with subordinate amount of hollandite, cryptomelane, rhodonite, spessartite and jacobsite. Over fifty percent of the manganese ore deposits of Madhya Pradesh-Maharashtra are of high grade.

Madhya Pradesh-Maharashtra Manganese belt is derived partly from primary braunite deposits and partly from associated Gondite formations. The manganese deposits of Madhya Pradesh like Balaghat and Ukwa deposits occur in Sauser series (Precambrian) and produce high manganese, low phosphorous ore having an excellent Mn/Fe ratio. All other deposits contain more or less high manganese and high phosphorous. Dongri Buzurg is the largest known supergene oxidized deposit in Madhya Pradesh-Maharashtra manganese belt. This is the only deposit which yields manganese dioxide ores.

2.3.2.1 Manganese Ores of Madhya Pradesh (MP-Maharashtra Manganese Belt): Madhya Pradesh is India's foremost source of manganese ore with reserve of 55.7 million tonnes accounting for about 13% of the country (NMI 01.04.2010). These resources are mainly in Balaghat (40 million tonnes) and Jabalpur district (11 million tonnes). The deposits are mostly located in Balaghat and Chhindwara districts constituting the bulk of deposit available in the state. The geological environment comprises Precambrian meta-sediments of the Sausar Group represented mainly by Mansar and Sitasaongi Formations. These deposits are associated with the Archean rocks, included in the Gondites. Three types of deposits are found viz., the primary bedded type, the supergene lode type and the boulder types.

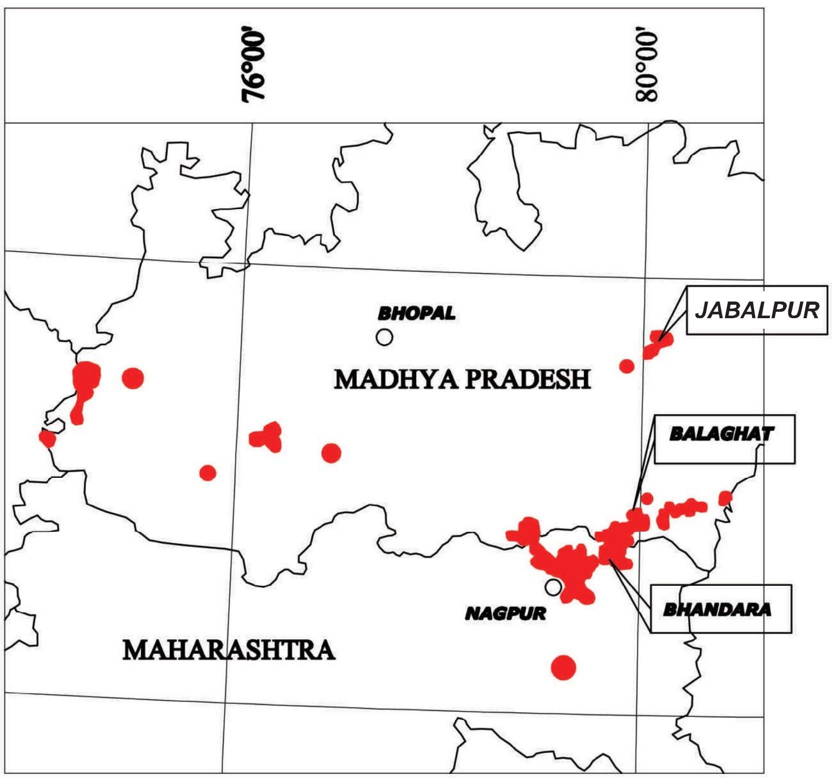
In Balaghat district, conformable bedded deposits and lensoid bodies of manganese ores as well as their residual weathering products are found in intensely deformed metasedimentary rocks belonging to the Mansar formation (which includes the Gonditic rocks), belonging to the Precambrian Sausar series. Braunite is the important mineral. Other manganese ores noticed include cryptomelane, pyrolusite type oxides, hollandite and jacobsite. The most important deposits in Balaghat district include Ukwa, Tirodi, Bharweli, Ramrama, Sithapathor-SukriLangar etc.

The bulk of reserves of manganese ore found in Balaghat belt are of blast furnace grade and the reserve of Ferromanganese ore is very limited.

The Bharweli deposit is located at the eastern end of the Balaghat plain and near the foot of the Baihar plateau. It is one of the biggest manganese ore deposits in India. The

MAJOR MANGANESE DEPOSITS OF CENTRAL SECTOR MADHYA PRADESH & MAHARASHTRA

Index :- Manganese Deposits. ....



Source :- 1) Annotated Index of Indian Mineral Occurrences. G.S.I.
2) Mineral Index Map I.B.M.

MAP NO-III **(DWB)Dt: Jan,29the,2014**

principal ore is compact massive psilomelane with some hollandite but in southern portion of the ore band a small percentage of braunite is also found along with psilomelane.
The Ukwa manganese ore deposit is located near Ukwa village on the Baihar plateau. Both psilomelane and braunite are found. Some amount of pyrolusite is also noticed especially in the northern portion of the mine.

In Tirodi group of mines the manganese ore horizon belongs to the Lohangi zone at the contact between Tirodibiotite gneiss and Mansarmuscovite schist. The rocks are immensely folded and faulted. The manganese ore deposits are represented by metasedimentary beds of braunite-quratzite and gondite forming "Reef deposits" as well as 'boulder ore' or detrital deposit derived from the above primary deposits. The bedded deposits occur as conformable tabular bodies as well as lenses and bands ranging in thickness from a thin lamena to seven metres. The ore bands are of variable length and thickness. The ore consists of primary braunite with subordinate amounts of psilomelane-cryptomelane type oxides, pyrolusite and other minerals. The Tirodi group comprises the principal reef deposits at Tirodi, Jamrapani, Pawnia and Chikmara. Of these, the south Tirodi includes the largest and richest mine in the area.

In the Chhindwara deposits, the manganese deposits cover an area of 297 sq. km in a portion of the Kanhan valley. The ores are associated with manganese silicate rocks (Gondites and rhodonite bearing rocks) which form lenticular bands intercalated along the strike of a complex series of metamorphic rocks traversed by granites and pegmatites.

In Jabalpur distrcit, manganese ores are associated with quartzites traversing the phyllites and dolomitic limestones of Aravalli system. The chief ore minerals are braunite with some psilomelane, pyrolusite and hollandite. The major occurrences are at Kajlidogri, Tumdia, Mandli and Rampura. In Bilaspur district, low grade manganese ore comprising pyrolusite, psilomelane, manganite and wad occur between Ratanur and Kori.

In Jhabua district, manganese ores are associated with quartzites traversing the phyllites and dolomitic limestones of Aravalli system. The chief ore minerals are braunite with some psilomelane, pyrolusite and hollandite. The major occurrences are at Tumdia, Mandli and Rampura.

2.3.2.2 Manganese Ores of Maharashtra (M.P.-Maharashtra Manganese Belt): Manganese ore deposits of Maharashtra are a part of the famous manganese ore producing Nagpur-Bhandara-Balaghat region of India. The area comprises meta-sediments of the Sausar Group of Precambrian age.

There exists about 34.1 million tonnes of total Resources of manganese ore accounting to about 7.9% of the country's share (NMI 01.04.2010). The resources estimated in Bhandara (16 million tonnes) and Nagpur (18 million tonnes) districts.

The manganese ores are present in three different rock formations: (i) those associated with laterite, called lateroid type in Satara district, (ii) those present in Kamthi rocks occurring in Yavatmal district, and (iii) those associated with Precambrian metasediments occurring in Nagpur (Taluka: Saoner, Parseoni, Ramtek) Bhandara (Taluka: Tumsar) and Yavatmal (Taluka: Pandharkawada) districts.

The first two do not form sizable or economic ore deposits. The last category is important as it includes good number of economically viable deposits with considerable quantities of high grade ore. The deposits in this category are associated with gonditerock.
Ore bodies are predominantly composed of a mixture of braunite, pyrolusite, cryptomelane and psilomelane. They occur as reefs or lenticular pockets parallel to the strike of enclosing rocks which may be gondite, manganiferous quartzite or mica schist. The ore bodies are enclosed at three horizons – top, middle and bottom of the Mansar Formation of the Sausar Group. Out of these, the horizon at the bottom of Mansar Formation and top of the Lohangi Formation are the most important as here are present the largest and the best ore body. The manganese ore deposits of Maharashtra are metamorphosed sedimentary deposits.

In Bhandara district, the ore minerals present and the mode of occurrence of the manganese ores are similar to those in the adjoining Balaghat district in Madhya Pradesh. In fact, Bhandara deposits can be locked upon as the southern extension of Balaghat ones.

Less important occurrences are also reported from Ratangiri district which are associated with lateritised Dharwarian metasediments. The deposit of Ratangiri district is more ferruginous and cannot be utilized without beneficiation.

2.3.3 Western Sector (Rajasthan, Gujarat)

2.3.3.1 Manganese Ores of Rajasthan: District: Banswara, in villages: Kalakhunta, Sevania, Utala and Tambesara, Sagan-Lankai area and Podwal-Gosikhonta area. Although manganese ore deposits located in Banswara district occur within Phyillites, quartzites and limestones belonging to Aravalli system, deposits/occurrences are also present in Udaipur and Sawai Madhopur districts.

The ore deposits and their association can be clearly compared to the gonditic ores of Madhya Pradesh and Maharashtra region. Ores consist mainly of braunite, pyrolusite and psilomelane. The deposits extend in a NW-SE direction along Sevania-Tambesara-Nilwari belt over a strike length of more than 20 km. Typical analyses of Banswara ores are Mn: 30-45%; Fe: 3.5-15%; SiO_2: 8.5-22%; AI_2O_3: 1.0- 5% and P: 0.05-0.30%.

There exists about 5.8 million tonnes of total Resources of manganese ore accounting to about 1.4% of the country (NMI 01.04.2010).

2.3.3.2 Manganese Ores of Gujarat: These deposits occur in villages of Shivrajpur, Bamankua and Pani in the PanchMahals and Vadodara districts. Manganese ores of the state are primary bedded deposits occurring in association with phyllites, quartzite, cherts and schists of highly folded Precambrian rocks.

The ore zones occur as bands and lenses alternating with and parallel to the bedding of phyllites, quartzites and cherts. The deposits are known to extend to a depth of more than 170 metre below the surface. Ore minerals are psilomelane, pyrolusite and braunite. Manganese ores are of primary type and have been later subjected to supergene enrichments. Lateritic ores are also seen in the districts.

There exists about 2.95 million tonnes of total Resources of manganese ore accounting to about 0.7% of the country (NMI 01.04.2010).

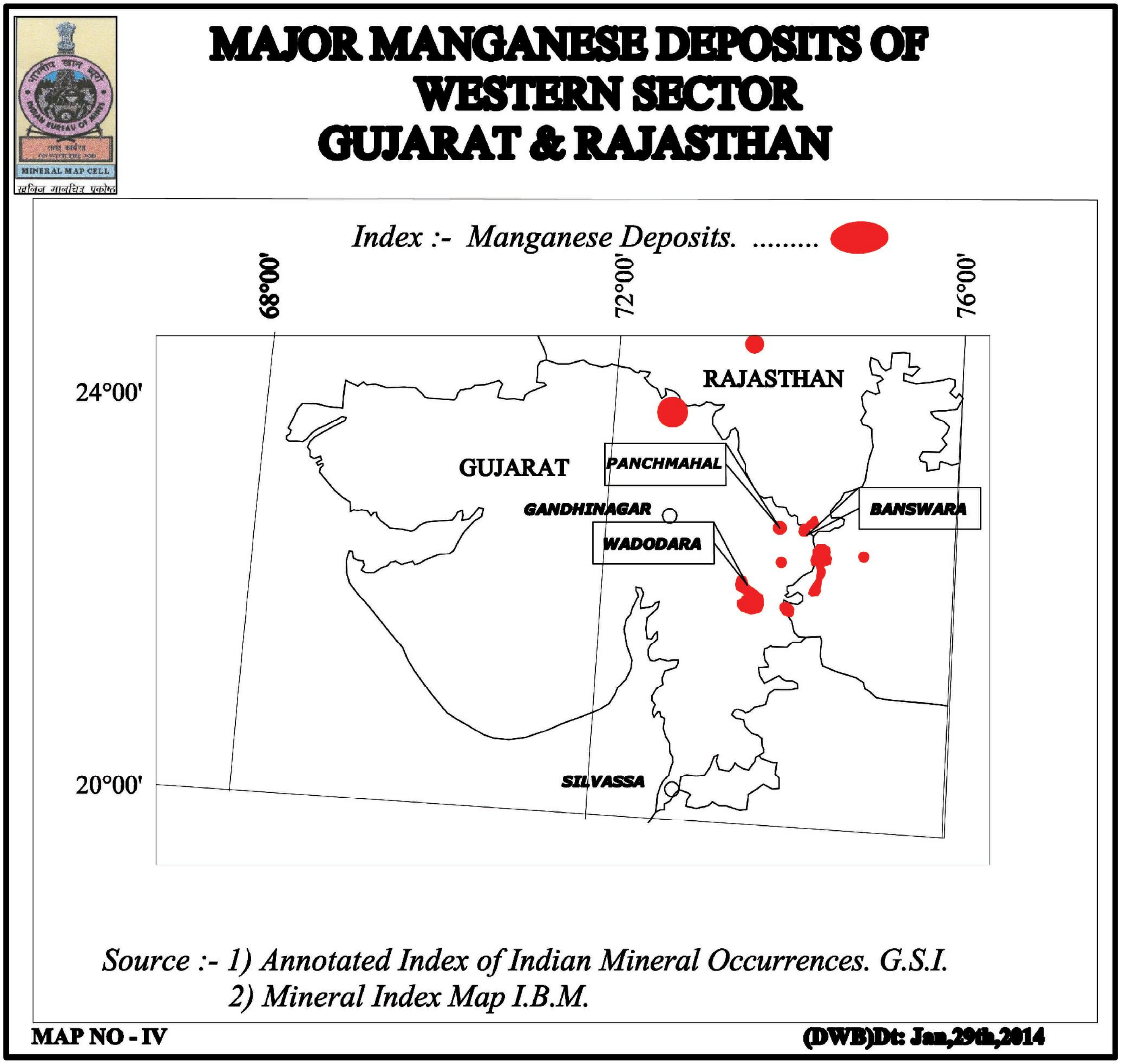
2.3.4 Southern Sector (Goa, Karnataka and Andhra Pradesh)

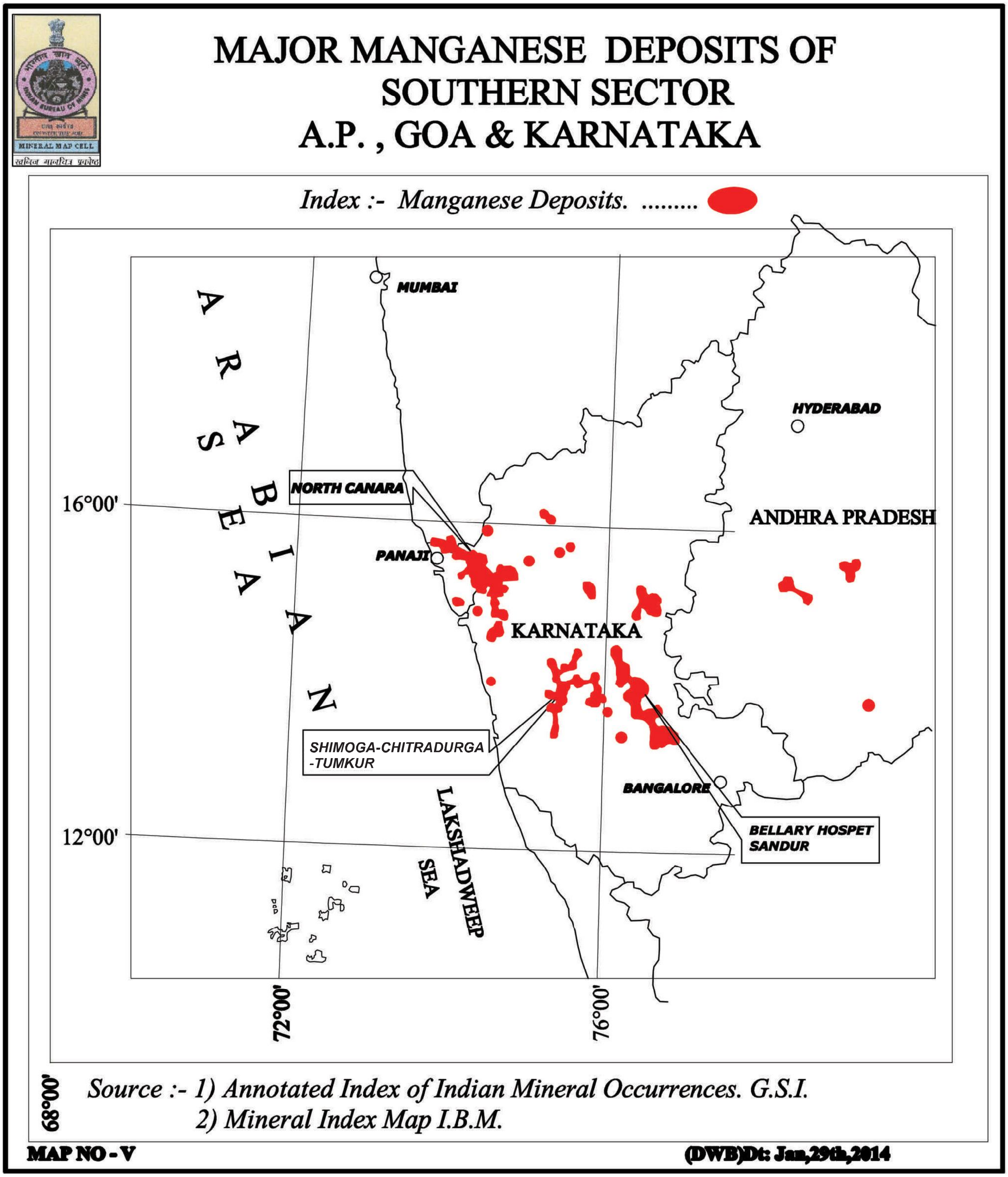
2.3.4.1 Manganese Ores of Goa: Goa is endowed with fairly good deposits of iron and manganese ore. Manganese ore deposits occur partly in laterites and partly in the decomposed Dharwar rocks like phyllites, quartzite's etc. The Goa ores are characterized by high iron and low manganese contents.

Most of the manganese deposits of Goa are located in Sanguem and Quepem taluks of South Goa. The deposits are at and around Rivona, Kolamba, Murge, DevanDongar, BorgaDongar, Kanure, Naveli, Pirl, Sulkarn, Talauli, Veliane, Natrolim, Tudou, Verlem, Galgirin, Netravoli, Nune, Devn, Vichundre, Kurpe, Viliyan, Talavalin, Chichigal, Salgineum and other areas.

Geologically, the State constitutes northwesterly extension of the granitoid-greenstone terrain of Karnataka comprising rocks of Precambrian age mostly represented by gneiss, migmatite and granitoids at the base, followed by meta-volcanics (both acidic and basic), meta greywacke, banded ferruginous quartzite associated with manganiferous phyllites/argillites, limestone, dolomite and thin bands of quartzite. These rocks have been intruded by granite and meta-mafic-ultramafic complex. Deccan Trap is seen on the northeastern border of the State.

These meta-volcano-sedimentary sequences belong to Goa Group which is equivalent to Chitradurga Group of Dharwar Super-group. The manganese ore deposits of Goa are lateritised in nature occurring at or near the


MAJOR MANGANESE DEPOSITS OF
WESTERN SECTOR
GUJARAT & RAJASTHAN
MINERAL MAP CELL
Index :- Manganese Deposits. ....
68°00'
72°00'
76°00'
24°00'
20°00'
RAJASTHAN
GUJARAT
PANCHMAHAL
BANSWARA
GANDHINAGAR
WADODARA
SILVASSA
Source :- 1) Annotated Index of Indian Mineral Occurrences. G.S.I.
2) Mineral Index Map I.B.M.
MAP NO - IV
(DWB)Dt: Jan,29th,2014


MAJOR MANGANESE DEPOSITS OF
SOUTHERN SECTOR
A.P. , GOA & KARNATAKA
MINERAL MAP CELL
Index :- Manganese Deposits. ....
MUMBAI
ARABIAN SEA
HYDERABAD
NORTH CANARA
16°00'
ANDHRA PRADESH
PANAJI
KARNATAKA
SHIMOGA-CHITRADURGA
-TUMKUR
LAKSHADWEEP SEA
BANGALORE
BELLARY HOSPET
SANDUR
12°00'
72°00'
76°00'
68°00'
Source :- 1) Annotated Index of Indian Mineral Occurrences. G.S.I.
2) Mineral Index Map I.B.M.
MAP NO - V
(DWB)Dt: Jan,29th,2014

surface over areas occupied by iron-manganese phyllites. They are irregular lensoid bodies and pockets of varying dimensions. The deposit is lateritised at the surface with concretions of black coloured iron and manganese ores followed at depth by bouldery manganese ores and then by manganiferous clay or wad. The ore minerals are pyrolusite, psilomelane, partly cryptomelane and manganite.

Most of the area is under lease to various companies who are carrying out the mining operations. The size of the deposits varies from a few tens of metres to about 5 km in length and 5-30 m in width. The workings have a depth up to 30 m. Important manganese ore belts of Goa are:(i) Rivona-Colomba; (ii) Netrolim and (iii) Verla – Salginem in Taluk, Sanguem.

Manganese ores in Goa are associated with the iron ore deposits extending across the State from north-west to south east. The ores are associated with phyllites, schists and banded iron formations belonging to the Chitradurga Group, a part of Dharwar Super Group. The deposits are mainly of lateritic type and occur as pockets of various sizes in the form of concretionary pebble within shales. The ore minerals are pyrolusite and psilomelane.

There exists about 13.6 million tonnes of total Resources of manganese ore accounting to about 3.2% of the country's share (NMI 01.04.2010). Mining operation for manganese is being carried out for several decades and the areas are under lease to various companies.

2.3.4.2 Manganese Ores of Karnataka: Karnataka hosts the largest recoverable reserves of manganese ore in the country. The manganese ores occur in the stratigraphic level of the Chitradurga Group of Dharwar Supergroup. The deposits of manganese ore are mainly found in Sandur schist belt (Bellary district), Shimoga schist belt (Shimoga district), Chitradurga schist belt (Chitradurga and Tumkur districts) and North Canara schist belt (Uttara Kannada district). They are stratiform, tabular, lenticular, patchy or pockety deposits of varying dimensions. Psilomelane, pyrolusite, cryptomelane and wad are the major minerals of manganese ore. The commercially viable manganese ores are mainly mixtures of pyrolusite and psilomelane.

The Karnataka Manganese ore deposits are believed to have been derived mainly by the process of supergene enrichment of manganiferous phyllites belonging to Dharwar system.

There exists about 96.2 million tonnes of total Resources of manganese ore accounting to about 22.4% of the country's share (NMI 01.04.2010). These resources estimated in nine districts, major being North Canara (29 million tonnes), Chitradurga (26 million tonnes), Tumkur (20 million tonnes) Bellary (13 million tonnes), Shimoga (4 million tonnes) and Belgaum district (3 million tonnes).

The chief rock types encountered in the schist belt areas where manganese ore occurs are meta-basalt, meta greywacke and argillite, quartzite and limestone with laterite capping's. Banded iron formations with manganese are inter-bedded invariably with argillite and at times follow the carbonate band.

2.3.4.3 Manganese Ores of Andhra Pradesh: Manganese ore deposits in Andhra Pradesh occur as localized pockets in the Eastern Ghat metamorphics of the Archaeans and Proterozoic Penganga sediments. The deposits associated with the Archaean metamorphics are found in Visakhapatnam, Vizianagaram and Srikakulam districts and those with the Penganga in Adilabad district. District Srikakulam and Vishakhpatnam manganese deposits are associated with Kodurite formations.

Andhra Pradesh contributes about 9% of the total production of manganese ore in the country. The manganese ores are generally of low grade with high phosphorus content and hence need beneficiation or blending with suitable high grade ores.

There exists about 17.6 million tonnes of total Resources of manganese ore accounting to about 4.1% of the country's share (NMI 01.04.2010).

2.4 STATUS OF EXPLORATION

Except the already known deposits, no new potential manganese bearing areas have been discovered in course of the recent exploration. A good number of manganese

Table-2.4: Action Plan of Manganese Ore Exploration for the XII Plan Period

Agency	Area	Nature of Exploratory work
GSI	Odisha: Bonai-Kendujhar belt Maharashtra: Sausar belt, Nagpur district.	LSM (950 sq km), DM (10 sq km), Pitting-Trenching (5000 cum) and Drilling (4800m)
DMG, Maharashtra	Parseoni-Gumgaon, Nagpur district	Proposed for drilling.
MOIL	Mines of Balaghat district in Madhya Pradesh and Bhandara & Nagpur districts of Maharashtra	Detailed exploration by drilling

ore provinces are located in Peninsular India which includes deposits of Madhya Pradesh and Maharashtra, Odisha, Karnataka, Andhra Pradesh and Goa. Two states, namely, Karnataka and Odisha dominate the reserve of manganese ore. Exploration strategy in XIIth five year plan aretentatively identified an area of about 4600 sq km as potential geological domain of manganese belt which comprises the following:

1. Sandur Fe-Mn-Au zone (Karnataka)
2. Chitradurga polymetallic (Fe, Mn, Au) zone (Karnataka)
3. Shimoga Fe-Mn, Cu (Karnataka)
4. Goa Fe-Mn belt
5. Sausar Mn Belt (Maharashtra)
6. Bonai-Noamundi Fe-Mn province (Jharkhand & Odisha)
7. Eastern Ghat Mn-Al province (Odisha & A.P.)
8. Gangpur Mn Province (Odisha)

Although India has substantial amount of metallurgical grade manganese ore, the chemical grade and battery grade ores are rare. Consumption pattern and future needs of metallurgical grade manganese also indicates that the resource position is reaching critical stage and requires augmentation. Search for metallurgical and chemical grade manganese ores in the extension areas of known mining districts and geologically potential belts would continue during the XII Plan period involving large scale mapping (LSM), Detailed mapping (DM), Pitting-Trenching and Drilling. Exploration activities would be focused in the areas by various agencies is presented in Table-4.

The Central Geological Programming Board (CGPB Committee-I) recommended general strategies on manganese ore exploration. The highlights of the recommendations are:

1) Structure and genesis of ore deposits to be considered as prime factor for exploration of any ore deposit.

2) The optimum values of other constituents (such as Silica, Phosphorous, etc. in case of Mn-ore) may be considered when fixing the revised threshold value/s of any mineral commodity.

3) Advanced integrated exploration techniques are needed to thoroughly explore deeper deposits or deposits in complex geological environment. As most of the present exploration efforts are restricted to area near ancient mine workings or near surface deposits by conventional exploration techniques.

4) State-of-the-art drilling techniques with sophisticated rigs (such as RC) for three dimensional sub-surface delineation of ore body as well as for directional drilling and underground exploratory drilling are needed to be employed.

2.5 STATUS OF EXPLOITATION (MINING)

Most of the larger manganese ore belts have been explored for high grade ores and many exploited for high and medium grade ores over last six decades. The low-grade fines, including those from operating mines have not been utilised adequately and has gone wasted. The states of Madhya Pradesh, Maharashtra, Odisha, Karnataka and Gujarat are major producers of manganese ore in the country. The status of manganese ore mining leases in India is presented in Table-5.

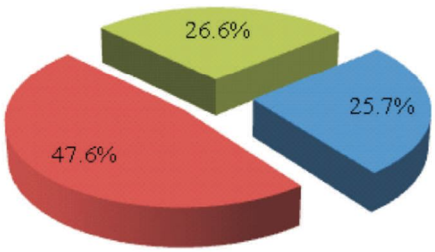
Table-2.5: Status of Manganese Ore Mining Leases in India

(As on 31-03-09)

No. of Leases	Lease Area(In Hectares)
769	94307.86

The total resource of manganese ore occurs both in leasehold as well as freehold area. Of the total resources of manganese (430 million tonnes), about 110.70 million tonnes (26%) have been placed in freehold, 204.78 million tonnes (48%) in leasehold private and 114 .49 million tonnes (26%) in leasehold public areas. Total resources of Manganese ore in free hold and lease hold areas in India is presented in Fig-7.

Fig. 2.7: Total resources of Manganese ore in free hold and lease hold areas



Source: IBM

2.5.1 MINING PRACTICES

Both manual and mechanized workings of manganese mines in India can be broadly classified into three groups viz., (a) opencast, (b) underground, and (c) dump workings.

2.5.1.1 Opencast Mining: A majority of manganese mines in the country is worked by opencast method. Labour intensive opencast workings are practiced for shallow depth. In a manually operated open pit, the height of a bench is normally kept at 1.5 m on benches of hard rocks; the fragmentation of this horizon is carried out by means of pneumatic drills hole blasting. Removal of waste rock is normally done manually. In some cases, waste is loaded into tub and pushed manually over the rail lines to the dump yards. The manganese ore is sorted and picked up manually.

The workings vary from shallow depth in lateritoid-type deposits in Odisha, Karnataka and Goa to deep operations in deposits of a more regular nature found in Madhya Pradesh, Maharashtra and Andhra Pradesh. Bulldozers are used where the overburden is soft. In a few cases, tramways are laid up to the working face and loaded tubs pushed manually to the dumping ground. In Odisha, Goa and Karnataka ore is worked by loosening the ground either with crow bars or by blasting. After picking up manganese ore, the waste is removed to the dumping ground. Mining of bedded ore in Madhya Pradesh and Maharashtra is generally carried out by drilling and blasting.

In majority of the mechanised open cast manganese ore mines in India, Shovel-Dumper combination are used for removal of overburden and extraction of manganese ore. In semi hard formation, a part of the overburden is removed with deep hole drilling and blasting and a shovel – dumper combination. In such cases, hang wall is developed partly mechanically and partly manually, whereas the development in the foot wall side is done manually. In mechanical development, blast holes are drilled either by wagon drills or Down the Hole (DTH) drills which are then blasted. For development work heavy earth moving equipments like excavators, dumpers and DTH drills are used for overburden handling. Dongri-Buzurg and Tirodi opencast mine of MOIL, Garbham opencast mine are the examples of mechanised open cast mining, whereas Sandur opencast mine is an example of semi-mechanised mining.

2.5.1.2 Underground mining: In manganese ore belt of Madhya Pradesh and Maharashtra, underground method of mining is resorted to with the extension of the ore bodies in depth. All the underground mines are mechanised or semi-mechanised and adopt cut and fill method of stoping. Mining method practiced in these underground manganese mines is labour intensive. Mechanisation is confined to drilling and blasting, partial support, hoisting and transport.

In Indian context, only eight mines are underground, which are presently under operation in the states of Madhya Pradesh and Maharashtra. All the remaining mines are worked by open cast method. Some of the prominent underground mines are Ukwa, Balaghat mines in Madhya Pradesh and Chikla, Mansar, Kandri and Gumgaon in Maharashtra.

In some of the MOIL operated underground mines, hydraulic sand stowing (Kandri mine) is introduced in place of manual filling system. The system is faster, cheaper and requires less manpower. Conventional timber supports are replaced by cable bolting pre-mining support to increase safety and productivity. In Balaghat underground mechanised mine, overhand flat back cut and fill method with rock bolting support and sand stowing to fill up the voids is being practiced with a level interval of 30 m and size of stope block as 30 m x 30 m to 60 m x 30 m. Side Dump Loaders (SDL) of 0.66 cu m bucket capacity were also deployed in underground levels for mechanised loading of run of mine (r.o.m.) in stopes. Tyre mounted Rocker shovel was also introduced in Balaghat mine for mechanised loading of ore from ore drive at stripping area. Deepening of vertical shaft was completed in Balaghat and Beldongri mines of MOIL. Sinking of vertical shafts is in progress at Mansar and Ukwa mines.

In these mines square set method of stoping with filling is practiced. Timber was hitherto used for square setting. With the increase of cost of timbers and due to its deteriorating quality, stone masonary pack-pillars are used in recent years. To support the ground 1m x 1m stone masonary pack-pillars are normally constructed in a grid pattern with a centre to centre spacing of 3m to 4m. These pillars are then joined together by 0.5m thick stone masonary bracing walls. This is constructed both along and across the strike. This gives satisfactory results for ore bodies with width varying from 6m to 12m, though erection of pack pillars gives a slow process. Each pillar is designed to take a load of at least 70 tonnes.

2.5.1.3 Dump Mining: Stringent physical and chemical stipulation of manganese ore required by the industry made selective mining and sorting for winning the mineral in the past. This resulted in huge accumulation of manganese ore reject dumps particularly in the mines of Madhya Pradesh and Maharashtra region. Many of these dumps constitute the source of low grade ores for supplying to the steel plants in the country. Before the dump is chosen for working, no systematic sampling was done. After a few haphazardly placed trial pits up to a depth of 1.5m, if the presence of "recoverable" ore is observed, work is started by forming benches 1.2 to 1.5m high and 1.5 to 2.4m wide. No explosive is used. Only crow-bars and pick-axes are used to loosen and dislodge the material. While excavating, lumpy ore pieces are hand-picked, dressed and stacked. The left over finer material below 12.5mm size is screened and plus 6 mesh material is further hand-picked for bigger pieces and the rest are fed to jigs. Normally, the dump recovery of acceptable grade varies from 15 to 20 percent. The undersize comprising minus 3.2mm size material is dumped near the temporary site of the mobile screen and the good material is transported by tubs. The dumps have been so extensively worked in recent past that they are now nearly exhausted.

Normally, recovered ore from the dump mining with grade varying from 15% to 20% are acceptable in domestic market. Generally, it gives a production of both jigged and lumpy ore. The undersize (-) 3 mm material is dumped near the temporary site of the mobile screening plant and the processed manganese ore is dispatched by trucks.

2.6 PRODUCTION & CONSUMPTION OF MANGANESE ORE

2.6.1 Manganese Ore Production

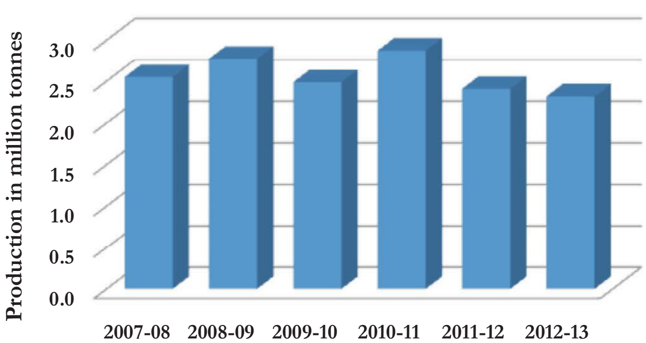
There were 144 reporting mines, one quartz and seven iron ore mines which produced manganese ore during 2011-12. Of these, only eight are underground mines, that are presently under operation in the states of Madhya Pradesh and Maharashtra. All the remaining mines are worked by open cast method. The mining operation is carried out both in public as well as private sector and captive and non-captive sector. Production of manganese ore in the country is through a combination of large mechanized mines in both public and private sectors and several smaller mines operated in manual or semi mechanised basis in the private sector.

There were 68 producers which reported production of manganese ore in 2011-12. Five principal producers operating 27 mines contributed 74% production. Around 83% of the total production was reported by 25 mines, while the remaining 17% production was reported by 127 small manganese mines, each producing up to 20,000 tonnes. Of these 25 mines, 16 are big mines each producing over 40,000 tonnes per annum. The remaining 9 mines have production capacity in the range of 20,000-40,000 tonnes per annum each.

Madhya Pradesh, Maharashtra and Odisha are the leading producing states of manganese ore followed by Karnataka & Andhra Pradesh. Other states which contribute in very minor amounts are Gujarat, Jharkhand, Rajasthan and Goa.

The overall production of manganese ore in the country and states wise production during the period from 2007-08 to 2012-13 is presented in Fig-8 & 9 respectively.

Fig-2.8: Production of Manganese ore in India (2007-08 to 2012-13)



Source: IBM

The major manganese producers in India during the year 2010-13 are presented in Table-6.

During last five year period from 2008-09 to 2011-12, the various grade-wise manganese ore produced in the country were below 25% Mn-15%; 25-35% Mn-50%; 35-46% Mn-10%; and over 46% Mn-10%. The grade-wise production of manganese ores in India is presented in Fig.10, while individual state-wise and grade-wise production of manganese ore is presented in Fig-11 to 18.

Table-2.6: Major Manganese Ore Producers in India

Producers	Location of Mine		Grade of Ore
	District	State	
MOIL Limited [Manganese Ore (India) Ltd]	Balaghat	M.P.	HG+MG
	Bhandara Nagpur	Maharashtra	
TATA Steel Ltd	Keonjhar Sundergarh	Odisha	MG
The Odisha Manganese and Minerals (P) Ltd	Sundergarh	Odisha	MG
M.L.Rungta	Keonjhar	Odisha	MG
RBSSD & FN DAS	Vizianagaram	Andhra Pradesh	MG+LG
The Sa ndur Manganese & Iron Ores Ltd Bellary, Karnataka	Bellary	Karnataka	MG+LG
Gujarat Miner al Development Corporation Ltd	Panchmahal	Gujarat	MG
Others	Goa, Jharkhand, Rajasthan		MG+LG

Fig-2.9: State-wise Production of Manganese Ore in India (2007-08 to 2012-13)

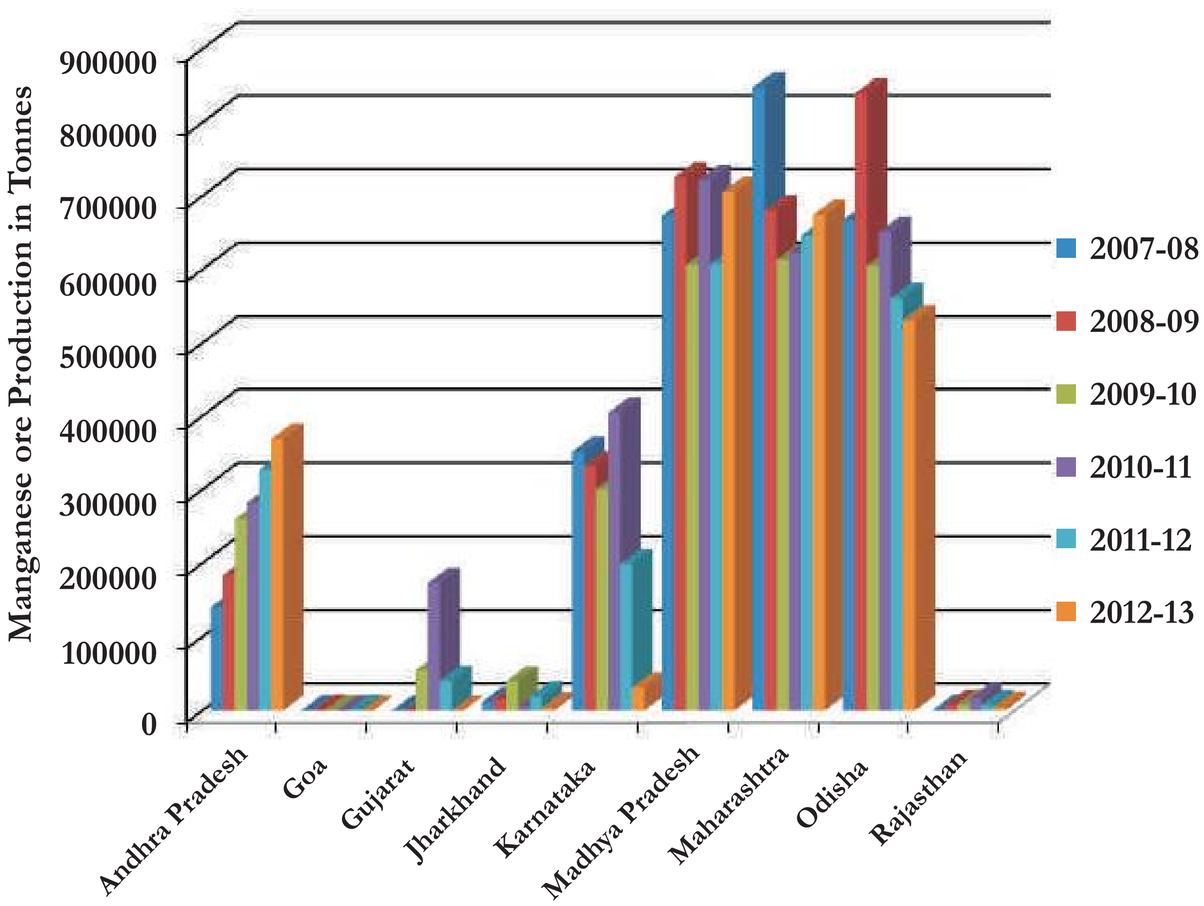


Fig-2.10: Grade-wise Production of Manganese Ores in India

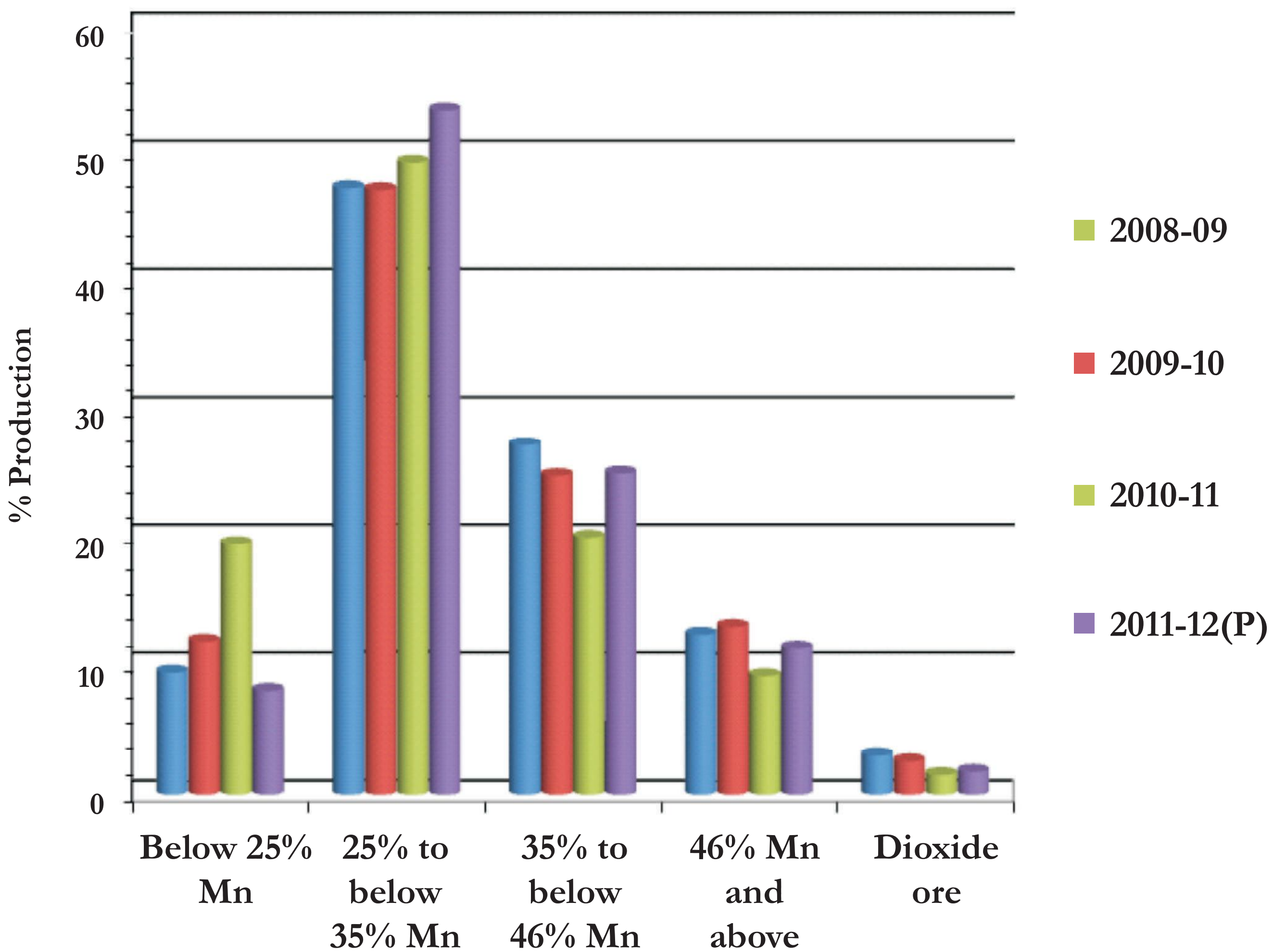


Fig-2.11: Grade-wise Production of Manganese ore in Andhra Pradesh

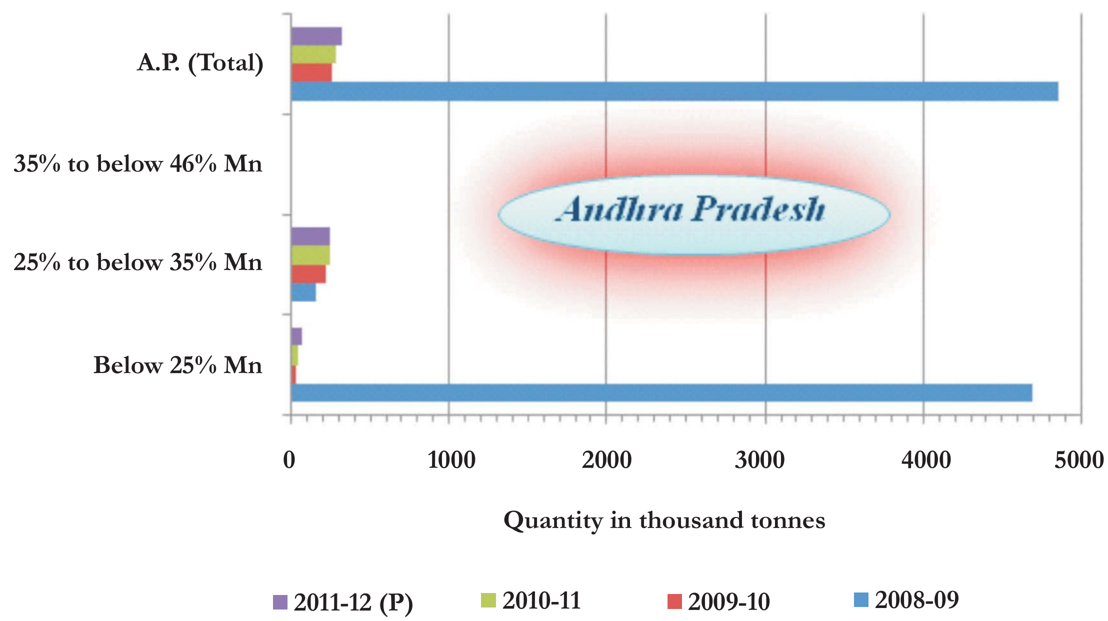


Fig-2.12: Grade-wiseProduction of Manganese ore in Goa

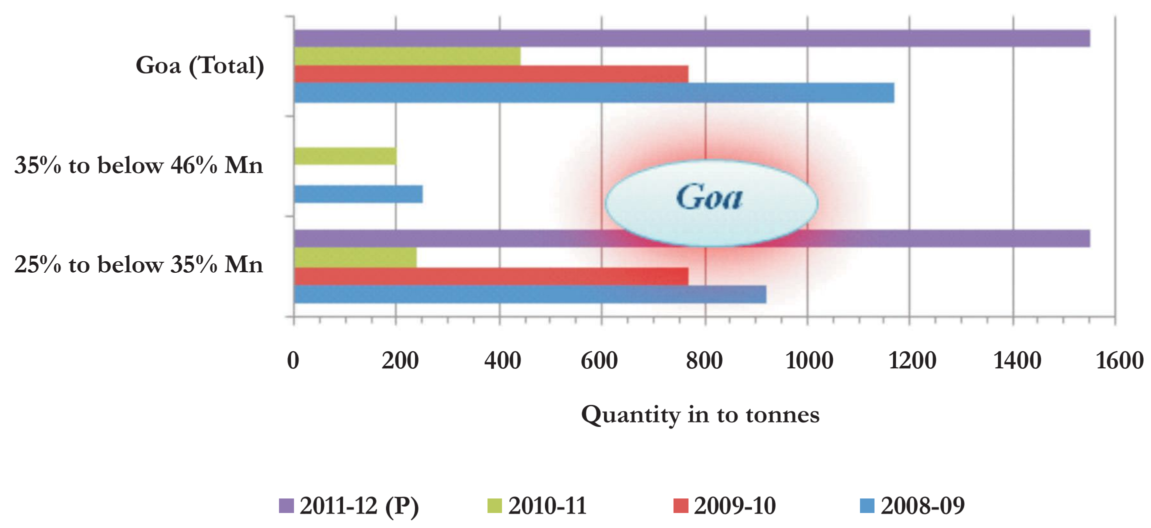


Fig-2.13: Grade-wise Production of Manganese ore in Gujarat

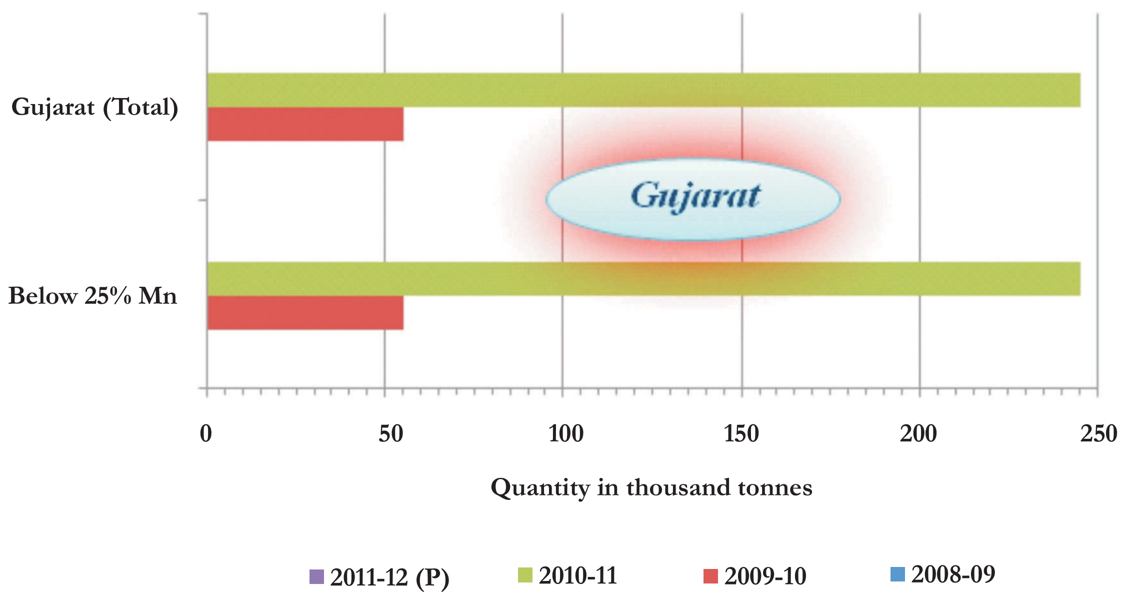


Fig-2.14: Grade-wise Production of Manganese ore in Jharkhand

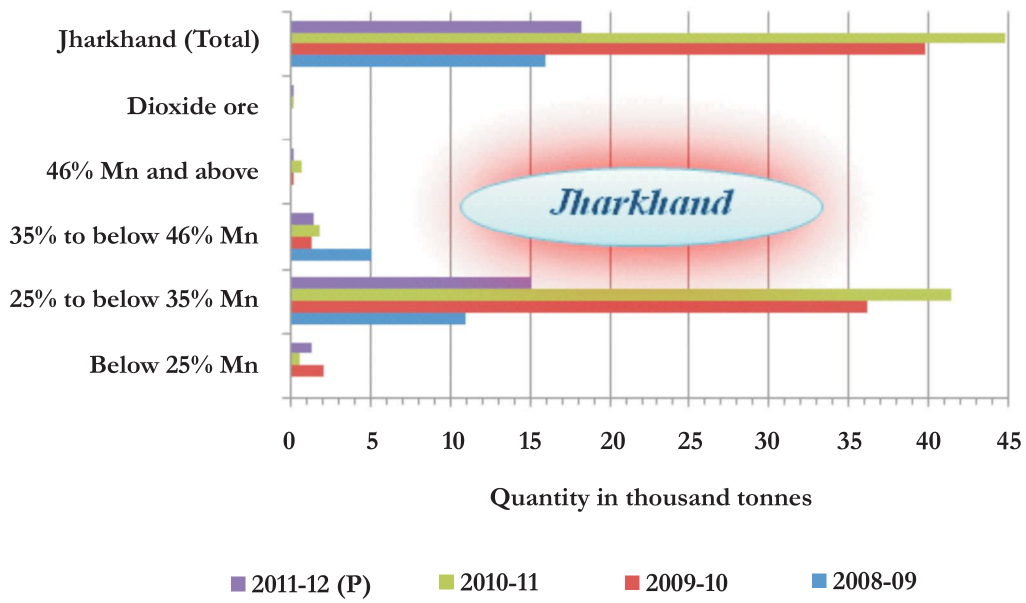


Fig-2.15: Grade-wise Production of Manganese ore in Karnataka

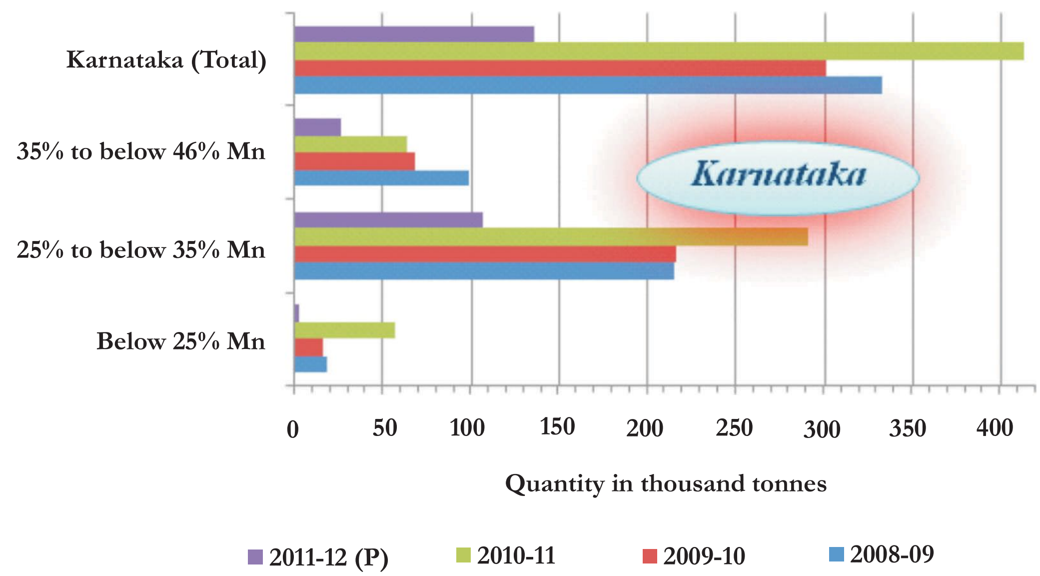


Fig-2.16: Grade-wise Production of Manganese ore in Madhya Pradesh

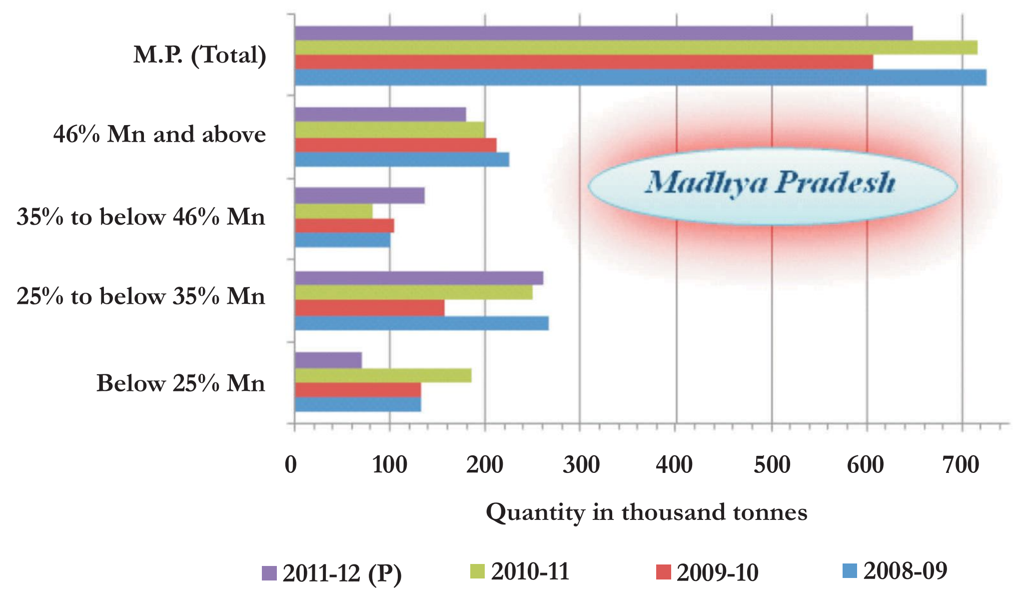


Fig-2.17: Grade-wise Production of Manganese ore in Maharashtra

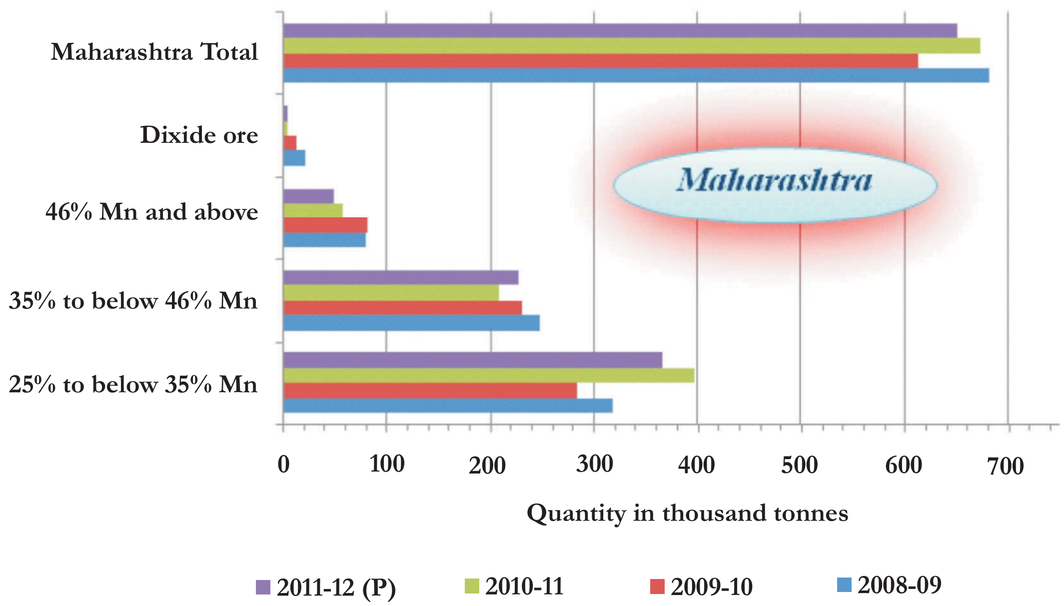
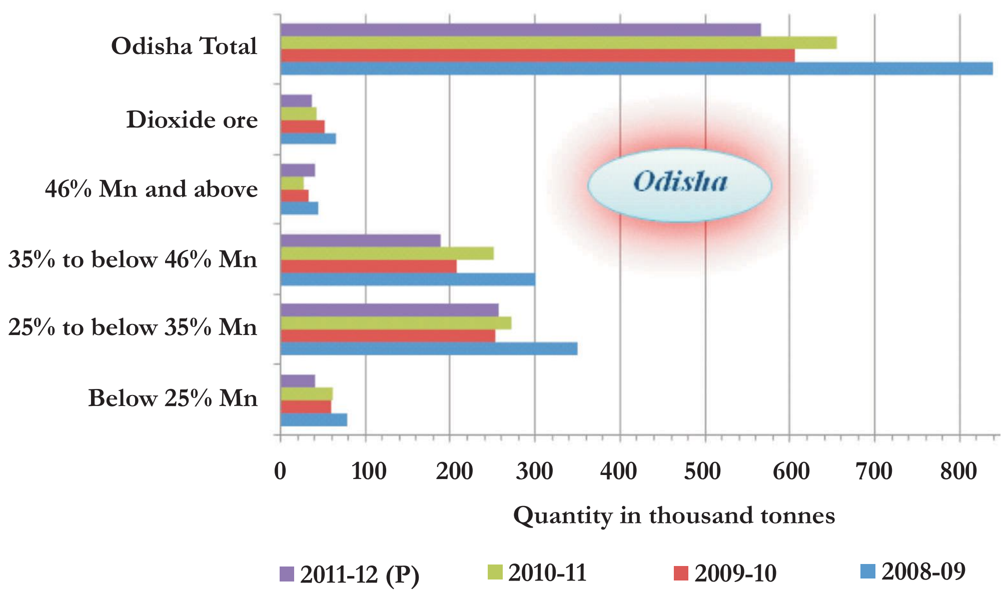


Fig-2.18: Grade-wise Production of Manganese ore in Odisha



2.6.2 Consumption of Manganese Ore

The total domestic consumption of manganese ore was reported to gradually enhance from around 2.5 million tonnes in the year 2007-08 to 4.0 million tonnes in 2011-12. Of this reported consumption, around 60-65% accounted for silicomanganese, 28-35% for ferromanganese, around 5% for iron & steel including sponge iron industries. The remaining 1-2% was consumed by other minor industries.

Various industries-wise consumption of manganese ore in the country from the year 2007-08 to 2011-12 is presented in Fig.19.

2.7 EXPORT OF MANGANESE ORE

The export of manganese ore of all grades has reduced down substantially from 2.5 lakh tonnes in the year 2008-10 to 0.5 lakh tonnes in 2012-13. Various industries-wise consumption of manganese ore in the country from the year 2008-09 to 2012-13 is presented in Fig.20.

2.8 IMPORT OF MANGANESE ORE

The import of manganese ore of medium and high-grade has shown a significant enhancement from 85,000 tonnes in 2008-09 to 2.17 million tonnes in 2012-13, mainly to cater to the need of silico-manganese industry (Fig-21).

Fig-2.19: Reported Consumption of Manganese Ore by Industries in India

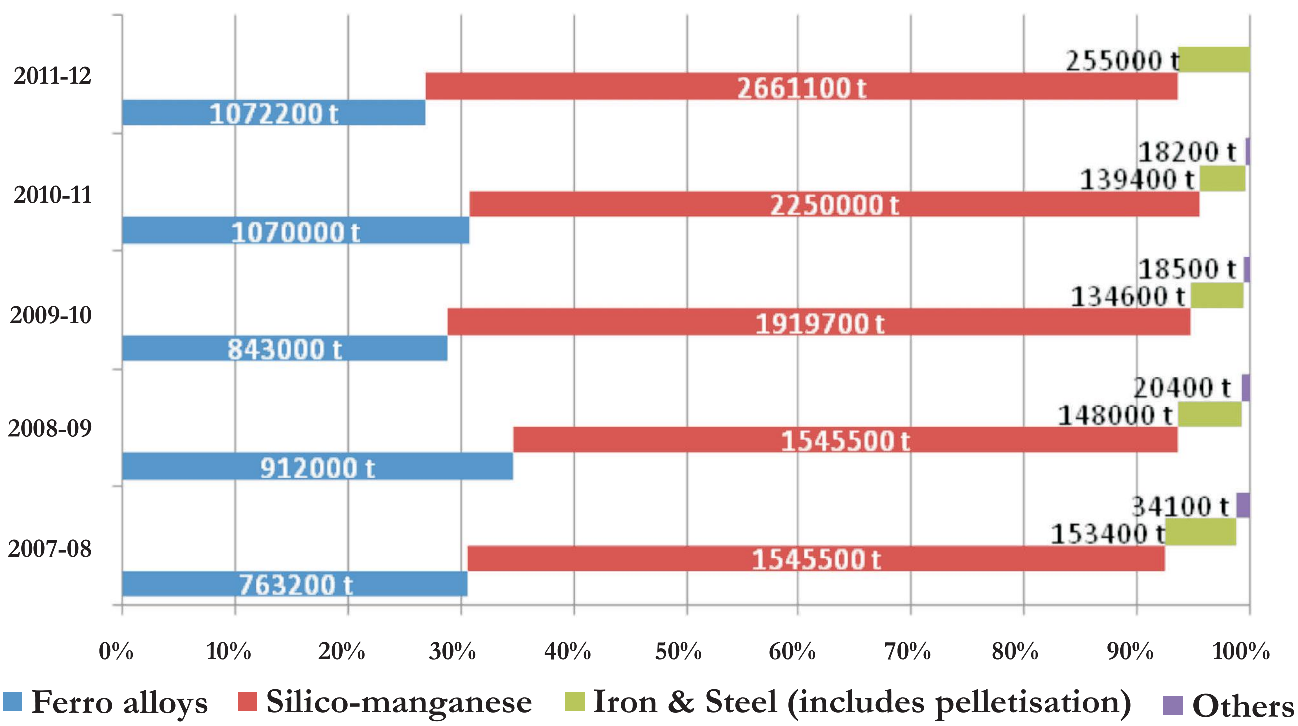
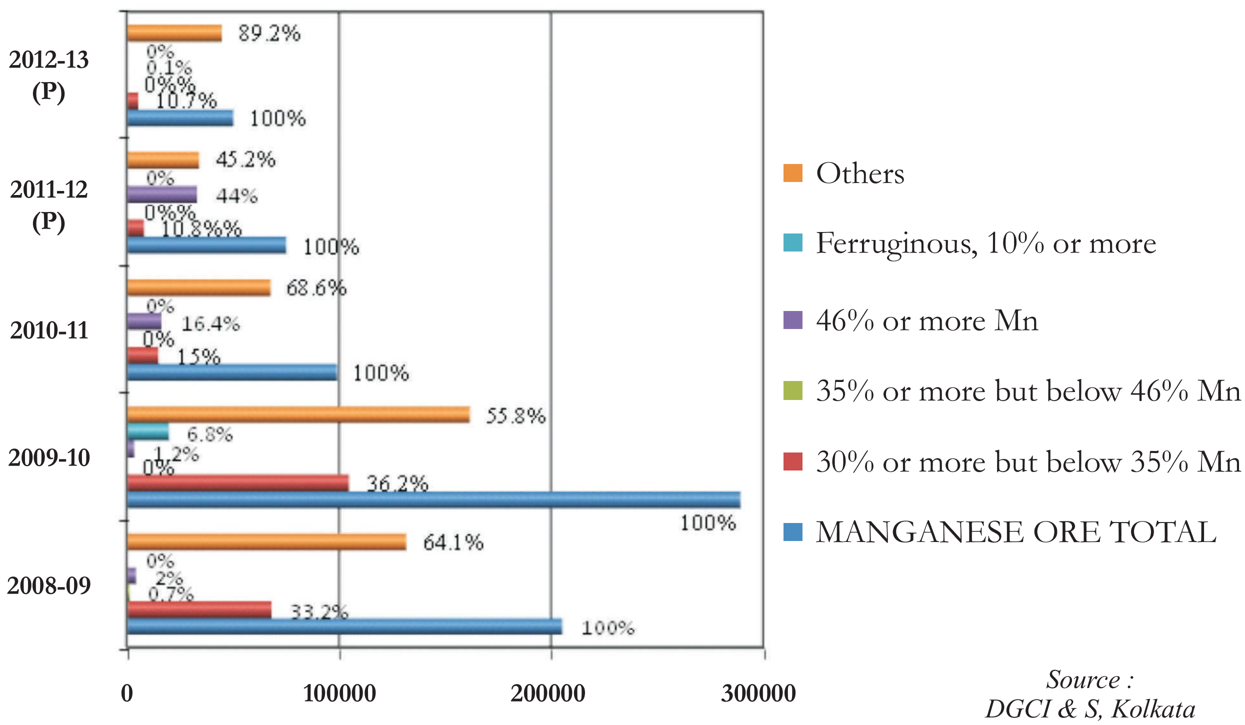


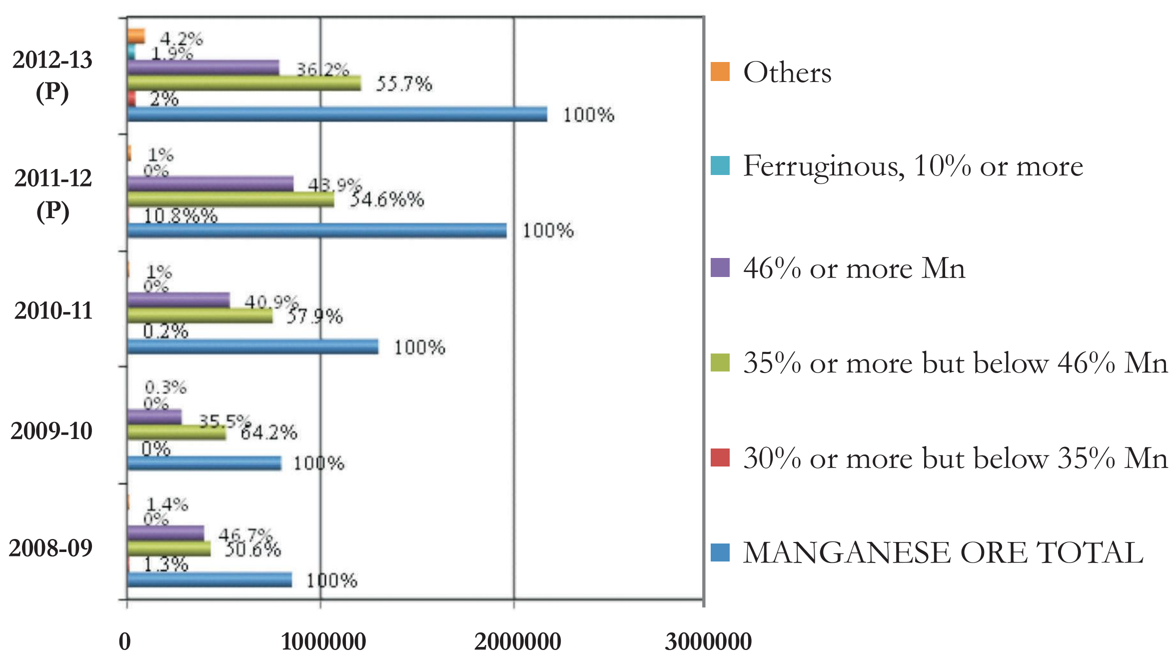
Fig. 2.20: Grade-wise Export of Manganese ore from India



Quantity in tonnes

Source : DGCI & S, Kolkata

Fig. 2.21: Grade-wise Import of Manganese ore in India



Source : DGCI & S, Kolkata

Quantity in tonnes

Mn ore Beneficiation

Manganese ore is the basic source to provide manganese input in iron & steel and is an indispensable raw material in all types of steel. The manganese addition is predominantly in the form of manganese alloy or ore. Thus, over 90% of the manganese ore demand is accounted for manganese alloy (Ferromanganese and Silicomanganese) and iron-making in the country. With the anticipated surge in the demand for steel and increase in its production by 2020, manganese ore requirement will also be enhanced proportionally. Manganese requirement for other metallurgical applications or for non-metallurgical uses do not represent a quantity large enough to significantly affect the creation of the overall manganese demand.

Though availability of the total resources of manganese ore in the country is quite extensive, the high-grade resources (>44% Mn) are very limited (below 10%) which is necessitated for making of ferromanganese. The majority of the manganese ore resources fall in the category of blast furnace (BF) and mixed grade (over 25% Mn)with very limited (below 3%) low-grade (<25%Mn).

With the advancement in technology in most of the iron and steel making units in the country, use of manganese ore has been gradually reduced and replaced by manganese alloy. Hence, value addition of indigenous manganese ore resources in the country becomes inevitable, for its utilisation in manganese alloy industry in the long run.

In the present Indian scenario, despite paucity of high-grade/ferromanganese grade ore (Mn>44%) resources, the mineral beneficiation and upgrading of low/medium-grade manganese ores have not received due attention. On the contrary, manganese alloys industries are rapidly increasing in the country which has led to import of medium and high-grade manganese ore, used as sweetener and blended it with indigenous BF and mixed grade ore. Thus, continued research into practical methods of beneficiation is limited by the lack of need in the country.

However, a realistic forward look reveals that available new sources of good quality ore will become non-existent. Under such circumstances the integration of more sophisticated beneficiation plants within the mining complex will become the rule rather than exception. Thus, the major manganese producers in the country have to consider building processing facilities to treat fines, low-grade ores, or ores with a mineral composition not compatible with existing market requirement.

The inherent benefits of the industry on account of indigenously available low cost primary raw materials (manganese ore) or low cost labour have been gradually eroding over the years in the country. Therefore, a greater focus is needed on technological aspects to reduce cost of production, improve quality and produce new and value added products which are needed by the customers.

3.1 MANGANESE ORE PROCESSING PRACTICED IN INDIA

Exploitation of manganese ore in India is invariably carried out as a "selective mining" coupled with hand picking and sorting of lumps. Hand sorting and picking is the most common practices in the country because the labour is cheap and the production in the individual mine is not high due to pocket nature of deposits. Though the overall recovery suffers, dry screening, hand sorting and picking is found to be the most efficient method of value addition on the basis of its specific gravity, colour & lustre, across most of the mines in the country.

A brief account of the processes of concentration and their practice for manganese ore in the country is as follows:

3.1.1 Preliminary washing

Dry screenings cum manual and mechanical washing is favourable method to reduce slag forming gangue from lumpy ores and are carried out to remove clay, shaly materials, etc. This clean feed is then further upgraded either by hand sorting or gravity.

3.1.2 Heavy Media Separation (HMS)

Heavy Media Separation (HMS) is also effective way for Indian manganese ores. Ferro-silicon was used as media in the HMS process. The size applicability of the process is -125+3 mm. In this method, a suspension of finely ground ferro-silicon in water produces a medium by making a parting density of 3.3, which behaves as a heavy liquid, the density of which is maintained between the valuable manganese mineral and the associated gangue. The heavy manganese mineral reported as sink, while lighter gangue in float fraction.

The medium after washing and screening of the lump is recovered by magnetic separation to recover media.

3.1.3 Jigging

Manual and mechanical washing and manual jigging is the most common practice across the country for value addition of manganese ore. The separation is achieved by the action of alternate upward and downward currents of water in quick succession on a bed of ore retained on a screen. The lighter gangue mineral is thrown away by upward current. Jigging process is normally deployed for size up to 1.6 mm.

3.1.4 Spiral & Tabling

Ideally suitable for mines generated fines below 2 mm size having contamination of lighter gangue mineral like shale, quartz etc. A very clean concentrate can be obtained. Only a few companies practiced it that too in a rare case.

3.1.5 Magnetic Separation

The common manganese mineral in the country are feebly-magnetic, and hence, can be separated from non-magnetic minerals like quartz, amphiboles, barite, apatite, calcite etc., by Dry High Intensity Magnetic Separation.

One or more combination of various methods are used for concentration of manganese valuables in the coarser size discarding fines. These concentrates are invariably in the form of coarse and can be used in subsequent metallurgical industry as it is.

A close look at the exploitation and processing practiced in the country reveals that:

1. Most of the manganese ore mines in India have been operated by selective mining for maintaining medium to high grade ore at a mining cut-off 20% Mn.

2. At this cut-off, blast furnace grade and mixed grade ore (+25%Mn) is readily exploited leaving low grade ores (<25% Mn) untouched.

3. The present industrial practice causes huge loss of manganese values in process/mine rejects and their stacking has adverse effects on environment causing ecological imbalance.

4. No low grade ores are exploited (below mine cut-off and threshold grade i.e., -20+10% Mn).

3.2 NEED FOR PROCESSING

Mineral consuming industries demand manganese ores in a tailor made format i.e., meeting physical, chemical and in very rare cases mineralogical stipulations. Manganese ore is invariably used for metallurgical processes (iron making in blast furnace as well as manganese-based alloys making). In the Indian context, the common gangue associated with manganese ores are metallic minerals, slag forming minerals and deleterious sulphur & phosphorus bearing mineral. In many cases, presence of these impurities beyond desired limits render the ore unsuitable for use in iron or manganese alloy making (blast furnace/EAF). The common gangue associated with manganese ore and its adverse effect in manganese alloy making is detailed below:

3.2.1 Metallic Gangue

Generally, these impurities report along with manganese metal during production process. Iron is the most common gangue contributed by iron minerals like hematite, goethite, limonite and manganese mineral like jacobsite. The other metallic gangue contributors are Pb, Zn, Cu, W, Ni, Ti & Ag compound and always present in minor trace amounts. Except zinc which is readily volatilized, remaining impurities are retained in the metal by a process of reduction during smelting.

Reducing efficiency of iron oxides during ferro alloy production is around 95% whereas that of manganese oxide is 70 to 75%. This means iron oxides are the first to reduce during smelting of ferromanganese which ultimately dictates the grades (%Mn) of manganese-based ferro alloys. Hence, higher Mn-Fe ratio or lower iron content is preferred.

3.2.2 Slag Forming Gangue

The slag forming constituents in the ore brings down its value. Acid insoluble are contributed by this type of gangue and these may be basic such as lime, magnesia & barite and acidic as silica or alumina.

Lesser silica means higher Mn/SiO_2 ratio. Lesser silica results in less slag formation during ferromanganese production resulting in less manganese loss in slag and reduced electricity consumption. The power consumption for ferromanganese production depends on the slag volume and temperature of slag which in turn depend on silica content of the manganese ore used. It is therefore important to have low silica in manganese ore for ferromanganese smelting. Every 1% increase in silica content increases manganese ore requirement by 60 kg and power consumption by 60 kwh/tonne ferromanganese produced.

3.2.3 Phosphorus & Sulfur Gangue

Sulfur is less dangerous than phosphorus since in normal furnace operation the sulfur passes away (into slag combining with manganese or lime) and only traces enter the alloy, whereas phosphorus passes completely to the alloy. The sulfur is contributed by sulfides including base metal. Phosphorus is contributed by discrete mineral phase like apatite and also chemically combined with manganese as a separate mineral i.e. Gorexite. The presence of arsenic is also harmful for certain industrial use of manganese.

The manganese-based alloys are used as de-oxidizers in steel making. Phosphorus present in manganese alloys which is inherited from manganese ore gets dissolved in steel, results in cold shortness i.e., development of cracks in steel during cold working.

3.2.4 Manganese Content

The cost structure of the manganese alloy production indicates that manganese ore dominates the cost component to the tune of 40%, thereby emphasizing the need for availing the benefits of using the high-grade ores. For the same manganese units input for alloy production, the low-grade ore requirement is about two-times that of high-grade ores and electrical consumption is one and half times. In addition, the performance of low grade ore in alloy production is substantially inferior to that of high-grade ores. It increases input cost, results in inferior quality end product and increases slag production thereby making the slag disposal an issue. On the other hand, the slag resulting from high grade ores is much rich in MnO content (35-38%) which is used for silicomanganese production.

Thus, the higher grade ores significantly reduce the cost, slag and improve the grade of the alloy products which requires up-gradation of manganese content.

Ferromanganese grade (>44% Mn) ore reserves are limited in the country. Acute shortage is being faced by the ferromanganese industries due to limitations of domestic manganese ore supplying companies. This has resulted in steep rise in the prices of manganese ore due to large demand supply gap. The grade of the manganese ores has deteriorated globally with manganese content falling and phosphorous and silica increasing alarmingly even in high-grade manganese ores.

In the present Indian scenario, manganese input is predominantly through manganese alloy in iron & steel making and hence value-addition of BF and mixed grade ore (>25%Mn) in the country is all the more necessary. Besides, optimum utilisation of locked-up valuables in low-grade, sub-grade/marginal-grade ore resources and fines are essential for survival of the industry and growth which can be achieved only through implementation of appropriate beneficiation technology.

3.3 COMMON UNIT OPERATIONS FOR BENEFICIATION OF MANGANESE ORE

In recent years, there is a lot of development taking place in manganese ore processing across manganese ore producing countries in the world. The emphasis is on development of cost effective flow sheets to beneficiate the low-grade manganese ores to produce concentrates suitable for sinter making that is to be used for manganese-alloys. Some of the development features in the processing equipment side are use of heavy media cyclone, jigging, innovations in spiral concentrator, Floatex Density Separator, hydro-cyclone, stub-cyclone, autogenous grinding, column flotation, high gradient magnetic separators (HGMS), fine size screening, etc.

Some of the common unit operations applicable for manganese ore processing are discussed below:

3.3.1 Washing & Wet Scrubbing

This process is very primitive and widely used in lumpy manganese ore processing to dislodge soft & friable clay, shaly materials, etc. adhered to the lumpy ore. The scrubbing practice is also helpful in hard and porous manganese lumps, which are invariably cavity/pores filled with goethite/limonite or lateritic clayey material, for their substantial elimination.

3.3.2 Gravity Concentration

This technique is deployed if valuable & heavy iron minerals are free from associated light gangue minerals or waste rock. The common manganese minerals have usually high specific gravity (Pyrolusite: 4.8-5.6, Manganite: 4.2-4.4, Braunite: 4.7-4.9, Psillomelane: 3.7-4.7, Hausmannite: 4.7-4.8) as compared to the most commonly associated gangue minerals like, quartz & chert (2.65), calcite/limestone (2.70-2.75), clay/shale (2.65), gibbsite (2.67).

Effectiveness of gravity concentration depends on proper feed preparation which includes, crushing, screening & grinding to liberation size and also to ensure feed of a proper size to a particular unit operation (machine), removal of slimes which affects the separation efficiency of the machine as it enhances viscosity of the pulp and hampers proper sizing of crude fractions before subsequent treatment.

There is an amazing array of mechanical devices that have been conceived, built, and marketed to separate minerals based on particle specific gravity differences and are available to treat particles across a wide size ranges from 50 mm to 0.03 mm (30 µm). Some of the most common gravity concentrators are discussed below:

3.3.2.1. Heavy-media Separation (HMS): The process is used for coarse ore in the size range of -50+3 mm. Ferro-silicon suspension is generally used in these separators as dense medium. Rotary drum (spiral & drum-type vessels) is most commonly used. Ferro-silicon ground or atomised (-300 mesh) is used as suspension to create a parting density of 3-3.2 that is sufficient to separate common gangue minerals to float. The suspension medium can be easily recovered by low intensity magnetic separator (LIMS). Media loss is the largest single cost factor in HMS. Normal losses are in the range of 0.1 to 0.4 kg/t of ore treated. Feed for the HMS should be hard & compact hematite with non-porous gangue mineral and are thoroughly washed to clean slimes before its use. In general, porous ores accounts for substantial loss of media (extent of 1 to 1.5 kg/t of ore treated) as cavities/pores of ore is filled up with the medium.

3.3.2.2 Heavy-media Cyclone (HMC): The process is used for fine ore in the size range of -6+0.2 mm. The cyclone type separator utilises centrifugal as well as gravitational forces to make separation between ore and gangue minerals. The centrifugal force makes it possible to bring about separation at a specific gravity lower than that required in the conventional separator. Ferrosilicon (-325 mesh) in water is used as a media in cyclones. A parting density of 3.2 (max.) can be maintained successfully.

3.3.2.3 Jigging: This is one of the oldest methods of gravity concentration technique where bulk materials are separated into light fraction, medium-density fraction and heavy-density fraction. Processing is possible for manganese ore at the size of 30 mm to 0.5mm. Batac jig is one of the commercial units available in the market (5 m x 6.2 m size) with a throughput capacity of 500 tph. This jig is reported to have capability to treat both coarse as well as fine feed.

3.3.2.4 Spirals: They have wide range of application in gravity treatment of manganese ores and can be used in almost all circuits of roughing, cleaning & scavenging. Feed size applicability is in the range of 1 mm to 0.03 mm (30µm). Spirals are normally operated at a pulp density of 25-30% solids. A single spiral can treat up to 3 tph and several different configurations to take care in feed characteristic variations.

3.3.2.5 Tables: They have wide range of application in gravity treatment of manganese ores and can be used in cleaning & scavenging circuit. Feed size applicability is in the range of 1 mm to 0.03 mm (30µm). Tables are normally operated at a pulp density of 25-30% solids. A single table can treat up to 2 tph capacity (max.).

3.3.2.6 Multi Gravity Concentrator (MGS): MGS is designed to treat fines & ultra-fine particles. It may be of use for processing of valuable from slimes or tails. However, high capacity industrial trials are yet to be established.

3.3.2.7 Floatex Density Separator: This is a very high capacity hindered settling classifier and is designed to treat particles below 1 mm size. It can be used for concentration, pre-concentration or compartmentalization of particles of different specific gravity mineral.

3.3.2.8 Cyclones: Cyclones comprehend the entire gamut of devices from hydro-cyclone, stub cyclone and heavy media cyclone (HMC) which offer a wide array of benefits. They offer the cutting edge technology for cost reduction. The use of cyclones with their simple construction, smaller size and low cost, high capacity per unit area, flexibility in operation, can be used for pre-concentration of iron ore mineral below 3 mm size. These cyclones would play an increasingly important role in Indian manganese ore industry either as classifier/dewatering devices or as a concentrator (stub cyclone).

3.3.2.9 Water only cyclone or Stub cyclone: This is obtuse angle short cone cyclone and uses water as a medium to separate particles based on specific gravity at a coarser size and produce a consistently high density well de-slimed spigot product. Stub cyclone offers various advantages namely, cheap and efficient method for beneficiation of -100 mesh (-150µm) size particles, high capacity (on account of very less residence time), have no moving parts, requires less floor space, better metallurgical performance, hence environment friendly and low operating cost.

3.3.3 Magnetic Concentration

The common manganese mineral in the country are feebly-magnetic. Hence, separation of valuable magnetic manganese minerals from that of non-magnetic associated gangue minerals like quartz, amphiboles, barite, apatite, calcite etc., can be achieved by exploiting the difference in magnetic properties. The magnetic separators are classified into low and high intensity/gradient magnetic separators that can be operated wet or dry circuit.

3.3.3.1 Low Intensity Separators (LIMS): These separators are designed with a magnetic intensity of 1200 gauss in the separation zone to recover highly magnetic jacobsite minerals from feebly magnetic manganese ore.

3.3.3.2 High Intensity Separators: These separators are designed with a magnetic intensity of 7000 to 20,000 gauss in the separation zone to recover feebly magnetic minerals of manganese from those of non-magnetic silicate gangue. Dry separators (DHIMS) can be used for concentrating manganese ore, but the ore should be bone dry and sized. Wet high intensity magnetic separators (WHIMS) are generally used for treating manganese ores at finer sizes.

3.3.4 Electrostatic Separation

Electrostatic or High Tension Separators are useful for removal of conducting garnet gangue from non-conducting manganese minerals. Both drum and plate type separator can be used.

3.3.5 Froth Flotation

The process of flotation is applicable for fine liberation mesh mineral for removal of gangue mineral.

Fatty acid collectors displayed possibility of separation of quartz and other silicate minerals. Removal of phosphate bearing apatite mineral can also be floated with fatty acid as collector. The Manganese minerals can be floated with same fatty acid at a pH of 6.5 leaving behind silica in the tails.

One or combinations of various methods are used for concentration of manganese minerals from its gangue. These concentrates are invariably in the form of fines and can be used in subsequent metallurgical industry only after suitable agglomeration like briquetting, sintering, pelletisation etc.

3.4 MINERALOGICAL CHARACTERIZATION OF INDIAN MANGANESE ORE

Various steps involved in mineral beneficiation are ore characterisation followed by separation of identified mineral phases by exploiting physical properties of hardness, specific gravity, magnetic susceptibility etc.

Characterisation of the r.o.m. manganese ore is the first step in developing a successful beneficiation flow-sheet and leads directly to selecting the most effective concentrating equipment. The basic objective of the ore characterisation is to understand the mineralogy of the ore. Once understood, especially as related to liberated particle size, then selection of appropriate separating equipment can proceed. For purposes of developing a successful gravity concentration process, the mineralogical analysis is best focused on the "nature of mineralization & mode of occurrence" and at times its paragenesis (an ordered chronological sequence of mineral formations) of both the valuable and gangue constituents.

A good mineralogical characterisation of the ore will result in knowing more about the following:

(i) The minerals of value, their chemical composition, and their specific gravity;

(ii) The gangue mineral, their chemical composition, and their specific gravity; and

(iii) The grain size range of both the value and gangue minerals, including information on intergrowth occurrence on both.

Characterization of Indian manganese ore revealed that predominating is soft nature Pyrolusite, followed by Psilomelane, Braunite, Hausmanite, Sitaparite, Hollandite etc., and quartz, mica, jacobsite, baryte, feldspar, clay, epidote, chlorite, gibbsite, limonite/goethite, hematite, apatite, garnet, spessartite, rhodonite, calcite etc., constitutes the gangue.

In India, bulk of the high-grade manganese ore is constituted by gonditic type (quartz, spessartite assemblages) of deposit, the medium and low-grade ore are largely contributed by the kodurite and lateroid type of deposits.

The gondite type of deposits comprises ore minerals like braunite, psilomelane, pyrolusite, sitaparite (bixybite), vredenburgite (jacobsite and hausmanite). The ore minerals occurring in the khondalite/kodurite type of deposits are psilomelane with some pyrolusite, braunite, manganite. The lateritoid deposits consist of ore minerals like psilomelane, pyrolusite, wad, and limonite.

3.5 INDIAN MANGANESE ORES & ITS BENEFICIATION POTENTIAL

Manganese ore characteristics of Indian deposits vary widely. The deposits in Maharashtra, Andhra Pradesh and Madhya Pradesh are mostly siliceous in nature with medium to high phosphorus content, while deposits in Odisha, Karnataka and Goa are ferruginous in nature with low phosphorus and high alumina content. Also, geologically the pattern of mineralization varies drastically from massive and compact ore bodies in Maharashtra and Madhya Pradesh to lean, lens and pocket occurrence in Odisha.

In Indian manganese ore deposits, psilomelane (Mn_2O_3, BaO, H_2O) and braunite (Mn_2O_3) ores account for over 90 per cent of the total reserves of manganese in the country, while pyrolusite (MnO_2) and cryptomelane are other important ores.

Major gangue and or deleterious impurities that need to be rejected for value addition of manganese ore are siliceous and ferruginous gangue and phosphorus impurities.

Siliceous gangue includes quartz, shale, clay, feldspar and other host rock impurities, while ferruginous impurities accounts for limonite/goethite & hematite mineral. Presence of apatite minerals accounts for phosphorus constituents.

Siliceous gangue constituent can easily be rejected at various sizes deploying conventional gravity concentration technique of HMS, Jig, Spiral, Table etc., followed by high intensity magnetic separation (dry/wet).

Alumina contributed by softer clay and harder altered feldspar. Removal of clay by impaction or compaction activities also accounts for loss of pyrolusite along with clay minerals in finer fractions. To this extent it is expected that some manganese losses will occur during the process of mechanical washing physical processes. The possible applicable processes identified for manganese ore are classification, washing, hand sorting or HMS at coarser size followed by jig, spiral or table of finer size fraction.

Ferruginous gangue are difficult to process as both the iron and manganese bearing minerals have similar physical properties like specific gravity and magnetic susceptibility even after liberation and they cannot be separated by simple physical beneficiation techniques.

Thus, such ore requires conversion of iron bearing minerals of limonite/goethite and hematite to magnetite by reduction roasting, which then can be separated by low intensity magnetic separation (1200 gauss) at which the manganese minerals are non-magnetic.

High phosphorous manganese ores contains invariably the apatite as main phosphorus bearing mineral that can either be floated with fatty acid collector or subjected to WHIMS for its rejection in the non-magnetic fraction.

3.6 BENEFICIATION OF INDIAN MANGANESE ORES: AN R&D PERSPECTIVE

In the present scenario, Indian manganese ores, on account of selective mining does not require elaborate treatment/processing. Hand sorting is just sufficient to upgrade the quality of lumps, especially with respect to manganese content.

IBM developed a number of flow sheets as per requirement ofclient onvarious kinds of manganese ore.Different manganese ores require varied types of upgrading treatment depending upon the gangue minerals present.

Indian manganese ores, based on its mineralogical impurity can be broadly classified under the following categories, a case study of each type is discussed as below:

3.6.1 Beneficiation of Siliceous Ores

A medium-grade siliceous manganese ore from Bharveli mines, Balaghat was subjected to process flow-sheet development for production of manganese concentrate in various size fractions.

The sample assayed 41.9% Mn, 19.0% SiO_2, 3.3% Fe, 1.6% Al_2O_3 and 3.7% $BaSO_4$. Psilomelane and Pyrolusite are the main manganese bearing minerals; quartz, mica and feldspar are the main gangue minerals.

The developed process route of beneficiation is presented in Fig-1 that comprised of wet screening to generate required size fraction of -75+25 mm, -25+6 mm & -6 mm. The process of concentration in each size fraction was carried out by hand sorting of reject/gangue constituent from -75+25 mm fraction; jigging of -25+6 mm fraction and from the screen undersize of minus 6 mm, the valuable concentrate is obtained after classification cum jigging of classifier overflow.

The hand sorted accept and both the jig concentrate (-25+6 mm & -6+0.212 mm) constitute the final concentrate.

The composite process concentrate obtained assayed 50.8% Mn, 9.2% SiO_2 with weight yield of 61.6%. The overall process rejects namely, classifier underflow (-65 mesh), both the jig tails (-25+0.212 mm) and manually sorted lump reject combined assayed 27.9% Mn, 50.28% SiO_2 with weight yield of 38.4%.

No further processing of composite process rejects were planned as these materials too have readily available market and hence not attempted.

Fig-3.1: Evolved Process Flow sheet for Siliceous Manganese ore

FLOW SHEET ADOPTED FOR BENEFICIATION OF SILICEOUS MANGANESE ORE FROM BHARVELI MINES, BALAGHAT, MP

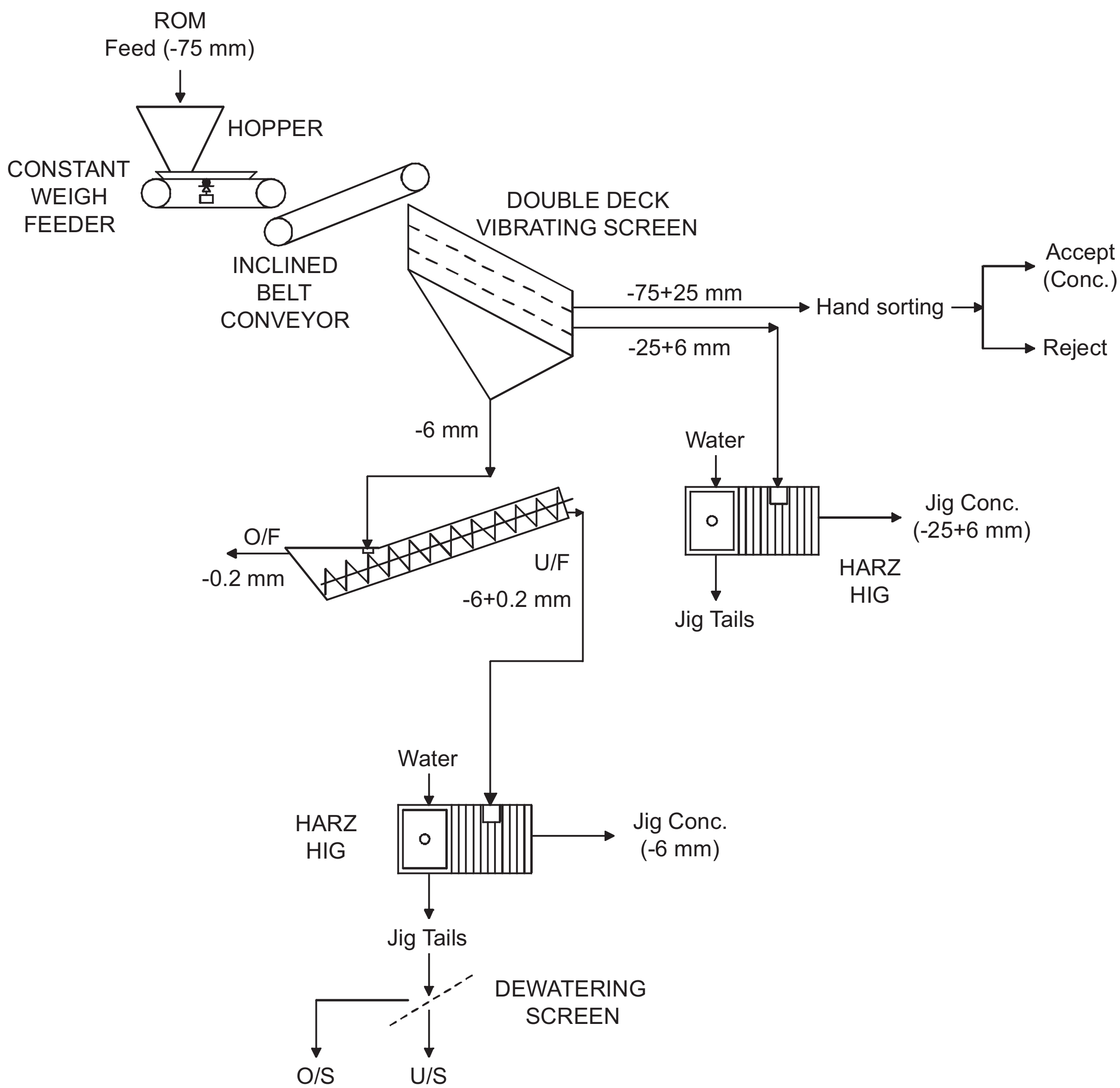
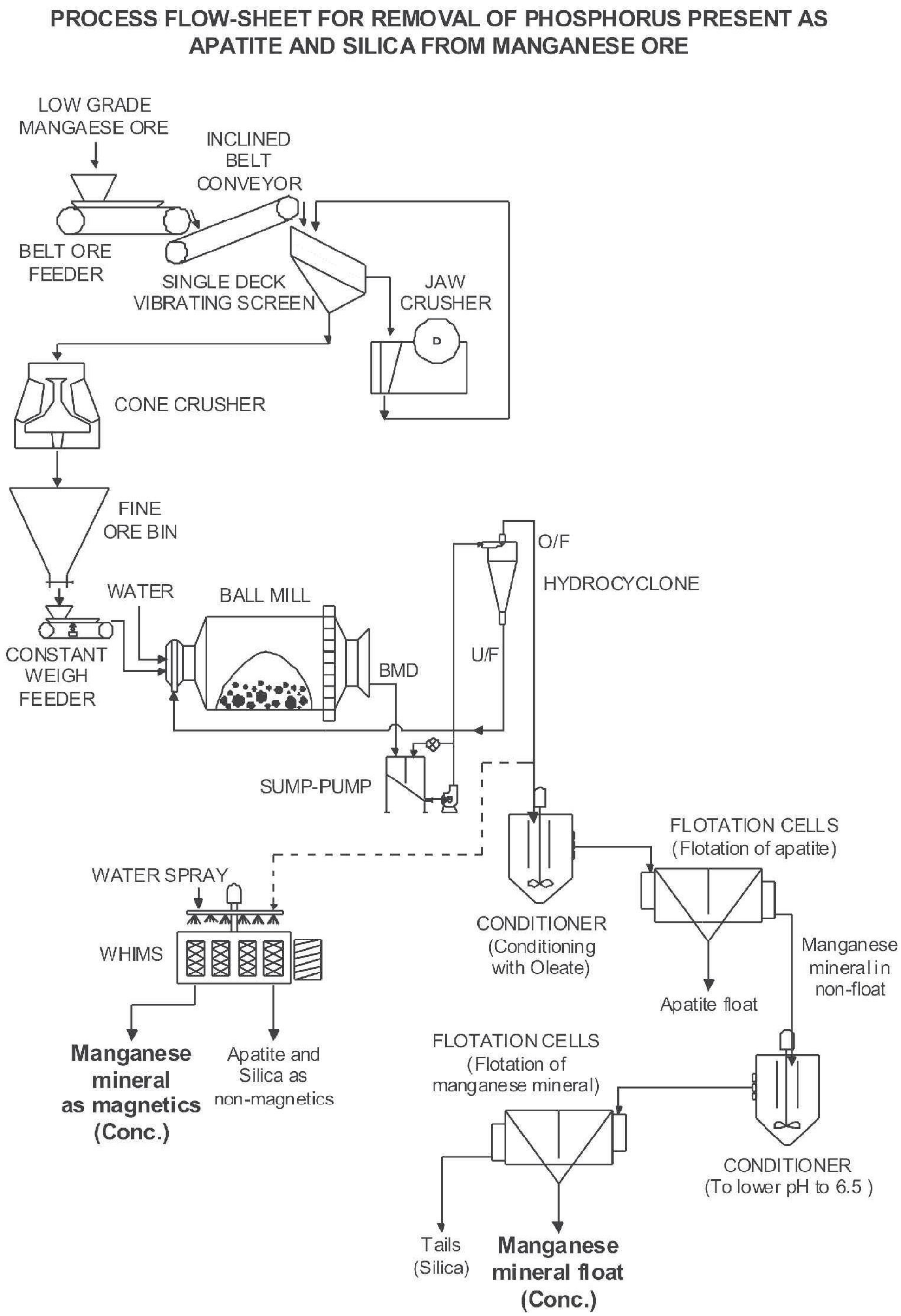


Fig-3.2: Evolved Process Flow sheet for high phosphorus Siliceous Manganese ore



3.6.2 Beneficiation of High Phosphorus Ores

Phosphorus content in manganese ore for ferromanganese industry desired to be below 0.15%. Phosphorous in manganese ore is present either in the form of discrete mineral apatite or thoroughly dispersed as solid solution in the manganese matrix.

Two different route of beneficiation process flow sheet has been developed for the same, one flotation; and other high intensity magnetic separation. A case study of each is discussed below:

3.6.2.1 Flotation route: A medium-grade manganese ore from Chikla mines assayed 38.2% Mn, 0.31% P, 22.84% SiO_2 and 8.32% Fe. Braunite was the main manganese bearing mineral followed by Jacobsite and hausmanite are in minor amounts. Quartz was the main gangue mineral followed by hematite in minor amounts. Apatite was observed to be the only phosphorous bearing mineral intimately associated with manganese minerals.

Evolved process route of beneficiation (Fig-2) at the grind of 70% minus 200 mesh and involves two-stage flotation. Firstly, of apatite at natural pH deploying fatty acid collector and secondly by flotation of manganese minerals with same fatty acid at 6.5 pH with single stage cleaning. Silica tails formed the reject.

The cleaner manganese concentrate assayed 45.5% Mn, 0.1% P with weight yield of 60.1%. The phosphorus float assayed 31.8% Mn, 1.65% P with weight yield of 8.8%. The overall process reject assayed 27.3% Mn, 0.58% P with weight yield of 39.9%.

3.6.2.2 Wet High Intensity Magnetic Separation (WHIMS): A sample from South Tirodi mines assayed 43.5% Mn, 9.4% Fe and 0.31% P. Braunite was the principal manganese bearing mineral followed by Jacobsite in minor amounts. Quartz was the main gangue mineral. Apatite was observed to be the only phosphorous bearing mineral intimately associated with manganese minerals that displayed a fair liberation from associated manganese minerals at 100 mesh sizes.

Evolved process route of beneficiation at the grind of minus 100 mesh and subjected to low intensity magnetic separation (1200 gauss) to reject jacobsite and then subjected to high intensity magnetic separation (over 10000 gauss) to recover manganese minerals as magnetics. The non-magnetics formed the phosphorous and silica rejects. The process flow-sheet is presented in Fig. 2.

The highly magnetic concentrate assayed 40.3% Mn, 0.22% P & Fe 18.8% with weight yield of 7.6%. The feebly magnetic assayed 46.9% Mn, 0.13% P & Fe 8.35% with weight yield of 71.8%. The combined magnetic concentrate assayed 46.27% Mn, 0.14% P & Fe 9.35% with weight yield of 79.4%. The non-magnetic reject assayed 32.25% Mn, 1.05% P & Fe 7.47% with weight yield of 20.6%.

In both the process route of beneficiation a substantial manganese values (around 30% Mn) were lost in tails that does not considered for further recovery of valuables on account of readily available market for the reject.

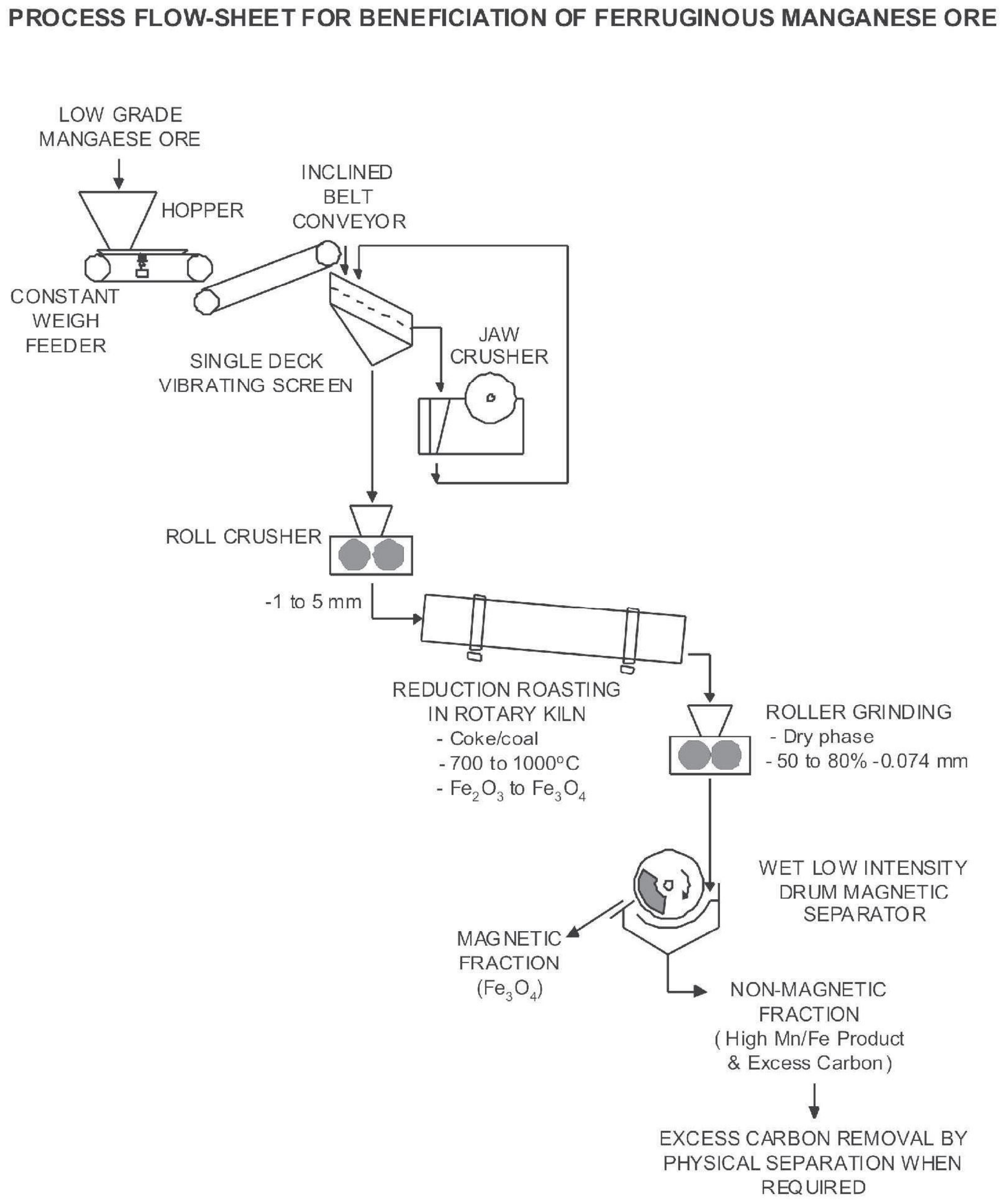
However, if the phosphorous is present in the form of solid solution in manganese ore, none of the ore dressing techniques can reduce it further and only way to use such ores for ferro-alloys production is to blend with low phosphorous ores.

3.6.3 Beneficiation of Ferruginous Ores

In Ferruginous manganese ore, both the manganese and iron bearing minerals have similar physical properties like specific gravity and magnetic susceptibility. Even after liberation from one another they cannot be separated by deploying physical beneficiation techniques. The iron bearing minerals could be converted to magnetite by reduction roasting which can be pulled out as magnetic fraction deploying a magnetic intensity of 1200 gauss at which manganese minerals are non magnetic.

A ferruginous manganese ore from Sandur area, Karnataka assayed 34.1% Mn, 17.7% Fe, 6.9% Al_2O_3, 8.5% SiO_2 and 0.5% $BaSO_4$. Psilomelane and Pyrolusite were the manganese bearing minerals. Hematite and goethite were the iron minerals present in the sample.

Fig-3.3: Evolved Process Flow sheet for Ferruginous Manganese ore



The evolved process route of beneficiation carried out at -10 mesh size and subjected to reduction roasting at 600-8000C for an hour. Reduced mass was then quenched in water to retain the reduced phase. The quenched mass was further crushed to -65 mesh and subjected to low intensity wet magnetic separation at 1200 gauss to reject the converted magnetite. The process flow-sheet is presented in Fig. 3.

The highly magnetic concentrate assayed 24.4% Mn, 24.2% Fe & 7.8% SiO_2 with weight yield of 60%. The non-magnetic assayed 49.5% Mn, 9.1% Fe & 9.2% SiO_2 with weight yield of 40%.

The reduced mass contained iron in the form of Fe_3O_4 and also jacobsite ($MnFe_2O_4$) which is highly magnetic and accounted for major manganese losses in magnetic fraction resulting in less manganese recovery in the non-magnetic fraction (manganese concentrate).

Extensive Research and Development (R&D) work has been undertaken by Ore Dressing Laboratory of IBM engaged in beneficiation of manganese ore, particularly on low/medium-grade manganese ore from different parts of India with varying mineralogical nature and physical characteristics to evolve a suitable process flow sheet for recovery of manganese ore in India over the years. R&D findings, established that piece-meal approach of value addition in the existing processing circuit may not be a good option for production of quality product for long. Thereby much emphasis has to be given to concept of beneficiation of Indian manganese ores in its entirety i.e., concept of total beneficiation of r.o.m. manganese ore at its cut-off.

The aforesaid flow sheet may provide a user friendly guidelines that can be used successfully with minor modification in almost all types of manganese ore deposit in India.

3.7 COST-BENEFIT ANALYSIS OF BENEFICIATED CONCENTRATE

The beneficiated concentrate are generally fines that needs agglomeration before its use. The fact of the problem is the comparison of cost of the agglomerated product with that of lumpy ore of the same quality. An attempt has been made to have a approximate cost-benefit analysis of beneficiated concentrate vis-à-vis high-grade lumps.

3.7.1 Beneficiation Cost for siliceous & High Phosphorus Ore

In the above processes route of beneficiation, the weight recovery of the concentrate is around 60%. Therefore, about 1.7 tonnes of low/medium grade ore is required to produce 1 tonnes of concentrate.

Feed Grade	:	Mn-28 to 32%
Concentrate Grade (Beneficiated)	:	Mn- 45 to 48%,
Cost of the low grade ore	:	Around Rs. 5000/- per tonne
Cost of the ore per tonne of concentrate	=	1.7 x 5000 = Rs. 8,500/-
Cost of beneficiation	=	Rs. 1000 per tonne (Approx.) of ore.
Cost to produce per tonne of concentrate	=	1000 x 1.7 = Rs. 1700/-
Cost of beneficiated concentrate	=	8,500 +1700 = Rs.10,200/-
Cost of sintering	=	Rs. 1500/- per tonne
Cost of the high grade sinters	=	10,200 + 1,500 = Rs. 11,700/-
Cost of the high grade lumpy ore	=	Rs. 15,000/- per tonne

Hence, cost of the beneficiated sintered products compares well with that of high grade lumpy ore with a margin of over Rs. 3,000/-per tonne.

3.7.2 Beneficiation Cost (Operating) for ferruginous ore

Figures are based on actual data from bulk scale investigations on Odisha & Karnataka sector ores.

Feed Grade : Mn-28 to 32%, Fe-14 to 25%
Concentrate Grade (Beneficiated) : Mn- 45 to 48%, Fe-6 to 8%

Sl No.	Particulars		Quantity	Rate/unit	Rs/T
1.	Water		5 Cu M/T	Rs.10/-	50/-
2.	Power (including grinding)		75 Kwh/T	Rs. 6/-	450/-
3.	Coal Fines		150 Kg/T	Rs.8/-	1200/-
4.	Salary + Maintenance + OH	:			300/-
	TOTAL				**2000/-**

Recovery of Concentrate by weight : 40%
2.5 tonnes of R.O.M. is required to produce 1 tonne of concentrate
Cost of the ore around 30-32% Mn : Rs. 2800 per tonne (purchased fines)

Cost of the ore per tonne of concentrate = 2800 x 2.5 = Rs. 7000/-
Cost of beneficiation = 2.5 x 2000 = Rs. 5000/-
Cost of beneficiated fine concentrate = Rs. 12000/- per tonne (Rs. 7000 + Rs. 5000)
Cost of sintering = Rs. 1500/- per tonne
Cost of the sintered product = Rs. 13500/- per tonne (Rs. 12000 + Rs. 1500)
(A grade of the beneficiated concentrate of 48% Mn, 6% Fe, would produce sinter of around 50% Mn content.)

The cost of the high-grade lumpy manganese ore containing 48% Mn is Rs. 15000/-, clearly indicating the margin of Rs. 1500 per tonne in addition to utilisation of low-grade ferruginous manganese ores which are in major occurrence in India, thus, helping the conservation of these valuable minerals.

Cost of beneficiation of manganese ores followed by sintering of the concentrate so produced compares well with that of lumpy manganese ore of the same grade/quality.

3.8 POTENTIAL BENEFICIABLE MATERIAL IN EXISTING MINING AREA

The incessant demand for manganese ores from overseas markets have largely been met by exports from India of raw unprocessed ores of high-grade during the past few decades. The sub-standard grades have hitherto been chiefly neglected or wholly discarded. The high-grade manganese ore is generally hand-picked from the manganese ore burden after blasting in opencast mining leaving the low-grade manganese ore with no prospects at present of economic utilisation.

It is roughly computed that for every tonne of high-grade manganese ore mined, there remains discarded at the mine site 1-2 tonnes of the low-grade ore. It has been reported that large dumps of low-grade manganese ores have been accumulated in close proximity to most of the mines in the country over the period.

This material which so far has been dumped aimlessly is the future resource for the valuable manganese. The reserves of sub-standard grade ores are much greater. Deposits of high-grade manganese ores are not however inexhaustible. Whilst the indigenous manufacture of exportable grades of standard ferromanganese in place of large shipments of the raw high-grade manganese ore has been recognized as of utmost national importance, mineral beneficiation and upgrading of low-grade manganese ores have not received due attention.

Almost in all existing manganese ore mines and processing units in India, a substantial amount of unexploited sub-grade ore and process rejects (fines) are lying unutilized for lack of deployment of proper beneficiation technology. Besides, consequent upon lowering of cut off grade from 20% Mn to 10% Mn, a sizeable low grade reserve/resource of manganese ore will occur in the range of 10-25% Mn. All these are potential source of beneficiable ore that warrant immediate attention for value addition.

For most Indian manganese ores, upgrading flow-sheets have been drawn up based on IBM (Ore Dressing Division) investigations and which are currently being made use of by those in the manganese mining and export trade.

The results of a large number of investigations on low-grade manganese ores undertaken at Ore Dressing Laboratory, IBM show that concentration of manganese ores to render them suitable for standard grades ferromanganese production is not an easy task.

However, the process route of beneficiation on the predominant gangue characteristics of siliceous or ferruginous or deleterious constituent of phosphorus exceeding 0.15% P etc., will be more or less on similar lines to those discussed in item 3.6.

Situations where beneficiation will continue to prove both necessary and rewarding include: (i) utilisation of fines from crushing, washing, and screening activities associated with most manganese ore production; (ii) utilisation of the lower-quality material that occurs within and adjacent to higher-grade deposits; and (iii) utilisation of sub-grade individual deposits not suitable for use without upgrading.

The beneficiation of aforesaid materials and the selection of the process used will depend on the characteristics of each ore, the location of the deposits, and the relative economics of processing.

Based on the gained expertise, conceptual flow sheets for total beneficiation of Indian manganese ore may be drawn taking into account the recovery of manganese concentrate across all sizes of lumps and fines.

Some of the routes of beneficiation of manganese ore evolved in relation to its gangue constituent are summarized in Table-1.

Table-3.1: Process route of beneficiation of Manganese ore vis-à-vis gangue mineral

Ore Type	Gangue	Process of Upgradation
Siliceous ores	Quartz etc.	Gravity concentration methods such as heavy media separation (HMS), Heavy Media Cyclone (HMC), Jigging, Spiraling, Tabling or straight magnetic separation (High Intensity Magnetic Separation).
	Apatite, quartz	Flotation or Gravity concentration cum flotation.
	Garnet, quartz	Electrostatic separation has been found to be the most efficient for separation of garnet from manganese minerals though flotation in some cases has proved satisfactory.
Ferruginous ores	Hematite, Goethite, Limonite	A process of magnetising reduction roast to convert the ferruginous minerals to magnetite followed by low intensity magnetic separation at its liberation size.
Complex ore		
Manganese ore having very intricate relation with associated gangue.	Quartz, apatite, garnet, Clay, Feldspar, hematite, Hydrated Iron Oxide minerals	Requiring three or even more steps for the elimination of the gangue and production of high-grade concentrates. Combination of Gravity-Magnetic, ESS, Flotation.

3.9 INDIAN SCENARIO

Manganese ore beneficiation facilities in the country are highly inadequate. Dry screening followed by hand sorting and visual grading is adopted widely to upgrade the ore. Scrubber is also used for washing the ore at some mines. Manual as well as mechanised jigging is done in a few mines.

3.9.1 Manganese Ore Beneficiation Plants in India

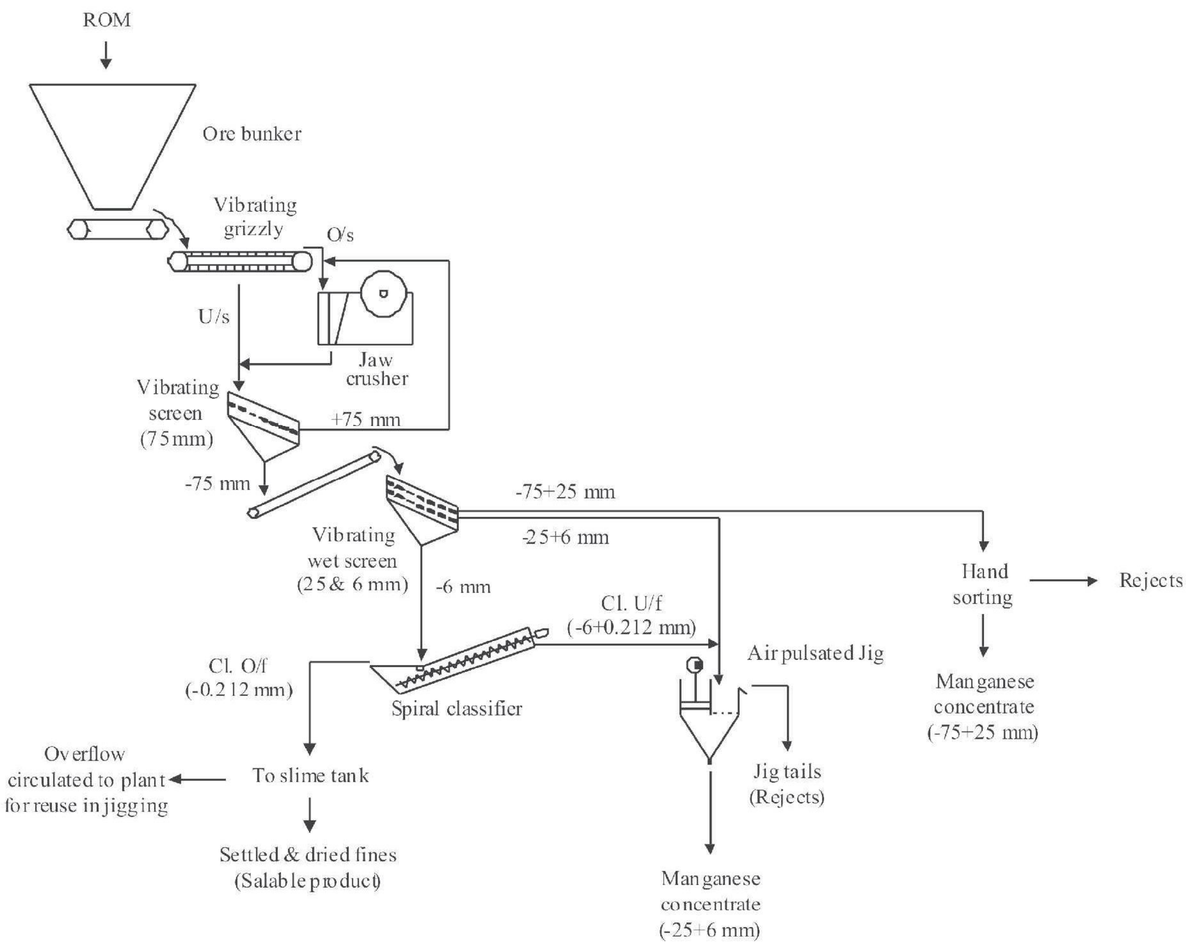
In Indian Scenario almost all the manganese mines resorted to selective mining followed by dry screening and hand sorting of manganese minerals. In none of the mine elaborate and sophisticated beneficiation is practiced. However, beneficiation practiced in a few plant are discussed herewith.

3.9.1.1 IMB Plant, Bharveli Mine, District:Balaghat, Madhya Pradesh M/s MOIL

In the Bharveli underground mine because of mechanization dilution occurs on ROM grade on account of inter-mixing of country rock with the ore. Manganese ore is hard and lumpy, mainly consists of braunite and other minerals such as psilomelane and holandite. The major physical impurities mixed with ROM are quartzite, schist, country rock, chert, quartz etc.

The process route of beneficiation is presented in Fig-4, encompasses crushing and screening to all minus 75 mm followed by wet screening at 25 mm and 6 mm aperture size to produce three size fraction of -75+25, -25+6 mm and minus 6 mm. The screen undersize of minus 6 mm is subjected to spiral classifier to produce two products of classifier underflow (-6+0.212 mm) and overflow (<65 mesh).

Fig. 3.4: Flow sheet of IMB Plant, Bharveli mine, MOIL



Each size fraction is than subjected to concentration of manganese ore namely, for -75+25 mm by hand sorting; -25+6 mm and classifier underflow fed to electronically controlled air pulsated coarse and fine jig respectively. High grade manganese ore concentrate produced from the jig is dewatered.

Classifier overflow containing (-) 65 mesh fines fraction is drained out and accumulated in slime tank. The settled and dried fines are saleable product of the plant. The overflow of slime tank is recycled back to the circulating water tank and this water is recycled for jig operation.

The Integrated Manganese Ore Beneficiation Plant has enhanced the recovery of cleaned ore to 76% compared to less than 50% in old manual system. The plant is based on IBM's developed flow-sheet.

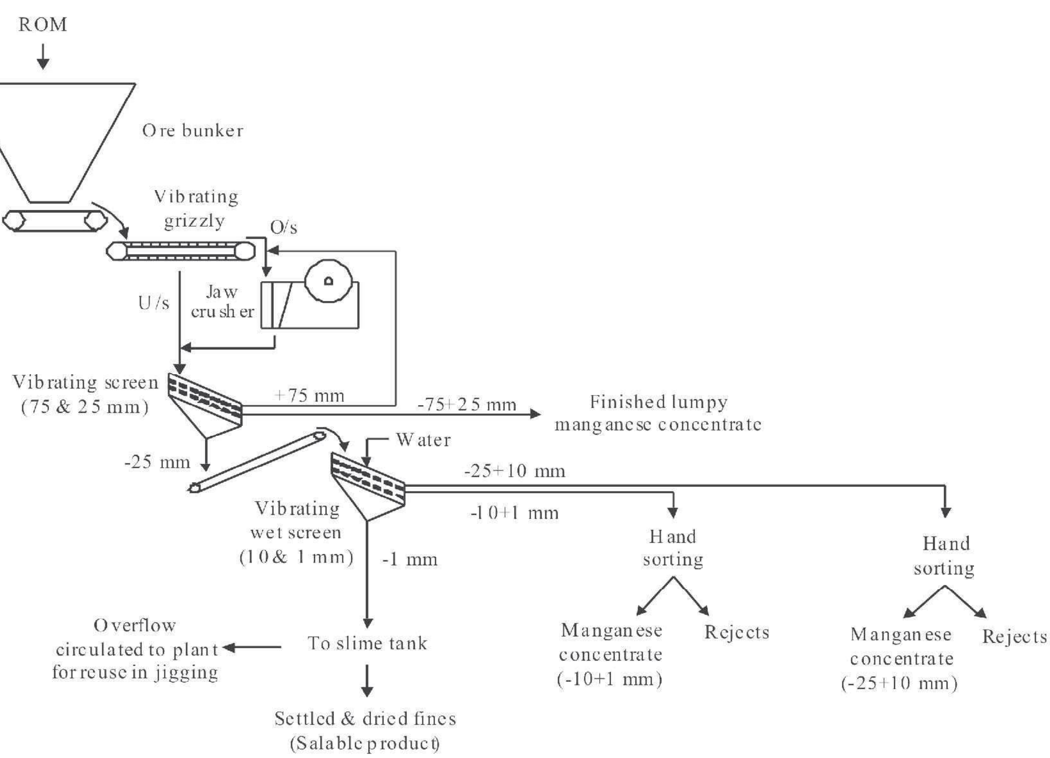
3.9.1.2 IMB Plant, Dongri - Buzurg Mine M/s MOIL

Dongri-Buzurg mine is a mechanized open cast mine. ROM ore comprises a mixture of soft as well as hard lumpy in nature mainly consisting of pyrolusite mineral. During mining operation, ROM is mixed with the country rock mainly schist, quartzite, soil, weathered rock, laterite etc. During mining and transportation, huge quantity of fines is generated, which makes it necessary to screen and wash the ore to separate out in various sizes. Certain portion of ores from the weathered zone is subjected to beneficiation activity at IMB plant.

The process route of beneficiation is presented in Fig-5, encompasses crushing of ROM ore to all minus 75 mm size followed by screening having aperture size of 25 mm. The screen undersize (-25 mm) is subjected to wet screening on double deck vibrating screen having aperture size of 10 mm and 1 mm aperture respectively to obtain three size fraction of -25+10 mm, -10+1 mm and -1 mm. The screen undersize -1 mm fraction is stored in a settling tank for recovery of fines.

The size fraction of -75+25 mm lumpy ore does not require any further treatment. While, the rest of the sized material (below 25 mm), are finally sent to sorting yard for hand sorting and stacking.

Fig. 3.5: Flow sheet of IMB Plant, Dongri-Buzurg mine, MOIL



3.9.1.3 Sandur Manganese and Iron Ores Limited

In the Sandur area, the manganese bearing mineral are pyrolusite, cryptomelane, psilomelane, manganite and lithiophorite with main gangue of ferruginous minerals. Besides selective mining, the value addition is practiced and manual or mechanized sorting is crushing and screening. The beneficiation plant is treating manganese ore of 22-24% Mn. The left over material after hand sorting, containing low manganese content is treated as sub-grade ore and is stacked separately (below 22% Mn and above 10% Mn).

The process of beneficiation involves crushing and screening of ROM ore to all minus 100 mm size followed by screening to produce three size fraction of -100+40 mm, -40+10 mm and -10 mm. The saleable product is collected from first two size fraction (-100+10 mm). The minus 10 mm fines are stacked separately.

Present Status & Suggested Action Plan

The Indian manganese mining industry currently is being run in fragmented lease holds. Besides a handful of big mines, most of the mines are operated by very small mine owners in very low scale as the ores mainly occur as pockets.

Selective mining coupled with dry screening and hand sorting is process route of beneficiation practiced by almost all the manganese producing companies barring a few.

The small and medium size entrepreneurs are reluctant to create beneficiation facility as it is capital intensive; and due to problems associated with procurement of land, water, power and environmental clearances.

Therefore, a concept of custom mill is suggested for beneficiation needs, whereby the low-grade ores and fines from near vicinity of small mines will be received and after blending, processed in a centralised processing unit due to their analogous mineralogical and chemical characteristics. The concentrate so produced would be sintered or supplied to the sintering units.

In the light of prevailing Indian scenario, it may be concluded that with the lowering of threshold value to 10% Mn for manganese ore, the reserves grade of manganese ore would be further lower down and the beneficiation would assume much significance. Thus, value addition of r.o.m. manganese ore in its totality (concept of total beneficiation) for both lumps and fine fraction is crucial and assumes significance. The beneficiation should be aimed to explore the possibility of obtaining concentrate in the range of over 35% Mn suitable for silicomanganese production which would reduce the load on imports and makes the country self-sustainable in manganese ore supply.

This will be useful for optimum utilisation and conservation of limited availability of high-grade reserves of the natural resources vis-à-vis take care of the environmental degradation on account of perpetual stacking of unprocessed material. i.e., low grade manganese ore, mines and process rejects.

Agglomeration

Manganese ore mining and processing in India generates a very high-amount of fines (20-30%). These fines cannot be added directly to the furnace for making of manganese alloy or iron (BF) as operational instability may arise that may lead to technological abuses in smelting process and pose a threat to human health and equipment health. The detrimental effect of fines is dependent on chemical composition, size of fines and also on the process itself; silicomanganese versus ferromanganese, open versus closed furnace, and the size of furnace. The fines therefore have to be screened out before using the ore in the furnace for metallurgical processing. Thus, huge quantity of fines is getting accumulated both at mines site and at the plant lying unused for the last so many years. From the economic and environmental point of view, full utilization of these fine raw materials is desired. The fines unless agglomerated to required size cannot be used for metallurgical applications.

Limited availability of high-grade lumpy manganese ore reserves in the country and high dependence for value addition of ROM manganese ore have resulted in generation of high-grade fine concentrate through beneficiation. This has necessitated agglomeration of manganese ore fines for its superior and consistent quality, which in turn enhances the productivity.

Of the three agglomeration techniques available, briquetting is not adoptable because of phase change during metallurgical operations. Pelletisation is ruled out because of quantum and cost involved. Manganese ore fines are generally agglomerated by sintering methods because of low softening point (1150 to 12000C), which can be further lowered by flux addition. Thus, sintering is the most appropriate and acceptable technology for manganese ore fines because of its flexibility and strength of the sinters in the country.

Sintering is the agglomeration technique of fine materials to produce clusters by incipient fusion at high temperature. Sinters are often used as raw materials in the Submerged Arc Furnace (SAF) producing ferro/silicomanganese. Sintering produces a feed of extremely consistent quality in terms of its chemical composition, grain size distribution, reducibility and sinter strength.

Advantages of sintering are: (i) Gainful utilisation of manganese ore fines; (ii) Improved charge permeability in the furnace; (iii) Deeper penetration of electrode due to increased charge resistivity; (iv) Considerable power saving per tonne of ferro/silicomanganese; (v) Reduction in explosions due to reduced oxygen levels in charge; (vi) Productive utilization of coke fines; (vii) Reduced pollution as fines are major land pollutants; and (viii) Conservation of lumpy ores.

The use of manganese ore sinters is claimed to have been advantageous over lumps because of their higher permeability and reducibility, though from a first consideration it will appear that the exothermic heat which would have been otherwise available when higher oxides of manganese reduced to lower oxides inside the furnace is lost in sintering. The pre-reduction of the higher oxides in the sintering process results in the loss to the furnace of exothermic reactions of reducing MnO_2 to Mn_2O_3 and Mn_2O_3 to Mn_3O_4. This heat being quite appreciable, and therefore, an explanation of the additional power required for smelting sinter. But there seems to be no appreciable increase with small amounts of sinter up to 20% in the charge. The reason is that a small proportion of sinter blended with ore increases the porosity of the charge and results in improved gas distribution.

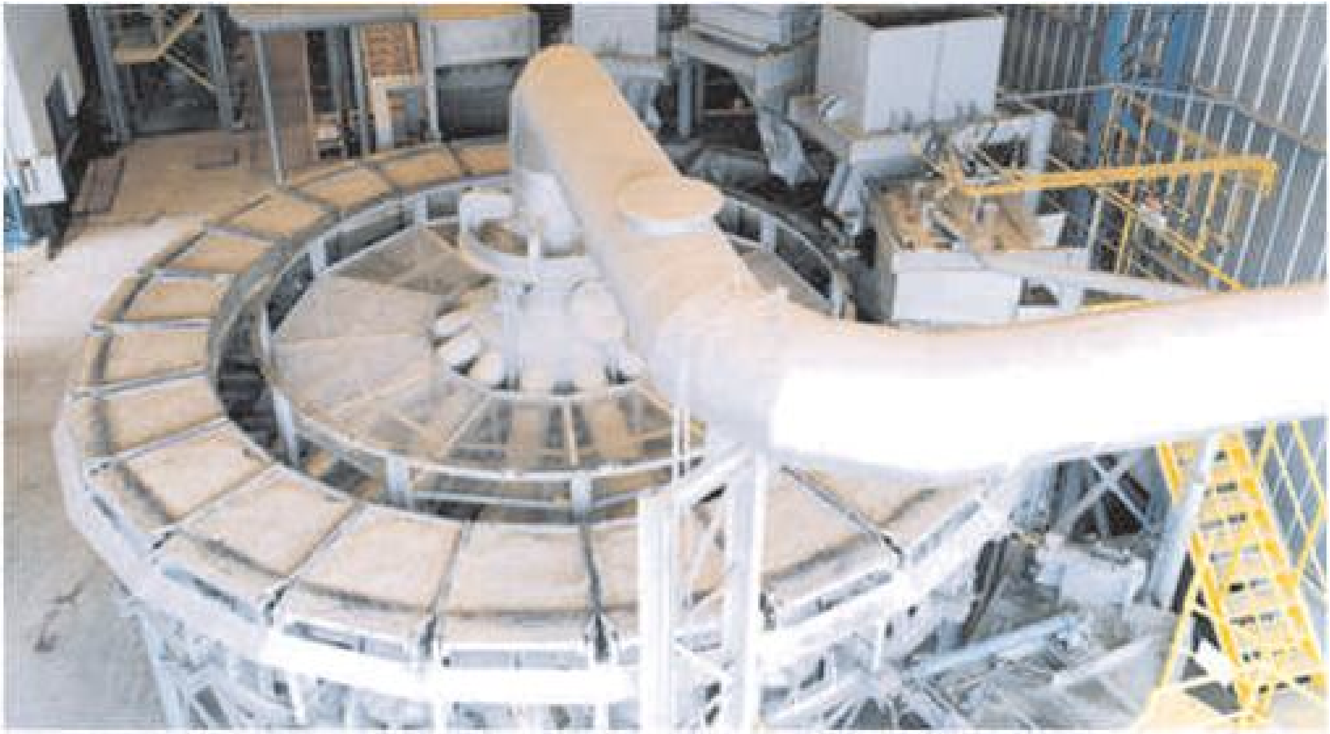
Historically, the sintering process started as a batch process in stationary pans. The need for establishing sintering unit for manganese ore fines was realised by the industry long back but the major constraint was the size (capacity) of the plant. The iron ore sintering units deployed for feeding the sinters to the blast furnaces for iron making in the integrated steel plants are of the capacity starting from 15,000 tonnes per day. A big 33 MVA Sub-merged Arc Furnace (SAF) for manganese-based ferro alloy on the other hand has a capacity of mere 500 tonnes per day.

An attempt to miniaturize (scale down) the conventional sinter machine did not prove to be viable proposition in view of the higher specific investment and high cost of production. Only a few companies ventured for establishment of such small manganese ore sintering plant. Recently, manganese sinters produced in small sinter pots on batch scale have been reported to be used by small capacity SAFs (2.5-9 MVA).

To overcome the basic difficulties like high capital cost, cumbersome design and heavy components like pallet body, a new concept of Mini Sinter Plant (MSP) was conceived and established in iron ore industry to cater to the need of the Mini Blast Furnaces (MBF) for production of pig iron. Mini Sinter Plants (MSP) gained enormous importance since the last 10-15 years as the concept of MBFs were proving to be economical for iron making. Sintering of manganese ore is akin to that of iron ore, and hence, this concept could well be applied to manganese industry also.

Conventional sintering is done on a moving grate as a continuous process. The new process developed by MINITEC MINITECNOLOGIAS is a semi-continuous one, consisting of a number of pans in a carrousel arrangement, which are successively fed, ignited, processed and discharged, turning in a circle. All steps are fully controlled by a supervisory station making the operation fully automatic.

Fig-4.1: Carousal Sintering Machine for Manganese ore fines



The MINITEC, Brazil has offered mini sinter machines called CAROUSAL with much better and unique design in circular type. There are number of small pots/pans rotating in a circular path. Each pot is fitted with a separate wind box (provided with suction control valve). The pans/pots rotate in horizontal motion with move and stop arrangements with time intervals which can be varied as per the sinterability characteristic of the manganese ore. The capacities of this Mini Sinter Plant (MSP) fulfill the requirement of the feed to the Submerged Arc Furnaces (SAF) ranging from 9 MVA to 33 MVA capacity furnaces and hence, the concept should well be accepted and adopted by the Indian Manganese-based ferro alloys industry. Pictorial view of the Carousal Sintering Machine is given in Fig-1.

Unfortunately, in India, the number of manganese-based ferro alloy units having 9 MVA or less capacity Submerged Arc Furnaces (SAF) is very large as compared to big units. Most of these furnace operators opted to use raw manganese fines because of non-availability of economically viable lumpy manganese ore and to reduce the cost of production even at the cost of equipment and human health, either to sustain for mere existence or earn more profit. They also have some mistaken belief that (i) Furnace of any size can easily tolerate fines of -6mm varying from 20% to 50% without any problem; (ii) During sintering, the silica content in finished sinter increases to great extent leading to higher slag volume, higher Mn losses and higher power, so sinters are uneconomical. (iii) Sinters are very weak, friable and generate excessive fines during handling inside the plant and hence, cannot be transported by road or rail.

It is, however, a fact that these furnace operators are charging manganese fines with all the risks of explosion, gas eruption, and slag boil. Fines continued to find its way to small smelting units may be due to unpredictable swing in the prices of manganese ore lumps. It is utmost necessary to suspend this practice immediately because of great risk to human lives and adopt agglomeration of fines. The fact of the problem is the comparison of cost of sintered product with that of lumpy ore.

The illustration presented below would justify the sintering of manganese ore fines.

1. Estimation of sintering cost : A case study

Item	Quantity	Rate (Rs.)	Rs. Per tonne
Coke fines	80 kg / t	8	640
Water	100 l / t	-	15
Fuel (FO/LDO)	5 l/ t	65	325
Power	65 KWH / t	6	390
Salary + Maintenance + Overheads 10%	-	-	140
Total	**Rs. 1510 /t of sinter produced**		

2. Cost of low grade fines

Manganese Fines	Manganese Ore	Cost Per tonne (Rs.)
Balaghat Hutch Fines	32.0%Mn	2800/-
Gumgaon Fines	35.0%Mn	3200/-
Kandri Fines	34.0%Mn	2650/-
Average	**33.6%Mn**	**2883/-**

If the blend of these fines is subjected to sintering, 1.1 tonnes of fines are required to produce 1 tonne of sinter.

Hence, cost of the sinter per tonne = cost of the ore + sintering cost per tonne

= 1.1 x 2883 + 1510 = ₹ **4681.3**

Since there is a loss of oxygen due to phase changes of manganese minerals during sintering, the grade of the sinter increases by 3 to 4 Mn units than the manganese ore used for sintering and hence, the grade would be more than 35% manganese.

Prices of the medium grade lumpy manganese ore are as follows:

3. Cost of medium-grade lumps

Source	Ore Grade	Cost Per tonne (Rs)
Samanpur	37% Mn	7600/-
Tirodi	37% Mn	7600/-
Sitapure	36% Mn	7400/-
Gumgaon	32% Mn	6900/-
Gumgaon	36% Mn	7700/-
Average	**35.6% Mn**	**7440/-**

Cost per tonne of sinter assaying 35% manganese comes to about Rs. 4680/-, clearly indicating the economic advantage of sintering the manganese fines and avoiding the human health risk by unnecessarily using fines in small manganese alloy furnaces.

Alternative use of Manganese fines/ Beneficiated fine concentrate

High grade beneficiated manganese ore fines can be accommodated in iron ore sintering up to 7% without any appreciable change in the strength and reducibility of the sinter. The productivity of the sintering also remains unaltered. Charging these iron ore sinters with 7% manganese fines meet the manganese requirement in hot metal and consequently would replace the lumpy manganese ore used presently.

Agglomerates, being consistent in size and uniform in chemical composition are better than natural lumps in their reducibility, and therefore, use of agglomerates lowers the specific power consumption and helps to attain smooth furnace operation. In India, ore sinters are used in the production of manganese alloys in a couple of plants.

Ferroalloys or Mn Alloys

Ferroalloys in general are essential ingredients used for desulphurization, de-oxidation, refining and alloying in the production of different types of steels, and hence, the ferroalloys industry forms a backbone of iron and steel making industry in the world. The term "ferroalloys" covers a wide range of metals alloyed with iron and other minor elements like carbon, phosphorus, silicon etc., and is classified according to principal base metal present. Use of ferro-alloys as alloying additions during steel making helps in adding a specially desired element which imparts specific property or set of properties or enhances particular property in Steel.

Manganese is an essential requisite for majority of steels due to its special capability of de-oxidation, sulphur fixing and several excellent alloying properties. No technology has so far been developed which combines the outstanding technical benefits at relatively low cost as offered by manganese which makes it irreplaceable in steel making. Manganese addition in steel enhances several mechanical properties like strength, hardness, toughness, stiffness, wear resistance, thus making it a highly useful engineering material. Manganese addition is done in the form of silicomanganese and ferromanganese.

Iron making through Blast Furnace route is a reduction process, while steel making through Basic Oxygen Furnace (BOF) route is an oxidation process where oxygen or air is blown through molten iron to oxidise or remove the excess silicon, phosphorus and carbon present to the desired level. In the process, some oxygen gets dissolved in steel. Residual oxygen in refined steel reacts with carbon to form CO or CO2. During solidification, it gets entrapped in steel ingots to form blow holes or pin holes porosity. It also forms oxides with other elements present in steel and retain as inclusions adversely affecting the quality of steel. Removal of dissolved oxygen from liquid steel is therefore very essential and accomplished by the addition of an element 'Mn' that forms an oxide having greater stability than that of iron oxide under given conditions of temperature, pressure and composition of steel.

Manganese has ability to combine with sulphur. With inadequate quantity of manganese in steel making, the sulphur combines with iron to form iron sulphides (FeS) along the grain boundaries which results in hot shortness i.e. development of cracks during hot rolling or forging.

Manganese ore is basic raw material used for manganese-based alloy production which is highly energy intensive process and apart from manganese ore electrical power shares substantial portion of the production cost. The production of manganese-based alloys is about 60% of the total ferroalloy produced in the country indicating its significance in steel industry. About 90% of manganese ore is converted into manganese alloys in the country, part of which consumed in steel production and remaining is exported. In the steel industry, around 30% of the manganese is utilized for its properties as a sulphide former and de-oxidant and remaining 70% is used purely as an alloying element.

The manganese contents of various steels are: carbon steel 0.5%Mn, constructional/structural steel 1-1.5% Mn, high strength low carbon alloy steel 1.5% Mn, Stainless steel "200 series" 12% Mn and Hadfield steel 13% Mn. The production of manganese ore and its alloys are in tandem with that of steel for the last several years. However, the manganese alloy demand would grow higher than steel demand due to higher growth rate of manganese intensive steels like HSLA, 200-S and stainless steel in particular (12% Mn), wherein manganese is replacing nickel and the consumption is about 110 kg/tonne of stainless steel produced.

High carbon ferromanganese (HC Fe-Mn) and silicomanganese (Si-Mn) are the two important manganese alloys widely used in steel industry. High carbon ferromanganese contains 65-80% Mn and requires high-grade manganese ore (+44% Mn). The silicomanganese contains 50-74% Mn which can be produced from a low-grade ores (33-35% Mn) but consumes maximum electricity.

Ferromanganese and silicomanganese are produced by the smelting of ores in a blast furnace, or more commonly, in an electric furnace. The latter process involving the reduction of manganese oxides by carbon is actually a complex thermodynamic problem. The higher oxides (MnO_2, Mn_2O_3, and Mn_3O_4) can all be reduced to manganous oxide (MnO) by carbon monoxide, but this lower oxide can be reduced to the metal only at elevated temperatures by carbon. Smelting is further complicated by the action of the gangue oxides. For example, silica, an acidic compound, can combine with MnO and prevent it from being reduced - a problem that can be corrected by the use of ores high in such basic constituents as lime and magnesia or by the addition of basic fluxes such as roasted limestone. However, this generates more slag which tends to dissolve manganese and lower the amount of metal recovered in the melt. In addition, depending on the smelting temperature and the acidity or basicity of the slag, silica can be reduced to silicon and enter the molten metal.

5.1 FERROMANGANESE

An alloy of iron and manganese containing usually 70-80% manganese and some silicon, phosphorus, sulphur and carbon. It is used as a deoxidizer and for the introduction of manganese into steel.

The primary product of the smelting process outlined above is a carbon-saturated ferroalloy containing 76 to 80 percent manganese, 12 to 15 percent iron, up to 7.5 percent carbon, and up to 1.2 percent silicon. It can be produced by two methods: (i) for acidic ores, on smelting, 70 to 80 percent of the manganese is recovered in the melt and a slag containing 30 to 42 percent manganese is also obtained. (This slag can be re-smelted to produce silicomanganese). The method consumes 2,400 to 2,800 kilowatt-hours of electric power per tonne of product, and (ii) basic ores or fluxes, recovers 85 to 90 percent of the metal and generates a slag low enough in manganese to be discarded. In this method, the higher energy needed to calcine the fluxes and continue smelting to a higher recovery of metal, consumes 2,600 to 3,100 kilowatt-hours per tonne.

High carbon ferromanganese can be produced either in blast furnace or in electric furnace. However, all ferromanganese in India is produced in submerged arc electric furnaces of capacities ranging from 9 to 33 MVA.

Specifications for manganese ore required by Indian ferromanganese producers are Mn 44-48%; Fe 10-12%; SiO_2 8-10%, P 0.15 % (max) and Mn/Fe ratio 3.5 (min). The Bureau of Indian Standards (BIS) indicated cleaned manganese lumps reasonably free from any slag and non-metallic residues. The sizes should be between 50 and 150 mm with the fines limited to 10 per cent (below 3 mm: 3% max.).

The important factors governing the selection of manganese ore for the production of ferromanganese are: (i) manganese/iron ratio; (ii) manganese content of the ore; (iii) phosphorus content; and (iv) content of slag

Table-5.1: Chemical Composition of Silicomanganese (IS: 1470-1990)

Sl No.	Grade (Si +Mn)	Constituents (%)						
		Mn	Si	C (Max)	P (Max)	S (Max)	As (Max)	Ni, Cr, Mo (Max)
1.	Si 18 Mn 72	70 to 74	16 to 20	1.5	0.20	0.03	0.01	-
2.	Si 23 Mn 68	65 to 70	20 to 25	1.5	0.30	0.05	0.01	-
3.	Si 18 Mn 68	65 to 70	16 to 20	2.0	0.30	0.02	0.01	-
4.	Si 19 Mn 63	60 to 65	17 to 20	2.0	0.30	0.03	0.01	0.75
5.	Si 16 Mn 63	60 to 65	14 to 17	2.5	0.30	0.03	0.01	-
6.	Si 26 Mn 53	50 to 55	24 to 28	1.5	0.30	0.03	0.01	-

forming constituents like silica and alumina. For production of one tonne of ferromanganese, inputs required are 2.3 tonnes of manganese ore, 0.5 tonne of reductant, and 3000kwh of electricity.

Ferromanganese plants generated manganese rich slag as byproduct. For every tonne of production of ferromanganese, approximate one tonne of slag is generated. This slag is consumed in the production of silicomanganese. The consumption of such slag for producing one tonne of silicomanganese is 600 kg per tonne of silicomanganese. Generally, ferromanganese is produced on high MnO slag practice basis, i.e., 35-38% MnO in slag. However, considering the limited availability of low Mn/Fe ratio of manganese ores in the country, ferromanganese producers are unable to produce ferromanganese with such high MnO slag.

5.2 SILICOMANGANESE

A ferroalloy is composed chiefly of silicon and manganese. It is smelted by carbon reduction in ore heat-treating furnaces. The standard grade silicomanganese contains 14 to 16% of silicon, 62 to 68% of manganese and 2% of carbon. The low carbon grade silicomanganese has carbon levels from 0.05 to 0.10%.

Manganese and silicon are crucial constituents in steel making as de-oxidants, de-sulphuriser and alloying elements. Silicon is the primary deoxidizer. Manganese is a milder deoxidizer than silicon but enhances the effectiveness due to the formation of stable manganese silicates and aluminates. It also serves as de-sulphuriser.

The main source of manganese in raw materials for silicomanganese production is manganese ore (over 35% Mn) and manganese-rich slag (over 35% MnO) from the high carbon ferromanganese production. The amount of slag per tonne of silicomanganese metal is mainly determined by the ore/slag ratio. Increasing share of ferromanganese slag at expense of manganese ore will lead to larger slag/metal ratio in the silicomanganese process. High volume of slag leads to an increased consumption of energy and probably to higher losses of metal inclusions in the final slag.

As per the BIS specifications (IS: 1470-1990) the silicomanganese contains 14-28% Si, 50-74% Mn and 1 to 2.5% C (Table-1). The presence of silicon has the added advantage of producing cleaner steel and also has the property of reducing the time required, from the stage of alloy addition to the pouring of ingot. Besides, it gives better mechanical properties due to change in morphology of de-oxidation products in regular round shape, and consequently the non-metallic inclusions are brought down in finished products.

Silicomanganese is produced by carbothermic reduction of oxidic raw materials in electric Submerged Arc Furnaces (SAF). The same type of furnaces is used for ferromanganese and silicomanganese alloys. Operation of the silicomanganese process is often more difficult than the ferromanganese process because higher process temperature is needed. The size of the silicomanganese furnaces is usually in the range 15-40 MVA, giving 80-220 tonne of alloy per day.

The economics of silicomanganese smelting is enhanced by minimising the loss of manganese as metal inclusions, as MnO dissolved in the slag, and by production of metal high in silicon and low in carbon. The silicomanganese production is typically integrated with the manufacture of HC Ferromanganese so that the slag from the HC Ferromanganese production is reprocessed in the production of silicomanganese. In this way, a very high total yield of manganese is achieved.

The discard slag from the silicomanganese process normally contains 5 to 10% MnO. Low carbon silicomanganese with around 30% Si is produced by upgrading standard alloy by addition of silicon wastes from the ferrosilicon industry.

In normal practice of ferromanganese making, the largest possible quantity of manganese is recovered from the ores, into the metal and slag, by following the high manganese slag practice. The apparently higher consumption of the manganese ore in this process is due to planned usage of slag for silicomanganese production. If silicomanganese is not produced in the electric furnace in conjunction with the ferro manganese, then the adoption of this particular slag practice shall be considered contrary to the interest of conservation.

Under Indian conditions, however, the adoption of high MnO slag practice is difficult due to available quality of ore. On the contrary, the discard slag practice which offered solution earlier is running into difficulty because of relatively higher power consumptions and higher power tariffs. Some manufacturers have found semi-flux or 25-30% MnO slag practice, which is a half way between the high MnO and discard slag practices, more economical considering all aspects.

Manganese ores normally contain unwanted elements that cannot be removed in the mining and processing stages. Of special importance is phosphorus due to the strict demands in respect of this element both in the ferromanganese and silicomanganese alloys. Iron, phosphorus and arsenic are reduced more easily than manganese and will consequently go first into the metal. Their content in the final alloy must therefore be controlled by selection of ores. The HC Ferromanganese slag is a very pure source of manganese because the easily reduced impurities in the ores have been taken up by the HC Ferromanganese metal in the preceding process step. The content of impurities like phosphorus in silicomanganese alloys is therefore controlled not only by the selection of manganese ores, but also by the relative amounts of manganese ores and HC Ferromanganese slag in the raw material mix.

A process temperature of 1600 to 16500C is necessary to obtain metal with sufficiently high content of silica and discard slag with low MnO. Ferromanganese slag has a relatively low melting temperature (about 12500C) compared with manganese ores. Accordingly, a high share of ferromanganese slag will tend to give lower process temperatures. When the manganese ore starts melting at around 13500C, it will contain a mixture of a solid and a liquid phase, where the solid phase is MnO. Further heating and reduction to 15500C or more is necessary before the melting ore will mix with the slag and flow freely. With a high share of manganese-ore in the mix, the surface temperature and process temperature in the coke-bed zone will be higher.

The specific power consumption for production of standard silicomanganese from a mixture of manganese ore, HC Ferromanganese slag and Si-rich metallic remelts, can typically be 3500-4500 kWh/tonne metal, dependent first of all on the amount of metallic's added to the feed. The power consumption will increase with the silicon content of the metal produced, and also with the amount of slag per tonne of silicomanganese. Each additional 100 kg slag produced will consume additionally about 50 kWh electric energy. About 100 kWh per tonne of metal and some coke will be saved if the ore fraction in the charge is reduced to MnO by CO gas ascending from the smelt reduction zone.

5.3 Estimation of Manganese Ore for Manganese Alloy Making in India By 2020

A target of 180 MTPA of domestic steel production by the year 2020 has been set by the revised National Steel Policy-2008. In view of this, the demand of manganese-based ferro alloys vis-à-vis requirement of manganese ore is bound to increase in the country.

The requirement of manganese-based alloys (Grade 65-72% Mn) will be around 15 kilograms per tonne of steel produced in the country. Thus, for the entire anticipated steel production (180 MTPA) the requirement of manganese alloys would be 2.7 million tonnes per annum. The manganese alloys used in the steel making are in the form of either ferromanganese or silicomanganese. The requirement of manganese alloy varies widely depending upon the process of steel making and the product quality envisaged. The consumption pattern of ferromanganese (high carbon or refined) and silicomanganese for the above purpose in Indian steel sector would be in the ratio of 2:3 indicating thereby the requirement of ferromanganese as 1.1 million tonnes and that of silicomanganese as 1.6 million tonnes.

To produce one tonne of ferromanganese about 2.3 tonnes of high-grade manganese ore/concentrate (+44% Mn) is required. Due to limited availability of high-grade manganese ore, BF-grade (30-35% Mn) manganese ore has to be upgraded to produce high-grade concentrate. The manganese concentrate yield in the beneficiation process is about 60%. To produce 2.3 tonnes high-grade concentrate 2.3/0.60=3.83 tonne of manganese ore per tonne of ferromanganese production or 3.83*1.1 = 4.2 MTPA of ROM manganese ore need to be processed for the production of required ferromanganese (1.1 MTPA).

On the other hand, about 2.3 tonnes of medium-grade ore (around 35% Mn) is required to produce one tonne of silicomanganese. Requirement of ROM manganese ore to produce the envisaged 1.6 million tonnes of silicomanganese would be 2.3x1.6= 3.7 million tonnes. Thus, total requirement of ROM manganese ore for manganese-based alloy (2.7 MTPA) would be 4.2+3.7=7.9 MTPA.

The revised National Steel Policy-2008 also suggested that around 60% of the total envisaged steel production (180 MTPA) in the country is expected through Blast Furnace Route i.e., around 110 MTPA by the year 2020. In this route of iron making, on an average around ten kilogram of BF-grade manganese ore is required per tonne of iron produced. Thus, the BF route will require manganese ore (around 30% Mn) to the tune of 1.1 million tonnes per year by 2020.

Hence, the total requirement of ROM manganese ore (25-35% Mn) for the Indian iron & steel industry by 2020 would be 4.2+3.7+1.1=9 million tonnes per annum for ferromanganese, silicomanganese and pig iron (BF), respectively.

5.4 Raw Materials and Process concept for manganese-based alloys production

5.4.1 Ferro-Manganese

The basic raw materials (charge) for the production of ferromanganese are manganese ore, coke and dolomite and/or limestone. Electrical power is supplied by secondary side of transformer with very high amperage and low voltage. Various oxides are reduced by carbon in coke at high temperature which is provided by electric arc. Arc is sub-merged inside the raw material and hence the name SAF or Submerged Are Furnace.

Three products are generated during smelting of manganese alloys i.e., alloy, slag and gas. Oxides of Mn, Fe, P and Si lose their oxygen and are reduced during smelting i.e., reduction to their elemental form in molten state and form a solid solution called alloy.

Oxides of Ca, Mg, A_1, Ba, Mn (partial) combine together to form a waste product called slag. The third product is fumes. Exact reducing condition determine the degree of reduction which can be controlled by the basicity of slag $\{(CaO+MgO)/SiO_2)\}$ and quantity of coke.

The recovery of manganese into alloy is higher with basicity of 1 and above, but this practice forms a slag with low MnO (15-18%) content which has high melting point and requires more electrical power to melt.

A basicity of around 0.65 results into lower recovery of manganese in alloy but forms a slag with higher MnO content (34-38%) which has lower melting point and consumes less electrical power (200-250 KWH Per tonne) for smelting. Difference in cost of manganese ore per tonne of alloy vis-a-vis cost of electrical power per tonne of alloy is the basis of selection of high MnO or low MnO slag practice in production.

This is an issue of conservation of manganese ore against cost of power. Most of the manganese alloy producers prefer saving power than saving manganese ore and produce a high MnO slag giving the justification that this slag is used for silicomanganese production.

During smelting of ferromanganese, various elements are distributed in alloy, slag and gas in following manner:

Element	% of Total element in charge		
	In alloy	In slag	Loss in fumes
Mn	Depends on slag practice		8
Fe	93	2.5	4.5
SiO_2	2	94.0	4.0
Al_2O_3	-	95.0	5.0
CaO	-	98.0	2.0
MgO	--	98.0	2.0
P	92	-	8.0

Except Manganese other elements pass into different products as shown above irrespective of slag practice.

Ferro Manganese Production

Basic reactions involved during Fe/Mn production:

$$MnO_2 \xrightarrow{CO} Mn_2O_3 \xrightarrow{CO} Mn_3O_4 \xrightarrow{CO} MnO \quad \text{(i)}$$

$$Fe_2O_3 \xrightarrow{CO} Fe_3O_4 \xrightarrow{CO} FeO \quad \text{(ii)}$$

$$7MnO + 10C = Mn_7C_3 + 7CO$$

$$FeO + 4C = Fe_3C + 3CO \quad \text{(iii)}$$

$$P_2O_5 + 5C = 2P + 5CO$$

$$SiO_2 + 2C = Si + 2CO \quad \text{(iv)}$$

Alloy : $Mn\text{-}Fe\text{-}Mn_7C_3\text{-}Fe_3C\text{-}Si\text{-}P$

Slag : $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3\text{-}MnO\text{-}BaO$

Gas : $CO_2\text{-}CO\text{-}SO_2NO_x\text{-}C_xH_y$

1. **Charge calculation for IS:1171-1988 Fe-Mn 72 grade**

Mn 70-72%, Fe 18-20%, C 6-8%, P 0.4% Max.

Average - Mn = 72%, Fe = 19%, Si = 1.5% (Max), C = 7% & P 0.4

Chemical analysis of raw materials used for Ferromanganese

Mn Ore*		Coke		Limestone	
Mn	46%	Ash	26%		
Fe	8.8 %	FC	72%		
SiO_2	9%	SiO_2	12%	SiO_2	4%
P	0 .14%		0.14%		
Al_2O_3	2%			Al_20_3	1.5%
	5.2			CaO +	48%
Mn/Fe				MgO	
		V.M.	3%		

*Single or blend of different ores

Calculations

For 72% grade Fe-Mn Production, high MnO (35%), Slag practice is deployed

1 tonne of alloy will contain 720 kg of Mn and 190 kg of Fe
For High MnO slag practice, Mn recovery in Alloy is 70%.
Therefore, Mn units required in the ore = 720/0.7 = 1030 kg
The blend of Mn ores contained 46% Mn
Therefore, Ore quantity required = 1030/0.46 = 2300 kg
Fe reduction is 93%
Fe in the ore = 2300 x 0.088= 202.4
Therefore, Fe in alloy = 202.4 x 0.93 = 190 kg approx.

Coke requirement for reduction

For carbothermic reduction (smelting) carbon is added in the form of metallurgical coke.

Requirement of fixed carbon/T of Fe-Mn

For Mn -	Mn in alloy x 12/55	= 720 x 0.218	=	157.0 kg
For Fe -	Fe in alloy x 12/56	= 190 x 0.214	=	40.7 kg
For Si -	Si in alloy x 24/28	= 15 x 0.857	=	12.85 kg
For P -	P in alloy x 60/62	= 4 x 0.96	=	3.8 kg
				214.3 kg
Alloy contain 7% C			=	70.0 kg
Total C			**=**	**283.3 kg**
Burning loss ~ 11%				31.2 kg
Total C requirement			**=**	**315.5 kg**
Coke contains 71% F.C.				
Therefore, Coke requirement (Dry basis)			=	445 kg

Requirement of SiO_2

Silica contributed by ore:	2300 x 0.09	= 207 kg
Silica in coke:	445 x 0.12	= 53.4 kg
Silica in flux		= 10 kg

Total = 270 kg

Requirement of Flux

To produce 35% MnO slag, basicity should be 0.65

CaO/SiO_2 = 0.65

CaO = SiO_2 x 0.65

CaO = 270 x 0.65 = 175.5 kg (flux contains 48% CaO)

Therefore, Limestone (Flux) requirement = 175.5/0.48 = 365 kg

Total Mn available	**=**	**1030 kg**		
Mn joining the metal (70%)	=	720 kg.		
Loss in fume (8%)	=	82 kg.		
Balance Mn is with slag	=	228 kg		
MnO equivalent	**=**	**228 x 71/55**	**=**	**294 kg**

Apart from SiO_2 and MnO, slag also contains Al_2O_3 which is contributed by ore, coke and limestone (flux).

Al_2O_3 from ore	=	2300 x 0.02	=	46 kg
Al_2O_3 from coke	=	445 x 0.14	=	62.3kg
Al_2O_3 from limestone	=	366 x 0.015	=	5.5 kg
Total Al_2O_3 in slag	=	**113.8 kg**		

Slag = $MnO+CaO+Al_2O_3+SiO_2$

Total Slag weight =294 + 175+ 114 + 270= 853 kg

P input

From Ore	=	2300 x 0.0014	= 3.22 kg
From coke	=	440 x 0.0014	= 0.62 kg
Total			= **3.84 kg**
P input joins alloy (92%)			= 3.64 kg

Composition of Ferromanganese produced Quantity per tonne

Product	Mn Ore	Ferromanganese
Mn	720 Kg	72%
Fe	190 Kg	19%
P	3.64 kg	0.36%
C	70 kg	7.0%
Si	15 kg	1.5%

5.4.2 Silicomanganese Production

Ferroalloy industry enjoys broad banding facility of switching over form one ferroalloy to another. Thus, the producers can change over to any other ferroalloy depending upon the economic and market conditions. For instance, the ferromanganese furnaces can be switched over to silicomanganese production.

Furnaces of the same design which are used for smelting ferrosilicon and carbon ferromanganese can also be used for smelting silicomanganese. However, because of the increased concentration of silica in the charge and in the slag, a higher voltage than that used in smelting ferromanganese is needed for smelting silicomanganese (5-7 % higher).

Silicomanganese containing 16-20% silicon corresponds to the standard grades, and no difficulties are encountered in its production.

When silicomanganese is smelted using high MnO slag or from a mixture of slag with ore, the electric power consumption is higher, while the extraction of manganese is lower than when ore alone is used, because there is less manganese in the slags, and moreover, it is present in the form of stable silicates. However, the recovery of the manganese from such slag is always more than 70%.

1. Consumption of materials electric power in Smelting of Silicomanganese

Material	Unit	Consumption per 1 t of alloy		
		Ore only	Ore and Slag	Slag only
Manganese ore (33% Mn),	kg	2,300	1,700	-
Self-flux slag (35% MnO),	kg	-	600	2,400
Quartzite (96% SiO_2),	kg	400	380	360
Coke dust (5 25 mm)	kg	530	480	480
Iron ore	kg	75	-	95
Electric power,	kwh	3,600	4,000	4,400
Manganese extracted	%	70.0	74.0	72.0

2. Charge calculations for Silicomanganese Production

The basic raw materials required for silicomanganese production are manganese ore, quartzite, high MnO slag (optional), coke and limestone. The thermodynamic calculations are more or less similar to those for ferromanganese production. A sample charge calculation to produce 1 tonne of silicomanganese of the following grade/specification is presented below:

Grade of Silicomanganese: Mn-63%, Si-17%, Fe-17%, C-2.5%, P-0.4% (Max.)

Specification of Raw materials used

Constituents	Mn ore (Blend)	Slag (35% MnO)	Mn burden for SiMn
Mn	36.13	27	33.8
Fe	9.25	0.5	7.0
SiO_2	18.2	30	21.24
Al_2O_3	3.7	10.0	5.2
P	0.15	0.06	0.11
CaO+MgO	-	19.0	

Calculations: Following are some of the Thumb Rules followed:

1. Basicity of the slag 0.5
2. Mn reducing efficiency 80%
3. Fe reducing efficiency 95%
4. Mn/SiO_2 ratio 0.9 to 1.1.

The Mn burden used for smelting Silicomanganese is a composite mixture of blend of various manganese ores and 600 kg of 35% MnO slag.

For 1 tonne of Si-Mn, Mn in the alloy = 630 kg

With 80% reducing efficiency

Weight of Mn in the burden = 630/0.8 = 787.5 kg

Mn burden = 787.5/0.338 = 2330 kg; Out of these 600 kg is slag.

Blend of ore = 1730 kg

Fe in 1 tonne SiMn is 170 kg.

Fe reducing efficiency is 95%

Fe requirement in the burden = 170/0.95 = 180 kg

Fe present in the burden = 2330 x 0.07 = 163 kg

(Some iron ore has to be included in the burden for the adjustment of Chemistry.)

Requirement of Coke for the smelting

For carbothermic reduction (smelting) carbon is added in the form of metallurgical coke.

Requirement of fixed carbon/T of Si-Mn:

For Mn	Mn in alloy x 12/55	= 630 x 0.218	= 137.3 kg
For Fe	Fe in alloy x 12/56	= 170 x 0.214	= 36.4 kg
For Si	Si in alloy x 24/28	= 170 x 0.857	= 145.7 kg
For P	P in alloy x 60/62	= 4 x 0.967	= 3.8 kg
	Alloy contain 2.5% C		= 25.0 kg
	Total		= 348.2 kg
	Burning loss ~10%		= 34.8 kg
Total C Requirement			**= 383 Kg**
Coke requirement @71%FC (Dry)			= 540 Kg

Available SiO2

Silica contributed by ore	1730 x 0.182	= 314.8 kg
Silica from slag		= 180.0 kg
Silica from quartzite		= 290 kg
Silica from coke	(445 x 0.145)	= 64.5 kg
Silica from flux		= 10 kg
Total silica		**= 860 kg**
Fume loss (5%)		= 43 kg
Available silica		= 817 kg

Silica requirement

For 170 kg of Si in 1 tonne of SiMn,
SiO_2 required is 364 kg
Silica joining slag = 453 kg.

Requirement of Flux

For slag, basicity should be 0.5
$CaO/SiO_2 = 0.5$
$CaO = SiO_2 \times 0.5$
CaO = 453 x 0.5 = 226.5 kg (CaO &MgO contributed by slag & coke=129 kg)
Therefore, CaO to be contributed by Flux- 97 kg (flux contains 48% CaO+MgO)
Flux requirement = 97/0.48=200 kg.

MnO in slag

Total Mn available	= 787.5 kg
Mn in alloy	= 630 kg
Fume losses (5%)	= 40 kg
Mn in slag	**=117.5 kg**
MnO equivalent	= 152 kg

Apart from silica & MnO slag also contains CaO+MgO, Al_2O_3, FeO/BaO

Al2O3 contribution

Slag also contains Al_2O_3 which is contributed by ore, coke and limestone (flux)

Al_2O_3 from Mn blend	=	2330 x 0.052	=	122 kg
Al_2O_3 from coke (5%)	=	540 x 0.05	=	27 kg
Al_2O_3 from limestone	=	200 x 0.02	=	4 kg
Total Al_2O_3 in slag			=	**153 kg**

Slag = MnO+CaO+MgO+Al_2O_3+SiO_2+FeO/BaO

Total Slag weight	=152 + 226.5 + 153 + 453+43	=	**1027.5 kg**
Therefore, MnO in slag	**= 152/1027.5**	=	**15%**

P input

From Ore	=2330 x 0.0011	= 2.56 kg
From coke	=540 x 0.0014	= 0.76 kg
TOTAL		**= 3.32 kg**
80% of the P input joins alloy		**= 2.65 kg**

Constituents	1000 kg Si-Mn contains	Composition of Silicomanganese
Mn	630 kg	63%
Fe	170 kg	17%
Si	170 kg	17%
C	25 kg	2.5
P	2.65 kg	0.265

5.5 Indian Manganese Alloy Industry: Present Status

Ferro alloys industry in India has never been globally competitive despite its substantial ore reserves and low cost manpower. This is essentially due to low quantity of overall quality manganese ore production; insufficient availability and high cost of electric power besides other allied bottlenecks of infrastructure, market demand etc.

Steel is one of the basic engineering materials with versatile applications and the demand for structural steel (over 50% of Global steel consumption) in particular is ever growing, especially in the developing countries like India and China where continued investment in infrastructure and new urban real estate is fast growing. Silicomanganese is commonly used in production of long products (Mn up to 1.4% & Silicon 0.4% max.), a critical component in constructional industry.

China was the main exporter of the manganese alloy till 2009. Since then it became the net importer particularly of silicomanganese. This situation offered India an opportunity to (i) consolidate its position as manganese-based alloy exporter and (ii) meet the envisaged requirement of alloy in Indian steel industry, particularly for low nickel austenitic stainless steel where manganese is replacing Nickel. As a consequence, the share of silicomanganese in the total Indian manganese alloy production has increased from 45% to 60% in the last several years.

However, it is very interesting to note that the Indian manganese-based alloy industry at present is producing sufficient quantity of manganese alloys to meet the domestic demand and export inspite of available reserves, inadequate manganese ore production coupled with incomplete processing of exploited material in the country. This is because of the fact that in the present scenario Indian manganese-alloy industries import considerable quantity of medium/high-grade manganese ore and produce manganese-alloy after blending it with indigenous ores to a limited extent. This import of manganese ore is basically with the purpose of export of manganese alloy after meeting the internal demand which is very meager at present.

The import of manganese ore of medium and high-grade has shown a significant enhancement from 85,000 tonnes in 2008-09 to 2.17 million tonnes in 2012-13, mainly to cater to the need of silicomanganese industry.

Installed capacity of manganese alloy in the country is 3.16 MTPA and is presently operating around 60% of its installed capacity. The industry produces 30% of manganese alloys in the form of HC ferromanganese the rest 70% is silicomanganese. The production of HC ferromanganese remained volatile from quite some time in the country. Therefore, availability of ferromanganese slag as well as old stacked slag quantity is very low for producing silicomanganese. This slag is consumed in the production of silicomanganese. Despite this, silicomanganese continued to grow steadily in the country totally dependent on imported medium/high-grade ore.

Almost 90% of manganese ore produced in the country is used for manganese alloy making viz., ferromanganese and silicomanganese. In the year 2010-11, the Indian manganese alloy industry has produced 1.70 MT manganese alloy. Of this, silicomanganese is 1.25 MT and high carbon ferromanganese 0.39 MT, after importing medium-high grade manganese ore in large volumes (around 1.3 MT in 2010-11).

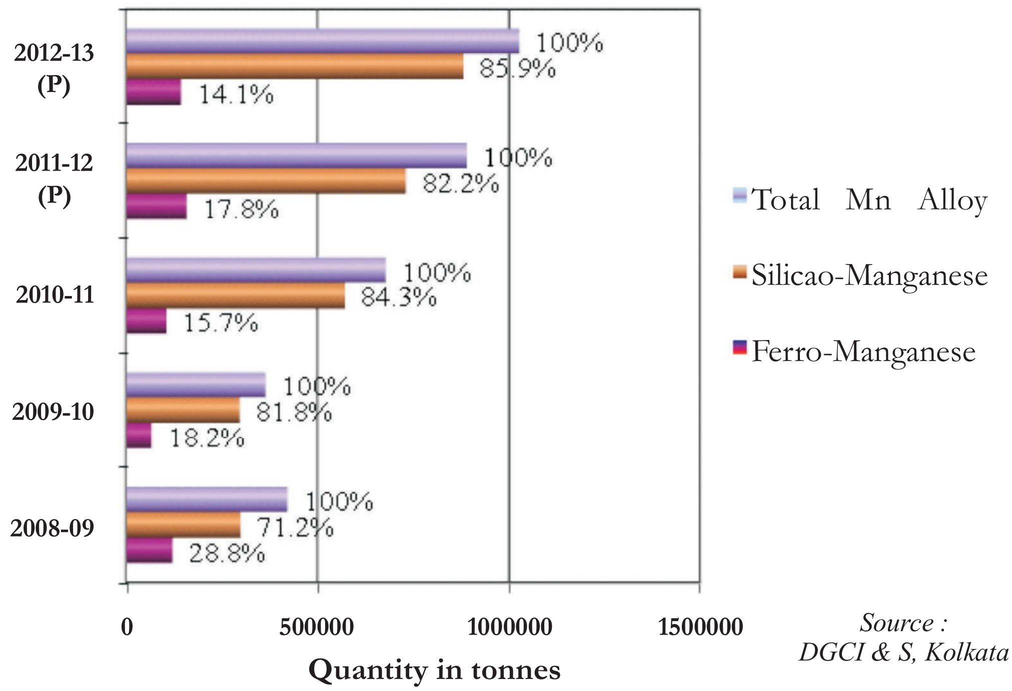
The Indian manganese alloy industry is highly fragmented with top 7 players contributing just 30% of the total production, while the remaining 70% is contributed by 150 small furnaces ranging from 4MVA to 33 MVA.

The manganese-alloy units are concentrated in Andhra Pradesh, Arunachal Pradesh, Chhattisgarh, Jammu, Jharkhand, Kerala, Maharashtra, Meghalaya & West Bengal, basically producing manganese-alloys for the purpose of export after meeting the meager domestic needs.

India is established as a regular exporter of silicomanganese, with major exports into countries like Bangladesh, Europe, Germany, Indonesia, Japan, Korea, Pakistan, Sri Lanka, UAE, USA, etc. Currently, India is the world's largest exporter of silicomanganese.

The domestic requirement of manganese alloy for iron & steel industry is very limited and this resulted in export of these material in large quantity. The export of ferromanganese and silicomanganese in the year 2008-09 to 2012-13 as reported by DGCI & S, Kolkata is presented in Fig-1.

Fig-5.1: Export of Ferromanganese and Silicomanganese from India



Source : DGCI & S, Kolkata

The present installed capacity of manganese-alloy in the country is (3.16 million tonnes) likely to be enhanced by 50% in immediate future. The augmented capacity of the manganese-based alloy plant will be quite high and would fulfill the requirement of envisaged steel production by 2020 apart from export commitment.

However, the present day manganese ore production of all grade catering to the need of domestic alloy production is around 2.5 million tonnes (30-35% Mn) from the major producers like MOIL, TATA, OMC, Sandur etc., and their future expansion plan envisaged a total production of around 5 million tonnes as against envisaged requirement of 9 million tonnes (30-35% Mn) by 2020.

The situation would remain unchanged in coming years due to limitations of domestic suppliers as the futuristic expansion target is far less than the requirement. Thus, a huge gap will persist in demand and supply position by 2020, which is matter of grave concern and in the existing situation, needs immediate attention to revamp the entire mining activity on a large scale by the companies.

Nevertheless, the situation of producing manganese-alloy based on imported ore cannot go on perpetuity as the availability of high grade manganese ore in the world is limited and there is great risk of uninterrupted supply of manganese ore in the context of global scenario coupled with unpredictable exchange rate (Rupee-Dollar conversion). The largest manganese deposits, particularly for high grade ore are with the Kalahari region in South Africa. The production is also restricted because of the weak logistical network in the country. Even the low-grade ores cannot be beneficiated because of weak in land network and scarcity of electricity. Therefore, manganese ore availability will remain a major challenge in long run.

The total global resources of manganese ore are in billions of tonnes including sea beds (nodules). But the proven reserves stand at 540 million tonnes only. Besides, as on date there is no technology available to extract sea bed reserves. Thus, the global ore availability would also be a matter of grave concern in near future. However, total dependence on imported ore for country's need is highly risky and should not be allowed to sustain for long and warrants immediate exploitation of indigenous resources for value addition.

Manganese alloy Industry will have to play a key role in immediate future in the development of steel sector as per National Steel Policy i.e., Steel industry has to depend a great deal on manganese alloy industry for the supply of ferromanganese and silicomanganese in future. Therefore, thrust should be given to enhance exploitation, beneficiation and sinter making of indigenous manganese ore which will in turn replace use of imported medium-high grade lumpy manganese ore in manganese alloy units in the country.

TO AUGMENT MANGANESE ORE PRODUCTION

Manganese ore is the basic source to provide manganese input in iron & steel and is indispensable in all types of steel. Manganese input is predominantly in the form of manganese alloy. The estimated requirement of manganese alloys in the country for the anticipated/projected steel production of 180 million tonnes per annum by 2020 would be around 2.7 MTPA at the ratio of 2:3 for ferromanganese and silicomanganese, respectively. To achieve this level of manganese alloy production, ROM ore of 30-35% Mn grade of around 7.9 MTPA will be required to be exploited and processed. Besides, around 1.1 MTPA manganese ore (28-30% Mn) will be required for Blast Furnace for pig iron making. Thus, a total of 9 MTPA ROM manganese ore will be required for iron & steel industry by 2020.

India is completely self-sufficient with regard to manganese ore reserves. However, the major producers of manganese ore like MOIL, TATA, OMC, Sandur etc., have produced mere around 2.5 MTPA during the last five years and their future expansion plan envisaged a total production of around 5 MTPA as against envisaged requirement of 9 million tonnes (30-35% Mn) by 2020. The situation would remain unchanged in coming years due to limitations of domestic suppliers as the futuristic expansion target is far less than the requirement. Thus, a huge gap will persist in demand and supply position by 2020, which is matter of grave concern and in the existing situation, there needs immediate attention to revamp the entire mining activity on a large scale by the companies.

At the envisaged ore requirement of 9 MTPA, the existing manganese ore reserves of 142 million tonnes (NMI) as on 1.4.2010 may last for 10-15 years maximum beyond 2020. Hence, necessary steps should immediately be initiated for optimum utilization of the existing reserves and to convert the resources to reserves.

Most of the larger manganese ore belts have been already explored for high grade ores and many exploited for high and medium grade ores over last six decades at a cut-off of 20% Mn. The exploration agencies lay emphasis on establishing the resource of manganese ores to over 25% Mn grade (BF grade) for its use in iron industry. The low grade fines, even from operating mines have not been utilised adequately and hence, wasted. The states of Madhya Pradesh, Maharashtra, Odisha, Karnataka and Gujarat are major producers of manganese ore in the country.

The Indian manganese mining industry currently is being run in fragmented lease holds. Besides, a handful of big mines a large number of the small mines operate on a very low scale as the ores mainly occur as pockets/lenses. Selective mining coupled with dry screening and hand sorting is process route of beneficiation practiced by almost all the manganese producing companies across the country, barring few.

The present manganese ore beneficiation facilities in the country are highly insufficient and do not utilise the appropriate beneficiation practices. The beneficiation process technology in vogue is limited to sizing, washing and manual sorting to meet the size requirement with rejection of fines fraction. Such processing facility was basically successful on account of selective mining of medium and high grade ore. Even the fines generated from such plants were not processed any further. In these operations, around 50% by weight of the valuable manganese is recovered and rests are lost. This practice generates large amount of fines left unused at the mine site. However, deployment of appropriate beneficiation technology will be needed, once low-grade ores are mined to augment production.

The small and medium size entrepreneurs are reluctant to create beneficiation facility as it is capital intensive; besides, problems associated with procurement of land, water, power and environmental clearances.

Therefore, a concept of custom mill is suggested for beneficiation needs, whereby the low-grade ores and fines from near vicinity small mines will be received, and after blending processed in a centralized processing unit due to their analogous mineralogical and chemical characteristics. Such consortium will work on certain defined objectives:

(i) Consistent supply of raw material for which they must sign an MOU amongst themselves.

(ii) Land, Power, fuel (coal) and water requirement should be made available by the Government at the subsidised rate to incentivize these small players to venture for such highly capital intensive project.

The concentrate produced mostly in the form of fines that cannot be used as such and needs agglomeration before its use. Sintering is the only acceptable agglomeration technique for manganese ore.

In general, the cost of beneficiation of manganese ores followed by sintering of the concentrate so produced compares well with that of lumpy manganese ores of the same grade. Hence, much emphasis needs to be given for accelerated exploitation of known low-grade resources coupled with beneficiation and sintering for the production of quality sintered concentrate that can be used for manganese alloy industry.

In the light of prevailing Indian scenario it may be concluded that with the lowering of threshold value to 10% Mn for manganese ore in the Indian context, the reserves grade of manganese ore would be further lower down and the beneficiation would assume much importance. Thus, value addition of ROM manganese ore in its totality (concept of total beneficiation) for both lumps and fine fraction is crucial and assumes significance.

The beneficiation of ROM ore at a cut-off of 10% Mn should be aimed to explore the possibility of obtaining concentrate in the range of over 35% Mn suitable for silicomanganese production, in particular which would reduce the load on imports and makes the country self-reliant in manganese ore supply.

This will be useful for optimum utilisation and conservation of limited availability of high-grade reserves of the natural resources vis-à-vis take care of the environmental degradation on account of perpetual stacking of unprocessed material. i.e., low grade manganese ore, mines and process rejects.

In the light of aforesaid, it can be emphasized that anticipated steel requirement by 2020 has necessitated the dynamic expedition in the whole gamut of activities for manganese ore right from its mining at the threshold value to value-addition / beneficiation and sintering followed by manganese alloy making.

It can therefore be concluded that the production and consumption pattern of manganese ore can be considered as a yardstick to measure the industrial development of any country based on steel production. The mining fraternity should ensure that the manganese ore input is comprehensively met in quantity as well as quality. For a long term business, the manganese ore resources are to be planned at least for a period of fifty years with similar growth rates. As we look into our strength regarding availability of manganese ore reserves, the present level and anticipated manganese ore production by the major mining companies are not at all encouraging for the projected demand of the ore by 2020.

To keep pace with the likely growth of the manganese ore industry by 2020, quality raw material is the need of the hour; it is imperative to address timely execution of the following aspects:

1. Short Term Measures

(i) Enhancement in exploitation quantum either in the existing mines or by opening of new mines to meet the quantitative futuristic demand.

(ii) Developing new mines with total beneficiation facility.

(iii) Preparation of feasibility of mining of the several small/low grade deposits/old mine dumps already identified and proved earlier, needs to be ascertained in view of enhanced requirement and deployment of appropriate beneficiation technology.

(iv) Introducing concept of total beneficiation by big manganese ore mines for value addition across all sizes of lumps and fines.

(v) The small and medium size entrepreneurs cannot afford a mechanized beneficiation plant, hence alternatively consider for a common beneficiation facility like custom mill that can be developed and deployed. The low-grade ores and fines from near vicinity small mines will be received and after blending, processed in a centralized processing unit which is possible due to their analogous mineralogical and chemical characteristics in these contiguous mines. Such consortium will work on certain defined objectives.

(vi) The concentrate so produced would be sintered or supply to the sintering units.

(vii) Recovery of Ferromanganese from the huge quantities of ferromanganese slag accumulated at various ferromanganese plants in the country deploying gravity methods. This would not only help in recovering ferromanganese globules entrapped in the slag, but also reduce the load on manganese ore requirement for ferromanganese production.

2. Long Term Measures

(i) Detailed exploration within existing lease/mine area.

(ii) Converting the existing manganese ore resources into reserves at the current threshold of 10% Mn, on priority by detailed exploration followed by feasibility with proper state of art beneficiation facility.

(iii) Exploration in freehold area within known manganese ore belts. Besides, ideal lease/relinquished areas may be thoroughly assessed by drilling as well as within lease area.

(iv) Advanced integrated exploration techniques are needed to thoroughly explore deeper deposits or deposits in complex geological environment. As most of the present exploration efforts are restricted to area near ancient mine workings or near surface deposits by conventional exploration techniques.

(v) State-of-the-art drilling techniques with sophisticated rigs (such as RC) for three dimensional sub-surface delineation of ore body as well as for directional drilling and underground exploratory drilling are needed to be employed.

Indian manganese industry has to go for massive expansion of mining, beneficiation and agglomeration facilities in the country. In the National interest, a Statutory Regulation should be brought to ensure full utilisation of the mined ore which automatically will lead to adoption of latest efficient technologies of beneficiation and agglomeration/sintering, for protecting individual industry over a long period and to the revival of Mineral Industry in general and Manganese Ore Industry in particular, towards a bright future.

LIST OF FIGURES

LIST OF MAPS

LIST OF TABLES

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ABBREVIATIONS

ABBREV.	Full Form
	B
BHQ	Banded Hematite Quartzite
BIF	Banded Iron Formation
BOF	Basic oxygen furnace
BF	Blast furnace
	C
CGPB	Central Geological Programming Board
	D
DHIMS	Dry high intensity magnetic separators
	E
EAF	Electric arc furnace
	F
Fe-Mn	Feromanganese
	G
GOI	Government of India
	H
HMC	Heavy- Media Cyclone
HMS	Heavy- Media Separation
HC	High Carbon
HGMS	High Gradient Magnetic Separators
HTS	High Tension Separator
	I
IBM	Indian Bureau of Mines
IF	Induction furnace (Electric)
ISP	Integrated Steel Plants
	K
kwh	Kilowatt hour
	L
LIMS	Low Intensity Magnetic Separator

ABBREV.	Full Form
	M
MOIL	Manganese Ores of India Limited
MOU	Memorandum of Understanding
MT	Million tonnes
MTPA	Million tonnes per annum
MBF	Mini Blast Furnace
MVA	Millivolt ampere
MSP	Mini Sinter Plant
MoS	Ministry of Steel
	N
NMI	National Mineral Inventory
NSP	National Steel Policy
	O
OMC	Orissa Mining Corporation
	R
R&D	Research and Development
R.O.M.	Run-of-mine
	S
Si-Mn	Silicomanganese
SAIL	Steel Authority of India
SAF	Submerged Arc Furnace
	T
TISCO	Tata Iron & Steel Company
TPD	Tonne per day
TPH	Tonne Per Hour
	U
UNFC	United Nations Framework Classification
	W
WHIMS	Wet high intensity magnetic separators

ACKNOWLEDGEMENTS

Indian Bureau of Mines is obliged to convey its profound gratitude to the various organizations, Government Departments and Associates whose direct & indirect cooperation, assistance and technical inputs have added immeasurable value to this publication. Special thanks are due to a notable few- SAIL, TATA Steel Ltd, TATA Sponge Iron Ltd, JSW Steel Ltd, IDCOL Kalinga Iron works Ltd, IMFA, Kirloskar Ferrous Industries Ltd, Odisha Mining Corporation, Sandur Manganese & Iron Ore Ltd and Mr. Rajendra Sane, Director, Ghalsasi Group, Pune etc. - whose generous contribution vis-à-vis technical data, guidance and knowledge were of immense worth in shaping the contents of the publication.

Vast bodies of prevalent and existent information that have connection with the object of study in this publication were resourced and consulted during the course of the preparation of the publication. Plenitude of published and unpublished reports of Geological Survey of India (GSI) and Central Geological Programming Board (CGPB) Committee-I, have had their share in formulation and manifestation of the technical details reflected in the publication. The Bureau is grateful to each one of these Source Agency and would place on record its indebtness and appreciation.

Contribution of in-house Divisions of Indian Bureau of Mines viz. Mines Control & Conservation of Minerals (MCCM) Division, Mining & Mineral Statistics Division, Mineral Economics Division, Mineral Map Cell, Ore Dressing Division and Publication Section, besides efforts of several in-house experts have been instrumental in the evolvement of the publication from its nascent stage to what it is today. Every modicum of contribution received is worthy of praise and is thankfully acknowledged.

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