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INTEGRATION OF IRON ORE DEPOSIT EVALUATION AND MINE PLAN FOR SELECTING COST EFFECTIVE BENEFICIATION OPERATIONS TOWARDS IMPROVED RESOURCE UTILISATION: EXPERIENCE AT TATA STEEL

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ABSTRACT

In the recent past a paradigm shift in terms of resource utilization and beneficiation practices is experienced by the Indian mining and mineral sector. Depleting iron ore reserves coupled with increasing demand for low-alumina iron ore fines to improve blast furnace performance in terms of productivity and reduced slag rate necessitate intensive beneficiation of iron ore. The task is even difficult for Indian iron ores which are generally high in iron content and at the same time characterized by aluminous gangue and thereby calls for capital investment of higher order for beneficiation.

In another direction, any beneficiation means rejecting some mined ore as waste for obtaining the desired product grade and involves costs. Hence, beneficiation option has to be used judiciously. Towards this, the enabler available is characterization and assessment of geological resource to explore the options of segregation, scheduling, sequencing and blending.

Joda East Iron Mines (JEIM), which caters to approximately 45% of iron ore requirement of Tata Steel plant in Jamshedpur, and has its ambitious plan for upgrading existing beneficiation facilities in the form of 'Total Beneficiation'. The paper describes the judicious beneficiation and effective utilization efforts made, in the light of characterization and assessment of deposit, mine planning over last 10 years as experienced by JEIM plant and also discuss the importance of blending of processed ores in achieving despatchable product grades to meet customer requirement while optimizing overall ore resource utilization.

JEIM has modified to earlier only washing plant to present two beneficiation circuits, namely Wet and Dry Processing plants, to take care of off - and high grade ores, respectively. The Dry processing plant is quite simple, comprising crushing and dry screening with no tailings/wastes. Off grade material is concentrated through primary and secondary crushing followed by screening and oversize crushing and re-screening, washing and sizing, scrubbing, classification in classifier and hydrocyclone, with a overall weight recovery of ~87%. The journey in improving product quality while optimizing plant production in JEIM relates to changes in operational philosophy which basically could be related as "identifying correct methods of ore dressing for correct ore" in line with deposit ratio.

The paper also discusses about the continual advancement of geological knowledge as a result of new exploration and pit-mapping with an overview of ore genesis which provides new solution and insight into the varied geological and grade problem. With changing needs, in order to achieve an improved grade control operation suitable for plant operation and blending at dispatch point, mine scheduling and in-pit geological mapping has become definite and ultimate guide to achieve target grades and grade predictions.

In effect of the aforesaid developments Joda East has been able to reduce beneficiation losses while meeting product quality requirements as desired by the customer. Careful integration of geology, ore reserve, mining and processing systems has led to major improvements in performance and optimizing cost options in solving capacity and technical problems and make best use of available resources.

Keywords: *Iron ore, Beneficiation, Characterization, Deposit assessment, Blending, Exploration, Grade prediction, Mining, Capital investment.*

INTRODUCTION

Joda East Iron Mine (JEIM) is one of the major captive sources of iron ore to the Tata Steel plant at Jamshedpur and supplies approximately 45% of work’s total iron ore requirement. The mine produces iron ore fines (0.15–10 mm) and sized ore (10–40 mm). The iron ore, which belongs to the Banded Iron Formations of Iron ore Group in Singhbhum-Bonai synclinorium (Fig. 1) occurs as hard massive, friable flaky, powdery blue dust and soft lateritic iron ores with varied physical, mineralogical, chemical and metallurgical properties. Mineralogically these ores are classified as high grade hematite with varying proportions of goethite, limonite and martite. The iron ores as

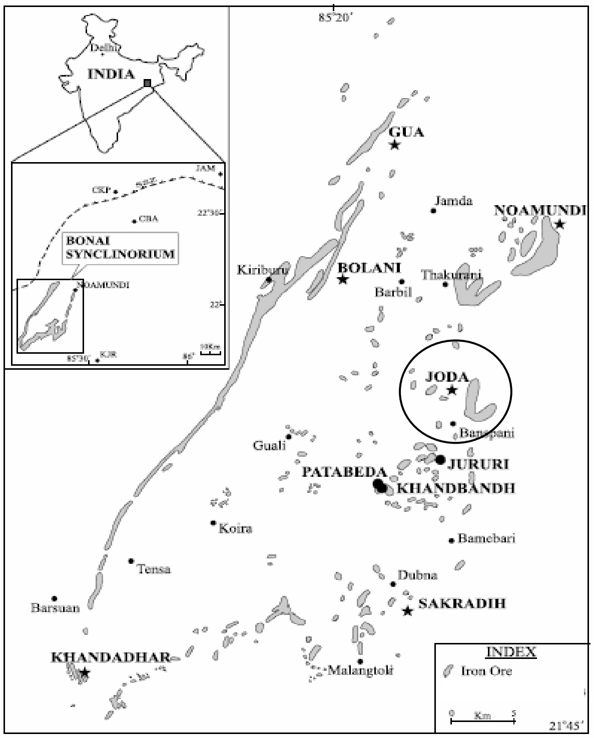


Fig. 1: Location of Joda East (circled) as a part of Bonai synclinorium (map modified after Jones 1935).

occur in the mine, like all other Indian iron ore of Indian origin are characterized by high iron content and low in gangue but high in alumina content.[1] Clay and gibbsite are the predominant mineral phases present as surface coating, fracture filling and/or free occurring and are responsible for alumina content being higher.

JEIM is a fully mechanized truck and shovel operation with drilling and blasting carried out for all waste and ore materials. Blastholes are drilled by rotary and hammer drill rigs to 6–9 m benches designed to suit geology of individual pit areas. Blasthole sampling forms the basis for day to day production and quality control. A cut-off grade on the alumina content in ROM combined with physical characteristics such as lump yield and strength defines the Dry Circuit (high grade) and Wet Circuit (off grade) crusher feed.

The saga in improving product quality while optimizing plant production in JEIM relates to changes in operational philosophy from crushing and screening of high grade lumps through wet beneficiation to suitable processing methods for high grade and low grades. All these developments are integrated with continual advancement of geological knowledge as a result of new set of exploration and pit mapping with an overview of ore genesis which provides new solution and insights into the varied geological and grade problem. An effort has been made, in this paper, to summarize the lessons learned over the years.

PREVALENT ORE PROCESSING PRACTICES AND INITIAL EXPERIENCE

The Wet Circuit plant commenced its operation in 1995 with 2MTPA production capacity, which was 35 years after the mined started producing high grade lump ore only. The plant throughput was increased to 4MTPA by 2004 to cater to the enhanced iron ore requirement of the steel works and this is the time when it was also necessary to reduce plant losses to enhance production level coupled with more stringent quality requirements from works.

The need for increasing production while controlling overall product grades necessitated the mine to look for alternate processing options e.g. dry crushing and screening of high grade ores, which called for optimization of mine design and excavation planning processes. The ore reserve (> 58%Fe) was classified accordingly with low (0–2% Al_2O_3), medium (2–4%) and high (4–7%) alumina ore keeping in mind the requirement for producing iron ore fines with 2% alumina. The cut-off alumina grade was decided as 2.5% based on alumina distribution in the deposit. This classification also took into account lump yield, ore strength for genetic ore groups as well as occurrences and distribution of aluminous phases within different ore types (Table 1). Low alumina friable flaky ore and blue dust found to be most suitable for dry processing to crush to fines unlike hard ore, which test works revealed may miss targeted fines alumina, if dry crushed and screened, because of high alumina friable ore/ shale intercalation in between as well as presence of interstitial clay.

By the end of 2004, processes established for producing direct despatachable ore and the fines produced thereby started to be blended with classifier fines to achieve the targeted fines quality when dispatched to Works (Fig. 2).

As the mine progressed deeper into the ore body during long years of mining operation, availability of hard ore became less and increased physical and chemical variation in the deposit added to the complexity in processing. The change in overall granulometry resulted in increased slime losses. In the year 2006, the Wet plant was integrated with Hydrocyclones in order to recover Fe-value from slimes so as to reduce slime loss and improve percent utilization of the deposit. Fig. 3 represents the reduction in overall slime losses in JEIM over the years.

Table 1: Genetic ore groups and their classification

Genetic Ore Groups	Alumina Band	Dominant Mineralogy	Gangue	Relative porosity	Relative Lump Yield	Relative Abundance	% of resource
BIF-Derived Iron Deposit	Low Alumina (0–2%)	Hematite +Magnetite: 80–90% Goethite: 5% Martite:1%	4–5% (Clay, mica, quartz)	Low	High (Hard Ore) Low (Blue Dust and Flaky Ore)	High	~ 43%
	Medium Alumina (2–4%)	Goethite (crypt): 60% Hematite/ matrite/ specularite: 30%	10% (Clay, Gibbsite, Quartz)	Low to medium	Medium	Moderate	~ 32%
	High Alumina (4–7%)	Goethite-Limonite: 35% Hematite/ matrite/ specularite: 30%	35% (Kaolinite, Gibbsite)	Medium to high	Low	Low	~ 25%
Detrital Iron Deposit	CANGA	Goethite/ Crypt. Goethite : 25% Hematite: 20%	40–45% (Clay, Gibbsite, Quartz)	Low	High	Very Low	–

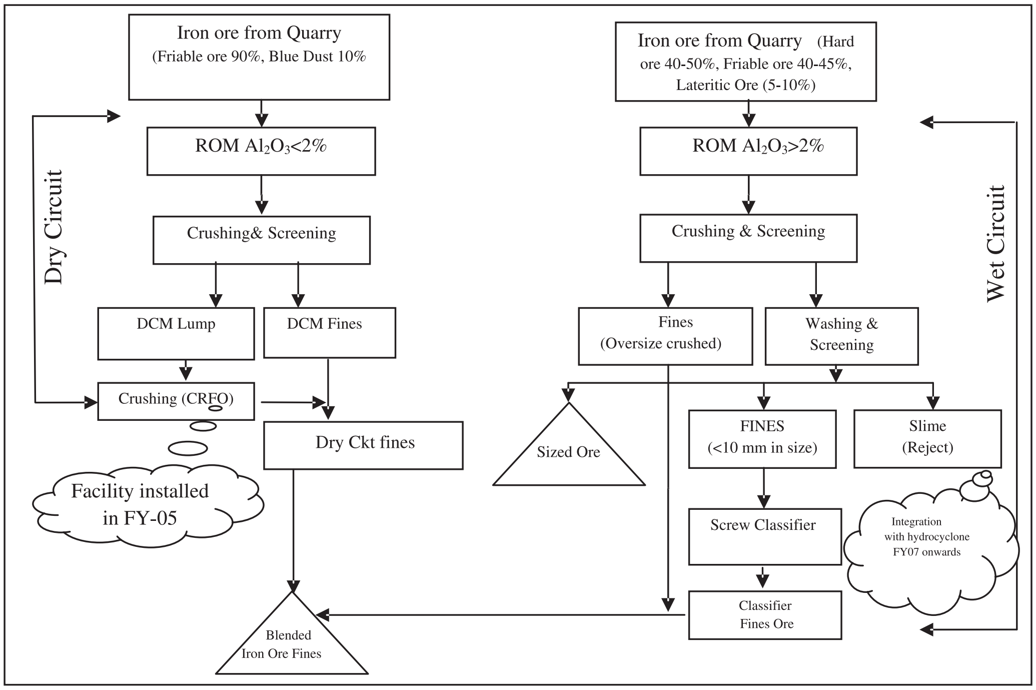


Fig. 2: Process flow of Joda East iron ore processing plants.

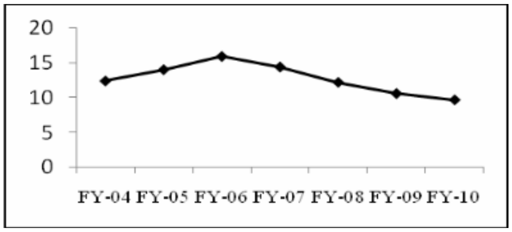


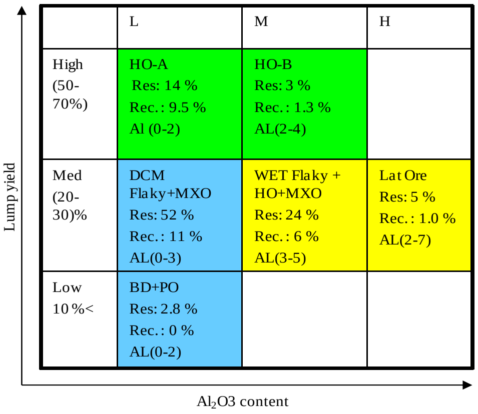
Fig. 3: Reduction in plant losses, JEIM.

As a result of the aforesaid initiatives JEIM has been able to achieve overall product grade and tonnages. But by the year 2007 stricter quality requirement for both sized ore (in terms of alumina, mean size, lesser undersize and lesser sticky coating) and fines (reduction in rake to rake variation while maintaining 2% alumina) necessitated some major improvements in the overall ore processing and blending practices, not only in the final product stage but also in feed to the plants.

DEVELOPMENTS IN OPERATING PRACTICES 2007 ONWARDS

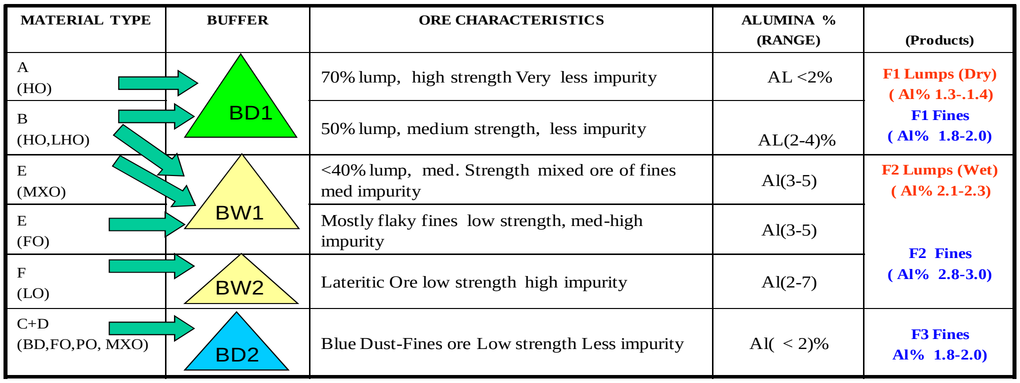
To address customer requirements during this period, lump yield in the plant, coating problem in sized ore as well as variability in product grades were critically reviewed. The variable nature of the ore fed directly to the plant resulted in wide swings in plant feed grade leading into variable product grade and thereby complexity in blending during loading iron ore fines and sized ore. The coating problem and increasing undersize in sized ore were analyzed to be the result of mixed ore processing where sized ore generated from hard ore being coated as a result of autogenous breakage of friable ore lumps, also leading to increase in finer fractions during transfers and transits. Over and above, the feed size variability, in particular, was greater than the expected, resulted in tonnage imbalance for coarse and fine circuits leading several operational difficulties.

Therefore in order to reduce variability in feed to both Wet and Dry Circuit plant, it was suggested to process different ores separately, in batches, rather than conventional mixed ore processing. Accordingly batches were defined on the basis of physical (mainly strength and lump yield) and chemical (Figs. 4 and 5).



	L	M	H
High (50-70%)	HO-A Res: 14 % Rec.: 9.5 % Al (0-2)	HO-B Res: 3 % Rec.: 1.3 % AL(2-4)	
Med (20-30)%	DCM Flaky+MXO Res: 52 % Rec.: 11 % AL(0-3)	WET Flaky + HO+MXO Res: 24 % Rec.: 6 % AL(3-5)	Lat Ore Res: 5 % Rec.: 1.0 % AL(2-7)
Low 10 %<	BD+PO Res: 2.8 % Rec.: 0 % AL(0-2)		

Fig. 4: Ore categorization based on strength and alumina.



MATERIAL TYPE	BUFFER	ORE CHARACTERISTICS	ALUMINA % (RANGE)	(Products)
A (HO)	BD1	70% lump, high strength Very less impurity	AL <2%	**F1 Lumps (Dry)** **(Al% 1.3-.1.4)** **F1 Fines** **(Al% 1.8-2.0)**
B (HO,LHO)		50% lump, medium strength, less impurity	AL(2-4)%	
E (MXO)	BW1	<40% lump, med. Strength mixed ore of fines med impurity	Al(3-5)	**F2 Lumps (Wet)** **(Al% 2.1-2.3)**
E (FO)		Mostly flaky fines low strength, med-high impurity	Al(3-5)	**F2 Fines** **(Al% 2.8-3.0)**
F (LO)	BW2	Lateritic Ore low strength high impurity	Al(2-7)	
C+D (BD,FO,PO, MXO)	BD2	Blue Dust-Fines ore Low strength Less impurity	Al(< 2)%	**F3 Fines** **Al% 1.8-2.0)**

Fig. 5: Feed batch design and product quality plan.

While BD2 refers to Dry ckt feed, BD1 stands the hard ore batch and BW1 and BW2 for friable ore batch separately processed in wet circuit plant. With batch processing a good improvement in the quality of sized ore with regard to slime coating and undersize content is observed. The sized ore produced from hard ore batch is with low moisture, high tumbler index (T.I.) and with low decripitation index. The lump generated from friable ore batch, being high in alumina content (1.8–2.0%) and less T.I. used to crush to fines through dry ckt plant and blended with fines dispatched to Jamshedpur. Blending of this friable lump crushed fines helped to improve consistency fines ore alumina to a great extent. This process also helped to increase ROM feed grade to Wet plant as off grade ores (4–5% alumina) now started finding rooms as part of friable ore batch.

The changed feed mix to the plant, from earlier mixed ore to current batch processing a change in product grade and overall lumps-fines balance was envisaged, which required review of the product mix at loading point depending on availability and alumina range of different alumina range for lumps and fines. Depending on recovery patterns during trials of the batches ROM requirement for hard ore and friable ore batches defined. All these exercise necessitated reclassification of ore categories in block model to prepare suitable excavation plan.

As batch processing was created driven by a strong focus on internal customers, real time support to production for a consistent output placed a continuous emphasis on day to day mine grade control. In-pit geological mapping has become definite and ultimate guide to achieve target grades and grade predictions. The reconciliation of the actual plant feed grade realized with the predicted feed quality, started to be monitored in fixed intervals. Also the reconciliation of the actual plant feed grade with the feed grade as per ore reserve, which is perhaps the best indicator of total ore reserve utilization started to be monitored from FY10 [cf. 2]. A review of the existing sampling systems in all product streams also carried out to obtain more detailed and scientific data. In the absence of any direct measurement system available for determining actual plant feed grade, daily mass balance using weightometer tonnages, product and slime quality and some assumptions for minor product streams like hydrocyclone started. This also enabled to understand at a glance the delta improvement in alumina in the plant. Each batch is normally reconciled, through this process, to plant production and back to the ore sources.

The plant, however, suffered from production losses initially due to lesser throughput rate (tph) during hard ore batch operation which was subsequently overcome with modifications of screens, apron feeder, tertiary loop conveyor etc. With further increase in sized ore requirement by works in view of enhanced hot metal production FY-09 onwards. This additional sized ore was supplied by rescreening of friable ore lumps in 20 and 10mm and blending of this 20 × 40 mm fraction with sized ore generated from Hard Ore batch. Since 20 × 40 mm fraction of friable ore lump comparatively better in tumbler index and alumina, a suitable blend of this material actually improved further the granulometry of sized ore dispatched to works.

GROWTH PLAN AND STRATEGIES FOR IRON ORE PROCESSING IN LINE WITH RESERVE

In line with the ambitious growth plan of Jamshedpur steel plant for achieving 10MTPA hot metal production by FY12. In order to cater to the additional iron ore requirement from Joda East Iron Mine, a review of the Joda East ore body model was carried out to optimize pit design and review the cut off grades for high grade ore and wet ckt plant feed grade with respect to the ore reserve available. Also it was necessary to ensure that overall balance of lumps and fines w.r.t quantity and quality from all sources were optimized and sufficient reserve was available to produce ~8MTPA iron ore from the mine sustainably. Another important aspect in this exercise was to identify potential areas for slime disposal and its mode in view of the space constraint in the mining lease. Accordingly in-pit slime disposal for backfilling of the mined out pits were considered.

To arrive at a logical solution on plant upgrade to meet required lumps and fines tonnage and grades on expansion, long term mine scheduling was carried out to ensure availability of hard ore, friable ore and dry circuit material batches in the deposit and their availability year on year, keeping in mind the requirement for resources to be deployed for ore-waste excavation and rehandling. The review stressed upon the approach of balanced mining and suggested capacity (throughput) distribution of the Dry Ckt Material Plant and Wet Ckt Plant, in accordance with their distribution in the ore reserve and also mining suitability year on year (Fig. 6).

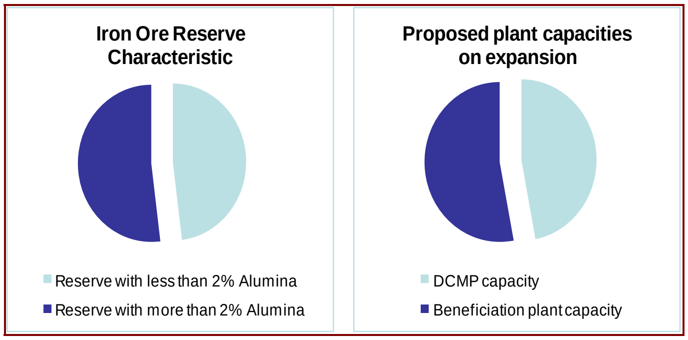


Fig. 6: Wet and Dry batch distribution based on deposit ratio.

Considering the need to utilize subgrade ores which could not be utilized otherwise with the original wet plant flow sheet and arising out of the plan that indicated the grade of the wet plant product, particularly low alumina level of its fines and lumps was important in controlling overall alumina levels in total product. Also as the lower grade ores have been included in the overall lump and fines product blend, the beneficiation plant's ability to eliminate particular impurities has become increasingly important in optimizing the overall product blend. Beneficiation and metallurgical test works were conducted to develop suitable beneficiation flow sheet for wet circuit material in reputed international laboratories with bulk samples collected as per the desired feed grade to the beneficiation plant to optimize ore reserve utilization.

As the mine design has been optimized over the mine life, changes in the plant feed grade occurred, time to time and the plant and all down stream processes had their performance to these changes.

CONCLUSION

Optimization of wet plant feed grade and deposit ratio of such material helped to significantly reduce the capital investment in wet plant as it is planned for upgrade to a full fledged beneficiation circuit. This has been possible by careful investigation of the available deposit and segregation of such ore types, which do not require any beneficiation and can be used for blending by simple crushing and screening to match overall product grade requirement. This work also shows that careful integration of deposit evaluation, excavation planning with day to day mine grade control, processing and loading can achieve a minimum cost option in solving capacity and technical problems and make best use of all the components of the ore reserve.

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