CHAPTER 3

Iron Ore Beneficiation

Iron & Steel Industry in India grew exponentially during the last decade. On the basis of the growth witnessed, the National Steel Policy 2008 revised the estimated domestic steel production projection as 180 million tonnes by the year 2019-20.

Iron ore is the basic raw material for iron & steel making. Of the total domestic consumption of iron ore, about 98% is accounted for by pig iron and sponge iron industries. Lumpy iron ore (-30+10 mm) and agglomerates like sinter & pellet form the feed for the production of pig iron in blast furnace, whereas steel scrap, lumpy iron ore (-18+6 mm) or pellet are the feed for sponge iron production.

Hematite and magnetite are the most prominent of the iron ores found in India. Of these, hematite is considered to be the most important iron ore because of its high-grade quality & lumpy nature, which is consumed by a large number of pig & sponge iron industries in India. Magnetite deposits are not exploited so far for domestic use on account of their poor grade lumps (~40% Fe). However, it can be utilised after beneficiation at a finer size followed by pelletisation.

As per United Nations Framework Classification (UNFC) of mineral resources as on 1.4.2010 (NMI), the total resource of iron ore in the country is estimated to be around 28.5 billion tonnes, of this hematite & magnetite accounted for 62.7% and 37.3% respectively. The detail of the total iron resources in India is presented in Fig-20.

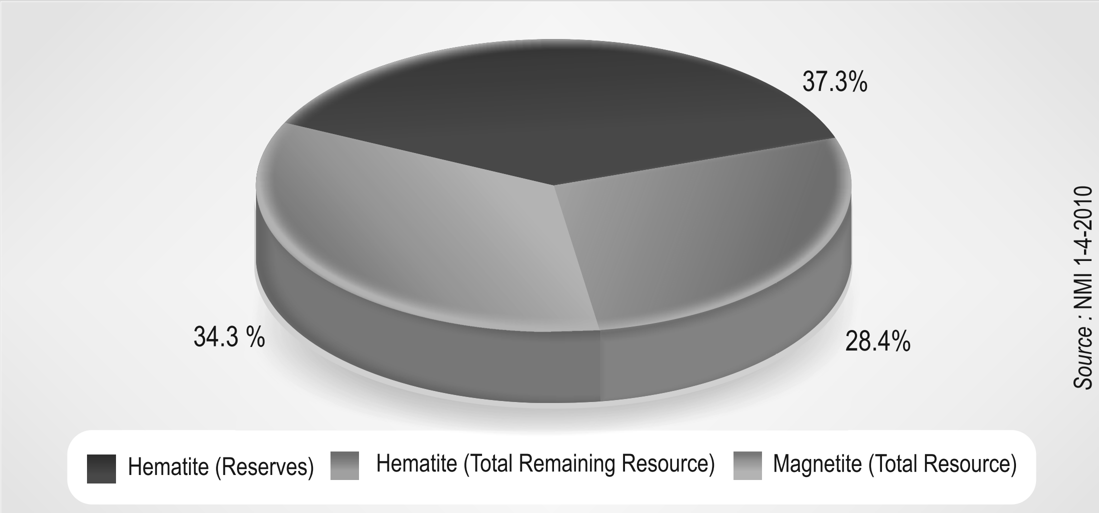

Fig-20: Total Resources of Iron Ore in India as on 1.4.2010 (NMI)

Almost all of the present-day production comes from hematite reserves. The overall hematite reserve in the country is of medium-grade (+62% Fe) and accounts for around 28% of the total iron resource of the country.

Domestic iron ore production is mainly in the form of lumps and fines in the ratio of around 2:3. Of these, domestic consumption in iron & steel making is only around 40–45% in the form of lumps & sinters, the remaining is exported. The bulk (around 90%) of the iron ore fines get exported, as they cannot be utilised in iron making without agglomeration.

3.1 IRON ORE PROCESSING PRACTICED IN INDIA

The blast furnace route of iron making is predominant in India. The raw materials used in the blast furnace for hot metal (pig iron) are lumpy iron ore, agglomerates (sinters & pellets), metallurgical coke and fluxes (limestone, dolomite). It has been established over the years that the productivity of the blast furnace increases and energy consumption decreases by using superior quality of raw material particularly of iron inputs. Thus, higher the iron content in feed, the lower is the slag volume generated in blast furnace, which automatically increases the productivity and reduces the coke rate. One percent increase in iron content improves the productivity by 2% and reduces the coke consumption by 1%. Therefore, higher iron content in the feed to the blast furnace (over 60%) is preferred.

Indian hematite, though rich in iron content have higher percentage of alumina (Al_2O_3 1 to 7%) and low silica content i.e., high alumina: silica ratio (1.5–3.0 for lumpy ore and 3–4 for fines). This adverse alumina to silica ratio is detrimental to blast furnace as well as sinter plant productivity and should be less than 1.5 and preferably below 1. Alumina is refractory in nature. High alumina content in the blast furnace burden irrespective of its composition (lumps, sinters and pellets) generates highly viscous slag. This needs higher amount of fluxes and coke, thereby producing large slag volumes, thus decreasing the productivity of the blast furnace. The adverse impact of high alumina content is well quantified. In the Blast Furnace burden 1% increase in Al_2O_3 content increases coke rate by 2.2%, a decrease in the productivity by 4% and an increase in flux consumption by 30 kg/t of hot metal production. Hence, beneficiation/processing of iron ore are necessary to reduce alumina in the feed.

In Indian iron ores alumina is contributed by clay (kaolinite), gibbsite, lateritic material as well as solid solutions in hydrated iron oxides.

In general, the practice adopted by major steel plants in India is to consume medium to high-grade ores (+62% Fe). It is achieved by resorting to selective mining keeping the cut-off up to as high as 58–60% Fe. Therefore, prime objective of beneficiation is to meet the physical standards as required for iron making.

The entire run of mine (r.o.m.) iron ore is processed for domestic consumption as well as export. The beneficiation practices in vogue for improvement of iron content and reduction of alumina and silica, in the country, comprise :

3.1.1 Dry Processing

In India most of the high-grade (> 65% Fe) hematite iron ore are subjected to dry process of beneficiation to meet the size requirement involving multistage crushing and screening to obtain calibrated lumps i.e., -40+10 mm (for blast furnace); -18+6 mm (for sponge iron) and fines (-10/6 mm) products. The fines are stacked at mine site as waste. Almost all the non-captive mines follow this practice (Fig-21).

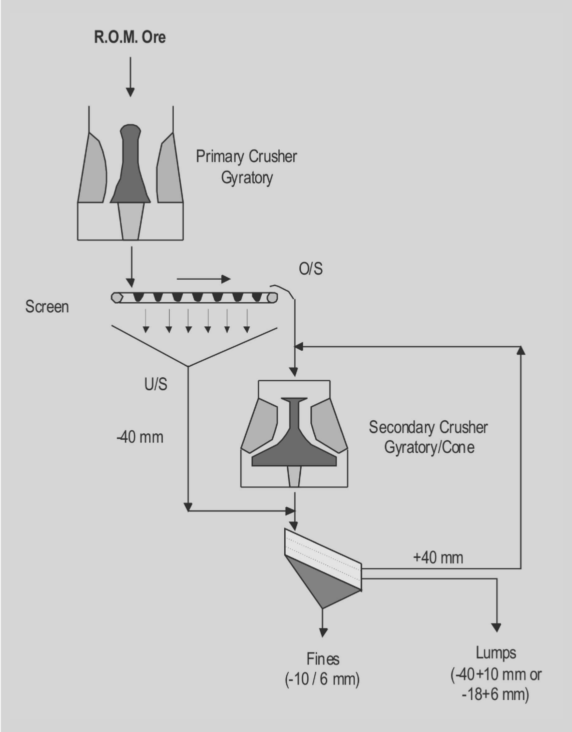

Fig- 21: Dry Processing

3.1.2 Dry-cum-wet Processing

In some of the captive iron ore mines, fine fraction (-10 mm), generated after dry processing, is further processed (Fig-22) in mechanical classifiers, hydro-cyclones, etc. to obtain -10+0.15 mm size products that constitute the feed for sintering. The classifier/ hydro-cyclone overflow, i.e., -0.15 mm (100 mesh) size product constitutes the slime and is dumped into tailing pond. The Indian iron ores, being soft in nature on account of high alumina bearing laterite and the friable portion breaking up preferentially into a finer size during crushing and sizing, generate large quantities of fines. This leads to concentration of alumina in iron ore fines, the slimes (-100 mesh fraction) too are rich in alumina (6–10%). The process flow sheet is in practice in the deposits of Donimalai (Karnataka) and Bailadila (Chhattisgarh) of NMDC.

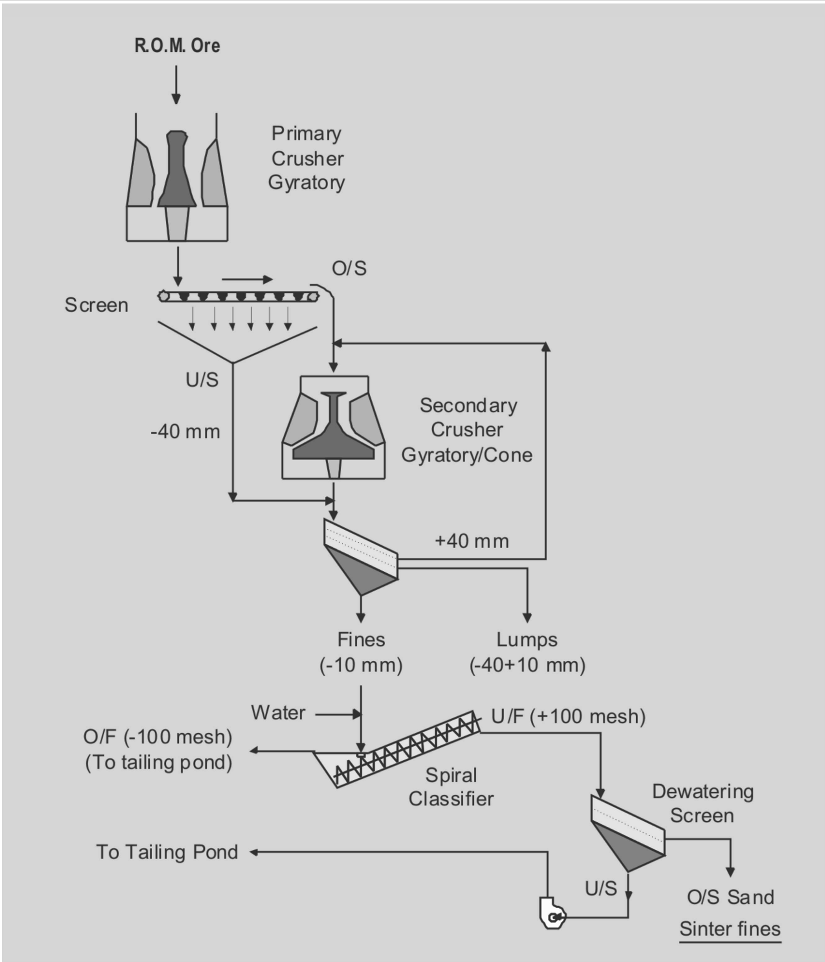

Fig-22: Dry-cum-wet Processing

3.1.3 Wet Processing

The wet processing circuit is generally practiced for low/medium-grade (60-62% Fe) hematite iron ore. The process consists of multi-stage crushing followed by different stages of washing in the form of scrubbing and/or wet screening, classification etc., but the advantage is only partial removal of adhered alumina & free silica in the calibrated lumpy size fraction (-40+10 mm) that just meets the blast furnace grade. The classifier underflow (-10+0.15 mm) directly used for sinter making, while classifier overflow (-100 mesh) is dumped in the tailing pond. The above washing practice marginally improves the handling properties of the mineral because of removal of adhered clayey matter. However, the quality of the sinter feed is impaired due to presence of lateritic material in the classifier underflow. The plant where the above process followed is known as washing plants (Fig-23). Many deposits of Jharkhand, Orissa and Chhattisgarh etc. catering to ISPs, come under this category of treatment. Typical metallurgical results of iron ore washing plants from Noamundi (TATA) & Barsua (SAIL) are presented in Table-7.

Product	Size mm	%Wt	Noamundi (Tata Steel)			%Wt	Barsua (SAIL)		
			%Fe	$\%SiO_2$	$\%Al_2O_3$		%Fe	$\%SiO_2$	$\%Al_2O_3$
Feed		**100.0**	**64-65**	**1-1.2**	**3-3.2**	**100.0**	**58.6**	**3.1**	**4.6**
Lumps	-40+10	53.6	66.5	0.7-0.9	1.7-1.9	36.0	61.7	1.4	2.4
Fines	-10+0.15	32.9	64.0	1-1.5	3.3-4	39.2	59.5	1.8	5.0
Slimes	-0.15	13.5	56-59	4-5.5	6-10	24.8	52.5	7.4	7.8

Table-7: Typical Assays of Feed & Products from Iron Ore Washing plants in India

The production of lumps and fines by the above process routes are of the order of 40:60. The slimes -100 mesh contributes about 20-25% of the ROM and are dumped in valleys between iron bearing mountain ranges. Extensive mining over the period of last six decades has resulted in these slime ponds holding several million tonnes of locked up iron values besides causing irreparable damage to land & environment.

The flow sheets followed by several Indian iron ore processing plants covering iron ores of all the five zones are presented in Figs-24 to 31.

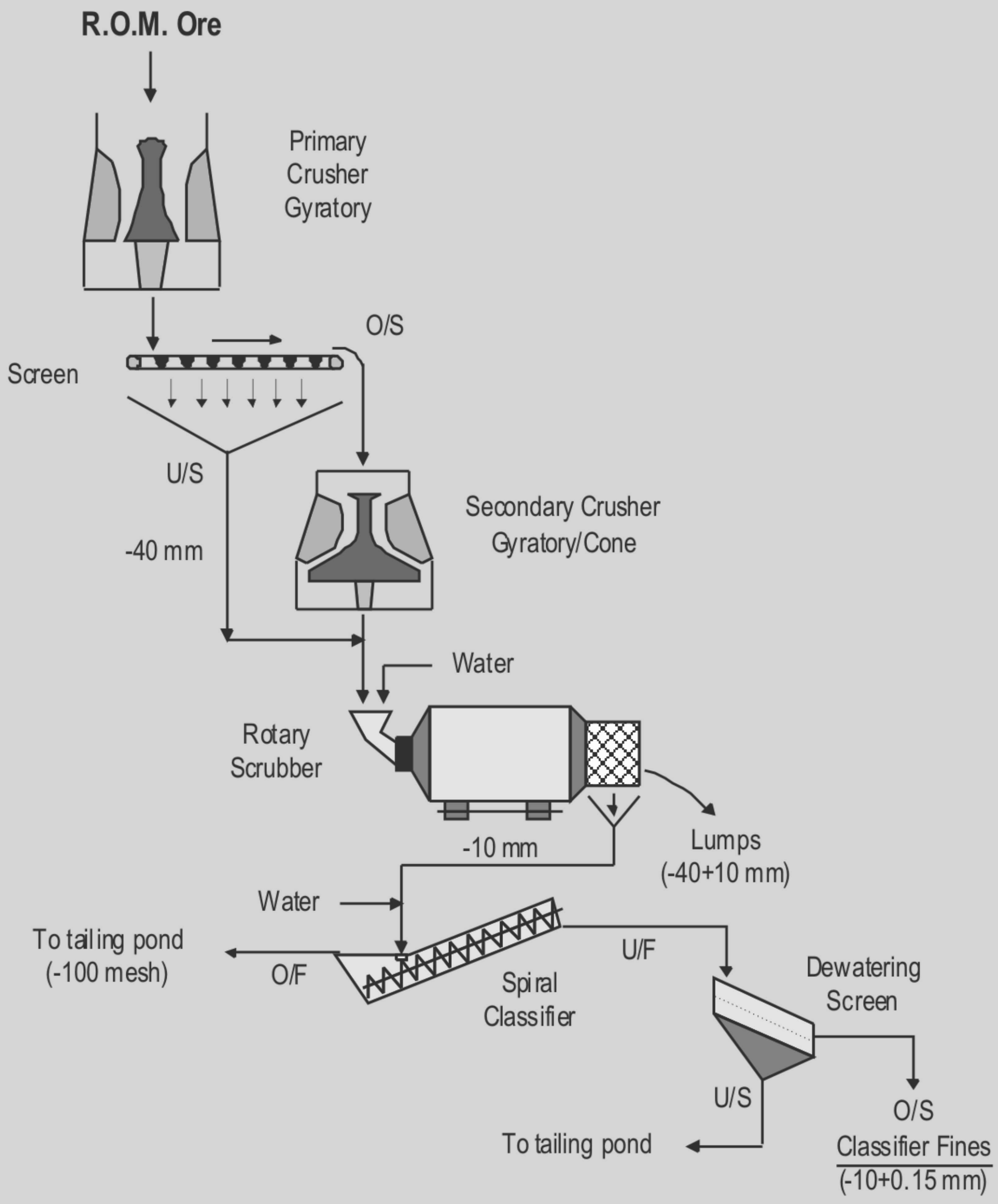

Fig- 23: Wet Processing

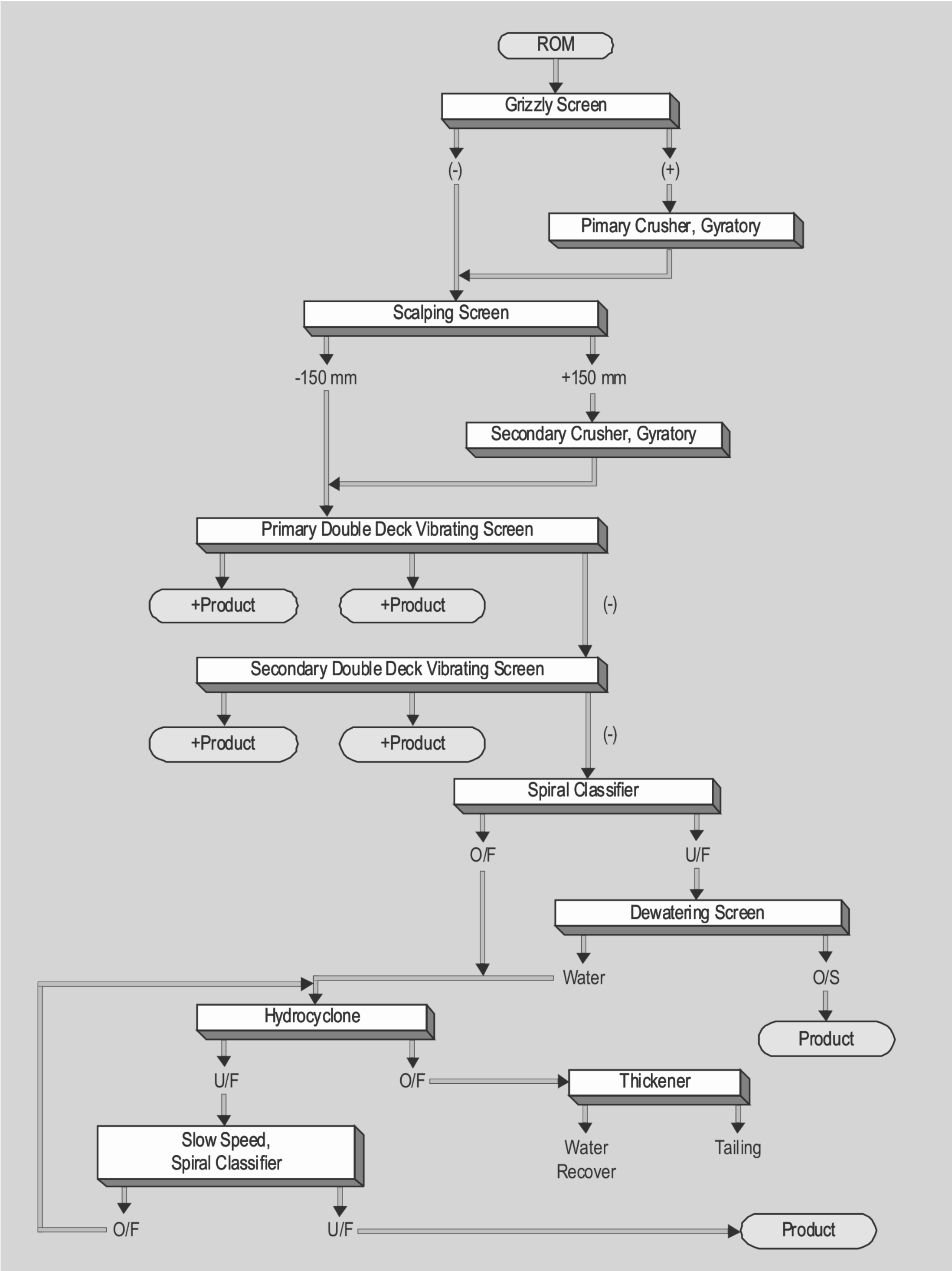

Fig-24: Process Flow Sheet of Bailadila (Deposit-14), NMDC

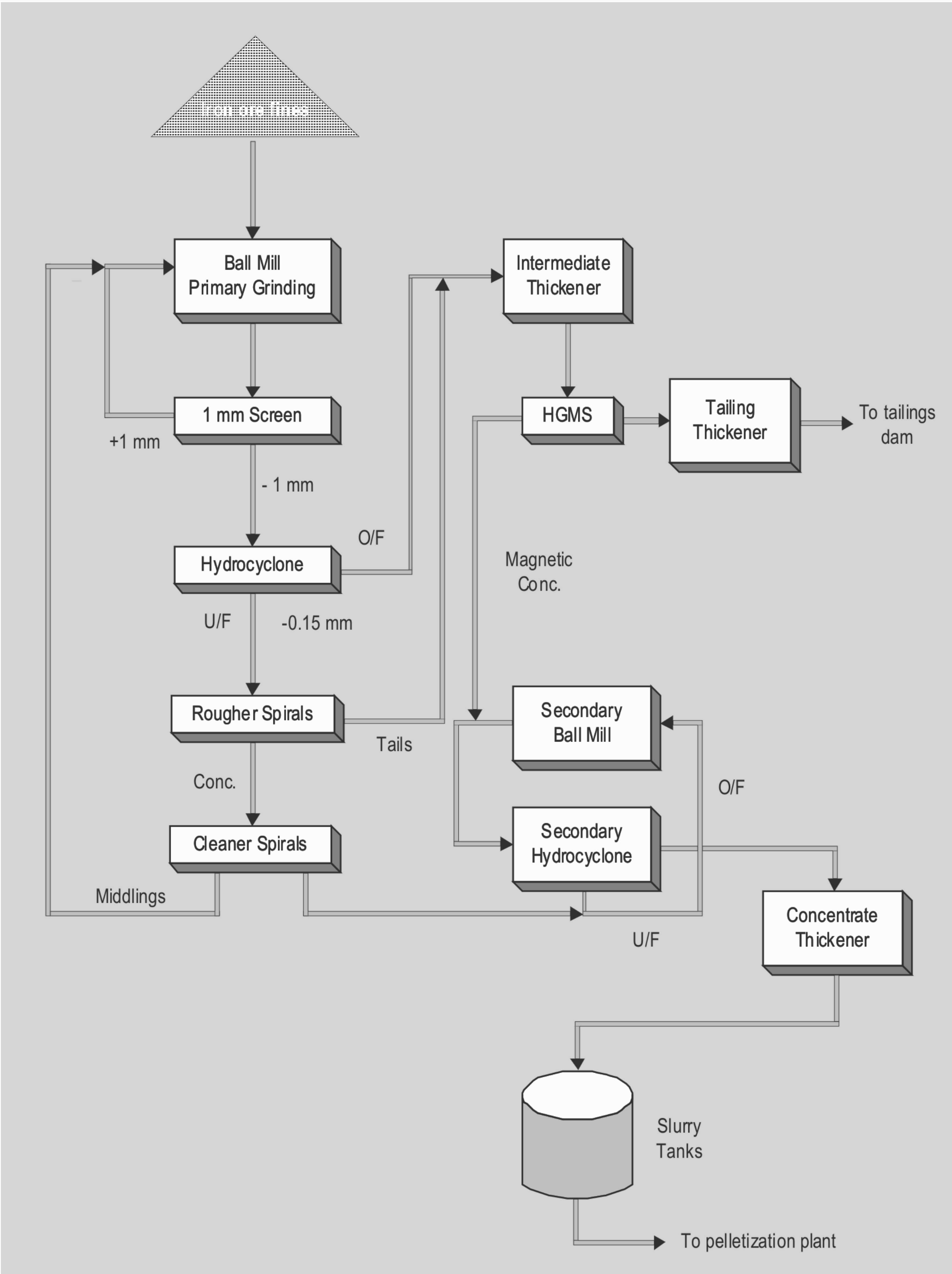

Fig-25: Process Flow Sheet of ESSAR Concentrator, Kirandul, Bastar

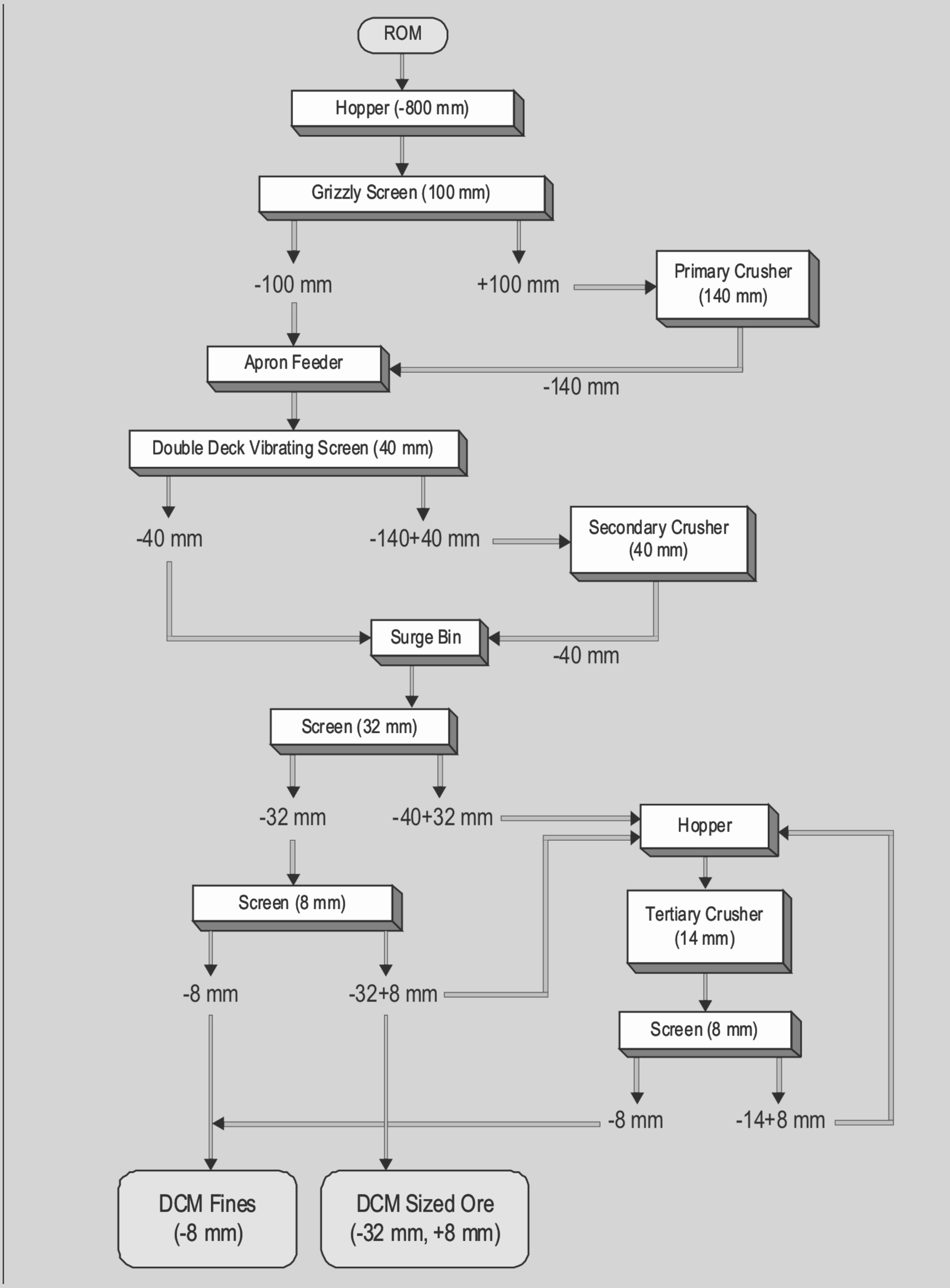

Fig- 26: Process Flow Sheet of Noamundi, Singhbum, Jharkhand, TISCO

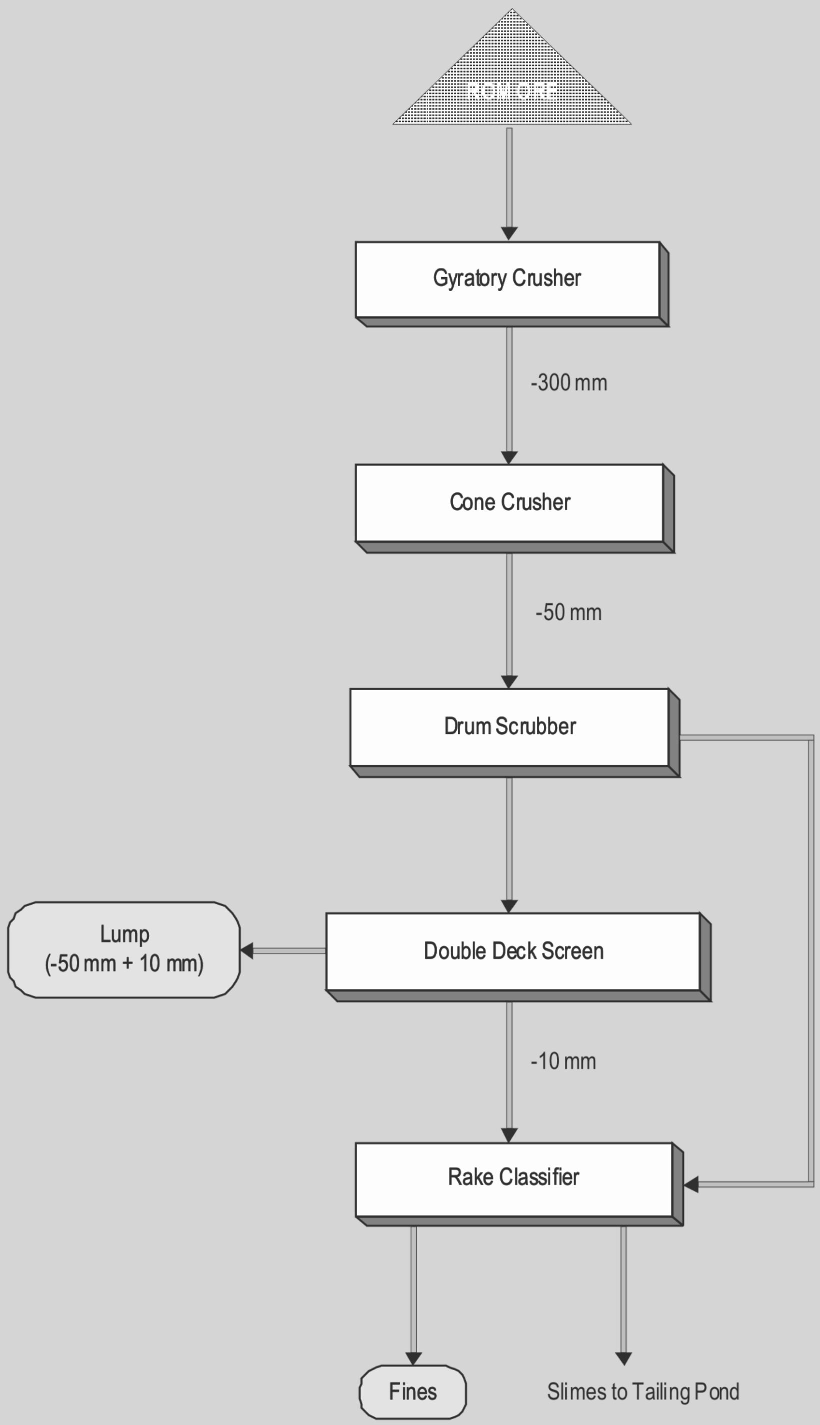

Fig-27: Process Flow Sheet of Bolani, SAIL, Orissa

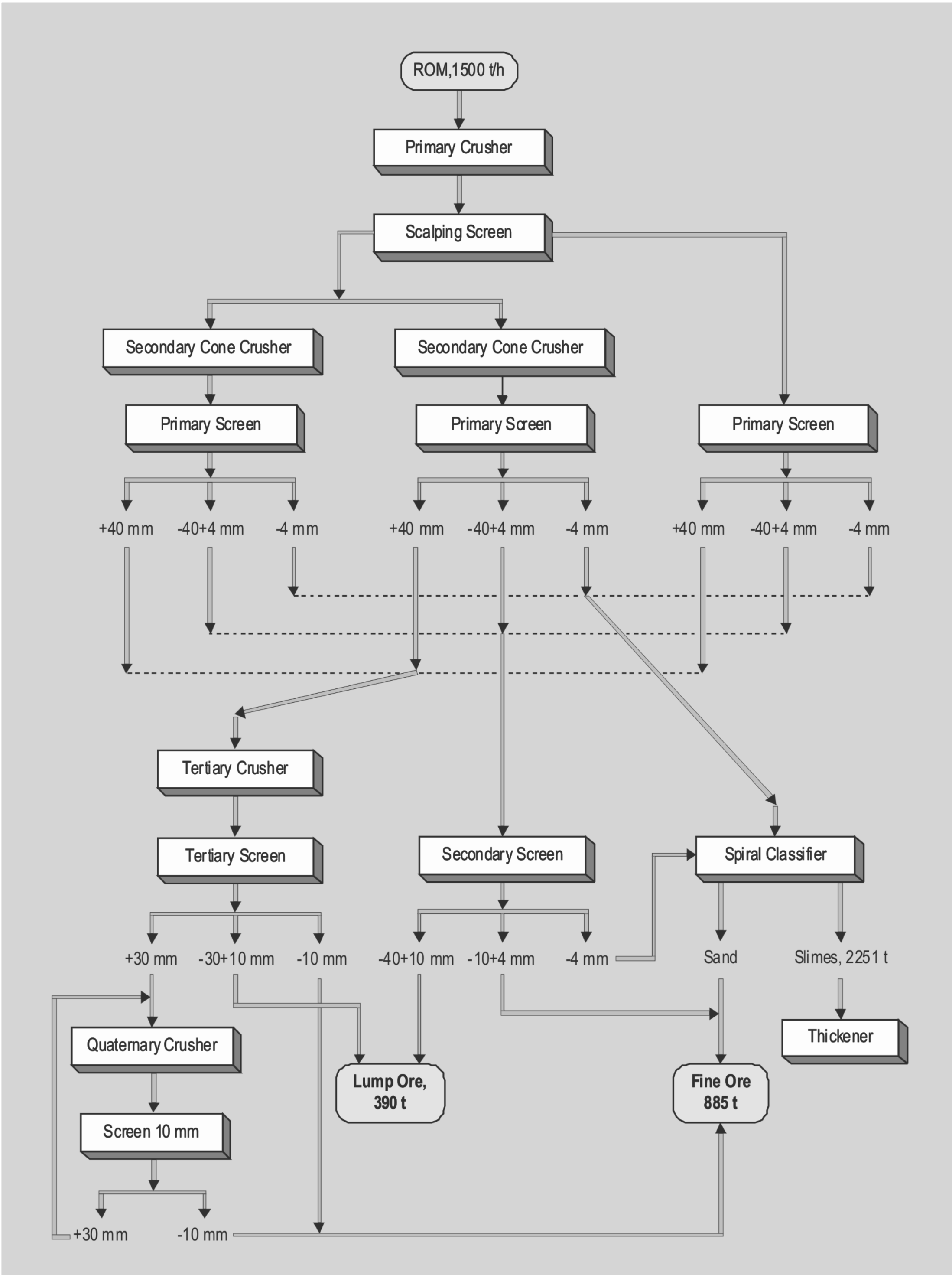

Fig-28: Process Flow Sheet of Kiruburu, SAIL, Orissa

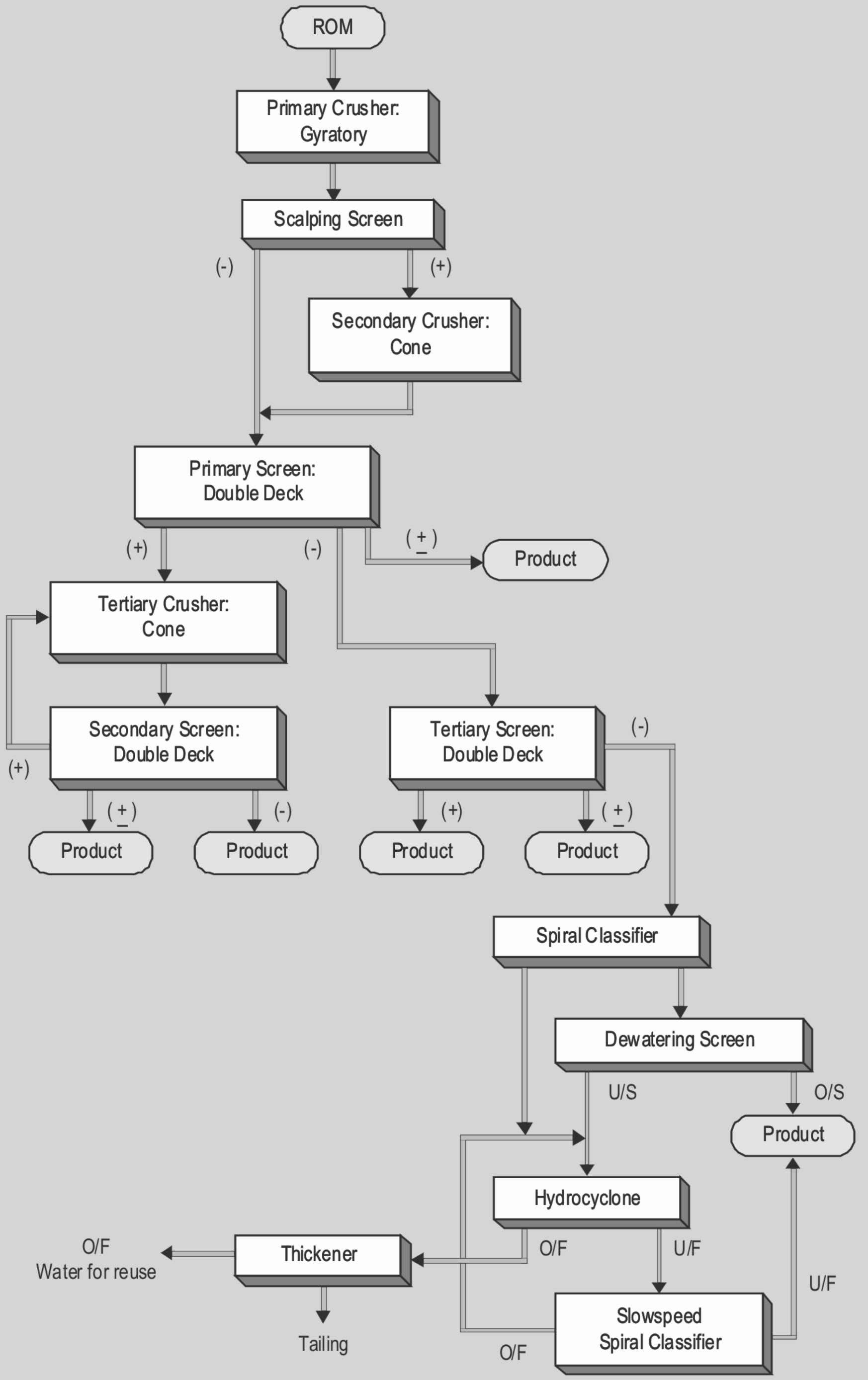

Fig-29: Process Flow Sheet of Donimalai, Bellary, NMDC

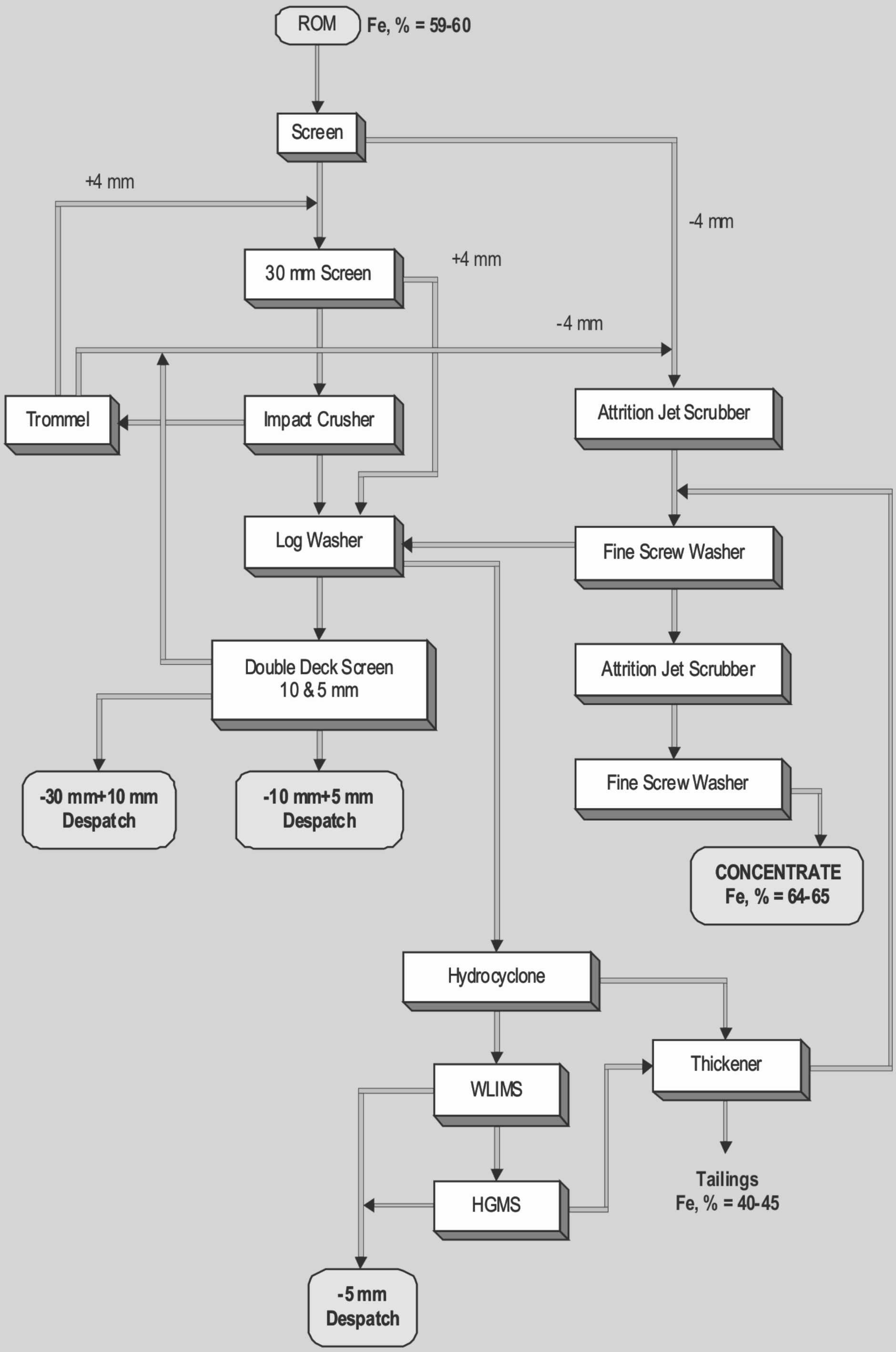

Fig-30: Process Flow Sheet of Fomento, Goa

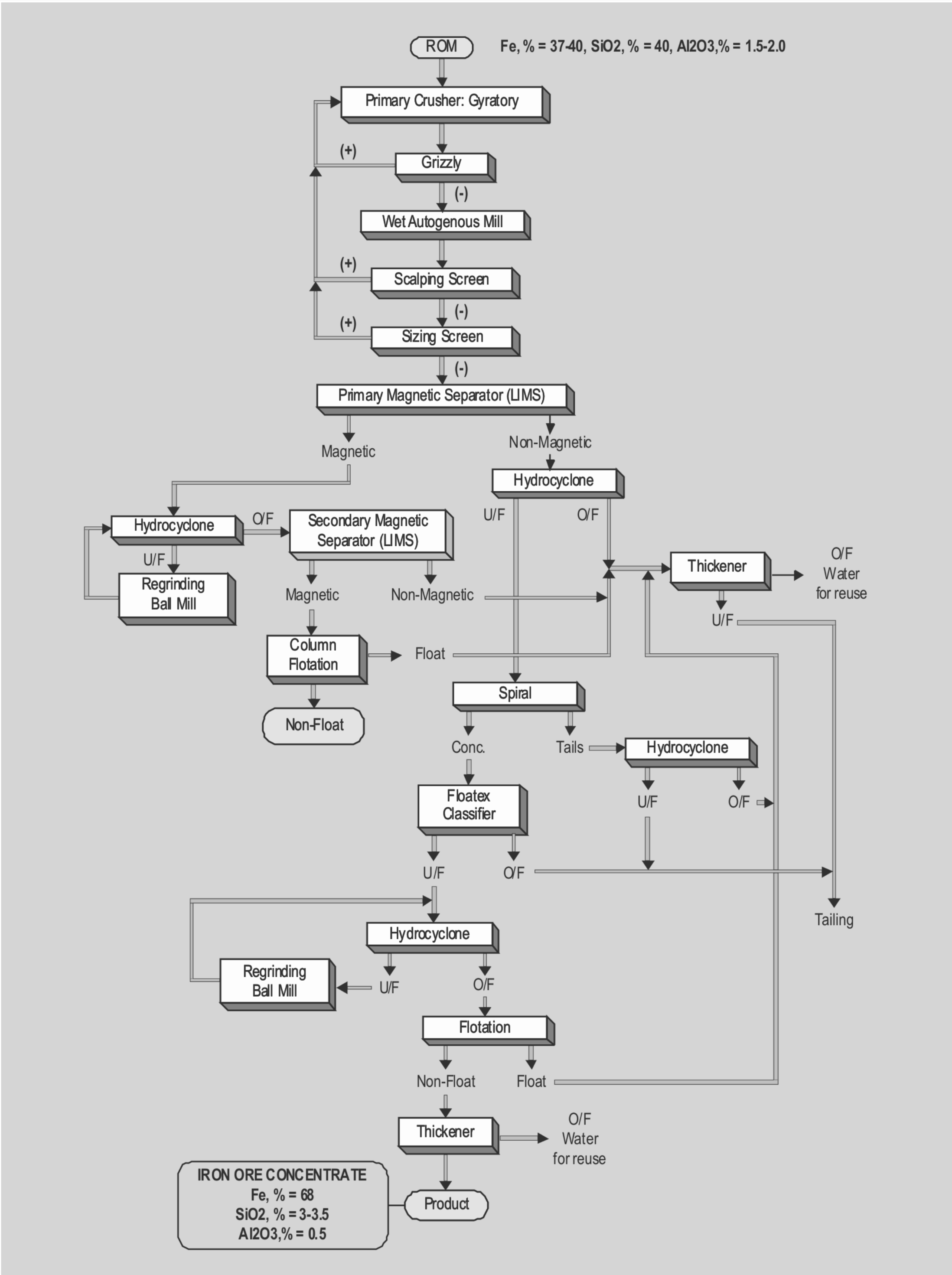

Fig-31: Process Flow Sheet of Kudremukh, Karnataka, KIOCL

A close look at the beneficiation/processing practiced in the country reveals that:

1. Most of the iron ore mines in India have been operated by selective mining for maintaining high-grade of ore.

2. To maintain high-grade ore, low-grade lumps and laterite are rejected. Generally, classifier fines (-10+0.15 mm) are not processed any further and as such used for sinter making.

3. The current industrial practice of iron ore washing is oriented towards product with 2.5–3.0 Al_2O_3 in lumps and around 5% Al_2O_3 in sinter fines.

4. The present iron ore washing circuit produces slimes, particles below 0.15 mm (-100 mesh) which are discarded as waste. The generation of slimes is about 20–25% of the feed to the plant.

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

6. No low-grade ores are exploited.

3.2 NEED FOR PROCESSING

Any ore in general, seldom occurs in its purity and form required by the industry and iron ore is no exception to it. In many cases, presence of deleterious impurities like silica, alumina, sulphur & phosphorus beyond desired limits render the ore unsuitable for use in iron making (blast furnace) or adversely affects its productivity and quality both.

Efficient and economic production of pig iron in blast furnace depends to a very large extent on the input of appropriate quality of raw materials. There has been a change, over the years in the nature of the feed particularly for iron ore i.e., from a totally lump oriented feed to use of higher sinter & pellet in the blast furnace burden. Therefore, the requirement of fines has gone up considerably. Hence, the emphasis on enriching the quality of fines through techno-economically viable beneficiation process has become more and more essential.

High-grade lumpy ore reserves are limited and hence optimum utilisation of locked-up valuables in sub-grade/marginal grade iron ore resources and fines are essential for survival of the Industry & growth that can be achieved only through implementation of appropriate beneficiation technology.

In most of the iron ore deposit of banded iron formation (BIF), almost all the different types of iron formations (massive, laminated, lateritic ore, blue dust etc.) are encountered and it is not always possible to mine it selectively for obvious reasons. Therefore, during commercial exploitation, two or more types of iron formations are mixed together thereby diluting the high-grade ore with lower grade one and vice versa. Therefore, run-of-mine (r.o.m.) iron ore also needs appropriate beneficiation in its totality.

The overall characterisation (physical, mineralogical & chemical) of the various types of hematite iron ore formations (Table-4) indicated that massive iron ore as well as blue-dust formations which are invariably very high in iron content (Fe >65%) at times contain impurities of silica & alumina beyond the required stipulations. Therefore, it needs consideration for beneficiation for rejection of silica & alumina.

Other iron formations like laminated ore, lateritic ore etc., however needs not only value addition in respect of iron content, but also substantial rejection in their silica and alumina content before its use.

Further, during last six decades of selective mining a large chunk of sub-grade or marginal grade ores (-60+45% Fe) is available *in situ* or stacked in dumps. These, together with stacked fines (-10 mm) and slimes (in tailing ponds) where a large tonnages of valuable hematite are locked up, calls for value addition for its utilisation.

3.3 COMMON UNIT OPERATIONS FOR BENEFICIATION OF IRON ORE

Lot of developments in iron ore processing have taken place in recent years in many iron ore producing countries of the world. The emphasis is on development of cost effective flow sheets to beneficiate the low-grade iron ores to produce concentrates suitable for blast furnace, sinter or pellet making. 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 methods/techniques applicable for iron ore processing are discussed below:

3.3.1 Washing & Wet Scrubbing

This process is very primitive and widely used in lumpy iron ore processing to dislodge soft & friable lateritic masses, fine sand and limonitic clay particles adhering to lumps. The process is invariably practiced when iron ores consists essentially of coarse and fine granular particles of hematite intermixed with barren sand or adhered limonitic clay. The scrubbing practice is also helpful in hard and porous hematite lumps, which invariably have cavity/pores filled with goethite/limonite or lateritic clayey material, and that need 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 iron ore minerals have usually high specific gravity (hematite: 5.1, magnetite: 5.2, goethite: 4.2 & siderite: 3.85) as compared to the most common 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 m). 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 iron 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. Some Brazilian iron ore plants are already operating Batac jig.

3.3.2.4 Spirals: They have wide range of application in gravity treatment of iron 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 iron 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 compartmentalisation 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 iron 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 (-150 µm) 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

Hematite ore displayed a wide range of magnetic susceptibility (2000 to 20,000 gauss intensity). Separation of valuable magnetic iron minerals from that of non-magnetic associated gangue minerals 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: Magnetite which has very high magnetic susceptibility (1000-2000 gauss), almost invariably uses low intensity magnetic separators (LIMS) for its concentration. This is one of the cheapest and most effective processes for magnetite mineral. Rotary drum separators with permanent magnet or electro-magnets are commonly used. For treatment of coarse ores (up to 6 mm), dry rotary-type are generally used. Fine material (<6 mm) is almost invariably concentrated by wet separators.

3.3.3.2 Medium Intensity Separator: These separators are designed with a magnetic intensity of 2000 to 7,000 gauss in the separation zone to recover medium magnetic minerals of hematite.

3.3.3.3 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 hematite. Dry separators (DHIMS) can be used for concentrating iron ore but the ore should be bone dry and sized. Wet high intensity magnetic separators (WHIMS) are generally used for treating hematite and limonite ores at finer sizes.

3.3.4 Froth Flotation

Froth flotation is now used in a number of major iron ore processing plants in the world. For effective flotation, the feed should be finer than 65 mesh. Anionic flotation employing fatty acid or petroleum sulfonate collector is adopted to float out most of the iron oxide minerals leaving behind the gangue minerals (quartz & chert) in the tailings. Crystalline hematite, such as, specularite can be effectively floated. Earthy hematite and limonite do not respond well to flotation and hence is not recovered by this method. Anionic flotation is also resorted to for selective flotation of apatite from iron ore by depressing iron minerals with starch. Cationic floatation using amine as collector is adopted for selective flotation of quartz/silicate minerals from magnetite iron ore. Cationic flotation is effective in de-slimed feed and useful only for cleaning of gravity and magnetic concentrate.

3.4 MINERALOGICAL CHARACTERISATION OF INDIAN IRON ORE

The Indian iron ores are considered to be rich in iron content (>58% Fe) invariably from valuable hematite mineral followed by limonite & goethite (iron hydroxide minerals). The silica and alumina are the main impurities contributed by clay, shale, quartz/chert, gibbsite, clayey laterite material etc.

Detailed mineralogical analysis by Electron Probe Micro Analyser (EPMA), X-ray Diffraction (XRD) & Differential Thermal Analysis (DTA) provided conclusive information regarding the specific minerals containing silica and alumina in the iron ores, its nature of mineralization, mode of occurrence and its textural disposition, grain size etc. Quartz occurs as bands with hematite in BHJ/BHQ formations and also occurs as inclusions within hematite. Some of the phases identified during characterisation study were found to be of alumino-silicates were kaolinite, illite and montmorillonite. Other phases identified are those of hydroxides and that possibly of diaspore and gibbsite. The later phases were invariably found associated with goethite/limonite phase (an iron bearing hydroxides) in intimate association. Electron probe micro analysis (EPMA) of these ore established the elemental composition of the aluminum containing grains. Most of the aluminosilicate as well as aluminum hydroxide mineral phases occur within the iron ore mineralisation were extremely fine grained, their grain sizes mostly being in the size range of few microns (Photo Plate 1-17).

Limonite & goethite (hydroxides of iron) are the other gangue mineral responsible for lowering of iron values vis-à-vis enhancement in alumina content, forming a part of the complex group in which proportion of the various radicals can undergo considerable variations. Their colour is brown to ocherous yellow having specific gravity in the range of 3.3 to 4.3 (average 3.8) and contains 10 to 14.5% combined water. These are secondary minerals, being the product of alteration. They occur as thin to thick capping formed by weathering and hydration of the iron ore (hematite). These minerals form flakes and needles generally of micro/tiny dimensions occurring as intergrowths with the original iron constituents (hematite). Therefore, in such ores, effective liberation is seldom achieved amongst the different iron bearing minerals i.e., between hematite and those of goethite (Photo Plate 1-17).

3.5 INDIAN IRON ORES & ITS BENEFICIATION POTENTIAL

Various steps involved in mineral beneficiation are mineral identification, quantification and their liberation characteristics followed by separation of identified mineral phases by exploiting physical properties of hardness, specific gravity, magnetic susceptibility etc.

Mineralogical characterisation of ore is the most important aspect in beneficiation, which includes identification of various mineral phases present, its textural disposition, nature of mineralization, mode of occurrence and at times its paragenesis (an ordered chronological sequence of mineral formations). A detailed mineralogical characterisation study of an ore will not only reveal the distribution of a particular element like, Fe, Si, Al etc., available in one or different group of minerals and its liberation characteristics but also highlights the likely process route of concentration (based on physical properties of minerals & its liberation) and valuable concentrate grade likely to be achieved.

In Indian scenario, most of the available irons bearing minerals are hematite, martite, goethite, limonite & magnetite. Two or more of these mineral phases are invariably present in an iron ore deposits. Predominant presence of hematite, martite and or magnetite minerals in any ore deposit will easily give a high-grade iron concentrate of over 65% Fe, as its entire constituent mineral contains around 70% Fe in it. On the other hand, with hematite, limonite & goethite mineral assemblages, achieving high-grade iron concentrate of over 65% Fe will be difficult proposition and will be totally dependent on amount of limonite-goethite mineral (percent availability) and its association with hematite, as these minerals (iron hydroxide) contain around 60–63% Fe and their presence, dilute the overall grade of iron concentrate (hematite). Besides, these iron hydroxide minerals are breeding ground for host of aluminous impurities (clay, lateritic clay, gibbsite etc.). Thus, in order to achieve a quality concentrate from such ore, limonite & goethite has to be considered as gangue mineral and rejected as far as possible (Photo Plate 1–17).

In these circumstances, liberation amongst various iron bearing minerals is of prime importance. Of the two iron hydroxide gangue mineral of limonite & goethite, the former occurs as earthy/colloidal fines occurring within the pores & cavities and/or as coating around other mineral grains and displayed high solubility in water. Goethite mineral displayed various mode of its occurrence viz., colloidal to amorphous/earthy, crystalline forming distinctive individual mineral phases. At times, it occurs as alteration product of hematite and forms concentric rims over it. These minerals forms tiny flakes and needles that occur as intergrowths with the hematite. Thus, amongst the iron bearing gangue mineral, separation of limonite and to certain extent liberated goethite is possible. However, wherever, goethite occurs as surface alteration (concentric rim) product to those of hematite grains, effective liberation is not attainable and therefore dilution of hematite on account of iron hydroxide is inevitable.

Similarly, in a few iron ore deposits (BHQ) a few micron size quartz blebs occur within hematite mineralisation. Reduction of such silica is not possible. In other cases of titaniferous hematite ore, a few micron size lath-shaped illmenite occur within groundmass of hematite. Reduction of such illmenite is not possible. In both these cases an iron concentration in the range of 58-60% Fe could be achieved (Photo Plate 18-21).

In the light of mineralogical characterisation of iron ore (hematite) in India, type of associated gangue constituent in iron ore and extensive Research & Development (R&D) work carried out in IBM's Ore Dressing Laboratory, for its beneficiation potential—such ore types can be categorised broadly into the following groups:

3.5.1 Hematite with Impurities of Goethite, Alumina & Silicate Minerals

In Indian iron ores, impurities are mainly of clay & gibbsite mineral in intimate association with goethite-limonite mineral phases. Therefore, rejection of this iron bearing mineral (goethite-limonite) is essential for containment of deleterious constituents, particularly of alumina. In Indian context, the percent distribution (availability) of goethite-limonite in the r.o.m. iron ore (hematite) dictates its beneficiation potential and can roughly be classified into the following groups:

(i) Hematite with little limonite/goethite (<20%) and other gangue minerals;

(ii) Hematite with moderate limonite/goethite (>20 & <40%) and other gangue minerals;

(iii) Hematite with high limonite/goethite (>40%) and other gangue minerals.

In the first scenario, where associated goethite-limonite impurities are below 20%, high-grade iron concentration (>65% Fe), with low silica & alumina impurity (around 4%) with good iron recovery (%Wt. yield 65-75) is possible in lumps, sinter fines and pellet size fractions. Such concentration is possible in iron ore formations of medium/high-grade hard lumpy ores, hard laminated ores, soft laminated ores and blue dust.

In the second scenario, where associated goethite-limonite impurities are in the range of 20 to 40%, high-grade (>65% Fe) iron concentrate is difficult to obtain. However, medium grade concentrate (>62% Fe) with moderate recovery (%Wt. yield 50-65) in lumps, sinter fines and pellet size fractions is a possibility. However, alumina impurity will be around 2.5%. Such concentration is possible in iron ore formations of low/medium-grade lumpy ores, hard & soft laminated ores and to some extent in lateritic ores (>60% Fe).

In the third scenario, where associated goethite-limonite impurities are over 40%, even medium-grade (>62% Fe) iron concentration is difficult to obtain with moderate recovery (%Wt. yield 35-50) in sinter fines and pellet size fractions. However, alumina impurity will be around 3%. Such concentration is possible in iron ore formations of low-grade lumpy ores, hard laminated ores, soft laminated ores and to some extent in lateritic ores (<60% Fe).

However, in all the aforesaid characteristic of ore, recovery of iron will be corresponding with the available hematite only and therefore loss of iron values in tails will be on much higher side (50-55% Fe) on account of rejection of limonite/goethite minerals.

3.5.2 Hematite with Impurities of Silica, Titanium, Alumina etc. Minerals

In some of the hematite occurrences in India, the valuable hematite is intimately associated with blebs/laths of quartz and/or illmenite (EPMA Photo Plate-18-21). High-grade concentration from such mineral assemblages is not at all possible. However, in former case, a low/medium-grade hematite concentration (around 60–62% Fe) is possible albeit with silica in the range of 5 to 10%. In the later case, only low-grade hematite concentration (58–60% Fe) is possible with very high titanium (10 to 15% TiO_2).

Physical characteristics of valuable hematite mineral in respect of its hardness, specific gravity, magnetic susceptibility is quite different from those of its associated ferrous and/or non-ferrous gangue mineral. Exploiting those properties, the valuable hematite can be successfully beneficiated at various sizes of lumps (-30+10 mm), sinter fines (-10+0.15 mm) and pellet fines/slimes (-0.15 mm or -100 mesh) by deployment of gravity concentration viz., jig, spiral, tabling etc. and or magnetic concentration processes.

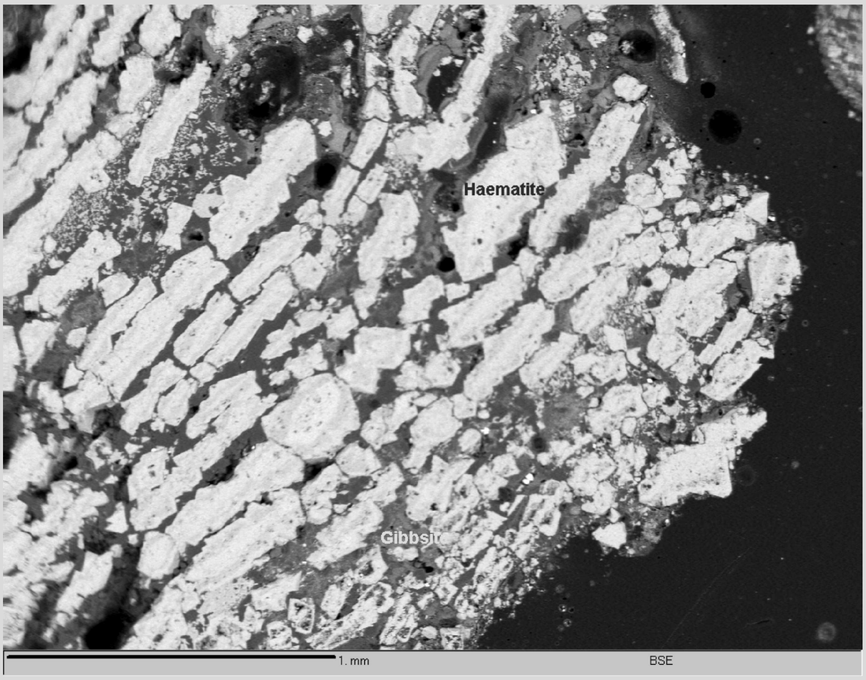

Photo plate -1: Iron ore sample from Barsua mine, SAIL
Showing intimate association between hematite with gibbsite (Original sample)

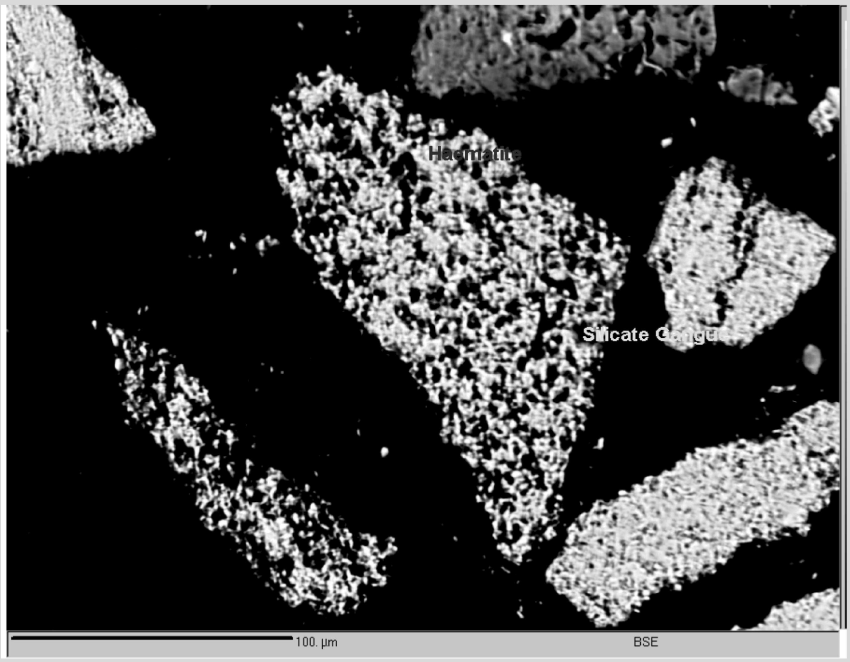

Photo plate - 2: Iron ore fines sample from JODA mine, TISCO
Showing extremely fine (<25 microns) intermixing of silicates/gibbsite (black) with hematite grains (white) is seen.

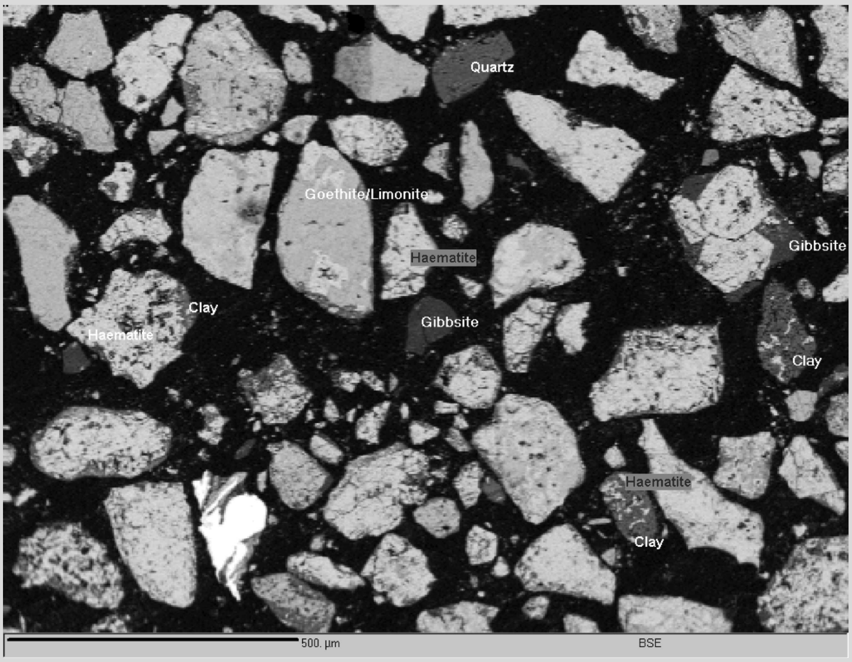

Photo plate - 3: Iron ore sample from Taldih, SAIL

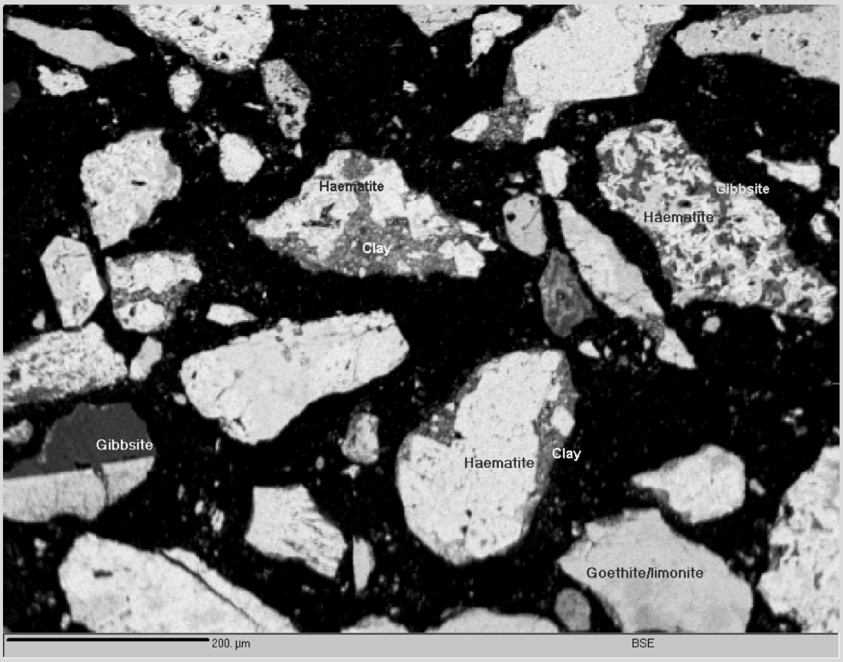

Photo plate - 4: Iron ore sample from Taldih, SAIL
Showing interlocking and association between iron oxide/hydroxide minerals and aluminous minerals.

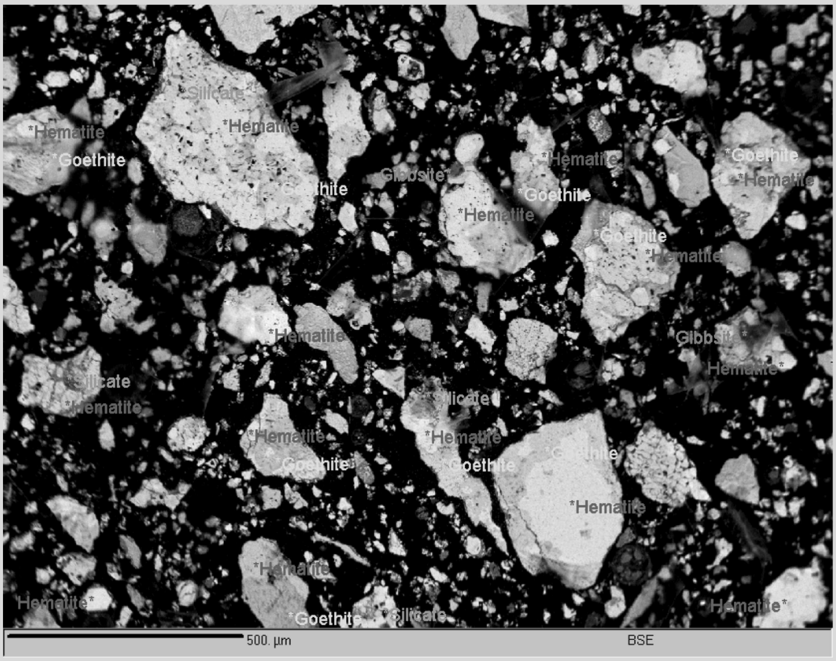

Photo plate - 5: Iron ore (HLO) from Chiria mines, West Singhbhum, SAIL

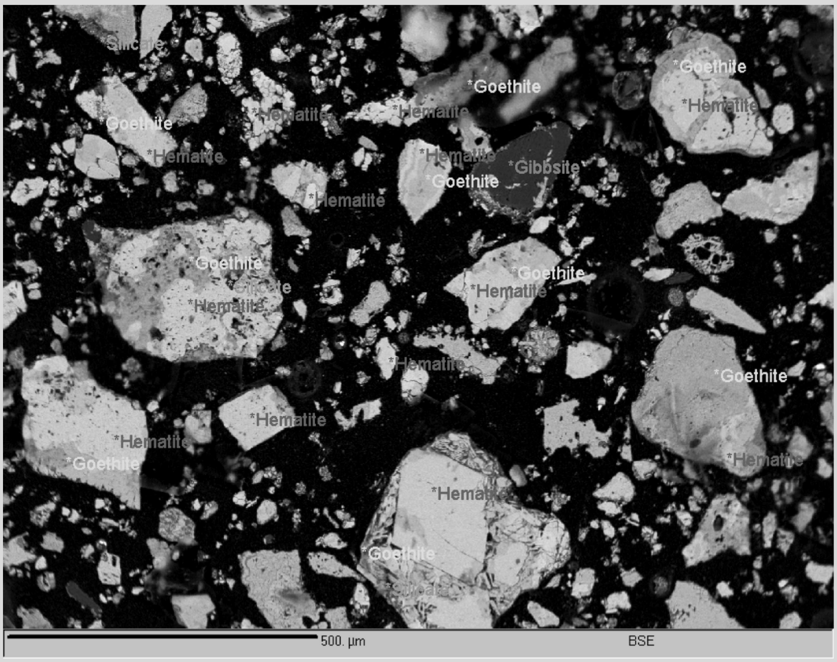

Photo plate - 6: Iron ore (HLO) from Chiria mines, West Singhbhum, SAIL
Showing the association of hematite and goethite with silicate. Fine inclusions of silicates are noticed within hematite and goethite.

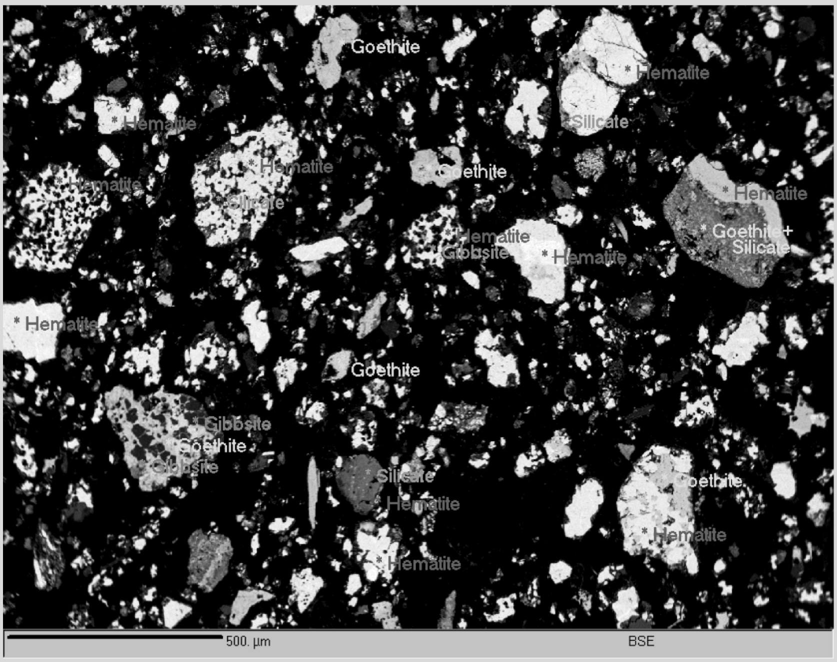

Photo plate -7: Iron ore (BIS) from Chiria mines, West Singhbhum, SAIL

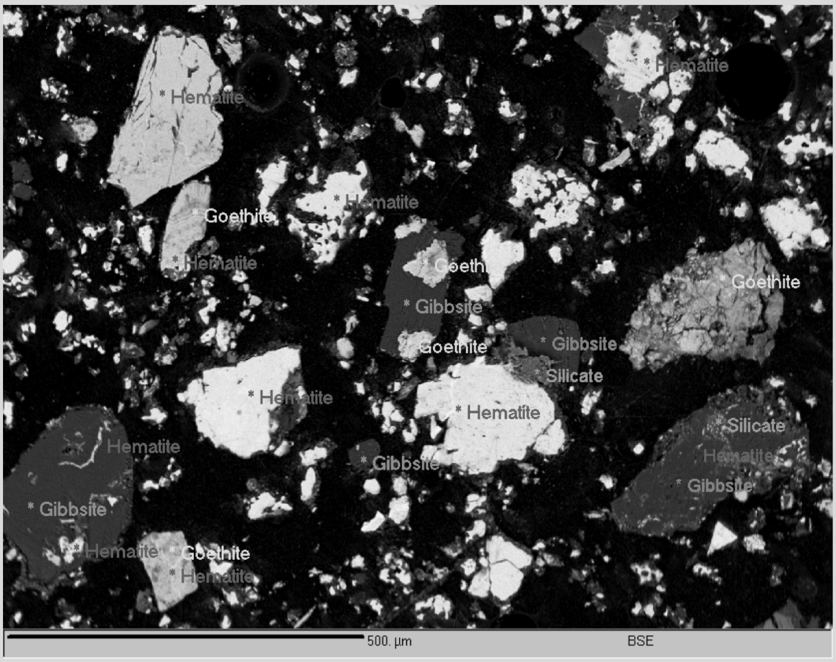

Photo plate - 8: Iron ore (BIS) from Chiria mines, West Singhbhum, SAIL
Showing the association of hematite and goethite with silicates and gibbsite

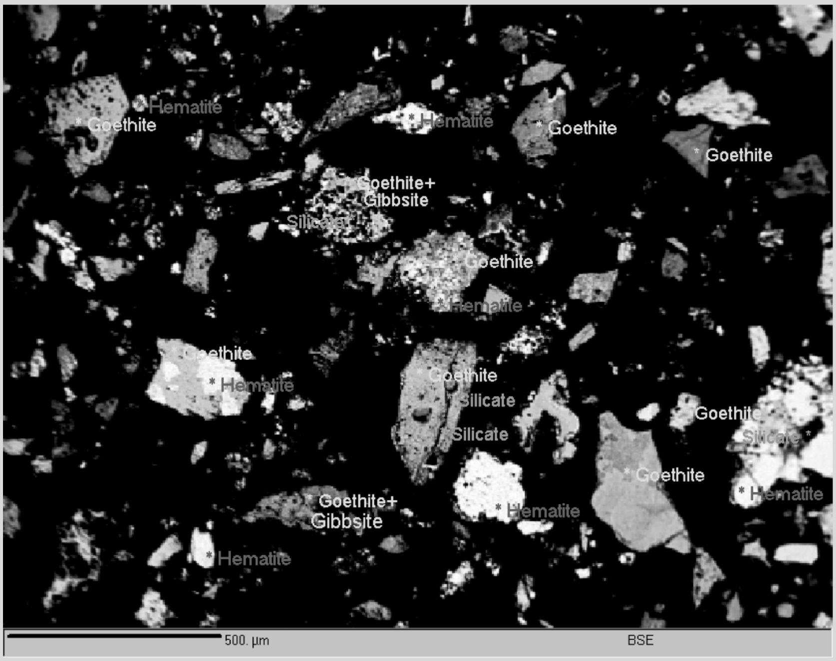

Photo plate - 9: Iron ore (Lateritic) from Chiria mines, West Singhbhum, SAIL

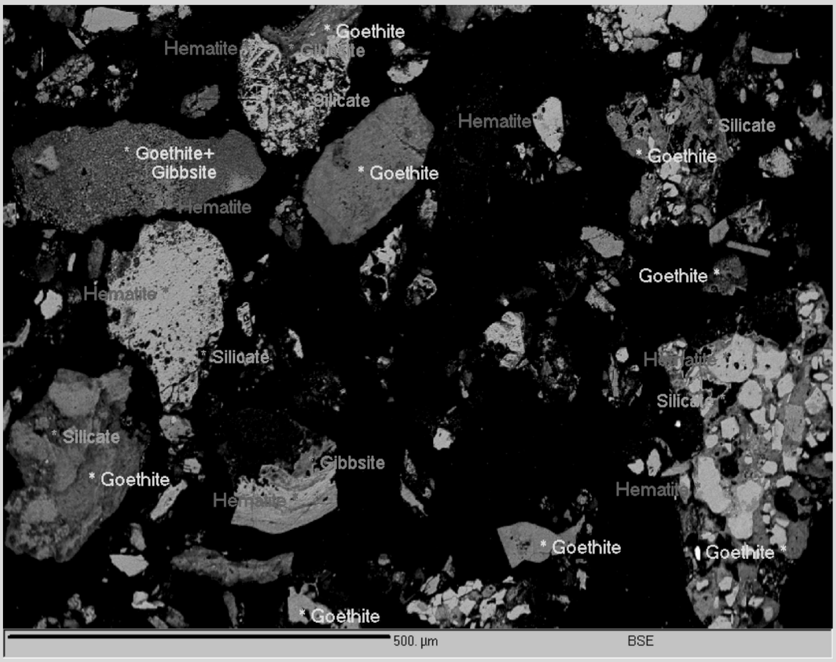

Photo plate - 10: Iron ore (Lateritic) from Chiria mines, West Singhbhum, SAIL
Showing the association of hematite and goethite with gibbsite and silicate

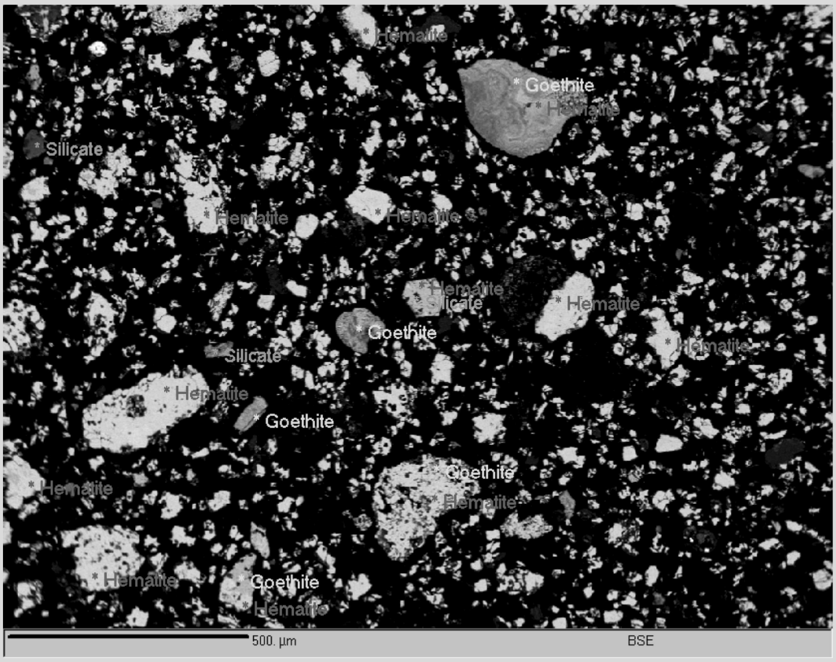

Photo plate -11: Iron ore (Blue dust) from Chiria mines,
West Singhbhum, SAIL

Photo plate - 12: Iron ore (Lateritic) from Chiria mines, West Singhbhum, SAIL Showing the association of hematite and goethite with silicates and gibbsite.

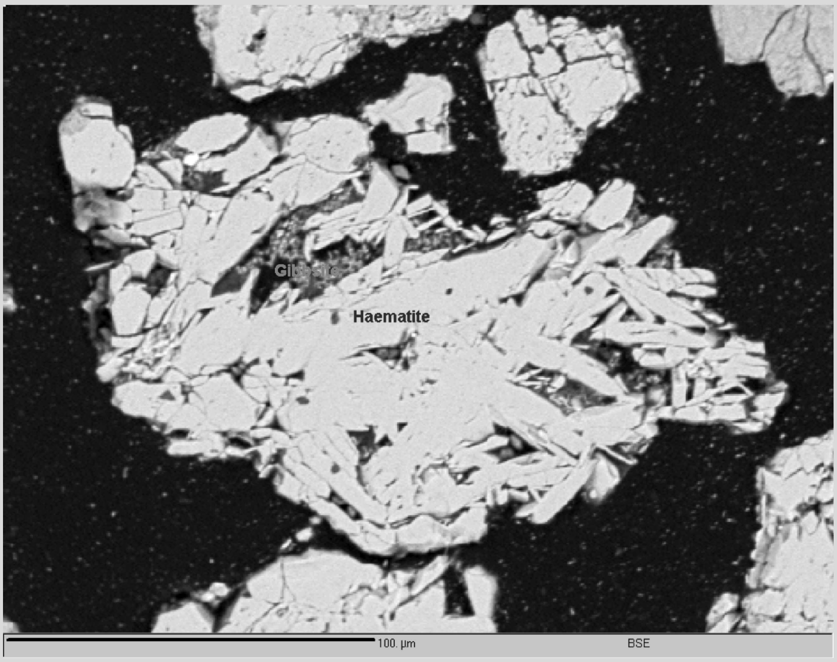

Photo plate - 13: Jig tails of iron ore sample received from TISCO Showing very fine inclusions of gibbsite (dark), in the inter-granular spaces of hematite grains.

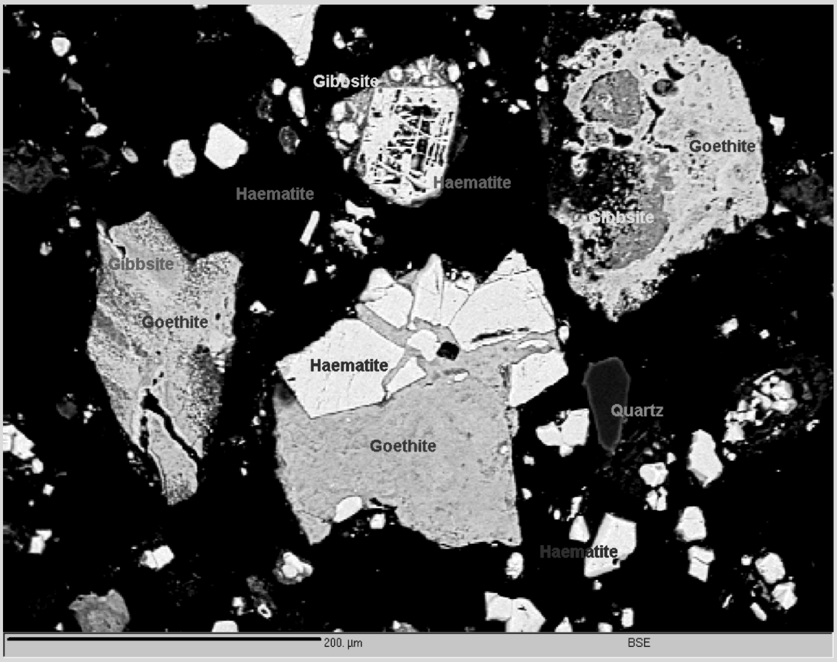

Photo plate - 14: Iron ore sample from Sindursi mines, Jabalpur
Showing that (i) association of goethite with gibbsite is more than that with that of hematite and (ii) Overall clear nature of hematite grains which lack any inclusions.

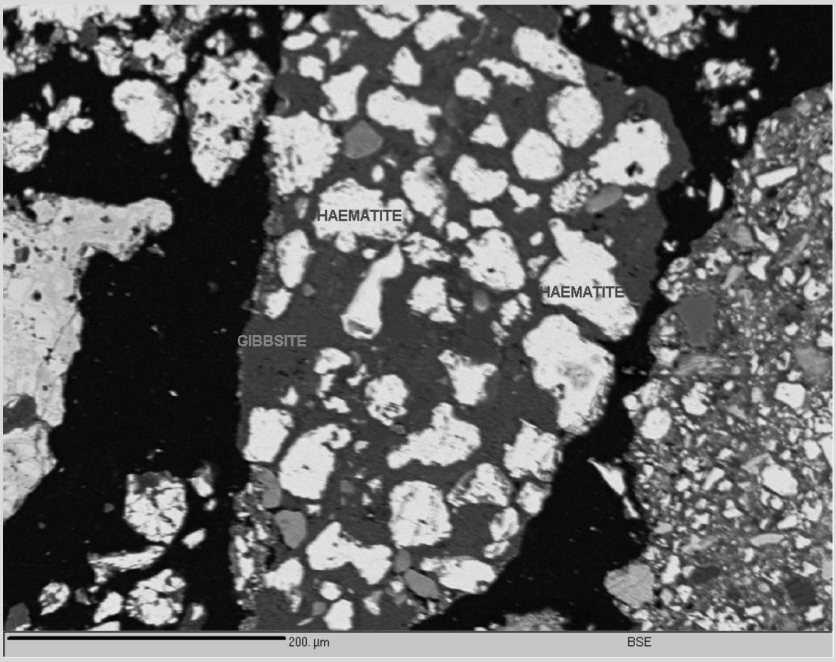

Photo plate - 15: Iron ore fines from Kirandul mines, ESSAR Steel
Showing gibbsite grain (dark gray ground mass) carrying sporadically disseminated grains of haematite and goethite (size – 5 micron to 70 micron)

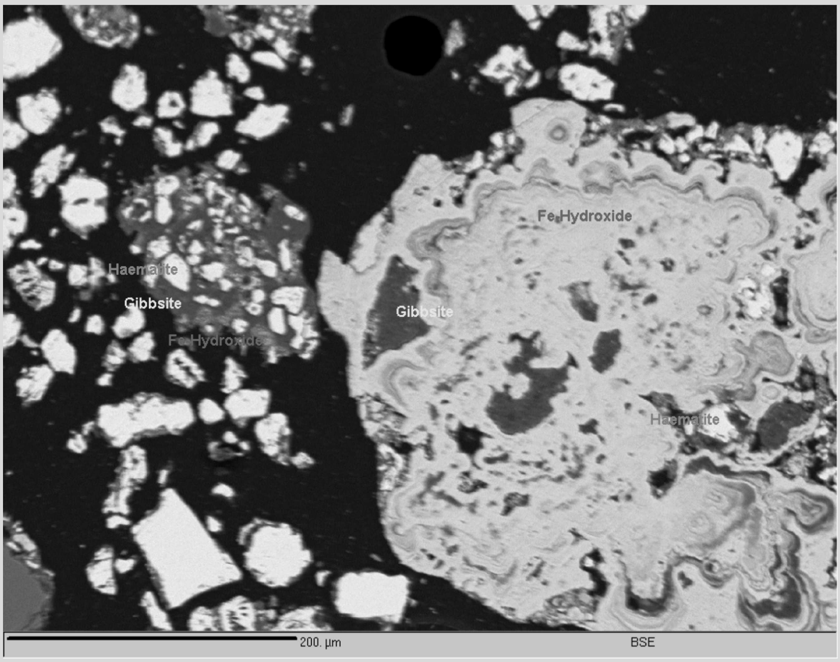

Photo plate - 16: Iron ore fines from Kirandul mines, ESSAR Steel
Showing rounded colloform bands of goethite. Note that the goethite and hematite grains are associated/interlocked with gibbsite.

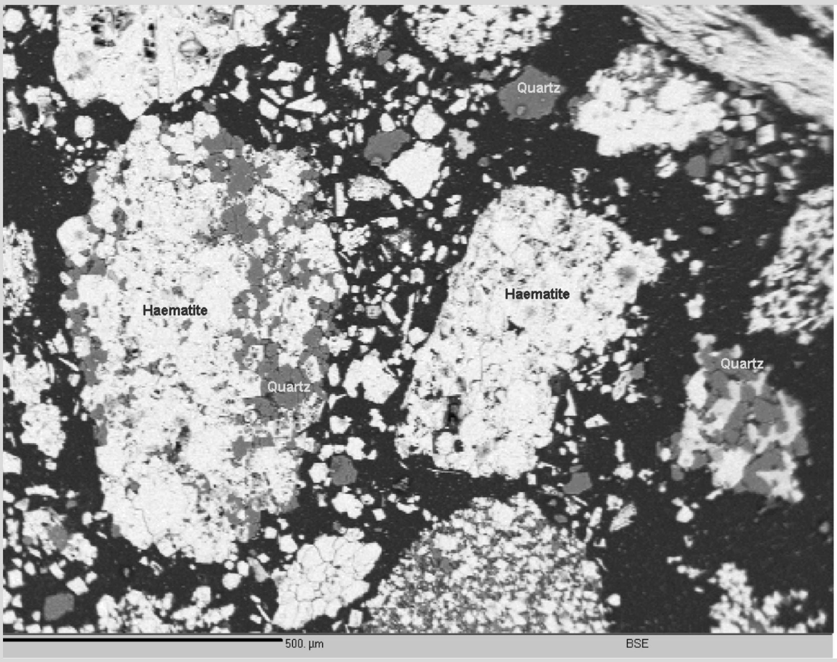

Photo plate - 17: Iron ore fines associated with schist, Jabalpur
Showing intimate association between iron oxide (white) phases and quartz (dark gray). Free quartz grains of <70 microns are also in appreciable amounts.

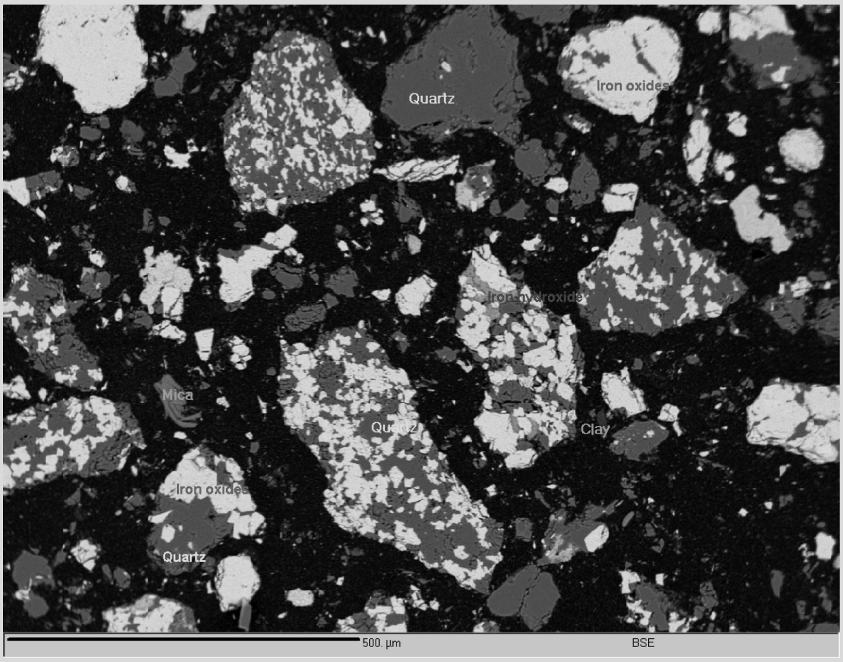

Photo plate - 18: BHQ sample from Hospet, Bellari district, Karnataka Showing the complex interlocking between, iron oxide and quartz, this may be difficult to liberate. Some of the quartz ranging in size from 5 to 20 microns grains is sitting within the groundmass of hematite or vice versa.

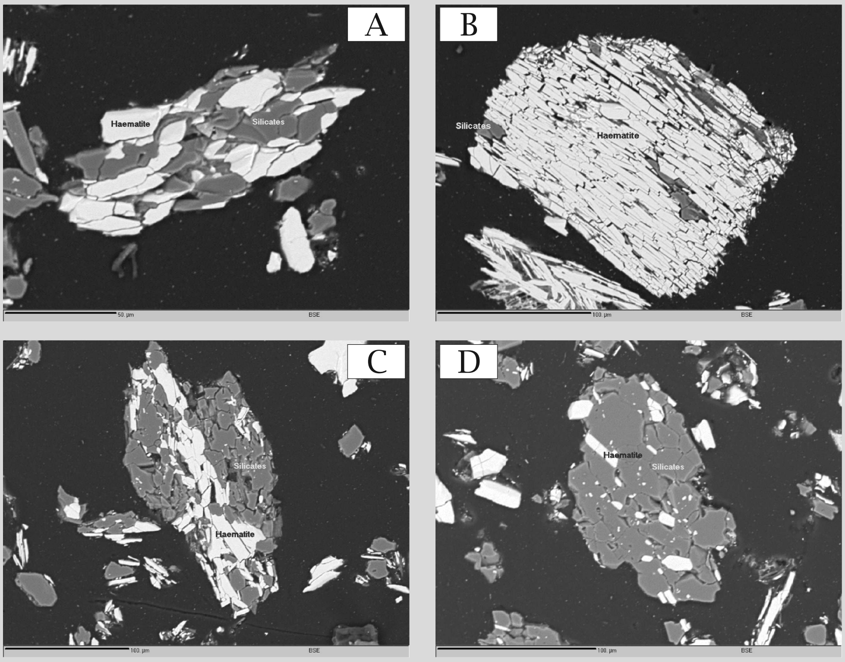

Photo plate – 19: BHQ from Shihora district, Jabalpur
Demonstrating the character of the sample wherein iron ore minerals (white) are embedded within silicate host phases (gray) even up to a size of <20 microns

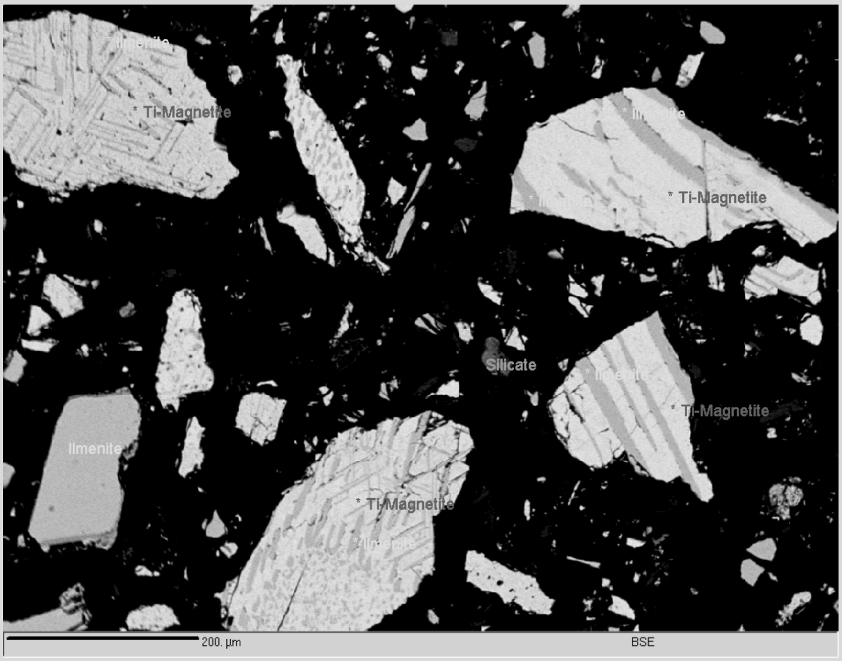

Photo plate -20: Titaniferous iron ore, Gondia
Showing fine elongated lamellae of Ilmenite (dark gray) within Ti-magnetite (light gray). This intergrowth texture is predominantly seen in almost every Ti-magnetite grain.

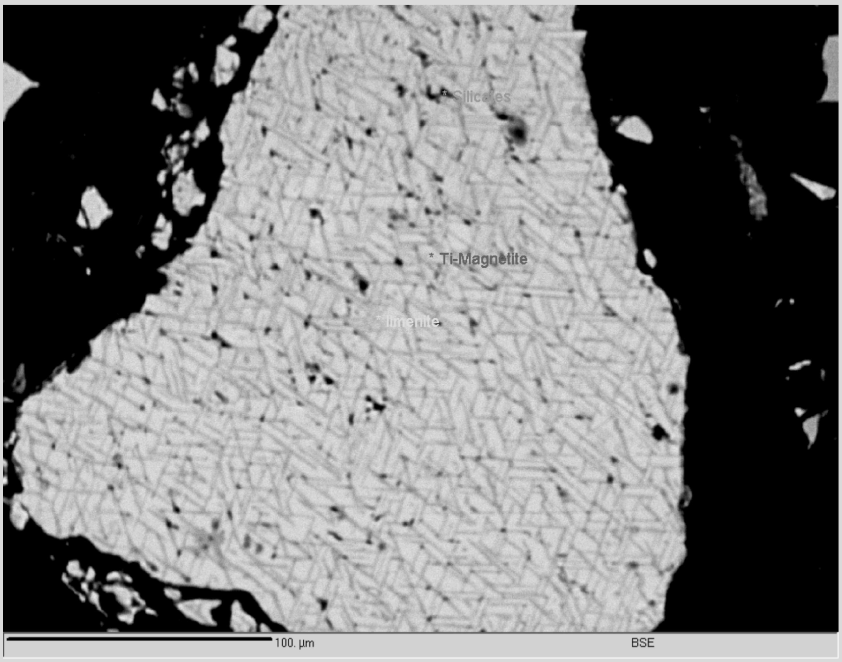

Photo plate - 21: Titaniferous iron ore, Gondia Showing extremely fine lamellae of Ilmenite within Ti-magnetite. These lamellas are Finer than 5 microns. Extremely fine (5 microns) inclusions of silicates are noticed within Ti-magnetite grain.

3.6 BENEFICIATION OF INDIAN IRON ORES—AN R&D PERSPECTIVE

In the present scenario, Indian iron ores, on account of selective mining does not require elaborate treatment/processing to upgrade the quality of lumps and fines especially with respect to iron content but the alumina content is not significantly lowered. One of the most important aspects in the beneficiation of Indian iron ores is their complex nature from the stand point of elimination of alumina. The aluminous minerals generally occur as adhering to the coarse pieces, as cavity fillings and as lateritic material.

Extensive Research and Development (R&D) work has been undertaken during last decade by Ore Dressing Laboratory of IBM engaged in beneficiation of iron ore, namely r.o.m. ore (high, medium, low & sub-grade), stacked fines from old dumps (-10 mm), slimes (-100 mesh) from tailing ponds and various process stream products of existing processing plant, to evolve a suitable process flow sheet for recovery of valuables from various types/characteristics of iron ore in India. 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 iron ores in its entirety i.e., concept of total beneficiation of r.o.m. iron ore.

IBM developed a number of flow sheets on various kinds of iron ore and based on gained expertise evolved flow sheets for total beneficiation for Indian iron ore. The aforesaid flow sheet may provide a user-friendly guidelines that can be used successfully with minor modification in almost all types of iron ore deposit in India. A few of the typical flow sheets are discussed below:

3.6.1 High-grade Iron Ore Associated with Little Shale & Quartz Gangue Impurity

Such ores after multi-stage crushing and screening produce high-grade lumps directly. The fines fraction need value addition for alumina reduction by unit operations like spiral classifier, jigging (-6+0.5 mm), spiralling/tabling and WMIMS (-0.5+0.15 mm) and WMIMS of classifier overflow (-100 mesh) fraction. The process will produce high-grade lump, sinter and pellet fines grade material with relatively high percent weight yield. The schematic process flow sheet is presented in Fig-32.

3.6.2 Medium-grade Iron Ore Associated with Shale & Quartz Gangue Impurity

Such ores after multi-stage crushing & screening subjected to attrition scrubbing in a rotary scrubber produce lumps and fines. The washed lump is subjected to Heavy Media Separation (HMS) at a parting density of 2.9–3.0 to reject light gangue as float. The sink constitutes the high-grade lumps. The scrubber fines (-6 mm) after classification and wet

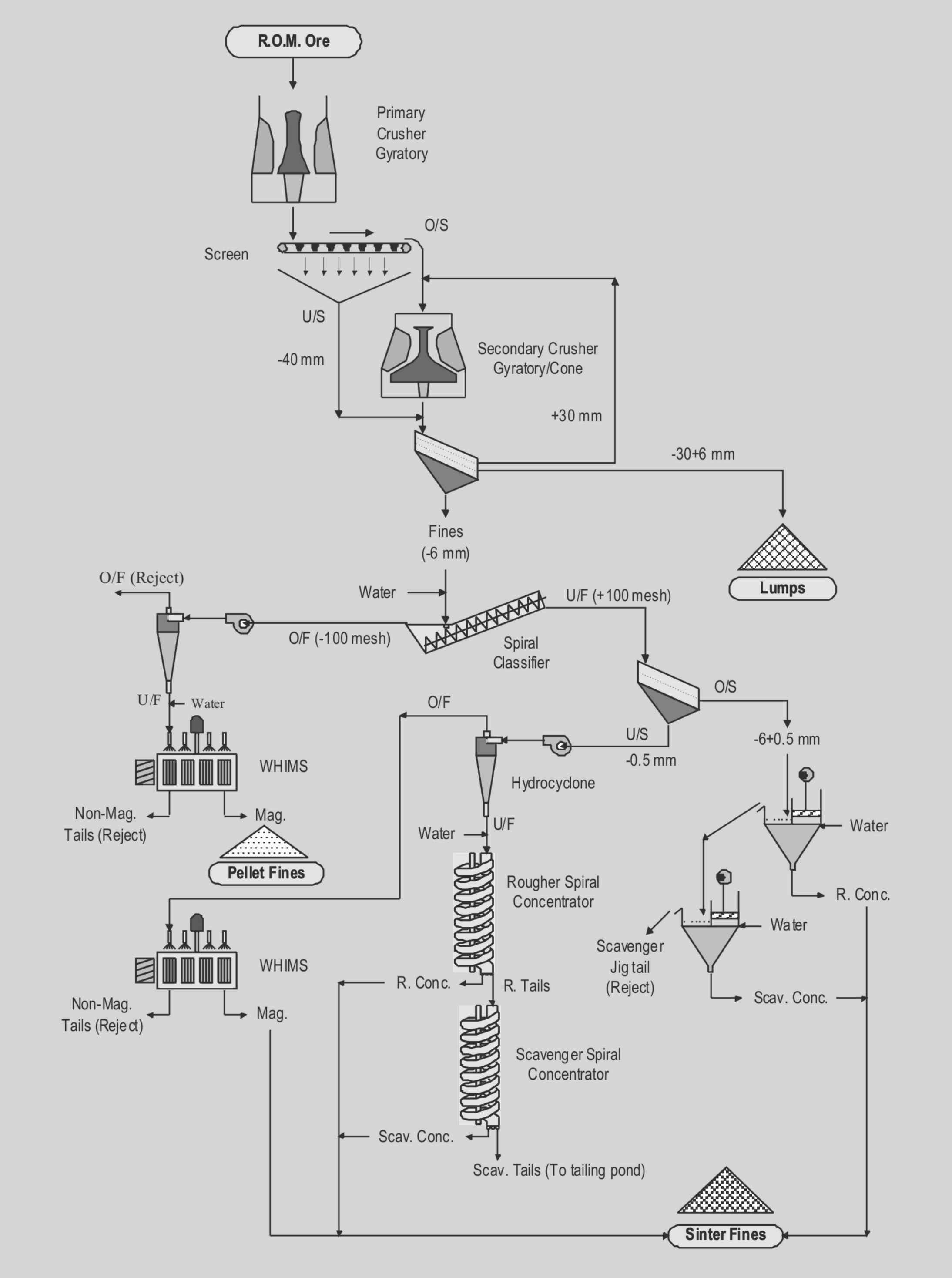

Fig-32: Flow sheet for high grade ore

screening (-6+0.5 mm size fraction) subjected to Heavy Media Cyclone (HMC) at a parting density of 2.9–3.0, spiraling cum WMIMS of -0.5+0.15 mm size fraction and WMIMS of -0.15 mm (-100 mesh). The process will produce medium to high-grade lumps, sinter and pellet fines grade material with relatively high percent weight yield. The schematic process flow sheet is presented in Fig-33.

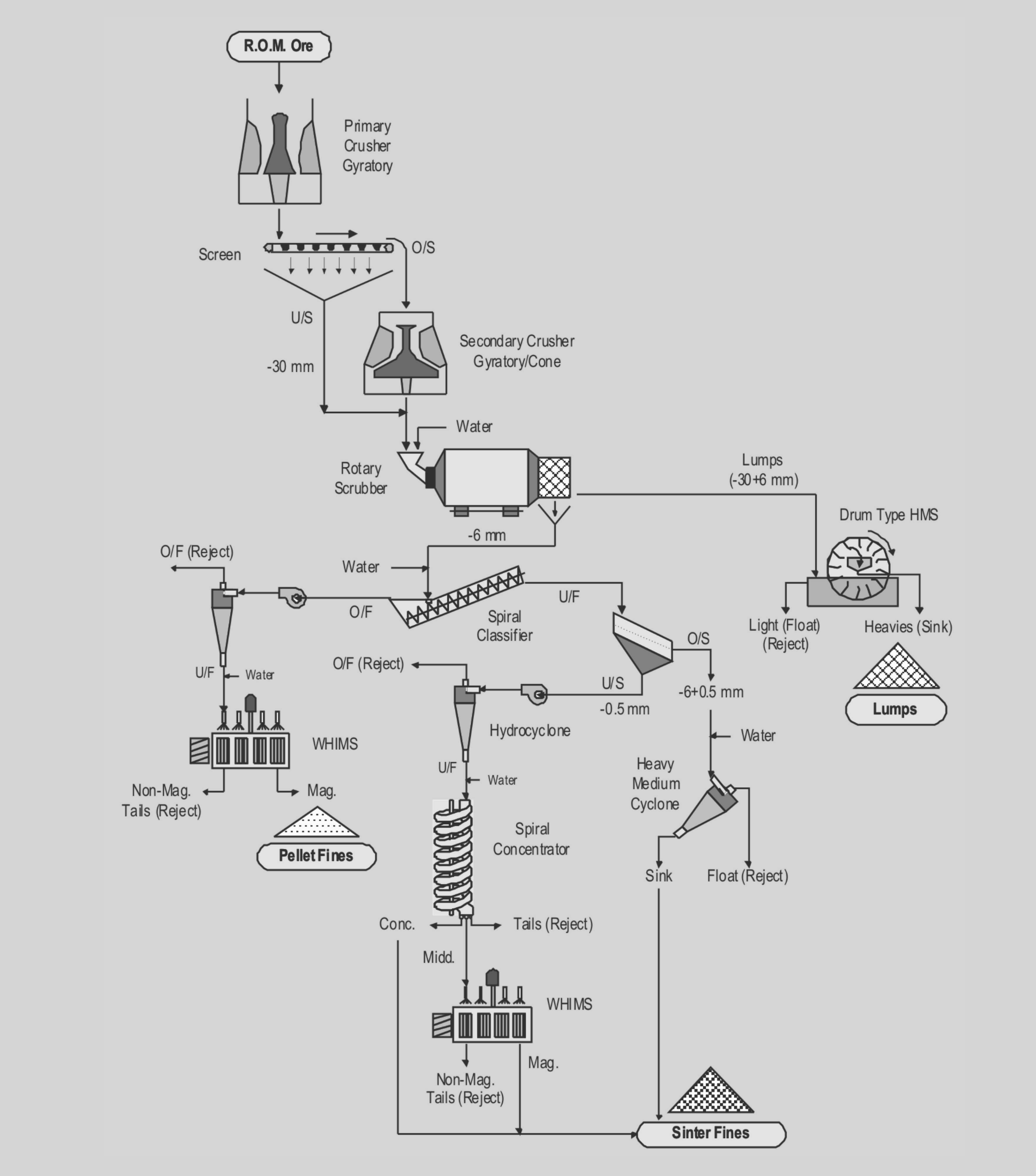

Fig-33: Flow Sheet for Medium-grade Ore

3.6.3 Low/Medium-grade Iron Ore Associated with Goethite (over 20%) Impurity

Such ores after multi-stage crushing & screening are subjected to attrition scrubbing in a rotary scrubber produce lumps and fines. The washed lumps fraction is subjected to two stage jigging to produce medium grade lumps (>62% Fe). The scrubber fines after classification and wet screening are subjected to jigging (-6+0.5 mm), spiraling cum tabling of -0.5+0.15 mm size fraction and WMIMS of -0.15 mm (-100 mesh). The scavenger jig tails (lumps) are then crushed to fines size (-6 mm) and screened to produce three size fraction of -6+0.5 mm, -0.5+0.15 mm and -0.15 mm and subjected to jigging, spiral-tabling and WMIMS along with scrubber fines fraction. The process will produce medium-grade lumps; sinter and pellet fines grade material (Al_2O_3<2.5%) with moderate weight yield. The schematic process flow sheet is presented in Fig-34.

3.6.4 Low/Sub-grade Ore Associated with Goethite/Limonite (over 40%) Impurity

Such ores produce low-grade lumps (-30+6 mm) assaying around 58–60% Fe and alumina around 5%. Value addition by jigging does not have any noticeable effect. However, at a lower size of -10/6 mm after imparting marginally improved liberation, it is possible to obtain a medium-grade iron concentrate (+62% Fe) by process of jigging with marginal weight recovery. The schematic process flow sheet is presented in Fig-35.

The process involved multistage crushing of sample to -10/6 mm size, followed by attrition scrubbing in a rotary scrubber cum spiral classifier to produce three size fraction of lumps (-10+6 mm), sinter fines (-6+0.15 mm) & pellet fines (-100 mesh) size material. The sinter fines size is then screened through 0.5 mm screen for ease of unit operation of jigging of oversize (-6+0.5 mm) fraction and tabling cum WMIMS of screen undersize (-0.5 mm) fraction. The lumps (-10+6 mm) and -6+0.5 mm size fraction are individually subjected to two stage roughing followed by scavenging before its rejection from the circuit. The classifier overflow (-100 mesh) is subjected to WMIMS after classification in a hydro-cyclone. The process will produce medium-grade lumps (-10+6 mm); sinter and pellet fines grade material (Al_2O_3<3%) with moderate percent weight yield corresponding with available hematite mineral in the feed sample.

3.7 POTENTIAL BENEFICIABLE MATERIAL IN EXISTING MINING AREA

Almost in all existing iron ore mines and processing units in India, a substantial amount of unexploited sub-grade ore and process rejects (fines & slimes) are lying unutilised for lack of deployment of proper beneficiation technology. Besides, consequent upon lowering of

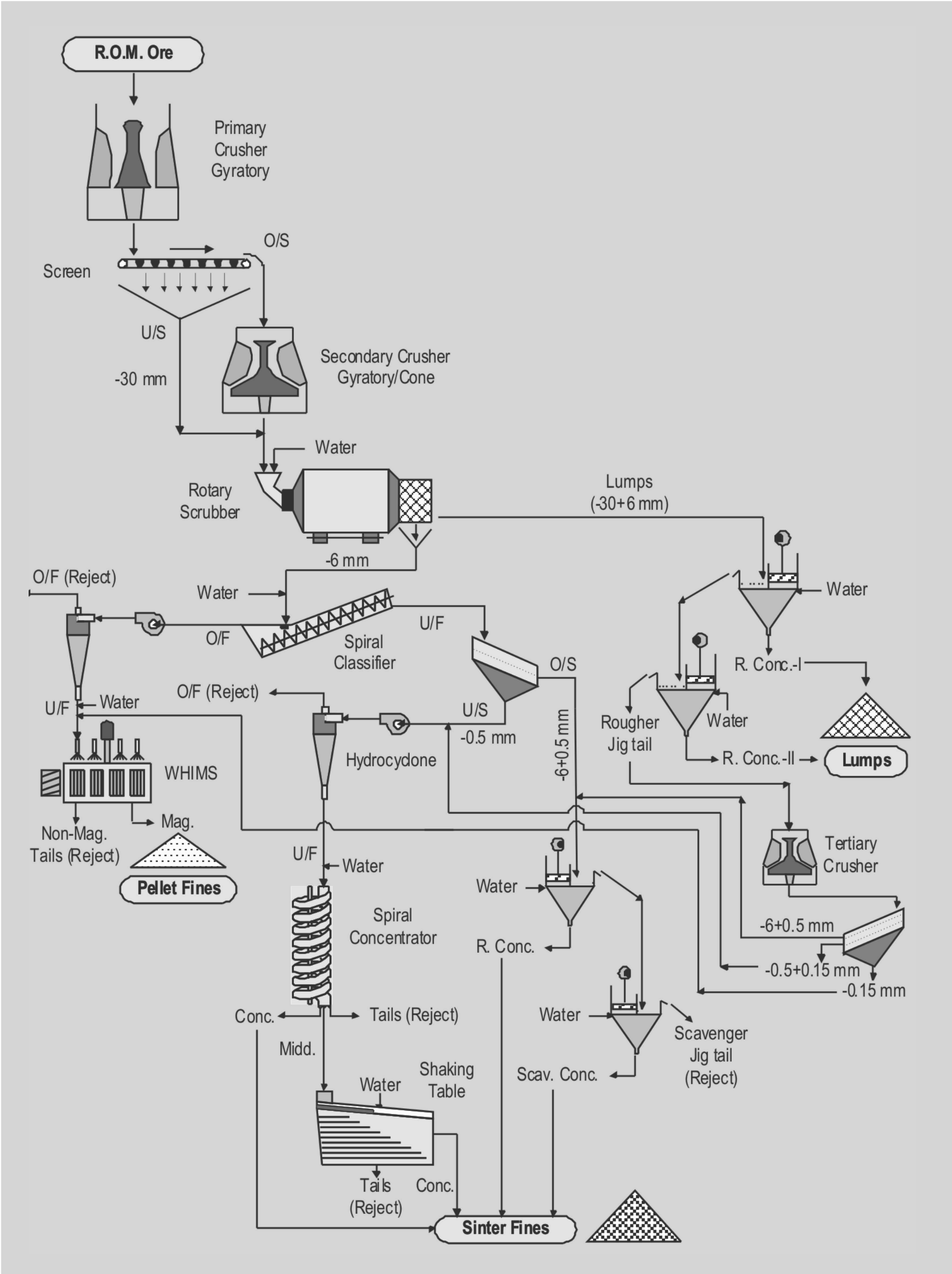

Fig-34: Flow Sheet for Low-medium Grade Ore

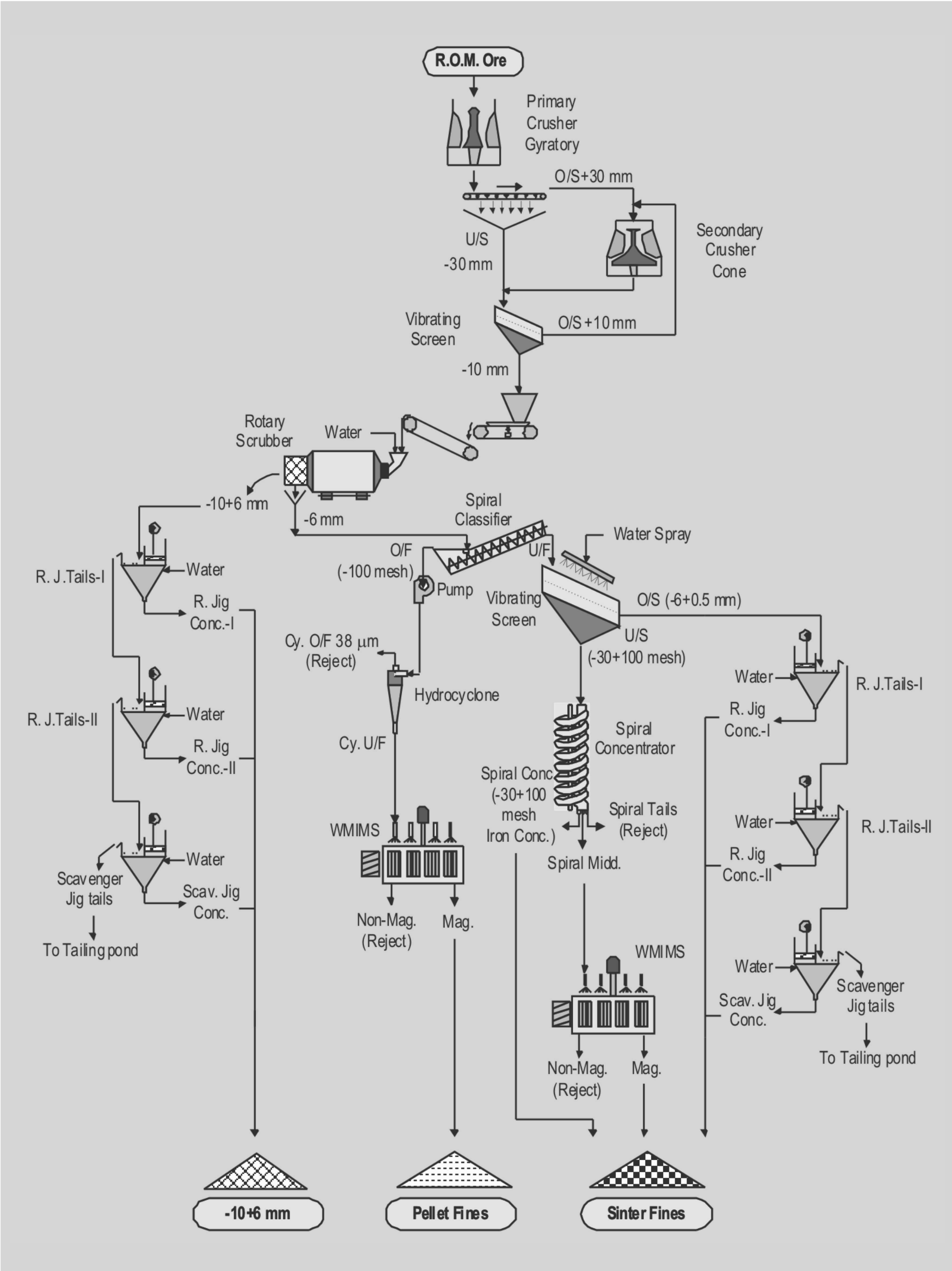

Fig-35: Flow Sheet for Low/Sub-grade Ore cut-off grade of 45% & 35% Fe (T) from hematite and siliceous hematite ore respectively, a sizeable low-grade reserve/resource of iron ore will occur in the range of 50-55% Fe. All these are potential source of beneficiable ore that warrant immediate attention for value addition. IBM's Ore Dressing Laboratory evolved flow sheets for beneficiation of various beneficiable iron ore material in the existing mining area and are discussed below:

3.7.1. Iron Ore Fines (-10 mm) Stacked at the Mine Site

There are huge hills of waste dumps of million tonnes in Eastern iron ore sector along with high-grade blue dust which can be beneficiated by adopting wet screening, gravity and magnetic separation techniques to recover about 50-70% of this material as sinter and/or pellet feed grade concentrate.

3.7.1.1. For Making of Sinter and Pellet Fines Grade Concentrate : The medium to low-grade fines (-10 mm) produced from the washing plants of the captive mines (ISPs), that are invariably high in silica and/or alumina content, presently being used as inferior quality sinter feed (Al_2O_3 3–5%) in their Integrated Steel Plant. These fines can successfully be upgraded to quality sinter fine and pellet fine grade concentrate after deploying jig, spiral-table and WMIMS unit operation. The process will produce sinter and pellet fines grade material (SiO_2 & Al_2O_3<5%) with relatively good weight yield. The schematic process flow sheet is presented in Fig-36.

3.7.1.2. For Making of Pellets Fine Grade Concentrate : Sinter making is confined only to Integrated Steel Plant and as such non-captive mines needs to find suitable use of its stacked fines for making value-added pellet grade concentrate for its utilisation. Medium to sub-grade fines can successfully value-added to pellet fine grade concentrate after grinding it to liberation size of various mineral assemblages and subjected either through hindered settling floatex density separator or stub cyclone followed by WMIMS or spiral cum tabling process. The schematic process flow sheet is presented in Fig-37.

3.7.2. Tailing Pond Slimes

Huge quantities of slimes (below 100 mesh) assaying around 50–55% iron have been dumped in the tailing ponds of the washing plants of all the integrated steel plants as well as merchandise mines over the years. The iron ore values (hematite) locked is estimated to be up to the tune of 15–20 million tonnes per annum. In addition the slimes stored pose enormous environmental hazards.

These tailing ponds slime predominantly a limonite/goethite and clay/gibbsite mineral assemblages also contains hematite, quartz, mica etc. Size analysis of these

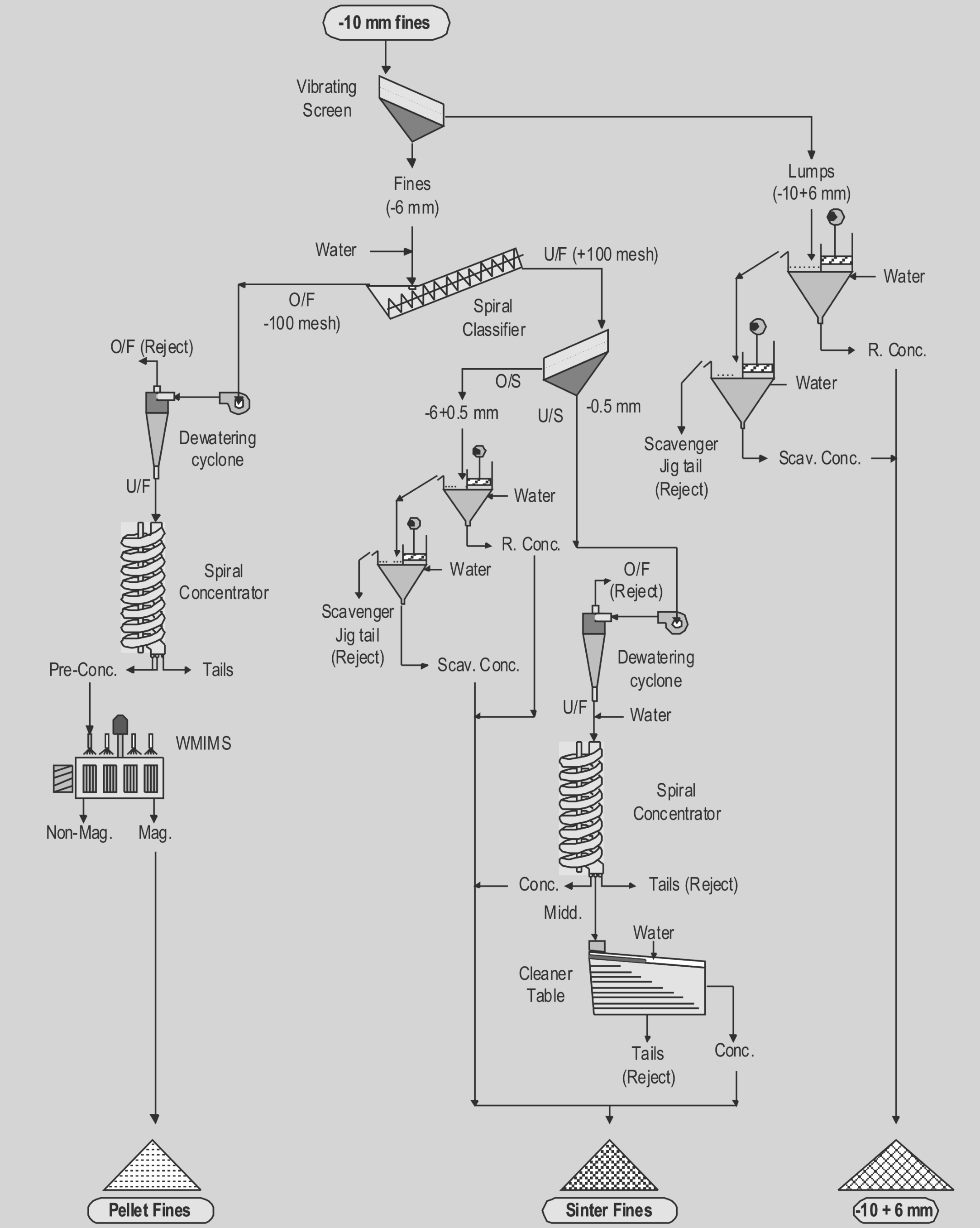

Fig-36: Flow Sheet for Making of Sinter & Pellet Fine Grade Concentrates from Fines (-10 mm)

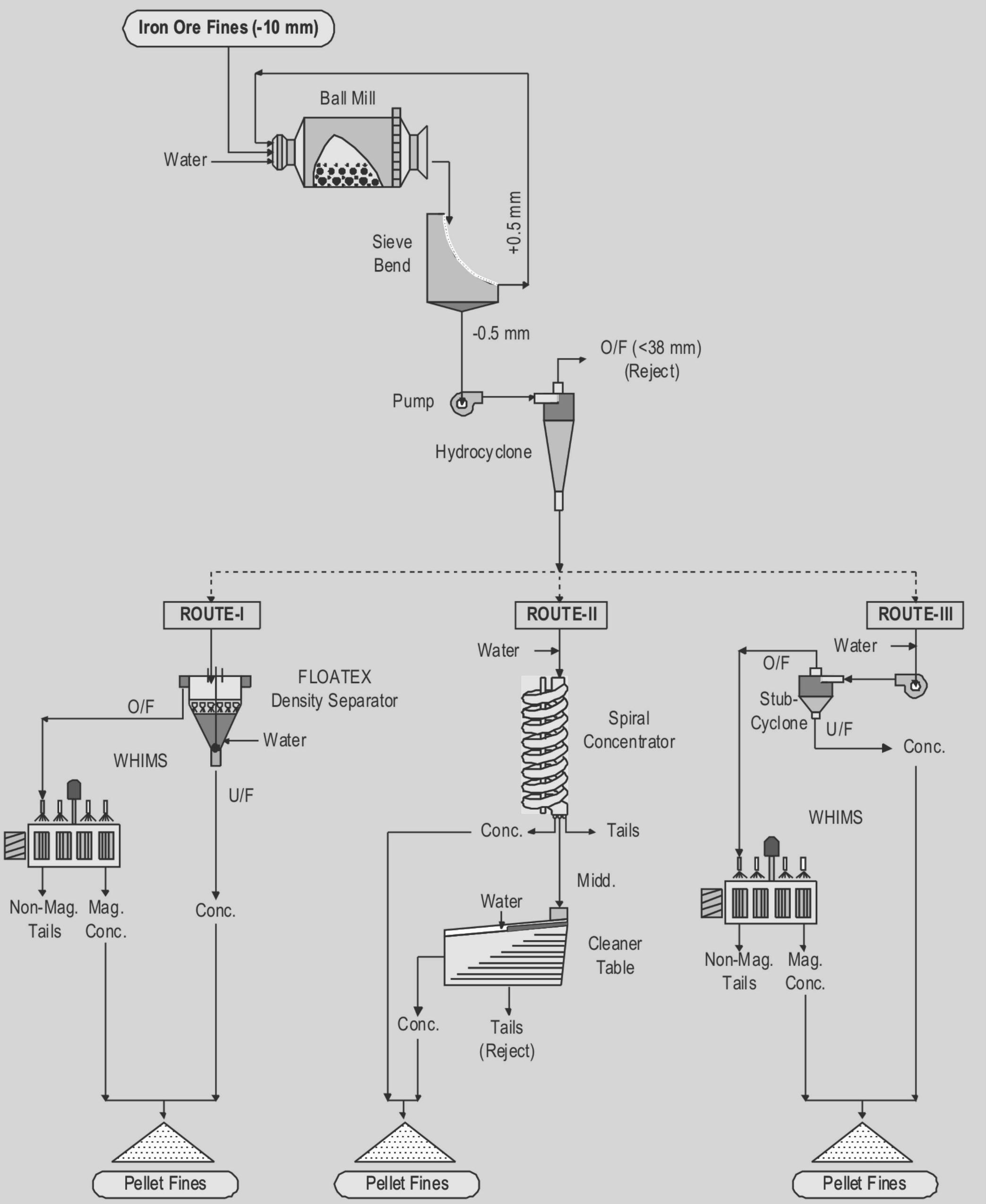

Fig-37: Flow Sheet for Making of Pellet Fine Grade Concentrate from Fines (-10 mm) slimes (-150 µm) invariably contains around 75–80% by weight material below 325mesh (45µm) in which 35-50% are particles below 10 µm size. Thus, rejection of these ultra-fine size particles (below 10 µm) enhances the overall recoverable iron content in the oversize fraction. This can form a potential source for feed material for recovering medium/high-grade iron concentrates (around 64%Fe), low in alumina (around 2–2.5%) in large quantities suitable for pellet making.

The probable beneficiation process would be a combination of suitable unit operations like hydro-cyclone, stub cyclone, floatex density separator, spiral, table and high intensity/gradient magnetic separator. The valuable concentrate recovery would be corresponding with the available hematite mineral only i.e., around 15–30% by weight. This would not only increases fines recovery but also increase the life of the tailing pond. IBM evolved flow sheets for beneficiation of tailing pond slimes are given below:

3.7.2.1. For r.o.m. Medium/High-grade Iron Ore Tailing Pond Slimes: The tailing pond slimes generated from medium/high-grade iron ore washing plant can be successfully treated for recovery of pellet grade concentrate of stipulation with fairly good weight recovery (25–30%). The tailing pond slimes (-150 µm) generated from low or sub-grade iron ore washing plant are characterised as:

Mineralogy:Mainly limonite/clay followed by hematite, goethite, quartz, mica etc.

Chemical Analysis : Fe (T) 50-55%; SiO_2 10-15%; Al_2O_3 5-7%; & LOI 4-6%.

Size Analysis :

Size in µm	+75µm	+45µm	-45µm	+20µm	+10µm	-10µm
%Wt. (Dist.)	8-10%	12-15%	75-80%	20-25%	15-20%	35-40%

Such slimes can be treated for recovery of medium grade pellet concentrate. The schematic process flow sheet is presented in Fig-38.

3.7.2.2. For r.o.m. Low/Sub-grade Iron Ore Tailing Pond Slimes: The tailing pond slimes (-150 µm) generated from low or sub-grade iron ore washing plant are characterised as:

Mineralogy : Mainly limonite clay/goethite followed by hematite, gibbsite, quartz etc.

Chemical Analysis : Fe (T) 50-55%SiO_2 5-10%; Al_2O_3 5-8%; & LOI 7-10%.

Size Analysis :

Size in µm	+75µm	+45µm	-45µm	+20 µm	+10µm	-10µm
%Wt. (Dist.)	8-10%	10-12%	~80%	20-25%	10-15%	40-50%

Such slimes can be treated for recovery of medium-grade pellet concentrate with alumina & silica around 5% with weight recovery of 15–25%. The schematic process flow sheet is presented in Fig-39.

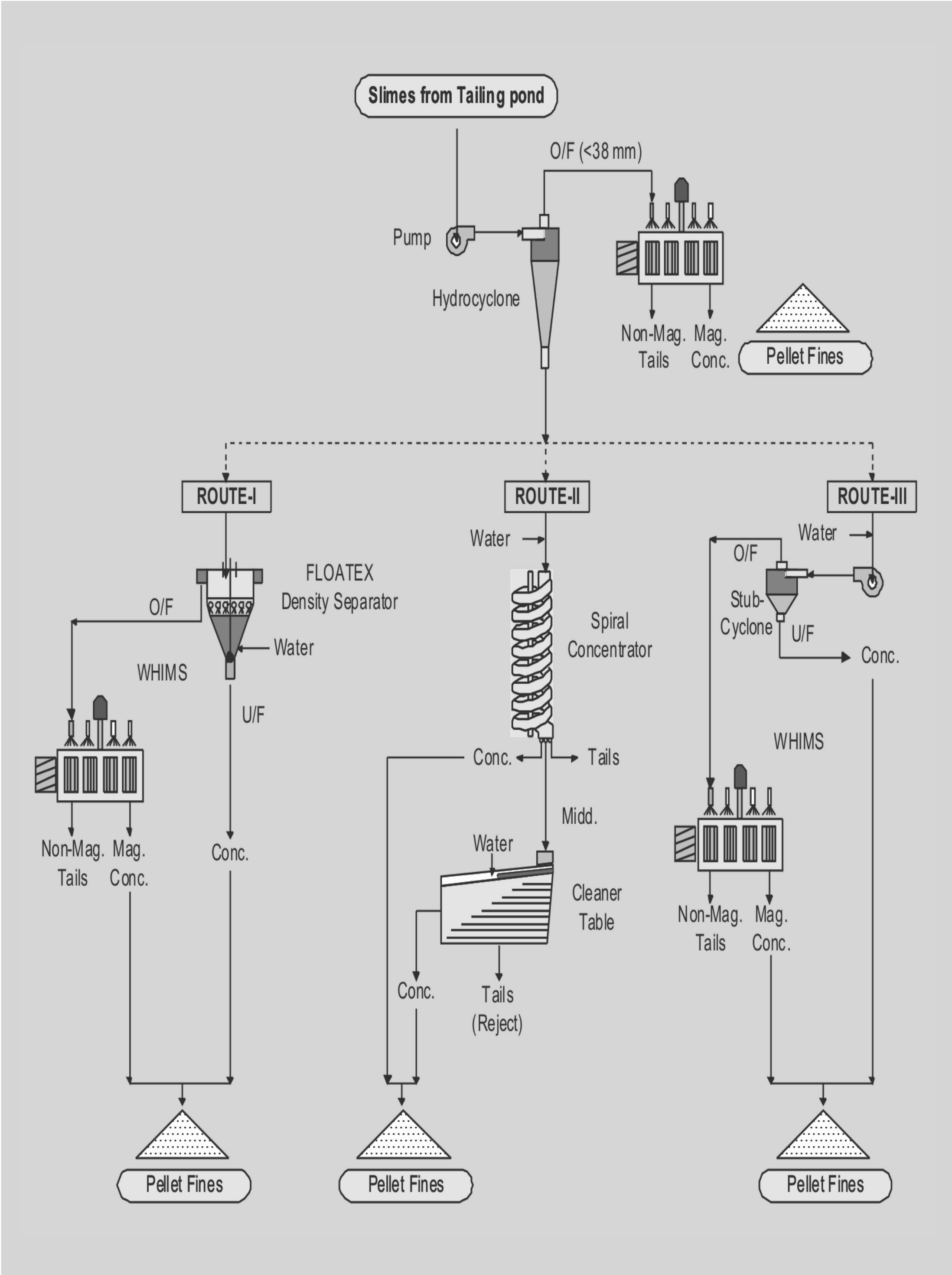

Fig-38: Flow Sheet for r.o.m. Medium/High-grade Iron Ore Tailing Pond Slimes

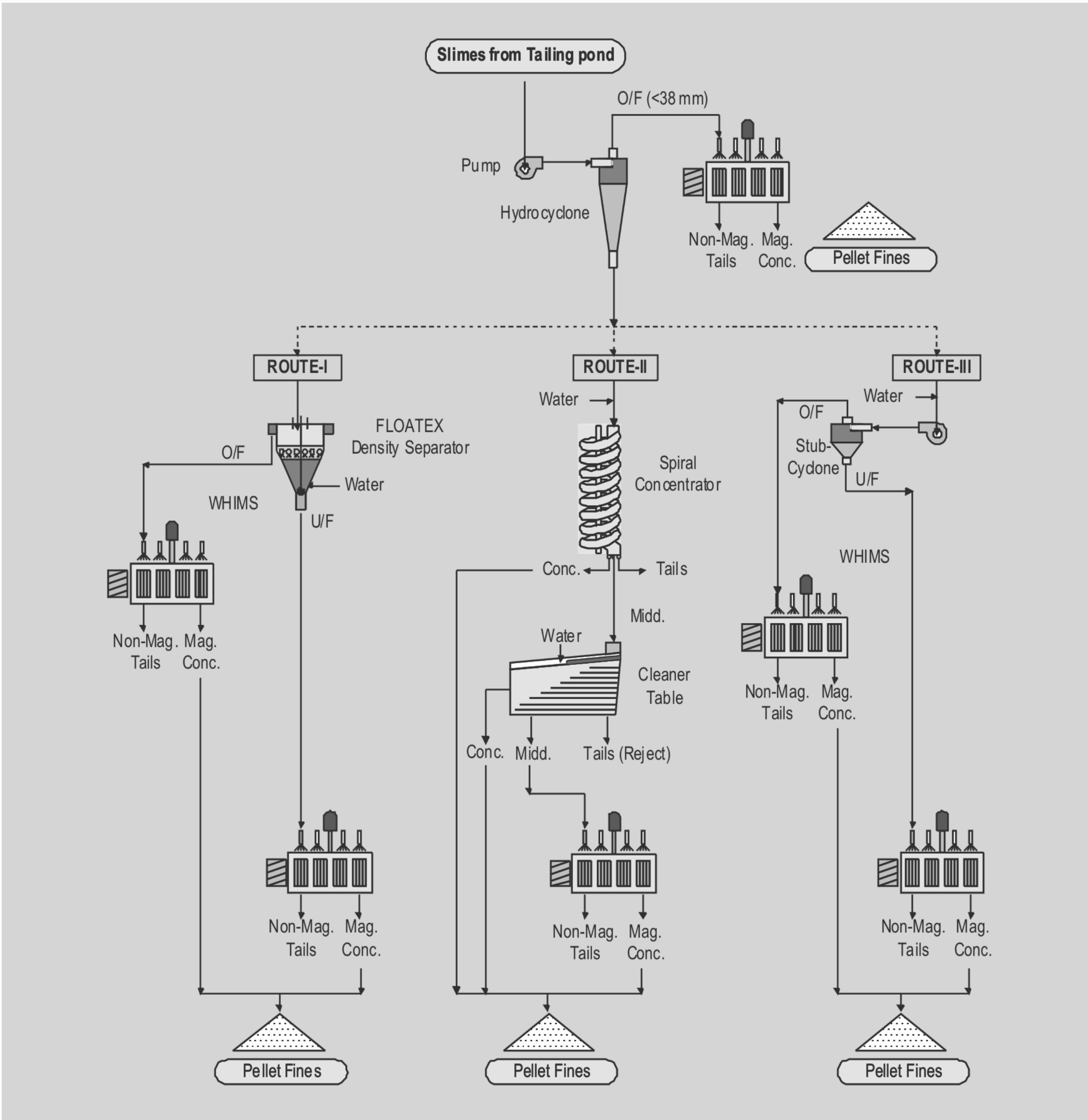

Fig-39: Flow Sheet for r.o.m. Low/Sub-grade Iron Ore Tailing Pond Slimes

3.7.3 Sub-grade/Marginal-grade Ores, *In situ* or Stacked at Mine Site

Selective exploitation to raise iron ore of over 62% Fe, practiced during last six decades period, caused a very large quantity of sub-grade & marginal-grade ores assaying in the range of -60+45% Fe that occurred either as *in situ* and or as stack/dump yard to be unutilised. Recovery of sinter/pellet grade iron ore concentrates from this sub-grade or marginal-grade iron ore was made possible by adopting suitable process route of beneficiation. IBM evolved flow sheets for beneficiation of low/sub-grade ore are presented in Figs-35, 40 & 41.

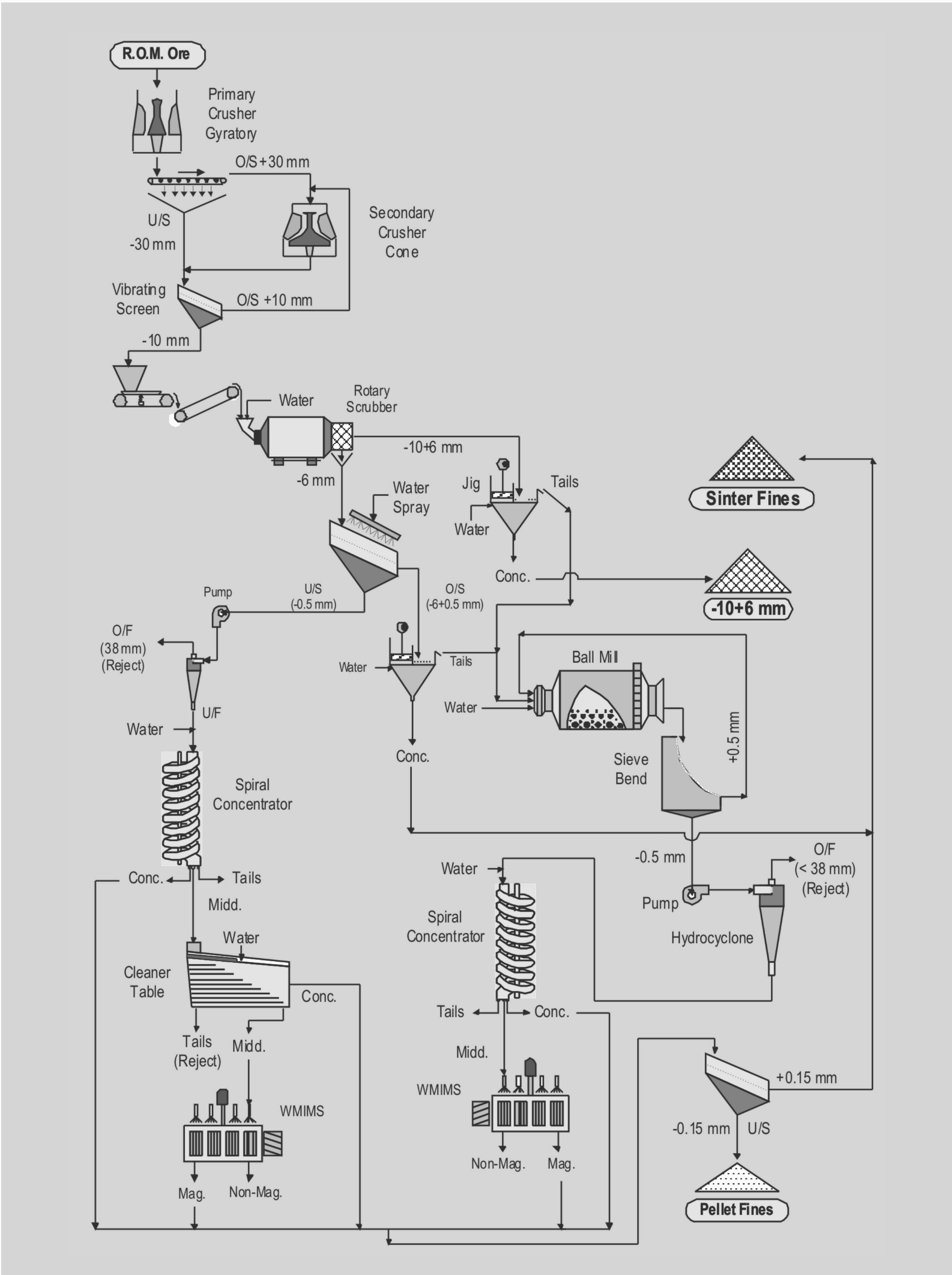

Fig-40: Flow Sheet for Making of Sinter & Pellet Fine Grade Concentrate from Sub-grade Ore

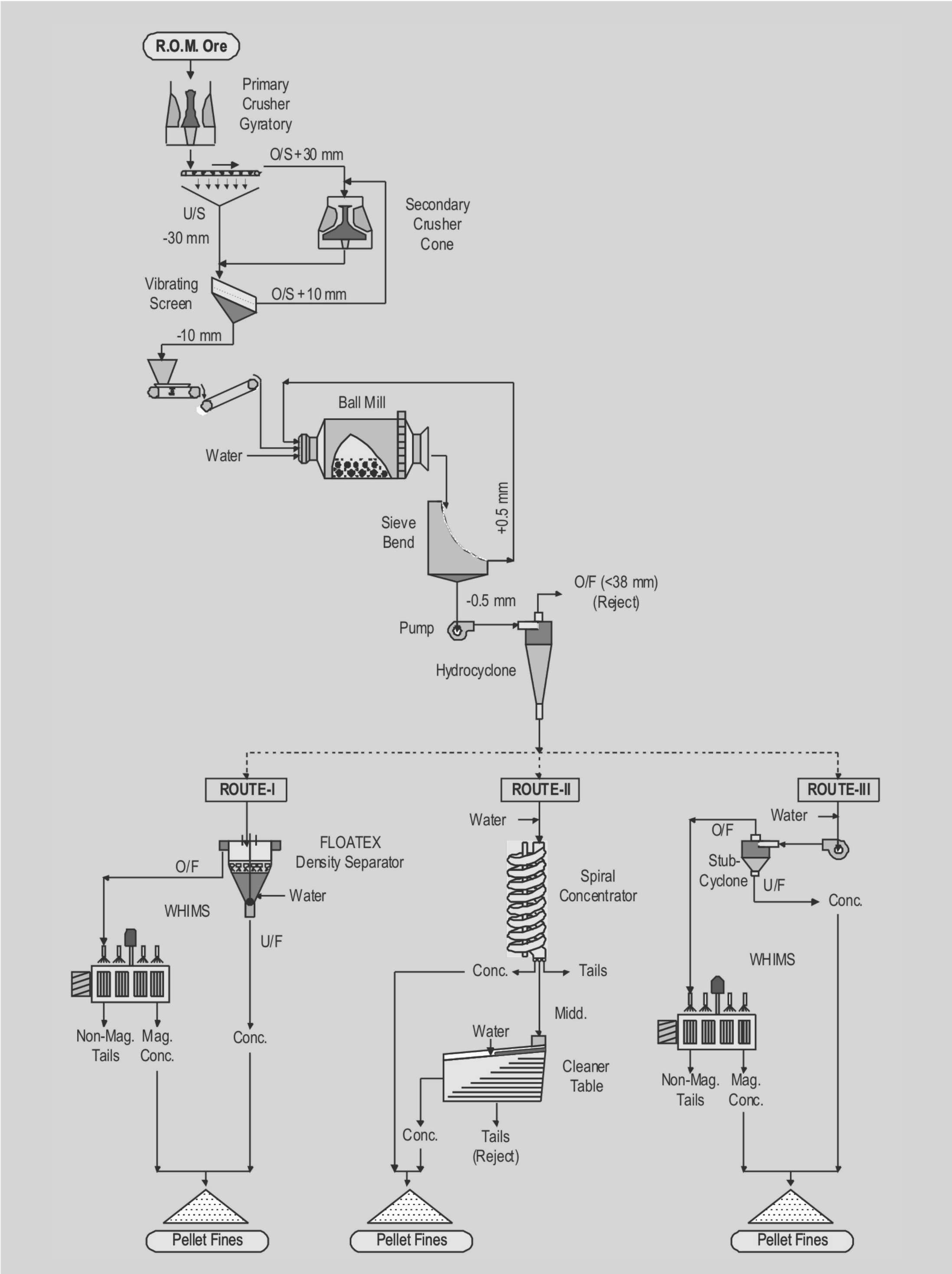

Fig- 41: Flow Sheet for Making of Pellet Fine Grade Concentrates from Sub-grade Ore

3.8 BHQ/BHJ AND ITS BENEFICIATION POTENTIAL

The world's Iron & Steel Industry is based almost exclusively on iron ores associated with banded iron formation. Banded iron formation itself may be the primary ore, from which hematite or magnetite is concentrated after crushing. But the main ore now mined globally is high-grade (greater than 60% iron) material that formed within banded iron formation by natural leaching of its silica content.

The most common names used in India to designate Banded iron ore formation (BIF) are Banded Hematite Quartzite/Jasperite (BHQ/ BHJ) and Banded Magnetite Quartzite/Jasperite (BMQ/BMJ). Hematite/magnetite too are found associated with higher amount of quartz/chert as in Banded iron formation (BHQ/BHJ & BMQ/BMJ). BIF is a sedimentary rock that was commonly deposited during the Pre-Cambrian Age. It was probably laid down as a colloidal iron-rich chemical precipitate, but in its present compacted form it consists typically of equal proportions of iron oxides (hematite or magnetite) and silica in the finely crystalline form of quartz known as chert. Its chemical composition is 50% silicon dioxide (SiO_2) and 50% iron oxides (Fe_2O_3 and Fe_3O_4), to give a total iron content of about 30%. Banding is produced by the concentration of these two chemical components into layers about 1–5 cm (1/2–2 in.) thick; typical banded iron formation consists of pale silica-rich cherty bands alternating with black to dark red iron-rich bands. These contrasting layers are sharply defined, so that the rock has a striped appearance; banded iron formation is normally a hard, tough rock, highly resistant both to erosion and to breaking with a hammer.

India has large resources of Banded Hematite Quartzite/jasper (BHQ/BHJ) ore with lower iron content of 30–35% Fe and hence cannot be directly used in iron making. Commercial extraction of iron ore from banded hematite jasper (BHJ) and banded hematite quartzite (BHQ) rocks, which are naturally mined along with the ore during normal mining operations, is need of the hour. These rocks can also be exploited only if they are purified and enriched to around 65% Fe that can be charged in a pellet plant.

R&D studies at IBM laboratory on beneficiation of iron mineral from BHQ/BHJ formations indicated that a fraction of the available iron mineral can produce high-grade concentrate (>65% Fe) and in large majority of the cases only a low/medium-grade siliceous iron concentrate (60-62% Fe) could possibly be obtained with weight recovery commensurate with the available iron mineral (hematite/magnetite) only i.e., around 30%. Non-attainment of high-grade iron concentrate is mainly due to presence of high amount of silica mineral (quartz, chert, jasper etc.) in intimate association and or as inclusion within iron mineral. IBM evolved flow sheet for beneficiation of BHQ/BHJ is presented in Fig-42.

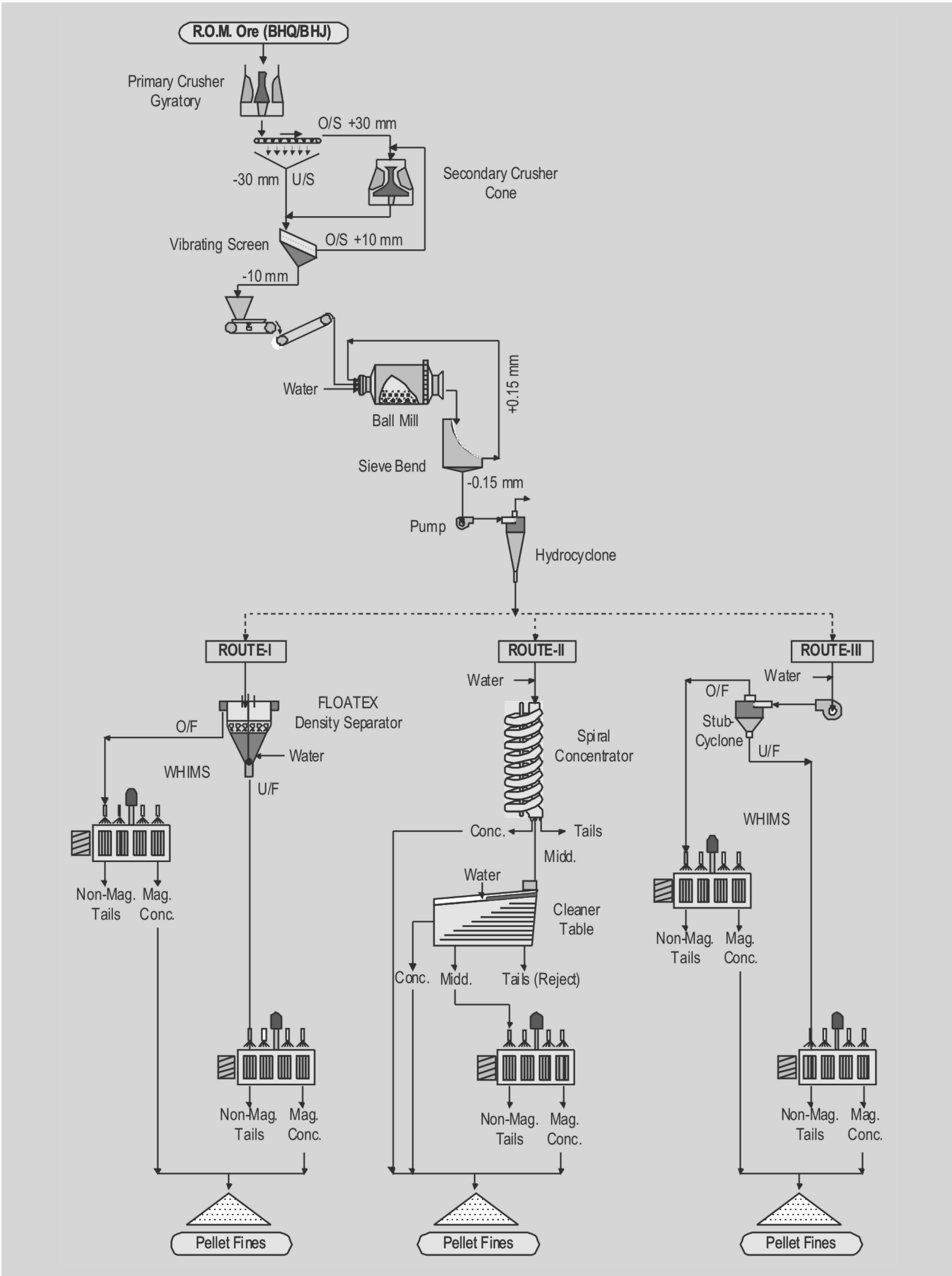

Fig-42: Flow Sheet for Making of Pellet Fine Grade Concentrates from BHQ / BHJ

3.9 INDIAN SCENARIO

3.9.1 Iron Ore Beneficiation Plants in India

Iron ore beneficiation facilities in the country are highly inadequate i.e., only 52 concentrators cater to the need for iron ore production of about 220 MTPA (mines-316). Of this around 50% of the concentrators are exclusively in Goa region (production 33 MTPA; mines 72) dedicated solely for export and not meant for domestic consumption. In most of these concentrators, beneficiation process technology is limited to sizing, washing and classification to meet the size requirement with nominal rejection of silica and alumina impurities. Such washing facility was basically successful on account of selective mining of medium to high-grade iron ore at a cut-off grade of 60% Fe. However, such practice of processing may not be of any help once low-grade ores are mined at the threshold value i.e., 45% Fe to augment production. Statewise number of operating Beneficiation Plants (2008-09) in India is presented in Fig.-43. Major beneficiation plants in the country are owned by M/s SAIL, NMDC, TISCO, OMC, JSW Steel Ltd, M/s V.M.Salgaoncar Pvt. Ltd, Sesa Goa Ltd, Socedade de Fomento, Goa etc.

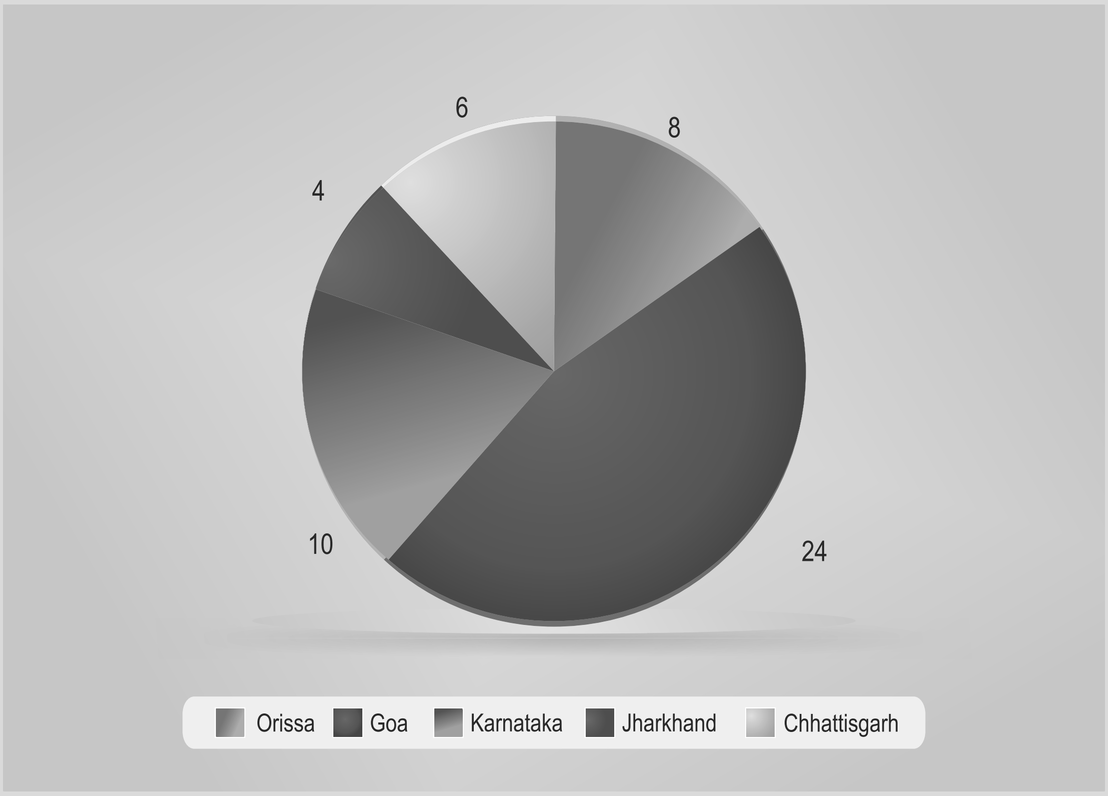

Fig-43: Statewise Beneficiation Plants in India

3.9.2 Present Status & Proposed Action Plan

The Indian Mining Industry currently is being run in fragmented lease holds and operated by captive & non-captive consideration producing iron ore in the ratio of 1:4. The non-captive sectors are the sole source of supply of high quality lumpy ores (-18+6 mm) to coal based DRI Plants, leaving behind huge stock of fines (-6 mm) at the mines head and are being exported. However, this fine forms the ideal feed for value addition through beneficiation for the production of quality iron concentrate suitable for sintering/pelletisation.

Further, most of the captive mines used its fines (-10 mm) for sinter making without consideration of making of quality sinter feed. Similarly, only a few organisations endeavor for pellet making concentrate from its fines. Thus, making of pellet grade concentrate in the country is highly inadequate. The merchandise mines also lacks facility for making of pellet grade concentrate although they generate substantial quantities of low/medium-grade fines in their mines.

A tentative estimate of the capital cost of 250 tph iron ore beneficiation plant works out to be around Rs 100 crore. Establishing a beneficiation facility by small and medium size entrepreneurs would be a daunting ask as such projects are usually capital-intensive in nature, besides, issues associated with procurement of land, water, power and environmental clearances would need to be tackled.

Therefore, concept of custom mill for beneficiation needs to be introduced whereby; the fines from near vicinity small mines could be received, blended, processed in a centralised processing unit and the concentrate so produced be pelletised or supplied to the pelletisation units. Such consortium could be made to 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 Govt. at the subsidised rate to incentivize these small players to venture for such highly capital intensive project.

In India, huge iron ore fines are stacked at mine head in eastern sector (Orissa & Jharkhand) and Bellary-Hospet sector (Karnataka), a large number of small mines located nearby can go for some sort of consortium to have their beneficiation and/or pelletisation facility erected.

Almost in all the existing mine area, a substantial iron ore raw material is available for value addition. The source of such materials are from stacked fines (-10/6 mm) of the non-captive sector in particular, tailing pond slimes (iron washing plant) of the captive sectors and unexploited and or stacked sub-grade material (45 to 58% Fe). These materials are ideal raw material for sinter and pellet making after beneficiation.

Extensive R & D work have been carried out at various laboratories in India and at IBM's Ore Dressing Laboratory in particular on low-grade/sub-grade iron ore, iron ore fines (-10 mm) and classifier/tailing pond slimes and the flow sheet developed on almost all types of ore, producing concentrate suitable for sinter & pellet making. By taking advantage of the same, beneficiation work can be commenced by existing operators without any delay. Thus, commencement of beneficiation facilities is a must and needs to be commissioned at the earliest. The cost of beneficiation in respect of fine for sinter feed will be around Rs 200/- per tonne whereas for pellet feed it would be in the range of Rs 250/- to 350/-per tonne.

At NMDC's mines, huge layers of BHQ rocks are piled up at the mine sites, and they are reportedly venturing for its commercial use. The company, which produces about 30 million tonnes of iron ore, plans to set up the first BHQ beneficiation plant with a capacity of three lakh tonnes a year at an estimated cost of Rs 150 crore, which will actually demonstrate the commercial viability of the technology developed by them. It is reported by NMDC that "Roughly, 100 kg of BHJ rock can yield 30 kg (30%) of iron ore if enriched to 65% level.

In the light of prevailing Indian scenario it may be concluded that value addition of r.o.m. iron ore in its totality (concept of total beneficiation) is crucial. This will be useful for optimum utilisation and conservation of limited availability of high-grade reserves of the natural resources and besides it offers viable remedial measure for preventing environmental degradation caused on account of perpetual stacking of unprocessed material. i.e., low-grade iron ore, mines and process rejects.