Challenges in Processing of Iron Ores of India

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Overview

• Indian iron ore scenario
• Low grade/difficult to treat ore
• Process synthesis/optimization
• Alternate methods
• Pelletization
• Future directions
• Conclusions
Iron Ore Scenario

### Iron ore production (million tons)

<table>
<thead>
<tr>
<th></th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
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<td>Odisha</td>
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<td>76.1</td>
<td>67.0</td>
<td>64.2</td>
<td>72.0</td>
<td>62.0</td>
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<tr>
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<td>39.0</td>
<td>13.2</td>
<td>11.2</td>
<td>17.0</td>
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<td>Goa</td>
<td>38.1</td>
<td>35.6</td>
<td>33.4</td>
<td>10.6</td>
<td>-----</td>
<td>10.0</td>
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<td>Chhattisgarh</td>
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<td>29.3</td>
<td>30.5</td>
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<td>Jharkhand</td>
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<td>22.3</td>
<td>18.9</td>
<td>18.0</td>
<td>22.0</td>
<td>22.0</td>
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<tr>
<td>Others</td>
<td>7.6</td>
<td>5.7</td>
<td>4.1</td>
<td>3.9</td>
<td>4.0</td>
<td>4.0</td>
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<tr>
<td>Total</td>
<td>218.5</td>
<td>208.0</td>
<td>167.1</td>
<td>135.8</td>
<td>145.0</td>
<td>150.0</td>
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**Past**
- Selective mining
- Scrubbing and classification
- Sintering

**Present**
- Gravity and magnetic separation
- Sintering & Pelletization

**Future**
- Roasting followed by beneficiation
- Flotation & Pelletization

**Policy issues:**
- Mining lease
- Environment
- Sustainability

**There are technical issues:**
- Low grade ore utilization
- Waste treatment
- Use of secondary resources
Types of Iron Ore

- Hard Ore—banded type
- Flaky/Friable ore
- Lateritic ore
- Goethitic ore
- Black goethite
- Limonitic ore
- Secondary sources

Types of Iron Ore:

- Hematite
- Goethite
- BHJ
- BHQ
- Limonite
Problems in Low Grade Iron Ore Processing

- Intimate association of goethite, clay, and hematite - Liberation is a problem
- Higher amount of ochreous goethite, which contain more alumina compared to massive vitreous goethite
- Colloform-banded goethite has higher phosphorus contents ($P_2O_5$: 0.90–2.25%)
Problems in Low Grade Iron Ore Processing (contd.)

<table>
<thead>
<tr>
<th>Constituents</th>
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<tr>
<td>Fe(T)</td>
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<tr>
<td>Fe$_2$O$_3$</td>
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<tr>
<td>Al$_2$O$_3$</td>
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<td>SiO$_2$</td>
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<td>LOI</td>
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## Beneficiation of Hematite

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<th>Sample, Locations</th>
<th>Weight, %</th>
<th>Fe, %</th>
<th>Al$_2$O$_3$, %</th>
<th>SiO$_2$, %</th>
<th>Al$_2$O$_3$/$$SiO_2$</th>
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<td>2.2</td>
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<td>48.9</td>
<td>9.84</td>
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<tr>
<td>Barjamada</td>
<td>100</td>
<td>55.4</td>
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<tr>
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<tr>
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<td>8.0</td>
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<td></td>
<td>69.1</td>
<td>43.4</td>
<td>12.8</td>
<td>13.5</td>
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Flotation Response of Hematite

Hematite Ore:
- Si:Al>1
- Si:Al<1

- Preprocessing of ore affect flotation response
- Quartz containing ores are more suitable for flotation compared to their high alumina counter parts
- Crystalinity plays a role

- Sample with 42% Fe contains more of quartz with some blue dust
- Sample with 54% Fe contains Al bearing kaolinite clays
BHQ ore: Easy to float

- BHQ is easy to float
  - Anionic & cationic collectors work well
- Works well in cell (lab and large scale)
BHQ vs. BHJ Ore: Anionic Flotation Behavior
Jasper/Quartz derived from the respective ore

Dissolution study

- Silica derived from
  - Top: BHJ
  - Bottom: BHQ
- Clearly jasper is contaminated with iron which decreases the flotation response
- Silica in BHQ has no trace of Fe
BHJ Ore

Coarse and fine quartz grains and fine intergrowth of quartz with hematite

Disseminated minute hematite grains are within jasper
Difficult to treat ores

Ore Characteristics

- Goethitic ore
- Some amount of limonite is present
- Small amount of hematite present within goethite
- Collector selection is critical to float such type of ores

<table>
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<th>Reagent</th>
<th>Products</th>
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<th>Fe, %</th>
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<td>Anionic</td>
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<td>Non-float</td>
<td>80.7</td>
<td>39.7</td>
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<tr>
<td>Cationic</td>
<td>Float</td>
<td>19.5</td>
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<tr>
<td></td>
<td>Non-float</td>
<td>80.5</td>
<td>37.5</td>
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Difficult to treat ores (contd.)

Hematite-ring structures
Liberation is a problem
Process Synthesis & Plant Optimization
Mineral Liberation
Mineral Liberation
Mineral Liberation

![Bar Chart]

- Number of subcubes
- Grid Sizes
- % of black (in subcube)
Image Processing
Volumetric Grade
Modelling & Simulation

• Plant Scale Testing
  – Site-Specific
  – Identifies Upgrade Options
  – Explicitly Defines Reliability

• Process Modeling
  – Range of Options with Varying Sophistication
  – Requires Differing Degrees of Knowledge

Millsoft© → Modsim© → Data Interpretation
Process Modeling and Simulation Approach
Process Synthesis

Ball mill → Cyclone Bank → Jig → Spiral cluster → Ball mill

Reject (Non-magnetic) → Magnetic separator → Thickener

Final Product
Ball Mill: DEM Simulation

\[ m \frac{d\nu}{dt} = f_c + f_d + f_b + mg \]

Fluidization liquid

\[ m a_y + m'(a_y - a_f) = F_d + mg - F_b \]

Secondary flow along the radial direction of the spiral is responsible for separation of heavier particles from lighter particles of same size and larger particle from smaller particles of same density.
Wet High Intensity Separator

Experimental set-up

Contour of the square of the strength of the magnetic field, A^2 m^-2

Concentration on an iso-surface at z = 0.1 m.

Fluidized bed

- Fluidized bed find wide application in industries because of better fluid–solid contact.
- Suitable for feed with wide size distribution and exothermic reaction.
- Velocity of gas decreases with increasing cross sectional area.
- Larger particles at the bottom are lifted by the fluid at a higher velocity.
- Lighter particles at the top are prevented from getting entrained.

*Applied Mathematical Modelling 35 (2011) 2265–2278*
Alternate Techniques

• Reduction roasting followed by magnetic separation
• Microwave-assisted heating and reduction
• Colloidal magnetic carrier technology
• Liberation
  – Shock-plasma treatment
  – HPGR
  – Ultrasonic
• Use of sea water
Reduction Roasting

- Some low grade ores are not amenable to conventional treatment e.g. goethitic, limonitic, and banded ores
- Reduction roasting allows phase transformation which favors separation

<table>
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<tr>
<th>Exp. No.</th>
<th>Reduction time (hr)</th>
<th>Reductant conc. (%)</th>
<th>Temp (°C)</th>
<th>Fe Grade (%)</th>
<th>Reco (%)</th>
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<td>6</td>
<td>950</td>
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<td>4</td>
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<td>6</td>
<td>1050</td>
<td>62.16</td>
<td>39</td>
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45% Fe

Q: Quartz
M: Magnetite
H: Hematite
G: Goethite
F: Fayalite
K: Kaolinite
Hematite Ore (52% Fe)

<table>
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<tr>
<th>S.No.</th>
<th>Temp, C</th>
<th>Time, m</th>
<th>Reductant, %</th>
<th>weight, %</th>
<th>Fe, %</th>
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<td>950</td>
<td>120</td>
<td>8</td>
<td>59.7</td>
<td>64.2</td>
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</table>

*Magnetic separation of Non-Magnetics
Magnetic weight% Fe= 29.0, Fe% 57.4%, N. Mag. weight% 11.0, Fe, 40%
Microwave Heating

- Microwave: non-contact heating; rapid & material selective heating; heating starts from interior of the material body
- Treatment of ores with complex mineralogy to enhance the liberation
  - Microwave assisted grinding
  - Carbothermal reduction of oxide ores
  - Roasting & Leaching
Magnetic Carrier Technology

Separation can be achieved at a lower Magnetic field strength.

Hematite
High Voltage Pulse Assisted Breakage

- Comminution assisted by high-voltage pulses
- Selective fragmentation at grain boundaries and better liberation
- Generates a coarser product (less fines)
- Enhanced liberation at coarser sizes

PSD curves of the products comminuted mechanically and electrically for copper sulphide-gold ore particles in a mono feed size of 9.5–12.5 mm. Equipment used: SelFrag

Wang et al., Miner. Eng., 2012
High Pressure Grinding Rolls

- HPGRs were first applied in 1994.
- More than 10 HPGRs operate in pellet plants in Sweden, Brazil, India and Russia.
- Configurations for comminution circuits that utilize HPGR technology
  - Replacing *crushing* and pre-grinding stages (Los Colorados plant, CMH, Chile, Empire iron ore, US)
  - Replacing AG/SAG *grinding* SNIM, Zouerate iron ore, Mauretania
  - Regrinding stage for surface generation for *pelletizing* (Kudremukh)
  - Phosphate ore, *(RSMML, Udaipur)*

*Retro-fit to an existing plant*
HPGR test for lead zinc ore

HPGR products exhibits higher Zn & Pb recoveries as compared to conventional grinding by ball mill.
Sea Water in Mineral Processing

• The use of inorganic electrolytes in flotation, is known as Salt Flotation

• It is not widely developed because of their corrosive properties but today shortages of fresh water has forced several mills to conduct flotation in sea water

• Sea water is a frother since inorganic salts are known to raise the surface tension of water

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<tr>
<th>Elements</th>
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<td>Sea water</td>
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<td>*pH</td>
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<td>Na</td>
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<td>Mg</td>
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<td>Cl</td>
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Use of Sea Water

- **Sea water**
  - Structure breaker
  - Structure former

- **Usage**
  - Graphite beneficiation
  - Settling of iron ore slurry and red mud
  - Gravity separation using spirals

![Graph showing Fe, rec.% vs pH for normal water and sea water](image)
Pelletization

Existing: 54 Mt
To be installed: 73 Mt
Pelletisation Process

- Raw material preparation
- Green pellet formation
- Induration
  - Drying
  - Preheating
  - Firing
  - Cooling
- High LOI
- High Blaine
Low Grade Indian Iron Ore

- Fragile nature
- Liberation size < 200 micron → High Blaine No.
- Goethite + Kaolinite → High LOI

Flotation as a part of beneficiation process
- Hydrophobic nature of iron ore concentrate
Pelletisation Kinetics

B. K. Mishra, C. Thornton, and Dhaksha Bhimji

Effect of LOI
Relationship between compression strength and firing temperature
Kiln Design

Green pellets (10 – 18 mm)

- Preheating zone
- Induration zone
- Cooling zone

- Oil firing
- Rotary Kiln
- Rotary cooler

Downdraft

- Hardened pellets
- Stack
Future Direction: Need to develop a compressive utilization plan for Indian iron ore
Conclusions

• Low grade ore processing has been a challenge particularly with respect to presence of goethite, clay, LOI, and intermixing of phases
• Care should be taken from accurate process synthesis and optimization
• Alternate techniques must be pursued to achieve suitable concentrate
• Agglomeration of concentrates must be carried by considering the nature of the ore
• Finally, a comprehensive method for optimal utilization of difficult-to-treat mineral resources must be determined