New Ironmaking Processes: Relevance to India

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Emerging Scenario in Iron Making

- More than 90% of world iron production is through Blast furnace technology route

- Driving forces: Alternative Ironmaking technologies
  - Costly and scarce coking coal: Need to look beyond coking coal
  - possibility to use iron ore fines directly
  - Land-constraint
  - Environmental considerations
    - eliminate pollution-intensive sintering and coke-making processes
  - Water scarcity
  - Large scale of economy
    - High capital cost
  - Scientific/ engineering knowledge to think/ design alternative processes
Possible Solutions: Alternatives for Ironmaking

1] Production of non-liquid Iron (DRI)
   - Direct Reduced Iron (DRI) has emerged as an excellent substitute for scrap for electric furnaces.
   - That's why, DRI production has zoomed throughout the world (~63 mt in 2010)
   - *SL/RN, MIDREX, ITmk3 etc.*

2] Alternative method for Liquid Iron (Hot Metal)
   - Smelting Reduction (SR) processes:
   - *COREX, FINEX, Hismelt etc.*
     - using non-coking coal
     - obviating the need for coke oven batteries and sinter plants
       - needing smaller land/area
       - Iron ore fines can be used directly (except COREX)
       - Lesser pollution
DRI Production Technologies

• DR processes have overcome many of theirs conceptual & engineering problems, and hence have been commercialized throughout the world in a big way.

• Two major production technologies:
  – Coal Based Rotary Kiln process
  – ~20% of world DRI production
  – SL / RN Process, Jindal Process, TDR etc.

• Gas Based Shaft Reduction processes
  – ~80% of world DRI production
  – MIDREX (~60% among all DRI processes),
DRI Technologies

- Both gas-based & coal-based DRI technology readily available

- Scale of operation
  - Gas based: 0.8 – 1.2 mtpa/module
  - Coal based: 0.03 – 0.15 mtpa/module

- Feed stock:
  - Gas based processes
    - Pellet (8-15mm): 33 – 100 %; Iron ore (6-30mm): 0 – 67%
    - Natural gas / Coal gas (not practiced yet)
  - Coal Based Processes (rotary kiln)
    - Iron Ore (10-20 mm): 100%,
    - Non-coking Coal

- Any of these can be adopted based on techno-economics

- India: World Leader: ~ 20 mtpy: 1/3rd of world production

- India: Pollution specially rotary Kiln processes
New Scheme: Coal Gasification based DRI

Example: Angul Plant (6/12mt) of JSPL at Orissa

• The **DRI-BF-EAF** route technology would be adopted for steel production.

• The **DRI plant (2mt)** has a unique feature of using Syn Gas from the coal gasification plant as reductant.

• *The DRI-Gasification route: first time in the world: using high ash coal.*

• JSPL in agreement with Lurgi Sasol Technology Company, South Africa, for coal gasification technology.

Blast Furnace and DRI can co-exist!

Cricket: Test, ODI and T-20
ITmk3 Process: Production of Iron nuggets

- Disadvantage in DRI: gangue remains within it
- Kobe Steel, Japan: ITmk3
- Ore + coal composite pellets: Reduction & melting at 1500°C in RHF
- It produces almost low sulphur pure iron nuggets (& slag globules)
- 0.25 mtpy plant at Minnesota, USA
SMELTING REDUCTION PROCESSES for IRONMAKING
Advantage: Smelting Reduction Processes

- They produce **hot metal**; hence more relevant to BOF based Integrated Steel Plants

- **Direct use** of non-coking coal and Iron ore fines

- They need much **less land** as compared to conventional BF complex
Available Smelting Reduction (SR) Processes

4 SR Technologies currently commercially exploited or ready for commercial exploitation

- **COREX** (Two stage): Operating commercially
- **FINEX** (Two stage): Operating commercially
- **HISMELT** (Single stage): Not being Operating commercially at present
- **ROMELT** (Single stage): Not being Operating commercially at present

- Single stage: Reduction & melting in the same vessel
- Two stage: Reduction in one vessel; melting in the 2nd vessel
COREX Process for Ironmaking
A schematic diagram of COREX process
COREX: Process Features

- Developed by Siemens VAI
- Commercially most successful amongst SR Technologies

- Commercial units in operation
  - Korea: POSCO (COREX C-2000 – Capacity: 0.8 Mtpa)
  - India: JSW Steel, India (2 Units) (COREX C-2000)
  - South Africa: Mittal-SALDANHA, (COREX C-2000)
  - China: Baosteel, (COREX C-3000) – Capacity 1.5 mtpa
Experience of COREX at JSW

- Total fuel rate requirement = 950 kg/thm. Out of which ~200 kg coke is required.
- All the non-coking coal is imported. NCC of very high VM or very low FC cannot be used.
- ~100% pellets are charged.
- Oxygen requirement = 550 Nm3/thm (very high!)
- Corex HM ~ BF HM:
  - Typical HM Composition: C~ 4%, Si=0.5-0.9%, S=0.025-0.07%, P=0.13-0.19%, temp= 1480-1515°C
COREX: Process Limitations

- Can't use ore fines directly

- Restriction on non-coking coal
  - VM of carbonaceous material to be maintained at ~25% (blending of coal and coke.

- Net export gas (1650 nm3/thm; CV:1800 Kcal/Nm³) to be utilised very economically, the process becomes un-viable.
  - Hence, gas is used for production of DRI in MIDREX shaft (SALDANHA) and Power Generation (POSCO, JSW Steel and Bao Steel)
FINEX Process for Ironmaking
FINEX Process Flow Sheet: Jointly developed by VAI and research Institute of Industrial Science & Technology, Korea
Off-shoot of COREX Process: to use iron ore fines (-8 mm) directly

Direct use of non-coking coal (-6 mm)

VM of carbonaceous material to be maintained at ~25% by proper blending of coal and use of coke

Fine ore is pre-heated and reduced to DRI in a four stage fluidised bed system. R4 & R3 for preheating. In R2, fine ore is reduced to 30%. In R1, final reduction to 90%. Operational pressure: 4-5 bar.

The DRI is melted in the COREX like melter-gasifier.
FINEX: Process Features

- FINEX HM ~ BF HM \( [C= 4.5\%, \ S = 0.03\%, \ Si = 0.60\% , \ Temp= 1520\degree C] \)

- Export gas \((CV\sim 2000 \text{ Kcal/Nm}^3)\) can be utilised for production of DRI or generation of power

- Coal consumption @ 720 kg/t HM achieved:
  - Pulverised coal injection @ 150 Kg./t HM.

It is claimed by Finex Technology that Capital cost is lower by 20% and production cost is 15% lower as compared to BF process.
Limitations of FINEX Process

- Commercial unit of 1.5 Mtpa at Pohang, Korea – commissioned in 2007 and in operation since then.
- No other unit so far
- POSCO not interested in selling the technology

Recent GoI approval for POSCO plant in Orissa: FINEX being considered!
HISMELT Process
for
Ironmaking
Smelting Reduction Vessel of HIsmelt

- Off-gas
- Oxygen-enriched hot air blast
- Ore and coal fines: Injection lances
- Slag notch
- Fore hearth
- HM
HISMELT: Features

- Developed by Hismelt Corporation, Australia
- 1-Stage hot air based Smelting Reduction Process using metal bath as primary reaction medium which is unique:
- Bulk of smelting of ore takes place via dissolved carbon resulting in high reaction rate
- Direct utilisation of ore fines (-0.6 mm) and non-coking coal fines (-0.3 mm): feed material is directly injected thru water cooled lances into metal bath.
- No oxygen requirement – only preheated air is used
- Variety of coals containing 10 to 38 %VM can be used, Low coal rate (600-620 kg/thm)
- HM: Low P (0.02-0.05% based on ore of 0.12% P) and very very low Si
- Off-gas not rich (CV ~700 Kcal/Nm³) – no need to generate value from off gas
First industrial Hlsmelt Plant (capacity 600,000 tpa) commenced operation in Kwinana, Australia in 2005.

The plant is under maintenance as per their press-release.

No other plant in the world

Currently, there are two other licencees in China who have signed a Hlsmelt Process Licence. Under the agreements, the groups can replicate the 800,000 tonne per year Hlsmelt Plant.

Process seems to be suitable under Indian conditions, specially for Flat product plant producing API X70/80 products needing low P steel.
ROMEILT Process for Ironmaking
Schematic Flowsheet of Romelt Process

Ore Fines

Coal & Flux

Waste Heat Boiler

Active Bath

Slag

Metal

Romelt Smelter

Pig Iron

Stream Turbine

Oxygen
ROMELT: Process Features

- Developed by Moscow Institute of Steel and Alloys (MISA in mid 1980s)
- Process operates under a slight negative pressure (1-5 mm WC)
- Greater raw material flexibility
  - Accepts iron ore, slimes and other iron bearing materials in a wide range of sizes (0 – 20 mm) without any pre-treatment
  - Non-coking coals of size 0 – 20 mm with moisture content < 10% are acceptable. High VM non-coking coals can be used without any preparation
ROMELT: Process Features

- Small scale production of 200,000 to 1,000,000 tpa HM
- Excellent quality of hot metal (C ~4%, Si ~0.6%, S ~0.040%, Temp. ~1400°C). Approx. 40% of input P goes to slag phase & 90% of input S goes to gas phase
- High coal (1.3 – 1.5 t / thm) and high oxygen (900-1100 – Nm³/thm) consumption
- Fairly high degree of combustion. It produces rich off gas (CV ~1000 Kcal/Nm³) – has to be utilised efficiently (e.g. power generation to meet the demand of oxygen plant) to make economic production of hot metal.
- No commercial plant anywhere in the world
## Comparison of Commercially exploited/ Potential SR Processes

<table>
<thead>
<tr>
<th></th>
<th>COREX</th>
<th>FINEX</th>
<th>HISMELT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of development</strong></td>
<td>Fully Commercially</td>
<td>One 1.5 mtpy commercial plant in operation since 2007</td>
<td>One 0.8 mtpy plant was in operation in 2005, but not now</td>
</tr>
<tr>
<td><strong>Ability to use ore fines</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Reductant</strong></td>
<td>Non-coking coal (VM ~ 25 %) (to be imported)</td>
<td>Non-coking coal (VM ~ 25%) (to be imported)</td>
<td>Non-coking coal fines (-0.3mm) (to be imported)</td>
</tr>
<tr>
<td><strong>Oxygen (Nm³/thm)</strong></td>
<td>~ 550 (High !)</td>
<td>~ 550 (High !)</td>
<td>~ 300</td>
</tr>
<tr>
<td><strong>HM Quality</strong></td>
<td>Comparable with BF</td>
<td>Comparable with BF</td>
<td>Very low P &amp; Si</td>
</tr>
<tr>
<td><strong>Viability dependent on use of off-gases?</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Ease of obtaining the technology</strong></td>
<td>Commercially available</td>
<td>Uncertain</td>
<td>Available</td>
</tr>
</tbody>
</table>
Conclusions: Selection of SR Processes under Indian Conditions

- Out of 3 potential SR processes, only COREX is commercially exploited till date. FINEX is on the verge of commercialisation.

- COREX & FINEX processes: sensitive to quality of input material particularly w.r.t. VM and ash of coal. Type of coal required for these processes is scarcely available in India.

- Experience of COREX at JSW suggest that still ~ 15% coke is required in the process to control VM of the input reductant. Same may be the case for FINEX process.

- Use of pellet atleast partially is a must for COREX process. For FINEX & HISMELT process, iron ore fines can be directly used.

- For COREX & FINEX processes, large amount of oxygen is required.

- For COREX & FINEX processes, rich off gas generated in the process need to be used either for generation of power or for production of DRI.

- Hismelt is suitable for steel product with low P.
THANK YOU
Midrex Process Flow Sheet - HBI Production
Production Technologies

• Coal Based Rotary Kiln process

Lump ore/ pellets → Rotary Kiln → DRI
Coal → Char

Scheme for DRI Production in Rotary Kiln
Production Technologies
Gas based Process

Lump Iron ore or Pellets

Reformed Natural Gas

Shaft Reactor

Hot Briquetting Press

Scheme for HBI Production in Shaft Reactor

Cold DRI Product
Salient Features of Midrex Process

- Both pellets (8-15 mm) & sized lump ore (6-30 mm) (upto 50% can be charged).
- Reformed Natural Gas: CO=80%, H₂=20%
- Specially suitable for countries/ locations where natural gas is available in plenty and less expensive
- Indian Scenario:
  - Essar Steel, Hazira
  - Ispat Industries, Raigad

Coal gassification based DRI plant (JSPL plant at Angul, Odisha) may open a new trend in India/ world
**ITmk3 COMPARE TO OTHER DIRECT REDUCTION/SMELTING PROCESSES**

**ITmk3 technology has the better economics at small scale production compare to other competing processes**

<table>
<thead>
<tr>
<th>Relative cost to ITmk3 process</th>
<th>ITmk3</th>
<th>Midrex Coal Based (DRI)</th>
<th>Corex</th>
<th>Rotary kiln + melter</th>
<th>BF+CO+SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost, 500,000 t/y</td>
<td>1</td>
<td>1.58</td>
<td>2.4</td>
<td>1.5</td>
<td>1.98</td>
</tr>
<tr>
<td>Operating cost, 500,000 t/y</td>
<td>1</td>
<td>1.11</td>
<td>1.53</td>
<td>1.2</td>
<td>1.27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relative cost to ITmk3 process</th>
<th>Hlsmelt</th>
<th>Romelt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost, 500,000 t/y</td>
<td>1.16*</td>
<td>1.1</td>
</tr>
<tr>
<td>Operating cost, 500,000 t/y</td>
<td>1.1</td>
<td>1.34</td>
</tr>
</tbody>
</table>
## RELATIVE ECONOMICS OF COMMERCIAL EXPLOITED SR PROCESSES vis-à-vis MINI BLAST FURNACE (MBF)

[A] Assessment of Raw Material & Energy

<table>
<thead>
<tr>
<th></th>
<th>COREX</th>
<th>FINEX</th>
<th>HISMELT</th>
<th>ROMELT</th>
<th>MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IRON BEARING MATERIALS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Sized Ore</td>
<td>Indigenous</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Indigenous</td>
</tr>
<tr>
<td>• Pellets</td>
<td>Indigenous</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>• Fines</td>
<td>-</td>
<td>Indigenous</td>
<td>Indigenous</td>
<td>Indigenous</td>
<td>-</td>
</tr>
<tr>
<td><strong>REDUCTANT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Non-coking coal</td>
<td>Imported</td>
<td>Imported</td>
<td>Imported</td>
<td>Blended*</td>
<td>-</td>
</tr>
<tr>
<td>• Coke</td>
<td>Imported</td>
<td>Imported</td>
<td>-</td>
<td>-</td>
<td>Imported</td>
</tr>
</tbody>
</table>
## RELATIVE ECONOMICS OF COMMERCIAL EXPLOITED SR PROCESSES vis-à-vis MINI BLAST FURNACE (MBF)

### [B] Comparison of Specific Consumption Norms

<table>
<thead>
<tr>
<th></th>
<th>COREX</th>
<th>FINEX</th>
<th>HISMELT</th>
<th>ROMELT</th>
<th>MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Hot Metal Capacity ('000 tpa)</td>
<td>800</td>
<td>800</td>
<td>600</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>B. Raw Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Sized iron ore (t)</td>
<td>0.40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.52</td>
</tr>
<tr>
<td>• Iron Pellet (t)</td>
<td>1.20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>• Iron ore fines (t)</td>
<td>-</td>
<td>1.60</td>
<td>1.65</td>
<td>1.60</td>
<td>-</td>
</tr>
<tr>
<td>• Imported coke (t)</td>
<td>0.16</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>0.63</td>
</tr>
<tr>
<td>• Non-coking coal(^{1}) (t)</td>
<td>0.90</td>
<td>0.90</td>
<td>-</td>
<td>1.27</td>
<td>-</td>
</tr>
<tr>
<td>• Non-coking coal(^{2}) (t)</td>
<td>-</td>
<td>-</td>
<td>0.82</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>• Limestone (t)</td>
<td>0.16</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>0.09</td>
</tr>
<tr>
<td>• Dolomite (t)</td>
<td>0.09</td>
<td>0.09</td>
<td>-</td>
<td>-</td>
<td>0.11</td>
</tr>
<tr>
<td>• Calcined dolomite (t)</td>
<td>-</td>
<td>-</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>• Lime (t)</td>
<td>-</td>
<td>-</td>
<td>0.05</td>
<td>0.13</td>
<td>-</td>
</tr>
<tr>
<td>C. Energy inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Oxygen (Nm(^3) / t)</td>
<td>570</td>
<td>570</td>
<td>253</td>
<td>1100</td>
<td>-</td>
</tr>
<tr>
<td>• Electric power (Kwh/t)</td>
<td>69</td>
<td>69</td>
<td>125</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>• Fuel gas (Nm(^3) / t)</td>
<td>-</td>
<td>-</td>
<td>27</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^{1}\) Based on 50% Indigenous & 50% imported coal

\(^{2}\) Based on imported coal with 10% VM & 10% ash
### [C] Relative Costs of Hot Metal

<table>
<thead>
<tr>
<th>Process</th>
<th>Capital Cost</th>
<th>Production Cost (with power credit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COREX</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>FINEX (1.5 mtpy)</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>HISMELT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROMELT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast Furnace</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
### Comparison of Power Generating Potential from Surplus Gas

<table>
<thead>
<tr>
<th>Item</th>
<th>COREX</th>
<th>FINEX</th>
<th>HISMELT</th>
<th>ROMELT</th>
<th>MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot metal capacity, ‘000 tpa</td>
<td>800</td>
<td>800</td>
<td>600</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>Gas generation, Gcal/thm</td>
<td>3.7</td>
<td>3.7</td>
<td>1.03</td>
<td>2.4</td>
<td>1.6</td>
</tr>
<tr>
<td>CV of gas, Kcal/thm</td>
<td>2000</td>
<td>2000</td>
<td>Low</td>
<td>1000</td>
<td>800</td>
</tr>
<tr>
<td>Power plant capacity, MW</td>
<td>130</td>
<td>130</td>
<td>27</td>
<td>54</td>
<td>28</td>
</tr>
<tr>
<td>Energy credit (After internal consumption), kWh/thm</td>
<td>1161</td>
<td>1161</td>
<td>221</td>
<td>1210</td>
<td>359</td>
</tr>
</tbody>
</table>