HIsmelt® - The Alternative Ironmaking Technology

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Synopsis

The Global Steel Industry needs an alternative to conventional ironmaking technology to meet the challenge of increasing environmental and cost pressures. The extensive and very successful testing of the HIsmelt® Process provides the basis to commercialise this technology to meet these challenges. The technology addresses key issues that currently confront the industry, such as, high capital and operating costs, environmental constraints and lack of production flexibility.

In the final phase of demonstrating the commercial viability of the technology, the first commercial scale HIsmelt® plant will be constructed at Kwinana in Western Australia. The plant will produce around 820,000 tpa of high-grade pig iron that will be marketed as a high quality feed for the global EAF sector. Construction will commence in early 2003 with first production planned for last quarter of 2004.

Importantly for India, the HIsmelt® Process has the potential to deliver a low cost, quality metal feed utilising fine iron ore and domestic non-coking coals in a process that has significantly reduced capital expenditure and is more environmentally friendly than traditional ironmaking routes.

Introduction

Even without the prevailing worldwide economic climate, the global nature of the steel industry creates a fiercely competitive environment. The pressure to make incremental improvements in operating costs and product quality continually increases, as does the pressure for significant improvements in environmental performance.

In the field of ironmaking this pressure has led to improvements in blast furnace technology and productivity - much of which has revolved around control and conditioning of the material inputs to the furnace and add-on equipment for control of emissions. The technology surrounding the blast furnace has reached a level where it becomes increasingly difficult to make further significant improvements. The complexity of modern furnaces and their associated infrastructure has raised capital requirements, reduced operating flexibility and the impacts of downtime (relines), has become a major logistical hurdle.

The driving force behind the interest in alternative ironmaking is:

- The ability to utilise cheaper and more abundant raw materials such as non-coking coals and non-agglomerated ores,
- Smaller economic plant sizes,
- Competitive capital and operating costs,
- Reduced environmental problems through the elimination of coke ovens and sinter/pellet plants, and
- Flexibility of operation.

With a growing domestic and regional steel demand, India has the potential to become a major player in the steel industry. Large reserves of high-grade iron ore, low labour costs and high quality management provides India with a competitive advantage.(1) Impasse to the expansion of the Indian steel industry include (2):

- The lack of good quality domestic coking coals forcing a dependence on costly coking coal imports to meet blast furnace coke requirements,
- High Al_2O_3 content of the ore negatively impacting on sinter quality and tapping practice,
- High silicon in the hot metal due to unfavourable cohesive zone formation as a result of sinter properties,
- High cost of capital.

The alternative ironmaking technologies offer the Indian iron and steel industry the opportunity to overcome some of these issues.

History

The HIsmelt® Process has its origins in the early 1980's when Rio Tinto Limited identified the potential to adapt the high scrap rate steelmaking and iron bath coal gasification processes developed by Klockner Werke to the direct smelting of iron ore.(3) Development of the HIsmelt® Process commenced with a 60 tonne K-OBM converter. After successfully proving the concept, a small scale pilot plant was constructed and operated at Maxhutte Works in Germany. The plant design was based on an enclosed horizontal vessel to overcome process containment issues experienced in the 60 tonne converter trials.

Following the successful conclusion of these trials the HIsmelt® Research and Development Facility (HRDF) was established in Kwinana, Western Australia. The plant had a rated capacity of 100,000 tpa and was a direct scale-up of the small scale pilot plant. The principle objective of the HRDF was to demonstrate scale-up of the core plant (process and engineering) and provide operating data for commercial evaluation of the technology.

Whilst the process scale-up was successfully demonstrated, the complexity of the engineering, poor plant availability and difficult operational requirements brought into question the commercial viability of the plant design. After three years of operation the plant was substantially reconfigured to address these issues. The horizontal Smelt Reduction Vessel (SRV) was replaced with a vertical vessel. This allowed extensive use of water cooled elements in the process top space to address availability issues. Injection of solids was through water cooled top injection lances as opposed to submerged tuyeres thereby simplifying the engineering and overcoming operational issues encountered with the submerged bottom tuyere used in the horizontal vessel.

Installation of the vertical vessel proved successful. The plant achieved very high plant availability as shown in Table 1 whilst still maintaining high process performance despite the increased vessel heat losses due to the added water cooling.

	Duration	Availability	Metal Production [t]
Campaign 7 (Feb - Dec 1997)	52 days (8 Periods)	98.9 %	8450
Campaign 8 (Mar - Sep 1998)	32 days (4 Periods)	98.9 %	5390
Campaign 9 (Dec 98 - Jun 99)	48 days (3 Periods)	99.6 %	8270
Cumulative	132 days	99.2 %	22 100

Table 1: **Vertical Vessel Availability**

Having successfully demonstrated the commercial viability of the technology, the HRDF was put under care and maintenance in mid 1999. The plant has been partially demolished in preparation for the construction of the Kwinana Commercial HIsmelt® Plant. The same location will be used to take advantage of some of the existing infrastructure.

The HIsmelt® Process

HIsmelt® is an air based direct smelting technology which is simple yet innovative. The HIsmelt® process is illustrated in Figure 1. The process occurs within a vertical Smelt Reduction Vessel (SRV) under pressure. The vessel is refractory lined within the hearth and water cooled in the top-space. The refractory hearth contains the molten iron bath. A thick slag layer is situated above the metal bath. Iron ore fines, coal and fluxes are injected directly into the melt in the SRV. Upon contact with the iron bath, dissolution of the carbon in the coal occurs, which reacts with the oxides in the iron bearing feeds, forming carbon monoxide. Rapid heating of the coal also results in cracking of the coal volatiles releasing hydrogen.

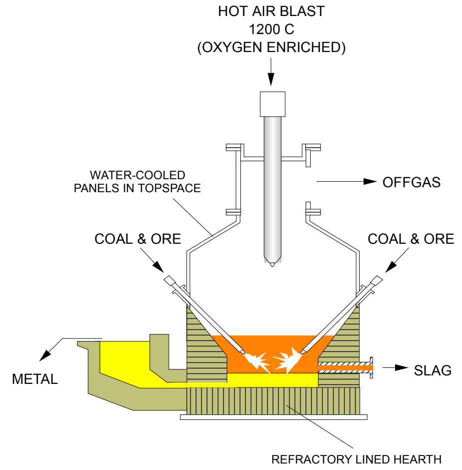

Figure 1: ***HIsmelt®* Vertical Vessel**

A fountain of molten material, consisting largely of slag, erupts into the top space by the rapid expulsion of the carbon monoxide, hydrogen and nitrogen carrier gas from the molten bath. Hot air at 1200°C is blasted into the top space through a water-cooled lance. The carbon monoxide and hydrogen is post combusted with oxygen (from the hot air blast). The heated metal and slag fall back into the bath providing the energy for direct smelting of the iron ore. Ejected slag coats the water-cooled panels, which reduces energy loss. The offgas from the process is partially cooled in a membrane tubed hood. The sensible and chemical energy in the offgas can then be used to effect some preheating, pre-reduction and/or calcination of the metallic feed and fluxes. Then the offgas is cleaned in a scrubber and used as fuel for the hot blast stoves or in a co-generation plant.

The vessel is equipped with a forehearth for continuous tapping of hot metal. This maintains a optimum bath level within the SRV and provides a clean product stream without the need for external slag and metal separation. Slag is tapped periodically through a water cooled notch.

HIsmelt® has a number of unique features that sets it apart from the other direct smelting processes. Firstly, HIsmelt® uses the metal bath as the primary reaction medium. Other direct smelting processes generally top-feed ore and coal, with smelting via char (plus a small amount of metal) in the slag layer. Dissolved carbon in metal is a more readily available reductant than char in slag, since the latter requires a gas-phase intermediate (CO). In other words, HIsmelt® achieves significantly faster smelting rates by using carbon in a more active (i.e. dissolved) form.

A second differentiating factor is the degree of mixing in the melt. Injecting feed materials directly into metal generates a large volume of “deep” gas. This creates a strong buoyancy-driven upward plume that in turn causes rapid turnover of liquid. It has been calculated that this turnover is in the order of tonnes per second. Under these conditions there is very little potential for establishing significant temperature gradients (greater than 20-30 ^{o}C) in the liquid phase and the system operates with an (essentially) isothermal melt. The rapid mass turnover promotes good heat transfer from the top space to the bath without significant over-heating of individual liquid droplets. Implications are significant for hearth refractories in the slag-line region, since good mixing leads to the bricks being exposed to low FeO and uniform (low) temperature.

HRDF Operations

The major achievements of the Kwinana HIsmelt® Research and Development Facility during the vertical vessel phase of the development were:

(1) The Kwinana plant was run cumulatively for over 3000 hours (132 days). Total metal production was around 22100 tonnes, together with 8600 tonnes of slag. A total of 63000 tonnes of solids (primarily ore, coal and flux) was injected through the two injection lances. Plant availability in excess of 99% was demonstrated in several continuous operating campaigns. The longest of these was a 38 day run during which 99.8% plant availability was achieved.

(2) Production capabilities have been assessed across the full range of ferrous feed reduction levels from hematite ores through to DRI feed. Intermediate levels of pre-reduction were tested by blending ore fines with DRI. Oxygen enrichment of the hot air blast (up to 30% oxygen content), has been successfully utilised to increase the operating intensity of the vessel, resulting in the expected increases in productivity.

(3) Extended pilot plant operation with high post combustion (PC) and low coal consumption has been demonstrated repeatedly. PC in the range of 60-80% has been achieved routinely and, with cold iron ore fines as ferrous feed, coal rates of around 880 kg per tonne of hot metal (kg/thm) have been recorded. This translates to a coal rate of 600-620 kg/thm for a scaled-up plant with an ore preheater.

(4) A significant portion of the pilot plant operation utilised ore fines with a high phosphorus content (0.12% P). The phosphorus removal capability of the process has been readily demonstrated with an average of 85-95% of the phosphorus input reporting to the slag phase.

(5) Typical steelplant waste materials have also been successfully utilised. A mixture of blast furnace and LD dusts and sludges, millscale, pellet fines and casthouse dusts were blended with ore fines and injected without any need for feed agglomeration. These trials resulted in the expected increase in productivity and reduction in coal consumption. Dust losses were not increased, achieving iron unit yields of greater than 97% which was similar to the operation using ore fines. The zinc and lead components of the waste materials were found to partition to the dust, suggesting that reasonably high levels of zinc and lead can be accommodated and potentially recovered. In a commercial facility, these waste materials have a high value, reducing coal consumption to less than 650kg/thm without the need for preheat.

(6) The range of coal types used has allowed their impact on process performance to be quantified. Coals with higher volatile contents have the expected negative impact on production as a result of the energy loss due to gasification and cracking of the volatile components. Other potential production impacts from coal, oxygen, moisture and ash content have been examined and the findings accounted for in commercial flowsheeting. All coal used have exhibited an ability to be used in the process and coal selection remains an economic decision. (Table 2). Throughout these trials, the plant produced a consistently high quality hot metal (see Table 3).

Ferrous Materials	Fe (T)	Fe (Met)	C	Silica + Alumina
Hamersley – DSO Fines (0.075% P)	61.0 %			7.5 %
Hamersley - Brockman Fines (0.12%P)	62.4 %			5.6 %
DRI	90.5 %	84.2 %		5.5 %
Steelplant Wastes	53.3 %		10.1 %	5.5 %
Coals	Fixed C	Volatiles	Ash	CV
Coal A	73.2 %	9.8 %	12.0 %	28.3 GJ/t
Coal B	69.3 %	16.8 %	6.9 %	30.5 GJ/t
Coal C	68.8 %	25.7 %	4.8 %	32.9 GJ/t
Coal D	49.9 %	38.5 %	9.4 %	30.2 GJ/t

Table 2 Range of Raw Materials Used

Hot Metal Analysis			
	Typical Analysis	**Range Possible**	**Comment**
Carbon	4.0 ± 0.2%	3.5 - 4.5%	Easily controllable
Silicon	-	-	No silica reduction in the Process
Manganese	0.1 %	0 - 0.2%	Depends on Mn in ore
Sulphur	0.1 ± 0.02%	0.08 – 0.15%	Desulphurised prior to use
Phosphorus*	0.03 ± 0.01%	0.02 – 0.05%	Based on ore with 0.12% P
Temperature	1480± 15°C	1450 -1550°C	Easily controllable

Table 3 Typical Analysis of HIsmelt® Hot Metal

(7) Plant operating parameters have been developed to allow close control of hot metal carbon and temperature. Slag chemistry and inventory have been optimised to achieve hot metal quality, productivity and minimise refractory wear. Refractory wear rates less than 1 kg per tonne of hot metal were achieved, implying hearth refractory life well in excess of 1 year.

(8) No water leaks have occurred and no repairs have been required on any of the water cooled elements in the Smelt Reduction Vessel.

(9) Handling of hot process offgas in a membrane-type hood has been demonstrated over a period of 1100 operating hours. Results show that, despite the steady-state nature of the HIsmelt® process, the hood readily comes to equilibrium in terms of accretion behaviour. Operation is simple and self-regulating, requiring little or no operator intervention.

Kwinana Commercial HIsmelt® Plant

The outstanding success of the HRDF operation convinced Rio Tinto Limited to pursue the commercial realisation of the HIsmelt® Process. In 2002 an unincorporated joint venture was formed between subsidiaries of:

- Rio Tinto Limited;
- Nucor Corporation;
- Mitsubishi Corporation; and
- Shougang Corporation;

for the purpose of constructing and operating a commercial HIsmelt® facility. The Kwinana Commercial HIsmelt® Plant will produce around 820,000 tpa of high quality pig iron. The new plant will be built on the existing HRDF site in Kwinana, Western Australia.

Construction of the new plant will commence from the beginning of 2003 with expected completion by the end of 2004. Figures 2 and 3 illustrate a simplified flowsheet and a computer generated image of the commercial plant to be built at Kwinana.

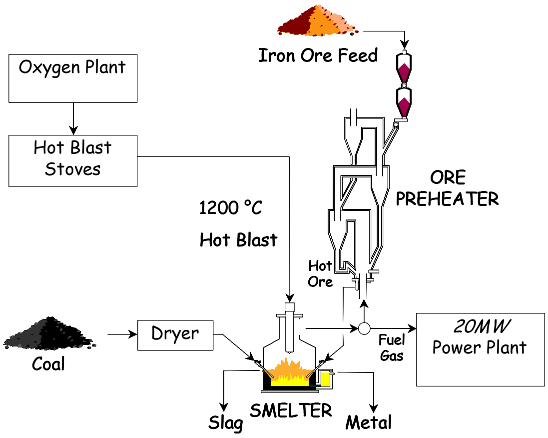

Figure 2: Simplified Kwinana Plant Flowsheet

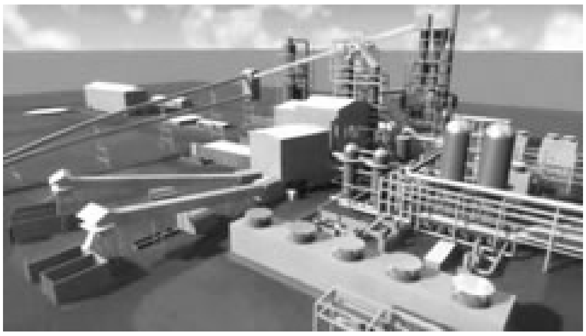

Figure 3: Future Kwinana Plant

The Future of HIsmelt®

The successful operation of the 6M unit proposed for Kwinana will open the way for general applications of this type of smelter. The 6M HIsmelt® facilities are ideally sized to provide high quality metallics to the EAF producer. From the proposed Kwinana plant the scale-up from 6M to 8M is only two-fold, and should not pose any significant additional development hurdles. The 8M HIsmelt® unit, or a combination of 8M units, would be able to replace a blast furnace in situ.

Value to Mini Mills

Stable supply of high-quality virgin iron units is a major issue for EAF producers, especially those with plans to penetrate further into flat products. EAF operators can feed up to 30-50% hot metal as a feed. Hot metal is a high quality substitute for cold pig iron, DRI and premium quality scrap, providing high value-in-use in the charge mix due to the following:

- increased productivity,
- reduced tap to tap time,
- lower energy consumption per tonne,
- lower residual contents,
- consistent high quality products,
- reduced flux consumption, and
- reduced refractory consumption.

The ease with which the HIsmelt® process can be started, stopped and idled provides flexibility that is fundamental to the EAF producer. This allows the effective coupling of iron and steelmaking operations without the need for expensive and under-utilised facilities for holding and disposing of, surplus hot metal production.

Value to Integrated Mills

By far, the major value to the integrated producers is the fact that the HIsmelt® process produces hot metal without the need for coke ovens and sinter plants. The direct use of low value grades of iron ore fines without pre-treatment increases the flexibility of raw material supply for steel producers, assuring a greater competitiveness in costs. The use of steaming coals also brings substantial costs advantages. The flexibility to vary feedstock with productivity demands, allows the operator freedom to continuously optimise operating costs.

A HIsmelt® facility uses much of the same equipment as a blast furnace. Hence, a HIsmelt® plant can be easily ‘retro-fitted’ into an integrated site.

Raw material selection along with critical operating parameters (e.g. hot blast rate and level of oxygen enrichment) can be readily adjusted to maximise the efficient use of the process in line with steelmaking requirements. Again process flexibility is important.

The economic performance of the process at relatively low production capacities permits the use of multiple units to replace large blast furnaces. This, coupled with the potential for significant increases in productivity of each unit through raw material selection, means that the site wide impacts of downtime and relines can be more easily accommodated.

The metal can be mixed directly with blast furnace iron or alloyed to provide precise low silicon content for the LD charge. Methods of “slag-less” steelmaking are widely practised throughout Japan. Blast furnace iron is being desiliconised and dephosphorised before it is charged to the LD. (4) Thus compared to a blast furnace hot metal, HIsmelt® hot metal has the following potential advantages:

- reduced flux consumption,
- increased liquid steel yield,

- increased productivity due to a reduced blowing time,
- production of higher quality (low phosphorus) grades,
- reduced re-blows,
- reduced refractory consumption,
- decreased consumption of ferro-alloys, and
- production of ultra-clean steel.

Conclusion

The HIsmelt® process has moved from pilot plant status to a position where it is ready for commercial application. The Kwinana Commercial HIsmelt® Plant will be the final step in demonstrating the commercial viability of the HIsmelt® process. The HIsmelt® Process addresses all of the key requirements of the industry for a successful alternative ironmaking technology, combining a high level of technical achievement with simple engineering concepts and existing proven plant technology. The flexibility offered by the process, results in a wide range of opportunities for steelmakers in both the integrated and EAF sectors, to add value to their operations in a way that suits their particular circumstances.

In particular for India, the HIsmelt® Process will deliver a low cost, quality metal feed to either a LD plant or EAF facility utilising domestic fine iron ore and non coking coals, in a process that has significantly reduced capital expenditure and is more environmentally friendly, compared to the traditional ironmaking technologies.

References

1. A. Chatterjee, “Steel Industry in South East Asia with Particular Reference to India”, 1998 ICSTI/IRONMAKING CONFERENCE PROCEEDINGS, 1999, p93.
2. S. Dewan, “Techno-economic Evaluation of Smelting Reduction and Other Alternative Iron Making Processes in India”, SEAISI Quarterly April 2000.
3. K. Brotzmann, Howe Memorial Lecture, “New Concepts and Methods for Iron and Steel Production”, ISS AIME 70th Steelmaking Conference, 1987, pp 3-12.
4. Development of New Slag-less Steelmaking Process at NKK Fukuyama Works.