

Hlsarna Pilot Plant Project

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SUMMARY

Hlsarna™ represents a new phase in the global direct smelting development cycle. It is, in essence, a merger between Tata Steel-developed smelt cyclone technology and Hlsmelt™ (Rio Tinto)-developed bath smelting technology. A pilot plant at IJmuiden, Netherlands with a nominal capacity of 60,000 t/a is nearing completion and is due to start shortly.

The catalyst that brought these technologies together and made the pilot plant project possible is ULCOS. The key driver from this perspective is efficient, cost-effective carbon dioxide collection for potential geological storage. Hlsarna's inherently simple, once-through gas flow path provides an easy carbon dioxide collection option without the need for a carbon dioxide scrubber.

Other potential benefits include an ability to use thermal (steam) coals rather than metallurgical coals, plus ability to use lower grade iron ore types. It is expected that high phosphorous ores will be tolerated in much the same way as in Hlsmelt (with around 90% phosphorous rejection to slag). There is also potential for direct utilisation of titanomagnetite ore types, which could open a vast new and lower-cost paradigm in iron ore supply.

Hlsarna has a long way to go to reach commercial maturity, but it has the economic imperatives and technical pedigree to successfully navigate the development path. Patience and in-principle support are sought from the ultimate beneficiary of success - the international steel industry.

1. INTRODUCTION

The blast furnace is becoming more and more a victim of its own success. With the recent boom in blast furnace capacity over the past decade in Asia (China in particular), raw material demand has escalated dramatically. With supply-constrained market conditions, prices have escalated to an alarming degree. Not even the Global Financial Crisis was enough to suppress metallurgical coal and iron ore prices for more than a few months. As a

result, the desire for alternate ironmaking processes which are capable of using lower-cost feed materials has never been stronger.

Environmental factors are also becoming more significant. In particular, it is becoming increasingly important that carbon dioxide output is decreased and capture of a high proportion of the carbon dioxide is possible with relative ease – this is a key enabling step towards responsible carbon management.

Hlsarna is an emerging technology which aims at these twin goals: (i) lower-cost feed materials and (ii) efficient carbon dioxide mitigation with the option of collection for possible geological storage.

2. PROJECT HISTORY

Hlsarna represents the merging of two known technology streams: (1) Cyclone Converter Furnace (CCF) and (2) Hlsmelt™ Smelt Reduction Vessel (SRV).

Tata Steel IJmuiden (Hoogovens as it was then) developed pilot scale CCF technology in the early to mid 1990's at the scale of around 15-20 t/h (ore feed). These trials consisted of ore and oxygen injection into a CCF unit in the presence of artificial hot smelter gas, with molten (partly reduced) ore being collected in a slag pot(1).

Several units were tested as the technology evolved. The final CCF unit used in the IJmuiden trials was stored after the campaigns, awaiting an opportunity for coupling with a pilot plant direct smelting unit. The same physical unit is now incorporated in the IJmuiden Hlsarna pilot plant.

Hlsmelt™ originally started as an ironmaking modification of bottom-blown KOBM steel converter technology. A 2 t/h (hot metal) Hlsmelt pilot plant was built and operated at Maxhütte, Germany in the 1980's, and this was followed by an 8 t/h (hot metal) pilot plant in Kwinana, Western Australia in the 1990's (2).

In the first decade of the current century Hlsmelt built and operated a commercial plant that produced over 80 t/h in Kwinana. Although this plant has since been closed due to unfavourable market conditions and

business outlook, the core process worked and considerable experience was gained with scale-up for this type of direct smelting vessel (3).

ULCOS brought these technology streams together in 2006-2007. The basis was a “win-win” technology combination, leading to an ULCOS-supported pilot plant project in Europe to prove the new arrangement.

The initial site selected for the pilot plant was Saarstahl at Völklingen, Germany. The Global Financial Crisis brought about a delay in the project and, during this period, a decision was taken to move the project to Tata Steel IJmuiden, Netherlands.

The Hlsarna pilot plant is now at an advanced stage of construction, and is due to commence operation in the next few months. It enjoys strong support from Tata Steel, ULCOS and Hlsmelt (Hlsmelt™ being 100% owned by Rio Tinto).

3. PROCESS DESCRIPTION

The overall Hlsarna concept involves two-stage countercurrent contact between iron ore and process gas. Both stages are operated above melting temperature, with molten partly reduced ore running downwards from the CCF into the SRV into the SRV.

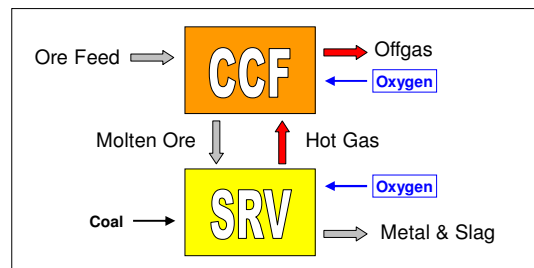


Figure 1 Two-Stage Concept.

This two-stage process is highly integrated in a physical sense, and the two components are essentially operated as a single smelting furnace. The physical vessel arrangement is illustrated in Figure 2.

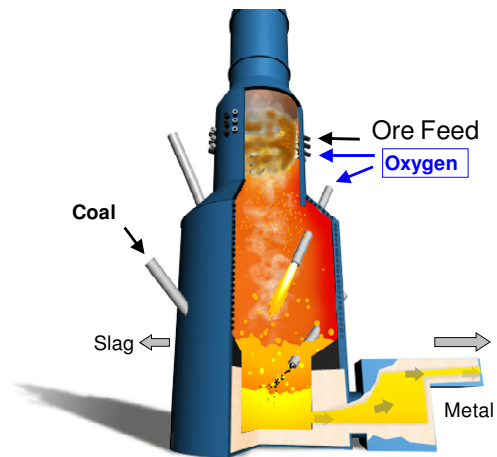


Figure 2 Hlsarna Smelting Vessel

The process sequence can be described as follows:

- (1) Iron ore and oxygen are injected into the CCF, where hot SRV offgas is burned and the resulting heat is used to melt and partially reduce the ore. The resulting (partly molten) ore then runs downwards under gravity into the SRV below. The temperature of this material is expected to be around 1450 °C, and the degree of pre-reduction 10-20%.
- (2) Coal is injected at high velocity (using a carrier gas such as nitrogen) into the bath. The primary process objective for this component is to dissolve carbon into the metal to replace dissolved carbon which is used in the smelting step (see below). Coal injection conditions are critical, and the metal bath runs at 1400-1450 °C with dissolved carbon around 4.0%. There is essentially zero silicon present in the metal, and other minor impurities such as manganese are also present at very low levels (compared to blast furnace hot metal). Phosphorous and Titanium partition largely to the slag phase as oxides.
- (3) Molten ore dissolves directly into the slag, and metal-slag mixing (generated by the coal injection plume) creates a large metal-slag interfacial area for smelting. Slag FeO is typically around 5-6%. Dissolved carbon in metal removes oxygen from the ore and a significant amount of CO gas is liberated. This reaction takes place in the reducing lower part of the vessel and is strongly endothermic. A heat source is needed to keep this part of the vessel in balance (see below).
- (4) CO gas from smelting, together with conveying gas and devolatilisation products from coal, provide an upward-

moving stream of hot fuel gas. This upward movement generates a large amount of splash, with metal and slag cycling through the upper section of the vessel as droplets. Oxygen is introduced into the upper section via lances, and heat is generated by combustion. Heat is carried from the upper region to the lower region by these droplets. Droplet numbers passing through the hot combustion zone are so great that the average per-pass temperature rise in each droplet is less than about 10 °C. This allows heat to move downwards without compromising the oxygen potential gradient in the system (relatively oxidising at the top, strongly reducing at the bottom).

- (5) Partly combusted gas leaving the SRV then provides the necessary hot fuel gas for the CCF. This gas is typically around 1450-1500 °C and has a post-combustion degree around 50%. The definition of post-combustion (PC) is as follows:

$$\%PC = 100(\%CO_2 + \%H_2O) / (\%CO + \%CO_2 + \%H_2 + \%H_2O)$$

4. TECHNOLOGY ATTRACTIVENESS

At this stage Hlsarna is still classified as an emerging technology - several development steps are needed to establish it as a fully commercial option for the steel industry. Of course, the motivation for bringing Hlsarna forward needs to be sufficiently compelling to justify the time and cost involved.

Hlsarna's high-level attractiveness is based on the following points:

- (1) Ability to use thermal coals instead of metallurgical coals.
- (2) Ability to use low-quality iron ore feed materials.
- (3) Easy ability to capture a high proportion of CO₂ for possible geological storage.
- (4) 20 % primary energy and CO₂ saving (without geological storage).

Conventional Hlsarna uses low volatile (PCI-type) coals in order to maximise PC and metal production. Ten years ago it appeared that such coals were not in any particular demand and would therefore be suitable for direct smelting. However, in the meantime blast furnace demand for this type of coal has grown dramatically and pricing has risen accordingly.

In Hlsarna coal type requirements are different: the CCF requires hot fuel gas feed (from the SRV) with a certain minimum heating value.

This translates to lower PC than would be "normal" for the SRV, so the SRV needs to "slow down" by performing less smelting and more coal gasification than would normally be the case. This "slowing down" provides a natural opportunity for higher volatile coals (such as those normally used for power generation). A higher volatile coal will, by virtue of higher fuel gas generation, provide the kind of balance needed between SRV gasification and smelting.

This does not mean, of course, that the SRV is not able to run on low volatile coal. It simply means that low volatile coal is not *necessary* for optimum economic performance. This in turn means that Hlsarna can "naturally" break out of metallurgical coal types, and use more widely available (lower cost) thermal coals. When future BF-related coking coal supply options are considered, it becomes clear that this is a major potential attraction of Hlsarna.

In terms of ore type, Hlsarna will have the same (well proven) ability as Hlsarna to reject phosphorous to slag. In Hlsarna around 90% of the phosphorous reports to slag – this is a direct result its relatively oxidising condition (slag contains around 5% FeO). Although phosphorous tolerance may not be a major issue in some parts of the world, it does open possible exploitation of certain iron ores that would normally have been considered too high in phosphorous.

A second possibility for non-conventional ore types is titano-magnetite (4). This type of ore (either rock or sand) is characterised by titania levels around 5-12% and iron content around 55-60%. There appears to be at least as much of this type of resource as there is conventional iron ore, although the geographic distribution is quite different. Some Chinese blast furnaces use a blend of titano-magnetite ore with normal iron ore, but it is clear to the general BF community that this type of ore is not suitable for a range of technical reasons (had it been otherwise, normal blast furnace practice would include substantial amounts of this type of feed).

Hlsarna offers potential to smelt this type of material directly (using 100% of the ore feed). Investigations to date suggest it may be possible to operate with a slag somewhat similar to that used in SAF-based operations that currently use titano-magnetite feeds (5). If this turns out to be correct, it will open up a vast new paradigm for iron ore, with associated benefits for steelmakers.

The last of the key advantages (points 3 and 4 above) is associated with energy efficiency and carbon mitigation. This is the main driver for ULCOS which underpins the pilot plant project in IJmuiden. Within the formal ULCOS ranking system, Hlsarna performed best in terms of carbon collection efficiency (for coal-based

ironmaking). This has much to do with the simple, once-through nature of gas flow in the process, leading to a flue gas stream with a high enough CO₂ content to allow direct compression (with flash release of non-condensable gas components) for geological storage. No carbon dioxide scrubber is needed – this offers significant advantages in terms of capital cost and energy efficiency.

These features, when taken collectively, place Hlsarna in a very strong position with regard to fundamental attractiveness. This combination is, in the opinion of the authors, unmatched by any competitor.

5. PILOT PLANT STATUS

The pilot plant in IJmuiden has an SRV bath diameter of 2.5 m and, as stated earlier, uses the same physical CCF unit that was last used in the mid 1990's. Design output is 8 t/h of hot metal (from around 13 -14 t/h of ore feed).

The CCF and the upper SRV are water-cooled (copper panels) and only the SRV hearth is refractory lined. A set of water-cooled copper slag-zone coolers (supplied by Berry Metal) is incorporated into the design to provide adequate hearth refractory life.

Construction is essentially complete and cold commissioning activities have started. Hot commissioning will take place over the next few months.

Figure 3 shows a general overview of the facility. It has been built within the framework of a former desulphurisation station, and utilises as much existing infrastructure as possible.



Figure 3 Pilot Plant Overview

The CCF unit is shown in Figure 4. It consists of multiple ore/oxygen injectors arranged in such a way that a horizontal swirl motion is achieved. This helps to throw molten ore onto the walls, and from there it is free to run downwards into the SRV.



Figure 4 CCF Unit

Figure 5 shows a somewhat earlier view of the CCF plus SRV shell. This shows the two main components in correct proportion to one another, with the SRV forehearth in the foreground and four of the six SRV oxygen injection lance positions on the roof clearly visible. The SRV will be operated with two oxygen lances at a time, with an ability to test various combinations of nozzle position and lance insertion depth.

Also visible (lower down) is one of the two solids (coal) injection lance ports. There will be two solids injection lances at fixed positions.

Unique features of the combined process that will be tested for the first time include

- (i) CCF operation with “real” smelter offgas, including process dust which contains significant amounts of carbon.
- (ii) SRV operation with 100% cold oxygen (Hls melt has always used oxygen-enriched hot blast, not cold oxygen).
- (iii) SRV operation with ore feed arriving via molten drops from above (Hls melt has always injected ore into the bath via solids injection lances).

These aspects will become the focus of considerable attention as the plant starts up, and results will be reported to the steel industry in due course.



Figure 5 CCF and SRV Shell

6. CONCLUSIONS

Hlsarna currently represents the front line of direct smelting technology evolution. It is a step-change from Hls melt™ (albeit backwards in scale), with potentially stronger and more competitive features. The Tata Steel/ULCOS IJmuiden project is a particularly exciting development which potentially opens the way to a future revolution in ironmaking.

The attraction that justifies this is based on the following advantages relative to conventional blast furnace technology:

- (1) Ability to use lower-cost thermal coal.
- (2) Ability to process lower-grade (high phosphorous and potentially titanomagnetite) ore types.
- (3) Ability to lower capture carbon dioxide output and capture carbon dioxide (for possible geological storage) with greater efficiency and lower cost.

In addition, Hlsarna offers a very compact footprint and a simple (easy to operate) plant configuration.

Quite apart from proving the process at pilot scale, Hlsarna still has to address the scale-up issue at some point. This will be the subject of future deliberation, and Hls melt's experience in dealing with this will play an important role.

Developments at IJmuiden are eagerly awaited and will be monitored closely by the European

steel industry. In addition to Tata Steel and Hls melt personnel, on-site presence of personnel from each of the ULCOS (EU steel industry) participants is an inherent part of the operating plan. The whole exercise is based on a strong sense of teamwork.

Seasoned observers will recognise that the path will not necessarily be easy, and stakes are high. In-principle support, patience and understanding are sought from the ultimate beneficiaries of success - international steel community.

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