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Circored Fine Ore Direct Reduction – A Proven Process to Decarbonize Steelmaking

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The possible role of Circored in the industry's transition toward green steel

In 2019, the United Nations announced that over 60 countries had committed to carbon neutrality by 2050. This tremendously accelerated the dynamics for the development of green, carbon-neutral steelmaking technologies. One way to replace the carbon-intensive blast furnace/basic oxygen furnace (BF/BOF) steelmaking route is to use hydrogen-based direct reduction and an electric arc furnace (EAF).

About 70% of the world's steel is produced via the BF/BOF route, an efficient but highly carbon-intensive production method. With limited investment cycles left until 2050, the steelmaking industry must decide which alternative technology for the reduction of iron ore to invest in within the next five to ten years.

One widely discussed alternative to traditional BF/BOF steelmaking is the hydrogen-based direct reduction of iron ore and EAF. Most of the current pilot projects focus on applying shaft furnaces for direct reduction with hydrogen. However, applying this method would generate the need for several hundred million tons of additional high-quality DR-grade pellets annually, with the associated impacts on pellet availability and prices.

An alternative is hydrogen-based direct reduction using fine ore instead of pellets. Metso Outotec's Circored technology is the only process for iron ore reduction based on 100% hydrogen that has proven its functionality and performance in an industrial-scale demonstration plant.

Circored technology is flexible in its production setup. Besides merchant cold HBI (hot briquetted iron), which can easily be shipped, hot and cold DRI (direct reduced iron) can be produced and directly linked to EAFs and BOFs as a substitute for hot metal and/or other virgin iron units. This guarantees the production of the high-quality steel products that have been traditionally the strength of integrated steel plants.

In this paper, the principle of the Circored process and the results of the demonstration plant operation are described, along with the possible role of the Circored fine ore direct reduction process in the industry's transition toward green steel.

Metso Outotec's proven track record in the development of new processes

In the last 150 years Metso Outotec and it's predecessors have proven the capability to develop new game-changing technologies to comply with the challenges of the mining and metals industries and the society.

In the direct reduction of iron ore Metso Outotec has been involved since this technology was first introduced, as one of the inventors of the SL/RN-process based on the rotary kiln and as a successful licensee of the Midrex shaft furnace process (the Lurgi legacy of the company).

Circored is based on the fluidized bed technology, for which Metso Outotec has been over decades a leaders in the development of this technology, which has been applied over decades in hundreds of plants for different applications, including alumina calcination, roasting of sulfidic ores, sewage sludge combustion, and other special processes.

The main advantages of fluidized bed processes are excellent heat and mass transfer conditions, precise temperature control, short solids retention times leading to higher plant capacities, and lower investment and operating costs. It has been shown that this technology can also be applied for the direct reduction of iron ore to eliminate the cost and energy-intensive agglomeration step of iron ore fines in the form of sintering or pelletizing.

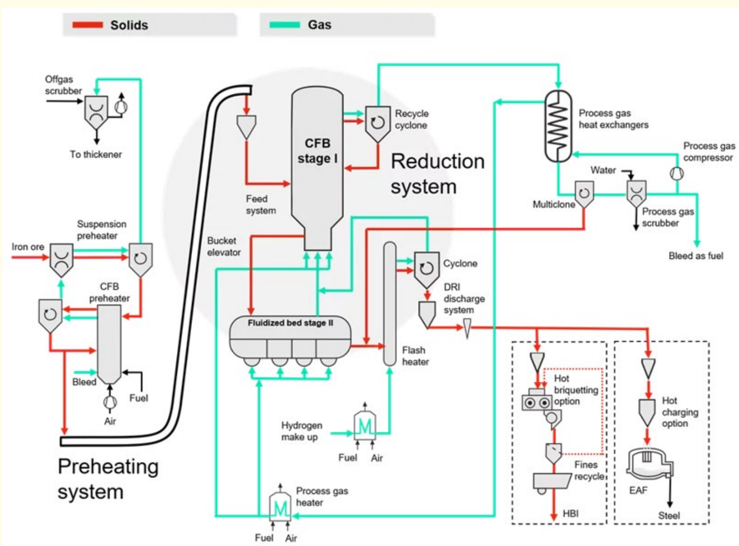

Figure 1: A simplified process flow diagram of the Circored process.

The Circored process

Based on the reduction behavior of iron ore, Circored applies a two-stage reactor configuration with a circulating fluidized bed (CFB) followed by a bubbling fluidized bed (FB) downstream.

Generally, the Circored process can handle feeds with a particle size of up to 2 mm; depending on the decrepitation behavior, particle sizes of up to 6 mm are possible. If an ultrafine concentrate is used, a microgranulation step should be applied to make the material fluidizable. Along with this option comes the opportunity to recycle any kind of dust or fines originating at different points in the plant.

The key features of the process can be summarized as follows

- Preheating the iron ore fines to 850 – 900 °C in a separate CFB reactor for calcining prior to charging in the primary CFB reduction stage. If an ultrafine concentrate shall be reduced, a very simple microgranulation can be integrated in the preheating stage.
- Prereduction in a CFB in about 20 – 30 minutes to a reduction degree of 65 – 80%.
- Final reduction in a compartmentalized FB reactor to 93 – 95% reduction.
- The use of hydrogen as the sole reductant enables low temperatures of 630 – 650 °C in the CFB and the FB; this low temperature avoids particle sticking and means that the reaction is easy to control.
- The reduced fines are heated in a flash heater up to about 700 – 715 °C, where preheated make-up hydrogen is utilized for heating and transporting. A minimum briquetting temperature of around 680 °C is ensured to obtain high-density HBI (> 5.0 g/cm^3).

- As the reduction of iron ore with hydrogen is an endothermic reaction, the energy must be supplied by heating both the ore and recycled gases. In the past this was done using natural gas and process gas bleed. To achieve a totally carbon emission-free process, it is now foreseen to replace natural gas with electric heating by (green) power using renewable sources.

Comparison of different steelmaking routes

Looking at the Circored/EAF steelmaking route versus other state-of-the-art routes, especially in terms of CO_2 emissions and cost, common battery limits need to be defined. We look here at the conversion of an iron ore concentrate to raw steel with all the required intermediate steps, forming the references for this comparison (see figure 2). Both Circored and shaft furnace direct reduction technologies produce DRI or HBI that can be used directly in an EAF. The product from the blast furnace, pig iron, is fed to an oxygen converter (BOF). These downstream processes are considered in the CO_2 and cost figures.

The Circored process uses a natural gas reformer to provide the hydrogen for reduction. For future scenarios, we further included a Circored + process variant that applies green hydrogen produced from renewable sources for direct reduction and electrical heaters for drying and preheating.

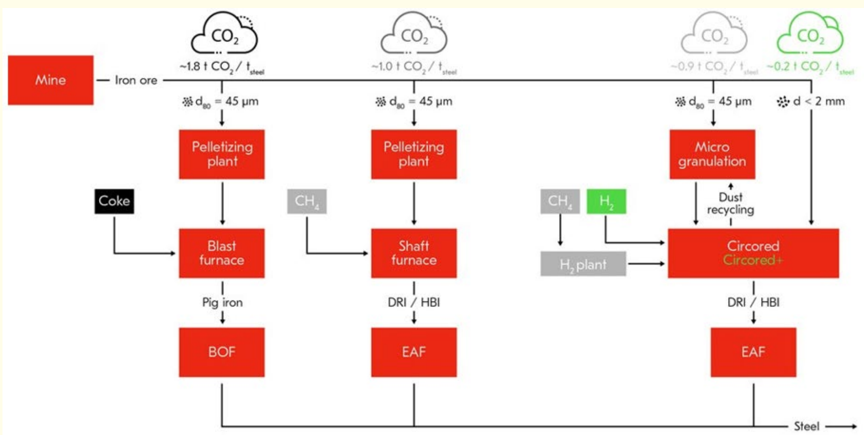

Figure 2: A comparison of the main components, feeds, and products of different steelmaking routes.

It is apparent that the BF/BOF route is by far the largest emitter of CO_2; furthermore, the technical solutions to minimize emissions are limited for this route. While the CO_2 emissions of the Circored process and shaft furnace direct reduction are in the same order of magnitude, Circored benefits from the omission of the pelletizing step. As the Circored+ process is designed to produce fully green steel, its CO_2 emissions are negligible.

When it comes to cost, Circored can be considered as a very economic route, partly because the CO_2 taxes are lower than for the BF/BOF route and because there is no pellet premium (versus the shaft furnace route). The Circored+ process variant requires assumptions on future green hydrogen and green electricity cost. Summarized, in terms of CO_2 emissions and cost, the 'regular' Circored process is already competitive today, and the Circored + variant predicted to be even more so.

Experiences from the Circored plant in Trinidad

After an extensive period of test work and process development the investigations showed that the use of pure hydrogen as a reducing agent in a two-reactor (CFB and FB) combination would ideally suit the direct reduction characteristics of iron ore fines. Shortly after finishing test work and a conceptual engineering study, a contract for the first Circored plant, to be built in Trinidad, was awarded by Cliffs and Associates Limited in 1996. The plant started operation in May 1999; after the discharge system was modified it reached its process design parameters in March 2001 and was operating at up to 105% of its design capacity.

Despite functioning normally, the plant was unfortunately idled after a short period of successful operation. This was due to several changes in ownership and to economic and political reasons including steel-market developments and the lack of availability of natural gas.

The Trinidad plant fulfilled process expectations in terms of a high and uniform degree of metallization achieved from the outset. The key performance figures achieved in are summarized below.

Key achievements of the Circored plant in Trinidad

- Over 300,000 tons of high-quality HBI were produced and were subsequently processed in electric arc furnaces located in the US.
- Plant design HBI production of 63 t/h periodically exceeded.
- High HBI product quality with maximum metallization degrees greater than 95% and constant briquette densities above 5.2 g/cm^3.

Figure 3: HBI stockpile at the Trinidad plant.

Since the design, erection and operation of the first Circored plant in Trinidad, numerous modifications compared to the original setup were investigated and developed, as

- Plant capacity increased to 1.25 Mt/y per line, now considered the technical and economical optimum for an industrial-scale plant.
- Replacing natural gas with green electricity for preheating to achieve complete carbon neutrality
- Microgranulation: for processing ultrafine (< 50 μm) ores and scrubber dust, Metso Outotec has a patented a very simple microgranulation process. The process does not require any additional heat-hardening equipment as the hardening of the granules takes place in the preheating section of the Circored plant.
- Direct feeding of hot DRI in an EAF to further improve energy efficiency.
- For low-grade iron ores, a combination of a single reduction stage Circored process (metallization degree of 75 – 85%) with smelting reduction in an electric smelter for hot metal production is feasible.

From discussions with clients, it became obvious that – at least for the transition period in existing steel plants – the feed material for the EAF is expected to be a mixture of different materials like HBI, DRI, and scrap. The carbon content can be adjusted to the required level in the EAF operation.

With the Circored process, Metso Outotec provides an alternative process route for the reduction of iron ores, using hydrogen as the sole reductant and fine ore instead of pellets as feed material. Circored is currently the only process for iron ore direct reduction based on pure hydrogen and has proven its functionality and performance in an industrial-scale demonstration plant with a capacity of 500,000 t HBI/y.

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