PRIMUS® - Iron for Minimills

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Summary:
This paper presents the application of the PRIMUS® process for the production of liquid pig iron at the mini-mill scale.
PAUL WURTH S.A. has developed this process using the multiple-hearth furnace technology for the prereduction of iron oxide combined with an electrically heated melting furnace. Highly metallized DRI fines (>90% metallization) are hot charged (T> 1000°C) into an especially designed melting furnace which is operated as EAF.
The PRIMUS® process uses coal fines as reductant and main energy source.
A trial plant with a capacity of about 2 t/h was built and has been successfully operated for about two years at the ProfilArbed Belval site in Luxembourg.
This paper reports on trial campaigns carried out for reducing iron ore and melting of DRI fines both of which have given most promising results.

Keywords: direct reduction, pig iron, multiple hearth furnaces

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1 Introduction

While the blast furnace still represents the most efficient ironmaking route for high capacity plants, the search for alternative routes for producing low cost virgin iron is focusing on the mini-mill scale, i.e. for capacities up to 1 million t per year.

In countries having low cost natural gas, feeding an electric furnace with DRI was established as a mature production route. In these area the lump or pellet fed shaft furnace processes (MIDREX, HYL) account for nearly 90% of the production, but new processes using fine ore are about to reach industrial maturity.

In areas lacking natural gas, the use of coal as reductant and energy source has been applied with lump ore and coarse coal (SLRN – DRC). However the economically ideal combination of ore fines reduced with coal fines has been tackled only recently with the development on new technologies using the fluidized bed, the rotary hearth or the multi-hearth furnace.

The coal based prereduced iron is handicapped by a high sulfur content, which limits its massive use in the steelmaking EAF. It is now admitted that an intermediate melting to a low sulfur iron is necessary to meet the more and more severe metallurgical aims of the electrically produced steel.

For the developing of ironmaking routes using ore fines and fine coal, the success will rely mainly on following features:

- low overall investment cost ;
- low energy costs, meaning high thermal efficiency of coal and minimized other inputs (gas, electricity, oxygen) ;
- minimized preparation, i.e. direct use of ore fines and coal fines in the reduction reactor;
- high value in use of the iron feeding the steelmaking EAF.

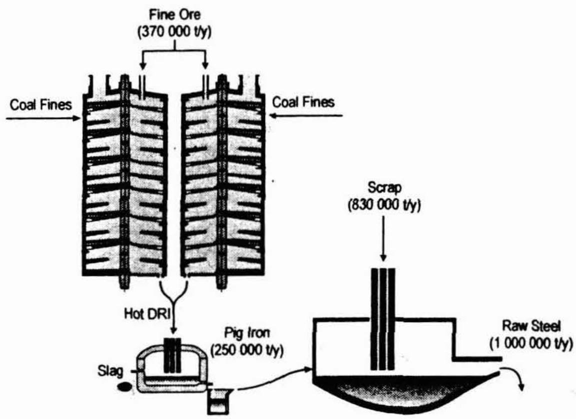

Figure 1: PRIMUS® as virgin iron unit for a mini-mill

To meet the above-mentioned objectives, PW developed the PRIMUS® process using a multiple-hearth furnace feeding directly an arc melter to produce a low cost and high value hot metal (pig iron).

Fig. 1 shows how the PRIMUS® process line can feed a mini-mill producing 1 million tons of raw steel per year and requiring a proportion of 25 % low residual charge to ensure the targeted steel quality. The new line enables to replace imported low residual scrap or pig iron, which is becoming scarce and expensive, by locally produced 250 000-t PRIMUS® pig iron.

2 Process description

2.1 Reduction of iron ore in the multiple hearth furnace

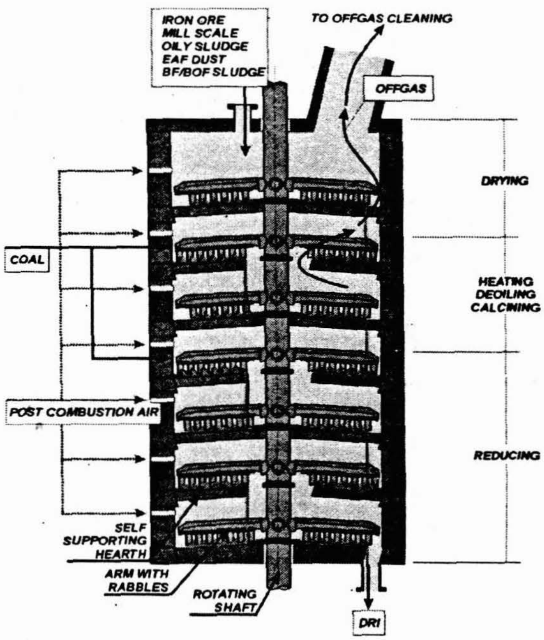

Figure 2: Multiple-hearth furnace - principle

The principal characteristic of the PRIMUS® process is the use of the multiple-hearth furnace technology for reducing metal oxides. As shown in fig. 2 the charge is introduced at the top level of the furnace and transported by rabble arms, which are driven by a rotating cooled axial column. The furnace volume and the number of hearth levels is variable and adapted to the requirements of the material to be processed. The DRI produced is discharged from the lowest level of the furnace with a temperature of 1050-1080°C. The furnace is operated at temperatures up to 1100°C.

Coal fines are charged with the metal oxide containing material (e.g. iron ore fines) into the furnace. The coal or other additions can also be added on any other level, if the process requires it. The charged materials are actively stirred, as they cross each hearth, which enables a fast and homogenous heating of the material layer avoiding the formation of agglomerations. The mixing of both materials is achieved in the furnace without any prior mixing being required. Inside the furnace, the charged materials are submitted to different process steps, including drying, heating and reduction of the metal oxides as the final process step. Coal volatiles and excess CO gas, generated during the different process steps, escapes from the material layer and can be burned by air injection directly above the solid material as shown in fig. 3. The energy generated during the postcombustion of CO and volatile components is sufficient to maintain the required process temperatures of 1000-1100° C. In stationary state, the PRIMUS® process does not require any additional energy supply, burners are only required to preheat the furnace. The high degree of postcombustion, the counter current flow of the off gas and the relatively low process temperatures, make the PRIMUS® process very energy efficient.

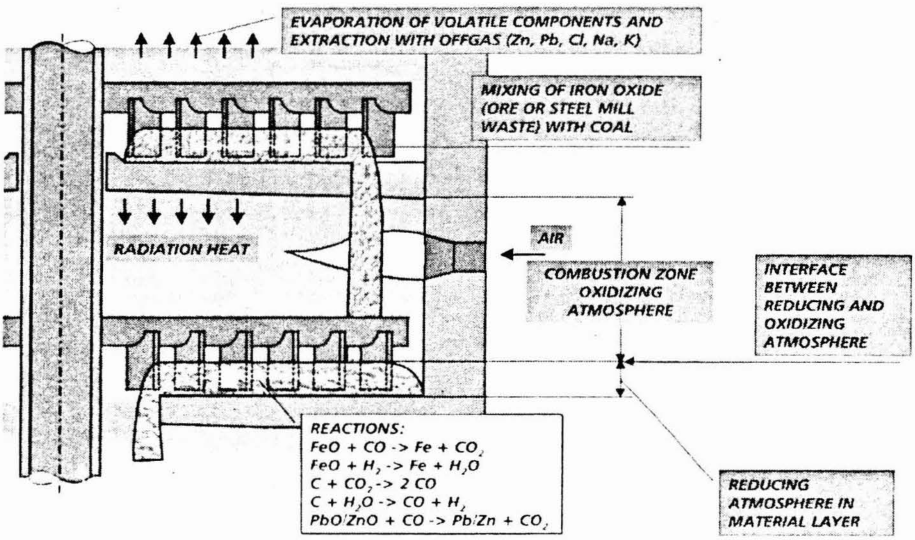

Figure 3: Process metallurgy

The PRIMUS® process can be used to treat by-products containing zinc oxide and lead, such as sludge or dust from oxygen steelmaking or EAF dust. The heavy metal oxides are reduced together with the iron oxide in the material layer. Unlike iron, the more volatile zinc and lead evaporate as metallic fumes. The oxidizing gas atmosphere of the furnace then favors reoxidization. ZnO and PbO are entrained by the fumes in the form of dust particles and are separated by filtration in a bag filter. In addition to zinc and lead alkaline compounds are also evaporated and collected.

Thus the PRIMUS® process enables the iron fraction to be separated from the heavy metals zinc and lead, the alkali metals sodium and potassium, and also chlorine. The separation of the volatile elements from the charged material leads to a highly metallized iron concentrate which is suitable for further processing. At the same time a filtered dust is produced with a concentration of volatile elements higher than in the initial material. The zinc content in the recovered dust achieves a level that allows the dust to be sold to the zinc industry as a value-added product.

2.2 Melting of PRIMUS® DRI

2.2.1 General task of the melting furnace

The task of the melting furnace is to transform the PRIMUS®prereduced iron (DRI) containing ~80% Fe, ~10% gangue, ~8% Carbon, and ~0,1~0,3% S in a high value pig iron to be used as a virgin iron source in the EAF. Beside the virgin iron role, two features of the produced pig iron are important for its economical assessment:

- a low sulfur content, obtained directly in the melting furnace
- a high Carbon content, representing an ideal carbon input in the EAF.

Inversely to the use of DRI that strongly increases the energy requirement and the tap to tap of the EAF, charging of liquid pig iron decreases energy needs and power on time. For an optimized hot metal charging process in the EAF, PAUL WURTH has established a saving ratio of 3,5 kWh per % hot metal charged. This leads to energy savings of 90 kWh/t liquid steel for a charging ratio of 25% hot metal and a reduction of the power on time of about 10 min.
A secondary task is to transform the gangue into an inert low iron containing slag, suitable for valorization in road or building construction.

2.2.2 Power source

Electrical melting of scrap or pig iron pieces is traditionally realized in arc furnaces (EAF), while melting of prereduced ore fines is performed in slag resistance furnaces, often called submerged arc furnaces (SAF).
But there were two incentives for developing an arc melting method for the specific task of melting hot DRI fines. An arc is a much more concentrated heat source, which enables to develop high power in a smaller vessel than resistance heating; the specific power ratio of free arc melting furnaces is in the range of 1 to 2 MW / m2 active power over bath surface, this ratio being about 0,4 MW / m2 for the SAF – resistance melter. The higher specific power ratio of the arc furnace results in a strongly reduced size of the furnace vessel, and in reduced investment costs.
Using 3 free arcs for melting gives a central overheated slag area, which ensures high melting kinetics for centrally charged fine material

2.2.3 Basic design and operation of the melting reactor

Fig.4 presents the conceptual design of the pilot-melting reactor. The inputs of the melting process are hot DRI, continuously charged from the multiple-hearth furnace through a vertical chute located in the center of the furnace roof and slag formers (lime, magnesia...), added in form of fines as required into the DRI chute.
The outputs of the melting process are:

- the liquid pig iron periodically tapped from a taphole using drilling and gunning equipment, enabling to keep an appropriate metal heel
- the slag, periodically removed by overflow through a slag door
- the offgases continuously collected and cleaned in the primary exhaust line.

While the DRI and the additions are continuously charged, the tapping of metal and the deslagging are operated in a cyclic sequence, defined in order to maintain the minimum height of metal and of slag necessary to an efficient melting process. The metal tapping cycle time is in the order of 2 hours, deslagging made only every 2 or 3 metal tapping periods. Deslagging is done by overflow of the slag door.

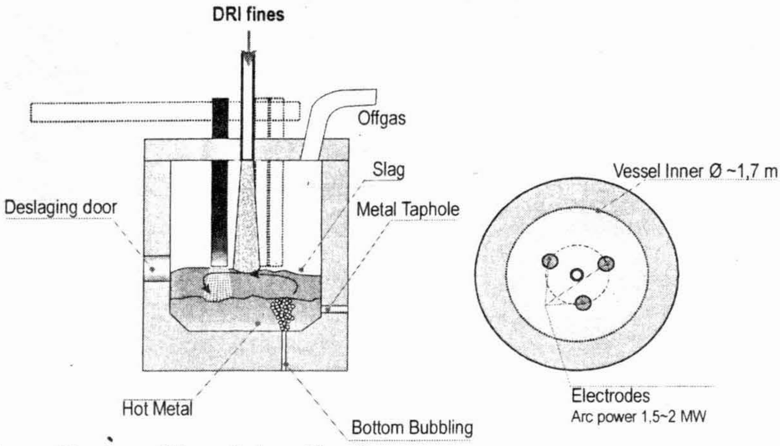

Figure 4: Design of the pilot melting furnace

3 Test installations

To develop the PRIMUS® process PAUL WURTH S.A. has built two test units: a laboratory reactor enabling basic metallurgical testing, and a pilot plant including all components required for an industrial installation.

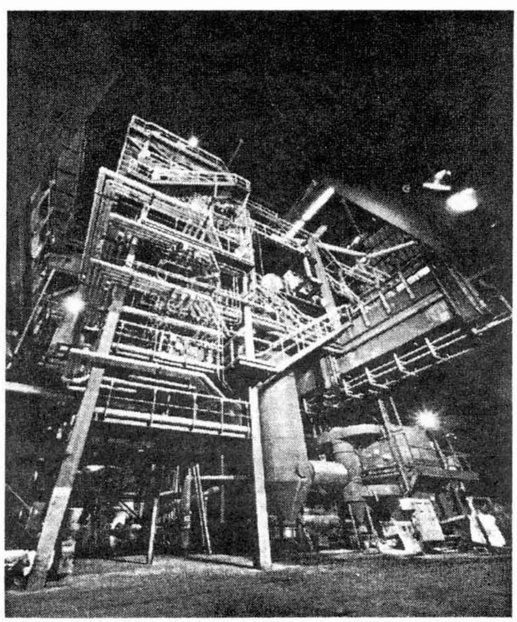

Figure 5: Pilot installation

The laboratory furnace is a one-hearth design for batch operation and is used for basic reduction tests with new input materials or material combinations. As a result the feasibility of the treatment in the PRIMUS® process is demonstrated and basic process parameters are determined.
In co-operation with ProfilARBED, Paul Wurth has built a pilot plant in the steel works of Esch-Belval in Luxembourg. The plant was designed for a throughput of 1-2 t/h. A photo of the plant is shown in Fig. 5. The multiple hearth furnace has a diameter of 3 m and 11 hearth levels. Since 1999 various input materials have been tested in different trial campaigns. Extensive experience is available in the field of the reduction of iron ore, steel-making by-products and in the treatment of EAF-dust. Important technical improvements of the multiple hearth furnace technology have been developed and successfully tested in this plant
The installation was completed by the construction of a melting unit in September 2000 shown in fig. 6. It was the aim to demonstrate the feasibility of continuously melting of PRIMUS® DRI fines in an EAF-type furnace. This melting unit consists of a classical EAF with an installed power of 2 MW. The melting vessel has an inner diameter of 1.7 m. The furnace design allows continuos operation. Cold DRI fines are continuously charged and molten up to a feed rate of 2.5 t/h.

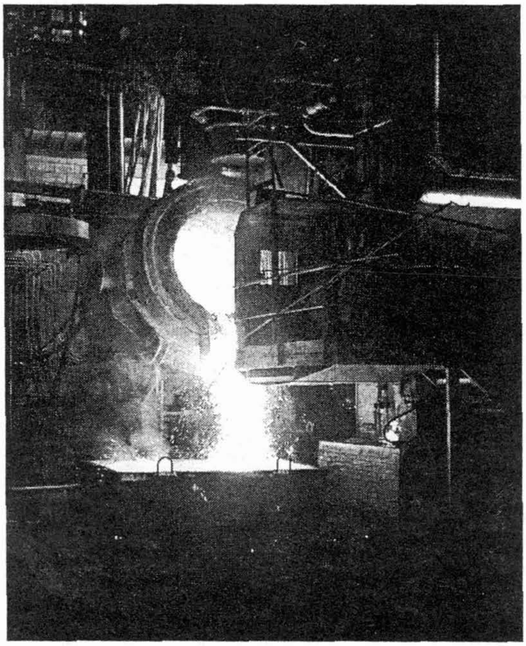

Figure: 6 Tapping of the melting furnace

Several trial campaigns have been carried out to melt the DRI produced on the basis of iron ore and EAF dust since September 2000. The results of these tests are used as basic design parameters for industrial installations.

4 Results of laboratory and pilot plant trials

Several trials with iron ore have been run on this pilot plant since 1999. These campaigns have resulted in more than 150 tests with a total duration in excess of 1000 hours. The trials have successfully demonstrated the feasibility of the reduction process on a continuous basis. Results and conclusions are available on the productivity, the energy consumption and on all other figures required to evaluate the process for different iron oxide bearing materials.
Table 1 shows the composition of PRIMUS® DRI based on Samitri ore. Metallization levels between 90 and 95% are obtained. The composition of PRIMUS® DRI is similar to almost any other coal based DRI. Sulfur and gangue content are determined by the composition of the used reductant.

Met.	Fe	C	S	Gangue
>90%	80%	5-8%	0.1-0.3%	10%

Table 1: Composition of PRIMUS® DRI

The definition of limiting parameters was an important aim of the trials that have been carried out. Fig. 7 shows the differences in the progress of the metallization of various iron ores; measured at 1100°C. The diagram illustrates the influence of the reactivity of iron ore on the reduction process. The characteristics of the iron ore is one limiting parameter for the speed of reduction and hence for the productivity of the process.

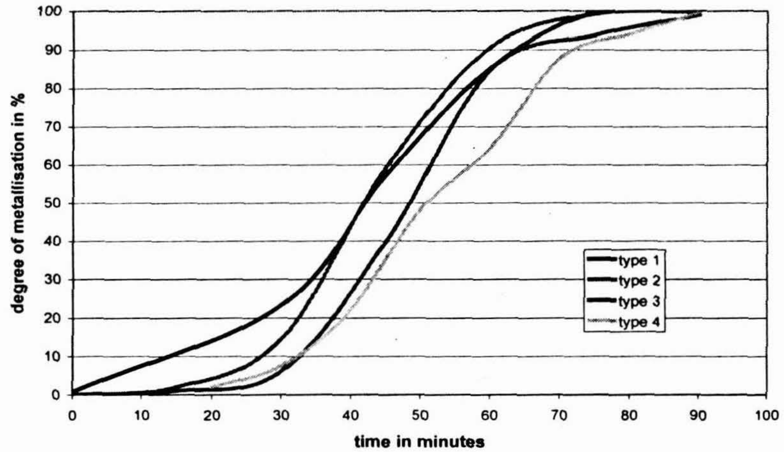

Figure 7: Metallization of different iron ores

Another important parameter is the reactivity of the reductant. Fig. 8 shows a comparison of different coal types in combination with the same iron ore. It can be seen that the highest speed of reduction was obtained with a steaming coal type, which is economically the most interesting reductant due to the low market value

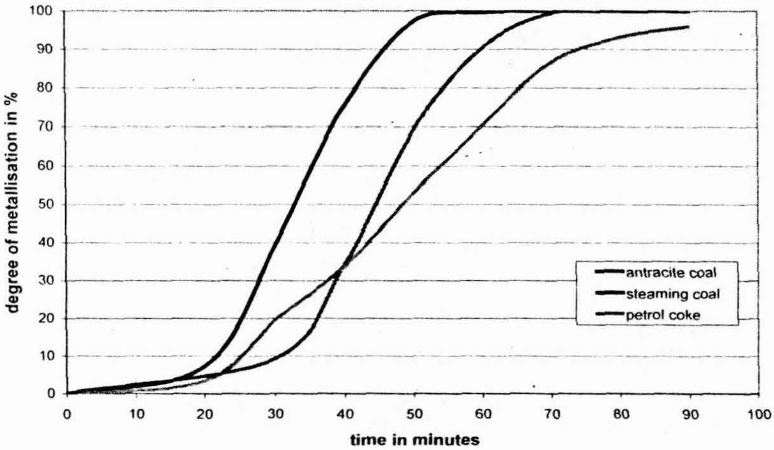

Figure 8: Reduction of iron ore with different coal types

Table 2 presents the characteristics of the iron produced in the melting furnace, which is similar in quality to that produced in a blast furnace

C	Si	S	Temperature
3~4,5%	0~0,2%	0.02-0.04%	1500-1550°C

Table 2: Main features of PRIMUS® liquid iron

5 Industrial plant design

Fig.9 shows the basic flowsheet of the PRIMUS® process for the reduction of iron ore or other iron oxide containing input material. The multiple-hearth furnace is the core equipment of the process.

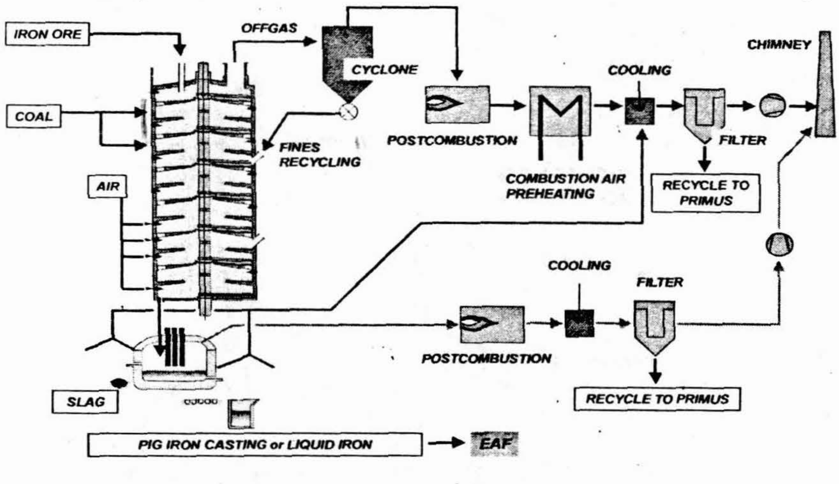

Figure 9: Process flowsheet for pig iron production

Iron ore fines are charged on the top-level and coal on one or several levels underneath. The produced DRI is discharged and directly fed into the melting furnace. The off-gases rise in the furnace and are evacuated at the top level. Dust particles conveyed by the gases are separated in a cyclone and returned to the furnace. The subsequent gas cleaning has to be adapted to suit the process and environmental requirements. For example, this flowsheet shows postcombustion, heat recovery, cooling and dedusting. The pig iron produced can be tapped into a ladle to be transported to an EAF melt shop. If smaller quantities of pig iron are produced it is also possible to cast the pig iron and add PRIMUS® metal in solid state to an existing EAF.

6 Economical considerations

From the pilot plant operation the basic consumption figures for the PRIMUS® process have been derived. Table 3 summarizes the most important figures for the combination of Samitri ore and a South African steaming coal. The electrical energy consumption is related to the melting of hot DRI and includes the specific consumption of all the complete installation. Natural gas is only consumed during stand-by periods when the furnace is kept at 1100°C and DRI is not produced.

	Unit	Consumption Unit/t hot metal
iron ore (Fe~67 %)	Kg	1450
coal (c_{fix}=60%)	Kg	550
electricity (total)	KWh	470
natural gas	Nm^3	5
fluxes	Kg	40
electrodes	Kg	2
nitrogen	Nm^3	15

Table 3: consumption figures for PRIMUS® pig iron

The production costs for pig iron can be calculated using the appropriate unit prices for each item mentioned above. Taking into account the local market prices for the raw materials in South America, costs for PRIMUS® pig iron will be in the range of 100 to 105 USD/t including capital and labor costs. The specific invest for a PRIMUS® plant will be in the range of 110 to 180 USD/t, depending on the plant size.

5 Conclusions

The PRIMUS® technology developed by PAUL WURTH S.A. at a pilot scale of 1~2 t/h fully meets the initial objectives.
Excellent quality DRI is produced using ore fines and low cost coal fines as the single energy source; no preparation of the raw materials is required, and metallization levels exceeding 95 % can be easily achieved. The carbon content can be adjusted to the requirements of the following melting process. This DRI is transformed into a high value liquid metal enabling to strongly improve the performance of a steelmaking EAF. The consumption and productivity figures established on the pilot plant show that the new technology is economically attractive for steelmakers.

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