Direct reduction—are we moving in the right direction?

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INTRODUCTION

Numerous forecasts predict a rapid growth rate for direct-reduction processes. The figures quoted are so impressive that many a top manager must fear that he will fall behind in technical development if he does not base a substantial part of his future steelmaking for mass production on direct reduction. In this context, the question whether we are moving in the right direction seems to be somewhat out of place. But something that seems to be out of place arouses curiosity, which is needed to raise interest on a subject that is the theme of numerous publications.

DIRECT REDUCTION OR DIRECT STEELMAKING?

All direct-reduction processes are based on the 'indirect reduction' of iron ores with carbon monoxide or hydrogen. This misnomer helps to obscure the reasons why these processes, which are correctly called 'direct steelmaking' or sponge-iron processes, were ever invented.

Until the middle of the sixteenth century, all steel (i.e., iron) that could be forged was made direct from ore. Indirect steelmaking via blast furnaces, followed by a refining process, was slowly introduced to meet the ever-increasing demand for steel, which could not be manufactured by the direct-steelmaking process. It was certainly a detour to convert iron ore first into an iron-carbon alloy, which contained not only silica and manganese, but also phosphorus and sulphur. A second step, i.e., a costly refining process, is required to convert the 'dirty pig' to clean steel. It was more than fifty years ago that, for various reasons, metallurgists took up the thread where it had ravelled out centuries ago. One of the main reasons was the excessive energy consumption in the indirect process. The blast furnaces needed 1400 kg of coke and more per tonne of hot metal. Steel refining in open-hearth furnaces also required a considerable amount of energy. Very forceful economic arguments invoked the efforts to reintroduce an old art into modern steelmaking. In 1933, more than 350 patents on direct reduction were known.

INDIRECT STEELMAKING TODAY

During the last decades, the technology of indirect steelmaking underwent drastic changes. The coke consumption is now about 500 kg and less per tonne of hot metal. Hot metal is refined to steel without extraneous fuel. Liquid steel can now be made in the conventional way at a lower heat consumption than via sponge-iron production and electric melting. A comparison made by Mashlanka, Knapp, and Kehl[1] for the Mini Steel Works at Hamburg shows the following: 4,02 Gcal is required per tonne of liquid steel made by conventional methods, and 4,33 Gcal is required per tonne of liquid steel made in the Mini Steel plant and based on 80 per cent sponge-iron and 20 per cent scrap.

This, of course, is not the full story, because energy in coke is more expensive than energy in natural gas. However, it is a good illustration of the drastic changes in iron and steel technology that once upon a time gave birth to many concepts in the field of sponge-iron production.

Unfortunately, some of the advances made in technology have been erased by rising coke costs. In 1939, the cost of a tonne of coke in Europe was DM 19 (about R5); in 1971, DM 145 (about R36). In the past, the blast furnace was not good enough because it consumed too much coke. Today, its weak point is that coke is still used.

What can be done about it? Is sponge-iron production followed by electric melting the only alternative method for steel production on a large scale?

Let us imagine that sponge-iron processes are unknown. Let us further imagine that the top management of an integrated iron and steel plant instructs the Chief Metallurgist, as a first step, to reduce the coke consumption in the blast furnaces and, as a final step, to eliminate, if possible, the use of coke completely. Let us also make the not unlikely assumption that top management expects results in the not-too-distant future.

It is hardly conceivable that the Chief Metallurgist would sit down to invent a sponge-iron process, to nurse it from basic research in the laboratory to the pilot stage, to arrive finally at the production stage—which certainly would not have been reached in the 'not-too-distant future'. Instead, we expect our Metallurgist to look critically at the various methods for the injection of substitute fuels into the blast furnace. He will find that some of the results obtained by the injection of fuels like natural gas and oil are impressive, but he will also realize that one cannot achieve a drastic decrease in coke consumption.

After further studies, our Metallurgist will come to the conclusion that the most promising injection gas should contain no hydrocarbons, should have a low carbon dioxide and water content, and should be available at high temperatures. In his studies he will come across the results obtained by Coheur[2] on the Liège low-shaft furnace. Coheur predicts a possible coke rate of 225 kg per tonne of hot metal when a hot reducing gas is injected. Sironi[3] calculated that coke rates of the same order of magnitude can be expected if a reducing gas is correctly used.

We could take advantage of these findings provided a reducing gas could be produced at an attractive price in South Africa.

THE PRODUCTION OF A REDUCING GAS IN SOUTH AFRICA

In countries in which natural gas, oil, or naphtha is available at a reasonable price, a reducing gas can be made by a reforming process, which is considered to be the only economic method for the production of a reducing gas for iron ore reduction.

In South Africa, a reducing gas can be produced at an attractive price from coal, which, because of its ash content, has a rather limited market value. These coals can be gasified in the Koppers-Totzek Process[4], which is based on the partial oxidation of powdered coal with oxygen. Up to now, all Koppers-Totzek installations are geared for the production of a gas for ammonia synthesis, and the hydrogen content has to be as high as possible.

This is not needed for blast-furnace injections, but no difficulties will be encountered in the adaptation of the Koppers-Totzek Process for metallurgical purposes.

Preliminary cost studies have shown that a reducing gas can be produced at lower cost from South African coal than is possible from natural gas in Europe or from oil or naphtha in South Africa.

THE APPLICATION OF THE KOPPERS-TOTZEK PROCESS IN BLAST-FURNACE OPERATION

In the Koppers-Totzek Process, pure oxygen is used as a carrier gas for powdered coal. Thus, complete gasification of the coal is possible over a short distance, and it is possible to attach a gasifying device direct to the blast furnace. The powdered carbon entering the furnace will be converted in front of the burner to a hot gas consisting of carbon monoxide and hydrogen, the hydrogen content depending on that of the coal. Because no steam is added, the degree of oxidation of the gas is low.

Because powdered lime can be added to the powdered coal, it is possible to combine the advantages of an acid bosh slag with good desulphurization in the hearth.

The numbers and positions of the injection points, the gas volumes, and the best temperature have still to be determined. The heat distribution in the furnace will be affected, depending on the gas quantities injected, because less hot nitrogen is ascending from the hearth, as a heat carrier, to the shaft. This may require gas injections on different levels.

The conditions for low coke consumption are ideal when the degree of indirect reduction in the blast furnace approaches 100 per cent, i.e., when sponge iron is made in the blast furnace.

It is hoped that design parameters for a low-shaft furnace of medium capacity can be deduced from experimental data obtained in a production blast furnace. Scaling down should be more reliable than scaling up, i.e., the evolvement of design data for an iron-making unit for Mini Steel plants could be a further outcome of development work on a larger furnace.

THE APPLICATION OF THE KOPPERS-TOTZEK PROCESS IN SPONGE-IRON PRODUCTION

The results of experimental work on a production blast furnace will be useful for the application of the Koppers-Totzek Process in the production of sponge iron. It will not be possible to attach a gasifier direct to a shaft furnace for sponge-iron production because the gas temperatures are too high and the gas has to be cleaned. The hot gas leaving the gasifier can be desulphurized in a column of lime as was practised at the Norsk-Staal sponge-iron plant at Bochum[5].

In the sponge-iron processes using shaft furnaces, part of the top gas is used to reform natural gas. The recirculation of the top gas improves the heat economy of these processes but complicates layout and operation. In a sponge-iron process based on gas from coal, part of the top gas should be used as fuel for the heating of fresh reducing gas, and part should be burnt with air in the upper section of the shaft to preheat the burden as is done in the Wiberg Process[6]. Briquetting of the hot sponge iron should not present difficulties. The advantages of sponge-iron briquettes in storage, handling, and charging are obvious. Depending on the degree of reduction that can be achieved economically and on the gangue content of the ore, sponge-iron briquettes can be used as feed stock for electric furnaces or as a partially reduced burden in blast furnaces.

CONCLUSION

Our imaginary Chief Metallurgist would apparently be well advised to concentrate his efforts on coal gasification and blast-furnace injection. So doing, he will have a good chance of giving his top management, in the not-too-distant future, an answer to the pressing question on how to make iron with little or no coke. He has not to invent a new process or to develop existing processes, but to perfect a metallurgical tool, which so far is the King—or Queen—of metallurgical devices, i.e., the blast furnace.

The direction in which we are moving in respect of direct reduction is, of course, determined by the position of the target. In broad terms, the target is to by-pass the blast furnace. As outlined, we should set another target, namely, the making of sponge-iron in the shaft of a blast furnace.

Sponge-iron production in a separate process (i.e., moving in the fashionable direction) is one way of saving coke. Perfecting blast-furnace operation (i.e., moving in another direction) will, it is hoped, not require fifty years of hard development work to produce results that are still not entirely satisfactory.

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