SUBMERGED ARC FURNACE, AN ALTERNATIVE FOR SMELTING OF SPONGE IRON ?

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Abstract

The paper describes the pattern of the conventional submerged arc pig iron furnace and the influence and consequences of introducing preheated and prereduced charge. The features of the ELKEM prereduction process are presented and the theoretical philosophy of the process as compared to other direct reduction processes is discussed. It is found of importance that prereduction in rotary kiln is not carried so far as to create problems due to agglomeration and ring-formation of the feed, the last port of the reduction can more favourably be completed in the electric furnace. Experience and operating results from installations at Highveld and Skopje are reported. Formation of fines in the kiln and accumulation of fines in the electric furnace have proven to be major obstacles.

The paper emphasizes consequently the importance of material strength and advocates the use of sintered pellets. A simple shaft sintering equipment of Elkem Spigerverket design is presented.

On basis of experience from smelting of FeNi from calcined, hot fed oxide ores in submerged arc furnaces and some preliminary smelting tests in Elkem—Spigerverket a/s' Research Center at Kristiansand, Norway, the paper proposes submerged arc smelting technics for smelting of sponge iron to crude steel as an alternative to open arc furnaces to use (semi-steel) in a continuous process. Pilot tests indicate that the chemistry could be easily controlled, procedures and design for industrial installation will have to be developed.

Introduction

The traditional way of considering use of sponge iron in steel making has been as replacement of scrap in the open arc steel furnace. One of the factors therefore to hamper the breakthrough of sponge iron as a major steel raw material has been the comparison with scrap prices as basis for its economy. Further smelting of sponge iron has developed some problems both processswise and with respect to refractory wear that has made it less attractive than scrap.

Considering the time-load configuration in an open arc furnace to that of a submerged arc furnace it is obvious that the utilization of installed capacity is radically better in the submerged arc furnace. Further the lining wear in a submerged arc furnace is minimal as compared to that of the open arc furnace. It would therefore be a potential rationalization if the melt down of sponge iron could take place in a submerged arc operation and only the refining process be left for an open arc furnace or some other refining equipment.

In the present paper the author wants to report some tests that have been carried out in the Elkem-Spigerverket a/s' Research Center at Kristiansand, Norway. These tests indicate that it should be possible to smelt sponge iron to semi-steel in a continuous process in submerged arc furnaces.

The Pattern of The Electric Pig Iron Furnace

First let us have a look at the conventional ELKEM electric pig iron furnace, the Tysland-Hole-furnace as it was called after the engineers who contributed its characteristic features. More than 30 of these furnaces are in operation around the world, the biggest unit being the two 60 MVA furnaces at A/S Norsk Jernverk, Norway.

Characteristic for the process is that the electrode will penetrate through the raw material downward up in the hearth on top of the metal pool. Normally the slag will penetrate into this coke bed, but not as far as to be in contact with the tip of the electrode. The electric heat for smelting is developed in the immediate neighbourhood of the electrode tip where the major part of the voltage drop is concentrated. The heated coke bed has a very high electric and thermal conductivity compared with the cold charge. Consequently only a minor part of the current goes out from the electrode flanks. The coke bed also conducts the heat to the smelting zones away from the electrode. Reaction gases from the smelting zone, mainly CO-gas will pass upwards through the decending raw materials partly preheating these giving off its sensible heat and partly causing solid state reduction of the higher iron oxides.

However, the thickness of the zone where materials are heated to reaction temperature is so small that the gas will not have sufficient retention time to give an extensive reduction, 10—20 per cent prereduction is normal in cold charge operation.

We will not here go deeply into the question of electric parameters of the smelting furnace, only remind of the basic equation for the power in-put into the furnace:

$$P = 3E \cos \theta \ I = 3RI^2$$

Here P is the power, E the face voltage between transformer and furnace hearth, I is the electrode current and R the ohmic hearth resistance.

As for the power factor we have the equation:

$$\cos \theta = \frac{R}{\sqrt{R^2 + X^2}}$$

where R and X respectively are the ohmic resistance and the reactance of the system. The furnace reactance X, is mainly determined by the furnace dimensions and electric arrangement and will be close to constant as long as the same general operating conditions are maintained. Not considering the power factor on the electric grid, the ohmic resistance on the hearth and the allowable amperage in the electrodes are the determining parameters for the load in a furnace. Anyhow, the effect of a low power factor can easily be compensated by installation of capacitor banks to correct the power factor on the grid.

There are different means of regulating the ohmic resistance by selection of raw materials and especially granulometry and quality of the carbon material(1). However, there are a few major factors that should be specially considered in the context of this paper.

(a) The tendency to accumulate a large coke bed will normally give decreasing ohmic resistance.

(b) Conductive material in the charge may tend to give flow of current from the flanks of the electrodes which will again result in reduced resistance.

(c) Increased temperature on the flanks of the electrodes will increase the possibility of current flow from the flanks and thereby decrease the total resistance.

ELKEM Preheating/Prereduction Processes

The experience of conventional electric pig iron smelting has been that its economy is heavily linked to the availability of inexpensive electric power. Further the requirements of specific types of reducing agents in order to control the electric resistivity in the furnace has increased. The low retention time in the furnace as compared to that of the blast furnace gives opportunity to lower solid state reduction and gas utilization inside the furnace.

The off gases therefore represent a large proportion of the heat input in the process and meaningful utilization of the gas has become a major factor in the economy of the process.

This does not mean that conventional electric pig iron furnaces may not be an economical proposition in special areas. However, in order to make the electric smelting process competitive also under normal conditions, it became increasingly important to find solutions to the problems above. Elkem-Spigerverket a/s therefore, at a very early stage, started research work for finding means of utilizing the furnace gas for preheating and prereducing the charge (2, 3, 4, 5).

The major contributors to power saving beside prereducing of the ore would be calcination of carbonates and sensible heat of the prereduced

material. When smelting hot prereduced pellet charge made from Syd-Varanger concentrate, which would in conventional operation give power consumption in the range of 2.460 kWh per ton, it appears that even by a prereduction only to 60 per cent oxygen removal at 900 degrees C, the total power saving will be in the range of 1,300 kWh per ton of pig iron.

It is well known that in order to obtain 100 per cent metallization, iron ores will have to be treated at temperatures of 900—1.100°C. It is also well known that solid state reduction at such temperatures is very difficult to control because of the tendency of fusion of the wustite face and sintering of the material. The way of overcoming this in some kiln processes, has been to add an overcharge of carbon and limestone to the kiln charge. This surplus has to be removed after the prereduction has been completed and necessitates either hot screening or cooling of the entire kiln discharge before separation and introduces serious handling problems.

The major difference between the ELKEM processes and the pure sponge iron processes is the desired degree of prereduction of iron oxides. The sponge iron processes carry the reduction to almost 100 per cent metallization whereas the ELKEM processes have restricted the prereduction to a level not giving cause to sintering in the equipment. In tests and actual operation prereduction is restricted to the range of 30 — 70 per cent dependent on the nature of the specific raw materials. In so doing it is possible to avoid surplus carbon and lime in the feed and the product can be fed hot directly to an electric pig iron furnace.

By charging electric pig iron furnace with hot charge the retention time in the furnace at elevated temperatures will be substantially increased compared to cold feed smelting. This makes possible a higher solid state reduction in the furnace itself and compensates for a lower degree of reduction in the pretreatment process. In pilot tests power saving of more than 50 per cent has been achieved in the smelter unit.

The Pattern of Electric Furnace Operated on Preheated/Prereduced Charge

The reaction gases at the electrode tip pass through a bed of raw materials which has in advance been heated to 800 to 900 degrees Centrigrade. thus giving considerably improved conditions for prereluction in the furnace as explained above. In the case of preheated raw materials from the shaft process better than 40 per cent prereduction has been observed in the smelting furnace (1)

As for the other important parameters in the smelting furnace, one might have the fear that the increased resistance in the furnace caused by reduced concentration of coke would be overruled by the higher temperature and the prereduction of the charge. Observations from pilot tests and industrial operations; however, show that this may not be the case. If only preheated charge is fed to a furnace the tests show that this will have a detrimental effect on the furnace resistance. However, as soon as prereduction is introduced the picture changes. The explanation probably is that the reduced concentration of carbon in the charge and the reduced size of the coke bed in the furnace gives a stronger effect on the resistance than the increased tem perature and prereduction of the charge. Even when the iron ore is partly metallized this does not seem to have a detrimental effect on the resistance. The use of bitumenous coal in the kiln process as replacement of the coke in the cold charge process as replacement of the coke in the cold charge process, certainly also contributes to the increased resistance in the furnace. The experiences are, however, that a small part of the carbon may have to be charged as coke in order to stabilize furnace operation.

Today's Experience With The ELKEM Preheating/Prereduction Process

As will be known, the ELKEM prereduction process has been introduced in two major steel plants in the world, at Rudnici in Zelezara Skopje in Yugoslavia which commenced operation in 1966 and where 5 ELKEM furnaces, the last two of 45 MVA transformer capacity and each with a 96 metres long rotary kiln, and at Highveld Steel and Vanadium Corporation, South-Africa, where 4 ELKEM furnaces, each of 30 MVA transformer capacity.(6)

The Highveld rotary kilns operate with co-current firing, but otherwise the principle of the process is the same as that of the ELKEM process. Both operations are based on rather abnormal raw materials which cannot be processed in blast furnaces. This fact certainly has also caused problems for the kiln — electric furnace process. At Highveld, however, they have been overcome and today it is reported that Highveld Steel and Vanadian Corporation operate their plant above rated capacity and with good economic results. At Skopje the operation of the prereduction kilns has temporarily been abandoned as it has proved very difficult to use the indigenous lignite coal which creates too much fines by grinding and decrepitation in the rotary kiln.

The experience of today may generally be

summarized as follows:

(1) Availability of the rotary kiln has been good and problems due to ringformation can easily be checked by good control of temperatures in the kiln.

(2) Stable prereduction can be maintained. The most serious problems in the kiln are caused by formation of fines.

(3) Good metallurgial control can be kept in the pig iron furnace. The most severe problems have developed due to accumulation of fines from the kiln process inside the electric smelting furnace. By small cave-ins or settling of the charge inside the furnace these fines may pour into the hot reaction zones causing violent eruptions and gas blows.

(4) The resistance of the electric furnace has rather increased than decreased as compared to cold charge operation when prereduced charge has been used.

(5) The resistance of the furnace has been reduced as compared to cold charge operation when only preheated charge has been used.

As a consequence of above experience it is our opinion that any ore of low physical strength or ores that depreciate in the rotary kiln will have to be transferred preferably into sintered pellets before they can be used in the process.

This is the reason that our company has concentrated its research also in the field of pelletizing and sintering. In order to make the process more competitive, we have developed a small sintering shaft which can be built for capacities up to 500,000 tons of ore per year. Investment cost for such a pelletizing and sintering plant of the ELKEM design will be about 5 US$ per annual ton of ore.

Total cost for pelletizing and sintering will amount to approximately 3 US$ per ton. These costs compare favourably with large size sintering plants and could make small size operations economical. Thinking of the huge stock-piles of 'blue dust' reported from mining operations in Ind a, we believe that pelletizing and sintering of these fines ores and processing the pellets in a prereduction/electric furnace operation as described, could be an economical way of utilizing these fines as raw materials for Mini Steel Mills.

Submerged Arc Furnace For Smelting Of Sponge Iron

The tapped product when smelting prereduced change according to the ELKEM process will normally be a pig iron with 3—4 per cent carbon content. However, the further the prereduction is carried the tendency in the smelting process will be towards lower carbon contents in the product, approaching the analysis of semi-steel with lower than 2 per cent carbon. Raw materials that lend themselves to heavy prereduction without major processing problems may therefore be smelted to a semi-steel in the normal ELKEM rotary kiln/electric furnace process.

An obvious question would be if not sponge iron with higher than 90 — 95 per cent degree of metallization also could be processed in submerged arc operation?

In our Research Center back in the 1950ties, we developed a process for smelting of FeNi from oxide ores based on calcining and partial prereduction of the ore in a rotary kiln prior to smelting in electric submerged arc furnaces. Since then more than 20 FeNi installations of different sizes have been installed in different parts of the world.

The largest ELKEM installation is a 40 MVA FeNi furnace in Japan. The metal tapped from a FeNi furnace is in reality a crude nickel steel containing 20 — 25 per cent Ni and 2 —2.5 per cent C. Tapping temperature is in the range of 1.450 — 1.550°C, whereas the slag is tapped at temperatures above 1.600°C.

The metal is tapped at intervals, but always kept in the furnace with a head above the metal taphole. As a matter of fact, the furnace can be u'ilised as a holding vessel for metal so that drawing of metal can be regulated according to the requirements of the refining equipment. The metal taphole is plugged with a mud gun utilsing a refractory plugging material which repairs the taphole after every tapping. A pneumatic drill in used for opening the metal taphole.

The slag pool above the metal is kept at a constant depth by intermittent slag tapping through water cooled slag tapholes. The charge bed on top of the slag is kept at sufficient depth to keep the heat losses at a minimum. The refractory lining of the furnace is protected by efficient outside cooling to control slag attacks. A FeNi furnace can operate for several years without repairing the lining neither of the side wall nor of the roof. The reason for this, of

course, is that there are no open arcs as the electrodes penetrate through the charge bed to contact or almost contact with the slag bath.

The electric resistance in the FeNi furnace is primarily determined by the character of the slag. For normal serpentinite ores the resistance is very good and electrical conditions very favourable as compared to pig iron furnaces operating with a large coke bed. Power factors better than cos. $\theta = 0.9$ are quite normal for FeNi furnaces. Good penetration of the electrode in the charge bed is no problem and heat losses are brought to a minimum.

Considering the same procedure for smelting of sponge iron it would be superior way of transferring sponge iron from the solid to the liquid state as compared to the open arc smelting technics. The obvious advantages would be as follows :

(1) The average load of a 39 MVA submerged arc furnace would be about 32 MW as compared to only 12, 6 MW in an open arc steel furnace. The refining period and the down time for tapping and repair severely reduces the utilization of installed capacity in the open arc furnace to only 40 per cent of that in a submerged arc furnace.

(2) Power consumption in a submerged arc furnace would be lower due to the fact that the arc always is covered.

(3) Refractory costs in submerged arc furnace would be minimal as compared to that in open arc furnaces.

(4) The submerged arc furnace can to a certain extent be used as a holding and equalizing vessel giving better flexibility to the refining process.

(5) The submerged arc furnace would give a much greater flexibility for accepting sponge iron with silica content. Due to the large slag bath in the furnace in contact with the smelting zone, any surplus silica will very quickly be neutralized by the basic components of the slag and disastrous lining wear can be avoided.

At our Research Center at Kristiansand we have carried out some preliminary tests for smelting of sponge iron with submerged arc technics. In the pilot furnace with loads of 300 — 400 kW, power consumption slightly higher than the theoretical was obtained. Operating conditions otherwise prove to be very similar to that of FeNi-smelting. Electrode consumption was very low compared to that of the normal pig iron process and less than half of the consumption in arc furnaces.

Conclusion

The tests already carried out prove that it is possible to produce semi-steel with 1 — 2 per cent C in a submerged arc furnace using sponge iron as raw material.

Further we believe, if selected raw materials were used it should be possible to reduce the carbon content below 1 per cent.

The semi-steel will have to be refined in a special equipment which most readily could be a special electric refining furnace of very simple design and transformer capacity, less than 30 per cent of that of the open arc furnace for same volume.

It is our opinion that the kiln prereduction/hot feed submerged arc furnace process will be favourable for ores that are not economical for beneficiation to high purity and where the slag refining obtained in a pig iron process would be desirable. If the ores are of such nature that the prereduction in a rotary kiln may be carried to a high degree of metallization, say around 80 per cent, these types of ore could even be processed directly into a semi-steel in the submerged arc furnace.

Our alternative for smelting of sponge iron would be to utilize a submerged arc furnace by building up a layer of synthetic slag in the furnace and tapping the sponge iron as fluid semi-steel can be refined in a separate process.

The trend in price development of natural gas and carbonaceous reducing agents is such that electrical power in the future will be more and more economical in smelting processes as compared to thermal energy. We will therefore do well in preparing ourselves for this development and one of the ways of doing so is to develop the electric smelting processes to a stable well-controlled alternative to the more conventional iron and steel processes.

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