Bottom-stirring in an electric-arc furnace:Performance results at Iscor Vereeniging Works

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Synopsis

An account is given of the performance of a 37 MVA electric-arc furnace in which bottom-stirring with inert gas by an indirect-contact stirring-plug system was applied. The system, which was developed and patented by Thyssen-Stahl AG, and which is the first inert-gas stirring system to be installed in South Africa, was commissioned in January 1992.

Initial problems were experienced due to the blockage of stirring plugs by molten steel. The causes of these malfunctions are examined, and an account is given of how they were overcome.

The system is described and evaluated. A comparison with direct-contact stirring systems shows why Iscor Vereeniging Works considered it to be more suitable for their Vaal Melt Shop.

The results show that, through the successful application of this technology, Iscor Vereeniging Works has achieved an annual cost saving of more than R2,5 million.

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Introduction

Stirring with inert gas through the bottom of electric-arc furnaces has been practised widely during the past few years[1–5]. Inert-gas stirring, or bottom-stirring, agitates the steel bath, and this accelerates the homogenization of the chemical composition and temperature of the steel in the bath, as well as the chemical reactions between the steel and the slag. Inert-gas stirring therefore allows shorter tap-to-tap times to be employed, and leads to lower refractory, electrode, and power consumption, improved yields of iron and alloys, and improved control of the temperature and chemical composition of the steel[1–5].

Because of the benefits obtained with bottom-stirring in electric-arc furnaces in Europe and North America, Iscor decided to install and evaluate the first inert-gas stirring system in South Africa at its Vereeniging Works. Following an extensive evaluation of the different systems available, the indirect-contact stirring-plug system developed by Thyssen-Stahl AG was chosen. This system, which was installed in the ultra-high-power arc furnace in the Vaal Melt Shop, was commissioned in January 1992, and has been in successful operation for more than a year. This paper discusses the operation of the system, and reviews the results that were obtained.

Systems available for bottom-stirring in electric-arc furnaces

Industrial systems for bottom-stirring in electric-arc furnaces can be classified into two categories: direct-contact and indirect-contact stirring-plug systems. Figure 1 compares these two types of systems. In direct-contact stirring-plug systems, the stirring plugs extend through the refractory material of the hearth, and are in contact with the steel bath into which the stirring gas is injected directly. Indirect-contact stirring-plug systems use much shorter stirring plugs, which are covered by the refractory material of the hearth. This refractory material is a specially developed dry ramming mix, the grain-size distribution of which is such that the sintered hearth is permeable to gas but of sufficient density to prevent penetration by the liquid steel. As a result, the stirring plugs are not in contact with the steel bath; the stirring gas is introduced into the bath through the refractory hearth.

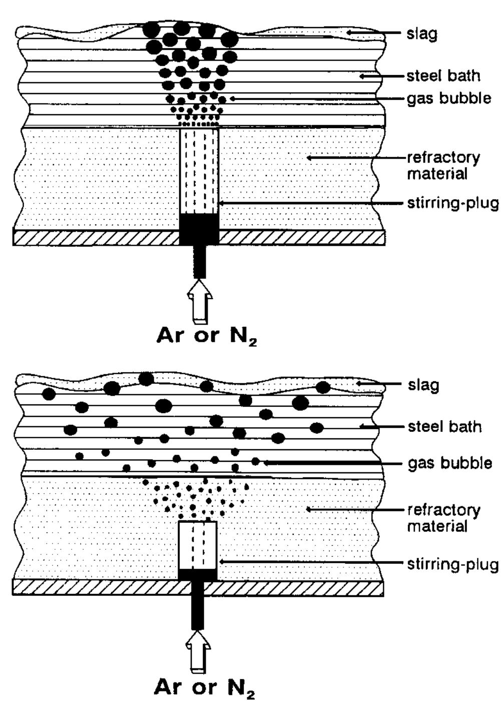

Figure 1—Schematic representation of the differences between direct-contact (upper) and indirect-contact (lower) stirring-plug systems

Because of the differences in their design, direct-contact and indirect-contact stirring-plug systems have distinctive and characteristic properties, advantages, and disadvantages.

In the direct-contact stirring-plug systems, the stirring plugs, being in direct contact with the steel bath, are exposed to the same wear as the refractory material of the hearth. The plugs therefore wear at a relatively high rate, and need to be replaced after about 400 to 600 heats[2,3,5]. This requires additional downtime for the furnace, and is a distinct disadvantage for a high-productivity electric-arc furnace.

Since the stirring plugs in an indirect-contact stirring-plug system are covered at all times by a protective layer of refractory ramming material, they do not wear, and only the protective layer of ramming material needs to be repaired regularly. The stirring plugs can therefore last as long as the hearth of the furnace (about 5000 heats) and need to be replaced only when the hearth is relined[1]. This is probably the most significant advantage of indirect-contact stirring-plug systems.

Another important difference between the two types of systems lies in the effect that is achieved by stirring. In a furnace equipped with a direct-contact stirring-plug system, stirring is confined to a small area directly above the stirring plug. The stirring in that area tends to be fairly intensive, and the layer of the slag is pushed away, leaving the steel bath exposed to the atmosphere[5]. This, in turn, may lead to an increase in the absorption of nitrogen and hydrogen. However, with such locally concentrated stirring, the intensity of the stirring can be finely controlled, and the slag can be pushed away from the taphole area, thus reducing the carry-over of furnace slag during tapping.

In a furnace equipped with an indirect-contact stirring-plug system, stirring is spread over a wide area and tends to be relatively gentle[1]. This ensures effective mixing over a wide area, and the molten steel remains covered by the slag, thus minimizing the absorption of nitrogen and hydrogen. However, since the position and intensity of stirring depend on the gas permeability of the sintered ramming material covering the plugs, which may vary with the position in the hearth as well as with time (e.g. before and after repair of the hearth), the position and intensity of the stirring cannot be controlled accurately. In the worst case, some of the stirring gas may even escape through the banks and sidewalls of the furnace instead of through the hearth, thus seriously reducing the effectiveness of the stirring system[6]. As a direct consequence, the system does not allow slag to be easily pushed away from the taphole area during tapping.

After careful consideration of the salient characteristics of the two types of stirring-plug systems, it was decided that indirect-contact stirring-plug systems would be more suited to the electric-arc furnace operating at Iscor Vereeniging Works. The decisive factor that led to this conclusion is the existence at the Works of a high-productivity electric-arc furnace, which requires repair of the refractory lining of the furnace only every 1000 heats. If a direct-contact stirring-plug system were to be installed, the stirring plugs would have to be replaced every 400 to 600 heats, which would have a detrimental effect on the availability and productivity of the furnace.

The Thyssen-Stahl system installed at the Vaal Melt Shop

The indirect-contact stirring-plug system installed at the Vaal Melt Shop was developed and patented by Thyssen-Stahl AG, and is called the TLS system[1].

The Vaal Melt Shop at Iscor Vereeniging Works contains a 37 MVA electric-arc furnace with a tapping capacity of 55 t, a 9 MVA ladle furnace, a vacuum-oxygen-decarburization (VOD) tank degasser, two continuous-casting machines that cast billets 100 and 140 mm square, and extensive facilities for the casting of ingots. The products range from normal low-, medium-, and high-carbon steels to low- and medium-alloyed steels, including free-machining, spring, chain, reforging, and bearing steels. Approximately 80 per cent of the production is cast continuously, the balance being cast into high-quality ingot material that is used mainly internally for rolling and forging.

The furnace is equipped with three purging plugs, which are located between the electrodes on a pitch-circle diameter of 1600 mm, as shown in Figure 2. Figure 3 presents a schematic side view of one of the three stirring plugs in the electric-arc furnace. Two important features of the design are the deflector plate and the steel cylinder surrounding the stirring plug. The deflector plate covers the stirring plug, and promotes the distribution of gas over a wide area, thus increasing the effect of the stirring gas. The deflector plate also helps to prevent clogging of the stirring plug by molten lead, which tends to accumulate in the hearth of electric-arc furnaces. The steel cylinder round the stirring plug prevents the purging gas from escaping through the lower areas of the hearth towards the sidewalls of the furnace. It has been found that, with this arrangement, possible problems due to the escape of gas through the banks and sidewalls of the furnace can be avoided.

Figure 4 shows a schematic diagram of the gas-control system, which was installed for the operation and control of the bottom-stirring. The system, which can use either argon or nitrogen gas, can independently measure and control the flowrate of gas to each plug. An important feature of the system is the inclusion of a back-pressure indicator and a pressure-relief valve on the gasline of each plug. The back-pressure indicator allows the resistance to the gas flow through the plug and hearth to be monitored. This is essential for, should there be excessive build-up of back-pressure, the hearth might lift, and steel might break through the hearth. To avoid such a catastrophic occurrence, the back pressure is set (by adjustment of the gas flowrate) not to exceed 1,0 bar. The pressure-relief valve is set at 1,5 bar.

Under normal operating conditions, each plug uses a gas flowrate of 4 to 5 Nm^3/h. This flowrate has been found to be the optimum to ensure gentle stirring and effective mixing over a wide area. Figure 5 illustrates the effect of the stirring in the electric-arc furnace, at a flowrate of 4 Nm^3/h per plug, just before tapping. It can be seen that the stirring is relatively gentle, and is spread over the whole area of the bath.

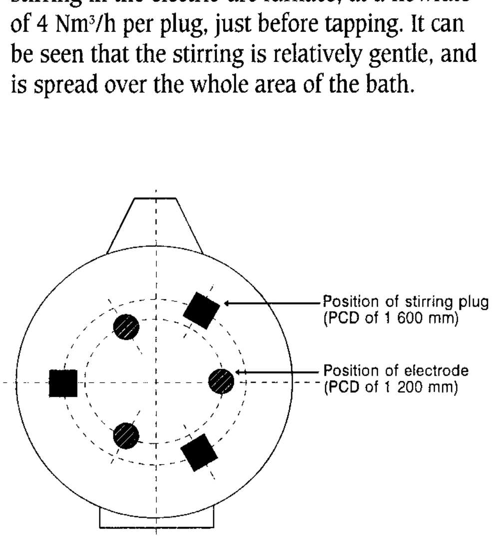

Figure 2—Plan view of the electric-arc furnace, showing the arrangement of the stirring plugs

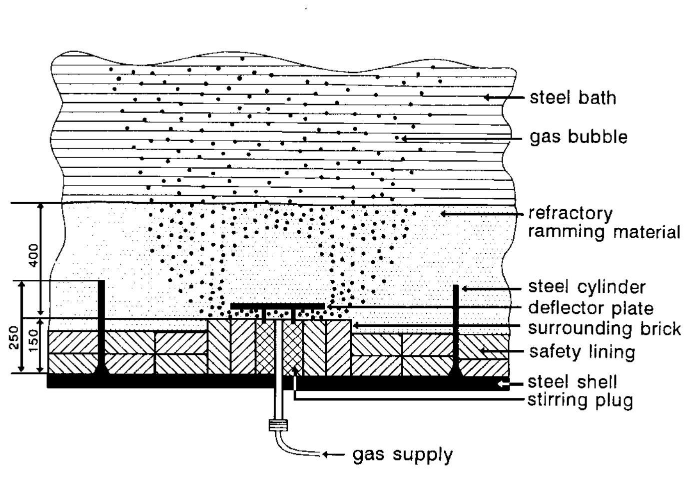

Figure 3—Side view of the furnace, showing the arrangement of the stirring plugs

Performance of the stirring plugs

From the design of the TLS system, it would appear that the stirring plugs should last as long as the hearth of the furnace, viz typically 5000 heats. However, at the Iscor Vereeniging Works, it was found that partial or complete blockage of the stirring plugs could occur easily. Those blockages, which damaged the plugs irreparably, consisted of molten steel that penetrated the protective layer of refractory material covering the plugs. When such blockages occur, the flow of gas through the blocked plug has to be stopped, and the plug has to be replaced at the end of the furnace campaign. Although sufficient stirring of the steel bath can be achieved with only two stirring plugs in operation, blockages are nevertheless undesirable, because the replacement of a damaged plug requires not only removal of the ramming material covering the plug, but also removal of the bricks surrounding the plug, and this results in increased refractory costs. Damage to the stirring plugs should therefore be avoided wherever possible.

During the first 15 months of operation of the TLS system at Iscor Vereeniging Works, problems due to the blockage of stirring plugs were experienced on two occasions. However, it was found that, in each case, there had been deviations from the standard operating practice for the TLS system or from the refractory practice, and that the problems had been caused by those deviations.

In the first campaign, two stirring plugs were damaged within the first 4 weeks of operation, and the campaign was completed with only one stirring plug still functioning. Figure 6 shows a photograph of the hearth material after the damaged plug had been dug out. Two distinct layers of metal can be seen about 150 mm and 200 mm above the top of the stirring plug. The position of the steel layers indicates the residual thickness of the hearth when a hot repair of the hearth material was carried out. It can therefore be assumed that, at some time during the campaign, the residual thickness of the ramming material above the stirring plugs was only approximately 150 mm.

It is well known that the refractory ramming material used in the hearth forms a very dense slag-penetrated zone during normal operation of the furnace. This dense zone usually contains vertical cracks that are up to 150 to 200 mm deep[6,8]. Hence, when the residual thickness of the ramming material covering the plugs is less than approximately 200 mm, there is a great risk that molten steel will pass through the cracks in the sintered material and block the stirring plugs.

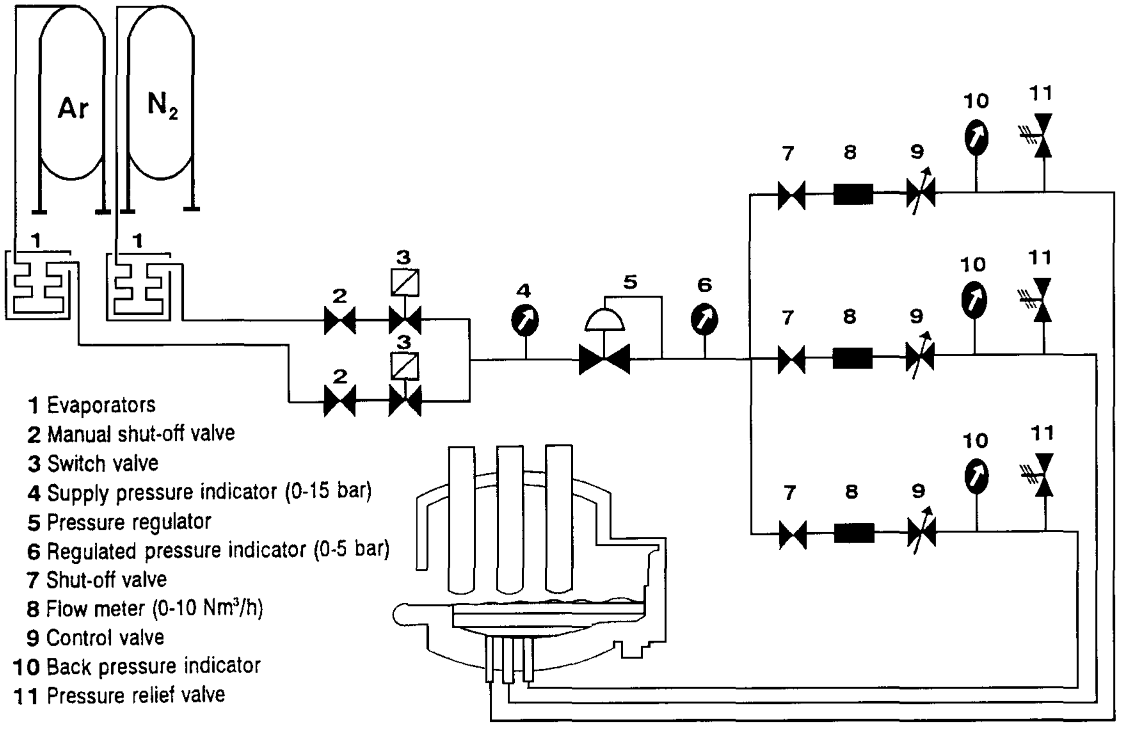

Figure 4—Schematic diagram of the gas-control system

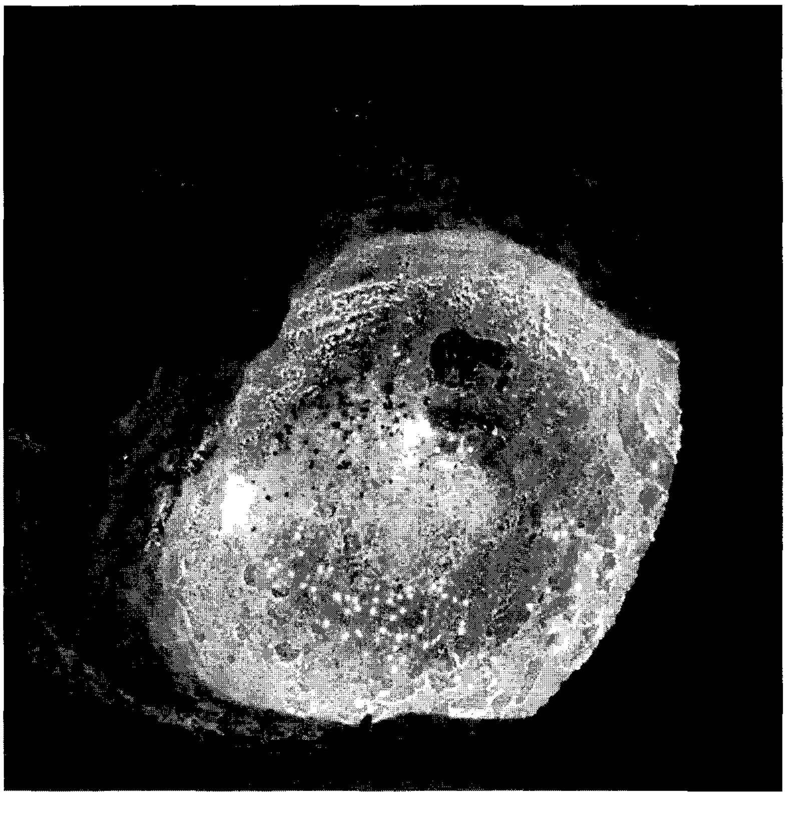

Figure 5—Stirring with the TLS system in the electric-arc furnace

It therefore seems safe to assume that the failure of the two stirring plugs during the first campaign occurred because the layer of protective ramming material above the stirring plugs was too thin. Hot repair of the hearth was therefore carried out more regularly in subsequent campaigns to ensure that the minimum thickness of the ramming material above the stirring plugs was maintained at 250 mm.

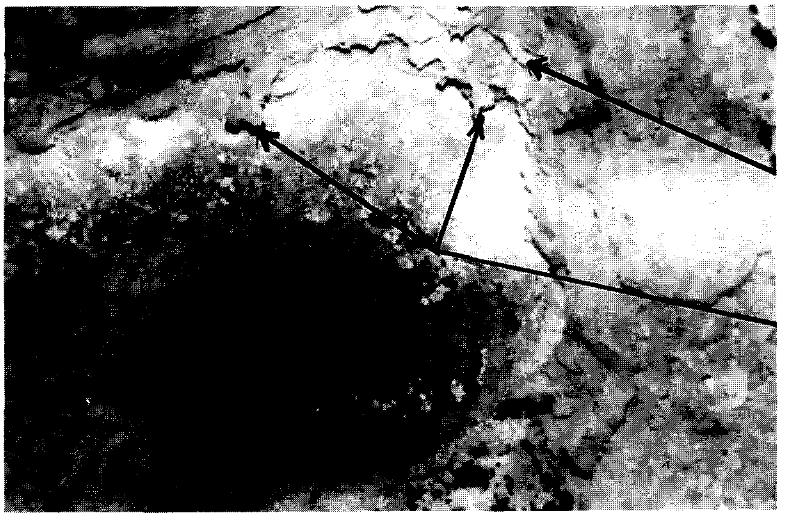

Figure 6—The hearth material after a damaged stirring plug had been removed

In the fourth campaign, blockage again occurred, two stirring plugs being damaged after, about 5 weeks of operation. Inspection of the damaged plugs after they had been removed from the furnace showed excessive penetration by steel in the areas directly above the plugs, as well as clear evidence of steel round the deflector plate and inside the small gas tube of each stirring plug. Figure 7 is a photograph of a piece of ramming material that had been penetrated by steel, and that had been removed from the top of one of the stirring plugs. The arrows point to the areas where the steel is clearly visible. The round nipple of proud steel jutting from the piece of ramming material (top arrow) is in fact steel that was inside the gas tube of the stirring plug. The larger piece of steel indicated by the lower arrow was attached to the deflector plate of the stirring plug. An investigation into the possible causes of the excessive penetration of the ramming material and blockage of the plugs by steel in that campaign showed that, as the result of an operator error, the gas flowrate through each plug was maintained at 15 to 20 Nm^3/h for an unknown period before the blockages of the plugs occurred. At such a high flowrate of gas, channels form in the unsintered zone of the ramming material, and these channels provide the liquid steel with paths through the ramming material. It is therefore considered that the extremely high gas flowrate that was maintained in that campaign caused the excessive steel penetration and blockage of the plugs.

It is noteworthy that no problems due to excessively high back-pressures or blockage of the stirring plugs occurred in the other campaigns. The hearth of one furnace is currently nearing the end its third campaign, representing more than 2500 heats, and all three stirring plugs are still in operation. This proves clearly that, with the correct refractory and stirring practice, the TLS system is reliable, and that the stirring plugs can indeed achieve lives that are comparable in length to the life of the hearth of the electric-arc furnace.

Results

Metallurgical aspects of bottom-stirring

In an evaluation of the effect of bottom-stirring on the metallurgical aspects of the electric-arc furnace operation at Iscor Vereeniging Works, the following parameters were monitored: the nitrogen content of the liquid steel, the oxygen potential of the slag and the liquid steel, and the distribution of sulphur and manganese in the slag and the steel.

Nitrogen content

For economic reasons, nitrogen is used as the stirring gas in the electric-arc furnace at Iscor Vereeniging Works. Figure 8 illustrates the effect of stirring with nitrogen gas on the nitrogen content of the metal bath immediately before tapping of the furnace. It can be seen that stirring increases the average nitrogen content of the steel only slightly. However, the variation in the nitrogen content is much higher with nitrogen stirring than without stirring. The use of argon instead of nitrogen as the stirring gas is therefore advisable when nitrogen-sensitive steels are being produced.

Oxygen potential

The effect of bottom-stirring on the iron oxide content of the slag is shown in Figure 9 as a function of the carbon content of the steel immediately before tapping of the furnace. It can be seen that bottom-stirring significantly reduces the iron oxide content of the slag. The effect is more pronounced at lower carbon contents. The lower iron oxide content results from the improved contact between the slag and the steel, which causes the slag–metal reactions to occur more rapidly and to move closer to equilibrium.

Figure 7—A piece of ramming material that had been penetrated by steel, and that was removed from the top of a damaged stirring plug

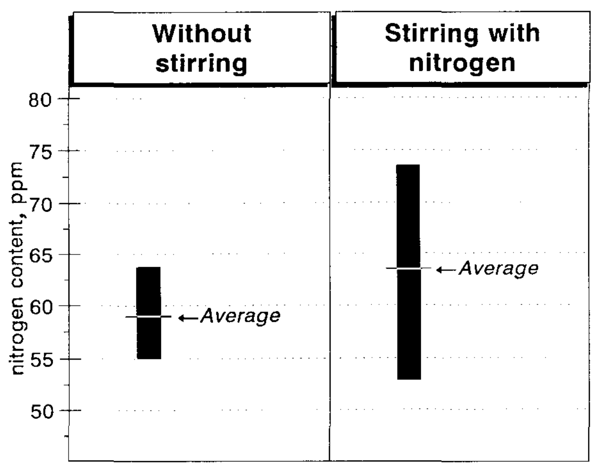

Figure 8—Effect of stirring on the nitrogen content of the steel bath

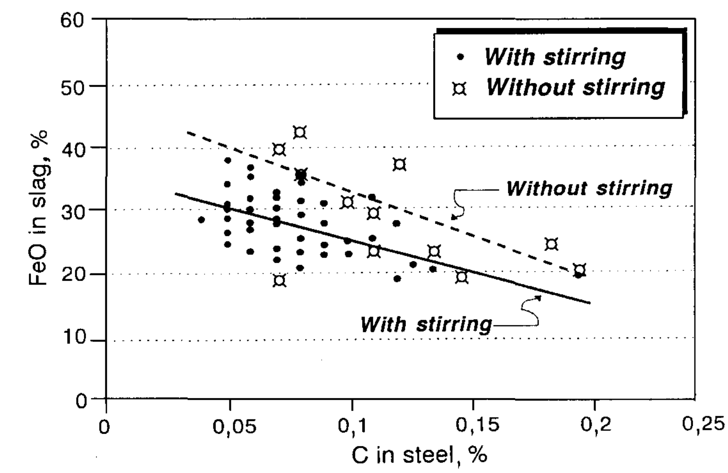

Figure 9—Effect of stirring on the iron oxide content of the slag

Figure 10 illustrates the effect of bottom-stirring on the total oxygen content of the steel just before tapping of the furnace. Although it should be noted that the total-oxygen measurements are not very accurate, since their reproducibility is very low, the data can be used to indicate general trends. It is clear that the total oxygen content, and therefore the dissolved-oxygen content, of the steel bath is decreased considerably by bottom-stirring. This trend is in agreement with the results of several similar studies[1,5], and also corresponds to the lowering of the iron oxide content of the slag by bottom-stirring as depicted in Figure 9. These results confirm that the stirring effect in the bath accelerates the carbon–oxygen reaction, and pushes it closer to equilibrium.

Desulphurization

The effect of bottom-stirring on desulphurization was evaluated by monitoring the distribution of sulphur between the slag and the steel, as shown in Figure 11. It can be seen that stirring increases the distribution ratio of the sulphur, and thus contributes to improved desulphurization. The improved desulphurization is the result of the lower oxygen potential (Figures 9 and 10), as well as the intensified contact between the slag and the steel that is achieved with stirring.

Manganese distribution

The effect of bottom-stirring on the distribution of manganese between the slag and the steel is illustrated in Figure 12. Although the scatter in the data is fairly wide, the general trend shows that stirring decreases the manganese distribution ratio. This means that less manganese is lost to the slag, and hence the yield of manganese increases with bottom-stirring. The lower oxygen potential and the improved slag–metal contact also contribute to reducing the manganese distribution.

Operational aspects of bottom-stirring

The effects of bottom-stirring on the performance of the electric-arc furnace were evaluated through an assessment of its influence on the tap-to-tap time, power consumption, iron yield, and electrode and refractory consumption. The results of that evaluation are summarized in Table I.

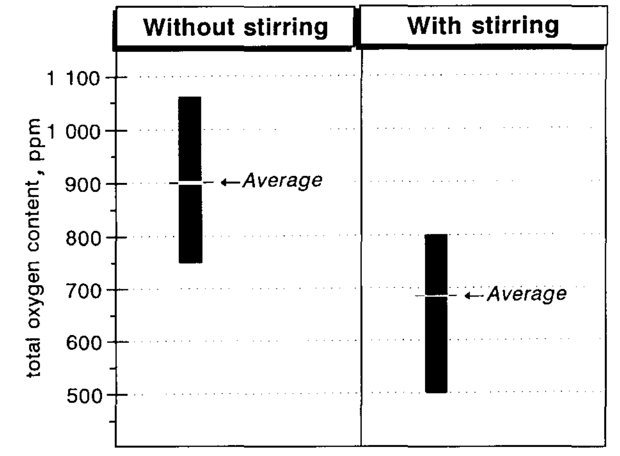

Figure 10—Effect of stirring on the total oxygen content of the steel bath

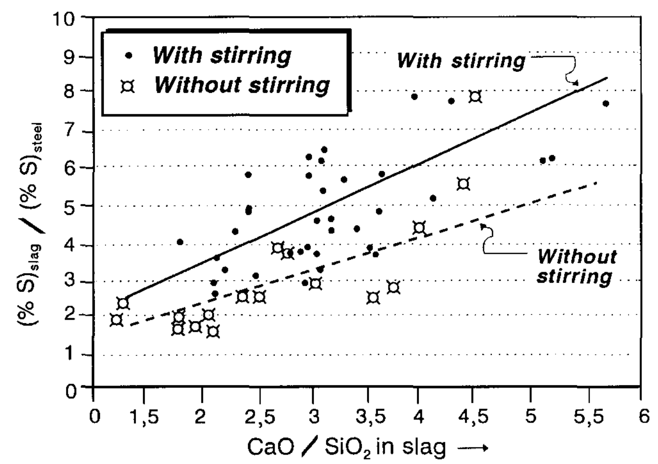

Figure 11—Effect of stirring on the distribution of sulphur between the slag and the steel bath

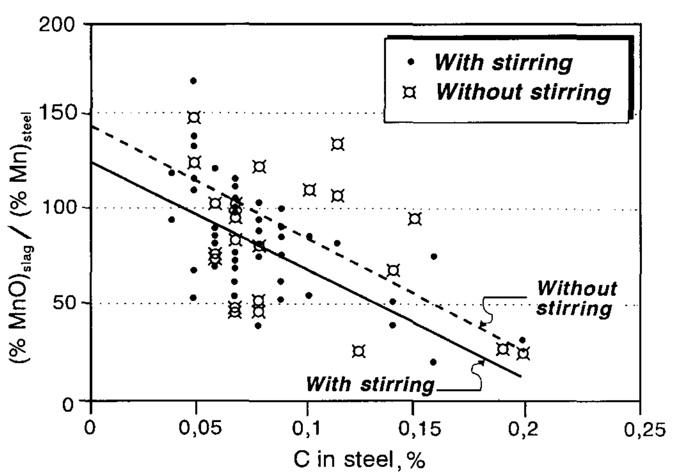

Figure 12—Effect of stirring on the distribution of manganese between the slag and the steel bath

Table I

Influence of bottom-stirring on the performance of the electric-arc furnace at Iscor Vereeniging Works

Parameter	Improvement
Tap-to-tap time, min	3
Electrode consumption per tonne of steel produced, kg	0,15
Iron yield, %	1,2
Power consumption per tonne of steel produced, kWh	None
Consumption of hearth material per tonne of steel produced, kg	0,4

It can be seen from Table I that considerable operational benefits were obtained by the application of bottom-stirring. The improvement in tap-to-tap time, electrode consumption, and iron yield result directly from an enhancement of heat transfer in the steel bath, acceleration of the slag-metal reactions, and a significant improvement in the foaming-slag practice, all of which were observed after the introduction of bottom-stirring. The improvement in the heat transfer in the metal bath was particularly noticeable because of the very heavy scrap (pieces up to 5 t in mass) that is used at the Vereeniging Works. Before the introduction of bottom-stirring, it was fairly common for large pieces of unmelted scrap to be found in the furnace after tapping. The presence of unmelted scrap is highly undesirable, because it gives rise to a large temperature gradient in the steel bath, and causes a localized boiling action, which results in excessive wear of the refractory hearth. With the introduction of bottom-stirring, these problems disappeared completely.

It is surprising that no improvement was observed in the power consumption. Most steelmakers report an improvement in power consumption of 10 to 20 kWh per tonne of steel produced after applying bottom-stirring[1,3,5,7]. A possible explanation for this is that the lowering of the iron oxide content of the slag is considerably more at Iscor Vereeniging Works (approximately 10 per cent) than that reported by other steelmakers (typically 5 per cent[1,5,7]). The reduction in the iron oxide content requires energy (approximately 10 kWh per tonne of steel produced), which may counteract the possible power savings due to the shorter tap-to-tap times and improved heat transfer.

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The decrease in the consumption of the refractory hearth material is a result of the cooling of the hearth material by the stirring gas, as well as the elimination of localized wear of the hearth resulting from extended boiling caused by large pieces of unmelted scrap.

Conclusions

Bottom-stirring by the indirect-contact stirring-plug system leads to considerable cost savings as a result of higher productivity, lower electrode consumption, improved yield of iron and alloys, lower refractory consumption, and improved desulphurization. By the successful application of this technology, Iscor Vereeniging Works has achieved an annual saving of more than R2,5 million.