AUTOMATIC SLAG DOOR PRACTICE: ACHIEVEMENTS AND DEVELOPMENTS BASED ON 7 YEARS OF EXPERIENCE

BY

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SYNOPSIS:

After 7 years and more than 10 installations worldwide, the results achieved by Condoor® –automatic slag door by SMS Group- are presented as well as the lessons learnt that led to the present technical solution through three major steps, summing up hundreds of technical improvements, each born from steelmakers’ experiences and requirements.

Starting point for the new developments are the proven performances achieved and the fast Return-On-Investment, driven by remarkable savings in:

- Energy consumption
- Electrodes consumption
- Power-off time

Developed essentially for safety requirements, Condoor® turned out to be an efficient solution and a key Technological Module of the modern Electric Arc Furnace concept by SMS Group. In the past years a survey of the plants was carried out in order to define the new roadmap for its constant upgrade. Today, SMS Group counts more than ever on Condoor® to provide a safer, sustainable and efficient electric steel making process.

This paper describes the current status of the installations and introduces new technical details and operating results. A specific focus is dedicated to Electric Arc Furnaces based on flat bath operations, where the proper control of de-slagging is a key factor for process and operation quality.

Keywords: Electric Arc Furnace, Safety, Energy Saving, Efficiency, Operational Results, Residence Time, Slag Door, Deslagging, Power Off, Consistency

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**Introduction: conventional slag door – a hole in the EAF?**

Slag door is a part of EAF that has not been changed since many decades. Except for a few minor changes in dimensions and construction, slag door remains mostly unaltered. While alternatives for some of its functions have been devised, its main function – deslagging – remains quite unchallenged. Use of alternative iron sources like Hot Metal (HM) and DRI/HBI has remarkably changed the needs of the process over the years. Looking at the way EAF slag volume has gone up in the last few decades and the process time has been drastically reduced, it is surprising that the method of deslagging has not gone through any major upgrade. One of the basic limitations of the slag door lies in its poor control of deslagging which still depends on the Operator’s skill and judgement. With little control over its shape, it is nearly impossible to know how much slag has been lost or retained at any point of time. There is always a possibility of metal seeping through the “V” channels formed on the breast. The quantity of metal found in the slag pots often tells that this process of deslagging is not very accurate. Furthermore many automatic machines and equipment are found nowadays on the working platform close to the EAF, insisting on the slag channel area. Sampler, Oxygen lances, Carbon injection, Hot metal launder require the slag channel to keep a proper shape: incorrect sill profile may result in incorrect or unsuccessful operations, thus in an increased power off time.

Above all, there can be no argument that slag door and EBT areas remain the most unsafe zones in EAF Area.

**Loss of Fluxes and Yield**

Compared to scrap melting furnaces, EAFs with longer flat bath operation often generate more slag. The EAFs using HM/DRI/HBI must provide enough flux to neutralize the acidic content coming from the burden. Typically DRI with higher gangue content requires bigger quantities of basic fluxes. With different plants using different qualities of DRI/HBI, it is difficult to compare the process parameters like flux consumption and Liquid Metal (LM) yield. Within the MENA Region itself, the plants using 100% DRI/HBI have been remarked using lime and dololime quantity varying from 25 kgs to 120 kgs per Ton of steel. Of course, the main reason for this is the different quality of input DRI/HBI in terms of gangue content and quality.

This is true not only in the same region, but in the same plant too, as easily understood from the graph below taken from a 10 months analysis on a DRI process based 120 Tons AC furnace.
We tried to analyze whether the DRI/HBI quality is the only variable affecting the consumption of lime and dololime.

Process data of 425 consecutive heats from a meltshop in MENA region was analyzed to examine the utilization of fluxes towards slag making. The meltshop - designed and supplied by SMS Group - has an EAF of 120 Tons capacity using a combination of hot and cold DRI received from a captive DRI plant. The basicity of the oxides portion of DRI was more than 0.20 during this period. The theoretical basicity of slag, IB3T, was calculated from the mass balance of EAF taking into account incoming and outgoing quantities of CaO, MgO and SiO₂. The losses of slag builders through exhaust gases were considered. The actual slag basicity, IB3A, is recorded by slag samples taken during the heats.

\[
IB3_T = \frac{(CaO + MgO)}{SiO_2}
\] calculated from material data.

\[
IB3_A = \text{Basicity of slag sample taken during the heat}
\]

The graph plotting values of IB3T and IB3A show that a significant part of flux addition is not reflected in the slag sample, see Figure 3. From the mass balance of the heats, the percentage of missing lime was 25.7%! This means one quarter of the added lime fails to dissolve and mix with the slag. This loss of lime can be explained by a variable called “Residence Time” of slagbuilders. Considering an infinitely long Residence Time, the two basicities would be equal. But a smaller Residence Time would allow only a certain degree of mixing and reaction in the slag resulting in a gap.
What are the factors affecting the Residence Time of slag builders?

If two geometrically identical EAFs, namely A and B, have equal process time, and the lime consumption of A is higher than that of B,

\[ \text{Residence Time of lime in B} > \text{Residence Time of lime in A} \]

If two EAFs have equal process time and equal lime consumption and their slag holding capacities are different, the EAF with bigger volume for slag will have a longer Residence Time. In other words, if the slag holding capacity of an EAF is increased, the Residence Time of lime increases at the given process time.

Therefore, the Residence Time of any slag builder, K, in electric arc furnace can be defined as the ratio of the total volume utilized by slag during process and the volumetric input flow rate or the consumption rate of K. This is true for all slag builders such as lime, dololime and the oxides in DRI. Compared to conventional scrap melting process, EAF process based on Hot Metal and DRI involves much lower Residence Time for slag builders because of higher slag generation with similar slag holding capacity of reactor.

Another factor that plays a significant role is the distribution of Residence Time of the slag builder. In a plug flow reaction vessel, the Residence Time for all the particles of slag builder is equal. But in EAF, at the time when material addition and deslagging happen simultaneously, the particles of slag builder which follow the shortest route between the entry and exit points have considerably less Residence Time than others. This is very important in smaller EAFs where the distance between lime feeding point and slag door is often less than the radius of the vessel. This is equally important for the EAFs that use slag door for DRI Injection.

For EAFs using Hot Metal Charge the challenge of retaining slag is equally big. Loss of lime-rich slag retained from the previous heat is a common event when HM is
poured into the low carbon hot heel and oxidizing slag. For continuous scrap charging in EAF, volume of slag cannot be increased beyond a certain limit, due to design constraints, and lost volume of slag must be restored by continuously adding slag builders.

EAF has a distinct advantage of ultra-high temperature in the feed zone of lime and DRI due to electrical arcs. This temperature is much lower in case of BOF and EOF making the process of dissolution of lime much slower. Due to the presence of an EAF-like slag door, the residence time for slag builders in EOF is considerably less than that in BOFs. And that is perhaps the reason behind the lower LM yield in an EOF when compared to a BOF.

**Fig.4: Slag Volume and Residence Time**

**Poor Atmosphere Control**

Conventional slag door has always been the biggest source of cold air ingress in EAF. Since most of the EAFs are not recovering heat from the waste gases, this deficiency is often ignored. But this can be very crucial in case of scrap preheating by use of exhaust gases. Many of such EAFs can improve their performances if the air ingress can be controlled.

Therefore, the challenges for a new approach to slag door operation are:

1. control over the slag volume
2. control over the atmosphere

The old fashioned approaches to slag door management do not meet the above requirement. A forklift with ram can initiate the process of deslagging in a few seconds but it cannot stop the flow of slag upon request of the Operator. Lifting the sill level by depositing basic material or by adding artificial barrier on the door is both unsafe and time consuming.

One of the solutions for enhancing the Residence Time of slag builders in EAF is Condoor®.

**What is Condoor®?**

Condoor® (former ESD, Enhanced Slag Door) is a two axis robot developed by the SMS Group from a joint idea with the steelmakers. It can act as the perfect valve for
slag control and it can push any jam on sill inside the shell with its hydraulic force of 24 Tons at 120 Bar. Its water cooled pusher not only cleans the tunnel, but actually can sit on the door tunnel sealing it completely. It can withstand mechanical erosion of slag and radiations from arc. Thanks to Condoor®, the Operator can choose the exact time of deslagging as the door can be opened in a few seconds. Forklift and/or Operators do not need to be present in front of the slag door any longer.

Fig.5: Evolution of Condoor® (a) Version 1.0 (b) Version 1.5 and (c) Version 2.0

The first Condoor® installed in Nucor Jewett in late 2009 (aka Texas Tailgate) raised many eyebrows due to its big and sturdy design. Soon it was discovered that a pushing stroke more than 300 mm was not enough: furthermore the force itself was a factor underestimated at that time (only 6 Tons at 120 bar). In the very next version, the need for a stronger pushing force with bigger stroke was targeted. Since then, through its several upgrades, Condoor® has come a long way: today’s design enables a pushing stroke of 800 mm with 24 Tons force and a pulling force of 16 Tons. It has been tested in different kinds of steelmaking process ranging from structural steels to stainless steels. It has been tried successfully for different kinds of iron sources ranging from scrap to Hot Metal.

One feature that sets Condoor® apart from any other slag door solution is the design of the pusher. It has become evident that the control over the slag door is not possible without the capability to control the door opening from 0 to 100% and back to 0%.

Fig.6: Condoor® (a) 100% closed (b) fully open showing perfect rectangle

The pusher is the most exposed part of the equipment, subject to wearing due to heat, radiation and slag actions. It goes without saying that each furnace has its own story but some common lessons learnt have driven to the present solution based on a full
copper water-cooled front panel. For less aggressive environment, replaceable stainless steel mono-blades are available for installation on the lower section.

Fig.7: Latest design of pusher withstanding more than 1500 heats

Since 2016, compact Condoor® design has been available (overall height only 1815 mm) which can fit most of the EAF bigger than 50 Tons and shaft furnace with fixed roof. Installation of Condoor® does not require a long shutdown and can be clubbed with other routine stoppages of the plant.

Process Analysis with Condoor®

Optimization of slag Residence Time is the key to maximum utilization of fluxes and ferrous raw materials. By enhancing the slag volume inside the EAF, Condoor® ensures better mixing of slag builders resulting in a better efficiency of slag.

Fig.8: Slag Volume can be increased by about 100% with Condoor®

Equally important is the knowledge of the slag quantity inside the EAF. Condoor® can help the operator choose:

1. The exact time of deslagging for optimization of Residence Time
2. The flow rate of deslagging by creating the same size/shape of door opening every time

Figure 9 shows a detailed melting profile for 50% Scrap and 50% HBI charge with one deslagging window at the end. With a conventional slag door, deslagging starts in the middle of the process and continues till the end. Condoor® squeezes this window by more than 10 min, enhancing the slag Residence Time by the same measure. In such EAFs the total deslagging time is often less than one minute because of a wide and clear door opening.

![Figure 9: Melting Profile with single deslagging](image)

An EAF with Condoor® opens the door only few minutes before tapping to make the best use of the slag and minimize furnace cooling by air ingress through the door. Condoor® brings savings in

- Power Consumption
- Electrode consumption
- Raw materials (higher Liquid Metal yield)
- Process time

as demonstrated by 9 installations worldwide (limited to Version 2.0 only).

In case of HM/DRI based process, multiple deslagging can be planned to optimize the Residence Time of slag (and thus slag builders). Condoor® operation can be programmed into the automatic cycle of the process to achieve consistent results. While DRI, scrap and flux feed rates are controlled by the EAF Control System, the Operator must get a feedback on slag foaming while the slag door is closed. SCAD is the tool designed by the SMS Group, SCAD meaning Slag Control and Detection system. By analyzing the data from the electrical system, it can provide the status of slag foaminess in real time based on CAI, Covering Arc Index.
Based on the SCAD feedback, EAF Control System regulates carbon and oxygen injection to achieve consistent foaming of slag. Carbon consumption in EAF is reduced by avoiding an overdose of injected carbon. This is particularly important for EAFs with long flat bath operations.

EAF Control System can use SCAD inputs to achieve maximum DRI Feed rate in EAFs as the volume and quantity of slag changes gradually. The higher volume of slag inside the EAF not only improves the heat transfer efficiency, it also reduces the requirement of slag builders. As the weight of slag in the slag pots is reduced, so is the loss of iron and the LM yield improves.

In EAFs using maximum Hot Metal, a different strategy can be adapted to get rid of the first slag after the entire silicon is oxidized. The door can be closed afterwards as the oxygen blowing progresses.

Figure 12 shows the changes in slag volume (slag level) during a heat cycle with 100% DRI charge with feeding rate varying between 1200 to 3500 Kgs/min. With a conventional door, as the % Charge increases, volume of slag generated increases with decreasing slag holding capacity in EAF. The window of deslagging is more than half length of the process, 20 to 25 min for a 52 min tap-to-tap cycle.
With Condoor®, more than one deslagging step can be planned for the optimal utilization of slag. The first deslagging can be positioned in a way to make full utilization of the lime-rich slag from the previous heat. The Operator can keep track of the inside slag quantity from the material input data and the exact time of deslagging. The second deslagging step can be merged with the final temperature and sample collection. With the tunnel sealed completely by Condoor®, there is no need to tilt EAF backwards, thus altering the distance between the wall-mounted lance and steel bath. Another remarkable gain with Condoor® is that the short circuiting between feeding zone and slag door can be ruled out completely. The Operator stops feeding of lime and DRI when the door is open. Longer Residence Time of Lime and DRI results in A. smaller slag generation and B. reduced loss of iron through the slag door.

Experience learnt from a 100% Scrap based 98 Tons AC furnace has shown the possibility to use the entire volume for slag holding until the so-called Sealed level, in order to reduce the overall consumption of Electrical energy (-2.9%) and Electrodes (-6.7%), at the same time increasing the Liquid Metal yield by 0.7%. The winning strategy has been achieved at the minimum cost of +1% Carbon charged and +1% slag builders charged.

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**Table 1: Savings in Electric Power and Electrode thanks to Condoor®**

Due to the uncontinuous production, most of the plants worldwide find it difficult to keep consistency on their operation, which is reflecting on high variation of the total operation time (TTT, tap-to-tap time). This is a new area to look at. As a consequence
of the market demand, the production is nowadays planned on short notice. Furthermore, electricity price variations during the day/night force the steel makers to operate electric arc furnaces only on few shifts per day.

The SMS Group was aware of the importance to provide equipment flexibility in respect of the raw material charging; today, SMS is also aware that flexibility is necessary in respect of the production scheduling. Having a short period of time (like a night-shift) to produce a certain amount of steel calls for a repeatable and precise operation time, thus a constant tap-to-tap time. A delay of 10 min (not abnormal in a steel making plant) is not acceptable any longer, just because the average TTT is mitigated only by 10-12 heats and not by 60-80 heats like in the past. Condoor® is targeted to grant the highest level of repeatability and operation consistency: a new approach matching the requirements of modern steel makers.

This is coming mainly from the higher predictability in the power off time: the usual time losses during sampling and breast maintenance are nearly eliminated. It is quite impressive to record the increase of consistency of TTT of two EAF plants, namely 100 Ton and 120 Ton heat size in South America and Asia. The measure of this can be represented by the standard deviation associated with the power off time, a factor often not analyzed by the steelmakers.

Condoor® stabilizes and decreases the power off time: a remarkable 6 min less per heat averaged on 200 heats, and above all the elimination of the unpredictable peaks, which means process consistency at all levels (standard deviation decreased by 20%). For the South American plant, the stabilization was even higher, with a reduction of the power off time by 3 min, and a standard deviation decrease by more than 50% (from 6.2 to 2.7 min).

![Fig.13a: 200 heats with conventional slag door on 120 t AC EAF](image)
Data from an EAF plant in USA were analyzed to assess the impact of Condoor® on the final Phosphorous content of bath. Data of 793 consecutive heats processed before Condoor® installation was compared with that of 1420 heats made consecutively after the installation. The result is shown in Figure 14. There was a slight increase in the average Phosphorous content but the standard deviation was strongly reduced.[1] Again, process consistency has been improved.

Fig. 14: Change in %P before and after Condoor® installation
Technological Modules integration

Condoor® is a Technological Module part of the Synergy control platform. Together with the Advanced Electrode Regulation system (AEREG), Slag Control and Detection system (SCAD), Conso/SiS burner/injector technologies, robotic TS-Pro Sampler, FEOS optimization modules, Raw Material control modules and Off-gas Analyzer it enables the steelmaker to achieve the best performance at the lowest cost on existing and new installations. The platform provides the integration of hardware equipment and software control modules: it is built on a modular approach, granting a step-by-step investment strategy for the steelmaker who can decide which solution to prioritize on the basis of the current results.

Conclusion

The intense use of alternative iron sources on EAF demands better control over slag which is not possible with the conventional door. The lack of control can lead to the loss of slag builders and yield, too. Enhancing the Residence Time is the key for a better utilization of slag.

Condoor® can provide the complete control over de-slagging: combined with SCAD, it can help the operator optimize several parameters such as carbon injection, flux consumption and Liquid Metal yield.

Use of Condoor® in EAF brings saving in terms of:

1. Power consumption,
2. Electrode consumption,
3. Liquid Metal yield,
4. Lime and Carbon consumption,
5. Tap to tap time.

Most of the installations experienced stabilization on the total cycle time due to the capacity of Condoor® to grant repeatable conditions heat after heat.

No significant impact on dephosphorisation was observed during a study of the EAF process in a melt shop in USA.
References

1 †Wally Aggarwal, A. Partyka, Mauro Milocco, “Enhanced Slag Door For Electric Arc Furnace (ESD)”