THE EFFECT OF ARCSAVE^{TM} ON THE EAF PROCESS WITH ECCENTRIC BOTTOM TAPPING*

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Abstract
ArcSave^{TM} is a new generation of electromagnetic stirrer (EMS) from ABB for electric arc furnace (EAF) operation. Its goal is to improve the safety, increase the productivity and reduce costs. Electromagnetic stirring in the melt bath during arc furnace operation will affect the scrap smelting, bath temperature distribution, refining reactions, and also the tapping practice. This paper has summarized the investigation results obtained from the first ArcSave^{TM} system installed in a 90 ton EBT arc furnace in USA. The hot test results show that ArcSave^{TM} has enhanced the heat and mass transfer in the arc furnace process. This results in a faster scrap melting rate, lower slag superheat during arcing, more homogenous melt bath, higher decarburization rate and higher EBT free opening frequency. ArcSave^{TM} has also reduced the tapping temperature and tapping oxygen in the steel. This brings a higher scrap yield and saves ferroalloy consumption in the downstream ladle furnace operation. The lower energy consumption, short tap-to-tap time, and consistent furnace operation bring increased productivity and safety.
Keywords: Electric arc furnace, ArcSave^{TM}, steel yield, EBT tapping, EMS.

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1 INTRODUCTION

For 70 years ABB Metallurgy in Sweden has been committed to the development of new electromagnetic products for improving steel quality and productivity. The first electromagnetic stirrer for electrical arc furnaces (EAF-EMS) was delivered to Uddeholms AB, Sweden in 1947. Since then some 150 units have been supplied worldwide. Recently, a new generation of EAF-EMS (named ArcSave^{TM}) has been developed by ABB. It's goal is to meet the need for stronger stirring power in the EAF process for both plain carbon and high alloyed steel productions. ABB Metallurgy have discussed the history and development of EMS system and installation elsewhere [1]. Over the past couple of years ABB have studied systematic numerical simulation and water modeling for EAF with magnetic stirring [2-4]. Two ArcSave^{TM} systems were delivered in 2014. One was installed on a 90 ton EBT furnace for carbon steel production in Steel Dynamics, Inc. (SDI), Roanoke, VA, USA [1]. The other ArcSave^{TM} has been installed on a 90 ton spout tapping furnace for stainless steel production at Outokumpu Stainless Steel AB (OSAB) in Sweden. In the current paper, the effect of ArcSave^{TM} on the EAF process with EBT tapping has been studied in detail based on the metallurgical hot test results from SDI plant. The key performance improvements with ArcSave^{TM} will be discussed and compared to that without stirring.

2 ArcSave^{TM} SYSTEM

The ArcSave^{TM} installation system includes an electromagnetic stirrer, a frequency converter, a transformer, and a water station. The general system overview of ArcSave^{TM} is presented in Figure 1. The electromagnetic stirrer is placed under a non-magnetic (austenitic stainless steel) steel plate window, which is part of the furnace bottom, as illustrated in Fig. 2. The low frequency electric current running through the stirrer windings generates a traveling magnetic field. This magnetic field penetrates the furnace bottom thereby generating forces in the molten steel. Since the magnetic field penetrates the whole depth of the melt, the melt will then flow in the same direction across the entire diameter of the furnace and down to the whole depth of the bath. After reaching the furnace wall the melt will flow back along the sides of the furnace.
Operation is characterized by low stirring cost, reliable and safe operation: Optimum conditions for reproducible production of high quality steel and precise logistics. Compared to bottom gas stirring by porous plugs, ArcSave^{TM} creates a global circulation in the arc furnace bath and thereby provides efficient mixing of the complete bath melt. This mixing effect accelerates homogenization of the temperature and the chemical composition of the steel, as well as the chemical reactions between steel and slag.
ArcSave^{TM} stirring is fully automated and controlled by the customer-specific stirring profile which includes stirring direction, stirring power, and optimized frequency. The stirring profile has been customized to match the need of different process steps, as scrap heating, melting of alloys, decarburization, and homogenization, de-slagging and tapping.

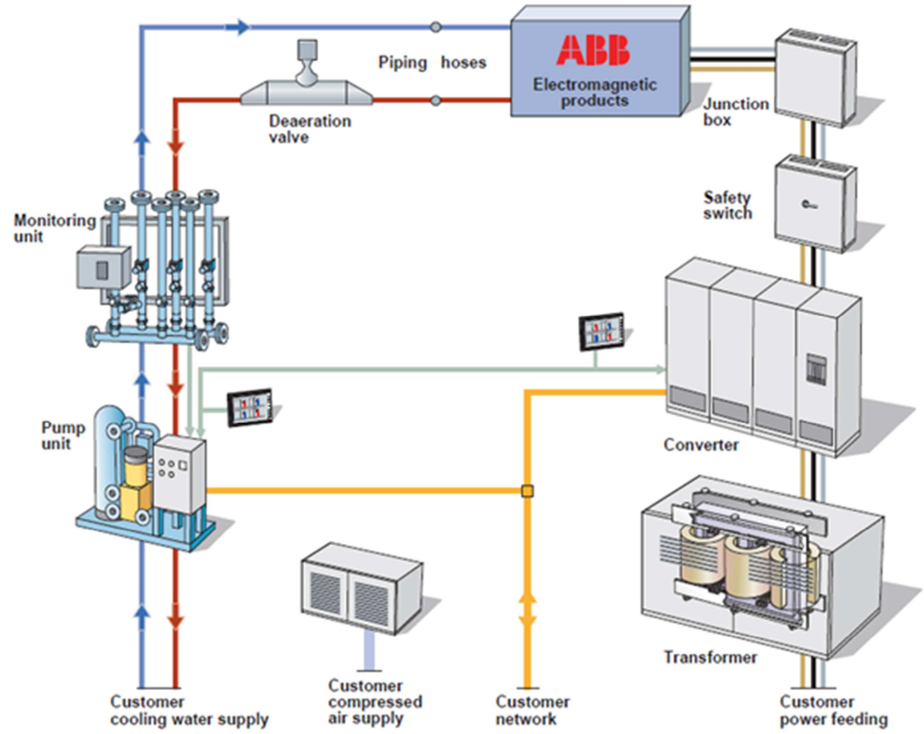

Figure 1. System overview of ArcSave^{TM}.

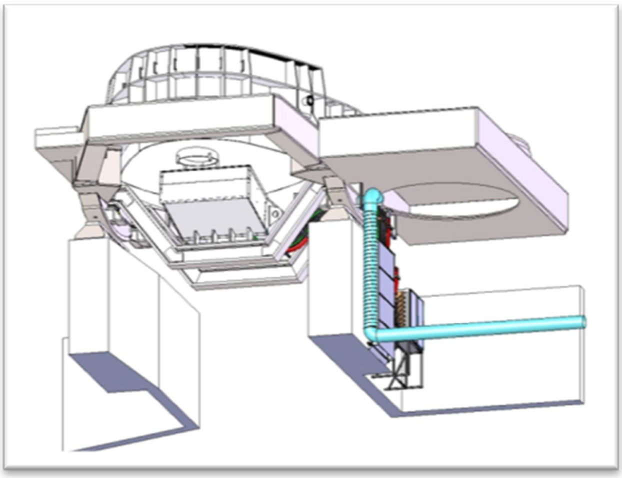

Figure 2. Arc Furnace with ArcSave^{TM} stirrer mounted underneath the furnace bottom.

3 RESULTS AND DISCUSSION

The intensive convection flow of the melt, which is induced by the magnetic force, will improve the EAF process's heat and mass transfer. Several process benefits have been achieved due to these improved kinetic conditions. ArcSave^{TM} has also improved the arc stability and power input efficiency.

3.1 Scrap Melting and Arc Stability

The main difference between the EAF with and without ArcSave^{TM}. is the intensity of convection in the melt bath. The forced convection, which is induced by

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electromagnetic stirring, will enhance the melting of larger scrap pieces and bundles, and make scrap stratification less significant. The strong convection inside the melt contributes to a homogenous temperature distribution and high scrap-melting rate. ArcSave™. has stabilized the arc by melting big scrap bundles faster and reducing scrap cave-ins. Figure 3 is a comparison of the secondary current of electrodes with and without ArcSave™ stirring. Electrodes current swings were shown to be reduced with- ArcSave™. The standard deviation of current change is reduced by almost 50% with ArcSave™. The reduced electrode current swings has resulted in a higher power input, as presented in Figure 4.The higher power input has been reduced the power on time around 5% in average and therefore brings a 4% potential of productivity increase.

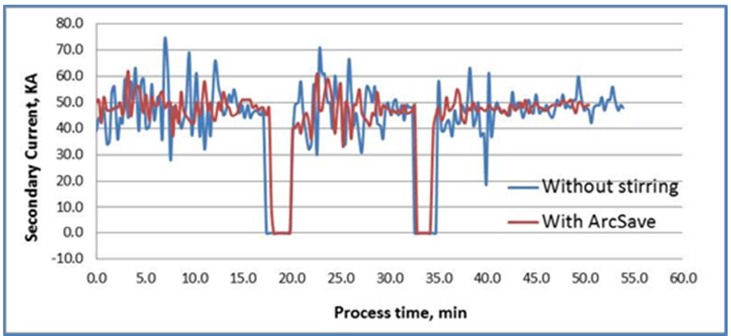

Figure 3. Effect of ArcSave™ on the electrode current swings

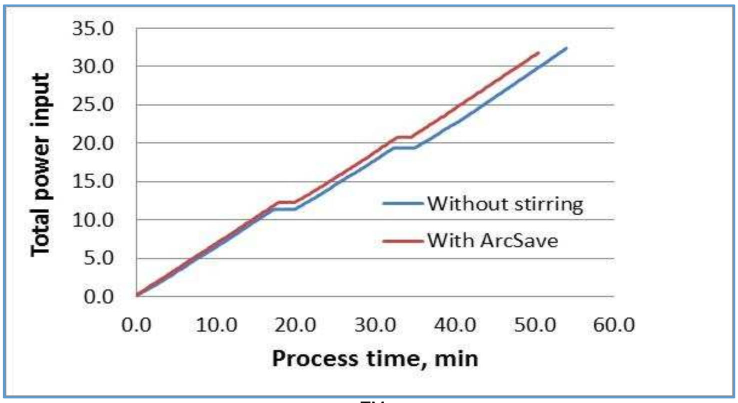

Figure 4. Effect of ArcSave™ on the electric power input

3.2 Bath Homogenization and Heating Efficiency

The bulk turbulent flow induced by the ArcSave™ brings a thorough mixing of the melt. The result is a very good temperature and composition homogenization. The temperature distribution with ArcSave™ after power off has been measured in two positions with the time interval of 1-2 minutes for the same heat. The 7 heat measurement results show that the corresponding temperature difference at two positions is less than 5°C.
Temperature gradients during scrap melting in a conventional AC arc furnace without stirring have been reported in the range of 40-70°C [5]. Stirring will reduce the melt surface superheat and the heat from the arc zone is quickly transmitted to the melt. The decreased surface superheat will reduce heat losses to the furnace wall and roof during power on period, and thereby reduce electricity consumption [6]. Similarly, ArcSave™ stirring will increase the scrap melting rate and decarburization rate, and therefore save furnace process time. This also reduces heat loss. In SDI ArcSave™

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tests, the total energy saving was 15 kwh/ton which is equivalent to 4% of electrical energy saving.

3.3 Decarburization and O_2 Yield

After the scrap is completely molten (flat bath formed), the refining period will start. This involves mainly decarburization by injected oxygen. At high carbon content in the steel the mass transfer of carbon is generally higher than the rate of oxygen supply. The decarburization rate is then determined and limited by the rate of oxygen supply. When the carbon content is less than a certain level the rate of carbon supplied to the reaction zone is lower than that of oxygen. Then the rate of decarburization is limited by the rate of carbon mass transfer. This critical carbon content is dependent on the specific furnace operation practice but is generally in the range of 0.2-0.4% C. This implies that below the critical carbon content, the injected oxygen should be decreased to avoid the excess oxygen reacting with iron to form FeO. If not, the oxygen yield will decrease as the carbon content decreases. This as reported by Jones [7]. With the aid of ArcSave^{TM} at SDI, the mass transfer coefficient of carbon in the steel has been increased, as shown in Figure 5. The initial carbon content in steel is around 0.15~0.3% and the final carbon content is 0.08~0.12%. Figure 5 also demonstrates that the de-carburization rate with ArcSave^{TM} at SDI arc furnace is almost doubled when compared with no stirring. The oxygen yield has been increased with a 5% of oxygen saving in the operation at SDI.

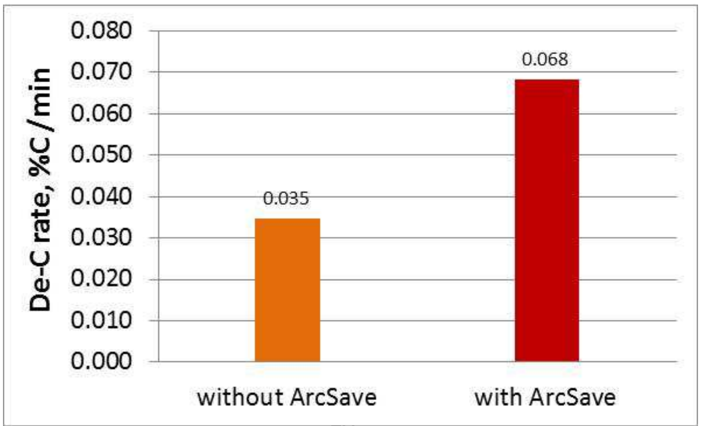

Figure 5. Effect of ArcSave^{TM} on the de-carburization rate.

3.4 Steel De-oxidation and Ferroalloy Savings

Bath stirring in EAF is known for pushing the carbon-oxygen reaction closer to the equilibrium value [8]. In SDI tests, the tap oxygen was reduced from 618 ppm to 504 ppm with a slight increase in tap carbon. These results indicate that with the help of ArcSave^{TM} it is possible to reach a low carbon and low oxygen content at the same time. FeO content in the slag is also reduced 3% after ArcSave^{TM}. This reduction in the slag has given a 0.2% steel yield increase from the materials balance calculation. The scrap in the dumped slag was also found to be significantly reduced. This provided a further contribution to steel yield increase. When combined, the oxygen decrease in the steel, the FeO decrease in the slag, and the carryover slag decrease in the tap ladle, will result in a ferroalloy saving in the ladle furnace operation.

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3.5 Delayed Vortex Formation and Carryover Slag Reduction

Theoretically, an Eccentric Bottom Tap (EBT) hole should have the feature of slag free tapping in EAF operation. However, slag carryover is always evidenced in the tapping ladle. The amount of slag carryover is dependent on the size of the hot heel, the geometry and the age of the EBT, the melt bath movement (stirring), and the actual tapping practice (operators). The main reason for the slag carryover is the vortex phenomenon occurring in the later stage of EBT tapping. The previous work carried out at ABB shows that the flow pattern induced by magnetic stirring in the melt bath has a clear influence on EBT vortex formation [9]. Water modeling results show that vortex formation is mainly enhanced by vortices concentration above the tapping hole during tapping. At the same time stirring induces a special flow dynamics that moves vortices away from the region above the EBT, thereby delaying the vortex formation.
The slag thickness in the tap ladle was measured by aluminum-steel-pole method. Some of the results with and without ArcSave^{TM} are shown in Fig. 6. The measured data were scattered to some extent but the average difference without and with ArcSave^{TM} from 96 heats is approximately 3 cm. The scattering of the measured data could be due to the different furnace operators, ladle lining age, and the measurements themselves.

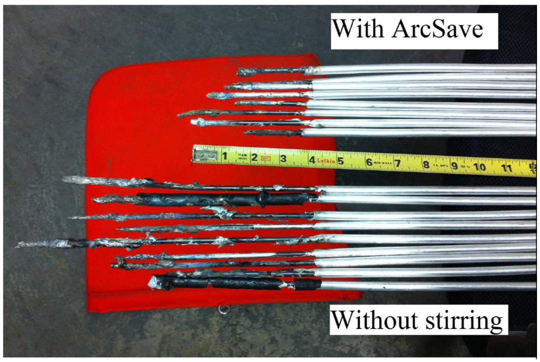

Figure 6. Samples after slag thickness measurements in the tapping ladle

The reduction of slag carryover in the tap ladle has been further observed from the FeO content in the slag. The lower oxygen content in the steel combined with the lower FeO content in the carryover slag will contribute to saving de-oxidants for steel de-oxidation in the downstream ladle refining process. FeSi consumption was reduced some 12% and CaC_2 was similarly reduced 15%.

3.6 Superheat Reduction and Refractory Savings

Six months of operation at SDI demonstrate that stirring in the melt bath has reduced furnace repairing refractory consumption by some 20% compared to that without ArcSave^{TM}. The superheat reduction during power-on by ArcSave^{TM} stirring is probably the main contribution to this saving. This, since the most critical refractory damage is in the hot spots located in slag-line area. Another contribution to the refractory saving is the reduction of FeO in the slag and of oxygen in the steel. The refractory wearing process is usually controlled by the dissolution of MgO (magnesia-carbon refractory) and MgO solubility is reduced by a lower FeO in the metallurgical slags. This is because FeO is the most aggressive oxide for refractory wear. Therefore, the decreased FeO content in the slag and oxygen content in the steel is likely another contribution to lower refractory wearing in the slag-line area. The third contribution to lower refractory wearing is the reduced tap temperature after ArcSave™. The tapping temperature was reduced from 1639 ^{o}C to 1625 ^{o}C. One should keep in mind that the 14^{o}C tap temperature reduction has not affected the ladle furnace arrival temperature. The elimination of thermal stratification in the melt bath apparently reduces the tapping temperature. In the case of an unstirred bath where, in general, the steel is hotter near the surface, the measured temperatures are frequently not representative of average bath temperature. It can be concluded that ArcSave™ has positive effects on the bottom refractory lining and has reduced the repairing refractory cost of the furnace.

3.7 Process Reliability and Safety

Safety and reliability are always of great importance for EAF operation. The effect of ArcSave™ on the EAF process, discussed in the sections above, will have a significant impact on improving process reliability and safety. The EAF-EMS has been said to have stabilized the electric arc and reduced scrap cave-ins during the power-on period [6]. Stirring in the melt bath decreases the carbon boiling-out which is an advantage for pig iron charging practice. A homogeneous temperature in the whole bath, including the EBT area, provides a high opening EBT frequency and reduce tapping delays. The EBT opening frequency was around 78% before ArcSave™ and almost 100% after ArcSave™. The time saving, due to high EBT opening frequency and less EBT cleaning, will give a productivity increase of some 1.5%. A high EBT opening frequency is a very important benefit for both operational safety and productivity

3.8 Consistent Ladle Furnace Operation with Reduced Costs

The homogeneous bath temperature with ArcSave™ makes it possible to obtain an exact tapping temperature in EAF. The high target tapping temperature hit ratio provides a high porous plug opening frequency in the ladle furnace operation. The lower oxidized carryover slag in the tap ladle and the lower oxygen in the tapped steel have been also reduced ferroalloy and slag builder consumption in the ladle furnace. It is concluded that the ladle furnace is operated more consistently after the installation of ArcSave™.

4 CONCLUSION

ArcSave™ increases the safety and productivity, as well as reduces the cost of EAF operation. ArcSave™ improves the heat and mass transfer for the EAF process, speeds up the scrap melt-down, stabilizes the arcing, accelerates the homogenization of the temperature and the chemical composition of the steel bath, forces the metal/slag reactions closer to equilibrium state, increases the decarburization rate, and also improve the furnace tapping practice. ArcSave™ also reduces the metallic phase in the dumped slag and increases the iron yield. The key benefits from ArcSave™ are summarized as:

- Reduced process time and increased productivity;
- Reduced energy consumption;
- Increase yield for scrap and ferroalloys;
- Increased operational safety and reliability.

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