# ArcSave®, Innovative Solution for Higher Productivity and Lower Cost in the EAF


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## ABSTRACT


ArcSave® is a new generation of electromagnetic stirrer (EMS) from ABB for electric arc furnace (EAF) operation which aims to improve the safety, increase the productivity and reduce the cost. Electromagnetic stirring of the melt bath during arc furnace operation will affect the arc stability, scrap smelting, bath temperature distribution, refining reactions, and also the tapping practice. This paper has summarized the investigation results obtained from the first ArcSave® system installed in a 90ton EBT arc furnace at Steel Dynamics, Inc. (SDI), Roanoke, VA USA. The hot test results show that ArcSave® has stabilized the arc and enhanced the heat and mass transfer in the arc furnace process which result in a faster scrap melting rate, lower the slag superheat during arcing, more homogenous melt bath, and higher decarburization rate, and higher EBT opening frequency. ArcSave® has also reduced the tapping temperature and tapping oxygen in the steel which 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 greatly increases the productivity and operation safety.

## INTRODUCTION

ABB Metallurgy has been committed to the development of new electromagnetic products to improve the steel quality, productivity and safety for about 70 years. The first electromagnetic stirrer for electrical arc furnaces (EAF-EMS) was delivered in 1947 at Uddeholms AB in Sweden and since then more than 150 units have been installed worldwide. Recently, a new generation of EAF-EMS (named **ArcSave®**) has been developed by ABB to fulfill the requirement for a stronger stirring power in the EAF process for both plain carbon and high alloyed steel productions. The general information of the development history of EMS system and installation system has been discussed elsewhere by ABB Metallurgy [1]. Systematic numerical simulation and water modeling of electrical arc furnace with magnetic stirring have been studied by ABB during the past couple of years[2-4]. In 2014, the first new electromagnetic stirring system (ArcSave®) was installed in a 90 ton arc furnace at Steel Dynamics, Inc. (SDI), Roanoke, VA, USA, to improve the operation safety, energy efficiency and reduce the cost of production. The installation and commissioning of ArcSave® at SDI was completed in July 2014 and the metallurgical tests with ArcSave® have been studied for 6 months to obtain the key performance improvements compared to operation without stirring. In the current paper, the effect of ArcSave® on the EAF process will be discussed in detail based on the hot test results.

## ArcSave® PROJECT BACKGROUD

Steel Dynamics Roanoke Bar Division was founded as Roanoke Electric Steel by John Hancock Jr. in 1955. Roanoke Electric Steel remained competitive through the years by embracing and implementing technologies as they became available. The first instance of this was the installation of the first commercial continuous caster in the United States in 1962. In 2006 Roanoke Electric Steel became Steel Dynamics, Roanoke Bar Division. SDI has maintained the commitment to improve through technology. The Melt Shop today consists of a 90 ton AC EAF, a Ladle Refining Furnace and a 5 strand caster. The EAF has 3 Omni-Jector burners with post combustion, oxygen lance and carbon injection capabilities. There are 2 additional burners, a door tunnel burner and a panel burner with lime injection. The burners, post combustion and carbon injection are controlled by a Level 2 system that continuously monitors off gas from the furnace. The caster produces 4x4", 4x6", 4 ¾ x 6 3/8" and 6x6" billets. Most of the billets are rolled in house to make a variety of bar products including flats, angles, channel, rounds, and rebar. General Melt Shop Specifications for SDI Roanoke Bar are listed below in Table 1:

Table 1. Plant production data of SDI

| | |
|---|---|
| Product | Merchant Bar, Rebar |
| Annual Capacity | 660,000 Tons |
| Furnace | 90-Ton Danieli Electric Arc Furnace |
| Furnace Diameter | 18' |
| Transformer Size | 56 MVA |
| Electrodes | 22" |
| Caster | Danieli 5-Strand Continuous Caster |
| Sections Cast | 4x4", 4x6", 4 ¾ x 6 3/8", 6x6" billets |

In order to remain competitive, SDI believes that every ton of steel that is produced has to be done as efficiently and safely as possible. Due to this belief, SDI agreed to enter into the project with ABB to install ArcSave® on the EAF. Extensive engineering studies had to be completed to determine if the existing rockers and rocker foundations would support the additional weight of the new equipment and structure modifications. The existing EBT mechanism was too large to fit in the modified structure, so it was replaced with a smaller slide gate assembly. Modifications were also made to the platform for clearance purposes. Because of the requirements of the stirrer, a new non-magnetic furnace shell bottom had to be designed. After considering several designs, SDI, ABB, and Superior Machine settled on a full stainless steel bottom welded to the upper carbon steel shell. It was decided that the ArcSave® controls would be installed in containers that would be preassembled and tested before arriving on site. Most of the preparation work was completed during available down times with final installation of the completed shell occurring during down week in April 2014. Prior to installation and commissioning of the stirrer, the furnace ran with the new shell in place for 3 months so that external shell temperatures could be monitored on the bottom and at the weld seams.

## STIRRING PRINCIPLES AND MELT FLOW PATTERNS

Electrical Arc Furnace stirrer is placed under a non-magnetic (austenitic stainless steel) steel plate bottom, as presented in Figure 1. The low frequency electric current through the stirrer windings generates a traveling magnetic field which penetrates the furnace bottom and thereby generating forces in the molten steel. Stirring can be customized to match the needs of different EAF process steps such as scrap heating, homogenization, melting of alloys, decarburization, deslagging and tapping. The operation is characterized by low stirring cost, reliable and safe operation, optimum conditions for reproducible production of high quality steel and precise logistics.


Figure 1. Arc Furnace with stirrer mounted underneath the furnace bottom at SDI site.

The designed average melt velocity induced by the new generation of ABB ArcSave® is around 0.5 m/s. The mean flow pattern for the horizontal plane about 10 inches below the melt surface in a 150 ton EBT tapping EAF is presented in Figure 2[2]. It can be seen that the flow in the horizontal cross-section is slightly asymmetric. The detailed information of the numerical modeling of the melt flow pattern and velocity in the electrical arc furnace has been presented in SteelSim 2011[2]. Compared to the bottom gas stirring by porous plugs, the EMS creates a global circulation in the arc furnace bath and thereby provides a more efficient mixing of the complete bath melt. This mixing effect accelerates the homogenization of the temperature and chemical composition of the steel, as well as the chemical reactions between steel and slag.

The installation system of ArcSave® includes an electromagnetic stirrer, a frequency converter, a transformer, and a water station. The general system overview of ArcSave® is presented in Figure 3. The installation features are:

- No physical contact with the steel melt;
- Normal refractory lining can be used;
- The stirring direction can be reversed by changing the current direction;
- Very low maintenance required for the system.

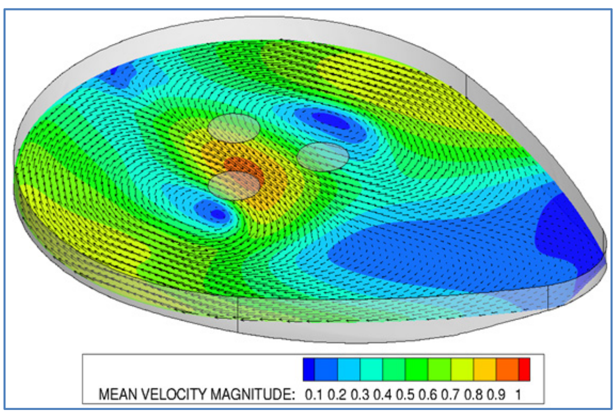


Figure 2. Melt flow pattern created by electromagnetic stirring [2]

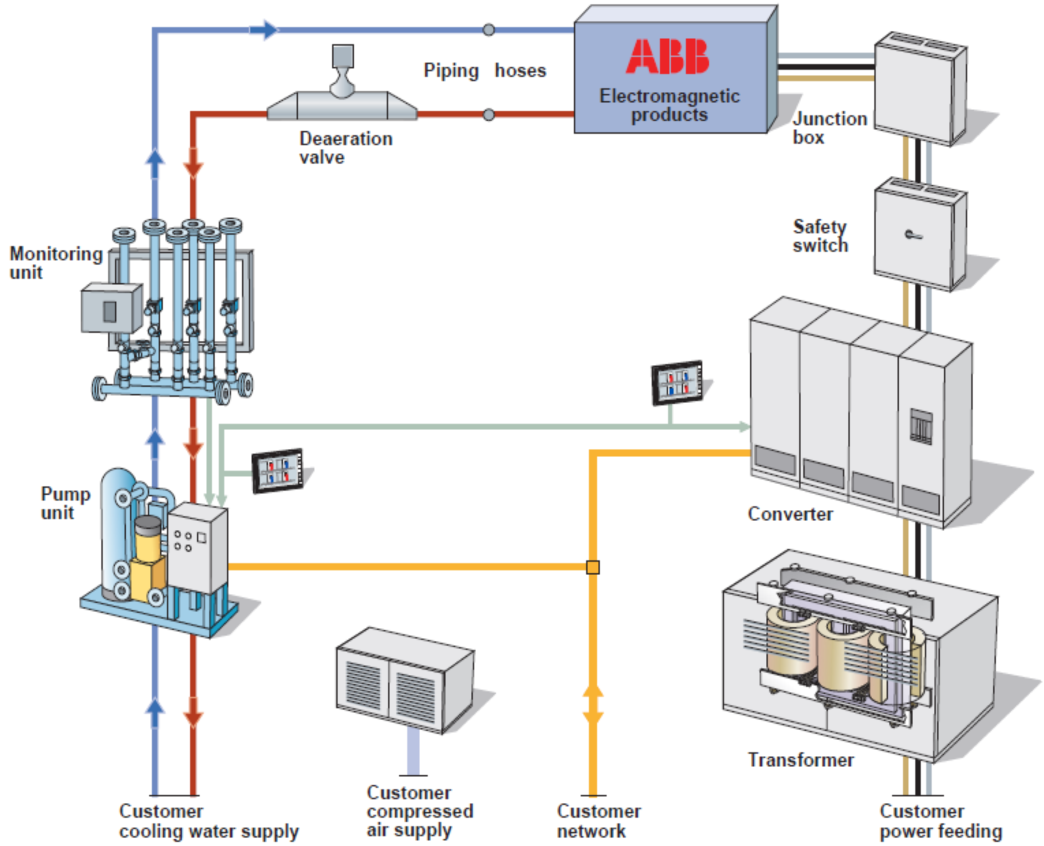


Figure 3. System overview of ArcSave®

## EFFECT OF ArcSave® ON THE EAF PROCESS

The heat and mass transfer of EAF process under the stirring conditions will be improved by the intensive convection flow of the melt induced by the magnetic force. Several process benefits have been achieved due to the improved kinetic conditions for heat and mass transfer with ArcSave®.

### Arc Heating Efficiency and Energy Saving

Temperature gradients during scrap melting in conventional AC arc furnace without stirring have been reported in the range of 70-125 °F [5]. It was also reported that a temperature difference of 47 °F with the EMS and 184 °F without stirrer has been measured when superheating a 10-ton melt of 3500 kW [6]. The temperature gradient with EMS is only 25% of that without EMS during power on period. This means that EMS reduces the melt surface superheat and the heat from the arc zone is quickly transmitted to the bulk melt. The decrease of surface superheat temperature will reduce the heat losses to the furnace wall and roof during power on period, and thereby reduce the electricity consumption. Simultaneously, the stirring will increase the scrap melting rate and decarburization rate and therefore save the furnace process time, which also reduces the heat loss.

In the ArcSave® test at SDI, the total energy saving includes the chemical energy decrease from the less consumption of natural gas, carbon, oxygen, and the reduction of FeO in the slag. The total energy saving is about 14 kwh/ton which is equivalent to 4% of electrical energy saving. Because of the higher power input and higher heating efficiency the power on time is reduced around 5%, from 49.3 minutes without stirring to 46.7 minutes with ArcSave®. This result is comparable to the previous test results reported by Samuelsson [7].

## Scrap Melting

The main difference between the EAF with and without ArcSave® is the intensity of convection in the melt bath. The forced convection induced by electromagnetic stirring will enhance the melting of larger scrap pieces and bundles, and make scrap stratification less significant. Without stirring there is only natural convection, and the motion is caused by the difference of densities, therefore the intensity of the natural convection is very low. CFD results show the melt velocity is increased by a factor of 10 by EAF-EMS compared with only natural convection in the melt bath [2]. The strong convection inside the melt contributes to a homogenous temperature distribution and high melting rate of the scrap. It has been indicated from the electrode regulation signal that the electrode stabilization time after bucket charging is decreased some 10% at SDI which is corresponding to 1.2 minutes power on time reduction for the first bucket scrap melting period. In addition, it is also found that EMS has stabilized the arc by faster melting big scrap bundles and by reducing scrap cave-ins. Figure 4 (left) is a comparison of the secondary current of electrodes without stirring and with ArcSave®. It can be seen that the current swings were reduced after ArcSave®. The standard deviation of current change for 3 buckets melting period is shown in Figure 4 (right) and it is reduced about 50% with ArcSave®. The reduced current swings of electrodes has resulted in a higher power input and therefore increased the productivity.

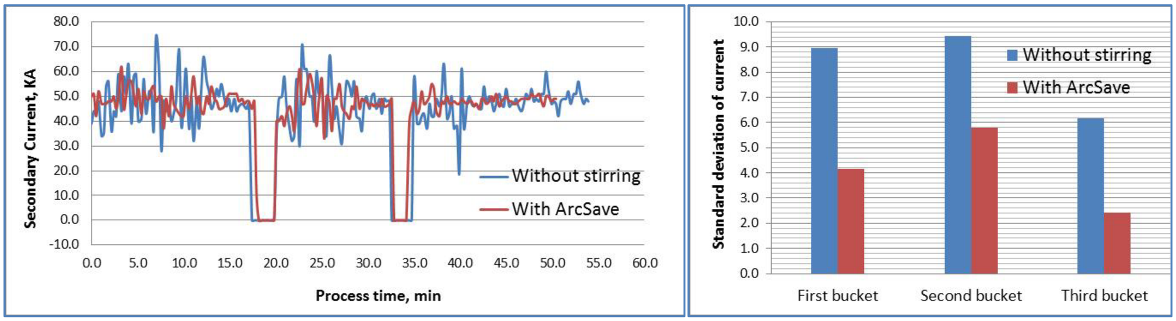


Figure 4. Effect of ArcSave® on the electrode current swings

## Bath Homogenization

The bulk turbulent flow induced by ArcSave® brings a thorough mixing of the melt, resulting in improved 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 results are shown in Table 2. It can be seen from Table 2 that the corresponding temperature difference at two positions is less than 4$^o$F. This is in good agreement with the CFD simulation result reported by Widlund et.al.[2]. ArcSave® thus makes it possible to obtain an exact tapping temperature for the different steel grades. Homogenous temperature distribution in the melt bath will give a hot EBT and smooth tapping without delays which will be discussed later in this paper.

Table 2. Temperature measurement results after power off with ArcSave®

| Heat Number | Sample 1 ( $^o$F) | Sample 2 ( $^o$F) | T difference ($^o$F) |
|---|---|---|---|
| H1 | 3128 | 3130 | 2 |
| H2 | 2885 | 2894 | 9 |
| H3 | 2876 | 2878 | 2 |
| H4 | 2921 | 2917 | -4 |
| H5 | 2835 | 2833 | -2 |
| H6 | 2961 | 2968 | 7 |
| H7 | 2943 | 2941 | -2 |

## Decarburization and $O_2$ Yield

After the scrap is completely molten (flat bath formed), the refining period will start which involves mainly decarburization by injected oxygen. The injection of oxygen into the bath creates a highly turbulent reaction zone where carbon from the bulk metal can react with oxygen or FeO. At high carbon content in the steel the mass transfer of carbon is generally higher than the rate of oxygen supply, and the decarburization reaction rate is then determined and limited by the rate of oxygen supply. The effect of ArcSave® on the decarburization rate during this period is negligible. However, 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, 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 implied that below the critical carbon content, the injected oxygen should be decreased to avoid the excess oxygen to react with iron to form FeO; otherwise the oxygen yield will be decreased with the decrease of carbon content, as reported by Jones [8]. With the aid of ArcSave® it is found that the mass transfer coefficient of carbon in the steel has been increased about 2 times compared with no stirring, as shown in Figure 5. In this figure, the initial carbon content in steel is in the range of 0.15~0.3% and the final carbon content is 0.08~0.12%. It is found that the oxygen yield have been increased with a 5% of total oxygen saving in the operation at SDI.

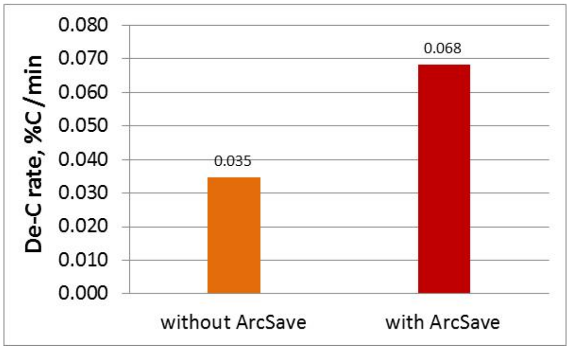


Figure 5. Effect of ArcSave® on the de-carburization rate in SDI furnace

## Steel De-oxidation

It is known that the bath stirring in EAF will push the carbon-oxygen reaction closer to the equilibrium value[9]. This has been proved by the test results from SDI. The tap oxygen was reduced from 618 ppm to 504 ppm with a slight tap carbon increase with ArcSave®, as shown in Figure 6. These results indicate that with the aid of ArcSave® it is possible to reach a low carbon and low oxygen at the same time. It is also seen that the $Fe_2O_3$ content in the slag is reduced 2.5% after ArcSave®. The 2.5% $Fe_2O_3$ reduction in the slag has been given a 0.2% of steel yield increase from the materials balance calculation. The steel yield increase will create a big scrap cost saving and conversion saving.

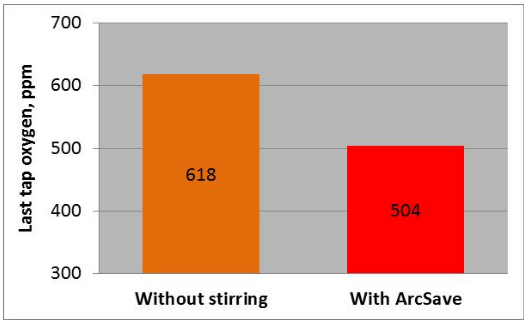


Figure 6. Effect of ArcSave® on the last tap oxygen in the steel in SDI furnace

## Vortex Formation and Slag Carryover

Theoretically, an Eccentric Bottom Tap (EBT) hole should have the feature of slag free tapping in EAF operation. However, slag carryover is always evident 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 occurred in the later stage of EBT tapping. The previous work carried out in ABB shows that the flow pattern induced by EMS in the melt bath has obvious influence on the EBT vortex formation[10]. Water modeling results show that vortex formation is mainly enhanced by vortices concentration above the tapping hole during tapping. ArcSave® induces a special flow dynamic that moves away vortices from the region above the EBT and thereby delays the vortex formation during tapping.

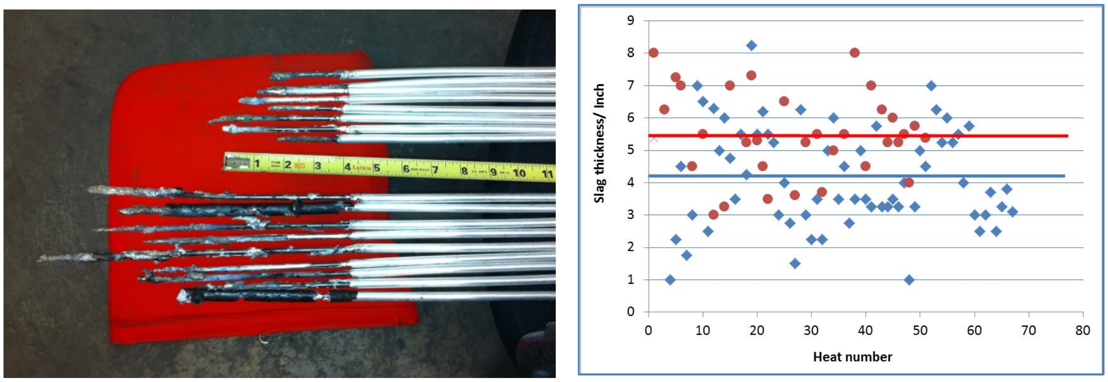


Figure 7. The slag thickness in the tapping ladle measured without (red points and line) and with (blue points and line) ArcSave®.

The slag thickness in the tap ladle was measured by Aluminum-Steel-Pole method and the results with and without ArcSave® is shown in Figure 7. As can be seen from Figure 7 (right) that the measured data were scattered but the average difference without and with ArcSave® is 1.2 inches. The scattering of the measured data could be explained by the different furnace tap operators, ladle lining age, and the measurement method itself. The reduction of slag carryover in the tap ladle has been further observed from the FeO content in the slag. The lower oxygen in the steel and the lower FeO content in the carryover slag will together contribute to the saving of de-oxidants in the downstream ladle refining process. The FeSi consumption was reduced 12% and $CaC_2$ was reduced 15%.

**Furnace Refractory**

Six months hot test results at SDI show that the stirring in the melt bath has reduced the furnace repairing refractory consumption some 15% compared to that without ArcSave®. The superheat reduction during power on by stirring under ArcSave® is probably the main contribution to the refractory repair savings since the most critical refractory damage is in the slag-line area. Another contribution to the refractory saving is the reduction of the FeO in the slag and the oxygen in the steel. It is known that the refractory wearing process is usually controlled by the dissolution of MgO (magnesia-carbon refractory). It is reported that the MgO solubility is reduced by a lower FeO in the metallurgical slags [11], as FeO is one of the most aggressive oxide for refractory wear. Therefore, the decrease of FeO content in the slag and the oxygen in the steel is probably another contribution to the less refractory wearing in the slag-line area. The third contribution to less refractory wear is the reduced tap temperature after ArcSave®, as shown in Figure 8. The tap temperature has been reduced 26 $^oF$ without affecting the ladle furnace arrival temperature. The elimination of thermal stratification in the melt bath would seem to reduce the tapping temperature. In the case of unstirred bath where, in general, the steel is hotter near the surface of the bath, the measured temperatures are frequently not representative of average of bath temperature. This implies that the decrease of the tapping temperature in the range of 20-30 $^oF$ with ArcSave® will not substantially change the energy consumption in EAF or ladle furnace. It can be concluded that ArcSave® has not created any negative effects on the bottom refractory lining but reduced the repairing refractory cost.

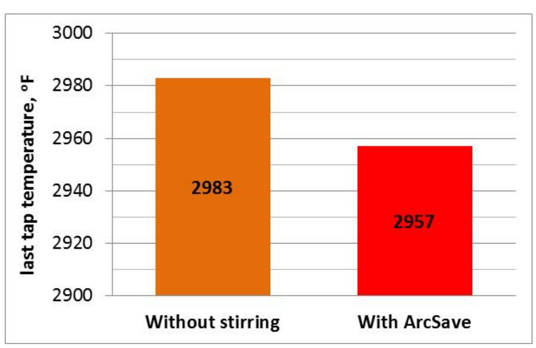


Figure 8. Change of tap temperature after ArcSave®

**Process Reliability and Safety**

Safety and reliability are always of great importance for EAF operation. The positive effect of ArcSave® on the EAF process discussed in the sections above will have a significant impact on improving process reliability and safety. The following process disturbances in EAF operation could be decreased or eliminated with the aid of ArcSave®:

1) Scrap cave-ins;
2) Un-molten big scrap or pig iron;
3) Carbon boiling-out
4) Not-targeted tapping weight and temperature;
5) Low EBT opening ratio;

It is reported by the Swedish steel plants that the EMS stabilized the electric arc and reduced scrap cave-ins during power-on period [12]. The fast melt-down of big scrap and ferroalloy will provide a quick homogenization of the melt bath on both chemical composition and temperature which will ensure the targeted steel tapping weight and temperature. The stirring in the melt bath will decrease the carbon boiling-out which is an advantage for pig iron charging practice. Homogeneous temperature in the whole bath including the EBT area will provide a high opening frequency of EBT and reduce the tapping delays. The EBT opening frequency was around 78% in average before ArcSave® and also there was a regular EBT cleaning needed every 4~5 heats with oxygen lancing. After ArcSave® the EBT cleaning activity is almost not necessary anymore and the EBT opening frequency is close to 100%, as shown in Figure 9. The time saving due to high EBT opening frequency and less EBT cleaning will give a productivity increase of about 1.5%. High EBT opening frequency is a very important benefit both for the operation safety and productivity

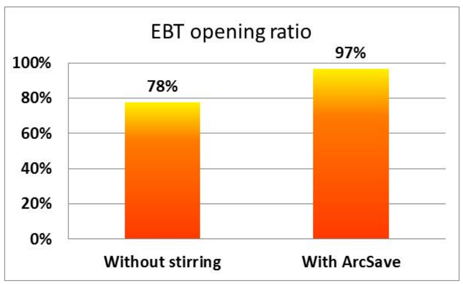


Figure 9. Change of EBT opening frequency after ArcSave®

**Ladle Furnace Operation**

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

## CONCLUSION

ArcSave® is a technology that helps the melting process to make liquid steel safer, quicker and with lower cost. ArcSave® improves the heat and mass transfer of EAF process, speeds up the scrap melt-down, accelerates the homogenization of the temperature and chemical composition of the steel bath, forces the metal/slag reactions closer to equilibrium state, increases the decarburization rate, and also improves the operation safety, reliability, and productivity. The ArcSave® impacts will be more significant on EAFs requiring more increase in productivity. As a summary, the proved process benefits obtained from SDI Roanoke plant test are listed in Table 3.

Table 3. Process benefits with ArcSave®

| Process items | Benefits |
|---|---|
| Total energy | - 3~5% |
| Electrode | - 4~6% |
| Power on time | - 4~6% |
| Oxygen | - 5~8% |
| De-oxidants | -10~15% |
| Steel yield | + 0.5~1.0% |
| Productivity | +4~7% |


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## REFERENCES


1. R. Stål, and C. Carlsson, ‘‘Electromagnetic stirring in electric arc furnace’’, Stahl und Eisen, vol. 129, No. 11, 2009, pp. 67-71.
2. O. Widlund, U. Sand, O. Hjortstam, and X.J. Zhang, Proc. of 4th Int. Conf. on Modelling and Simulation of Metallurgical Processes in Steelmaking (SteelSim), Metec InSteelCon 2011, Stahlinstitut VDEh, Düsseldorf, Germany, (2011).
3. X. J. Zhang, L. D. Teng, C. F. Lindberg, J. E. Eriksson, M. Lundh, Process Modeling and Simulation of EAF with electromagnetic stirring, MS&T14, Pittsburgh USA, 2014-10-14.
4. L. D. Teng, J. E. Eriksson, R. Badrinathan, O. Sjöden, A. Lehman, ‘‘Effect of Electromagnetic Stirring on the EAF Process’’, In: Proceeding of the International Conference on Science and Technology of Ironmaking and Steelmaking, December 16-18, 2013, CSIR-NML Jamshedpur, India.
5. E.H. McIntyre and E.R. Landry, EAF Steelmaking –Process and Practice Update, Iron & Steelmaker, vol. 17, No. 5 1993, 61-66.
6. S. Fornander and F. Nilsson, ‘‘Inductive stirring in arc furnace’’. Journal of Metals, vol. 188, No. 1, 1950, pp. 33-36.
7. P. Samuelsson, ‘‘ Energy saving using induction stirrer in an arc furnace’’, ASEA Journal, No. 5-6, 1985, pp. 18-23.
8. J. Jones, ‘‘Understanding Energy Use in the EAF: Practical Considerations and Exceptions to Theory’’, EAF Seminar at Jernkontoret, 2005, Stockholm, Sweden.
9. R.J. Fruehan, ‘‘The Making, Shaping and Treating of Steel (Steel Making and Refining)’’, vol. 2, pp.125-133
10. M. A. Rahmani, X. Zhang, O. Widlund, H. Yang, and J.E. Eriksson, C. Carlsson, “A Water Model Study of Vortex Formation and Prevention during Tapping of an EBT-type EAF’’, In: 8th International Conference on Clean Steel, 14 – 16 May 2012, Budapest, Hungary
11. Li Z.S., Mukai K., Tao Z.. Reactions Between MgO-C Refractory, Molten Slag and Metal, ISIJ International, 40 (2000), Supplement, S101-105.
12. H.F. Walther, ‘‘Induction Stirring Provides Better Control of Operating Techniques’’, Journal of Metals, vol.192, 1954, pp. 21-23.