New Generation in Pre-heating Technology
for Electric Arc Furnace Steelmaking

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INTRODUCTION

Increasing energy cost - electric energy as well as fossil energy - and increasing raw material cost are demanding actions from steel makers to reduce their conversion cost to gain a competitive edge. Using the chemical and latent energy of the off gas has been proven to reduce the total energy requirements in electric arc furnace operations. On the other hand, the threat of green house gases to climate change has captured not only the world’s attention but also that of engineering companies who provide EAF designs, as well as that of steel companies who use the Electric Arc Furnace to produce liquid steel.¹

The majority of global greenhouse gas emissions come from fossil fuel combustion for energy. About 30% of carbon emissions are generated by the industrial sector. This sector includes both Electric Arc Furnace steelmaking and electricity generation. The Iron & Steel Industry is particularly relevant in the climate debate because of the high energy input to produce the final product. For example, more than 50% of the energy used to produce rebar in Mini Mills is electric energy used in the EAF as shown in Figure 1.

This suggests that efforts to reduce Green House Gas emissions will impact electric steelmakers either directly or through electric power producers.

The scope of this paper is to explain different scrap pre-heating technology and to illustrate the benefits of scrap pre-heating for lower investment costs, greater production flexibility and lower environmental impact, as well as the latest developments in EAF meltshops regarding continuous charging of preheated scrap.
VARIOUS SCRAP PREHEATING SYSTEMS

Today's steelmakers are seeking for clever solutions to achieve more economical, ecological and flexible operations. These should be realized with less maintenance intensive equipments. These are the main objectives for maintaining commercial success and competitiveness within this sector. Continuing increase in electric energy costs, strict rules imposed on atmospheric CO2 emissions and ever tighter environmental regulations for land and waters lead the steelmakers to decrease their energy consumptions and to recycle the waste materials and medias. Scrap preheating has been used for over 30 years to offset electrical steel melting requirements. It normally involves the use of EAF hot off gas to heat scrap in the bucket, prior to its charging into furnace. The source of the hot gas can be either solely the off gas from EAF and/or gas from supplementary burner(s). The primary energy requirement for the EAF is for heating the charged scrap to its melting point. Thus, energy can be saved, if scrap is charged to the furnace hot. Preheating of scrap also eliminates the possibility of charging wet scrap into EAF and this eliminates the possibility of an explosion in the furnace, in case wet scrap deeps in liquid steel. Hence, preheating scrap also improves plant safety and accidental equipment damage. Scrap preheating reduces EAF electrical energy consumption and increases melt shop productivity.
Early scrap preheating systems used independent heat sources. The scrap was usually heated in the scrap bucket (Figure 2). Energy savings reported from this type of preheating were, as high as, max. 30 kWh/ton with associated reductions in electrode and refractory consumption due to reduced tap-to-tap times. As EAF fourth hole off gas systems were developed, attempts were made to use the EAF off gas for scrap preheating. A side benefit reported was that the amount of bag house dust decreased because the dust was sticking to the scrap during preheating. Scrap preheating with furnace off gas is difficult to control due to the variation in off gas temperature throughout the heat cycle. In addition, a temperature gradient forms within the scrap being preheated. Temperatures must be controlled to prevent damage to the scrap bucket and in order to prevent burning or sticking of fine scrap within the bucket.

A completely different approach was followed by Tenova with the CONSTEEL® process (Figure 3). This concept is focusing on the continuous charging of scrap to achieve scrap preheating, energy conservation and production increase. The key to obtain good operating results with this design is to control bath temperature, scrap feed rate and scrap composition. One of the advantages of this system is the fact that the scrap, which is partly preheated by the furnace off gas in a tunnel, is continuously fed into a large heel, allowing the operator to start the furnace with full power, assuming that the slag foaming is working. This is one of the reasons that the transformer can be 10% smaller, but the productivity is at least equal to a conventional arc furnace with a larger transformer. The stability of the arc, which is covered by the foaming slag throughout the process, reduces flicker, harmonics and noise.
With these two systems described above scrap temperatures can reach 315–450°C, (600–850°F), though; this will only occur at the hot end where the off gas first enters the preheater. Savings are typically only in the neighborhood of 15–40 kWh/ton. In addition, as operations become more efficient and tap-to-tap times are decreased, scrap preheating operations become more and more difficult to maintain. Eventually, scrap handling operations actually started producing reduced productivity and increased maintenance costs. Some of the benefits attributed to scrap preheating are increased productivity up to 10%, reduced electrical consumption, removal of moisture from the scrap, and reduced electrode per unit production.

Further preheating technologies are the FINGER SHAFT FURNACE by Siemens/VAI (Figure 4) and ECOARC by JP Plantech (Figure 5). The main benefits of both systems are to preheat 100% of the scrap and decrease the electrical energy consumption as well as electrode consumption. With the Finger Shaft Furnace energy consumption up to 70 kWh/t has been achieved. At the ECOARC Scrap is continuously fed into the preheating shaft and is in constant contact with the molten steel in the melting chamber. During the melting phase the furnace including the shaft is tilted backwards. An electric consumption rate of 150 kWh/t should be achieved with this furnace according to authors.

At both shaft systems the shafts are installed above the furnace shell which request higher meltshop buildings. Further disadvantage are the energy losses through the water cooled shaft and fingers which are in the range of 30 kWh/t.
Further preheating systems are not mentioned in this paper:

- BBS – Brusa Rotar Kiln Preheater
- IHI Shaft Furnace
- ESC – System
- Twin Shell Furnace

**EPC® SYSTEM / ENVIRONMENTAL PRE-HEATING & CONTINUOUS CHARGING SYSTEM**

In the steelmaking process, by scrap melting through Electric Arc Furnace route, substantial reduction in electric power consumption and associated increase in furnace productivity can be realized with Scrap Pre-heating Technique which pre-heats the scrap to about 700 - 800 °C by making use of the sensible heat carried in the furnace off gas. In this respect, KR Tec GmbH, which developed an “environmentally friendly” and “high efficiency” scrap preheating system to be “superior” over the existed systems developed so far.

This challenge led to the raise of a new and superior “Environmental Pre-heating and Continuous Charging (EPC®) System” (Figure 6). The EPC® System combine the advantages of 100% scrap preheating and continuous scrap feeding through its chambers, without the need of EAF roof and EPC® shaft opening. The EPC® System prevent totally, any dust emission and heat loss during furnace charging stage, as it is the case normally for other operations.
The EPC® System has many advantageous:

- **MINIMUM DUST EMMISION:** During charging procedure the system is always in a closed and airtight situation which results in minimum pollution level in the meltpool.

- **ENERGY SAVING:** The EPC® reduces the electric energy consumption by approx. 100 kWh/t compared to the conventional EAF.

- **INDEPENDENT SCRAP CHARGING:** Charging of the scrap basket is done with power-on and independently from the furnace operation. This improves the operation and reduces the power off time. Eliminating the need for EAF roof opening substantially reduces the heat loss from furnace.

- **LOW DOWNTIMES / MAINTENANCE & LESS HEAT LOSS:** No critical water cooled mechanical parts such as fingers, no need for conveyors and no extra water cooled parts requirements which may cause unforeseen stoppages, need intensive maintenance, and lead to excessive water cooling heat losses from the furnace.

- **HIGHER PRODUCTIVITY:** Due to shorter power-on and power-off times. The productivity of the furnace can be increased by 25% compared to the conventional EAF.
• LONGER EAF ROOF & ROOF DELTA LIVES: Due to, there is no need for opening/closing the furnace roof for charging and electric arc is always away from the roof, less arc damage results at roof WCP and the minimized thermal shock additionally helps in extending roof delta life.

• HIGHER RETURN ON INVESTMENT: The EPC® System features lower conversion cost due to the preheating effect. Furthermore higher productivity because of less power-on and power-off times is assured. Depending on the scrap quality, some yield gain can also be expected.

• LESS FLICKER: Related to the flat bath operation, preheated scrap and the constant energy input, a reduced flicker and harmonics level is reached up to 50%. This also leads to less arc noise generation.

• NO SCRAP TREATMENT: Due to the optimized shaft and telescopic feeder design, the EPC® - System does not require any special scrap treatment.

The new and superior EPC® System design considers the most flexible operational activities, its main features are:

• Flat bath operation with a hot heel between 30-40%.

• Controlled scrap charging rate through telescopic feeder system and integrated scrap weighing system.

• Continuous charging during power on optimized by the telescopic scrap feeding system.

• Scrap charging rate is tuned according to melting power/preheating temperature.

• Uniform and well controlled bath temperature.

• Well controlled preheating temperature.

• Minimized off gas volume related to airtight system.

Environmental benefits:

• Charging with closed system, into a separate compartment (EAF roof and EPC® - System are closed, de-dusting primary line is always on.
• Minimum fume emission during scrap charging

• Cleaner and safer working area

• min. 30% less off gas

• min. 30 % less dust at the filter

• Reduced arc noise level, (melting preheated scrap, melting flat bath conditions under foamy slag)

• Direct preheating, charged scrap is exposed to very high temperatures

• EPC® - System respects to most environmental standards.

Emission from steel making process is one of the biggest problems. Emission control regulations are worldwide getting tighter. In the EAF field, in a sense, power saving and scrap preheating are synonym. Various technologies have been developed to effectively preheat the scrap by the furnace exhaust gas. One of the issues of the EPC® System is to charge the scrap independent of the electric arc furnace melting by taking into consideration the environmental aspects. The preheating chamber of the EPC® is installed beside the EAF upper shell and the preheated scrap resides in this charged continuously, by the telescopic feeder system, into EAF for melting. This is while the furnace power is on. Even during charging of the scrap basket into the preheating chamber, the preheating chamber is closed with the hopper’s front wall and hence the furnace and preheating chambers are totally isolated. This ensures little or no dust escape during furnace charging. The scrap basket will be charged into the hopper of EPC® by opening top slide gate and while the charging hopper is positioned in the waiting deck. After charging, top horizontal slide gate is closed and the charged scrap inside hopper is in waiting position. Due to melting and preheating chambers are isolated during charging EPC®, melting and preheating don’t have to be interrupted. Then, the hopper is forwarded by two hydraulic cylinders towards over the preheating chamber, horizontally, and the scrap falls smoothly into the preheating chamber where it gets preheated. When the hopper is over preheating zone, its rear wall is closing the preheating chamber. A special design of the off gas duct together with a water cooled regulation flap allows to control the preheating effect in the preheating chamber. The scrap basket will be charged into the hopper of EPC® while it is positioned inside waiting deck. During charging, and when the charging hopper is positioned inside waiting deck, front wall of the hopper closes and isolates the preheating chamber and hence the melting process in EAF and the preheating don’t have to be interrupted. After filling the hopper by the raised scrap basket, the slide gate on top of the EPC® System is closed.
The EPC® System, currently developed, is a shaft type- preheat furnace, based on AC/DC technology. The furnace will maintain a large hot heel, nearly 40%, so that uniform operating conditions can be maintained. Steel is tapped out periodically via a bottom tap hole in the furnace. The scrap charging system consists of two main components, the preheating chamber with its telescopic feeder and the charging deck inside which a hopper operates. The scrap is fed into the upper part of the chamber from a receiving hopper. The exhaust gas from the furnace flows up through the chamber, preheating the scrap. Scrap preheating temperatures as high as 800°C can be achieved. Gas exit temperatures from the chamber are around 200°C. At the base of the preheating chamber, there is a Telescopic feeder system. These operate in two stages, allowing scrap feed into the furnace at a constant rate. Off gas leaves the top of the preheating chamber and flows to a bag filter. Some gas can be recycled to the furnace to regulate the inlet gas temperature to the preheater.

Scrap is fed continuously to the furnace until the desired bath weight is achieved. This is followed by a short refining and super heating period followed by tapping of the heat. Power input is expected to be almost uniform throughout the heat. Most furnace operations are fully automated. Charging rate of scrap into the preheating chamber is fully automated based on the scrap height in the chamber as well as temperature of the gas. Furnace feeding rate is interrelated to this, and to the actual power input. Carbon and oxygen injections are controlled based on the depth of foamy slag.

EPC® - System PROCESS STEPS (Figure 7)

**Step 1: Refining Phase**
- Preheating of scrap for next heat
- Telescopic feeder in back position
- 2nd scrap basket ready for charging
- Opening of slide gate for charging
- Charging of hopper in back position

**Step 2: After Tapping**
- Power on and start of melting on hot heel
- Start movement of telescopic feeder for scrap feeding
- Hopper front wall keeps shaft airtight while charging
- No interruption of off gas suction, no fume escape
- Independent charging/feeding and melting process
Step 3: Continuous scrap feeding/Preheating Phase

- Preheating of scrap while continuous scrap feeding
- Telescopic feeder in middle position
- Optimized scrap feeding in tunnel area with small feeder
- Rear wall of charging hopper keeps the shaft airtight
- Optimized suction/preheating from top of shaft

Step 4: Melting/Charging Phase

- Telescopic feeder allows scrap cave in tunnel area
- Telescopic feeder assures optimized off gas penetration
- Closed slide gate after scrap charging
- Hopper movement inside preheating chamber
- Independent scrap charging/feeding

Step 5: Scrap - Melting/Charging/Feeding Phase

- Preheating of scrap while continuous scrap feeding
- Telescopic feeder in front position
- Optimized scrap feeding in tunnel area with small feeder
- Rear wall of charging hopper keeps the shaft airtight
- Optimized suction/preheating from top of shaft

Step 6: Scrap - Melting/Charging/Feeding Phase

- Independent hopper movement into preheating chamber
- Independent scrap feeding by telescopic feeder
- Power On during scrap charging and continuous scrap feeding
- Hopper front wall keeps the shaft airtight while charging
- Optimized heat transfer from off gas

Figure 7. EPC® Process Steps
COMPARISON OF EPC® SYSTEM WITH CONVENTIONAL EAF, FINGER SHAFT AND CONSTEEL®

- EPC® System does not need high capacity on the secondary de-dusting for basket charging due to airtight system, no interruption of primary off gas suction (*). (Table I)

- CONSTEEL® requires to empty the furnace once a shift (refractory repair and hot heel management) and to run a conventional EAF process. Furthermore, the tunnel is open on both sides, which creates a lot of air ingress in the primary (**).(Table I)

- FINGER SHAFT has to open shaft during charging, the off gas suction is interrupted and the shaft is acting like a chimney and a lot of fume escapes during charging procedure into the meltshop (***) .(Table I)

- EPC® furnace is operated all time in flat bath conditions with foaming slag, like CONSTEEL®. This leads to the optimum metallic yield (FeO in slag and dust are under control) and reduction of Flicker.

- EPC® System has no energy losses while scrap charging related to the airtight system

- EPC® System is very flexible regarding charge mix and there is no special scrap limitation.

- EPC® System is installed on a weighing frame which gives in time the exact scrap weight in the shaft. The automation system calculates the weight of scrap feed into the EAF shell; so that the shaft can remain all time loaded with scrap for extending the preheating and the off gas energy is really used at the maximum.

- In CONSTEEL® only the top layer of scrap is preheated with the off gas, In the EPC® and FINGER SHAFT the off gas must cross the entire scrap pile.

- The EPC® System has no water cooled parts which are in contact with scrap. This reduces the energy losses to a minimum.

- No charging into the open vessel, thus no major dust formation and no pollution through organic substances which do not burn completely.

- With the EPC® System, minimum dust content inside the meltshop, which means reduced capacity at the secondary line of the filter plant (approx. 50%)

- The dust contains rather a lot of zinc and can normally be recycled in an economic manner.

- The overall dust quantity is considerably decreased (approx. 30%).

- Less energy consumption means less CO2 content at the stack and a further environmental protection (approx. 20%).
SUMMARY

Without doubt, current trends in EAF design indicate that high levels of both electrical and chemical energy are likely to be employed in future furnace designs. The degree to which form of energy is used over another will be dependent on the cost and availability of the various energy forms in a particular location. There are many new processes for steelmaking which are now being commercialized. In almost all cases the goal is to minimize the electrical energy input and to maximize the energy efficiency in the process. Thus, several technologies have attempted to maximize the use of chemical energy into the process. These processes are highly dependent on achieving pseudo equilibrium where oxygen has completely reacted with fuel components (carbon, CO, natural gas, etc.) to give the maximum achievable energy input to the process. Other processes have attempted to maximize the use of the energy that is input to the furnace by recovering energy in the offgases (Shaft furnace, Consteel, EOF). These processes are highly dependent on good heat transfer from the off gas to the scrap. This requires that the scrap and the off gas contact each other in an optimal way. All of these processes have been able to demonstrate some benefits. The key is to develop a process that will show process and environmental benefits without having a high degree of complexity and without affecting productivity. There is no perfect solution that will meet the needs of all steelmaking operations. Rather, steelmakers must prioritize their objectives and then match these to the attributes of various furnace designs. It is important to maintain focus on the following criteria:

Table I. Characteristic between EAF / Consteel® / Finger Shaft / EPC®

<table>
<thead>
<tr>
<th></th>
<th>Con. EAF</th>
<th>CONSTEEL</th>
<th>FINGER SHAFT</th>
<th>EPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power-off</td>
<td>Scrap basket 12-14 min</td>
<td>Continuous changing 6-8 min</td>
<td>Scrap basket fingers 12-14 min</td>
<td>Continuous changing 6-8 min</td>
</tr>
<tr>
<td>Pretreating</td>
<td>no</td>
<td>Low efficiency</td>
<td>Medium efficiency</td>
<td>Most efficient</td>
</tr>
<tr>
<td>Energy cons.</td>
<td>460 kW/ton</td>
<td>360 kW/ton</td>
<td>335 kW/ton</td>
<td>290 kW/ton</td>
</tr>
<tr>
<td>Gas supply</td>
<td>6 Nm³/h</td>
<td>3 Nm³/h</td>
<td>6 Nm³/h</td>
<td>3 Nm³/h</td>
</tr>
<tr>
<td>Required scrap density</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Metallic yield</td>
<td>0</td>
<td>+0.5%</td>
<td>+1%</td>
<td>+1%</td>
</tr>
<tr>
<td>Furnace captured</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Water-cooled parts</td>
<td>Panels</td>
<td>Car Tunnel</td>
<td>Shaft Fingers</td>
<td>No</td>
</tr>
<tr>
<td>Deducing capacity</td>
<td>100%</td>
<td>100% (**)</td>
<td>70% (**)</td>
<td>50% (*)</td>
</tr>
<tr>
<td>Building height</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Flicker</td>
<td>100%</td>
<td>approx. 30% less</td>
<td>approx. 50% less</td>
<td>approx. 40% less</td>
</tr>
</tbody>
</table>
• To provide process flexibility.
• To increase productivity while improving energy efficiency.
• To improve the quality of the finished product.
• To meet environmental requirements at a minimum cost.
• With these factors in mind, the following conclusions are drawn.
  • The correct furnace selection will be one that meets the specific requirements of the individual facility. Factors entering into the decision will likely include availability of raw materials, availability and cost of energy sources, desired product mix, level of post furnace treatment/refining available, capital cost and availability of a trained workforce.
  • Various forms of energy input should be balanced in order to give the operation the maximum amount of flexibility. This will help to minimize energy costs in the long run, i.e. the capability of running with high electrical input and low oxygen or the converse.
  • Energy input into the furnace needs to be well distributed in order to minimize total energy requirements. Good mixing of the bath will help to achieve this goal.
  • Oxygen injection should be distributed evenly throughout the tap-to-tap cycle in order to minimize fluctuations in off gas temperature and composition. Thus, postcombustion operations can be optimized and the size of the offgas system can be minimized. In addition, fume generation will be minimized and slag/bath approach to equilibrium will be greater.
  • Injection of solids into the bath and into the slag layer should be distributed across the bath surface in order to maximize the efficiency of slag foaming operations. This will also enable the slag and bath to move closer to equilibrium. This in turn will help to minimize flux requirements and will improve the quality of the steel.
  • The melting vessel should be closed up as much as possible in order to minimize the amount of air infiltration. This will minimize the volume of offgas exiting the furnace leading to smaller fume system requirements.
  • Scrap preheating provides the most likely option for heat recovery from the offgas. For processes using a high degree of chemical energy in the furnace, this becomes even more important, as more energy is contained in the offgas for these operations. In order to maximize recovery of chemical energy contained in the offgas, it will be necessary to perform post-combustion. Achieving high post-combustion efficiencies throughout the heat will be difficult. Staged post-combustion in scrap preheat operations could optimize heat recovery further.
  • Operations which desire maximum flexibility at minimum cost will result in more hybrid furnace designs. These designs will take into account flexibility in feed materials and will continue to aim for high energy efficiency coupled with high productivity. For example operations with high solids injection, iron carbide or DRI fines, may choose designs which would increase the flat bath period in order to spread out the solids injection cycle. Alternatively, a deeper bath may be used so that higher injection rates can be used without risk of blow through.
  • Operating practices will continue to evolve and will not only seek to optimize energy efficiency in the EAF but will seek to discover the overall optimum for the whole steelmaking facility. Universally, the most important factor is to optimize operating costs for the entire facility and not necessarily one operation in the overall process chain. Along with added process flexibility comes greater process complexity. This in turn will require greater process understanding so that the process may be better controlled. Much more thought consequently must enter into the selection of electric furnace designs and
it can be expected that many new designs will result in the years ahead. As long as there is electric furnace steelmaking, the optimal design will always be strived for.

All scrap preheating technologies if designed to the latest technical environmental standards help to reduce the energy consumption, increase the productivity of the furnace and based on a reduction in electrical energy reduce the Green House Gas emission. The EPC® - System developed by Technologies and KR Tec GmbH offer leading technology to optimize the productivity of an arc furnace, the conversion cost as well as minimize the emission of GHG into our environment.

ACKNOWLEDGMENTS

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