Information for steel plant managers

New Breaking Concept for Pollution control and Energy saving in steel production

Developed and assembled by eco-e AG
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MANAGEMENT SUMMARY

PREFACE

The world steel production comprises in 2015 approx. 1'300 Million tonnes. Steel is used in all kind of industries, such as automotive, construction, shipbuilding, machinery and tooling industries.

Steel is a recyclable material. The base materials of steel, carbon and iron are among the most abundant elements in the universe and the most abundant elements on earth.

For the production of 1 tonne of steel out of scrap (largest recyclable part of the waste) approximately 700 kWh are needed.

Since the 60’s great efforts to improve the Electric Arc Furnace (EAF) technology are ongoing.

The declared main objectives in EAF improvements are:

- Minimum specific energy demand
- Minimum electrode consumption
- Increase of productivity

SOLUTION

The proposed solution is the ultimate in waste heat recuperation and allows reusing most of the emitted heat. It resigns of all kind of mechanical elements in the flow of scrap and offers many safety and process advantages missed in the known solutions. All kind of emissions like smell, noise and wear are reduced and the transformation yield scrap to steel rises by more than 1.5%.

STEEL PLANT MANAGER’S VIEW

The proposed solution offers a quick return on investment (ROI) between 6 to 24 months after FAC depending on the plant size.

The proposed solution can be designed, produced, erected and started up within a 12 months’ period. The production interrupt is less than 30 days.

The achievable savings are: 10 to 16 €/t steel on the production side, 5 to 8 €/t on the overhead side and 5 to 10 €/t steel on the energy recuperation of the remaining heat.

The total investment for the proposed solution is approximately 5 Mio € depending of the plant size.

Interesting terms of payment.
2 TECHNICAL BACKGROUND

2.1 STEEL MAKING

We can subdivide steel making into two major routes – the ore route, where hot metal is made of iron ore, carbon and oxygen which is then refined by oxygen to steel and the recycling route, where scrap is molten with a lot of energy.

Initially, iron products, cast iron, forged steel, cast steel and rolled steel were mainly produced in integrated steel plants via the ore route. As more and more steel is produced, the amount of scrap raises consequently.

Actual estimations confirm a share of more than 40% of the world steel production (520 Mio t/y of 1'300 Mio t/y) being produced by recycling.

A typical recycling steel plant consists of: a scrap yard, Electric Arc Furnaces (EAF), secondary metallurgy consisting of a Ladle Furnace (LF), case wise of a vacuum degassing installation or other ladle treatment stations and a continuous caster.

With such a concise plant in general scrap can be transformed into semi-finished products.

Let’s concentrate on the recycling route.

2.1.1 State-of-the-art Electric Arc Furnace (EAF)

2.1.1.1 The thermal balance of an EAF

Since the 60’s the main objectives of technical improvements of Electric Arc Furnace (EAF) technology are:

- Minimum specific electric energy demand
- Minimum electrode material consumption
- Most important increase of productivity

![Thermal Balance Diagram]

Total energy input 700 kWh/t
El. energy input 60% = 420 kWh/t
Heat losses 37% = 256 kWh/t

Chemical Energy 35-40%
Steel 53%
Slag 10%
Electrical energy 60-65%
Heat 37%
The EAF consists of a lower part, i.e. the shell isolated by refractory bricks to contain the molten steel, a middle part consisting of water cooled panels and a top part, the cover to keep the hot off-gas and radiation heat inside the furnace. The cover usually has 4 holes, three for the electrodes, needed to produce the electric arcs and a fourth hole to evacuate the off-gas.

The size of the middle part is adapted to the scrap charging method - either a single bucket charge (very high middle part) or a 2- or 3- bucket charge. The advantage of the 1- bucket charge is that the cover has to be opened only once per heat, while two or three bucket charges need a corresponding number of cover openings. Each opening of the cover means a tremendous loss of heat energy, emission of dust and climate-wrecking gases resulting from burning varnish, oil, grease and plastics.

Nowadays, a state-of-the-art EAF filled with 2 to 3 scrap buckets per melt needs about 420 kWh/t electrical energy and about 280 kWh/t chemical energy (oxygen, carbon and natural gas), consumes about 1.5 kg/t electrode material and has a production time (Tap to Tap time) of about 48 min. This results in a productivity index of 1.25, e.g. an EAF of 100 t capacity can produce 125 t/h.

A single bucket charge furnace needs less energy, about 380 kWh/t and still about 280 kWh/t chemical energy, consumes about 1.6 kg/t electrode material, has a higher risk of electrode breaking due to the electrode length and some electromagnetic field effects and reaches a slightly lower production time of 44 min. (less cover openings (=less power off time)). This results in a productivity index of 1.36, e.g. an EAF of 100 t capacity can produce 136 t/h.

2.1.2 State-of-the-art scrap preheating

Continuously increasing electric energy costs has incited the engineers of the electric furnace producers to think about better use of the energy waste.

Scrap preheating has first been used in the 80’s. The first and yet still well working idea was the shaft furnace, invented and introduced by Mr. Gerhard Fuchs. The scrap preheating device consists of a vertical shaft with a retaining element on the bottom and a gate on the top. Through the top gate the cold scrap is charged. There are various types of shaft designs, above the furnace and beside it.

This preheating procedure normally involves the use of hot off-gas to heat the scrap prior to its charging into the furnace. Thus, energy usually released to the environment (37%) could partially be reused to flow through the scrap. This reduces the electrical energy input directly.

The scrap itself is hold back by hydraulically operated fingers and released into the furnace when required. These water-cooled fingers represent a weak point and an energy consuming item in the shaft construction, but are needed for preheating the scrap of the next heat.
2.1.2.1 The thermal balance of an EAF with scrap preheating

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percentage</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy input</td>
<td>70%</td>
<td>700 kWh/t</td>
</tr>
<tr>
<td>Heat recuperation</td>
<td>13%</td>
<td>92 kWh/t</td>
</tr>
<tr>
<td>Electrical energy</td>
<td>45%</td>
<td>315 kWh/t</td>
</tr>
<tr>
<td>Heat losses</td>
<td>14%</td>
<td>98 kWh/t</td>
</tr>
</tbody>
</table>

A well working modern EAF with scrap preheating needs about 315 kWh/t and about 280 kWh/t chemical energy (oxygen, carbon and natural gas), consumes about 1.4 kg/t electrode material and has a production time (Tap to Tap) of about 42 min. This results in a productivity index of 1.4, e.g. an EAF of 100 t capacity can produce 140 t/h.

2.1.3 Conclusion

As one may see out of the presented figures, there is an impressive difference between an EAF without scrap preheating and an EAF with scrap preheating. But there are more and more stringent environmental regulations which represent a problem to most of the existing scrap preheating projects. Consequently, there has to be a new, better solution to continue on this road.

2.2 Outlook

Today steel makers are seeking for economic, ecologically friendly and pragmatic solutions. These are the main objectives for maintaining commercial success and competitiveness in this sector.

There are various solutions available in scrap preheating, rendering good service at high maintenance costs, or maintenance poor solutions with some environmental issues and installations with limited productivity and solutions, which require new buildings and / or high revamping costs.

Mr. Gerhard Fuchs, consulting partner, bound to steel melting since 1964, has analysed all the existing scrap preheating solutions and has designed the ultimate solution.
2.3 THE ULTIMATE SOLUTION

2.3.1 ECOSHAFT®

The ECOSHAFT® is a consequent optimisation of the existing shaft furnace as installed and successfully operated many times all over the world.

In the shaft-furnace technology, the scrap is pre-heated using the off-gases of the furnace. Looking backwards among disadvantage of the earlier shaft-furnace technology were found in the charging process, the water-cooled finger system holding the preheated scrap and the discontinued scrap charging.

The ECOSHAFT® takes advantage of a new, brilliant idea of pre-heating the scrap in a non-vertical position. Doing so, the energy consuming since water-cooled and mechanically complicated finger system is omitted, and the charging of cold scrap is made in a partially isolated chamber. Thus, the hot off-gases are not escaping during charging cold scrap and the retaining valve opens as soon as the charging gate is closed, giving way to the hot off-gases passing through the cold scrap.

Compared to other scrap preheating solutions, ECOSHAFT® is the most effective energy-saving solution, brings most of the off-gas heat into the scrap and can use light scraps.

<table>
<thead>
<tr>
<th>Brand names</th>
<th>Unit</th>
<th>Consteel</th>
<th>Quantum</th>
<th>ECOARC</th>
<th>COSS</th>
<th>Finger Shaft</th>
<th>ECOSHAFT®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific el. energy input (kWh/t)</td>
<td>~380</td>
<td>~280</td>
<td>~280</td>
<td>~280</td>
<td>~320</td>
<td>&lt;260</td>
<td></td>
</tr>
<tr>
<td>Investment cost *) (calculated on a 120t EAF)</td>
<td>Mio €</td>
<td>&gt;20</td>
<td>&gt;20</td>
<td>&gt;20</td>
<td>&lt;15</td>
<td>&lt;12</td>
<td>&lt;12</td>
</tr>
<tr>
<td>Mechanical element to hold or transport scrap</td>
<td>-</td>
<td>Conveyor belt</td>
<td>Finger</td>
<td>Pusher</td>
<td>Pusher</td>
<td>Finger</td>
<td>No element</td>
</tr>
<tr>
<td>Number of preheating chambers</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Off-gas temperature leaving the system (°C)</td>
<td>&gt;750</td>
<td>&gt;750</td>
<td>&gt;750</td>
<td>&gt;750</td>
<td>&gt;750</td>
<td>&lt;450</td>
<td></td>
</tr>
<tr>
<td>Possibility to use all scrap qualities</td>
<td>-</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>

*) Greenfield installation
ECOSHAFT® is unbeatable in low cost, effectiveness and ease to maintain.

<table>
<thead>
<tr>
<th>Brand names</th>
<th>Unit</th>
<th>Consteel</th>
<th>Quantum</th>
<th>ECOARC light</th>
<th>COSS</th>
<th>Finger Shaft</th>
<th>ECOSHAFT®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific el. energy input</td>
<td>kWh/t</td>
<td>~380</td>
<td>~280</td>
<td>~280</td>
<td>~280</td>
<td>~320</td>
<td>&lt;260</td>
</tr>
<tr>
<td>Revamping of an existing furnace</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Maybe possible</td>
<td>Maybe possible</td>
<td>Possible</td>
<td>Possible</td>
<td></td>
</tr>
<tr>
<td>Investment cost *) (calculated on a 120t EAF)</td>
<td>Mio €</td>
<td>&gt;12</td>
<td>&lt;12</td>
<td>&lt;10</td>
<td>&lt;8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod. interrupt for erection</td>
<td>days</td>
<td>&gt;30</td>
<td>&gt;30</td>
<td>&gt;30</td>
<td>&lt;30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance frequency</td>
<td>Unknown</td>
<td>High</td>
<td>Unknown</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Lower shell exchange</td>
<td>Possible</td>
<td>Difficult</td>
<td>Difficult</td>
<td>Possible</td>
<td>Difficult</td>
<td>Easy</td>
<td></td>
</tr>
<tr>
<td>Dust tightness</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

*) Revamping of an existing 120t EAF

The main advantages of ECOSHAFT® are:

- **ECOSHAFT® offers a gas tight system**
  Almost no off-gas is emitted by the furnace, special attention is paid to the joint between furnace and shaft, to the slag door and to the electrode holes.

- **Optimized pre-heating**
  Pre-heated scraps should not be too hot (melting of thin scrap pieces) nor too cold (short dwell time). ECOSHAFT® allows optimizing the emitting off-gas temperature by melting burners and CO-post combustion burners.

- **No hydrocarbons and volatile organic compounds (VOC)** are emitted
  Hydrocarbons, dioxins and furans (PCDD/PCDF) are cracked by reheating and are then neutralized by active carbon or other methods.

- **Higher yield**
  Due to permanent arcing under foaming slag there is almost no iron oxide produced, thus the yield, i.e. the rendering of the scrap is higher.

- **Icy, snow laden scrap; no pressure leakage**
  Water can become a serious issue in electric arc furnaces, but not with ECOSHAFT®. During preheating, water which doesn’t evaporate will flow off the preheating drawer at the rear side. Cooled surfaces (panels) are pressure less.
- **Less dust**
  The dust passes through the preheated scrap, which acts as a filter, remains there and returns together with the scrap back into the steel bath.

- **No scrap pusher, no holding fingers**
  Mechanical parts need maintenance, especially when they are close to the molten steel.

- **Almost no scrap size limitation, use of light scrap is possible**
  The use of light scrap allows to reduce the prime costs.

- **Reduced construction height**
  **ECOSHIFT®** fits in almost all existing furnace situations without need for new buildings, crane tracks or special hoists.

### 2.3.1.1 The thermal balance of an ECOSHIFT®

<table>
<thead>
<tr>
<th>Energy Input 620kWh/t</th>
<th>El. energy input 42% = 260 kWh/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off gas (cleaned) 12% = 80 kWh/t for further use</td>
<td></td>
</tr>
<tr>
<td>Losses 5% = 31 kWh/t</td>
<td></td>
</tr>
<tr>
<td>Heat recuperation 20% = 124 kWh/t (~ 750°C) (estimated values)</td>
<td></td>
</tr>
</tbody>
</table>

We estimate, **ECOSHIFT®** has an electric energy input of 260 kWh/t, a consume of less than 1.0 kg/t electrode material, a shorter production time i.e. tap to tap of about 30 to 34 min. which raises the productivity index to 1.8 or higher, e.g. an EAF with **ECOSHIFT®** scrap preheating of 100 t capacity can produce 180 t/h.

## 3 Scope of an ECOSHIFT®

### 3.1 Modifications of the existing material

To add an **ECOSHIFT®** to an existing electric arc furnace there are a few modifications needed. On small furnaces the lower shell has to be modified by a kind of balcony. This is a minor work which can be made locally on a spare bottom part.
The middle part, the upper shell, needs to be modified in the area where the ECOSHIFT® is attached. As the upper shell consists of modular panels, this modification represents a kind of maintenance work like exchanging panels) and the preparation of a new frame of the upper shell. This work can also be performed locally.

The spare cover of the furnace has to be cut and adapted to allow an opening for the bottom part of the ECOSHIFT® to be installed thus replacing the fourth hole.

Cooling hoses and refractory bricking of the lower shell has to be modified – a periodical maintenance work made at the steel plant.

3.2 NEW MATERIAL

ECOSHIFT®, consisting of a reduced shaft, an elbow and a drawer type scrap container with a threshold flap for holding back the scrap when charging and limiting air inlet and off-gas escaping as well as a top gate for scrap charging. The ECOSHIFT® is sitting on support car where the lifting cylinder of the drawer box is attached. All together will come preassembled to site.

The connection part to the furnace, the steel structure for the ECOSHIFT® and the ductwork of between ECOSHIFT® and dust settling chamber/hot filter can be produced locally.

3.3 COST ESTIMATION

(Example for a 90t EAF with a yearly production of 800’000t)

Supply of an ECOSHIFT® including automatics approx. 7.5 Mio Euro
Modification at scrap yard and contingencies approx. 2.5 Mio Euro
Total investment approx. 10 Mio. Euro

4 SAVINGS

4.1 SAVING GROUPS

As described here above there are various savings achievable with ECOSHIFT®. First let’s look at the proven benefits of any shaft technology.

4.1.1 Scrap

Compared to the conventional, top charged EAF, the shaft technology and especially the ECOSHIFT® benefits of the almost continuous presence of foaming slag which covers the arc when arcing. This generates considerably less iron oxide (FeO), this means that the produced FeO in the arc plasma is recuperated in the steel bath and is not escaping with the slag. This effect, proven on existing shaft
furnaces and discussed in the specific literature counts as much as **1.5 to 2% yield** gain, or in other words the user of an **ECOSHAFT®** can save on scrap purchase.

Another, not to be forgotten factor is the scrap quality. Thanks to the design of the **ECOSHAFT®** light scrap, such as turnings and cutting waste can be used without restrictions. That might be another saving of some €/t.

### 4.1.2 Energy input

Due to the recuperation of the off-gas heat and the heat produced by the transformation of CO to CO₂ before entering the preheating drawer, the energy input, mainly electrical can be considerably reduced.

### 4.1.3 Electrode consumption

Less electrical energy input means consequently less electrode consumption. The saving potential is considerable.

### 4.1.4 Less dust

These costs are not directly countable to the production, even though there might be a certain filtering effect in the preheating drawer (steel wool effect) but they are among the overhead costs, listed as evacuation costs and maintenance of filter house and adjacent installations.

### 4.1.5 Less refractory wear and less furnace repair

This is a typical effect of the foaming slag technology and the continuous charge of scrap in the **ECOSHAFT®**. The number of ‘charges’ can be higher and the volume of the scrap basket is consequently smaller. Thus, a continuous charging effect during the melting phase could be achieved. This means less impact, less charges on the foundations and less splashes in the furnace. Usually these costs are comprised in the overhead costs as well.

### 4.1.6 Massive reduction of the off-gas volume

Due to the tightness of the **ECOSHAFT®** less cold air is sucked into the off-gas stream. There are less openings and as the partial pressure in the furnace is controlled the off-gas flow will decrease massively. This results in higher temperatures and a better yield of the off-gas energy, but it means also less ventilator power. Another overhead cost bullet.

### 4.1.7 Less flicker

Another side effect of the foaming slag technology is the reduction of the flicker effect. The reduced cost for grid compensation and losses in the installed reactor are considerable. These costs are usually listed in the overhead cost list as well.

### 4.1.8 Use of the remaining heat

Many approaches to reuse the hot off-gas produced in an EAF are documented, such as use for remote central heating, ORC-turbines to produce electric energy and other more creative ideas. All this is feasible together with an **ECOSHAFT®**. The off-gas filtering of **ECOSHAFT®** allows even to use dust clean off-gas for these applications, a fact that makes the heat transport easier compared to with dust laden off-gas. Here the benefit of this secondary application might be up the 10 €/t steel.
4.2 **SUMMARY OF SAVINGS**

Considering the three major saving groups we get the production savings:

<table>
<thead>
<tr>
<th>Based on a yearly production of 1'000'000 tonnes</th>
<th>Price / Unit</th>
<th>Savings *)</th>
<th>Basis</th>
<th>Savings €/t</th>
<th>Savings per year (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric energy</strong></td>
<td>0.07€/kWh</td>
<td>160 kWh/t</td>
<td>420 kWh/t</td>
<td>11.2</td>
<td>11'200</td>
</tr>
<tr>
<td><strong>Electrodes</strong></td>
<td>4.0 €/kg</td>
<td>0.5 kg/t</td>
<td>1.5 kg/t</td>
<td>2.0</td>
<td>2'000</td>
</tr>
<tr>
<td><strong>Production yield</strong></td>
<td>185 €/t</td>
<td>1.8%</td>
<td>87%</td>
<td>4.26</td>
<td>4'260</td>
</tr>
<tr>
<td><strong>Scrap (all scraps)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applies only in comparison with other preheating devices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Burners (melting and off-gas treatment)</strong></td>
<td>0.39 €/Nm³</td>
<td>-5 m³/t</td>
<td>5.3 m³/t</td>
<td>-1.95</td>
<td>-1'950</td>
</tr>
<tr>
<td><strong>Total savings</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>15.51</strong></td>
<td><strong>15'510</strong></td>
</tr>
</tbody>
</table>

*) Revamping of a 15-year-old EAF with 90t capacity and a mean electric energy input of 420 kWh/t (electrode consumption 1.5 kg/t) without scrap preheating.

The other savings, less dust, less maintenance, less wear, less repair, less flicker and less auxiliary power as well as possible saving on manpower due to improved automatics sum up to about 6 to 10 €/t makes a total of approximately **23 €/t steel**.
5 STEEL PLANT MANAGER’S VIEW

5.1 THE RETURN ON INVESTMENT (ROI)

The realisation of an ECOSHAFT® project comprises an engineering and realisation phase (1) and payback phase (2). The investment, step by step, covers phase 1. After PAC, the payback starts slowly as production ramps-up. ROI should be reached depending on the daily production within 6 to 18 month according to the savings calculation. It is advisable to clear in detail about the production and overhead costs in order to be able to evaluate the benefits of ECOSHAFT®.

5.2 EXAMPLE OF THE INVESTMENT AND THE PAYBACK

In the total cost of the installation, which amounts to Euro 10’000’000 is a large amount of locally fabricated parts and work that could be organized by the steel plant or in steel plant affiliated companies. In such a way, the direct investment lowers considerably.

Not considering the take-out of locally produced material, the investment graph would look like this (blue graph):

ROI would be reached in 12 months. Possible annual savings 11 Mio. Euro

We would be pleased to study your case in detail and make respective offers and cash flow calculations.