EVALUATION OF INTERNAL SLAG REUSE IN AN ELECTRIC STEELMAKING ROUTE: SIMULATION ANALYSES THROUGH THE EIRES MONITORING TOOL

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**World Steel Production**

- **70%**
- **30%**

**Main Feed**

- **Steel Scrap** $\to$ the *main raw material* (an end of life product) $\to$ in line with circular economy
- **Electricity** $\to$ *to melt* the scraps
- **Scoryfing agents** $\to$ lime, dolime, silica sand $\to$ *to remove* scrap contaminants
- **Iron Alloys** $\to$ *to achieve* the desired *steel composition*
Introduction

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Main By-Products and Wastes

- **Slags** → Electric Arc Furnace (EAF) and Ladle Furnace (LF) Slags → most important by-products in quantitative terms
- **Off-gases**
- **Sludges**
Introduction

EAF Slag
Main Components:
Iron and Calcium Oxides

LF Slag
Main Components:
Calcium, Silicum, Aluminium and Magnesium Oxides

Sources of valuable raw materials

Only in some cases this products are reused in the steelworks as raw material substitutes

Internal reuse can allow obtaining a lot of advantages

Variability of their composition

Not perfectly known effects on process behaviour, product yield and quality

Economic Advantages

Reduction of raw material exploitation

Environmental Advantages

Reduction of waste disposal

Reduction of waste disposal costs

Compliance with ever more stringent environmental regulations

The slag (or other by-products/waste) reuse could improve the Plant Sustainability and its Competitiveness following the Strategic Research Agenda of the European Steel Technology Platform
Introduction

Purpose of the work
Analysis of the process behavior, performance and steel composition when slags are reused in an Italian Steelworks

Case Studies
Replacement of lime and dolime by total LF Slag recovery (CS 1)
Replacement of lime and dolime by total LF Slag recovery and partial recovery of EAF slag (CS 2)

Two modules of the EIRES general purpose monitoring tool were used
KPI tool
Process Simulation tool

Evaluation of process modification on
production route
environmental impact
energy impact
steel quality
product yield
EIRES General Purpose Monitoring Tool

The EIRES general purpose monitoring tool allows:

- monitoring the behaviour of the plant in terms of sustainability in common and uncommon scenarios
- making online evaluations or offline simulations
- monitoring product quality in terms of steel composition

Only ASPEN® based-Simulation Tool and KPI tool were exploited in this work.

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Aspen®-based Simulation Tool \(\rightarrow\) three sub-modules:
- a production process model (the only one used in this work)
- a fumes network model
- a water network model

Production process model
- It was validated for 11 steel families that include steel grades with similar features
- Prediction error lies below the 2% for some parameters (e.g. EAF electric energy, steel quality and amount, temperatures during the process)
- For other parameters (e.g. amount of dust) the error is bigger but still lower than a threshold value
- it allows:
  - simulating the different steps of a real electric steel production route
    1. Electric Arc Furnace 
       Charge, Melting, Oxygen addition, Furnace opening, De-Slagging, Refining
    2. Ladle Furnace 
       Refining, De-Slagging
    3. Degassing (VD) if required and composition refining
    4. Continuous Casting (CC)
  - monitoring each mass and energy streams and transformations
  - controlling production yield and product composition
# EIRES Tool - Aspen®-based Simulation Tool

## Production process model

### INPUTS

<table>
<thead>
<tr>
<th>EAF</th>
<th></th>
<th>LF</th>
<th></th>
<th>VD</th>
<th></th>
<th>CC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrap Charge (different scrap types)</td>
<td><strong>Non-Scrap Charge (e.g. lime, anthracite)</strong></td>
<td>Burners (natural gas, oxygen)</td>
<td>Other additions (blowing graphite, oxygen)</td>
<td>Fe-Alloys during tapping</td>
<td>Temperature after melting (or EAF electric power)</td>
<td>Time of EAF Power ON</td>
<td>Fe-Alloys</td>
</tr>
</tbody>
</table>

### OUTPUTS

<table>
<thead>
<tr>
<th>Unit Operation</th>
<th>Output for KPIs</th>
<th>Other Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF</td>
<td>Electric Energy (or Temperature after melting)</td>
<td>Chemical Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy from Burners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAF slag</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric Energy (or Temperature input in VD/CC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass of Steel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Composition of Steel (also H₂ content)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mass and Composition of Fumes and Dusts before the fumes treatment</td>
</tr>
<tr>
<td>LF</td>
<td></td>
<td>Metallic Charge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LF slag</td>
</tr>
<tr>
<td>VD</td>
<td>Desired Steel</td>
<td>Non-Metallic Charge</td>
</tr>
<tr>
<td>CC</td>
<td></td>
<td>Output for KPIs</td>
</tr>
</tbody>
</table>

Simple **MS Excel® sheets** linked to the model by Aspen Simulation Workbook® represent the human machine interface (HMI) of the model.
EIRES Tool – KPI Tool

KPI tool allows:

- **providing the values of** some defined Key Process Indicators (**KPIs**) \(\rightarrow\) evolution of the environmental, energy and resources performance of the steelworks during common process or in case of modifications

- **obtaining global indexes** \(\rightarrow\) global view of the sustainability of the steelworks

**KPIs computed in this study:**

- **KPI\textsubscript{2}** required electric energy (ratio between the electric energy consumed in steel production and the amount of produced steel);
- **KPI\textsubscript{12}** specific non-metallic charge materials (ratio between weight of non-metallic charge materials and the amount of produced steel);
- **KPI\textsubscript{14}** metallic yield (percentage ratio between produced steel and the amount of metallic charge);
- **KPI\textsubscript{15}** specific EAF slag (ratio between the amount of EAF slag and the amount of produced steel);
- **KPI\textsubscript{18}** specific LF slag (ratio between the amount of LF slag and the amount of produced steel);
- **KPI\textsubscript{21}** total amount of slag (ratio between the total amount of produced slags and the amount of produced steel).
Simulation of internal reuse of slags

Simulations were carried considering one of the most produced steel family in the considered steel plant

<table>
<thead>
<tr>
<th>Steel Alloy Content [wt %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
</tr>
<tr>
<td>0.12–0.25</td>
</tr>
</tbody>
</table>

Simulations provided related EAF and LF slags’ compositions

Slags appear valid substitutes for some raw materials
Simulation of internal reuse of slags

Replacement of lime and dolime by total LF slag recovery (CS 1)

- LF was completely reused in the process but only a part of lime/dolime was replaced

Replacement of lime and dolime by total LF slag recovery and partial recovery of EAF slags (CS 2)

- EAF slag was added to LF slag in order to completely replace the lime/dolime

EAF charge phase

a. standard route

b. modified route
Simulation of internal reuse of slags

Replacement of lime and dolime by total LF slag recovery (CS 1)

**Positive effects**
- Reduction of non-metallic raw material feed (KPI12) → -18%
- No effect on metallic yield (KPI14)
- No effect on steel composition

**Negative effects**
- Slight increase of required electric energy (KPI2) → +2.5%
- Increase of produced slags (KPI7), especially of EAF slags (KPI13)

This scenario appears to be a good compromise between process efficiency and increased by product reuse.
Simulation of internal reuse of slags

Replacement of lime and dolime by total LF slag recovery and partial recovery of EAF slags (CS 2)

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   Positive effects
   - Reduction of non-metallic raw material feed (KPI$_{12}$) $\rightarrow -55\%$ $\leftarrow$ complete replacement of lime/dolime
   - Significant increase of required electric energy (KPI$_2$) $\rightarrow +7\%$ $\leftarrow$ bigger amount of matter to be melted

   Negative effects
   - Significant increase of produced slags (KPI$_{21}$) $\rightarrow$ increment of related management costs

   This scenario appears not economically and environmentally viable
Conclusions

Simulation studies were carried out through a general-purpose monitoring tool.

For one of the most produced steel family, simulated slags appear having high amount of valuable compounds (e.g. CaO, MgO).

The replacement of lime/dolime was evaluated by reusing LF slag with or without EAF slag.

LF slag could be a good material to replace partially lime and dolime, while maintaining a good steel quality and yield.

EAF slags addition into the process appears a not economically and environmentally solution.
Conclusions

The followed approach provides useful indications and information on non-standard scenarios preliminary to real plant implementation.

An early identification of most promising solutions is possible.

Risky and economically cumbersome plant trials related to non-viable options can be avoided.
Conclusions

Maximization of the internal reuse of by products and wastes in the electric steel cycle

Increasing the environmental sustainability of the production process

Increasing the electric steelworks competitiveness

This study is the starting point for deeper studies and real experimentations
Acknowledgments

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