Swedish Experience of Practical application of Process Integration

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What is Process Integration?

IEA:

“Systematic and General Methods for Designing Integrated Production Systems, ranging from Individual Processes to Total Sites, with special emphasis on the Efficient Use of Energy and reducing Environmental Effects.”

**Optimisation**: given a system or process, find the best solution to this process within given constraints.

**Objective function**: indicator of performance, e.g. emissions, energy, costs.

**Decision variables**: variables that influence process behaviour and can be adjusted for optimisation.
Holistic perspective for changes
- A standard European steel plant

Legends
- BFG: Blacksmith Furnace Gas
- COG: Coke Oven Gas
- BOFG: Blast Furnace Off Gas
- Natural gas
- Oxygen

Raw material available
- Sinter: 1111 kg
- Pellet: 341 kg
- Lump ore: 118 kg
- Coke: 345 kg
- PCI: 151 kg
- Scrap: 205 kg
- HM: 992 kg
- LS: 1081 kg
- Slab: 1053 kg

Unit: /t-HRC

Lime to BOF
Sinter to BF

COG
O₂

337.9 kWh
5.5 kWh

HRC: 1000 kg

pellet: 341 kg
Coke: 345 kg
Sinter: 1111 kg
PCI: 151 kg
Lump ore: 118 kg
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NG

Legends
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Holistic perspective for changes
- A standard European steel plant
PRISMA – Centre for Process Integration in Steelmaking

- System analysis & optimisation: 
  *Energy, materials, GHG*
- 7 Industrial members
- Joint research program

- Company specific program
- 10 full-time researchers
- External projects
- International networking
Communication and learning processes

Process Integration Forum

Annual Information and Project communication forum, open to everyone.
Production system models PRISMA

Scrap based steel production

Integrated steel production

Mining and benefication

CHP
Modelling tools used in the center

Optimization tools:
- Mathematical programming
- Pinch analysis
- Exergy analysis
- GAMS, etc.

Assisting tools:
- Aspen, FactSage, HSC, Matlab, Masmod, CFD, RIST, HEATSEP, etc.

Theory
- Heuristics
- Process data

reMIND
- Modelling
- Optimization
- MS Excel

Output
- Post processing
- Analysis

OK?

Results

\[ f(x, y) = cx + by \]

Minimize \( f(x,y) \)

Suggested solution

Modify

Analysis

Solution

MS Excel

Output

Post processing

Mathematical programming; Pinch analysis; Exergy analysis; GAMS, etc.

Assisting tools:
- Aspen, FactSage, HSC, Matlab, Masmod, CFD, RIST, HEATSEP, etc.

Secondary metallurgy
Ladle stirring

Open eye prediction with 2 gas injection points

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition</th>
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<tbody>
<tr>
<td>FeO</td>
<td>20%</td>
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<tr>
<td>SiO2</td>
<td>5%</td>
</tr>
<tr>
<td>MnO</td>
<td>1%</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.5%</td>
</tr>
<tr>
<td>S</td>
<td>0.2%</td>
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<table>
<thead>
<tr>
<th>Reduction degree</th>
<th>Calculated reduction degree</th>
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<tr>
<td>0</td>
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<tr>
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<td>0.3</td>
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<tr>
<td>0.4</td>
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Heat transfer model

Gas injection (CO2, H2O, TGR BF)

Hot metal & Slag

In the figure:
- The Hot Composite Curve
- Enthalpy vs. Temperature
- PINCH
- DTmin

Secondary metallurgy
Ladle stirring

- Open eye prediction
- 2 gas injection points

Metal reduction equation

- FeO + CO = Fe + CO2
- FeO + H2 = Fe + H2O

Metal removal equations

- Fe2O3 + 3CO = 2Fe + 3CO2
- Fe3O4 + 4CO = 3Fe + 4CO2

Coke ratio calculated

Feed CO2 and H2O ratios
Application examples of Process Integration

PRISMA projects in the area of

- Energy efficiency, and

- Material efficiency
Case studies at SSAB EMEA in Oxelösund, Sweden

Oxelösund’s integrated plant

- Coking plant
- Two blast furnaces
- Steel plant
- Rolling mill
- Power plant
- Own harbour
Change of hot stoves’ operation mode
- SSAB EMEA, Oxelösund

- **More energy to the hot stoves**
- **Less BFG to PP**
- **Possibility for increased hot blast temperature**
- **Reduced coke rate**
- **Improved process gas utilization**

- **Blast temperature**
  - calculated + 100 °C
  - achieved + 60 °C

- **Coke**
  - achieved – 9 kg/tHM·100 °C

- **Cost saving of 6.5 MSEK per year**
- **Non-investment cost!**

28 May 2012
Optimal coal injection at varying production rates

Question: How does different coal influence the operation costs?

- **Energy saving**
  - Less primary energy required and increased power generation
    - High heating value in the BFG when injecting the high volatile coal makes more COG gas available to the RF at RM, thus reducing the oil consumption.
    - The high volatile coal may lead to the highest electricity production in PP due to an increased energy in the BFG.
    - Fuel rate is slightly increased.

- **Cost saving**
  - High volatile coal most cost efficient at low production rate

Cost saving:
- 60-80 MSEK at a production rate of 1.5-2 Mton hot metal per annum
Case of Ruukki metals, Raahe Steelworks, Finland
- Optimised coal blending at the coking plant

Potential cost saving by optimised coal blending at the coking plant.

### Chart:

- **Coal blending reference case**
- **Coal blending optimized (cost) case**

### Table:

<table>
<thead>
<tr>
<th>Items</th>
<th>Opt. coal blending scenario, %</th>
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<tbody>
<tr>
<td>COG production</td>
<td>9.2</td>
</tr>
<tr>
<td>COG used at the rolling mill</td>
<td>19.9</td>
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<tr>
<td>Own Coke to BF</td>
<td>-1.0</td>
</tr>
<tr>
<td>Total purchased coke</td>
<td>8.0</td>
</tr>
<tr>
<td>LPG consumption at the strip mill</td>
<td>-28.7</td>
</tr>
<tr>
<td>Coal blending material cost</td>
<td>-5.7</td>
</tr>
<tr>
<td>Purchased electricity</td>
<td>-5.4</td>
</tr>
<tr>
<td>Coke production cost</td>
<td>-4.8</td>
</tr>
<tr>
<td>Total production cost</td>
<td>-2.6</td>
</tr>
</tbody>
</table>
Case of Stove oxygen enrichment (SOE) at different sites

Potential economical benefits and effects of SOE application at different steelworks under different conditions!

Evaluation 1: Fixed COG rate $\rightarrow$ highBl.temp $\rightarrow$ Coke/PCI saved

Evaluation 2: Fixed Bl.temp. $\rightarrow$ COG saving

COG saved for

- BF injection for coke saving
- Replace Oil/LPG/NG
- Power plant
- Hydrogen
- DRI production
Economical evaluation of SOE at Ruukki

Preferably use COG saved from hot stoves at the reheating furnaces to substitute LPG!

The cost saving are varying at different production rates!
Bird’s-Eye photo of SSAB EMEA Luleå
Distribution of COG saved in hot stoves at SSAB Luleå

(-6 °C; 153.3MW) ➔ (-11 °C; 183.8 MW)

Out door temperature, °C

Heat demand, MW

COG saved for BF injection or Power Plant, %

COG to BF inj. for coke saving

COG to PP

(6 °C; 153.3MW)

COG to BF/PP, %
Examples of material efficiency

- Ferrovanadium recovery from LD slag for the case of SSAB EMEA in Luleå

- Common Nordic solution
  - Regional efforts for untreatable wastes
LuVA/ViLD at SSAB EMEA, Luleå

- **Background**
  - High V in LD slag
  - Limits the LD slag external use
  - Meanwhile, valuable V product.

- **Aim**
  - Determine the best method to recover Vanadium

- **Method**
  - Modeling of different scenarios based on:
    a) Metallurgical knowledge
    b) Industrial trials with two-slag practice in LD
Results – LuVA/ViLD

▪ Optimal practice (based on LD trials and modeling)
  - Min V-content in HM (~0.36%) can be achieved by recycling of secondary, stored LD slag and secondary slag fines fraction.
  - Requires higher tolerance for P in the hot metal → lower tapping temp and no dolomitic lime in the LD.

▪ Consequences
  - Decrease of the LD slag storage,
  - Requires 100% MPBO pellet in the BF burden.
RHF – a common Nordic solution for untreatable wastes

Unit: kton/year

<table>
<thead>
<tr>
<th>Steelworks</th>
<th>Waste amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSAB EMEA, Luleå</td>
<td>60</td>
</tr>
<tr>
<td>SSAB EMEA, Oxel.</td>
<td>70</td>
</tr>
<tr>
<td>Ruukki</td>
<td>80</td>
</tr>
<tr>
<td>FN Steel</td>
<td>20</td>
</tr>
</tbody>
</table>

Graph showing:
- Landfill (kton/a) vs. Revenue - cost (M€/a)
- Data points for different locations:
  - Red - Location Ruukki
  - Blue - Location SSAB
  - Total landfill
  - Landfill at steel plants
Towards the industry symbiosis ...
On-going projects in the area of energy and CO₂ mitigation

- Biomass utilization in the BF
- Optimisation of BF hot stove operation
- Dry slag granulation and heat recovery
- Preheating and surface cleaning of scrap
- Reuse of low temperature heat (T< 350 °C)
- Process integration for resource management
- Flue gas recirculation with SOE - a new concept
- High efficiency low NOₓ BFG based combustion systems in steel reheating furnaces
Concluding remarks

- PI is a useful tool for the steel industry to improve its energy and material efficiency by finding optimal solutions in a most economic and sustainable manner.

- PI can be used for searching answers on strategic issues, e.g. how new processes will fit into the site, retrofit questions, investments, production planning, etc.

- The more complex the system, the higher probability to find new and improved solutions with a system oriented approach.

- Global integrated efforts are needed to further reduce CO₂ emission from the steel industry.
Thanks for your attention!

More information about Swerea MEFOS
Please visit www.swerea.se/mefos

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