Development of the Oxy-BF for CO₂ Capture Application in Ironmaking

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Outline

• Introduction
• ULCOS BF process concept (TGRBF)
• ULCOS BF Developments
• Experimental Blast Furnace
• EBF results
• CO2 emission reduction
• Conclusion and Next Step
History of ironmaking

First iron produced in Asia Minor (Turkey) 3000 B.C.

First iron produced by the Celts of Southern Britain 400 B.C.

Iron metallurgy brought to China via Scythes 800 B.C.

First iron weapons made by the Hittites (Turkey) 1800 B.C.

First iron casting in Western Europe 350

Asoka column of pure iron (Delhi) 300

Developing of the coking process and the use of coke in the blast furnace by Abraham Darby 1709

Begin of the modern blast furnace technology 1950

Early blast furnace in Sussex Weald 1480

First blast furnaces Han dynasty (China) 206 B.C.

Source: B. Korthas TKS
Developments of the conventional blast furnace ironmaking

475 kg/t HM

source: VDEh, Germany.
How can CO₂-emission from the blast furnace be reduced?

1st  Recycling of CO from blast furnace top gas

2nd  Capturing and storage of CO₂

3rd  Use of biomass

4th  Substitution of CO by H₂ for reduction

5th  Use of C-lean DRI, HBI or LRI

6th  Use of C-lean electrical energy
Conventional blast furnace

- **Partly reduced iron & biomass**
- **Energetic use of the top gas**
- **CO₂ capture & deposition**
- **Injection of hot reduction gas**
- **Biomass & hydrogen rich gas**
- **Waste plastic & animal grease**
- **Hot blast, moisture & oxygen**
- **Plasma torches**
- **Hot metal & slag**
- **Carbon input 407 kg/t HM**
- **Sinter, pellets, lump ore, flux & coke**
- **Scrap**
- **C-lean HBI, DRI**
- **CO, CO₂, N₂, H₂, H₂O & dust**
- **Coal or oil & oxygen**
- **natural gas, tar or COG**

**Carbon input**: 407 kg/t HM
History of alternative blast furnace processes

- 1920 Lance Hot reducing gas injection
- Mid 60’s CRM at Cockerill-Seraing (Belgium)
- Late 70’s Patent of Fink about a NFBF (Germany)
- 1984 NFBF-concept of Lu (Canada)
- Mid of 80’s Development of a NFBF by NKK (Japan)
- 1985 - 1990 HRG-trials at BF2 with recycling CO2 free topgas Toulachermet (Russia)

**Timeline:**
- 1920
- Mid 60’s
- Late 70’s
- Mid 80’s
- 1984
- 1985-1990
- 2004
The ULCOS project

• **Ultra Low CO$_2$ S teelmaking**

• Consortium of European steel companies
  • Aim: to decrease drastically (over 50 %) the CO$_2$ emitted by the steel industry
  • Budget: 60 M€
  • Numerous ideas to reach objective

→ **Modification of the conventional blast furnace to reduce the CO2 emission by 50 %**

Core members
Arce lorMittal
ILVA
LKAB
Rautaruulli Oyj
Saarstahl-DH
SSAB
voestalpine Stahl
Tata Steel
TKS
ULCOS BF Concept
The ULCOS Blast Furnace: Concept

- CO₂ removal from top gas
- Reheating of CO/H₂ gas
- Re-injection of CO/H₂
- Use of pure Oxygen
- Storage of CO₂ possible
The ULCOS Blast Furnace

• Benefits
  • 25 % less carbon usage
  • 60 % CO₂ reduction with CO₂ storage application
  • 35 % coke rate reduction
  • Productivity increase (to be determined)

CO₂ mitigation ~25 % at the BF

~55-60 % for the whole plant
ULCOS BF Developments
The Ulcos Blast Furnace Concepts

Coke

Top gas (CO, CO2, H2, N2)

Gas cleaning

Gas net (N2 purge)

CO2 scrubber

CO2 400 Nm3/t

CO, H2, N2

Gas heater

Re-injection

V4 900 °C

V3

V1 900 °C

1250 °C

25 °C

Expected C-savings

25 %

24 %

21 %
Developments

- Process conditions TGR BF
- Behaviour of existing raw materials
  - Ferrous (Sinter and Pellets)
  - Injection coals
- Raceway conditions and tuyere design
- Shaftgas heating
- CO$_2$-removal unit
- Design, engineering and modification of the EBF and its process
  - Start up and shut down procedure
  - Safety study

**Effect of shaft injection level**

**Reduction tests under TGR BF conditions**
Design, Engineering and Modification of the Experimental BF

Sinter/Pellets/Lump ore → Coke
Coal → Cold O₂

Coke → Top gas to export
CO₂ → CO₂ to storage

900°C
1200°C

Gas heater
Slag & Hot Metal

CO₂ Removal

1
2
3
The ULCOS Blast Furnace concept at EBF in Luleå

Sinter, pellets & coke

Gas cleaning system

BF gas
max. 2900 m³/h

VPSA

Tail gas

Product gas

Pebble heater

Hot metal & slag

O₂
max. 500 m³/h

Coal 170 kg/t HM

Product gas

BF gas

O₂
max. 500 m³/h

Coal 170 kg/t HM

Pebble heater

Gas cleaning system

BF gas
max. 2900 m³/h

VPSA

Tail gas

Product gas
### ULCOS Blast Furnace EBF campaigns

- 6 weeks test started Sept. 24, 2007
- 6 weeks test started Oct. 21, 2009
- 6 weeks test started Oct. 18, 2010
  - Production rate constant
  - Maximise gas injection rate

### Campaign Details

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<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
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<tr>
<td>Conventional start up</td>
<td>Reference Period</td>
<td>Stoppage: connecting the VPSA</td>
<td>Stoppage: Open shift tuyeres</td>
<td>Period of TG recycling Version 3</td>
<td>Period of TG recycling Version 4</td>
<td>Optimisation coal rate</td>
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<tr>
<td>Pellet Operation</td>
<td>Sinter and pellet Operation</td>
<td>Quench</td>
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### Technical Details

- Working volume: 8.2 m³
- Hearth diameter: 1.2 m
- Working height: 5.9 m
- Production: 35-40 t/day
- 3 tuyeres: 54 mm
- Top pressure: 1.5 bar (op)

- Reducing agents: 500-530 kg/t HM
- Tap to tap: 60-80 min
- Typical tap time: 5-10 min
- 5 workers/shift
- Normal campaign length: 8 weeks
ULCOS BF EBF Results
Basic operation data:

- Productivity = constant = 1.5 thm/h
  - (the possible effect of recycling on productivity was not in the scope of the test campaigns)
- Furnace charge: 70% sinter + 30% pellets
- Reference coal injection levels: 130 and 170 kg/thm
Blast Furnace and VPSA results

- No safety issue recorded.
- The EBF operation was very smooth:
  - constant productivity (production was not an aim)
  - smooth burden descent
  - good hot metal quality
  - high thermal stability
  - nearly no equipment failure
  - BF recovery after shut-downs was easy
- VPSA operated without any failure and with the required gas quality:
  - Recycling ratios up to 90% were possible;
  - It always provided the required gas amount and the required gas quality ($\text{CO}_2 < 3\%$);
  - The CO recovery was 88%.
- Good connection between EBF and VPSA
K-20 results: reductant rate, recycled gas injection and carbon saving

Reductant Saving K-20

![Graph showing reductant rate and carbon saving over time]

Reference Version 3

Version 4
K-23 results: reductant rate, recycled gas injection and carbon saving

Reductant Saving K-23

[Graph showing reductant rate and carbon saving over time for different versions: reference, Version 3, and Version 1.]
BF Results:
Carbon input and gas injection

CO + H2 as injected [Nm³/thm]
Carbon input [kg/thm]

Reference
Version 1
Version 3
Version 4

K 23: V3
BF results:
Carbon savings

The carbon savings are:

- In terms of (coke + coal): up to 140 kg/thm
- In terms of carbon: up to 129 kg/thm
- Results are in agreement with model calculations

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<th>K-23</th>
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<tr>
<td></td>
<td>Version 3</td>
<td>Version 4</td>
</tr>
<tr>
<td>Carbon saving [%]</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>Top gas recycle ratio [%]</td>
<td>72</td>
<td>90</td>
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</tbody>
</table>
BF quench results: Burden Material

Reduction profile:
- centre working furnace
Similar behavior as in conventional BF:
- Strength index shows linear trend with reduction degree;
- sinter disintegration

Reduction degree of sinter and pellet samples north-axis
CO₂ Emission Reduction
Oxy Blast Furnace
Carbon saving and CO$_2$ reduction

- A 24% C-saving/tHM at the BF should be feasible
- A 15% reduction of CO$_2$/tHRC emission should be feasible
CO₂ emission reduction

Total reduction of CO₂ emissions in percentage of the reference period

- CO₂ mitigation assuming VPSA tail gas storage
- Reduction of CO₂ emission in BF

Reduction of CO₂ emission [%]

Gas recycling at hearth tuyeres

Gas recycling at hearth & shaft tuyeres
Next Step and Conclusion
Scale up to industrial

The campaigns showed the possibilities of the ULCOS Blast Furnace for:

- Industrial operating point
- Safe closed loop operation
- Gas preheating
- Topgas de-CO$_2$
- Thermal control
- Reduction of ores in the shaft
- Low coke rates

Special attention for:

- Tuyere technology (product gas + Oxygen + Coal)
- Shaft gas injection, distribution of gas over radius
- Product gas heating
CO₂ emissions of the steel plant: -60%

-100 kg coke/t steel

Full CCS demonstrator in Florange, NER-300 proposal

Underground storage of CO₂
Conclusions ULCOS BF

- It has been possible to Oxy BF process concept at the EBF;
- No safety issue has been recorded with the new process;
- The EBF and VPSA operations were smooth with good results;
- Three different blast furnace concepts has been developed;
- The Carbon savings were up to 24 %;
- The VPSA plant was able to remove CO₂ efficiently from BF topgas;
- Campaigns showed that conventional burden material can be used.
- For the steelmaking site, with the application of CO₂ capture and storage saving of 60% is possible;
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2004

2007 – 2010 BF Campaigns with the CCS concept at the EBF (Zweden)

2015 – …. Demonstration of TGR BF in Florange (NER300) (France)
Thank you for your attention

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For more info on Ulcos: WWW.ulcos.org