Development of ULCOS-Blast Furnace:
Working toward technology demonstration
The ULCOS-BF developments in Europe

ir. Jan van der Stel

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Outline

• Introduction
• ULCOS
• ULCOS BF process concept (TGRBF)
• ULCOS BF Developments
• Demonstration of the ULCOS BF process concept at pilot scale
• ULCOS BF Experimental Blast Furnace results
• CO2 emission reduction
• Next Step and conclusion
1. Introducción
1.1. An integrated steel mill has numerous facilities to come from ore and coal to steel products.
1.2. Main CO₂ emitters

Source: IEA CCS workshop November 2011
1.3. BF main input & outputs

- Hot metal: 1 t
- Slag: 0.3 t
- BF Coke: 0.3 t
- Iron ores: 1.6 t
- Gas: 1500 m³
- CO₂: 1.4 t
- Coal Injection: 0.2 t
- Air: 1000 m³
- Slag: 0.3 t
- Hot metal: 1 t

- ~65% of plant emissions
2. ULCOS
2.1. ULCOS – Ultra Low CO₂ Steelmaking

- Reducing number of Blast furnaces in Europe
- Increasing productivity
- Increasing CO₂ concentration in the atmosphere
- Close to theoretical minimum regarding reducing agents
- BF is main producer of CO₂ within integrated steel works
- Small possibilities to reduce CO₂ emissions with existing blast furnace operation

Evolution of Hot Metal Production in the EU 15

ULCOS chart showing reduction of CO₂ emissions.
ULCOS – Ultra Low CO₂ Steelmaking

• Program launched in 2004
• 48 companies including all major steel producers from 15 European countries
• Aim to reduced CO₂ emissions by more than 50%
• Breakthrough technologies
  • ULCOS-BF
  • HISARNA
  • ULCORED
  • ULCOWIN/ULCOLYSIS
• Phase 1 ended in 2010
2.2. ULCOS – Process routes

- Coal and sustainable biomass
- Natural gas
- Electric Power

ULCOS BF

- Revamped BF/DR
- Brownfield/Greenfield
- CCS technology
- Carbon lean electricity
2.3. The ULCOS project objective

Modification of the conventional blast furnace to reduce the CO₂ emission by 50% per ton of steel
2.4. How can CO$_2$-emission from the blast furnace be reduced?

1$^\text{st}$ Recycling of CO/H$_2$ from blast furnace top gas

2$^\text{nd}$ Application of Capturing and Storage of CO$_2$

3$^\text{rd}$ Use of biomass as a CO$_2$ neutral carbon source

4$^\text{th}$ Substitution of CO by H$_2$ as reducing agent

5$^\text{th}$ Use of C-lean DRI, HBI or LRI

6$^\text{th}$ Use of C-lean electrical energy
2.5. History of alternative blast furnace processes

- 1920 Lance Hot reducing gas injection
- Mid 60’s CRM at Cockerill-Seraing (Belgium)
- Mid of 80’s Development of a NFBF by NKK (Japan)
- 1984 NFBF-concept of Lu (Canada)
- Late 70’s Patent of Fink about a NFBF (Germany)
- 1985 – 1990 HRG-trials at BF2 with recycling CO2 free topgas Toulachermet (Russia)
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2004
3. ULCOS TGR BF Concept
3.1 The ULCOS Top Gas Recycle Blast Furnace Concept

- CO$_2$ removal from top gas
- Reheating of CO/H$_2$ gas
- Re-injection of CO/H$_2$
- Use of pure Oxygen
- Storage of CO$_2$ possible
• **Benefits**
  - 25 % less carbon usage
  - 60 % CO\textsubscript{2} reduction with CO\textsubscript{2} storage application
  - 35 % coke rate reduction
  - Productivity increase (to be determined)
4. ULCOS BF Developments
4.1. Tests and planning prior to an Experimental Blast Furnace campaign

- 4 different ULCOS-BF concepts developed
- Recirculation of blast furnace top gas
- VPSA/PSA operation + CCS
- Injection of decarbonated top gas
  - Shaft
  - Tuyeres
  - Temperature
- Mathematical modelling to find process with highest carbon saving potential
- Process modelling according to data from a commercial European BF
- Laboratory testing
### 4.2. Tests and planning prior to an Experimental Blast Furnace campaign

<table>
<thead>
<tr>
<th></th>
<th>Version 1</th>
<th>Version 3</th>
<th>Version 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft tuyeres</td>
<td>900°C</td>
<td></td>
<td>900°C</td>
</tr>
<tr>
<td>Hearth tuyeres</td>
<td>25°C</td>
<td>1200°C</td>
<td>1200°C</td>
</tr>
<tr>
<td><strong>Gas distribution</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft tuyeres</td>
<td>80%</td>
<td></td>
<td>Optimized according to process</td>
</tr>
<tr>
<td>Hearth tuyeres</td>
<td>20%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td><strong>Concerns</strong></td>
<td>Small raceways</td>
<td>PCI combustion at low RAFT</td>
<td>Effect and position of shaft injection</td>
</tr>
<tr>
<td><strong>Calculated c-savings (%)</strong></td>
<td>21</td>
<td>25</td>
<td>26</td>
</tr>
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</table>
4.3. Developments

Behaviour of existing raw materials

[Graph showing temperature and CO2 levels over time]
4.3. Developments
Raceway conditions and tuyere design

Temperature distribution in the tuyere and raceway region (version 4)

Lance design for coal and oxygen injection

Test results at the TS single tuyere rig (TTC)
4.4. Preparations prior to the ULCOS trials

- Extensive HAZOP studies
- Erection of an PSA/VPSA plant on site – Air Liquide
- **Modification** of existing EBF equipment
- Installation of new EBF equipment
- **Simulated** ULCOS-BF operation using cold nitrogen
- **Training** of personnel

![Diagram of ULCOS-BF process](image.png)
4.5. 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

- Coal 170 kg/t HM

- Hot metal & slag

- O₂
  max. 500 m³/h
5. ULCOS BF EBF Campaigns
5.1. LKAB Experimental Blast Furnace, EBF

Production 36 tHM/day
Fuel rate ~540 kg/tHM
Injectants Coal, oil, gas, etc.
Top pressure 1,2 barG
Blast temp. 1200°C
Oxygen in blast 21-40%

Tuyeres 3
Hearth diameter 1,2m
Working volume 9m³

Flexible sampling possibilities
- In-burden probes
- Basket samples
- Quench and Excavation
5.2. Operating successful trials

- 3 ULCOS BF trials operated in the EBF in 2007, 2009 and 2010
- Varied BF operation tested:
  - Amount of recirculated gas;
  - Coal injection (130 and 170 kg/tHM);
  - Distribution (70% Ruukki sinter / 30% LKab pellets);
  - Temperature;
- Quenching and excavation of the blast furnace shaft after each campaign;
- Process evaluation of blast furnace and VPSA/PSA unit
- Metallurgical and mechanical testing of burden material samp
6. ULCOS BF EBF

Results
6.1. 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
6.2. Evaluation of process and equipment
Excavation of the Experimental BF

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
6.3. Evaluation of process and equipment K-20 results:
reductant rate, recycled gas injection and carbon saving

Reductant Saving K-20

<table>
<thead>
<tr>
<th>Operating time</th>
<th>Reductant rate [kg/tHM], Recycle gas [NMO/tHM]</th>
<th>Carbon saving [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>27/09/2007</td>
<td>Coal and coke</td>
<td>0</td>
</tr>
<tr>
<td>07/10/2007</td>
<td>Recycle gas</td>
<td>10</td>
</tr>
<tr>
<td>17/10/2007</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>27/10/2007</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>06/11/2007</td>
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Version 3

Version 4
6.3. Evaluation of process and equipment K-23 results:
reductant rate, recycled gas injection and carbon saving

Reductant Saving K-23

<table>
<thead>
<tr>
<th>Operating time [day]</th>
<th>Reductant rate [kg/THM]</th>
<th>Recycle gas [Nm3/THM]</th>
<th>Carbon saving [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/10/2009</td>
<td>1200</td>
<td>-30</td>
<td>6.3</td>
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<tr>
<td>27/10/2009</td>
<td>1000</td>
<td>-20</td>
<td>5.2</td>
</tr>
<tr>
<td>03/11/2009</td>
<td>800</td>
<td>-10</td>
<td>4.3</td>
</tr>
<tr>
<td>10/11/2009</td>
<td>600</td>
<td>0</td>
<td>3.4</td>
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<tr>
<td>17/11/2009</td>
<td>400</td>
<td>10</td>
<td>2.5</td>
</tr>
<tr>
<td>24/11/2009</td>
<td>200</td>
<td>20</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Reference Version 3 Version 1
6.3. Evaluation of process and equipment K-25 results:
reductant rate, recycled gas injection and carbon saving

![Graph showing reductant saving K25](image)

- Coke and coal
- Recycle gas
- Saving

**Operating time**

- 17/10/2010 to 06/12/2010

**Reference vs. Version 4**

- Version 4
7. CO$_2$ Emission Reduction
7.1. BF Results: Carbon input and gas injection

![Graph showing carbon input vs. CO + H2 as injected for different versions.]

- **Reference**
- **Version 1**
- **Version 3**
- **Version 4**

**K 23: V3**
7.1. 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
- In terms of coal and coke usage: up to 24%
7.2. CO₂ emission reduction

- Reduced emissions by 23% in version 4 for EBF case
- Evaluation of VPSA/PSA + CCS indicates possible reduction of CO₂ emissions by up to 50%

CCS technology needed to reduce CO₂ emissions by 50%
8. Next steps and Conclusion
8.1. Scale up to industrial

The campaigns showed the possibilities of the Top Gas Recycling Blast Furnace for:

- Industrial operating point
- Safe closed loop operation
- Gas preheating
- Topgas de-CO₂
- 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
8.2. Next steps

- ULCOS phase II
- Demonstrator plant on industrial scale for version 4
  - In a production Blast Furnace in Europe
- CCS storage of CO$_2$ should be included for the tests at demonstrator scale
1985 – 1990 HRG-trials at BF2 with recycling CO2 free topgas Toulachermet (Russia)

Mid of 80’s Development of a NFBF by NKK (Japan)

1984 NFBF-concept of Lu (Canada)

Late 70’s Patent of Fink about a NFBF (Germany)

1920 Lance Hot reducing gas injection

Mid 60’s CRM at Cockerill-Seraing (Belgium)

Demonstration of TGR BF

2007 – 2010 BF Campaigns with the CCS concept

2004
8.3. Outlook – ULCOS II

CO₂ emissions of the steel plant: - 60%

Full CCS demonstrator in Florange, LRF3-300 proposal

Withdrawn
Conclusions ULCOS TGR BF Developments

- It has been possible to apply the Top Gas Recycling Blast Furnace 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;
  - High recycling ratios;
  - Closed loop operation;
  - Gas quality according to set values.
- Three different blast furnace concepts has been developed;
- Achieved results close to modelled expected values
- The Carbon savings were up to 24 %;
- The VPSA plant was able to remove CO$_2$ efficiently from BF topgas;
- Campaigns showed that conventional burden material can be used;
- Calculations for industrial applications indicate that a reduction of CO$_2$ over 50%/tHRC could be achievable;
- Next step for technological developments: Demonstrator plant on industrial scale for version 4 on a full Production Blast Furnace
TGR –BF team members

- J. van der Stel, M. Hattink (Tata Steel RD&T, The Netherlands)
- D. Sert, J. Borlee (ArcelorMittal, France)
- A. Hirsch (TKS Europe, Germany)
- R. Lin, A. Feiterna, (Saarstahl/Dillinger Hüttenwerke, Germany)
- N. Ecklund, M. Pettersson (Lkab, Sweden)
- L. Sundqvist, B.-E. Sköld (Swerea Mefos, Sweden)
- J. Lovgren (SSAB, Sweden)
- M. Zagaria (Riva, Italy)
- C. Feilmayr (voestalpine, Austria)
- M. Grant (Air Liquide, France)
- O. Ansseau (CRM, Belgium)
- M. Sihvonen (Rautaruukki Oyj, Finland)
- J. P. Simoes (Paul Wurth, Luxembourg)
- J. Adam (BFI, Germany)
- W. Küttner, R. Schott (Küttner, Germany)
- A. Babich, S. Born (RWTH Aachen, Germany)
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For more info on Ulcos: WWW.ulcos.org