The Blast Furnace Process
- Requirements on coke

Verfahrenstechnik und Chemieingenieurwesen in Stahlindustrie und Kokereitechnik
18. November 2014, TU Clausthal

Prof. Dr.-Ing. Peter Schmöle
Head of Competence Centre Metallurgy, ThyssenKrupp Steel Europe

Introduction
- The blast furnace process
- Roles of coke
- Flooding effects
- Blast furnace performance
- Conclusion
Introduction

The speaker

• Studies of ferrous metallurgy and Dr.-Ing. at the TU Clausthal

• Started the industrial career in 1983 with Hoesch Stahl in Dortmund
  ➢ Process technique steel making (BOF shop)
  ➢ General manager for the hot metal production in the BF works Phoenix and Westfalenhütte and for the energy division of the integrated works of Hoesch-Hüttenwerke

• Since 1997 with ThyssenKrupp Steel in Duisburg
  ➢ Head of hot metal technology
  ➢ Deputy leader hot metal division
  ➢ Head of Competence Centre Metallurgy

Introduction

World crude steel production and metallic charge, 2013

![Bar chart showing percentages of different steel production methods and metallic charges.](chart.png)
Introduction
World crude steel and hot metal production

![Graph showing world crude steel and hot metal production](image)

Consumption of reducing agents in German blast furnaces

Total: 504.6 kg / t HM in 2013
Coke: 331.6 kg / t HM in 2013

![Graph showing consumption of reducing agents](image)
The blast furnace process
Introduction
The blast furnace process
- Roles of coke
- Flooding effects
- Blast furnace performance
Conclusion

The blast furnace process
The blast furnace as a counter current reactor

Ore burden, additions, coke

Top gas: 120 °C (CO, CO₂, H₂, H₂O, N₂)

Hot blast: 1,200 °C

Pulverized coal

Raceway gas: 2,200 °C (CO, H₂, N₂)

Liquid hot metal and slag: 1,500 °C

Gas

Ore, coke
The blast furnace process

The blast furnace as a counter current reactor

<table>
<thead>
<tr>
<th>Material</th>
<th>Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore burden</td>
<td>775,000 kg/h</td>
</tr>
<tr>
<td>Coke</td>
<td>175,000 kg/h</td>
</tr>
<tr>
<td>Slag</td>
<td>125,000 kg/h</td>
</tr>
<tr>
<td>Hot metal</td>
<td>500,000 kg/h</td>
</tr>
<tr>
<td>Shaft gas</td>
<td>750,000 m³ (S.T.P.) / h</td>
</tr>
</tbody>
</table>

**The blast furnace process**

Charging equipment “Parallel feed”
The blast furnace process
Example for charging sequence of burden and coke
The blast furnace process
Coke and ore burden distribution

The blast furnace process
Inner state of blast furnace and radial burden distribution
The blast furnace process
- Requirements on coke

- Introduction
- The blast furnace process
  - Roles of coke
    - Flooding effects
    - Blast furnace performance
- Conclusion
Roles of coke
Chemical and physical challenges

Chemical challenges
- Energy input
- Generation of reducing gases
- Regeneration of CO₂ (Boudouard - Reaction)
- Carburization of the hot metal

Physical challenges
- Gas permeability and distribution in the BF shaft
- Support of the burden column
- Vertical and horizontal drainage for liquid products

Roles of coke
Different challenges - different coke qualities

Small coke
- Mixed in ore burden
- High reactivity: Consumption in the upper BF

Layer coke
- Sufficient I₄₀, CSR, size and size distribution
- Low reactivity: Permeability and drainage

Centre or “hearth” coke
- High I₄₀, CSR and voidage
- Low reactivity: Permeability and drainage
All physical coke quality parameters and their interactions are to be discussed regarding the impacts on the mass and gas flows.
Roles of coke

Bad size distribution

- Voidage: small
- Gas permeability: low
- Drainage: low

Roles of coke

Good size distribution, low I_{40}

- Voidage: small
- Gas permeability: low
- Drainage: low
Roles of coke
Good size distribution, high $I_{40}$ and low CSR

Roles of coke
Good size distribution, high $I_{40}$ and high CSR

<table>
<thead>
<tr>
<th>Voidage</th>
<th>high</th>
<th>small</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas permeability</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Drainage</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

Good coke = excellent BF performance!
Roles of coke
Geometric lay-out of the blast furnace hearth

Volume of the reservoir for liquids
Volume of the sump
Roles of coke
Is the dead man swimming or sitting on the bottom?

Forces on the dead man

- Weight of the total material column
- Upstream gas flow
  \[ f = (\text{Volume}, \text{density}, \text{viscosity}) \]
- Friction of the descending burden on the walls
- Support of the material column on the bosh wall
- Lifting of the solid coke in the liquid materials
  \[ f = (\text{Height of the liquids in the hearth}, \text{coke bed voidage}) \]

Is the dead man swimming or sitting on the bottom?

Swimming dead man

- Hot metal and slag can flow over the free space between bottom and material column directly to the taphole
Roles of coke
Is the dead man swimming or sitting on the bottom?

Sitting dead man

- Hot metal and slag must flow through the coke of the dead man column to the taphole
- If the voidage of the coke is low, hot metal and slag must flow also around the dead man coke on the wall of the hearth refractory
The blast furnace process
- Requirements on coke

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  - Flooding effects
  - Blast furnace performance
- Conclusion
Blast furnace as counter current reactor

Flooding of slag influenced by

- Shaft gas composition, temperature, pressure and the resulting density
- Slag amount, density and viscosity
- Coke specific surface
- Coke bed voidage

Flooding effects
Slag flooding

Hans Beer, Gerhard Heynert: stahl und eisen 84 (1964), No. 22, p. 1353/1365


Counter current flow key figure log (k)
## Flooding effects

### Slag flooding

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>1,300.00</td>
<td>1,300.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>4.00</td>
<td>4.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Slag amount</td>
<td>250.00</td>
<td>250.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>1,500.00</td>
<td>1,500.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Coke specific surface</td>
<td>90.00</td>
<td>90.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Coke bed voidage</td>
<td>0.35</td>
<td>0.35</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Productivity Case 2 / Case 1 %**

### Flooding effects

### Slag flooding - Gas volume minus 10 %

<table>
<thead>
<tr>
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<th>Case 1</th>
<th>Case 2</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>1,300.00</td>
<td>1,170.00</td>
<td>-10.00</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>4.00</td>
<td>4.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Slag amount</td>
<td>250.00</td>
<td>250.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>1,500.00</td>
<td>1,500.00</td>
<td>0.00</td>
</tr>
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<td>90.00</td>
<td>0.00</td>
</tr>
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<td>0.35</td>
<td>0.35</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Productivity Case 2 / Case 1 %**

7.89
## Flooding effects

Slag flooding - Gas pressure plus 10 %

<table>
<thead>
<tr>
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<th>Case 2</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>1,300.00</td>
<td>1,300.00</td>
<td>0.00</td>
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<tr>
<td>Gas pressure</td>
<td>4.00</td>
<td>4.40</td>
<td>10.00</td>
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<tr>
<td>Slag amount</td>
<td>250.00</td>
<td>250.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>1,500.00</td>
<td>1,500.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Coke specific surface</td>
<td>90.00</td>
<td>90.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Coke bed voidage</td>
<td>0.35</td>
<td>0.35</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Productivity Case 2 / Case 1 %  3.49

## Flooding effects

Slag flooding - Slag amount minus 10 %

<table>
<thead>
<tr>
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<th>Case 1</th>
<th>Case 2</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>1,300.00</td>
<td>1,300.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>4.00</td>
<td>4.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Slag amount</td>
<td>250.00</td>
<td>225.00</td>
<td>-10.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>1,500.00</td>
<td>1,500.00</td>
<td>0.00</td>
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<tr>
<td>Coke specific surface</td>
<td>90.00</td>
<td>90.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Coke bed voidage</td>
<td>0.35</td>
<td>0.35</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Productivity Case 2 / Case 1 %  2.99
## Flooding effects

Slag flooding - Slag viscosity minus 10 %

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>m³ (STP) / t HM</td>
<td>1,300.00</td>
<td>1,300.00</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>bar (abs.)</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Slag amount</td>
<td>kg / t HM</td>
<td>250.00</td>
<td>250.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>cP</td>
<td>1,500.00</td>
<td>1,350.00</td>
</tr>
<tr>
<td>Coke specific surface</td>
<td>m² / m³</td>
<td>90.00</td>
<td>90.00</td>
</tr>
<tr>
<td>Coke bed voidage</td>
<td>m³ / m³</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Productivity Case 2 / Case 1</strong></td>
<td>%</td>
<td></td>
<td>1.06</td>
</tr>
</tbody>
</table>

## Flooding effects

Slag flooding - Coke specific surface minus 10 %

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>%</th>
</tr>
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<tbody>
<tr>
<td>Gas volume</td>
<td>m³ (STP) / t HM</td>
<td>1,300.00</td>
<td>1,300.00</td>
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<tr>
<td>Gas pressure</td>
<td>bar (abs.)</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Slag amount</td>
<td>kg / t HM</td>
<td>250.00</td>
<td>250.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>cP</td>
<td>1,500.00</td>
<td>1,500.00</td>
</tr>
<tr>
<td>Coke specific surface</td>
<td>m² / m³</td>
<td>90.00</td>
<td>81.00</td>
</tr>
<tr>
<td>Coke bed voidage</td>
<td>m³ / m³</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Productivity Case 2 / Case 1</strong></td>
<td>%</td>
<td></td>
<td>5.41</td>
</tr>
</tbody>
</table>
Flooding effects
Slag flooding - Coke bed voidage plus 10 %

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>m³ (STP) / t HM</td>
<td>1,300.00</td>
<td>1,300.00</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>bar (abs.)</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Slag amount</td>
<td>kg / t HM</td>
<td>250.00</td>
<td>250.00</td>
</tr>
<tr>
<td>Slag viscosity</td>
<td>cP</td>
<td>1,500.00</td>
<td>1,500.00</td>
</tr>
<tr>
<td>Coke specific surface</td>
<td>m² / m³</td>
<td>90.00</td>
<td>90.00</td>
</tr>
<tr>
<td>Coke bed voidage</td>
<td>m³ / m³</td>
<td>0.35</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Productivity Case 2 / Case 1 % 15.37

Flooding effects
Slag flooding

<table>
<thead>
<tr>
<th></th>
<th>Change</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume</td>
<td>-10.0</td>
<td>7.9</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>10.0</td>
<td>3.5</td>
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<tr>
<td>Slag amount</td>
<td>-10.0</td>
<td>3.0</td>
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<tr>
<td>Slag viscosity</td>
<td>-10.0</td>
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<tr>
<td>Coke specific surface</td>
<td>-10.0</td>
<td>5.4</td>
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<tr>
<td>Coke bed voidage</td>
<td>10.0</td>
<td>15.4</td>
</tr>
</tbody>
</table>
The blast furnace productivity is influenced by a lot of parameters like:

- Gas volume, temperature, composition and pressure
- Slag amount, density and viscosity
- Especially coke quality
  - Specific surface (Surface to volume ratio)
  - Coke bed voidage
Blast furnace performance
Coke quality CSR, ThyssenKrupp Steel Europe

A lot of influences
Blast furnace performance

CSR and BF productivity

![Graph showing Blast furnace performance and CSR productivity.](image)

- BF 9
- BF 1
- BF 2

Shares of profit pool HRC [%]

<table>
<thead>
<tr>
<th>Year</th>
<th>Steel</th>
<th>Coking coal</th>
<th>Iron ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>80</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>70</td>
<td>30</td>
<td>0</td>
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</tbody>
</table>

Source: SBB, McKinsey, BCG
The blast furnace process
- Requirements on coke

- Introduction
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- Roles of coke
- Flooding effects
- Blast furnace performance

- Conclusion
**Conclusion**
The blast furnace operation - 305 years of experience

1709: First coke based blast furnace in the world, Coalbrookdale, England
HM production 2 t / d

2012: Highest hot metal production in the world, Pohang 4, South Korea
HM production up to 17,000 t / d

Conclusion
Quality parameters of coke

- $I_{40}, I_{10}$
- CSR / CRI
- Medium grain size, grain structure, grain size distribution

After 305 years of the coke blast furnace there exists no integrated coke quality parameter to describe the blast furnace performance!
Conclusion
Coke quality and blast furnace performance

- Blast furnace performance depends on coke quality
- Postulation of a sufficient coke quality
- Coke production at a cost minimum from an integrated point of view
- Need for an integrated coke quality parameter
- Knowledge of the correlations between coking coal blend, coke quality and blast furnace performance

After 305 years of the coke blast furnace there exists no integrated coke quality parameter to describe the blast furnace performance!
Conclusion
Coke quality and blast furnace performance
The Blast Furnace Process
- Requirements on coke

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