Influence of blast furnace running intensity on the ironmaking process efficiency
Context of discussion

1. What is the blast furnace running intensity?
2. What is the blast furnace ironmaking process efficiency?
3. Which conditions are needed to achieve the highest efficiency of a blast furnace performance?
4. The reduction efficiency index estimation by Rist model
5. Method of investigating the influence of NLMK blast furnaces running intensity on the ironmaking process efficiency.
6. Discussion of the investigation results
Blast furnace process intensity was quantified in this study through the closely related parameters of specific productivity \((T/m^2/day)\), flow rate of oxygen injected with blast \((m^3O_2/m^2\cdot min)\) and outflow of reducing gases \((m^3(CO+H_2)/m^2\cdot min)\) calculated per 1 m\(^2\) of the hearth area. Quantitatively, the efficiency of a blast furnace performance is generally evaluated through the fuel rate at a given furnace productivity.
The highest efficiency of a blast furnace can be achieved through creating such physical conditions as necessary for the effective reduction and heat-exchange processes. Such vital conditions include:

- equalizing ratios of gas flows and iron ore material flows over the maximum possible area of the furnace shaft cross-section;
- optimum diameter of axial zone with high gas permeability and a quite permeable narrow peripheral zone;
- top gas temperature of 100-115 which excludes water vapor condensation on materials charged into the furnace and water circulation in the upper shaft;
- high permeability of coke deadman for hot iron and slag
The reduction efficiency parameter (ω, %) was calculated as the relation of actual gas oxidation (\(X_w(\text{act})\)) in the isothermal zone to the equilibrium (\(X_w\)) for the reaction of iron reduction from wustite at the temperature of isothermal zone

\[
X_w(950^\circ C) = 1.28 + h(1.39-1.28) \\
X_w(\text{act}) = 1 + (m_{O_{wi}} \cdot P_{\text{min}} \cdot 22.4/16)/V_{rg} \\
ω = X_w(\text{act})/X_w
\]

where: 1.28 and 1.39 – equilibrium oxidations of carbon monoxide (1 + η_{CO}) and hydrogen (1+ η_{H2}), respectively, at 950 °C; 
\(h\) – hydrogen share in the reducing gas (CO+H₂); 
\(m_{O_{wi}}\) – oxygen removed from wustite by gas, kg/t; 
\(P_{\text{min}}\) – furnace productivity per minute, t/min; 
\(V_{rg}\) – flow rate of reducing gas per minute (CO+H₂), m³/min.
The effect of blast furnace process intensity on its efficiency was evaluated based on monthly average data on BF performance in the months with different intensities from 2012 to 2016. The analysis used data from the months with no furnace stops or prolonged slow runs. Besides the reduction efficiency indicator, the rate of indirect iron reduction from wustite \((vO_i, \text{kg O}_2/\text{m}^2\cdot\text{min})\) and the degree of direct iron reduction \((r_d,\%)\) were calculated. The specific BF productivity was calculated per 1 m\(^2\) of hearth area \((t/\text{m}^2\cdot\text{day})\), as it is the only indicator that allows correct comparison between different volumes of BFs (specific capacity per 1 m\(^3\) of volume depends almost deterministically upon the BF volume and raises respective parameters of smaller BFs).
We have used in our analysis the results of BF No. 3, 4, 6, and 7 with natural gas injection.

BF-3
2000 m³

BF-4
2000 m³

BF-6
3200 m³

BF-7
4200 m³
“Rossiyanka”
The analysis shows with high confidence a direct relation of the specific productivity (P, t/m² per day) to both of the specific blast oxygen flow rate ($V_{sO_2}$, m³/m²-min), and the specific flow rate of the reducing gas ($V_{srg}$, m³/m²-min) for all BFs (fig. 1,2).

Relation of specific BF production to oxygen intensity of melting
Reducing gases output, m³/(m²·min)

Relation of specific BF production to reducing gas flow intensity

- BF-3: \( y = 1.0758x + 16,249 \)  
  \( R^2 = 0,9027 \)
- BF-4: \( y = 0.8696x + 28,02 \)  
  \( R^2 = 0,9122 \)
- BF-6: \( y = 0.8773x + 30,268 \)  
  \( R^2 = 0,8859 \)
- BF-7: \( y = 1,1124x + 25,236 \)  
  \( R^2 = 0,9802 \)
The rate of gas reduction of wustite was increasing pro rata the intensity of melting in terms of reducing gas which was fluctuating within the widest ranges (29.4-63 m³/m²·min) at BF “Rossiyanka” (fig.3).

Relation of wustite reduction rate to the reducing gas flow intensity
At the BF “Rossiyanka”, the wide-range increase of rate of gas iron reduction from wustite (from 5 to 12 kgO₂/m²-min) with the melting intensity increase was determined by the following factors:

- growth of the specific flow rate (from 2.8 to 3.6 m³/kg O₂ of wustite) and per-minute flow rate (from 29.4 to 63.0 m³/m²-min) of reducing gas;

- growth of the specific rate of hearth hydrogen gas (from 0.61 to 0.99 m³/kg O₂ of wustite);

- acceleration of burden descend (from 8 to 13 cm/min) and, consequently, increase of gas permeability of coke and iron ore layers and surface of contact between gases and materials;

- shortening of coke contact with CO₂ and alkalies, resulting in lesser breakage;

- shortening of low-temperature (500-600 °C) sinter reduction; sinter reduction in size;

- reduction of specific heat losses with the cooling water of the furnace cooling system [7], resulting in an increased inflow of heat with the gas used for iron ore heating and a faster rate of material heating and reduction;

- equalization of ratios of gas flows and burden material flows over the cross-section.
Despite the reduced duration of materials staying in isothermal zone, the degree of indirect wustite reduction was increasing with higher intensities of melting. At all BFs a significant reverse relation of the direct iron reduction degree (acc. to M.A. Pavlov) to the wustite reduction degree is demonstrated (fig. 4).

Effect of wustite reduction rate on the degree of direct iron reduction rate
It should be noted that for a long time top gas temperature at the blast furnace “Rossiyanka” was below 100 °C because of the particularities of the BF profile and cooling system (copper stave plates in bosh and lower shaft). As a result, the hydrogen was playing a much more significant role in the process of gas reduction of wustite than in any other BFs (Table ).

Limit values of changing parameters during BF operation with different intensities

<table>
<thead>
<tr>
<th>BF operation indicators</th>
<th>Blast furnaces</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No.3</td>
</tr>
<tr>
<td>Productivity (P), t/m²·day</td>
<td>51.34-65.1</td>
</tr>
<tr>
<td>Oxygen intensity, m³/m²·min</td>
<td>10.4-13.6</td>
</tr>
<tr>
<td>ηH₂, %</td>
<td>21.8-52.5</td>
</tr>
<tr>
<td>ηCO, %</td>
<td>44.7-48.6</td>
</tr>
</tbody>
</table>
The analysis shows that the reduction efficiency ($\omega$) calculated as the degree of approximation of the actual gas oxidation to equilibrium in the wustite reduction zone at all BFs did not show a valid statistical relation to either their operation intensity or the rate of wustite gas reduction.

Reduction efficiency and oxygen smelting intensity
An increase of the blast furnace process intensity at NLMK’s blast furnaces was associated with the higher CSR of coke, and has allowed a certain lowering of heat loss with the cooling water.

Reduction of heat loss with cooling water at the BF “Rossiyanka” at higher coke quality and process intensity.
Thanks to the reduction of heat loss with cooling water and heat input for the direct reduction of iron and silicon, the average coke consumption and total fuel rate were lower at all the blast furnaces during the maximum intensity months compared to the minimum intensity months.

Average productivity values of the blast furnaces, coke, carbon, total fuel and coke CSR in the months with minimum and maximum blast furnace process intensity

<table>
<thead>
<tr>
<th>Indicators</th>
<th>BF-3</th>
<th>BF-4</th>
<th>BF-6</th>
<th>BF-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{O2} ), ( m^3/m^2\cdot min )</td>
<td>10.4 -11.0</td>
<td>12.7 -13.6</td>
<td>10.9 -12.4</td>
<td>15.0-15.5</td>
</tr>
<tr>
<td>( P ), t/m²-days</td>
<td>52.9</td>
<td>63.4</td>
<td>60.2</td>
<td>75.2</td>
</tr>
<tr>
<td>( K ), kg/t</td>
<td>440</td>
<td>411</td>
<td>424</td>
<td>378</td>
</tr>
<tr>
<td>( \Sigma T ), kg/t</td>
<td>503</td>
<td>492</td>
<td>498</td>
<td>483</td>
</tr>
<tr>
<td>( \Sigma C ), kg/t</td>
<td>425</td>
<td>416</td>
<td>416</td>
<td>403</td>
</tr>
<tr>
<td>CSR, %</td>
<td>55.5</td>
<td>60.7</td>
<td>52.0</td>
<td>59.5</td>
</tr>
</tbody>
</table>
Conclusions

1. The growth of blast furnace process intensity through the increase of top gas pressure, blast rate and oxygen content in the blast with simultaneous growth of natural gas rate is accompanied by the growth of wustite indirect reduction rate because of the increasing: reduction gas rate, share of hydrogen in gas, coke and iron ore material layers porosity, surface of contact of the reduction gas with iron ore materials, heat input and iron ore material heating rate.

2. While blast furnace process was intensified and productivity of the BFs grew, the direct reduction degree diminishing and lower heat losses with cooling water promoted reduction of fuel consumption.

3. In the analysed period of the BF’s operation the indirect wustite reduction efficiency was determined first of all by the distribution along the radius of iron ore materials and coke, as well as by their quality and, in fact, did not depend on the process intensity.

4. With NLMK’s BFs running on properly prepared iron ore materials and coke with a satisfactory CSR index (58-63%), the increase of the blast furnace intensity in the wide range has not demonstrated any known extreme dependences of BF productivity and fuel consumption rate on the blast furnace process intensity. Productivity and fuel rate changed directly and inversely, respectively, in proportion to the change of intensity.
Thanks for attention