MARSH GAS REPLACEMENT WITH BLAST FURNACE GAS AT THE HEATING OF THE MIXER

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Abstract

Among the secondary energetic resources in metallurgical industry there are blast furnace gas and coke gas - which are combustion gases resulted in the technological processes of ironmaking in the blast furnace and of the coke obtaining in coking units. The paper presents a study of marsh gas replacement with blast furnace gas or bigas at the heating of the mixer in order to maintain the temperature of the liquid iron. It is estimated the efficiency of this substitution, leading to an important economy of marsh gas.

1. INTRODUCTION

The mixer represents a metallurgical aggregate used to assure a reserve of liquid iron for the functioning of the converter in optimal conditions:
- thermal homogenization of the liquid iron;
- maintaining of the temperature of the liquid iron;
- homogenization of the chemical composition.

In order to fulfil these desiderata the mixer is equipped with three burners which assure, by the burning of marsh gas, the necessary heat for the homogenization of the liquid iron and the maintaining of its temperature. The paper presents a study of marsh gas replacement with blast furnace gas at the heating of the mixer and to estimate the economy resulted in this substitution.

2. CALCULUS OF THE OXYGEN CONCENTRATION FROM THE AIR ENRICHED WITH OXYGEN IN THE CASE OF BURNING THE BLAST FURNACE GASES IN A PROPORTION OF 100%

In present marsh gas is used for the maintaining of the liquid iron in warm state in the mixers. At Mittal Steel Galati the marsh gas consumption for the three existing burners is 390 Nm³/h. The burning calculus is made in two varieties, namely marsh gas and furnace gas in a 100% proportion, respectively. The calculus relations are the following (VLADEA 1974, POPA 1975):
- the fuel chemical composition:

\[
\text{CH}_4 + \text{CO} + \text{H}_2 + \text{O}_2 + \text{N}_2 + \text{H}_2\text{O} = 100 \%
\]

\[
\text{[CH}_4\text{]} + \text{[CO]} + \text{[H}_2\text{]} + \text{[O}_2\text{]} + \text{[N}_2\text{]} + \text{[H}_2\text{O]} = 1 \text{Nm}^3
\]  \hspace{1cm} (1)

- the inferior calorific power \( H_i \), in [kJ/Nm³ fuel]:

\[
\text{H}^i = [\text{CH}_4\text{]} \cdot H_{\text{CH}_4} + [\text{CO}] \cdot H_{\text{CO}} + [\text{H}_2\text{]} \cdot H_{\text{H}_2}
\]

\hspace{1cm} (2)

where (Table 1):
- \([\text{CH}_4\text{]}, [\text{CO}], [\text{H}_2]\) - the quantities of the combustion elements, in [Nm³/Nm³ fuel];
- \( H_{\text{CH}_4}, H_{\text{CO}}, H_{\text{H}_2} \) = inferior calorific powers of the combustion elements, in [kJ/Nm³];
- \( H_{\text{CH}_4} = 35500 \text{kJ/Nm}^3 \); \( H_{\text{CO}} = 12740 \text{kJ/Nm}^3 \); \( H_{\text{H}_2} = 12765 \text{kJ/Nm}^3 \)
- the minimum amount of oxygen necessary for the combustion, \( O_2^\min \), in [Nm³O₂/Nm³ fuel]
O₂\text{min} = 2[\text{CH}_4] + \frac{1}{2}[\text{CO}] + \frac{1}{2}[\text{H}_2] - [\text{O}_2] \quad (3)

-the theoretic air necessary for the combustion, L₀, in [Nm³_air/Nm³ fuel]:

L₀ = \frac{100}{21} O₂\text{min} \quad (4)

- the real air used for the combustion, Lₙ, in [Nm³_O₂/Nm³ fuel]:

Lₙ = \lambda L₀

where \( \lambda \) is the coefficient of excess air - the adopted value \( \lambda = 1.05 \);

-the quantity of the burned gases, V_{\text{ga}}\text{, in [Nm³_gas/Nm³ fuel]}:

V_{\text{ga}} = V_{\text{CO}_2} + V_{\text{H}_2\text{O}_\text{vap}} + V_{\text{N}_2} + V_{\text{O}_2\text{excess}} \quad (5)

where:

V_{\text{CO}_2} = [\text{CO}_2] + [\text{CH}_4] + [\text{CO}]
V_{\text{H}_2\text{O}_\text{vap}} = 2[\text{CH}_4] + [\text{H}_2] + [\text{H}_2\text{O}]
V_{\text{N}_2} = 0.79 L_r \cdot [N_2]
V_{\text{O}_2\text{excess}} = 0.21(L_r - L_0)

-the participations of the component elements of the burned gases, \( r_i \sum r_i = 1 \):

r_{\text{CO}_2} = \frac{V_{\text{CO}_2}}{V_{\text{ga}}}; r_{\text{H}_2\text{O}_\text{vap}} = \frac{V_{\text{H}_2\text{O}_\text{vap}}}{V_{\text{ga}}}; r_{\text{N}_2} = \frac{V_{\text{N}_2}}{V_{\text{ga}}}; r_{\text{O}_2\text{excess}} = \frac{V_{\text{O}_2\text{excess}}}{V_{\text{ga}}} \quad (6)

-the real burning temperature, \( t_r \), in [°C]:

\begin{align*}
  t_r &= \frac{\eta_{\text{pyr}} \cdot 0.98 \cdot H_i}{V_{\text{ga}} \cdot c_{\text{ga}}} \\
  \text{where:} \\
  \eta_{\text{pyr}} &- \text{the pyrometric efficiency; the adopted value } \eta_{\text{pyr}} = 0.7; \\
  H_i &- \text{the inferior calorific power, [kJ/Nm³ fuel]}; \\
  V_{\text{ga}} &- \text{the volume of the burned gases, [Nm³/Nm³ fuel]}; \\
  c_{\text{ga}} &- \text{the specific heat of the burned gases [kJ/Nm³ grd]}. 
\end{align*}

-the specific heat of the burned gases \( c_{\text{ga}}, [\text{kJ/Nm}^³\text{grd}] \):

\begin{align*}
  c_{\text{ga}} &= \frac{4}{4} \sum c_i \cdot \eta_i \\
  \text{where } c_i &- \text{the specific heats of the components of the burned gases, which are tabulated as a function of temperature.}
\end{align*}

The thermodynamic parameters at the burning with atmospheric air of the marsh gas or furnace gas respectively, and the chemical composition of the fuel are given in Table 1.

The adopted value for the temperature of the burned gases is \( t_r = 1390 \degree C \) and \( c_{\text{ga}}\text{,}1390\degree C \) can be calculated with the relation (8), using the values for the specific heats presented in Table 1.

The oxygen concentration, \( x \), in the enriched air is calculated with the relation (IVANESCU 2002, IVANESCU 2005):

\begin{align*}
  x &= \frac{\lambda \left( \frac{1}{2}[\text{CO}] + \frac{1}{2}[\text{H}_2] + 2[\text{CH}_4] - [\text{O}_2] \right)}{\eta_{\text{pyr}} \cdot 0.98 \cdot H_i \cdot t_f \cdot c_{\text{ga}} - \frac{1}{2}[\text{CO}] - [\text{CH}_4] - [\text{CO}_2] - [\text{H}_2\text{O}] - [N_2] - \frac{1}{2}[\text{H}_2] - [\text{O}_2]} \\
  \text{where:} \\
  \lambda &- \text{the coefficient of excess air - the adopted value } \lambda = 1.05; \\
  H_i &- \text{the inferior calorific power, [kJ/Nm³ fuel]}; \\
  \eta_{\text{pyr}} &- \text{the pyrometric efficiency; the adopted value } \eta_{\text{pyr}} = 0.7; \\
  t_f &- \text{the real burning temperature, [°C]}; \\
  c_{\text{ga}} &- \text{the specific heat of the burned gases [kJ/Nm³ grd]}. 
\end{align*}
Table 1. The thermodynamic parameters of the used gases

<table>
<thead>
<tr>
<th>Fuel</th>
<th>The chemical composition of the fuel [%]</th>
<th>The calorific power, $H_i$ [kJ/Nm$^3$ fuel]</th>
<th>$O_2^{\text{min}}$ [Nm$^3$/Nm$^3$ fuel]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CH$_4$ CO H$_2$ CO$_2$ O$_2$ N$_2$ H$_2$O Tot.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marsh gas</td>
<td>100 - - - - - - - 100</td>
<td>35500</td>
<td>2</td>
</tr>
<tr>
<td>Furnace gas</td>
<td>0.20 22.45 6.15 18.00 0.20 50.70 2.30 100</td>
<td>3716</td>
<td>0.145</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel</th>
<th>$L_i$</th>
<th>$L_0$</th>
<th>$V_{ga}$</th>
<th>Participations in the burned gases, $r_i$</th>
<th>Burning temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Nm$^3$/Nm$^3$ fuel]</td>
<td>[Nm$^3$/Nm$^3$ fuel]</td>
<td>[Nm$^3$/Nm$^3$ fuel]</td>
<td>Tot.</td>
<td>$	ext{CO}_2$</td>
</tr>
<tr>
<td>Marsh gas</td>
<td>9.52</td>
<td>9.996</td>
<td>1 2 7.89 0.1 11</td>
<td>0.091</td>
<td>0.182</td>
</tr>
<tr>
<td>Furnace gas</td>
<td>0.690</td>
<td>0.724</td>
<td>0.4065 0.0885 0.0789 0.0071 1.581</td>
<td>0.2571</td>
<td>0.0560</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Specific heat [kJ/Nm$^3$ grd]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>H$_2$O</td>
</tr>
<tr>
<td>1300</td>
<td>2.2898</td>
</tr>
<tr>
<td>1400</td>
<td>2.3136</td>
</tr>
<tr>
<td>1500</td>
<td>2.3354</td>
</tr>
<tr>
<td>1390</td>
<td>2.3112</td>
</tr>
</tbody>
</table>

It results:

$$c_{ga}^{1390\degree C} = \sum_{i=1}^{4} r_i \cdot c_i, \quad c_{ga}^{1390\degree C} = 1.6816 \text{ kJ/Nm}^3\text{grd}$$

and the oxygen concentration calculated with the relation (9), $x \approx 0.653$.

In the case of the furnace gas burning with oxygen enriched air:
- the oxygen enriched air $L'_r$, in [Nm$^3$/Nm$^3$ fuel], is:

$$L'_r = \frac{100}{x} O_2^{\text{min}}$$  \hspace{1cm} (10)

- the flowrate of the oxygen enriched air, $D'_{\text{air}}$, in [Nm$^3$/Nm$^3$ fuel], is:

$$D'_{\text{air}} = D_{O_2} + D_{\text{air}}$$  \hspace{1cm} (11)

$$x = \frac{D_{O_2} + 0.21 \cdot D_{\text{air}}}{D_{O_2} + D_{\text{air}}}$$  \hspace{1cm} (12)
resulting:
\[
\begin{align*}
D_{\text{air}} &= \frac{D'_{\text{air}} (1-x)}{0.79} \\
D_{O_2} &= \left( \frac{x - 0.21}{0.79} \right) D'_{\text{air}}
\end{align*}
\] (13)

having the values:

\[ D_{\text{air}} = 363.388 \text{ Nm}^3/\text{h}; \quad D_{O_2} = 463.921 \text{ Nm}^3/\text{h}. \]

3. ECONOMIC EFFICIENCY

The costs are the following:

- CH$_4$: 269.9 USD/1000 Nm$^3$
- GF: 17 USD/1000 Nm$^3$
- Oxygen: 65.4 USD/1000 Nm$^3$
- Air: 9.29 USD/1000 Nm$^3$

Using the values of the average flowrates of marsh gas,

\[ D_{\text{CH}_4} = 390 \text{ Nm}^3/\text{h}; \quad D_{\text{air}} = L_r D_{\text{CH}_4}; \quad D_{\text{air}} = 3998.4 \text{ Nm}^3/\text{h} \]

the total costs are calculated as following:

\[ C_{\text{CH}_4} = 136.401 \text{ USD}/\text{h}; \quad C_{\text{GF}} = 97.063 \text{ USD}/\text{h} \]

resulting an economy of:

\[ E_C = C_{\text{CH}_4} - C_{\text{GF}} = 39.348 \text{ USD}/\text{h} \]

The marsh gas economy achieved by the using of blast furnace gas is of great interest taking into account the its deficit on the global market and, especially its putting up the price.

LITERATURE REFERENCES


VLADEA I., 1974, Treatise of technical thermodynamics and heat transmission, Editura Didactică și Pedagogică, Bucharest.