PARAMETERS OF THE PROCESS IN PNEUMATIC LIQUID METAL CARBURIZING

Krzysztof Janerka

Department of Foundry, Faculty of Mechanical Engineering, Silesian Technical University, 44-100 Gliwice, ul. Towarowa 7, Pl, janerka@zeus.polsl.gliwice.pl

Abstract
Carburizing of metal bath in a furnace by blowing the carburizer is a very quick and efficient method of carburization, mainly because of the diphase stream flow parameters. The paper presents the carburization rate in the function of flow number \( N_E \) and \( N_J \). Dependence in relation to the flow number and the stream for iron liquid alloy carburizing process has been determined by tests.

1. INTRODUCTION
Since many years the blowing of powdered materials into a liquid metal has been known technology. Comminuted reacting substance permits a large contact surface of the reacting phases (powder-liquid metal) to be obtained. In addition, the carrying gas forces a motion of liquid metal to homogenise its chemical composition through the whole volume. These factors cause that metallurgical processes being run (such as carburizing, desulfurization, introduction of alloy additions) are characterised by a large chemical reaction rate and a very high degree of the assimilation of particular elements by liquid metal [1, 2].

When cast iron heating in electric arc furnaces, one of the problems is to obtain an adequate carbon content in liquid metal. It is a very essential question at many modern foundries that sensibly an economically approach the production run, and which have resigned the pig iron in charge due to its high cost. An attempt is made to correct the carbon deficiency formed in this way. By conventional methods (adding an carbonising agent into charge and subsequent complement at the final heat stage, by throwing on the surface). However, these methods are time-consuming and not enough effective, that significantly elongate time of heat.

Thus a need for other effective solution has been resulted and such method of air-operated carburizing of liquid metal is being occurred.

2. STAND OF AIR-OPERATED CARBURIZING
The main member of the device is a pressure tank 1 (fig. 1) of 0,25 m³ volume. A bell seal is situated at the upper portion of the tank, and a mixing chamber 3 below. On the tank, a venting valve is mounted for pressure relief of the tank after the termination of each working cycle.

Air pressure supplied to the tank is controlled by a reducer 4. A master valve 10 makes it possible to supply or cut off the air supply. The valves (master 10, venting, bell closure and opening of mixing chamber) are electrically started from the tank control panel 2. The tank is founded on a strain gauge scales 5, the indications of which are displayed on the control panel 2.

In its initial position, the balance indicates a mass of material contained in the tank (net). At the moment of starting the haulage cycle, it shows a quantity of material which has been introduced into liquid metal. Switching off the haulage causes displaying the mass left in the device. It is very comfortable for the operators. Carbonising agent is displaced by a transport
pipe 11, terminated in a lance 13 that is introduced into an arc furnace 14. The lance was placed on a manipulator 12 so that it should be introduced into liquid metal. Its fundamental element is a protective screen with mounted rollers for moving and supporting the lance, and shifting along the guide bars. It facilitates the service thus eliminating physical effort, and at the same time, providing safety and greater process repeatability. Over the device, there is a storage tank 7 of 1 m³ for carburizing material. A screen 8 is placed at the tank top to catch oversize particles and impurities that may be contained in carbonising agent.

The bottom part of the tank 7 is a crevice damper 6, driven by a pneumatic servo-motor and controlled from the table 2. Between the storage tank 7 and the chamber feeder 1 there is a rubber compensator to eliminate the interaction of the former on the weighing system. Considering bad quality of compressed air at the plant network 9, it was a necessity to mount an air filter to eliminate water and oil impurities. The carburizing material is delivered by producers in big-bags of 1 m³, to be unloaded into the storage tank by means of a crane.

3. CHARACTERISTICS OF CARBURIZATION
Carburization is characterized by efficiency and rate [3] which show potential of the process. 

\[
E = \frac{m_m (C_k - C_p)}{m \cdot C_x} \tag{1}
\]

\(C_p\) - carbon content at the beginning of the process [\%], \(C_k\) - carbon content at the end of the process [\%], \(m_m\) - metal mass [Mg], \(m\) - mass of the carburizer [Mg], \(C_x\) - carbon content in the carburizer.
**Carburization rate:**

\[
S = \frac{(C_e - C_p)}{t}
\]  \hspace{1cm} \text{(2)}

\(t\) - time of carburizing [s]

As the tests were performed in furnaces of various size the carburization rate was assumed in relation to 1 Mg of liquid metal (S).

\[
S_j = \frac{S}{m_m}
\]  \hspace{1cm} \text{(3)}

According to the authors it allows to compare and analyse the values obtained for different masses of liquid metal.

### 4. DIPHASE STREAM IN A LIQUID MEDIUM

Based on the observations of the gas stream or the mixture of gas and powder introduced into the bath two kinds of flow were distinguished: a barbotage and a stream flow. The barbotage is typical for small rates of flow and lance outlet velocity. The material is transported only on the surface of the bubbles which are introduced into the liquid medium where they become deformed and burst out just under its surface. The stream flow is typical for big rates of flow and lance outlet velocity. Big bubbles become deformed and they burst out on the outlet from the lance; in this way the surface of the liquid reaction with the introduced material becomes larger. Such a kind of flow is better than barbotage, so there should be such parameters on the lance outlet that can ensure a stream flow kind. As it may be difficult to tell the difference between these two kinds of flow there are many theories concerning values of these parameters and their relation to different criterion numbers. E.g., Farias and Robertson have introduced a flow number \(N_E\), which is a product of particular components [4, 5], to the stream analysis:

\[
N_E = \frac{3}{8} \cdot \frac{m_c}{m_g} \cdot \frac{h}{r} \cdot \frac{r}{r_c} \cdot \frac{\rho_g}{\rho_l}
\]  \hspace{1cm} \text{(4)}

\(m_c\) - mass powder flow rate [kg/s], \(m_g\) - mass gas flow rate [kg/s], \(r\) - lance radius [m], \(r_c\) - radius of the blown particle [m], \(\rho_g\) - gas density on the lance outlet [kg/m³], \(\rho_l\) - liquid metal density [kg/m³], \(h\) - index of bubble size, \(V_b\) - bubble volume on the lance outlet

\[
h = \left(\frac{6}{\pi}\right)^{\frac{1}{2}} \cdot V_b^{\frac{1}{2}}, \quad V_b = 1,387 \cdot V_N^{1,2} \cdot g^{-0.6} \hspace{1cm} \text{(5)}
\]

\(V_N\) - volumetric gas flow intensity [m³/s], \(g\) - acceleration of gravity [m²/s]

Many authors suggest a simplified form of this formula:

\[
N_E = 0.75 \cdot \frac{m_v \cdot h \cdot \rho_g}{m_g \cdot d \cdot \rho_l}
\]  \hspace{1cm} \text{(6)}
It has been determined that for \( N_E < 3 \) it is a barbotage, and for \( N_E > 4.5 \) – a stream flow. The case when \( 3 > N_E < 4.5 \) is described as an intermediate state.

Kimura introduced a stream number \( N_j \) into the stream analysis, expressed by the following dependence [6]:

\[
N_j = 1.5 \frac{m_c w^2 \rho_j}{m_i w_i d_i \rho_j}
\]  

(7)

\( w, w_c \) - velocity of gas and particles, respectively, on the lance outlet [m/s]

For the number \( N_j \) below 1000 a barbotage has been assumed (in this range a cavitation which causes a discontinuous stream was observed during the tests), but when \( N_j > 1500 \) a uniform stream ensures a good penetration inside the metal bath. The range \( 1000 < N_j < 1500 \) is described as an intermediate state.

Practical determination of these values is tiresome because of such factors as: gas density, metal density and bubble size index. By taking into account the fact that densities of liquid cast iron and air used for the carburizing process do not change considerably the relations given above have been simplified to the form [4]:

\[
N_{E\text{mod}} = 1,1357 \cdot 10^{-4} \frac{m_c}{m_i^{0.6} d_c}
\]  

(8)

\[
N_{J\text{mod}} = 3,697 \cdot 10^{-4} \frac{m_c w}{m_c d_c}
\]  

(9)

5. ANALYSIS OF TEST RESULTS

Research cycle comprised several tens experiments in industrial conditions. Some calculation results concerning diphase stream and liquid metal are presented in the Table 1 below.

5.1. Carburization efficiency and rate

The tests appeared to have a very high efficiency and rate of carburization. The efficiency ranged from 60 to 99%, while the rate – from 0.0012 to 0.0063 % C/s. The result ranges are so big, because the pneumatic parameters and carburizers (particle diameter and carbon content) were considerably changed during the tests. The tests were carried out in industrial plants, so they had to match the liquid metal chemical composition necessary for production in a given foundry.

5.2. Diphase stream parameters

The ranges of diphase stream are the following:

- flow coefficient \( N_E = 0.34 - 3.84 \) and \( N_{E\text{mod}} = 0.33 - 4.08 \)
- stream coefficient \( N_j = 502 - 2182 \) and \( N_{J\text{mod}} = 494 - 2395 \)

The statistical analysis included an effect of diphase stream magnitude and pneumatic displacement parameters on carburization efficiency and rate. There were carried out
**Table 1**

Calculation results for diphase stream and liquid metal parameters

<table>
<thead>
<tr>
<th>Lp</th>
<th>( \eta_{\text{x}} )</th>
<th>( \rho_{\text{x}} )</th>
<th>( N_E )</th>
<th>( N_{E\text{mod}} )</th>
<th>( N_J )</th>
<th>( N_{J\text{mod}} )</th>
<th>( E )</th>
<th>( S )</th>
<th>( S_J )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.096</td>
<td>0.302</td>
<td>0.70</td>
<td>0.65</td>
<td>807</td>
<td>772</td>
<td>87.9</td>
<td>0.0042</td>
<td>0.021</td>
</tr>
<tr>
<td>2</td>
<td>0.097</td>
<td>0.300</td>
<td>0.56</td>
<td>0.52</td>
<td>639</td>
<td>593</td>
<td>92.7</td>
<td>0.0025</td>
<td>0.017</td>
</tr>
<tr>
<td>3</td>
<td>0.082</td>
<td>0.514</td>
<td>1.05</td>
<td>0.96</td>
<td>1103</td>
<td>1043</td>
<td>99.4</td>
<td>0.0057</td>
<td>0.032</td>
</tr>
<tr>
<td>4</td>
<td>0.082</td>
<td>0.300</td>
<td>0.75</td>
<td>0.70</td>
<td>806</td>
<td>774</td>
<td>94.3</td>
<td>0.0050</td>
<td>0.028</td>
</tr>
<tr>
<td>5</td>
<td>0.083</td>
<td>0.235</td>
<td>0.47</td>
<td>0.44</td>
<td>500</td>
<td>479</td>
<td>86.0</td>
<td>0.0020</td>
<td>0.012</td>
</tr>
<tr>
<td>6</td>
<td>0.059</td>
<td>1.476</td>
<td>2.52</td>
<td>2.52</td>
<td>1455</td>
<td>1508</td>
<td>99.7</td>
<td>0.0051</td>
<td>0.147</td>
</tr>
<tr>
<td>7</td>
<td>0.062</td>
<td>1.250</td>
<td>2.09</td>
<td>2.08</td>
<td>1246</td>
<td>1282</td>
<td>93.1</td>
<td>0.0036</td>
<td>0.116</td>
</tr>
<tr>
<td>8</td>
<td>0.055</td>
<td>1.818</td>
<td>3.15</td>
<td>3.25</td>
<td>1803</td>
<td>1925</td>
<td>91.7</td>
<td>0.0055</td>
<td>0.166</td>
</tr>
<tr>
<td>9</td>
<td>0.053</td>
<td>2.083</td>
<td>3.63</td>
<td>3.78</td>
<td>2080</td>
<td>2243</td>
<td>89.5</td>
<td>0.0061</td>
<td>0.186</td>
</tr>
<tr>
<td>10</td>
<td>0.054</td>
<td>1.923</td>
<td>3.36</td>
<td>3.44</td>
<td>1922</td>
<td>2039</td>
<td>89.9</td>
<td>0.0056</td>
<td>0.173</td>
</tr>
</tbody>
</table>

Statistical analyses considering different parameters of powder blowing in. The results of these analyses are as follows:

\[
S = -2,6 \cdot 10^{-3} + 1,5 \cdot 10^{-3} N_E - 2,8 \cdot 10^{-7} T_p - 5,0 \cdot 10^{-8} m_m
\]  \( (10) \)

of statistical parameters:

\[
F = 36.51 \quad S = 21 \quad R = 0.8419 \quad SY = 0.0035
\]

\( T_p \) - temperature of liquid metal before carburization, \( F \) - Fisher’s test, \( R \) - correlation coefficient, \( S \) - standard deviation, \( SY \) - mean value

\[
S = 2,7 \cdot 10^{-3} + 1,4 \cdot 10^{-3} N_{E\text{mod}} - 2,7 \cdot 10^{-7} T_p - 4,7 \cdot 10^{-8} m_m
\]  \( (11) \)

of statistical parameters:

\[
F = 32.86 \quad S = 22.02 \quad R = 0.8419 \quad SY = 0.0035
\]

\[
S = 1,3 \cdot 10^{-3} + 2,6 \cdot 10^{-6} N_j - 2,3 \cdot 10^{-7} T_p - 1,9 \cdot 10^{-8} m_m
\]  \( (12) \)

of statistical parameters:

\[
F = 44.16 \quad S = 19.81 \quad R = 0.8640 \quad SY = 0.0035
\]

\[
S = 1,6 \cdot 10^{-3} + 2,4 \cdot 10^{-6} N_{J\text{mod}} - 2,4 \cdot 10^{-7} T_p - 2,2 \cdot 10^{-8} m_m
\]  \( (13) \)

of statistical parameters:

\[
F = 39.53 \quad S = 20.63 \quad R = 0.8514 \quad SY = 0.0035
\]
Range of changes and statistical equations presented above show that it is possible to replace the flow coefficient $N_{E}$ and the stream coefficient $N_{J}$ with modified coefficients $N_{E_{\text{mod}}}$ and $N_{J_{\text{mod}}}$ to the calculation of carburization indices and to obtain similar values of statistical parameters.

\[
S_{J} = -4.3 \cdot 10^{-2} + 4.0 \cdot 10^{-2} N_{E_{\text{mod}}} + 9.7 \cdot 10^{-6} T_{p} + 9.2 \cdot 10^{-3} C_{p}
\]  
(14)

of statistical parameters:

\[
F = 203.11 \quad S = 24.56 \quad R = 0.9621 \quad SY = 0.0673
\]

\[
S_{J} = -9.3 \cdot 10^{-2} + 6.6 \cdot 10^{-5} N_{J_{\text{mod}}} + 2.2 \cdot 10^{-5} T_{p} + 1.2 \cdot 10^{-2} C_{p}
\]  
(15)

of statistical parameters:

\[
F = 138.85 \quad S = 29.21 \quad R = 0.9459 \quad SY = 0.0673
\]

A similar analysis for a unit rate of carburization (for 1 Mg of liquid metal) has been carried out. The dependence above show that by introducing a unit rate of carburization a considerable increase of statistical parameters can be achieved.

The unit rate describes carburization better, is more universal and is independent of liquid metal mass. Moreover, carburization velocities in different furnaces can be compared. It results from the dependence that the more stream coefficient $N_{J}$ and flow coefficient $N_{E}$ increase, the more carburization rate increases. It confirms a hypothesis that the stream dynamics increase causes the carburization index increase.

6. SUMMARY

The problem of powder blowing into a liquid metal has been developed in the Department of Foundry, Silesian University of Technology, Gliwice, for many years. Liquid metal carburizing by means of a pneumatic method has been put into practice in many Polish foundries. Such a practical application of the method can be a starting point to further research on the effect of diphasic stream parameters on rate and efficiency of the process as well as on the quality of the alloys obtained. The Department also deals with the problem of manufacturing the aluminium matrix composites by introducing a dispersoid into the matrix [7, 8]. Also some model research enabling the observation of a diphasic stream in a liquid medium is carried out [9, 10, 11].

This work is sponsored by the state Committee for Scientific Research of the Republic of Poland under Grant No 4 T08B 038 23

BIBLIOGRAPHY

3. Janerka K., etc.; Szybkość nawęglania w funkcji parametrów strumienia dwufazowego w pneumatycznym nawęglaniu ciekłych stopów żelaza, Krzepnięcie Metali i Stopów, 1998, z. 38, s.207-212
7. Gawroński J., etc.: „Modelowanie pneumatycznego wprowadzania cząstek zbrojacych do osnowy kompozytu”, Acta Metallurgica Slovaca, 1999, v.5,
9. Janerka K., etc.: Szybkość procesu w pneumatycznym nawęglaniu ciekłych stopów żelaza, Krzepnięcie Metali i Stopów, 2000, vol 2, nr 44, s. 463-470
10. Janerka K., etc.: Analiza strumienia dwufazowego w procesie wdmuchiwania proszków, Archiwum Odlewnictwa, 2001, vol 1, nr 2/2, s. 489-494