Possibilities of rationalization of the melting process proceeding in Ø 700 cupola

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Received 14.07.2009; accepted in revised form 17.07.2009

Abstract

An attempt of rationalization of the cast iron melting process proceeding in a cupola has been taken on, based on the working parameters recorded during the first several hours of the cupola work. Examinations have been centred around the melting process taking place in a Ø 700 hot-blast cupola with a fixed receiver (forehearth). It has been found that a significant reduction in coke consumption is possible due to changes in cupola burdening without a detriment to furnace efficiency or the temperature of molten cast iron.

Keywords: Cupola; Coke consumption; Cupola efficiency

1. Introduction

Making cast iron by cupola melting is still a common practice both in countries leading in casting production and under our domestic conditions. It results from a variety of reasons, including the fact that the melting rates of modern cupolas are as a rule greater than the electric furnaces efficiencies. Furthermore, the cupola process has many advantages featured in a series of publications, including Ref. [1-4].

Wide-spread application of cupola for cast iron making results also from its great thermal efficiency (as compared with other fuel furnaces), high melting rate, and the continuous character of working, which enables easy adaptation to the alternating conditions of the moulding shop work [5, 6].

Basic methods of the intensification of cast iron cupola melting are applying of hot blast and oxygen-enriched blast. Both these methods ensure the more even cupola work and the achieving of higher cast iron overheating temperature; they also enable applying the coke of lower quality and give a contribution to the reduced coke consumption [7].

Many domestic foundries have cupolas equipped both in recuperators (mainly chimney-type ones) and in installations for enriching the blast with oxygen. Despite these additional installations, in many cases cupolas could work at lower coke consumption without significant drop in melting rate or the melt temperature.

It has been found fairy reasonable to determine the possibility of rationalization the cast iron melting process held in a hot-blast cupola of internal diameter of 700 mm equipped with a forehearth, which works in one of local foundries.

2. Authors’ investigations

The purpose of the investigations has been determining the possibly more beneficial conditions of cast iron melting in a cupola, determining the possibility of cutting down the cupola exploitation costs, and examination of the possibility of increasing its melting rate.

The cast iron melting has been performed in one of local foundries, using a cupola of 700 mm internal diameter, equipped with a forehearth and a counter-flow recuperator. The furnace has also an installation for enriching the blast in oxygen by introducing this gas to the air ducts running from the recuperator...
to the air box. A scheme of the cupola is shown in Fig. 1, while Table 1 gathers main dimensions of the furnace both prior to the melting operation and after the 7 hours of melting. The examined cupola has a single row of tuyeres and has been equipped neither with devices for measuring the quantity (or the pressure) of blown air, nor with a blast temperature recorder.

![Fig. 1. Scheme of the examined cupola](image)

The cupola has been lined with chamotte bricks and chamotte mortar, the same material has been used for fettling. Metal, coke and flux charges have been weighted and carried to the furnace by a charging car. The non-alloyed grey iron has been produced in the cupola. One melting campaign used to last for 6 to 10 hours.

To evaluate the cupola melting process, there have been determined quantities of charged materials, static and dynamic blast pressures along with blast temperature, as well as the temperature of cast iron at the spout of the forehearth. The measurements have been performed during a conventional production melting campaign, which has lasted in this case for seven hours.

### Table 1.

<table>
<thead>
<tr>
<th>Dimensions of the cupola</th>
<th>Before melting</th>
<th>After melting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Internal diameter [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- at the tuyere level</td>
<td>700</td>
<td>717</td>
</tr>
<tr>
<td>- upwards from the tuyere lower edge level by:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>250 mm</td>
<td>700</td>
<td>1040</td>
</tr>
<tr>
<td>500 mm</td>
<td>700</td>
<td>920</td>
</tr>
<tr>
<td>750 mm</td>
<td>700</td>
<td>850</td>
</tr>
<tr>
<td>1000 mm</td>
<td>700</td>
<td>750</td>
</tr>
<tr>
<td>2000 mm</td>
<td>800</td>
<td>750</td>
</tr>
<tr>
<td>2500 mm</td>
<td>850</td>
<td>850</td>
</tr>
<tr>
<td>3000 mm</td>
<td>850</td>
<td>850</td>
</tr>
<tr>
<td>2) Cross-sectional area of the cupola [m²]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- at the tuyere level</td>
<td>0.385</td>
<td>0.404</td>
</tr>
<tr>
<td>- maximum</td>
<td>0.567</td>
<td>0.849</td>
</tr>
<tr>
<td>- average</td>
<td>0.437</td>
<td>0.555</td>
</tr>
<tr>
<td>3) Number of tuyeres [pcs]</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Average area of tuyere cross-section [m²]</td>
<td>0.0160</td>
<td>0.0152</td>
</tr>
<tr>
<td>Total area of tuyere cross-sections [m²]</td>
<td>0.0800</td>
<td>0.0760</td>
</tr>
<tr>
<td>4) External diameter D [mm]</td>
<td>1220</td>
<td></td>
</tr>
<tr>
<td>5) Cupola well height h [mm]</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>6) Effective height H [mm]</td>
<td>4000</td>
<td></td>
</tr>
<tr>
<td>7) Internal diameter of a air duct supplying air to the chimney-type recuperator, where pressure has been measured, [mm]</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>8) Internal diameter of the forehearth [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- at bottom level</td>
<td>900</td>
<td>700</td>
</tr>
<tr>
<td>- upwards from the bottom level by:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>350 mm</td>
<td>900</td>
<td>850</td>
</tr>
<tr>
<td>700 mm</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>1050 mm</td>
<td>900</td>
<td>700</td>
</tr>
<tr>
<td>9) Length of a spout joining the cupola with its forehearth [mm]</td>
<td>750</td>
<td>840</td>
</tr>
<tr>
<td>10) Diameter of a spout joining the cupola with its forehearth [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- at the end joining the cupola well</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>- at the end joining the forehearth</td>
<td>65</td>
<td>150</td>
</tr>
</tbody>
</table>

The Pitot-Prandtl tube and Digilance II measuring lance fitted with the exchangeable non-splash immersion PtRh10-Pt thermocouple tips in silica casing have been used in the course of examinations.

General data characteristic for the working of the cupola are given in Table 2. The examined melting process can be divided in five stages significantly different with regard to the working parameters of the furnace; detailed data are shown in Table 3. The two first stages of melting have proceeded in the way appointed by the foundry engineering staff. Stages III to V of the examined melting process have been the experimental ones, during which the charged quantities of coke, flux and metal have been being changed in order to reduce the coke consumption. Simultaneously it has been examined if, and to the what degree, these changes...
influence the cast iron temperature and how the cupola melting rate has been changed.

Table 2.
General data characterising the operation of the cupola

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Data for the melting campaign</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The height of the coke bed</td>
<td>1.26 [m]</td>
</tr>
<tr>
<td>2</td>
<td>The time of appearing of the first metal drops after turning the blast on</td>
<td>5.5 [min]</td>
</tr>
<tr>
<td>3</td>
<td>The average weight of metal charge</td>
<td>375 [kg]</td>
</tr>
<tr>
<td>4</td>
<td>The average weight of coke charge</td>
<td>36 [kg]</td>
</tr>
<tr>
<td>5</td>
<td>The average weight of flux charge</td>
<td>11 [kg]</td>
</tr>
<tr>
<td>6</td>
<td>The temperature of initial cast iron (time after turning on the blast)</td>
<td>1438 [°C] (52 [min])</td>
</tr>
<tr>
<td>7</td>
<td>The average blast dynamic pressure</td>
<td>80 [mm H&lt;sub&gt;2&lt;/sub&gt;O]</td>
</tr>
<tr>
<td>8</td>
<td>The average blast static pressure</td>
<td>589 [mm H&lt;sub&gt;2&lt;/sub&gt;O]</td>
</tr>
<tr>
<td>9</td>
<td>The blast temperature</td>
<td>125-135 [°C]</td>
</tr>
</tbody>
</table>

Fig. 2 presents changes in the temperature of molten cast iron recorded during the operation of the cupola. During the first two hours this temperature ranged from 1471°C to 1380°C. During the further operation of the cupola, particularly during the fifth, the sixth, and the seventh hour of its work, when significant changes in cupola burdening have been applied, there have not been observed any drop in the temperature of cast iron taken from the cupola forehearth, it ranged from 1427°C to 1459°C.

Figure 3 compares average melting rates of the cupola and average coke consumption values for the considered stages of cast iron melting.

An inspection of the condition of lining after the melting process has revealed significant damages of both the cupola and the forehearth refractory lining (see Figs 1, 4-6). A diameter of the cupola has increased due to the wear of lining, e.g. from 700 mm to above 1000 mm at the level 250 mm above the lower edge of the tuyeres (see data in Table 1).

It should be noticed that the blast temperature has been relatively low – about 130°C as an average. The calculated apparent quantity of blown air determined accordingly to the Ref. [8] has been equal to 91 Nm<sup>3</sup>/min as an average.

Table 3.
Cupola melting rate along with coke and flux consumption during the operation of the furnace

<table>
<thead>
<tr>
<th>Stage of the cast iron melting (time of its duration)</th>
<th>Quantity of charged metal [kg]</th>
<th>Quantity of charged coke [kg]</th>
<th>Quantity of charged flux [kg]</th>
<th>Consumption of coke [%]</th>
<th>Consumption of flux [%]</th>
<th>Cupola melting rate [kg/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (246 min)</td>
<td>16973</td>
<td>1569</td>
<td>475</td>
<td>9.24</td>
<td>2.80</td>
<td>3847&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>II (37 min)</td>
<td>2605</td>
<td>294</td>
<td>56</td>
<td>11.29</td>
<td>2.15</td>
<td>4224</td>
</tr>
<tr>
<td>III (60 min)</td>
<td>4455</td>
<td>450</td>
<td>150</td>
<td>10.10</td>
<td>3.37</td>
<td>4455</td>
</tr>
<tr>
<td>IV (43 min)</td>
<td>3765</td>
<td>360</td>
<td>120</td>
<td>9.56</td>
<td>3.19</td>
<td>5253</td>
</tr>
<tr>
<td>V (48 min)</td>
<td>3800</td>
<td>210</td>
<td>75</td>
<td>8.08</td>
<td>2.88</td>
<td>4750&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> for calculating the melting rate it has been assumed that at the end of the I stage 1200 kg of non-melted metal charge has been left in the furnace;
<sup>2</sup> for calculating the melting rate it has been assumed that at the start of the V stage 1200 kg of non-melted metal charge has been left in the furnace;
<sup>3</sup> total value;
<sup>4</sup> average value.
3. Conclusion

A cupola in which the analysed melting process has been realised is properly constructed and fitted with a correctly selected centrifugal fan; it is revealed by proportions between the main dimensions of the cupola and the efficiency of the blower. Some objections can be raised about the performance of a chimney-type recuperator; the blow temperature at the level of 130°C is over by half lower than the expected one and significantly affects the melting process.

During the first stage of melting (lasting for 246 minutes) the cupola melting rate has been about 3800 kg/h, and the coke consumption has exceeded 9% (see data in Table 3). During the II stage the coke consumption has been increased up to about 11.3% because of the temporary drop in cast iron temperature measured at the spout of the forehearth below 1400°C (see Fig. 2); the cupola melting rate at that time has been equal to about 4200 kg/h. For both mentioned stages the melting process has proceeded according to the directions of the foundry engineering staff.

Taking into account that in the final period of the II stage the temperature of cast iron has exceeded 1450°C (see Fig. 2), it has been decided that both the cupola and the forehearth lining has been already strongly heated, and the research team have started to decrease the coke consumption. Simultaneously the cupola melting rate and cast iron temperature has been observed. It has been found that the reduction of coke consumption during the subsequent stages (III, IV, and V) is possible with simultaneous maintaining relatively high cast iron temperature (see data in Table 3 and in Fig. 2). The coke consumption during the subsequent stages has been reduced to the 10.10%, 9.6%, and 8.1%, respectively. The melting rate has been significantly increased during the III, IV, and V stages, reaching about 4500 kg/h, 5300 kg/h, and 4700 kg/h, respectively.

It should be noticed here that during the V stage the actual melting rate has been greater that its calculated value of 4750 kg/h, because the duration of this stage has been assumed for calculations as equal to the time for which the blower has been working, but during the several last minutes the furnace have not been charged any more (the melting campaign has been about to be finished).

To conclude, it should be said that after several hours of cupola installation (and relatively strong heating of the lining) it is possible, and even reasonable, to reduce the coke consumption. For the Ø 700 cupola the reduction of the coke consumption can be of the order of 20%; meanwhile the cupola melting rate increases (even by over 25%) without any detriment to the temperature of the molten cast iron.

References