Results and Trends on the Injection of Plastics and ASR into the Blast Furnace

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As an alternative to the injection of oil or pulverized coal, the injection of waste plastics is common operational practice in a number of blast furnaces. Over and above that the trend of using other waste materials as auxiliary reducing agents should also be noted. The injection of ASR has also been tested, but has not yet been introduced into normal operational conditions. From the metallurgical point of view it could be advantageous to inject synthesis gas made from ASR instead of the injection of granulated ASR itself. Such a synthesis gas could be injected into the tuyeres at the raceway level, as well as into additional tuyeres at the lower part of the shaft. Simulation model calculations promise considerable savings in coke consumption with higher productivity with shaft gas injection.

KEY WORDS: blast furnace; injection of waste plastics and ASR; gas injection.

1. Introduction

As a means of lowering the hot metal costs, the injection of auxiliary reducing agents, such as coal, oil or natural gas, represents the state-of-the-art in iron making. Apart from these traditional materials there is also a trend to use waste materials. Among them, waste plastics have proved particularly interesting due to their high caloric value and the gate-fee the recycling industry is willing to pay for it.

High caloric waste materials are also components of automotive shredder residue (ASR). However, the other chemical components of ASR as well as its physical nature make it less suitable for use as an auxiliary reducing agent. Therefore, a suitable and high grade preparation of ASR is necessary for economical and metallurgical reasons, as well as to avoid disturbances in BF operation. This process is quite expensive. The ASR preparation costs are estimated as being higher than the gate-fee the recycling industry is willing to pay for it.

From the metallurgical point of view, therefore, it should be worth thinking about the gasification of ASR rather than its mechanical preparation. The production of synthesis gas from ASR would offer the possibility of gas injection into the tuyeres at the raceway level or, as an alternative, the injection of reducing gas into additional tuyeres at the lower part of the shaft. Furthermore, ASR gasification would solve the problems connected with the non-ferrous metal content in the ASR. Therefore, this paper will put the main emphasis on this subject.

2. Injection of Waste Plastics

The reaction conditions existing within the BF are suitable for the utilisation of waste materials, under the condition that the material is injected into the tuyeres at the raceway level. As far as waste plastics injection is concerned, special investigations have been performed on contaminants emitted with the top gas or with the off gas from top gas combustion. The concentrations of contaminants have been found to be extremely low, fulfilling all requirements of the authorities.

The injection of high caloric plastics into the tuyere zone has been normal BF operational practice since 1995 at Stahlwerke Bremen GmbH, ARCELOR Group, Bremen/Germany, since 1996 at KEIHIN Works, NKK Corp., Kawasaki/Japan, and since 1997 at EKO Stahl GmbH, ARCELOR Group, Eisenhüttenstadt. The injection rate performed with German BFs is in the range of 50–70 kg/thm. For example, injecting waste plastics simultaneously with heavy oil at EKO Stahl GmbH led to consumption of all reducing agents with 460 kg/thm as an annual average for 2004 (Table 1).

In recent years rising prices of raw materials and energy

| Table 1. Consumption of reducing agents at BF 1 of EKO Stahl GmbH in 2004. |
|-----------------|-----------------|-----------------|
| Hot metal production | 553,100 | t/a |
| Blast temperature | 1,118 | °C |
| O₂ content hot blast | 23.8 | % |
| Coke | 377 | kg/thm |
| (incl. small coke <36 mm) | (39) | kg/thm |
| Heavy fuel oil | 16 | kg/thm |
| Agglomerated waste plastics | 67 | kg/thm |
| Total reducing agents | 460 | kg/thm |
has caused intensified investigations to use other waste materials than waste plastics. As a matter of fact, only high caloric waste materials have been found interesting as a substitute for coke or oil in any significant production scale rate. Such a material is animal fat, which has substituted up to 25% of the oil injection at EKO Stahl,\textsuperscript{4)} for example.

3. Injection of Automotive Shredder Residue (ASR)

There are a lot of different processes developed for the recycling of “end of life vehicles” and for the processing of ASR, a product of the car recycling.\textsuperscript{5–8)} The injection of ASR into the BF should make a welcome contribution to fulfilling the EU regulations on commodities such as car recycling. As a result of BF investigations it has been stated “that the injection of ASR into the BF is possible in principle with the prerequisite that requirements set for ASR are fulfilled”.\textsuperscript{9)} There is no doubt that with high grade processing of ASR the requirements concerning chemical composition and physical nature of the material to be injected will be fulfilled. It is likely to prove more difficult to guarantee the continuous ASR supply with sufficient and constant quality and sufficient quantity that is a fundamental demand on all the raw material supply of BF plants. In the final reckoning, the use of ASR as an auxiliary reducing agent will be regulated by the ASR processing costs, the gate-fee and the operational results of the BF. It has also to be related to the existing infrastructure of the steel mill concerned, as well as applicable in general.

Another way to fulfil the demand for the commodity of ASR recycling could be given by the gasification of ASR. For instance, an industrial scale gasification trial of 930 t of ASR was performed in 2003 at SVZ Schwarze Pumpe GmbH.\textsuperscript{7)} The ASR represented 25% of the input of the SVZ gasifier, mixed with lignite, waste plastics and municipal waste. The SVZ synthesis crude gas was processed for the methanol synthesis. The gas compositions are given in Table 2.

The processed SVZ synthesis gas could also be used as an auxiliary reducing agent, suitable for injection either into the tuyeres at the raceway level or into additional tuyeres at the lower part of the shaft. The two possibilities are discussed below.

3.1. Raceway Injection of Synthesis Gas from ASR Gasification

As acknowledged in general, the gasification of auxiliary reducing agents within the raceway runs overall without the formation of CO\textsubscript{2} or H\textsubscript{2}O. This acknowledgment has been confirmed in principle by the reports of Asanuma et al.\textsuperscript{3)} and Takaoka et al.\textsuperscript{6)} analysing appropriate BF operation and raceway hot model measurements (Fig. 1). They have demonstrated these correlations for the injection of more or less pulverized solid materials. With the injection of gaseous hydrocarbons the reaction velocity will be even faster. Thus, on raceway conditions it can be assumed that all the CO\textsubscript{2} and H\textsubscript{2}O primarily formed at the beginning of the raceway and resulting in appropriate energy gain will be completely reduced to CO and H\textsubscript{2} at the end of the raceway, coupled with an appropriate energy consumption. Therefore, the total energy gain of the gasification of hydrocarbon-gases can be described by the reaction (1).

\[
C_4H_8 + x/2 \cdot O_2 \leftrightarrow x \cdot CO + y/2 \cdot H_2 + \text{energy} \ldots \ldots (1)
\]

Therefore, if the C/H relation of the auxiliary reducing agent injected is low, the gain in energy of reaction (1) is also low. There is additional energy consumption due to the fact that the CO + H\textsubscript{2} volume must be heated up to the raceway temperature.\textsuperscript{10)} The dominant influence of the H\textsubscript{2} content is a consequence of its high thermal capacity of 14.2 kJ/kg and K compared to 1.04 kJ/kg and K for CO. That is the reason why CH\textsubscript{4} or natural gas has an extremely strong influence on the raceway temperature, corresponding both to experience of BF operation and to calculations by simulation models, which show that the temperature loss in the raceway will increase by increasing H\textsubscript{2} content of the auxiliary reducing agent injected.\textsuperscript{11)}

Regarding the theoretical case of the raceway injection of processed SVZ synthesis gas from partial ASR gasification (see Table 2), a relatively high energy loss is to be expected in the raceway due to the high content of H\textsubscript{2} and CH\textsubscript{4}. That means that the decreased reduction coke consumption in the shaft due to the additional reducing potential will partly be compensated by additional coke consumption in the hearth. Consequently, the raceway injection of synthesis gas from ASR gasification should not be recommended as an optimal solution.

3.2. Shaft Gas Injection of Synthesis Gas from ASR Gasification

The injection of reducing gas into additional tuyeres at the lower part of the shaft offers the possibility to lower the blast resp. the gas throughput in the hearth and to increase the reducing potential in the shaft, resulting in higher pro-

\[
\begin{array}{|c|c|c|}
\hline
& \text{SVZ synthesis crude gas} & \text{Processed SVZ synthesis gas} \\
\hline
\text{CO} & 29.6 & 23.5 \\
\hline
\text{H}_2 & 13.8 & 59.1 \\
\hline
\text{CO}_2 & 19.4 & 2.1 \\
\hline
\text{CH}_4 & 27.6 & 11.6 \\
\hline
\text{N}_2 & 9.6 & 3.7 \\
\hline
\end{array}
\]

Fig. 1. Gasification behaviour within the raceway.\textsuperscript{3,8)}
ductivity and decreasing coke consumption.

With regard to Table 2 it seems disadvantageous to inject the processed SVZ synthesis gas into the shaft due to its CH₄ content. The same goes for the “normal” SVZ synthesis gas, *i.e.* the synthesis gas made from the normal input mixture of SVZ without ASR. Therefore, by partial oxidation the “normal” SVZ synthesis gas has been converted into reducing gas, heating it up to 900°C simultaneously (Table 3).

The effect of the shaft gas injection on the BF efficiency has been checked by calculations with the BF simulation model of ThyssenKrupp AG.¹¹ In this manner, the reducing gas made from natural gas has been in place of those from ASR to secure a realistic fundamental. On the other hand, the analyses given in Table 3 show that both the reducing gases have some similarity of composition.

Some of the results of the simulation model calculations are given in Figs. 2 and 3. They are related to constant flame temperatures, *i.e.* to variable oxygen contents of the blast. The influence of shaft gas injection on the consumption of reducing agents is shown in Fig. 2. It promises a remarkable drop in coke consumption at constant quantities of waste plastics and oil—the latter will be indicated by the distance between the lower and the middle line, which is constant. However, the total consumption of reducing agents—the upper line—is increasing, certainly increasing more slowly than the coke consumption is going down. The economy of the shaft gas injection, however, will not only depend on the price relations of coke and natural gas, but will also be strongly influenced by the BF productivity.

Figure 3 shows the influence of shaft gas injection on the hot metal production at constant gas volumes of tuyere gas (upper line) respectively shaft gas (lower line) or top gas (middle line). All the data are related to constant flame temperatures, *i.e.* to variable oxygen contents of the blast. The upper line is particularly interesting here. This upper line shows that at constant tuyere gas volume, *i.e.* constant hot blast flow, the low coke consumption, caused by the shaft gas injection, is a prerequisite for high productivity.

Thus, the data indicate not only that the shaft gas injection of reducing gases offers remarkable possibilities to increase the BF efficiency. Over and above that, it can be stated that the increased BF efficiency could be realized by relatively low investment and relatively low operational risk.

Of course, this statement has been theoretical until now. However, it will soon be tested: at present, EKO Stahl is preparing its BF 1 for the injection of reducing gas by 15 additional tuyeres in the lower part of the shaft. The BF 1 is planned to enter operation as early as 2006, accompanied by an extensive research program.

### 4. Conclusions

(1) Waste plastics have been proven as an auxiliary reducing agent. The granulated waste plastics injection belongs to the state-of-the-art of the BF hot metal production.

(2) The use of granulated ASR as an auxiliary reducing agent is possible in principle with the prerequisite that the requirements set for the ASR are fulfilled. However, until now there has been no guarantee for the continuous ASR supply manifesting sufficient and constant quality and sufficient quantity.

(3) The gasification of ASR could provide a way to fulfill the demand for the commodity like ASR recycling. Synthesis gas made from ASR can be converted to reducing gas, which would preferably be used for the shaft gas injection.

(4) Independent of the use of plastics and ASR, the shaft gas injection of reducing gases offers remarkable possibilities for increasing the BF efficiency.

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**Table 3.** Hot reducing gas (900°C) made by partial oxidation.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Vol. %</th>
<th>Reducing gas made from synthesis gas</th>
<th>Reducing gas made from natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>23.3</td>
<td>23.3</td>
<td>31.8</td>
</tr>
<tr>
<td>H₂</td>
<td>62.5</td>
<td>62.5</td>
<td>61.7</td>
</tr>
<tr>
<td>CO₂</td>
<td>2.3</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>H₂O</td>
<td>10.4</td>
<td>10.4</td>
<td>4.1</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.2</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>N₂</td>
<td>1.3</td>
<td>1.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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**Fig. 2.** Consumption of reducing agents by shaft gas injection; basis: EKO Stahl, BF 1.

**Fig. 3.** BF productivity for constant gas volumes and densities; basis: EKO Stahl, BF 1.
REFERENCES

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