Analysis of Metallurgical Processes and Slag Utilisation in an Integrated Steel Plant Producing Advanced High Strength Steels

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Abstract

Some elements in the raw materials used in iron- and steelmaking make it difficult to maintain or further improve the steel quality, but also adversely affect the composition of generated slags and other materials, thereby reducing their potential for internal recycling and/or other utilisation.

A Process Integration (PI) approach was taken to analyse the dependence of the properties of a specific metallurgical slag on individual processes as well as on the interaction between processes. Analyses were made of how to obtain maximum usage of metallurgical slags without compromising the quality of the main product, i.e. crude steel. Based on a real case scenario, a number of approaches were studied with regard to the quality demands for maximised use of slags. The effects of changes in raw materials on blast furnace (BF) and basic oxygen furnace (BOF) processes were investigated. Altered composition of the raw materials affects material and BF reductant rate, generated slag amounts, slag recycling and material compositions, etc. In this study special attention was directed towards the magnesium oxide (MgO) contents in BF and BOF slags and, subsequently, the effects on phosphorus (P) refining in the BOF.

The analysis of system effects of changed quality of lime raw material, i.e. limestone and consequently on-site produced burnt lime, show that an increased MgO content raises the MgO level, exceeding the set maximum permissible MgO content in both the BF and the BOF slag. The increased MgO content in burnt lime charged to the BOF will have a strong negative effect on the P refining capacity of the slag; therefore, burnt lime with an increased MgO content cannot be used without taking further measures if maximum P refining is required.

Based on the results of the analysis, a number of approaches were further investigated in order to identify methods to preserve or decrease current MgO levels in generated slags and maintain, or further improve, slag utilisation potential without compromising the liquid steel (LS) quality. Analysed strategies were: diluting the MgO content in the BF slag by increased slag rate, decreased BOF slag recycling to the BF, increased P tolerance in BF produced hot metal (HM), lower MgO content in pellet mix or decreased use of dolomitic lime in the BOF. The most efficient approach to markedly increase the BOF slag recycling rate and simultaneously maintain the prerequisite MgO content in BF slag and LS quality is by increasing the tolerance of P in hot metal while at the same time excluding dolomitic lime in the BOF.
Introduction

Slag is an active ingredient in pyro-metallurgical processes for extracting and purifying metals. The generated compositions and amounts of slag will depend on the process in which the slag is formed and on the raw materials used in the process, e.g. iron input and fluxing ingredients such as burnt lime, governed by the proportions of materials required for an effective process. The large quantities of metallurgical slags generated annually in the steel industry necessitate finding options to make the slags useful in applications outside the internal steelmaking system. Examples of uses and criteria for the use of slags are presented in the literature [1-5]. Ways and aspects of the utilisation of ironmaking and steelmaking slags as valuable resources are presented by Das et al. [1] and Miho et al. [2]. Kumar et al. [3] argue the benefits of replacing cement clinker with slags. An increased utilisation of slags improves the material efficiency and helps reduce carbon dioxide (CO\textsubscript{2}) generation, use of virgin materials and energy demand. Some oxides like MgO in metallurgical slags used for civil engineering purposes, for example, in cement, are described to affect the quality of the cement adversely. Monshi and Asgarani [4] discuss the use of ironmaking and steelmaking slags as raw materials for Portland cement production and point out the obstacle posed by MgO content in slags due to its slow slaking when mixed with water (as this may cause cracks after the concrete hardens). Motz and Geiseler [5] describe the issues associated with free MgO in slags, such as volume expansion and instability, and the use of methods for testing the volume stability to get information about the volume expansion of steel slags to be used for road construction.

The most commonly used process for reduction of iron ore to liquid iron (i.e. hot metal) in the integrated steel plant is the blast furnace. Liquid steel is produced from the liquid iron output from the BF by treatment in the basic oxygen furnace. Limestone and burnt lime are used as slag formers in the BF and BOF processes, of which the burnt lime normally is produced on-site by calcination of the limestone. Roughly 45% of the generated BOF slag can be used as flux in the blast furnace with present slag processing, thereby reducing the need for limestone and improving the material efficiency. In the simulated iron and steel production system the phosphorus (P) level in produced hot metal limits recycling of BOF slag to the BF.

![Figure 1. Sources of MgO in the BF](image1)

![Figure 2. Sources of MgO in the BOF](image2)

The main sources of magnesium oxide to the blast furnace, illustrated in Figure 1, are iron ore pellets, by-product briquettes, recycled BOF slag and limestone. Future limestone quality will possibly be changed due to new sources of lime raw material. As the MgO content in the input lime raw material is expected to increase, the result will be a higher MgO level in the process chain, affecting the composition of generated slags. The major MgO source in the BOF is dolomitic lime, e.g. the main purpose of which is to preserve the refractory lining material. In Figure 2, the MgO amount to the BOF from different sources is illustrated. The
dolomitic lime is charged in the BOF to saturate the slag with MgO (approximately 10-12% of the BOF slag), thereby preventing dissolution of the alkaline magnesite lining material. However, an increased MgO content in the basic slag formers charged to the BOF has a strong negative effect on the P refining capacity of the slag and, hence, on the liquid steel quality, as the P partition ratio (P)/[P] decreases with increasing MgO content in the slag, Figure 3. This is due to the fact that the presence of MgO in the slag promotes the formation of low P-capacity tricalciumsilicate (3CaO·SiO₂) and/or wustite structures ahead of the high P-capacity dicalciumsilicate (2CaO·SiO₂).

![Graph showing BOF P partition ratio at end of blow as function of MgO content in slag and temperature, T (based on production data)](image)

Studies of structures and dissolution rate in slags, presented by Deo and Boom [6], show that the presence of MgO, already at an MgO content of 5% in the slag, promotes the early formation of tricalciumsilicate. Tricalciumsilicate has a negative effect on the dissolution of lime in the BOF process due to its higher melting point and thereby higher required dissolution temperature compared to dicalciumsilicate. Dogan et al. [7] developed a model to predict the dissolution rate of added fluxes, such as lime and dolomite, in the oxygen steelmaking process. The results from the model showed that the amount of flux dissolved in the process is enhanced if the addition rate of flux is increased or if the size of flux particle is decreased. Deo et al. [8] investigated parameters known to affect phosphorus distribution, i.e. basicity, temperature, FeO content of slag and slag mass etc., through models of the ionic theory of slag, optical basicity, regular solution approach and molecular theory of slag. From the ionic theory of slags, the MgO containing wustite tends to primarily become solid at steelmaking temperatures, when the slag has an MgO content of more than 7%. The solubility of phosphorus is presented to be much higher in dicalciumsilicate (4.2–5%) than in wustite solid solution (0.32% max). As wustite is primarily precipitated and the fluid slag becomes depleted in mobile cations before the PO₄³⁻ binding dicalciumsilicate is formed, both the amount of dicalciumsilicate and the phosphorus content of dicalciumsilicate are reduced. Conclusions from the study were that the presence of MgO in the slag decreases the phosphorus distribution ratio between steel and slag. Also, the slag morphology is altered by the presence of MgO and the size of dicalciumsilicate grains, as well as the dissolution of phosphorus in dicalciumsilicate decrease if the slag contains higher levels of MgO, thus hampering the dephosphorisation operation in the BOF. Consequently, burnt lime with an increased MgO content cannot be used, without considerable process modifications, when a low P content in the final steel is required.

In order to determine the system effects of changed lime raw material a process integration approach was taken. For this, a system analysis methodology has been used to simulate, estimate and analyse effects of changes in the production system on the whole system level,
thereby avoiding sub-optimisation. In an integrated steel plant it is not uncommon to optimise individual processes solely according to the specific needs of the process in question. However, small gains in one process step may transfer problems, limit the use of generated materials, i.e. slags, dusts, sludge, etc. and result in increased costs elsewhere in the plant. An example is the utilisation of metallurgical slags such as BF and BOF slag. If the slag composition is only governed by individual process issues, the result may well be a slag product with properties that limit its use in recycling and other, external applications.

**The objective of the study**

The objective of the performed system study was to analyse effects of an increased MgO content in the lime raw material, and based on the results investigate possible strategies to maintain or decrease present levels of MgO in generated slags, thereby preserving the slag use potential without compromising the liquid steel quality. Focus was directed towards effects on BF and BOF processes in regard to:

- raw material utilisation
- total slag generation, slag composition and slag recycling
- storage volumes of BF and BOF slags
- BF reductant (i.e. coke) consumption

**Method**

**Modelling tool**

The potential of the PI and system analysis method is that, within the defined system boundaries, it enables simultaneous representation of the industrial system, making it possible to optimise the whole system. This is in contrast to the optimisation of each sub-process individually. The PI method has been used for simulating and optimising complex material production systems. In the iron and steel industry the method has so far been used to a more limited extent and primarily for optimising energy systems. Some examples of applications of PI analysis in integrated steelmaking systems from the literature are presented by Spengler et al. [9], Schultmann et al. [10], Ryman and Larsson [11,12].

In this study, the modelling and analysis of the BF and BOF processes has been performed using a developed Excel spreadsheet model initially written in Super-calc 4, later converted to Microsoft® Office Excel and presented by Hooey et al. [13]. The model schematic is presented in Figure 4.

Figure 4. The system model's schematic and boundaries
The developed model is based on iterative heat and mass balances, including the element distribution between slag and metal, and can be used for process simulation and studies of various operating conditions as well as the influence by specific process parameters. The production units modelled in the system model are the BF and the BOF. The operating conditions for the system model are described using data from one year’s iron and steel production. The BF and BOF modules simulate the mass and energy balances of the processes for hot metal and liquid steel production with potential changes in charged amounts and compositions of raw materials.

**System study conditions and boundaries**

The model was calibrated to the reference case using data from a Swedish integrated steel producer. General conditions set for the modelling where:

- annual hot metal production approximately 2,200 ktonne
- 1.35% MgO in the pellet mix charged to the BF
- maximum BF slag rate 180 kg/tonne hot metal (kg/tHM)
- BOF slag rate 100 to 110 kg/tonne liquid steel (kg/tLS)
- desirable maximum MgO content in BF slag 15%
- desirable maximum MgO content in BOF slag 12%
- desirable maximum P content in hot metal 0.035%
- desirable maximum P content in liquid steel 0.008%
- BOF process P partition ratio, LP, according to MgO content in slag for a tapping temperature of 1720°C

The limestone and burnt lime compositions used in the modelling are presented in Table 1. The lime raw material currently used in the BF and BOF processes is denoted as limestone “A” and burnt lime “A” with an MgO content of 1.0% and 1.72%, respectively. The new lime raw material is denoted limestone “B” and burnt lime “B”, with an MgO content of 5% and 8.62%, respectively. As a consequence, due to a higher MgO content, the CaO content in the new lime raw material will be considerably lower than in the current lime raw material.

| Case study |

Studied cases and variable factors analysed for the system are described in Table 2. Investigations of the system effects of modelled strategies to maintain current MgO level in
the generated BF slag, maximising BOF slag recycling to the BF, without compromising the quality of the final product, were performed based on the results from analysis of using the high MgO lime raw material type B. The cases are therefore denoted A or B depending on lime raw material used. In case B the process parameters were held constant when compared with the reference case to evaluate changes resulting from introduction of lime raw material with increased MgO content.

Table 2. Case description and variables for the investigated cases compared to the reference case (t = tonne, = decrease, = increase)

<table>
<thead>
<tr>
<th>Case and type of lime raw material (A or B)</th>
<th>MgO in Limestone (%)</th>
<th>MgO in Burnt lime (%)</th>
<th>MgO in pellet mix (%)</th>
<th>P_max in HM (%)</th>
<th>Dolomitic lime to BOF slag (kg/tLS)</th>
<th>Burnt lime to BOF slag (kg/tLS)</th>
<th>Generated BF slag amount (kg/tHM)</th>
<th>Recycled BOF slag to BF (kg/tBF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference A</td>
<td>1.0</td>
<td>1.72</td>
<td>1.35</td>
<td>0.035</td>
<td>31</td>
<td>32</td>
<td>148</td>
<td>8.2</td>
</tr>
<tr>
<td>Case B</td>
<td>= decrease</td>
<td>= decrease</td>
<td>= decrease</td>
<td>= decrease</td>
<td>= decrease</td>
<td>= decrease</td>
<td>= decrease</td>
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<td>= decrease</td>
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<tr>
<td>Case B.2</td>
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<td>= decrease</td>
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<td>= decrease</td>
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<td>= decrease</td>
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<td>= decrease</td>
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<td>= decrease</td>
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<td>= decrease</td>
</tr>
<tr>
<td>Case B.6</td>
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<td>= decrease</td>
<td>= decrease</td>
<td>= decrease</td>
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<td>= decrease</td>
<td>= decrease</td>
</tr>
</tbody>
</table>

Investigated strategies in cases B.1 to B.6 were:

- increased BF slag rate to a maximum amount of 180 kg/tHM, thereby diluting the MgO content (case B.1 and B.4)
- decreasing the MgO input to the BF from recycled BOF slag by eliminating the dolomitic lime addition into the BOF (cases B.2 – B.5)
- no BOF slag recycling to the BF (cases B.3 and B.4)
- increased P_max in HM from 0.035 to 0.050% (case B.5), in order to increase recycling of BOF slag provided no dolomitic lime is added into the BOF
- decreasing the MgO content in the iron ore pellet to the level where the MgO limit in the BF slag is reached (case B.6)

Results

The case study results are presented in Tables 3 and 4.

Table 3. Summarised results from case studies on BF operations

<table>
<thead>
<tr>
<th>Case and type of lime raw material (A or B)</th>
<th>MgO in Limestone (%)</th>
<th>MgO in Burnt lime (%)</th>
<th>MgO in pellet mix (%)</th>
<th>Consumed Reductants in BF (kg/tHM)</th>
<th>Limestone to BF slag (kg/tHM)</th>
<th>Recycled BF slag to BF slag (kg/tBF)</th>
<th>Recycled slag to BF slag (kg/tBF)</th>
<th>Recycled slag to BF slag amount (kg/tHM)</th>
<th>P in HM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference A</td>
<td>1.0</td>
<td>1.72</td>
<td>1.35</td>
<td>0</td>
<td>60</td>
<td>8</td>
<td>0</td>
<td>5</td>
<td>0.035</td>
</tr>
<tr>
<td>Case B</td>
<td>5 8.62 13.5 16.5 13.3</td>
<td>459</td>
<td>62</td>
<td>8</td>
<td>0</td>
<td>5</td>
<td>149</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Case B.1</td>
<td>5 8.62 13.5 15.0 10.4</td>
<td>463</td>
<td>85</td>
<td>5</td>
<td>9</td>
<td>5</td>
<td>169</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Case B.2</td>
<td>5 8.62 13.5 16.1 4.2</td>
<td>460</td>
<td>63</td>
<td>7</td>
<td>0</td>
<td>5</td>
<td>149</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Case B.3</td>
<td>5 8.62 13.5 16.3 4.2</td>
<td>460</td>
<td>68</td>
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<td>0</td>
<td>6</td>
<td>148</td>
<td>0.033</td>
<td></td>
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<td>Case B.4</td>
<td>5 8.62 13.5 15.0 4.2</td>
<td>463</td>
<td>88</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>167</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>Case B.5</td>
<td>5 8.62 13.5 15.1 4.0</td>
<td>459</td>
<td>35</td>
<td>45</td>
<td>0</td>
<td>2</td>
<td>155</td>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td>Case B.6</td>
<td>5 8.62 1.19 15.0 10.4</td>
<td>460</td>
<td>65</td>
<td>8</td>
<td>0</td>
<td>5</td>
<td>149</td>
<td>0.035</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Summarised results from case studies on BOF operations

<table>
<thead>
<tr>
<th>Case and type of lime raw material (A or B)</th>
<th>Dolomitic lime to BOF (kg/t LS)</th>
<th>Burnt lime to BOF (kg/t LS)</th>
<th>MgO in BOF slag (%)</th>
<th>Generated BOF slag (kg/tHM)</th>
<th>Recycled BOF slag to BF (kg/tHM)</th>
<th>BOF slag to storage (kg/tHM)</th>
<th>[P] in LS (%)</th>
<th>[P] in BOF slag (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference A</td>
<td>31</td>
<td>32</td>
<td>11.1</td>
<td>109</td>
<td>8</td>
<td>101</td>
<td>0.008</td>
<td>0.29</td>
</tr>
<tr>
<td>Case B</td>
<td>31</td>
<td>32</td>
<td>13.3</td>
<td>109</td>
<td>8</td>
<td>101</td>
<td>0.009</td>
<td>0.29</td>
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<tr>
<td>Case B.1</td>
<td>21</td>
<td>42</td>
<td>10.4</td>
<td>110</td>
<td>5</td>
<td>105</td>
<td>0.008</td>
<td>0.30</td>
</tr>
<tr>
<td>Case B.2</td>
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<td>58</td>
<td>4.2</td>
<td>101</td>
<td>7</td>
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<td>0.006</td>
<td>0.35</td>
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<tr>
<td>Case B.3</td>
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<td>58</td>
<td>4.2</td>
<td>101</td>
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<td>110</td>
<td>8</td>
<td>102</td>
<td>0.008</td>
<td>0.30</td>
</tr>
</tbody>
</table>

From a case-by-case comparison to the reference case, the following is noted:

- In case B the processing parameters were kept constant when compared with the reference to evaluate changes resulting from introduction of lime raw material with increased MgO content. The results show that the MgO content is raised from 14.8% to 16.5% in the BF slag and from 11.1% to 13.3% in the BOF slag. The P content in the liquid steel is raised from 0.008% to 0.009%. The BOF slag recycling rate to the BF is constant compared to the reference.

- In case B.1 the dolomitic lime in the BOF process was decreased by adjusting the ratio of dolomitic lime/burnt lime to achieve the maximum tolerable P content in the liquid steel output. The recycling of BOF slag to the BF is consequently slightly decreased due to its increase in P content and the stored BOF slag is thereby increased by 4 kg/tHM. The BF slag rate was in this case increased from 148 kg/tHM in the reference to 169 kg/tHM, by raised limestone addition to 85 kg/tHM and also a quartzite addition of 9 kg/tHM to the BF, counteracting the MgO increase by dilution.

- In case B.2 the dolomitic lime was eliminated from the BOF process, which further improved the liquid steel quality regarding its thereby lowered P content to 0.006%. The BOF slag volume was at the same time reduced by 8kg/tHM compared to the reference. No improvement in BOF slag recycling rate to the BF was achieved from this action due to the P limit value in HM. However, a lower BOF slag rate of 101 kg/tHM resulted in a decreased volume of BOF slag to storage (to 95 kg/tHM). The MgO content in the BF slag exceeded the maximum value of 15% as the already low recycling rate of BOF slag, with lower MgO content, had no marked effect on the MgO content in BF slag.

- In case B.3 the BOF slag recycling to the BF was eliminated, as well as the dolomitic lime from the BOF process, to evaluate the impact of these actions on MgO and P flows in the system. The resulting P content in LS was 0.006% and P in HM was 0.033%. As in case B.2, less BOF slag was generated with an MgO content of 4.2%. The MgO content in the BF slag was in this case 16.3%. The results of case B.3 also showed a slight increase in the manganese slag addition to the BF of 5.8 kg/HM compared to 5.1 kg/tHM for the reference, depending on the lack of manganese to the BF from recycled BOF slag.

- In case B.4 the BF slag rate was increased to dilute the MgO content to meet the set maximum MgO in the BF slag without recycling of BOF slag. The BF slag rate in case B.4 was increased from 148kg/tHM in the reference to 167 kg/tHM by raising the limestone rate to 88 kg/tHM and also by quartzite addition of 8 kg/tHM as well as
manganese slag addition of 5.7 kg/tHM. In this case the BOF operation and results were similar to those of case B.3.

- Case B.5 resulted in an MgO content of 15.1% in BF slag and 4.0% in BOF slag achieved from increasing the P tolerance level in HM from the BF from 0.035% in the reference to 0.050%. By the strategy used in this case, the BOF slag recycling rate to the BF was increased from 8 kg/tHM in the reference to 45 kg/tHM. Hereby, the limestone consumption in the BF could be decreased to 35 kg/tHM and the stored BOF slag amount decreased to 60 kg/tHM (101 kg/tHM in the reference). Eliminating the dolomitic lime in the BOF, combined with a BOF slag rate of 105 kg/tHM, resulted in a P content of 0.008% in the liquid steel.

- In case B.6 the MgO content in the pellet mix to the BF was lowered to meet the set limit value on the MgO content in the BF slag. In this case the BOF slag recycling rate as well as the BF slag rate was similar to the reference. A slight increase in limestone to 65 kg/tHM was noted. The ratio of dolomitic lime/burnt lime to the BOF was similar to that in case B.1 (3/5), achieving the maximum tolerable P content in the liquid steel output.

Discussion

The system analysis shows that the maximum MgO contents set for the BF slag and the BOF slag are exceeded when the new lime raw material is used without any countermeasures taken (i.e. in case B). The maximum permissible concentration of MgO in the BF slag was exceeded also in cases B.2 and B.3, for which analyses were made regarding the effect of eliminating the dolomitic lime in the BOF (case B.2), combined with the elimination of BOF slag recycling to the BF (case B.3). Only a limited improvement in the MgO content in BF slag was achieved from a higher BOF slag recycling rate (case B.2) due to the generally limited recycling rate. However, the BOF slag quality was significantly improved in case B.3, as the MgO content was decreased to 4.2%.

The negative effect of MgO on P refining in the BOF is clearly noticeable already at very low levels in the slag (2-4% MgO). When only burnt lime is added, with an MgO content of 8-9%, the minimum achievable MgO content in the BOF slag is about 4-5%. Consequently, the burnt lime with an increased MgO content cannot be used without considerable process modifications if maximum P refining is required, as it limits the P partition ratio to somewhere between 50 and 60 (at 1720°C). The P content in liquid steel depends on the P content in hot metal and, as described above, the amount of dolomitic lime charged to the BOF. Hence, the P content in liquid steel is considerably reduced in the cases where no dolomitic lime is used. The generation of BOF slag can additionally be lowered by 4-8% in cases where no dolomitic lime is charged to the BOF. However, eliminating the dolomitic lime in the BOF will possibly have a negative effect on the durability of the refractory lining material.

The BF reductant rate is relatively constant in all cases compared to the reference case, except in cases B.1 and B.4, both with the strategy to increase the BF slag rate (by 14 and 13%, respectively) through increased limestone and quartzite additions. Both increased BF slag rate (cases B.1 and B.4) and using a pellet mix with decreased MgO content (case B.6) have a desirable effect on the MgO content in the generated BF slag. Unfortunately, an increased BF slag rate in case B.1 cannot be achieved by an increased BOF slag recycling rate, due to the set P limitation in the hot metal. Even when simultaneously altering the ratio of dolomitic...
lime to burnt lime, or when completely eliminating the dolomitic lime in the BOF, the recycling of BOF slag is limited by its P content.

The generally low BOF slag recycling rate in all the studied cases, except for case B.5, is due to the combination of a pellet mix with high P content and a rather restricted P content in hot metal. In case B.5 the maximum allowed P content in hot metal was raised in order to reduce limestone consumption by increased BOF slag recycling. In this case, to maintain the required liquid steel quality, it is necessary to eliminate the use of dolomite lime in the BOF.

Best found strategies, combined in case B.5, to achieve the objectives of the study are: increased tolerance of P in hot metal and eliminating dolomite lime in the BOF. These strategies result in an MgO content in BF slag within the tolerance level of 15%, an MgO content in the BOF slag of 4%, a P content in liquid steel of 0.008% and a considerably increased recycling rate of BOF slag, and thereby a decreased BF limestone consumption.

Conclusions

The maximum MgO content set for both the BF and the BOF slag is exceeded when the new lime raw material is used without any countermeasures taken. This may have negative effects on slag utilisation possibilities. However, this can be counteracted by:

- decreasing the recycling of MgO via the BOF slag
- increasing the BF slag rate, thereby diluting the MgO content
- decreasing the MgO content in the iron ore pellet

The best strategies from the results of the case study to achieve the objectives of maintained or decreased MgO levels in the generated slags, thereby preserving or further improving slag use potential, without compromising the liquid steel quality include:

- raising the maximum allowed P content in hot metal to increase BOF slag recycling, thereby reducing BF limestone consumption;
- eliminating the dolomitic lime in the BOF, as the lower MgO level in the BOF slag will improve P refining capacity and thereby not compromising the steel quality. However, with higher MgO in burnt lime, lowest possible MgO level in the BOF slag will be 4-5%, restricting further improvement in P refining capacity.

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