Energy and Pollutants Reducing Technologies in New Ironmaking Processes at POSCO


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The environmental assessment of new ironmaking processes at POSCO was carried out by focusing on the emissions reduction of air pollutants and CO₂ in comparison to blast furnaces. Through the assessment, the environmental benefits of new ironmaking processes can be elucidated especially in respect of the reduction of SO₂ and NOₓ emission levels. In addition the new ironmaking processes demonstrate that CO₂ emission reduction is enabled through the further energy optimization technological developments. In this respect, a technological approach to energy optimization in new ironmaking processes is introduced and discussed.

Key Words: environmental assessment; new ironmaking processes; air pollutants emission; CO₂ emission; energy optimization.

1. Introduction

In the past few centuries iron and steelmaking processes have developed in the direction of mass production, aiming for a stable supply to the steel consumers at low prices. This aim is expected to remain valid for the considerable period of the new century, and integrated steel works using fossil fuels, especially coal, are most relevant to the above aim under current technological and economical conditions. At present, most integrated steel works in the world are equipped with the blast furnace process because of its high technological relevance and the capabilities of massive production at low cost.

However, such integrated steel works are now faced with new situations in which the environmental standards and laws to regulate air pollutants have become strict. Additionally the reduction of CO₂ emission is emerging as the main problem in response to the Carbon tax proposed by the Kyoto Protocol on climate change. This situation is intensifying the pressure on steel makers in the world to introduce several environment-related technologies and facilities to their integrated steel works.

At POSCO, a great deal of effort is also devoted to reduction of air pollutants and CO₂ based on a precise and strict environmental assessment, which includes investment increases in environmental facilities, a change in raw materials and the optimization of energy utilization in exiting facilities. In such a procedure, new ironmaking processes such as COREX and FINEX have been assessed as not only cost saving processes, but also environmentally beneficial ones compared to the conventional blast furnace process.

In this paper, the environmental assessment of the new ironmaking processes in POSCO is described with a focus on the emissions reduction of air pollutants and CO₂ in comparison to the conventional blast furnace. Also, a technological approach to energy optimization in new ironmaking processes is discussed in relation to the reduction of CO₂ emissions.

2. New Ironmaking Processes at POSCO

The first COREX C-2000 which was scaled up to 0.6 million tons/year started its operation at POSCO's Pohang Works in November 1995. In the COREX process, the metallurgical work is carried out in the two separate process reactors, a reduction shaft furnace and a melter-gasifier. Iron ore and/or pellets are charged into the reduction shaft furnace where they are reduced to direct reduced iron (DRI) by a reducing gas ascending in counter-flow. Six DRI screws convey the DRI from the reduction shaft furnace into the melter-gasifier where final reduction and melting take place in addition to all other metallurgical and slag reactions. Hot metal and slag are then tapped in the same manner as in a conventional blast furnace. On the other hand, coal from 10 to 50 mm in size is charged into the melter-gasifier and converted to coal char by gasification of volatile matter. Combustion of coal char with oxygen occurs in front of tuyere generating heat and the gas necessary for metallurgical reactions in the melter-gasifier and reduction in the shaft furnace. The off-gas out of the reduction shaft furnace is available as a highly valuable export gas suitable for power generation or DRI production.

Because the COREX process can use only sized lump ore and pellets from 8 to 35 mm, a joint research program of POSCO/RIST (Korea) and VAI (Austria) commenced in December 1992 to develop a new ironmaking process which can directly use fine sinter feed ore up to 8 mm. The FINEX process is mainly comprised of multi-stage fluidized bed reduction furnaces for reduction of iron ore based on fluidization technology, and the melter-gasifier for smelting and gasification as shown in Fig. 1. Fine iron ore...
is stepwise reduced passing through 3–4’s multi-stage fluidized bed furnaces, where the necessary reducing gas is supplied directly from the melter-gasifier.

The finally reduced iron ore is charged into the melter-gasifier, wherein the coal gasification and metallurgical reaction takes place analogously to those in the COREX.

The sulfur content in the hot metal of the new ironmaking process is similar to that of the blast furnace. The main reasons for this result can be explained as follows. During the gasification of coal in a melter- gasifier, sulfur is converted predominantly to H₂S. And a small amount of SO₂ is formed by the combustion of H₂S with the oxygen in the dust burner region. The above H₂S and SO₂ along with reducing gases enter the reduction shaft furnace, where the additives, of which volume is about 30 – 40 % of charged ore volume, are descending. The calcined additives then react with H₂S and SO₂ included in the reducing gas and the involved reactions can be represented as follows:

\[
\begin{align*}
\text{CaO} + \text{H}_2\text{S} &\rightarrow \text{CaS} + \text{H}_2\text{O} \\
(\text{Ca, Mg})\text{O} + \text{H}_2\text{S} &\rightarrow (\text{Ca, Mg})\text{S} + \text{H}_2\text{O} \\
4\text{CaO} + 4\text{SO}_2 &\rightarrow 3\text{CaSO}_4 + \text{CaS}
\end{align*}
\]

Through these reactions, sulfur is captured in the calcined additives and then is fed into the melter-gasifier and formally dissolves into a molten-slag phase during the melting and slagging reactions in the char bed of the melter-gasifier. Accordingly, in the COREX process, 85 wt.% of input sulfur is removed as being contained in the molten slag. In the FINEX process, analogous de- sulfurization efficiency can be expected because the ore and additives mixture is fed into the fluidized reduction furnace in which the sulfur can be captured by the above reactions and the
same melter-gasifier is used in the process.

As shown in Fig. 2, it is clear that the emission level of NO, from the new ironmaking process is much lower than that from the blast furnace process. Most NO, is emitted from the sinter and coke plant, since it is produced mainly by the combustion of fuel with air for making coke and sinter. In new ironmaking processes, the majority of NO, is emitted from a power plant, but total NO, emissions correspond to 29% of those from the blast furnace process.

The CO, emission amounts from new ironmaking processes and blast furnace processes are calculated, respectively, by using the IISI assessment method defined as following formula.

\[
\text{CO}_2 \text{ emission amount} = \frac{(\text{Carbon Input to process directly and indirectly}) - (\text{Carbon output in product and by-product}) \times 44/12}{\text{Directly & Indirectly}}
\]

In this formula, the term “Carbon Input to process directly and indirectly” implies the carbon amount used in the process itself and the one used for the generation of utilities, such as steam, electricity, and oxygen, consumed in the process. The term “Carbon output in product and by-product” implies the carbon amounts in hot metal, wet sludge, and the export gas. In the calculation, the carbon balances in auxiliary facilities are also performed with the connection to main facilities, which include the power plant and oxygen plant in new ironmaking processes, and the coking plant, sinter plant, power plant and oxygen plant in the blast furnace process.

Table 2 shows the comparison of CO, emission amount per production unit between the new ironmaking and blast furnace process.

### Table 2. Comparison of CO, emission amount between COREX, FINEX and Blast furnace process (Unit: kg/t-Hot Metal)

<table>
<thead>
<tr>
<th></th>
<th>Blast Furnace Process</th>
<th>COREX Process (98 results)</th>
<th>FINEX Process (Estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (t-Hot Metal)</td>
<td>3,000,000</td>
<td>600,000</td>
<td>600,000</td>
</tr>
<tr>
<td>Carbon Input to Process</td>
<td>958</td>
<td>1,079</td>
<td>1,008</td>
</tr>
<tr>
<td>Directly &amp; Indirectly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Output in Product &amp; By-product</td>
<td>539</td>
<td>704</td>
<td>680</td>
</tr>
<tr>
<td>CO, Emission</td>
<td>1536</td>
<td>1375</td>
<td>1202</td>
</tr>
</tbody>
</table>

In spite of the higher carbon input amount, new ironmaking processes are showing lower CO, emission levels than the blast furnace process, which is attributed to relatively high deduction mainly due to the high export gas credit.

Considering that new ironmaking processes are still under development, optimizing and up-scaling, energy consumption rates will be reduced gradually with the technological development, accordingly CO, emission levels are expected to be lowered.

### 4. Energy Optimization in the FINEX Process

In large scale integrated steel works such as POSCO, the massive use of fossil fuel is inevitable under current technological and economical conditions. Accordingly the most realistic strategy to cope with a Carbon tax keeping with current production scales is the reduction of the fuel consumption rate through energy optimization.

Because the new ironmaking process was developed with the target of replacing a blast furnace, energy optimization has been of high priority over the other factors. The technological development for the energy optimization was performed by focusing on the 2 main process units, a coal packed bed type melter-gasifier and a fluidized bed type reduction furnaces.

In the process, the coal char packed bed in the melter-gasifier provides the main site of metallurgical reactions such as smelting, slagging, and gasification. The uniform distribution of gas super heat over the whole region is the decisive factor for energy optimization, which can be achieved by keeping the gas permeability over the whole bed as uniform as possible.

To ensure uniform gas permeability in a coal packed bed, an artificial size control of input material is introduced to the new ironmaking process. The corresponding main technologies are coal briquetting, and the compaction of hot fine DRI from the fluidized reduction furnace.

The peculiar coal briquetting process shown in Fig. 3 has been developed to utilize organic and inorganic species as the binder and hardening agent, respectively. Pre-treatment procedures before briquetting, such as mixing and hardening, are newly devised and optimized to achieve the stable production of coal briquettes of appropriate size (>10 mm), strength and reactivity. Coal briquettes manufactured by the above process were tentatively used in the existing melter-gasifier, wherein the fuel consumption rate was decreased by 7% and the pressure loss over the coal char bed was decreased by 18%. This shows that gas permeability and heat distribution over the coal char bed were apparently enhanced due to the use of coal briquettes.

The compaction of hot DRI fines is under development, wherein the compaction process and corresponding machinery have been devised and optimized to produce hot DRI compacts of appropriate size, strength and melting behavior for use in the melter-gasifier. In comparison to the conventional HBI process, the hot compaction process in FINEX is characterized as a high compaction speed with low energy consumption.

Because the fluidized reduction furnace in the new ironmaking process operates with a direct connection to the melter-gasifier, the available amount of reduction gas for the fluidized reduction furnace is strongly dependent on the level of fuel consumption in the melter-gasifier. In order to achieve an energy-optimized operation, the reduction degree should be attained as high as possible in the fluidized reduction furnace with the low reduction gas.
In the new ironmaking process, the iron ore is reduced by passing through the multi-stage fluidized bed reduction furnace, where the temperature and gas oxidation degrees in each furnace are adjusted to optimum values by using the partial combustion of reducing gas. Fig. 4 shows the optimized reduction path of iron ore in a multi-stage fluidized bed reduction furnace in the FINEX process, where the formation of a magnetite phase is prevented by increasing the temperature at the pre-heating stage.

Each furnace is designed to have a tapered profile, where the area increases upward, accordingly the superficial velocity decreases upward. This profile enables a high mixing efficiency, an even retention time distribution and lowering of the elutriation rate as shown in Fig. 5. This profile demonstrates favorably for the attainment of a high reduction degree at a low reduction gas consumption rate in pilot plant test runs.

In addition to the above technological development, the process configuration as shown in Fig. 6 is under consideration, where the additional fluidized bed reduction system is combined. Because the off-gas from the FINEX process includes a considerable amount of reduction agents such as CO and H₂, this process configuration enables around 50% increase of production scale without the large increase in fossil fuel consumption. In the mean time, as shown in Table 3, this process configuration results in only a 7% increase of CO₂ emission levels because of the decrease in export gas credit.

Therefore, this process configuration can be appreciated as a potential measure to increase the production scale without the large influence from carbon tax imposition.
Figure 6 Process configuration of FINEX® (HM)-FINEX® (DR1) combination.

Table 3. Comparison of CO₂ emission amount between FINEX and FINEX+FINEX DR1 process (Unit : kg/t-product)

<table>
<thead>
<tr>
<th></th>
<th>FINEX</th>
<th>FINEX + FINEX DR1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (t-Iron)</td>
<td>600,000</td>
<td>900,000</td>
</tr>
<tr>
<td>Carbon Input to Process Directly &amp; Indirectly</td>
<td>1,008</td>
<td>682</td>
</tr>
<tr>
<td>Carbon Output in Product &amp; By-product</td>
<td>680</td>
<td>329</td>
</tr>
<tr>
<td>CO₂ Emission</td>
<td>1,202</td>
<td>1,295</td>
</tr>
</tbody>
</table>

5. Concluding Remarks

To cope with strict environmental regulations and the Carbon Tax imposition, integrated steel works are establishing their own corresponding strategies such as development of several environment-related technologies and energy savings. As a part of such a strategy, R&D programs for the development of new ironmaking processes have progressed at POSCO, which have economical and also environmental benefits compared to conventional blast furnaces.

Through the COREX plant operation, the new ironmaking processes in POSCO have clearly demonstrated their environmental benefits compared to the blast furnace process, especially concerning the reduction of air pollutant emission levels. In the meantime concerning the CO₂ emission amount, the new ironmaking processes can not be concluded decisively to be more beneficial than the blast furnace at this time because of their high carbon demand for energy sources.

As described above, further technological developments in new ironmaking processes are mainly directed to energy optimization, which shall result in the reduction of fossil fuels consumption units, accordingly the reduction of CO₂ emission levels per production unit.

Through this development, the new ironmaking process at POSCO is expected to facilitate greater economic and ecological advantages.

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