CO_2 reduction technology through COG injection and low-reduced iron charging to the blast furnace

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To meet the demand for CO_2 reduction, in Korea, the COOLSTAR project has been promoting the development of technologies to reduce CO_2 emissions based on the blast furnace. The purpose of the project is to directly reduce CO_2 emissions by injecting by-product gas (COG) into tuyeres and charging low reduced iron (LRI) into the blast furnace, which is partially reduced in a fluidized bed reactor using reduction gas converted from by-product gas. To verify the CO_2 reduction effect of the blast furnace-based hybrid technology, partially reduced iron (LRI) was produced by a pilot-scale fluidized bed reactor, an appropriate blast furnace operation condition was derived by a mathematical blast furnace balance model, and the reaction characteristics at the shaft were investigated by a blast furnace reaction simulator test. Finally, the CO_2 reduction effect when 150 kg/t-p of LRI is charged into the blast furnace together with COG injection (H2 250 Nm3/t-p) was estimated. It was found that CO_2 emissions could be reduced by 7.7% through LRI charging and COG injection.

KEYWORDS: BLAST FURNACE, COG INJECTION, HYDROGEN REDUCTION, LOW REDUCED IRON, FLUIDIZED BED REACTOR

INTRODUCTION

As the demand for decarbonization increases in response to climate change, South Korea has declared carbon neutrality by 2050 and set a national greenhouse gas reduction target (NDC) of a 40% reduction by 2030 compared to 2018 levels in order to participate in climate crisis response. The Korean steel industry, which accounts for more than 14% of domestic CO_2 emissions, is developing various technologies to respond to this decarbonization demand. However, achieving net-zero through 100% hydrogen reduction in the steel industry requires time to establish infrastructure for hydrogen production and transportation. Therefore, there is a need for CO_2 reduction technologies based on existing blast furnace processes, so called bridge technology between conventional blast furnace and hydrogen-based ironmaking. In this regard, the Japanese steel industry has made significant efforts through the national project, focusing on introducing hydrogen gas into the blast furnace shaft, CO_2 separation, and improving raw materials. In Korea, the COOLSTAR project has been promoting the development of technologies to reduce CO_2 emissions based on the blast furnace. As part of this research, the possibility of reducing CO_2 emissions

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in the blast furnace process through the introduction of hydrogen gas into the furnace shaft and the use of low reduced iron (LRI) as a low-carbon alternative iron source was examined. The CO_2 reduction effect was evaluated using a thermochemical equilibrium model and a blast furnace shaft reaction simulator.

The objective of this study is to produce LRI with reduction degree over 65% with fluidized bed reactor and to predict the CO_2 reduction effect when 150kg/t-p of LRI is charged into blast furnace together with COG injection(H_2 250Nm^3/t-p). The research methodology is as follows. First, develop a model capable of calculating the heat & mass balance of the blast furnace depending on Air/O_2/COG blowing conditions and design optimum blowing condition using the model. However, since the reaction efficiency (gas utilization ratio) under the target conditions is unknown, it is necessary to evaluate the reaction efficiency through blast furnace simulation test. For the blast furnace simulation tests, LRI with a reduction degree of 65% was produced using a 50kg/batch pilot scale fluidized bed reactor. Based on the produced LRI and the operational conditions derived from the model, a blast furnace simulation test was conducted. Gas utilization efficiency derived from this, the final balance was calculated, and the CO_2 reduction effect was derived.

EXPERIMENTAL

LRI(Low reduced iron) production by fluidized bed reactor

In this study, a fluidized bed reactor was used for the production of LRI. The 50kg/batch fluidized bed reactor has a reactor height of approximately 2.7 meters and consists of an electric preheater for preheating the reaction gas, a reactor (including a dispersion plate), a cyclone/bag filter for dust collection, and a reaction gas cooling and combustion part. The reactor can inject reaction gases such as H_2/H_2O/CO/CO_2/N_2, and the interior of the reactor can be heated up to about 1000 degrees. Based on the expected thermal material balance of the 4-stage fluidized bed reactor under reformed COG-based reaction gas conditions, four fluidized reduction tests simulating each stage were sequentially conducted. Although the actual process involves four reactors connected in series for continuous reactions, we simulated each stage's reaction in batches. The tests confirmed the stable fluidization of Australian goethite ore under 5mm, and after the completion of the 4-stage reaction, LRI with a reduction degree of about 65% was produced. The produced LRI was introduced into a blast furnace reaction simulation apparatus along with sinter.

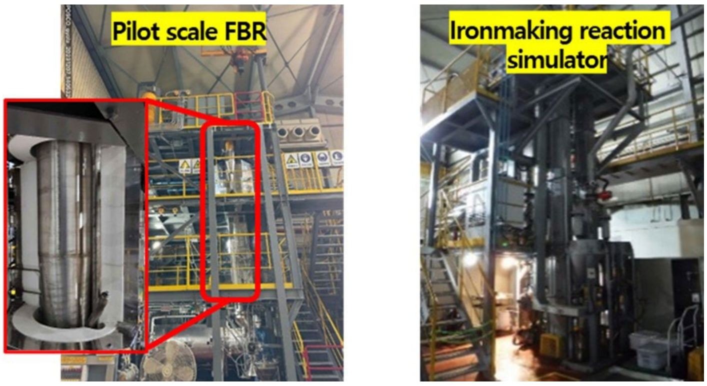

Fig.1 - Experimental apparatus used in this study.

Blast furnace reaction simulator experiment

To verify the effect of H_2-containing gas injection and LRI charging on blast furnace, the gas utilization efficiency for various operating cases was evaluated using a lab-scale ironmaking reaction simulator. The test apparatus can simulate the endothermic/exothermic characteristics according to the reactions between charged materials. It allows monitoring of changes in gas utilization efficiency, internal temperature caused by reactions between the continuously charged materials from the top, and the rising hot gas from the bottom. LRI (RD ~65%) produced in the pilot fluidized bed reactor was continuously fed into the reaction device along with sinter/coke, and the composition of the exhaust gas was measured while injecting preheated gas, which has the expected gas composition when H_2-containing gas is injected (H_2 250Nm³/t-p). The gas utilization efficiency was calculated from the $H_2/H_2O/CO/CO_2$ content in the exhaust gas and was finally used to calculate the balance of the blast furnace and the CO_2 reduction effect for each case.

RESULTS AND DISCUSSION

By utilizing the blast furnace balance model, we derived the appropriate blowing conditions that satisfy the blast furnace limit conditions such as tuyere frame temperature, top gas temperature, and volume of bosh gas, for the case of LRI 150kg/t-p and H_2 250Nm³/t-p. The injection of COG causes a decrease in T_f due to the heat of decomposition, but T_f can be maintained constant by increasing the oxygen enrichment. However, if the oxygen enrichment becomes too high, the top gas temperature decreases, so there are upper and lower limits of the oxygen enrichment rate that satisfy the limit conditions according to the hydrogen containing gas injection rate. Therefore, the oxygen enrichment ratio that satisfies the top gas temperature and Tf limit conditions can be represented as shown in the figure below, and the appropriate operation window can be set through this. When using LRI, it was generally confirmed that the operation window widens due to the effect of increasing the top gas temperature under the same H_2 containing gas injection conditions. Considering the results of the blast furnace reaction simulation test, it was found that the appropriate oxygen enrichment ratio when 150kg/t-p of LRI is charged into blast furnace together with COG injection(H_2 250Nm³/t-p) is around 10-13%.

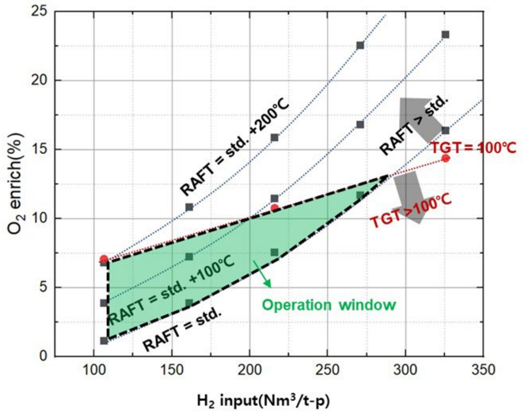

Fig.2 - Example of operation window derived by balance calculation.

Based on the above operation window and the results(shaft efficiency) of blast furnace shaft reaction simulation test, the carbon & heat balance and direct/indirect reduction ratio in the blast furnace for each case(LRI, COG, LRI+COG) were calculated as shown in the figure below. In all cases, the carbon consumption decreased compared to the standard case. The main reason for the reduction in carbon consumption is the increase in hydrogen gas, which leads to a decrease in direct reduction, and this is believed to be due to not only the replacement of existing carbon reduction by hydrogen reduction but also the fast reaction rate of hydrogen reduction itself. In the case of COG injection, additional tuyere combustion is required to compensate for the furnace top gas temperature, whereas in the case of LRI charging, the need for such additional tuyere combustion is unnecessary, so the simultaneous use of COG and LRI can efficiently reduce carbon consumption. Comparing the cases of using COG and LRI, it can be seen that the effect of reducing the direct reduction rate by using COG is relatively greater than that of LRI. This is because, as can be seen from the results of the blast furnace shaft simulation test, in the case of LRI, temporary reoxidation occurs in the upper part of the blast furnace rather than reduction, so the advantage of pre-reduction when entering the lower part of the blast furnace is not fully realized.

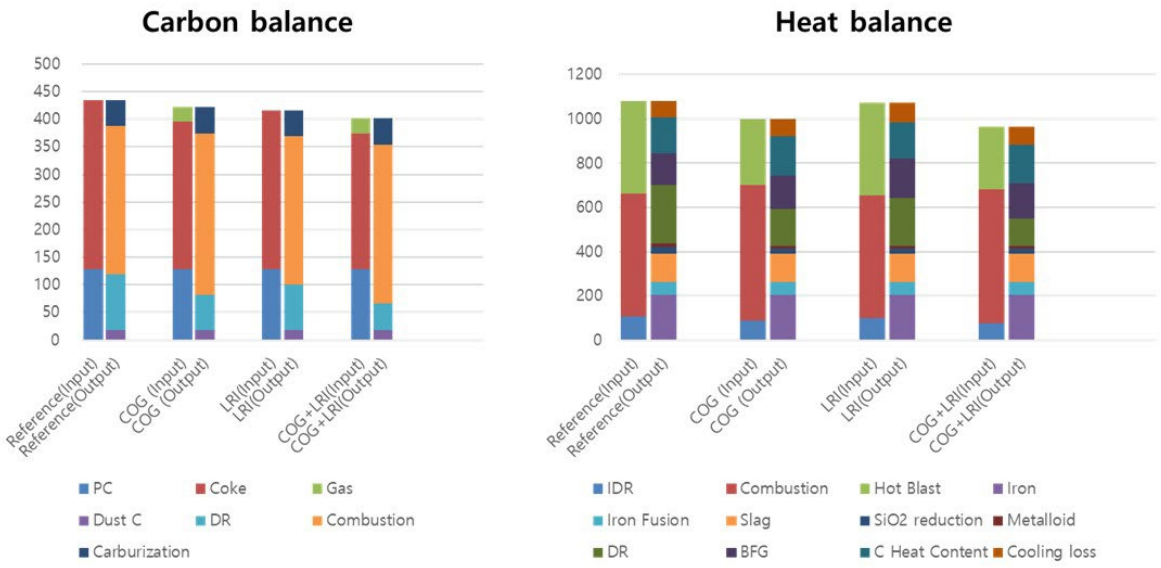

Fig.3 - Carbon and Heat balance of LRI/COG cases.

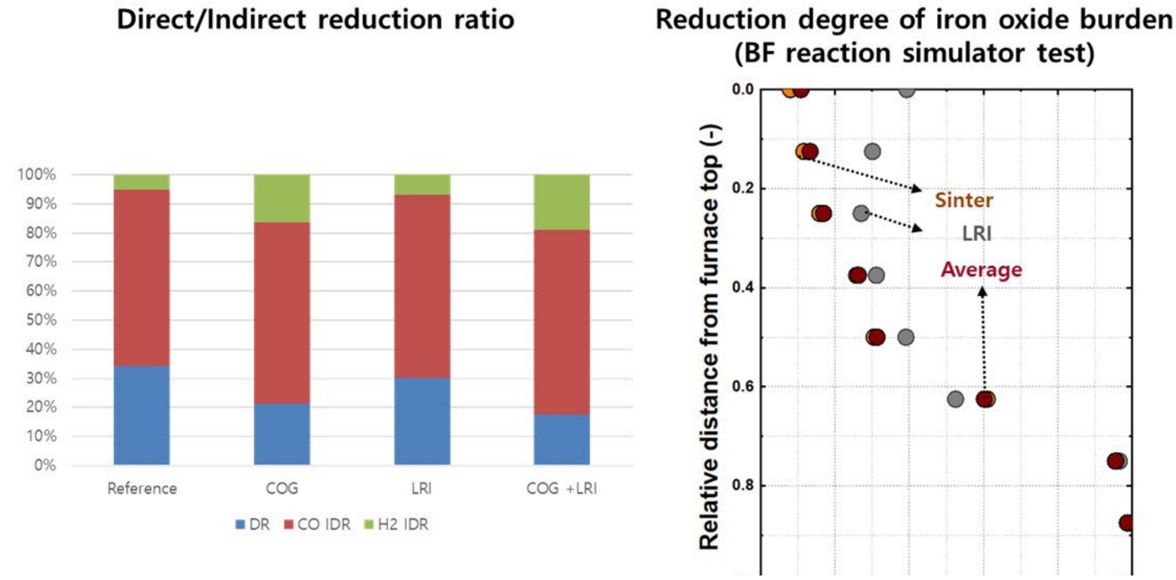

Fig.4 - Direct/Indirect reduction ration of each case and reduction degree of iron ore after BF shaft reaction simulator test.

Based on the tests of the pilot-scale fluidized reactor and blast furnace reaction simulator, the changes in the reducing agent ratio and CO_2 emissions were calculated for each case of blast furnace hydrogen-containing gas injection (H_2 250 Nm^3/t-p) and LRI charging (150 kg/t-p). The calculation results showed that in case of COG injection alone, the coke replacement ratio by COG was less than 1, leading to an overall increase in the consumption of the reducing agent ratio. However, due to the abundant hydrogen in COG, the net carbon consumption was expected to decrease by about 3%. When using LRI, the portion of direct reduction within the blast furnace decreases, leading to a carbon reduction of about 4.3%. Under the condition of COG injection together with LRI charging, a CO2 reduction effect of about 7.7%, higher than the simple sum of the individual cases, was confirmed. Detailed balance analysis results suggest that this is because the heat deficiency in the furnace caused by COG injection was partially resolved by the use of LRI.

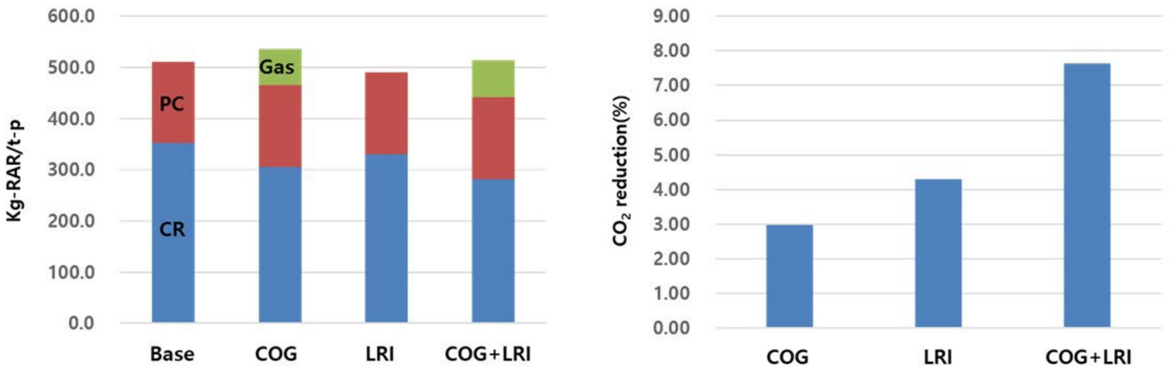

Fig.5 - Calculated reducing agent ratio and CO_2 reduction in each case.

CONCLUSIONS

To verify the CO_2 reduction effect by the blast furnace based hybrid technology, partially reduced iron(LRI) was produced by pilot scale fluidized bed reactor, appropriate blast furnace operation condition was derived by blast furnace heat and mass balance model and the reaction characteristics at shaft were investigated by blast furnace reaction simulator test. CO_2 reduction when 150kg/t-p of LRI is charged into blast furnace together with COG injection(H_2 250Nm^3/t-p) was estimated as 7.7%.

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