ISSN 2176-3135

ICSTI
6th International Congress on the Science and Technology of Ironmaking - ICSTI
42th Ironmaking and Raw Materials Seminar/ 42º Seminário de Redução de Minério de Ferro e Matérias-primas
13th Brazilian Symposium on Iron Ore / 13º Seminário Brasileiro de Minério de Ferro

POSSIBILITY OF HYDROGEN REDUCTION IN IRON-MAKING PROCESS
(Course 50 Programs in Japan)[1]

Shinroku Matsuzaki[2]
Kenichi Higuchi[2]
Akihiko Shinotake[2]
Koji Saito[2]

Abstract

Course 50 project is proposed by IISI with 6 major steel industries and related company. Course 50 stands for “CO2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50”. Basic idea of Course 50 is as follows. The low carbon environment harmony type iron making process development consists of it by development of the hydrogen practical use technology to iron ore reduction and development of cheap production technology of hydrogen (making to dry and amplification technology development of COG). Moreover, the CO2 separation collection technology development consists of it by CO2 separation collection technology in blast furnace gas and ironworks rejection heat technology used for CO2 separation collection. The outline of progress of technological development to use the hydrogen gas for the iron ore reduction is as follows. We attempt the decrease of CO2 exhausted from the blast furnace by blowing in reforming COG (The composition example; CO 30% and H2 60%) that contains hydrogen voluminously to the tuyere or the shaft of the blast furnace. It is important to clarify the diffusion behavior and the reduction behavior in the furnace of the hydrogen gas to use hydrogen in reforming COG effectively. The reduction behavior in the furnace was examined with BIS furnace. The result of the reduction efficiency's in the blast furnace improving even when blowing in from either the tuyere or the shaft was obtained. The diffusion behavior in the furnace was examined with a two dimensional experimental apparatus of 1/10 scales of a real furnace. As a result, it was confirmed that diffusion advanced from the furnace wall within the range from about 10 percent to 20 percent. Those results indicated that technology of injection of reformed-COG from shaft had a large possibility of reducing carbon consumption of blast furnaces, resulting in decrease CO_2 emissions in ironmaking process with thanks of higher reaction efficiency of hydrogen reduction compared with that of CO reduction.

Key words: Blast furnace; Hydrogen reduction; CO2 separation.

---

[1] *Technical contribution to the 6th International Congress on the Science and Technology of Ironmaking – ICSTI, 42nd International Meeting on Ironmaking and 13th International Symposium on Iron Ore, October 14th to 18th, 2012, Rio de Janeiro, RJ, Brazil.*

[2] *Iron making R&D Div., PTC. Nippon Steel Corporation, Shintomi20-1 Futtsu 293-8511, Japan.*

1 INTRODUCTION

We are promoting technology development through the innovative development program, Course 50(1) to decease CO_2 emissions in ironmaking. This program is conducted under active participation in joint programs operated by the World Steel Association and the EU(2) to grasp the latest trends in technology development and examine possibilities for joint research in basic fields in European nations.

Figure 1 shows the outline of COURSE50 project, consisting of two major research activities. One is development of technology to reduce CO_2 emissions from blast furnaces, involving with 1) development of reaction control technology to reduce iron ore by using hydrogen, 2) reforming technology of coke oven gas (COG) that increases the amount of hydrogen produced and 3) technology to manufacture high-strength and high-reactivity coke for hydrogen-reduction blast furnaces. The other is development of technology to separate and recover CO_2, involving with development of a high-efficiency CO_2 absorption method and technology to utilize unused waste heat in steelmaking plants for CO_2 separation and recovery.

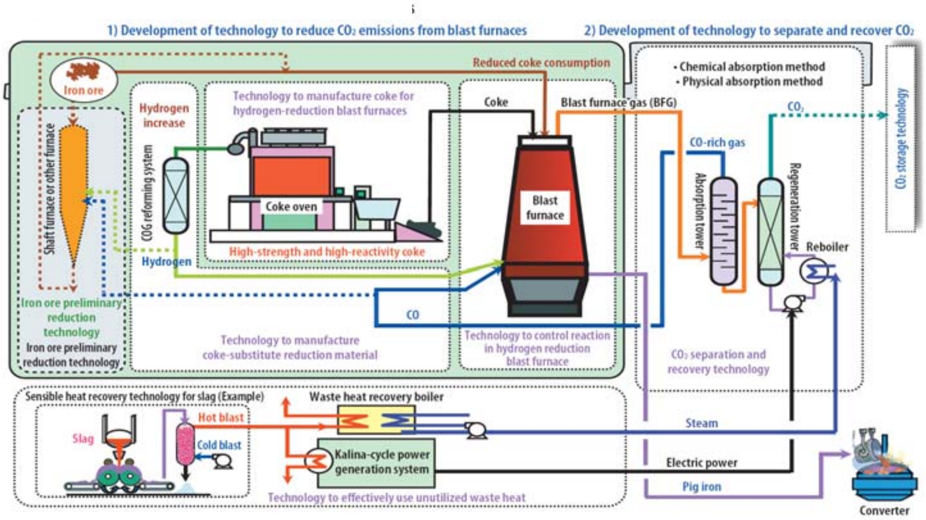


Figure 1. Basic idea of hydrogen reduction in Blast Furnace Process using reforming COG.

Expectation effect of hydrogen reduction can be summarized as follows.

1) Carbon-input reduce, the carbon input necessary for reduction is decreased by increasing the density of hydrogen in the reduction gas.

2) Reduction rate up, the reduction rate with hydrogen is faster than the reduction rate with CO.(3) Therefore, indirect reduction of the iron ore is promoted, and the input carbon and the input energy that is necessary for the direct reduction are decreased. As a result, the reduction at the low temperature can be expected to be promoted further. On the other hand, some demerit effect can be considered because the hydrogen reduction is an endothermic reaction. Heat shortage and the reduction degradation of sintered ore by appearance of low temperature thermal reserve zone seem to be problems. As for shaft injection of blast furnaces, the information is limited,(2,4) therefore this paper provides results on fundamental analysis of reduction behavior of sinter with hydrogen reduction. Furthermore a possibility of introducing hydrogen reduction in blast furnace through shaft injection to reduce CO_2 emissions in ironmaking is discussed.

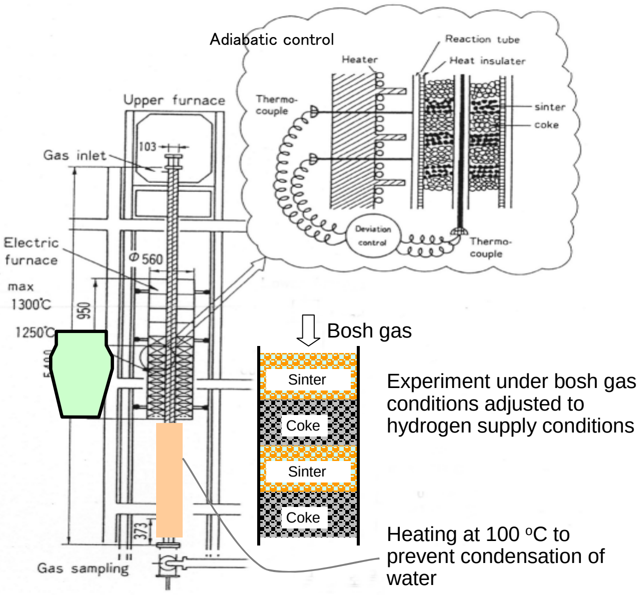


Figure 2. Schematic diagram of blast furnace inner-reaction simulator.(5)

2 TESTS WITH INNER REACTION SIMULATOR, BIS

To estimate reduction behavior of sinter at shaft with injection of reformed-COG, blast furnace inner-reaction simulator with an adiabatic control, BIS,(5) was used (Figure 2). BIS test demonstrating shaft condition of blast furnace up to 1100 degrees was conducted. Gas composition of reformed-COG was H_2 60% - CO 30% - N_2 10%. Due to a limitation of experimental apparatus, a simple case of injection was considered. 1) Hot reformed-COG (1,100 degrees) was injected from the portion where the temperature was 1,100 degrees. 2) There is no consideration gas distribution in radius direction of blast furnace. 3) As reformed-COG contained CO, bosh gas volume was decreased with increasing injection volume to keep constant ($CO+CO_2$) volume at 1,100 degrees after injection (Figure 3). Composition of gas before injection at 1,100 degrees was calculated based on 30% of direct reduction and 0.1 of CO_2/ ($CO+CO_2$).

After quenched by N_2 stream, sampled sinter was recharged into softening-melting test to estimate changes in permeability of sinter layer at high temperatures.

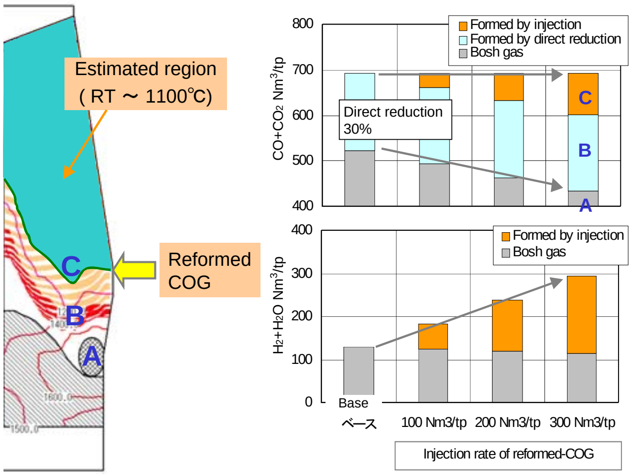


Figure 3. Schematic diagram showing test condition of BIS test demonstrating shaft injection of reformed-COG.

ISSN 2176-3135

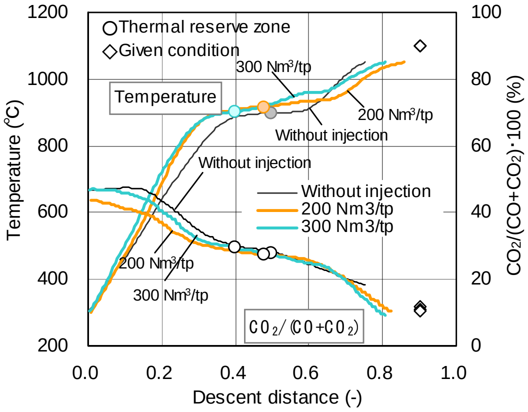
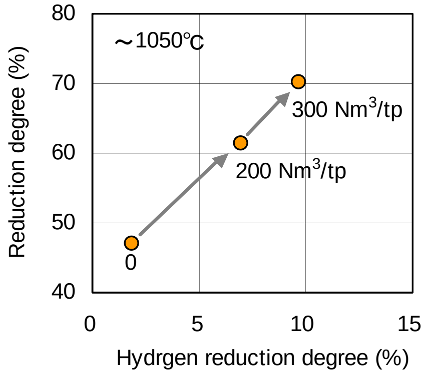


Figure 4. Changes in temperature profile and gas composition with increasing volume of reformed-COG injection from shaft.



Injection rate of reformed -COG	Nm^3/tp	0	200	300
Solution loss carbon (～1050℃)	kg/tp	54.5	69.9	83.2
Reduction degree (～1050℃)	%	49.0	63.7	72.8
by direct reduction	%	16.6	21.2	25.3
by indirect reduction (CO, H_2)	%	32.5	42.5	47.6

Figure 5. Changes in indirect / direct reduction and solution loss carbon with injected volume of reformed-COG in BIS test.

Figure 4 shows results of BIS tests with shaft injection showing changes in temperature profile and gas composition, $CO_2/(CO+CO_2)$ of shaft with injection of reformed-COG. Nevertheless introducing hydrogen into shaft, T_{TRZ}, temperature of thermal reserve zone shown as key in the figure, was increased by shaft injection. Furthermore, neither a retardation of elevating temperature nor one of reduction at shaft was observed in the test instead of introducing hydrogen into blast furnaces. T_{TRZ} and temperature profile of shaft are determined not only by reaction extent of endothermic reaction but also by heat flow ratio. Therefore the results of the increase of T_{TRZ} in and no retardation of reduction in this study were mostly due to changes in heat flow ratio and volume of reduction gas.

Figure 5 shows changes in reduction degree at 1,050 degrees by injection of reformed-COG. Here reduction degree was estimated by calculating removed oxygen from analysis results of exhaust gas. Total reduction degree was enhanced by injection. The increase was mostly due to hydrogen reduction and/or direct reduction as a result of water gas reaction. Detail analysis revealed that indirect reduction, sum of CO reduction and hydrogen reduction was enhanced by injection of reformed-COG although direct reduction was simultaneously increased. This result indicated that carbon consumption of blast furnace could be decreased by introducing hydrogen into blast furnace.

3 STUDY OF PENETRATION DEPTH INTO THE FURNACE OF THE REFORMED COG

Using a two-dimensional gas solid flow experimental apparatus (Figure 6), we examined how blown reforming of COG from the shaft. Experimental apparatus is about 4 m height and about 1m width, it is assumed a scale of 1/10 of the actual blast furnace.

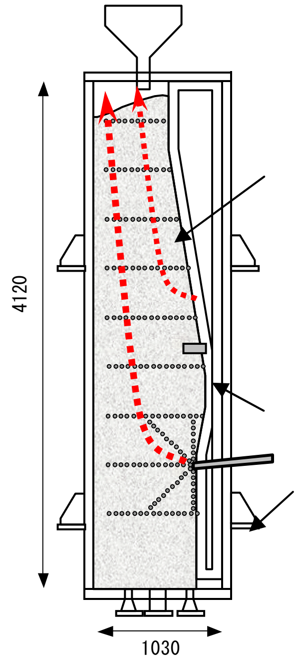


Figure 6. Figure of experimental apparatus.

Experimental method is as follows. Filled with coke of 2 ~ 5mm in experimental apparatus, injected 800l/min air at room temperature from tuyere, at the same time, injected CO_2 or H_2 from the shaft gas injection nozzle.
Sampling the gas from the sampling hole that was set up on the back of the experimental apparatus, and analyzed gas components by gas chromatography, to investigate the distribution of gas concentration (in increments of sampling; 50mm (max16point horizontal direction), 400mm (max9point height direction)).

Table 1. A list of the physical properties of the gas

	Diffusion coefficient	Viscosity coefficient μ	Density ρ
	m2/s 10^{-4}	Pa·s $\times 10^{4}$	kg/m^3
CO_2	0.142 (3.05℃)	0.148	1.82
He	0.6242 (3.05℃)	0.185	0.166
H_2	0.611 (0.05℃)	0.089	0.08
Air	–	0.184	1.2

In the gas injection from the shaft, to use a mixture, such as H2 and CO, the gas density and diffusion coefficient different. We confirmed whether or not does not affect the penetration in the furnace using the gas which physical properties different by using the experimental apparatus. Because there are a lot of issues on the safety to use of CO and H2 in this experiment, we substitute the CO2 and He gas which

ISSN 2176-3135

properties is relatively similar.

Figure 7 and Figure 8 show the CO2 concentration in the radial direction of furnace on the position 210 mm above shaft injection nozzle. Figure 7 is a case of changing the amount of injection gas volume. Figure 8 is a case of changing the nozzle diameter at a constant amount of injection gas volume. Now, the depth of penetration into the furnace, it is regardless of the gas velocity depends on the injection gas volume is understood.

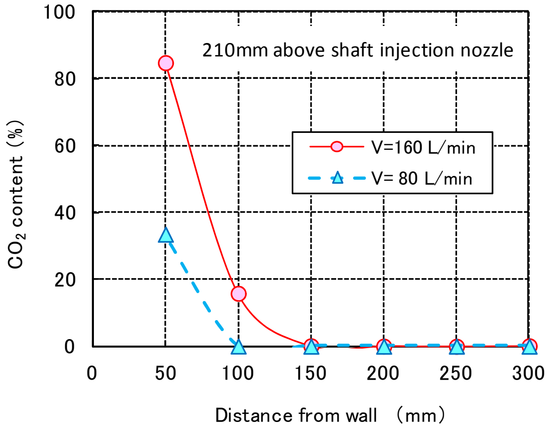


Figure 7. Comparison of penetration depths for different gas species.

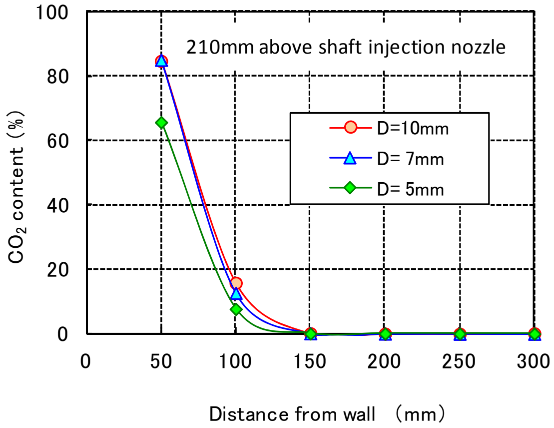


Figure 8. Comparison of penetration depths for different gas species.

In Figure 9, we compared the penetration depth for CO2 and He. Relative penetration depth from the furnace wall of the vertical axis was defined as follows. Penetration depth of 5% concentration of the gases / width of equipment.

Not much difference was observed between CO2 and He when compared in terms of relative penetration depth.

Also as well as Figure 2, the penetration depth becomes deeper larger the amount of gas injection, however, the depth of penetration is seen that there is a certain limit. Can lead to a similar phenomenon is also assumed, for CO and H2 that are used in an actual furnace.

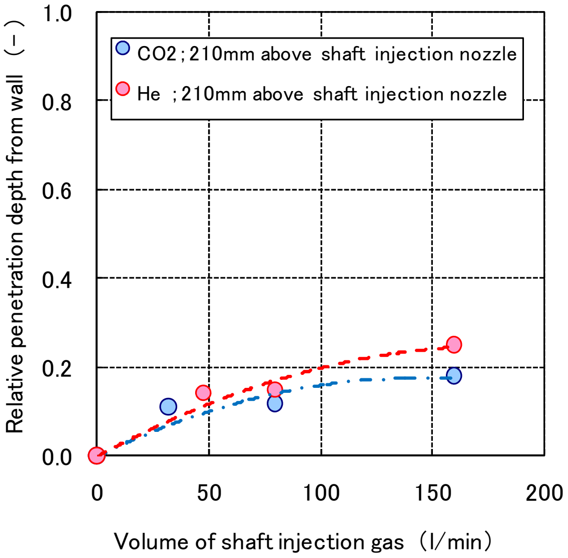


Figure 9. Comparison of penetration depths for different gas species.

4 CONCLUSION

To clarify the possibility of decreasing CO_2 emaciation of blast furnace with introducing hydrogen reduction of sinter, some fundamental reduction tests were carried out. Following conclusions were derived. Total reduction degree was enhanced by injection of reformed-COG in BIS test. Indirect reduction contributed the increase of total reduction degree. This fact indicated a possibility of decease of carbon consumption of blast furnace by injecting reformed-COG from shaft.
Performed using two-dimensional gas solid flow experimental apparatus to simulate the injection of reformed COG to the shaft, the following findings were obtained. Penetration depth of gas into the furnace is increased by the increase in the amount of blowing, there is a limit, and difference in the penetration depth of gas into the furnace by the species is not remarkably seen.

Acknowledgement

This work was financially supported by " Technology Development for Environmentally Harmonized Steelmaking Process <COURSE 50> ", founded by the New Energy and Industrial Technology Development Organization, Japan.

References

1 S. Matsuzaki, K. Yonezawa, K. Saito, M. Naito: CAMP-ISIJ, 22 (2009), p.268-269.
2 Birat, J.-P. et al.: SCANMET III, 3rd Inter. Conf. on Process Development in Iron and Steelmaking, (2008), p.61-75.
3 K .Ishii, T .Akiyama, N .Kasai, Y. Kashiwaya, and S .Kondo: Proc. of 5th Inter. Iron Steel Cong. ISS (1986), p. 9 -17.
4 T .Yatsuzuka, K .Nakayama, K .Ohmori, Y .Hara and M .Iguchi: Tetsu-to-Hagané, 58 (1972), p.624 - 636.
5 M .Naito, M .Nakano and S .Nomura: Proc. of 3rd ICSTI, Düsseldorf, VDEh, (2003), p.539 - 543.