Control of CO\textsubscript{2} Peak Position by Dual Lance Air Curtain Method

Morimasa ICHIDA, Kazuya KUNITOMO, Tsunehisa NISHIMURA, Masatoshi SAKATANI, Hiromitsu UENO and Kazumoto KAKIUCHI

Environment & Process Technology Center, Nippon Steel Corp., Shintomi, Futtsu, Chiba 293-8511 Japan.
1) Kimitsu Works, Nippon Steel Corp., Kimitsu, Kimitsu, Chiba 299-1141 Japan.
(Received on March 7, 2002; accepted in final form on June 26, 2002)

A phenomenon that a CO\textsubscript{2} peak position or temperature peak position of combustion (CO\textsubscript{2} or temperature peak position) in the raceway of blast furnace approaches a tuyere in step with the increase of pulverized coal rate (PCR) changes a gas flow at the lower part of the furnace into a peripheral flow or lowers the temperature at the raceway end, which may be one of the factors making the furnace operation unstable. Therefore, a pulverized coal combustion method (dual lance air curtain method) which interrupts temporarily a contact of pulverized coal and hot air in the vicinity of lance tip by injecting cold air through an opening between inner and outer tubes of the dual lance was examined by performing a hot model experiment and a single tuyere test of actual furnace. The hot model experiment results have revealed that with the increase of the flowing velocity of cold air sent from the outer tube of dual lance, the temperature around the tuyere tip falls and the temperature ranging from the raceway and to a dead man surface rises. According to the examination results of gas temperature under the raceway conditions of actual furnace with the use of one-dimensional raceway model, an estimated value of the moving distance of CO\textsubscript{2} or temperature peak position of combustion toward the dead man side is 480 mm when the dual lance air curtain method has been taken this time at Kimitsu No. 2 blast furnace. The combustion efficiency of pulverized coal could decrease due to movement of CO\textsubscript{2} or temperature peak position of combustion to the dead man side. And in the actual furnace test conducted this time with a single tuyere, the increase range of unburnt char ratio at the inside of dead man is as small as less than 1% relative to -1 mm fine and the packing structure of dead man surface has been improved.

KEY WORDS: high PC injection operation; PC combustion control; dual lance; air curtain; dead man; CO\textsubscript{2} peak position; temperature peak position.

1. Introduction

It has already been reported\textsuperscript{1–3)} that as a pulverized coal rate (PCR) rises, a CO\textsubscript{2} or temperature peak position of combustion (almost corresponding to CO\textsubscript{2} or gas temperature peak position) in the raceway of blast furnace comes nearer a tuyere. Since this phenomenon brings about a change of gas flow into a peripheral flow at the lower part of the furnace,\textsuperscript{1–3)} it is supposed to be one of the factors making the furnace operation unstable. As the means which keeps the CO\textsubscript{2} or temperature peak position of combustion approaching the tuyere away from the tuyere, so far, adjustments of lance tip position, blast velocity at tuyere and properties of pulverized coal (VM,\textsuperscript{2) particle diameter, etc.) have been examined.

It has however been found that the above means involves a difficulty of changing the CO\textsubscript{2} or temperature peak position of combustion during operation in response to the change in the operational conditions (for example, PCR level, radial distribution of ore to coke ratio and others).

Accordingly, a hot model experiment was performed with the use of a dual lance as the pulverized coal injection lance and further, a single tuyere test of actual furnace was also made to examine the possibility of control of CO\textsubscript{2} or temperature peak position of combustion in the raceway while the furnace operation is going on.

2. Points Involved in Approach of CO\textsubscript{2} or Temperature Peak Position in Raceway to Tuyere in High-PCR Operation and Countermeasures

Figure 1 shows the calculation results of gas composition and gas temperature in the cases of all-coke operation and high-PCR operation (PCR=181 kg/t) obtained by the one-dimensional raceway model\textsuperscript{4) developed by Tamura \textit{et al.} It is found from these results that the CO\textsubscript{2} or temperature peak position of combustion, that is, CO\textsubscript{2} or gas temperature peak position in the case of high-PCR operation is getting nearer the tuyere than that in the case of all-coke operation. According to the hot model experiment results, it comes out that when the CO\textsubscript{2} or temperature peak position of combustion (peak position of gas temperature) comes near the tuyere, the furnace wall temperature at bosh (a place of 500 mm above the tuyere center) is rising. (Fig. 2) It can be guessed that this is because of gas flow having changed into a peripheral flow. In addition, it is presumed that gas permeability and liquid permeability at the dead man surface have also become poor because of the temper-
ature at the raceway end having fallen due to approach of CO\textsubscript{2} or temperature peak position of combustion (CO\textsubscript{2} or temperature peak position) to the tuyere.

So, with the object of controlling the CO\textsubscript{2} or temperature peak position of combustion during operation, a pulverized coal combustion method (hereinafter referred to as a dual lance air curtain method) (Fig. 3) has been developed which interrupts temporarily a contact of pulverized coal and hot air in the vicinity of lance tip by injecting cold air through an opening between inner and outer tubes of dual lance (hereinafter abbreviated as a dual lance outer tube).

3. Hot Model Experiment

3.1. Experimental Method

Table 1 shows the experimental conditions. In the hot model experiment (tuyere diameter of 30 mm), coke having particle diameter of 9 to 13 mm was packed. The blast volume was set to 83 to 86 Nm\textsuperscript{3}/h with the blast temperature of 1250°C. Except a case of the conditions of cold O\textsubscript{2} injection from the dual lance outer tube, an enrichment O\textsubscript{2} volume was adjusted so that a theoretical combustion temperature at tuyere tip (Tf) and a bosh gas volume almost become fixed respectively as 2180°C and 126 Nm\textsuperscript{3}/h. An estimated value\textsuperscript{5}) of formed raceway depth is 209 to 225 mm.

The volume of pulverized coal injected through the dual lance inner tube was set to 144 g/Nm\textsuperscript{3}. Three species of gas, that is, N\textsubscript{2}, Air and O\textsubscript{2} were injected from the dual lance outer tube and the gas flow rate was changed to 3 levels.
Table 1. Experimental condition in hot model.

| Experiment No. | 1  | 2  | 3  | 4  | 5  |
|----------------|----|----|----|----|----|
| Blast volume  | Nm³/h| 86 | 85 | 86 | 90 | 83 |
| Blast temperature | °C | 1250 | 1250 | 1250 | 1250 | 1250 |
| N₂ volume for PC transportation | Nm³/h | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Gas volume from dual lance | Nm³/h | 5.0(N₂) | 5.0(O₂) | 5.0(Air) | 1.5(Air) | 7.5(Air) |
| PC concentration | g/Nm³ | 143 | 145 | 143 | 142 | 144 |
| Flame temperature | °C | 2180 | 2284 | 2180 | 2180 | 2179 |
| Air ratio | — | 1.03 | 1.10 | 1.03 | 1.00 | 1.04 |
| Blast gas volume | Nm³/h | 126 | 126 | 126 | 126 | 126 |
| Tuyere velocity | m/s | 158 | 155 | 158 | 164 | 153 |
| Raceway depth | mm | 216 | 213 | 218 | 225 | 209 |
| Average coke size | mm | 11 | 11 | 11 | 11 | 11 |

(1.5, 5.0 and 7.5 Nm³/h: Gas flowing velocities: 30, 100 and 150 m/s). Moreover, a center axis at a place of 80 mm on this side of the tuyere tip was taken as the dual lance tip position. The raceway internal gas temperature and the dead man temperature were measured with the use of a raceway probe and a dead man probe (Fig. 4) installed at the opposite side of tuyere.

3.2. Experiment Results

Figure 5 shows the experiment results obtained when N₂, Air and O₂ were injected 5.0 Nm³/h each from the dual lance outer tube. (Gas flowing velocity 100 m/s) In the case of N₂ and Air, compared with a case of O₂, temperature nearby the tuyere tip is low and temperature at the raceway end is high. And, there is no big difference in temperature distribution between the cases of N₂ and Air.

It is estimated that the above phenomenon is due to the fact that a local adiabatic effect between hot air and pulverized coal at the tuyere tip by cold N₂ and Air flow injected from the dual lance outer tube or a lowering effect of convection heat transfer coefficient is great (Fig. 6). In the case of blast temperature dropped, coke combustion increases because of combustion efficiency of pulverized coal (ηpc) drop and as a consequence temperature at the raceway end increases. But in this case the quantity of temperature increase is low because of broad temperature peak of coke combustion and input calorie in the lower part of blast furnace decreases. (As to O₂, a reaction acceleration effect between hot air and pulverized coal is supposed to be greater than the said local adiabatic effect between hot air and pulverized coal at the tuyere tip by O₂ or the lowering effect of convection heat transfer coefficient.

Next, Figs. 7 and 8 show the measurement results of the radial distribution of gas temperature in the raceway and dead man temperature in the case of Air flowing velocity (Air flowrate) having been changed, keeping eyes fixed on Air which is easy to put to practical use. These temperatures are measured by thermocouples equipped with tip of a raceway probe and a dead man probe shown in Fig. 4. These temperature are not gas temperature and solid temperature strictly. The former is almost the same as the gas temperature because of high void fraction in raceway. But the latter is the average value of the gas temperature and the
solid (coke etc.) temperature in the dead man. As obtained from these figures, with the increase of Air flowing velocity, gas temperature in the vicinity of tuyere tip is lowering and gas temperature ranging from the raceway end to the dead man surface and the dead man temperature are rising. The reason would be that because of the aforesaid local adiabatic effect between hot air and pulverized coal at the tuyere tip or the lowering effect of convection heat transfer coefficient having increased in line with the increase of Air flowing velocity (Air flowrate), the combustion of pulverized coal has been delayed and the CO₂ or temperature peak position of combustion has transferred to the dead man side, that is, gas temperature near the raceway end has been increased.

By virtue of the above-mentioned method, an original purpose which moves the CO₂ or temperature peak position of combustion in the raceway toward the dead man side has almost been accomplished. It is however necessary to control the lowering of combustion efficiency of pulverized coal resulting from the movement of CO₂ or temperature peak position of combustion to the dead man side. Accordingly, the combustion efficiency of pulverized coal (η_{pc}) was obtained from the alumina balance of ash contained in dust sampled from the inside of raceway and ash contained in injected pulverized coal to investigate the influence of the foregoing method on the combustion efficiency of pulverized coal (η_{pc}) in the raceway. At the same time, another dust was sampled from an uptake at the top of furnace to investigate the overall combustion efficiency of pulverized coal (η_{pc}). Even in any conditions of gas injection from the dual lance outer tube, the combustion efficiency of pulverized coal (η_{pc}) at the raceway end (a position of about 200 mm away from tuyere tip) is over 80%. (Fig. 9) The lowering range of combustion efficiency of pulverized coal (η_{pc}) at the uptake at the furnace top due to the increase of flowing velocity of gas (gas flowrate) injected from the dual lance outer tube is small. (Fig. 10) It may be that in the gas injection conditions set this time, the lowering of combustion efficiency of pulverized coal is little according to the dual lance air curtain method.

4. Results of Single Tuyere Test Conducted at Actual Furnace and Study

4.1. Actual Furnace Single Tuyere Testing Method

Tables 2 and 3 show the conditions and schedule of test by the dual lance air curtain method for the actual furnace test.

With the dual lance installed at No. 23 tuyere of Kimitsu No. 2 blast furnace, pulverized coal was injected from the dual lance inner tube and cold Air was injected (6.25 Nm³/h
and flowing velocity 250 m/s) from the dual lance outer tube for about 50 days. Moreover, the inner tube of dual lance used then was 20A (sch 80: Inside dia. 19.4 mm and Outside dia. 27.2 mm) and the outer tube was 40A (sch 40: Inside dia. 41.2 mm and Outside dia. 48.6 mm). Further, the dual lance tip was conformed to the center axis of tuyere by a sliding mechanism. A change of the position of CO2 or temperature peak position of combustion at the actual furnace was estimated based on the one-dimensional raceway model4) developed by Tamura et al. The packing structure of dead man surface was estimated referring to the analysis results (coke temperature estimated from graphitization, hold-up (HU) ratio, fine ratio (\( \frac{H1}{H1002} \) 3 mm) and others) of sample taken at the tuyere in the case of shut-down. In the evaluation of dead man made based on the analysis of tuyere sample during shut-down before and after execution of this test, the influence of operational change is also included. Consequently, when the furnace was shut-down immediately after the actual furnace test (January 28 1999), the sample of No. 8 tuyere for which the dual lance air curtain method is not effected yet was compared with the sample of No. 23 tuyere.

The sorting method6,7) of tuyere samples is shown below. Screening the tuyere samples by 3 mm, a sample obtained by removing lump coke from \( \frac{H1}{H1002} \) 3 mm sample was taken as a hold-up (HU) and \( \frac{H1}{H1003} \) one which lowers a void ratio by moving and accumulating to/on voids of the coke packing bed in the dead man was taken as a fine.

### 4.2. Estimation of Moving distance of CO2 or Temperature Peak Position of Combustion in Raceway of Actual Furnace

It was estimated from the knowledge acquired from the hot model experiment in Sec. 3.2 herebefore that delay in combustion of pulverized coal by injecting cold Air from the dual lance outer tube depends greatly on the local adiabatic effect between hot air and pulverized coal at the tuyere tip by cold Air flow or the lowering effect of convection heat transfer coefficient. Assuming here that the phenomenon described above is such that the coefficient of convection heat transfer from gas to particle lowers, the moving distance of CO2 or temperature peak position of combustion by the dual lance air curtain method taken at the actual furnace was obtained with the use of the one-dimensional raceway model4) developed by Tamura et al.

First, from a relation between the corrected factor of convection heat transfer coefficient and the CO2 or temperature peak position of combustion which has been obtained from the one-dimensional raceway model (Fig. 11) and the CO2 or temperature peak position of combustion under the actual furnace conditions shown in Fig. 12, the CO2 or temperature peak position of combustion in the actual furnace conditions set this time was obtained.

An estimated value of the moving distance of CO2 or temperature peak position of combustion toward the dead man side was 480 mm according to the dual lance air curtain method adopted this time (Fig. 12).
On the one hand, there is a fear of the combustion efficiency of pulverized coal decreasing due to the movement of CO$_2$ or temperature peak position of combustion toward the dead man side. In the recent actual furnace test performed with a single tuyere, the increase of unburnt char ratio in the dead man was as low as less than 1% relative to H$1\text{mm fine}$ (Fig. 13).

4.3. Dead Man Improvement Effect Gained Based on Tuyere Sample Analysis Result

As described below, the packing structure of dead man surface has been improved by applying the dual lance air curtain method to No. 23 tuyere of Kimitsu No. 2 blast furnace. This would become clear, from the knowledge of the hot model test in the foregoing Sec. 3.2 and the examination result on the moving distance of CO$_2$ or temperature peak position of combustion in the raceway of actual furnace in the above Sec. 4.2, that temperature ranging from the raceway end to the dead man surface has risen as the result of CO$_2$ or temperature peak position of combustion having moved in the direction of dead man.

4.3.1. Coke Temperature Estimated from Graphitization

The coke temperature estimated from graphitization (○ mark in Fig. 14) ranging from the raceway end to the dead man surface (a range of 1 to 2.5 m from tuyere tip) at No. 23 tuyere for which the dual lance air curtain method was performed for about 50 days is higher 200°C than that (● mark in Fig. 14) at No. 8 tuyere on which the dual lance air curtain method is not effected yet.

When keeping eyes fixed on No. 23 tuyere, the coke temperature estimated from graphitization (○ mark in Fig. 14) ranging from the raceway end to the dead man surface (a range of 1 to 2.5 m from tuyere tip) at a time of shut-down (January 28 1999) after about 50-day execution of the dual lance air curtain method was found to have risen over 200°C, compared with the coke temperature estimated from graphitization (● mark in Fig. 14) at a time of shut-down (December 8 1998) before execution of the dual lance air curtain method.

4.3.2. Hold-up (HU) Ratio of Metal and Slag

The ratio of hold-up (○ mark in Fig. 15) ranging from
4.3.3. Fine Ratio and Coke Mean Size

A fine ratio (● mark in Fig. 16) ranging from the raceway to the dead man surface (a range of 1 to 2.5 m from tuyere tip) at No. 23 tuyere on which the dual lance air curtain method was effected about 50 days is as low as about 20%, compared with HU ratio (● mark in Fig. 15) at No. 8 tuyere.

A coke mean size (● mark in Fig. 17) ranging from the raceway end to the dead man surface (a range of 1 to 2.5 m from tuyere tip) at No. 23 tuyere on which the dual lance air curtain method was effected about 50 days is larger about 6 mm than the coke mean size (● mark in Fig. 17) at No. 8 tuyere on which the dual lance air curtain method is not effected yet. This knowledge has clarified that even a relative coke mean size obtained by dividing a coke mean size by a coke mean size before charging was the same.

5. Conclusion

By applying the dual lance air curtain method to a hot model and No. 23 tuyere of Kimitsu No. 2 blast furnace, the possibility of controlling CO₂ or temperature peak position of combustion in the raceway and the dead man improving effect was examined.

In consequence of it, the following conclusion has been formed:

(1) According to the hot model experiment results, with the increase of flowing velocity of cold Air injected through the dual lance outer tube, temperature in the vicinity of tuyere tip falls and temperature ranging from the raceway end to the dead man surface is rising. It can be guessed that because of a local adiabatic effect between hot air and pulverized coal at the tuyere tip or a lowering effect of convection heat transfer coefficient having become great and combustion of pulverized coal having been delayed, the CO₂ or temperature peak position of combustion of pulverized coal has transferred to the dead man side.

(2) According to the examination results of gas temperature under the actual furnace raceway conditions with a one-dimensional raceway model, an estimated value of the moving distance of CO₂ or temperature peak position of combustion to the dead man side by the recent dual lance air curtain method at Kimitsu No. 2 blast furnace is 480 mm.

(3) The combustion efficiency of pulverized coal might decrease on account of the movement of CO₂ or temperature peak position of combustion toward the dead man side. And, it has become clear from the knowledge acquired from the hot model experiment that regardless of whether gas sent from the outer tube is N₂ or Air, decrease in combustion efficiency of pulverized coal due to injection of gas through the dual lance outer tube is slight.

(4) In the actual furnace test performed this time with a single tuyere, the increase range of unburnt char in the dead man was as small as less than 1% relative to ~1 mm fine and the packing structure of dead man surface was found to have been improved greatly. The reason would be that because of CO₂ or temperature peak position of combustion having moved in the direction of dead man, temperature ranging from the raceway end to the dead man surface has risen.

REFERENCES

1) T. Kamijo, N. Takahashi, G. Hoshino, Y. Yoshida, R. Ito, K. Shibata and H. Miyagawa: *CAMP-ISIJ*, 6 (1993), 848.
2) K. Miyagawa, K. Nozawa, T. Kamijo, M. Sato, Y. Yamakawa and T. Ariyama: *CAMP-ISIJ*, 7 (1994), 128.
3) M. Sato, Y. Yamakawa, T. Ariyama, N. Takahashi, R. Ono and T. Kamijo: *CAMP-ISIJ*, 7 (1994), 129.
4) K. Tamura, H. Ueno, K. Yamaguchi, M. Sugata, S. Amano and K. Yamaguchi: *Tetsu-to-Hagané*, 77 (1991), 775.
5) K. Tamura, M. Ichida, H. Wakimoto, K. Ono and Y. Hayashi: *Tetsu-to-Hagané*, 73 (1987), 1980.
6) M. Ichida, Y. Hida and T. Uno : *CAMP-ISIJ*, 11 (1998), 826.
7) M. Ichida, T. Orimoto, T. Tanaka and F. Koizumi: *ISIJ Int.*, 41 (2001), 325.