Behavior of Pulverized Coal Ash and Physical Property of Dripping Slag under High Pulverized Coal Injection Operation

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Based on the analysis of tuyere sampling performed in PCR increasing stage of Muroran No. 2 blast furnace of Hokkai Iron & Coke Corporation, examination was made on the influence of ash originated in pulverized coal in high-productivity, high PCR operation upon physical property of dripping slag or packed structure at dead man surface extending from raceway end. The amount of dripping slag with which ash originated in pulverized coal reacts and assimilates is 15–20% of the total amount of dripping slag, and the components of dripping slag distribute in a circumferential direction between inside of raceway and outside of raceway as well as in a radial direction including the inside of raceway and dead man. When PCR is high, high-vicious 1 mm fine at the dead man surface from the vicinity of raceway and high CaO/SiO2 1 mm fine and dripping slag between raceway and in dead man, with the increase of 3 mm fine, are supposed to be one of the main causes deteriorating the gas and liquid permeabilities at the dead man surface and lowering the dead man temperature. For establishing a technology assured a stable furnace operation over a long period, it is necessary to take the measures for improving deterioration in gas and liquid permeabilities at the dead man surface due to not only 3 mm fine and unburnt char but also pulverized coal ash.

KEY WORDS: high PC injection operation; raceway; raceway end; dead man; PC ash; dripping slag; fine; hold-up; viscosity; melting point.

1. Introduction

With recognition1–4) to the necessity of maintaining the packed structure at the lower part of the furnace in good condition of gas and liquid permeabilities at all times for establishing a technology promising a stable high-productivity, high PCR operation over a long period, a number of different sorts of research5–9) have hitherto been prosecuted on the generation, migration and accumulation of unburnt char or coke fine. On the one hand, in a high PCR, high O/C operation, the amount of dripping metal and slag to coke and the amount of ash originated in pulverized coal increase, whereby the packed structure at the lower part of the furnace is deteriorated as the case may be. There are however few reports10) stating that close investigation has been done so far paying attention to fine & metal and slag hold-up composition.

Accordingly in this report, based on the analysis of tuyere sampling performed in PCR increasing stage of Muroran No. 2 blast furnace of Hokkai Iron & Coke Corporation (hereinafter, Muroran No. 2 blast furnace), examination was made over the influence of ash coming from pulverized coal in high PCR operation on the property of dripping slag or the packed structure at the dead man surface extending from the raceway end.

2. Tuyere Sampling Time and Method of Investigation

2.1. Tuyere Sampling Time

Table 1 shows the tuyere sampling time in the case of blow-down and the major operation data acquired before blow-down. At Muroran No. 2 blast furnace, from the beginning of 1998 on, various measures have been taken round about the improvement of sinter quality and burden distribution control without lowering Al2O3 of sinter and in December, a high PCR, low FR operation was attained under high productivity condition (2.2 t/d/m3 or thereabout at a time of operation going on).11) During the blow-down in PCR increasing stage, tuyere sampling was done 5 times and the tuyere samples taken then were investigated. Especially, the tuyere samples taken during blow-down in February (PCR/H11005 157 kg/t) and December (PCR/H11005 190 kg/t) where PCR level greatly differs from each other were ana...
lished carefully.

2.2. Classification of Tuyere Sample

Figure 1 shows the classification method of tuyere samples. Screening the tuyere samples in 3 mm, a sample obtained by excluding a lump coke from +3 mm sample was taken as a hold-up (HU) and −3 mm one which moves and accumulates into voids of dead man coke bed and decreases the void fraction, as a fine. −3 mm samples were further screened in 1 mm to classify them into +1 mm and −1 mm fines. The hold-up was classified into a granular HU (metal & slag) and an indefinite shape HU. Again, the indefinite shape hold-up was classified into an indefinite shape hold-up (metal & slag) which is clear that it has melted down and an incompletely melted HU keeping the original form of sinter as it is.

2.3. Method of Investigation

Table 2 shows the idea of the method of investigation. As for the behavior of ash coming from pulverized coal, the whole composition was obtained by chemical analysis, keeping eyes fixed on −1 mm fine. The classification of particles was made by 80× polarizing microscopic observation. With reference to about 24 pictures taken every sample, about 500 particles were classified into coke, metal, slag and unburnt char. The composition of each particle was obtained by EPMA analysis. To put it in detail, a −1 mm fine embedded resin was coated with gold by evaporation and a 200× reflected electronic image was obtained by EPMA. As to a particle guessed to be a slag having low brightness in the reflected electronic image, the composition was quantified by using such standard substances as CaCO₃, SiO₂, Al₂O₃, CaOSiO₂ and NaAlSi₃O₈.

Concerning a dripping slag, attention was paid to an indefinite shape slag hold-up. Because this hold-up is supposed to have been trapped into voids of coke while dripping and to be amounting to more than 80% of slag hold-up. On the other hand a granular slag hold-up is supposed to have stayed in the furnace for a long time from its shape. And, the whole composition of hold-up having particle diameter of 2.8 to 5 mm was obtained by chemical analysis. The viscosity of dripping slag was estimated by substituting the above-mentioned composition (to give an example, 4 components: CaO, SiO₂, Al₂O₃ and MgO) and a temperature assumed based on the hysteresis temperature of lump coke for a slag viscosity model developed by Nakagawa et al. Also, by substituting the above-mentioned composition for an analysis model of non-metal inclusion composition made by Yamada et al., the melting point of dripping slag was estimated as a temperature at 100% of liquid phase rate.

3. Analysis Results of Tuyere Sample

3.1. Composition of −1 mm Fine and Its Origin

Figure 2 shows the polarizing microscopic observation result of −1 mm fine of tuyere sample at a time when PCR was 171 kg/t (June 1998), from which it comes out that the population of slag in −1 mm fine indicates a lowering tendency toward the furnace center from the tuyere nose. At a range of 1 m to 3 m from the tuyere nose, corresponding to the dead man surface extending from the vicinity of the raceway, 20 to 70 population of −1 mm fine is slag. To make the origin of the slag clear, the composition was obtained by the linear analysis of EPMA, paying attention to each particle. Based on EPMA linear analysis results, a slag of which CaO is 0 (zero) or extremely low, that is, less than a few percents was judged to have originated in ash of pulverized coal and coke. The results are shown in Table 3, Table 4 and Fig. 3. It has been clarified from the figure that in slag of −1 mm fine, a slag originated in ash exists about 40%.

Figure 4 shows CaO/SiO₂ distribution of slag in −1 mm fine, from which it is found that CaO/SiO₂ of slag in −1 mm fine is increasing toward the dead man from the tuyere nose. This bespeaks that ash generated by combustion of coke and pulverized coal is hard to be transported in the radial direction at the tuyere level because of sticking to a dripping substance or coke, or rising motion. And, the ris-
ing gradient of CaO/SiO₂ in the direction of dead man in the case of PCR being high (190 kg/t) is larger than that in the case of PCR being low (157 kg/t). The above view suggests that ash originated in pulverized coal is hard to be transported in radial direction at the tuyere level and apt to rise compared with ash originated in coke.

3.2. Composition of Dripping Slag

Figure 5 shows CaO/SiO₂ distribution at the tuyere level of dripping slag. It is to be understood therefrom that CaO/SiO₂ of dripping slag, like −1 mm fine, is increasing toward the dead man from the tuyere nose. CaO/SiO₂ in the case of high PCR (190 kg/t) is lower about 0.2 than that in the case of low PCR (157 kg/t) in the vicinity of tuyere. On the other, a variation of CaO/SiO₂ and Al₂O₃ of dripping slag in a radial direction at the tuyere level is smaller than those of /H₁₁₀0₂ 1 mm fine (Figs. 6 and 7). For instance, at a range up to 2.5 m from the tuyere nose, CaO/SiO₂ is high about 0.3 (Fig. 6) and Al₂O₃ is low 7 to 9% (Fig. 7) compared with /H₁₁₀0₂ 1 mm fine. The weight ratio between dripping slag and /H₁₁₀0₂ 1 mm fine is 2–15 at a range up to 2.5 m from the tuyere nose and 0.1–3 at a range up to center from 2.5 m. The above view implies that ash originated in pulverized coal exerts a great influence on the component distribution at the tuyere level of dripping slag.

Table 3. Chemical composition measured by EPMA line analysis of fine (−1 mm) sampled at 0.7 m from tuyere nose (PCR = 171 kg/t).

| Part | CaO | SiO₂ | Al₂O₃ | CaO/SiO₂ | Al₂O₃/SiO₂ | Origin |
|------|-----|------|-------|---------|-----------|--------|
| A-1  | 32.0| 32.7 | 19.9  | 0.98    | 0.59      | Slag   |
| A-2  | 3.3 | 12.6 | 5.4   | 0.26    | 0.43      | Sinter |
| A-3  | 23.1| 46.9 | 8.8   | 0.49    | 0.18      | Slag   |
| A-4  | 14.0| 23.5 | 24.2  | 0.53    | 0.56      | Slag   |
| A-5  | 1.8 | 24.0 | 2.9   | 0.07    | 0.04      | Ash    |
| A-6  | 14.8| 42.3 | 64.5  | 0.35    | 0.12      | Slag   |
| A-7  | 44.5| 27.4 | 17.2  | 1.62    | 0.63      | Slag   |
| A-8  | 0.0 | 0.0  | 0.102 | –       | –         | Ash?   |
| A-9  | 29.8| 24.0 | 19.4  | 1.23    | 0.81      | Slag   |
| A-10 | 9.9 | 33.1 | 18.3  | 0.30    | 0.25      | Slag   |
| A-11 | 6.8 | 36.6 | 29.0  | 0.18    | 0.39      | Slag   |
| A-12 | 21.4| 19.4 | 11.8  | 1.10    | 0.61      | Sinter |
| A-13 | 0.0 | 45.7 | 34.4  | 0.00    | 0.75      | Ash    |
| A-14 | 34.6| 24.0 | 7.0   | 1.44    | 0.29      | Slag   |
| A-15 | 12.4| 40.0 | 13.4  | 0.31    | 0.34      | Slag   |
| A-16 | 11.5| 22.9 | 16.1  | 0.50    | 0.70      | Slag   |
| A-17 | 0.0 | 0.0  | 0.0   | 0.0     | 0.0       | Metal  |
| A-18 | 4.0 | 30.9 | 18.3  | 0.16    | 0.13      | Slag   |
| A-19 | 0.0 | 44.6 | 16.1  | 0.00    | 0.36      | Ash    |
| A-20 | 3.2 | 30.9 | 25.8  | 0.43    | 0.83      | Slag   |
| A-21 | 0.0 | 41.1 | 44.1  | 0.40    | 0.97      | Ash    |
| A-22 | 3.3 | 17.1 | 59.1  | 0.19    | 3.46      | Ash    |
| A-23 | 1.1 | 30.6 | 32.3  | 0.13    | 1.05      | Ash    |
| A-24 | 16.5| 14.9 | 21.5  | 1.11    | 1.44      | Sinter |
| A-25 | 1.8 | 41.1 | 15.1  | 0.04    | 0.37      | Ash    |

Table 4. Chemical composition measured by EPMA line analysis of fine (−1 mm) sampled at 0.7 m from tuyere nose (PCR = 171 kg/t).

| Part | CaO | SiO₂ | Al₂O₃ | CaO/SiO₂ | Al₂O₃/SiO₂ | Origin |
|------|-----|------|-------|---------|-----------|--------|
| B-1  | 9.2 | 15.0 | 17.2  | 0.51    | 1.08      | Sinter |
| B-2  | 5.8 | 6.9  | 5.4   | 0.84    | 0.78      | Sinter |
| B-3  | 24.7| 30.9 | 10.8  | 0.80    | 0.35      | Sinter |
| B-4  | 37.1| 34.3 | 5.4   | 1.08    | 0.16      | Slag   |
| B-5  | 41.2| 30.9 | 21.5  | 1.33    | 0.70      | Slag   |
| B-6  | 4.1 | 21.7 | 32.3  | 0.19    | 1.49      | Ash    |
| B-7  | 2.5 | 29.3 | 29.5  | 0.05    | 0.96      | Ash    |
| B-8  | 37.1| 18.3 | 30.1  | 2.03    | 1.64      | Slag   |
| B-9  | 0.8 | 32.0 | 25.8  | 0.03    | 0.81      | Ash    |
| B-10 | 0.0 | 42.3 | 23.7  | 0.00    | 0.56      | Ash    |
| B-11 | 37.9| 33.1 | 10.8  | 1.15    | 0.33      | Sinter |
| B-12 | 18.1| 20.6 | 4.3   | 0.88    | 0.21      | Sinter |
| B-13 | 41.2| 22.9 | 31.2  | 1.00    | 1.36      | Slag   |
| B-14 | 0.0 | 0.0  | 0.0   | 0.0     | 0.0       | Metal  |
| B-15 | 29.6| 28.6 | 12.9  | 1.03    | 0.45      | Slag   |
| B-16 | 0.0 | 18.2 | 11.1  | 0.06    | 0.06      | Ore    |
| B-17 | 16.5| 40.0 | 32.3  | 0.41    | 0.81      | Slag   |
4. Study

4.1. Behavior of Pulverized Coal Ash in Vicinity of Raceway

Figures 8 and 9 show CaO/SiO$_2$ distribution and Al$_2$O$_3$ distribution of dripping slag during blow-down in which PCR level is different and during blow-out of Hirohata No. 1 blast furnace of which oil injection operation (35 kg/t) was going on. CaO/SiO$_2$ of dripping slag in the case of oil injection (35 kg/t) is the same as that of tapping slag just before blow-out. On the other hand, CaO/SiO$_2$ of dripping slag in the case of PCR operation is greatly lower than that of tapping slag just before blow-down at a range up to 2.5 m from the tuyere nose. In particular, CaO/SiO$_2$ when PCR is high (190 kg/t) is further lower than that in the case of PCR being low (157 kg/t). Al$_2$O$_3$ of dripping slag at a time of oil injection (35 kg/t) is almost the same as that of tapping slag just before blow-out. On the other side, Al$_2$O$_3$ of dripping slag in the case of PCR operation is considerably higher than that of tapping slag just before blow-down.

The slag balances in the case of PCR being low (157 kg/t) and high (190 kg/t) are shown in Tables 5 and 6. In both cases the amount of slag originated in coke ash and pulverized coal ash is 46–47 kg/t and almost the same. The ratio of slag originated in coke ash to slag originated pulverized coal ash changes. Therefore, the difference of radial distribution at the tuyere level of slag component between high PCR and low PCR is attributable to be the difference of ash behavior between coke and pulverized coal. This difference can be guessed that ash originated in pulverized coal is hard to be transported in the direction at the tuyere level compared with ash originated in coke as mentioned in the previous Sec. 3.1.

Coke reduces by solution loss reaction during descending over a period of about 1 hr to high temperature area in the lower part of the blast furnace. Ash that comes out at the surface of coke sticks and reacts with dripping slag and coke. At the higher temperature area near raceway, ash originated in coke evaporates and goes up to react with dripping slag. In the case of ash originated in coke, the ratio of ash that sticks and reacts with dripping slag is not small and its reaction area is large. On the other hand, ash originated in pulverized coal goes up with gas from raceway over a peri-
of less than 1 sec to stick and react with dripping slag. In this way because the reaction area near raceway between ash originated in pulverized coal and dripping slag is small, it seems that the influence of pulverized coal ash amount on radial distribution of dripping slag composition is large.

As shown in Tables 5 and 6, the amount of SiO$_2$ gasified in the vicinity of raceway is 12–13 kg/t and little less than 50% of the amount (26–27 kg/t) of SiO$_2$ originated in pulverized coal and coke. In spite of this gasification of SiO$_2$, CaO/SiO$_2$ of dripping slag in the vicinity of raceway decreases. This views implies that ash originated in pulverized coal exerts a great influence on the component distribution at the tuyere level of dripping slag.

From the views of the compositions of –1 mm fine and dripping slag mentioned in the previous Secs. 3.1 and 3.2 and further, the above-mentioned CaO/SiO$_2$ and Al$_2$O$_3$ distribution conditions, it can be guessed that contact, reaction and assimilation of ash originated in pulverized coal with a dripping substance originated in burden are occurring in the vicinity of raceway above the tuyere.

Table 5. Slag balance in Muroran No. 2 BF during 98 Feb. 2–8.

|        | CaO  | SiO$_2$ | Al$_2$O$_3$ | MgO  | Slag rate |
|--------|------|---------|-------------|------|-----------|
| Ore    | 128.1| 78.2    | 27.0        | 17.9 | 251.2     |
| Lump ore | 0.2  | 7.4     | 3.3         | 0.1  | 10.9      |
| Flux   | 0.0  | 0.0     | 0.0         | 0.0  | 0.0       |
| Na slag| 0.0  | 0.0     | 0.1         | 0.0  | 0.1       |
| Quartz | 0.0  | 0.9     | 0.1         | 0.0  | 3.0       |
| Fuel   | 0.9  | 5.5     | 3.3         | 0.3  | 9.9       |
| Coke   | 1.5  | 22.0    | 12.3        | 0.5  | 26.3      |
| Input total | 130.6 | 115.9 | 45.9        | 18.8 | 311.3     |
| Dust   | 0.5  | 0.7     | 0.4         | 0.1  | 1.7       |
| Dry dust | 0.7  | 1.0     | 0.6         | 0.1  | 2.4       |
| Wet dust | 0.7  | 1.0     | 0.6         | 0.1  | 2.4       |
| Sl transfer to iron | 12.9 | 12.9    |
| Output total | 12.9 | 14.1 | 1.0        | 0.7  | 17.1      |
| Slag   | 129.4| 101.3   | 45.0        | 18.6 | 294.2     |

Table 6. Slag balance in Muroran No. 2 BF during 98 Dec. 5–11.

|        | CaO  | SiO$_2$ | Al$_2$O$_3$ | MgO  | Slag rate |
|--------|------|---------|-------------|------|-----------|
| Ore    | 129.2| 71.6    | 26.8        | 13.6 | 237.3     |
| Lump ore | 0.6  | 5.7     | 4.0         | 0.2  | 10.6      |
| Flux   | 0.1  | 0.5     | 0.2         | 0.1  | 3.6       |
| Na slag| 0.1  | 0.5     | 0.2         | 0.1  | 3.6       |
| Quartz | 0.0  | 7.3     | 0.3         | 0.1  | 7.6       |
| Fuel   | 1.3  | 9.0     | 4.7         | 0.6  | 15.7      |
| Coke   | 1.6  | 17.9    | 11.4        | 0.5  | 31.4      |
| Input total | 128.8 | 117.2 | 47.4        | 18.7 | 312.0     |
| Dust   | 0.7  | 0.8     | 0.4         | 0.2  | 2.1       |
| Dry dust | 0.9  | 1.1     | 0.5         | 0.3  | 2.7       |
| Wet dust | 0.9  | 1.1     | 0.5         | 0.3  | 2.7       |
| Sl transfer to iron | 12.4 | 12.4    |
| Output total | 16.6 | 14.3 | 0.9        | 0.5  | 17.2      |
| Slag   | 127.2| 102.9   | 46.5        | 18.2 | 294.6     |

1. Slag dripping: Uniform velocity in radius and circumference.

2. Ash in coke: Homogeneous reaction with dripping slag

![Fig. 10. Assumption of reaction area of ash in PC with dripping slag.](image)

4.2. Ratio of Dripping Slag Which Has Reacted and Assimilated with Pulverized Coal Ash

In the previous Section, it was indicated that such phenomena as contact, reaction and assimilation of ash originated in pulverized coal with a dripping substance originated in burden are taking place nearby the raceway and at an upper local area. So, a ratio of the amount of dripping slag with which ash originated in pulverized coal has reacted and assimilated to the total amount of dripping slag was estimated from a material balance between burden charged from the furnace top and slag components in pulverized coal injected through the tuyere.

In making trial calculation, it was supposed that distribution of the dripping amount of slag is uniform in radial and circumferential directions and a dripping area of slag reacting with ash originated in pulverized coal, L is such sector as shown in Fig. 10. Setting a value obtained by dividing this L by the sectional area of sector per tuyere, X was obtained which satisfies CaO/SiO$_2$ distribution in radial direction at a time of tuyere sampling in February and December 1998. To be concrete, with the area of L divided into 2 parts A and B in radial direction (Fig. 10), such X as to satisfy a mean value of CaO/SiO$_2$ of indefinite shape slag HU at the respective areas was obtained based on the following material balance Eqs. (1) and (2).

The reason why the composition of indefinite shape slag HU has been employed here is that it has been judged that the slag hold-up is available quite typically as a dripping slag is pretty high, viewed from that more than 80% of slag hold-up is an indefinite shape HU, as described in Sec. 2.3 herebefore and the composition of granular slag HU is also nearly the same.

\[
(0.49 X M_{\text{CaO}} + a Y)/(0.49 X M_{\text{SiO}_2} + Y) = \alpha \ldots \ldots \ldots \ldots (1)
\]
Here, $b, Y$, and $b−Y$ are respectively the amounts of SiO$_2$ in pulverized coal ash reacting with slag dripping in area $L$, $A$ and $B$. $M_{SiO2}$ is the amount of SiO$_2$ in which the amount of SiO$_2$ (Tables 5, 6) equivalent to Si transfer (98 Feb. 2–8: Si=0.60%, 98 Dec. 5–11: Si=0.58%) into melted iron is taken from the amount of SiO$_2$ in ore, flux and coke ashes excluding pulverized coal ash. 0.49, 0.51 are relative area of region $A$ and region $B$. The dripping slag in this trial calculation contains indefinite shape slag hold-up and granular shape slag hold-up.

Figure 11 shows the results of trial calculation. From the fact that the amount of dripping slag with which ash originated in pulverized coal ash reacting and assimilated is as small as 15–20% of the total amount of dripping slag, it becomes clear that the components of dripping slag are distributing quite broadly in circumferential direction between inside of raceway and outside of raceway as well as in radial direction including the inside of raceway and dead man.

4.3. Viscosity and Melting Point of Dripping Slag and −1 mm Fine

In the case of high PCR, high O/C operation, there is a fear of the dead man becoming inactive with increase of load working on the dead man. As obtained from Fig. 12, even in the high PCR operation performed this time at Muroran No. 2 blast furnace, −1 mm fine is increasing at an area which is inner more than 2.5 m from the tuyere nose in PCR increasing stage (Fig. 12). It is clear from the previous Sec. 3.1 that 20 to 40 population of this −1 mm fine is a high Al$_2$O$_3$, low CaO/SiO$_2$ slag originated in pulverized coal ash.

And, the viscosity of dripping slag and −1 mm fine in high PCR (190 kg/t) and low PCR (157 kg/t) conditions was estimated. The slag temperature necessary for estimating the viscosity was obtained based on a numerical value obtained by a coke hysteresis temperature at a range of center from the tuyere nose shown in Fig. 13. For calculation, the slag temperature was supposed to be 2000°C at a range of 1.5 m away from the tuyere nose, 1550°C at a range of 1.5 to 2.5 m from the tuyere nose and 1500°C at a range which is inner more than 2.5 m from the tuyere nose.

Figures 14 and 15 show the viscosity of dripping slag and −1 mm fine estimated based on the viscosity model developed by Nakagawa et al. The viscosity of dripping slag indicates an increasing tendency with going away from the tuyere nose and it is 4 poise or thereabout maximally. When PCR is high, the increase in viscosity of dripping slag is hardly seen. On the other hand, the viscosity of −1 mm fine is greatly affected by PCR level, that is, ash contained in pulverized coal. Especially at a range of 2.5 m from the tuyere nose, the viscosity of −1 mm fine sharply increases attributable to high Al$_2$O$_3$ and low CaO/SiO$_2$.

However, CaO/SiO$_2$ of −1 mm fine at this range is as low as less than 0.6 and it is out of the range of the measured value of Gul’tyai used as a reference at a time when the viscosity model was made by Nakagawa et al. The improvement of precision of the estimated value of viscosity is the task from now on.

Figures 16 and 17 show the melting points of dripping slag and −1 mm fine estimated based on the model developed by Yamada et al. The melting point of dripping slag is almost the same in radial direction and affected little by the rise of PCR level. Whilst, the melting point of −1 mm fine is affected by ash contained in pulverized coal. At a range of 2.5 m away from the tuyere nose, the melting point rises due to high Al$_2$O$_3$ and low CaO/SiO$_2$.

At the high PCR (more than 180 kg/t) operation, the high viscous −1 mm fine at the dead man surface extending from the vicinity of raceway and high CaO/SiO$_2$ −1 mm fine and dripping slag between raceway and in dead man are
guessed to exert a bad influence on the gas and liquid permeabilities at the dead man surface extending from the vicinity of raceway. On the other hand unburnt char was few detected in spite of high PCR (190 kg/t) operation (Fig. 19) because of air ratio more than 0.80.\(^{15}\)

### 4.4. Mechanism Deteriorating Gas and Liquid Permeabilities in Vicinity of Raceway under High PCR Operation

Figure 18 shows the behavior of pulverized coal ash in the raceway under high PCR operation and a mechanism lowering the gas and liquid permeabilities at the dead man surface, which have been arranged based on the views put forth up to the previous Section. In the case of PCR being high, the viscosity of \(-1\) mm fine at a range of 2 to 3 m from the tuyere nose increases due to ash originated in pulverized coal. This high-viscous \(-1\) mm fine and high CaO/SiO\(_2\) \(-1\) mm fine and dripping slag between raceway and in dead man, with the increase of \(-3\) mm fine, might be one of the main causes deteriorating the gas and liquid permeabilities at the dead man surface and lowering the temperature with increase of dripping slag hold-up. The ratio of unburnt char increases in the case of air ratio less than 0.80\(^{15}\) during high PCR and low FR. The increase of this unburnt char might be one of the causes deteriorating the gas and liquid permeabilities at the dead man by the increase of the slag viscosity due to its suspension to the dripping slag and the increase of \(-3\) mm fine due to its preferential reaction with FeO slag and CO\(_2\). For establishing a technology providing a stable furnace operation at high PCR over a long period, there is a need to control deterioration of the gas and liquid permeabilities at the dead man surface due to not only \(-3\) mm fine and unburnt char but also pulverized coal ash.

### 5. Conclusions

With examination made on the influence of ash originated in pulverized coal upon the physical property of dripping slag or the packed structure at dead man surface extending from raceway end under high-productivity, high PCR operation based on the analysis of tuyere sampling performed in PCR increasing stage of Muroran No. 2 blast furnace of Hokkai Iron & Coke Corporation, the following conclusions have been formed:

1. Ash generated by combustion of pulverized coal is hard to be transported in the radial direction at the tuyere level of the furnace because of sticking to a dripping substance or coke, or rising and contacts with a dripping substance originated in burden above the tuyere level to react and assimilate quickly.

2. The amount of dripping slag with which ash originated in pulverized coal reacts and assimilates is 15–20%
of the total amount of dripping slag and the components of dripping slag distribute in a circumferential direction between inside of raceway and outside of raceway as well as in a radial direction including the inside of raceway and dead man.

(3) When PCR is high, the high-vicious \(1\) mm fine and high CaO/SiO\(_2\) \(1\) mm fine and dripping slag between raceway and in dead man, with the increase of \(3\) mm fine, supposed to be one of the main causes deteriorating the gas and liquid permeabilities at the dead man surface and lowering the dead man temperature.

(4) It is necessary, for establishing a technology promising a stable furnace operation at high PCR over a long period, to control deterioration of gas and liquid permeabilities at the dead man surface due to not only \(3\) mm fine and unburnt char but also pulverized coal ash.

**Nomenclature**

- \(a\) : CaO/SiO\(_2\) of pulverized coal ash (–)
- \(b\) : Amount of SiO\(_2\) of pulverized coal ash reacting on dripping slag at area \(L\) (kg/t)
- \(L\) : Dripping area of slag on which ash of pulverized coal injected through one piece of tuyere reacts (m\(^2\))
- \(M_{\text{CaO}}\) : Amount of CaO in ore, flux and coke ashes excluding pulverized coal ash (kg/t)
- \(M_{\text{SiO}_2}\) : Amount of SiO\(_2\) in ore, flux and coke ashes excluding pulverized coal ash and Si transfer into melted iron (kg/t)
- \(T\) : Sectional area of hearth per piece of tuyere (m\(^2\))
- \(X\) : \(L/T\) (–)
- \(Y\) : Amount of SiO\(_2\) of pulverized coal ash reacting on dripping slag at area \(A\) (kg/t)
- \(\alpha\) : Average value of CaO/SiO\(_2\) of dripping slag at area \(A\) (–)
- \(\beta\) : Average value of CaO/SiO\(_2\) of dripping slag at area \(B\) (–)

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