NIPPON STEEL TECHNICAL REPORT No. 123 MARCH 2020

Technical Report

UDC 669 . 162 . 215 . 244

Tracking Technique of Burden Materials for Blast Furnace with Bell-less Top by Using RFID

Kaoru NAKANO*
Yoshito ISEI
Takuya NATSUI
Kenta WATANABE
Tomoyasu KISHINO

Abstract

In the ironmaking process, improving permeability and reaction efficiency in blast furnaces are important issues in order to operate blast furnaces with high productivity and low reducing agent rate. Burden distribution is an important control factor. The burden distribution of bell-less top blast furnaces is controlled by adjusting the tilt angle of a rotating chute and charging sequence of each burden material discharged from the top bunkers. In order to accurately grasp the transport process of raw materials from their bins to the stock level inside the blast furnace, raw material sampling has been conducted during pause of furnace operation. However, it is difficult to obtain a lot of data under various conditions because it is necessary to temporarily stop the blast furnace. Therefore, we developed a new tracking technique of burden materials in the charging process by using radio frequency identification (RFID) tags. The developed tracing technique of burden materials is effective for precisely controlling the burden material distribution and improving the blast furnace operation.

1. Introduction

Recent blast furnace operation with high productivity and low reducing agent ratio in higher pulverized coal ratios and lower coke ratios has been conducted to deal with the rise in raw material prices and lower-quality raw materials, as well as reduce CO_2 emissions and pig iron production costs. Under these circumstances, securing the permeability in blast furnaces and improving the reaction efficiency at the same time is an important task.

One means to solve these issues is the appropriate control and management of the strength and reactivity of the raw materials themselves. Another effective and important means is controlling the state of stacks of raw materials in the radial direction in a blast furnace appropriately, that is to say, controlling the burden distribution appropriately. In burden distribution control, the height of coke and ore layers in the radial direction in a blast furnace is separately controlled, and particle size distribution control in the radial direction of a blast furnace and distribution control to place nut coke and specific raw materials at certain regions in ore layers are performed.

In recent years, bell-less charging systems have mainly been used. This type can charge burden materials into blast furnaces more flexibly compared to the conventional bell-type charging systems. To control the burden distribution for a bell-less charging system, the tilt angle of the tilting chute is changed and the sequence in which burden materials are discharged onto the charging conveyor that transports the burden materials to the blast furnace top is changed. The burden materials discharged onto the charging conveyor are first kept in the furnace top bunker, and then discharged from the tilting chute via the collection hopper. However, when the burden materials are charged into the furnace top bunker, they start rolling, which causes particle size and density segregation. In addition, when the burden materials are discharged from the bunker, a drift called funnel flow occurs where the downflow rate is high directly above the outlet and low near the side wall, and that changes the discharge sequence significantly. This indicates that the burden distribution cannot be controlled as intended just by discharging burden materials onto the charging conveyor in the desired charge sequence.

To solve this problem, discharge characteristics on actual furnaces have been predicted by bunker discharge characteristic researches using offline scaled models[1–3] and computer simulation by

* Chief Researcher, Ironmaking Research Lab., Process Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

the discrete element method (DEM).[4, 5] However, scaled models and computer simulation cannot help us to gauge states in actual blast furnaces quantitatively; they can only help us to understand the qualitative tendency. We have developed a 3D bunker model[6] that can predict the burden material discharge sequence by determining the characteristics of charged burden materials stacked in the bunker and funnel flow discharge characteristics when they are discharged from the bunker that are based on the results of raw material sampling researches on actual furnaces. Using this model can simulate discharging characteristics on actual blast furnaces. However, raw material sampling researches on operating blast furnaces are difficult and improving the accuracy by increasing the number of data pieces is not easy because it takes labor and time.

In addition, previous studies have proposed other techniques where a sensor is inserted into a blast furnace to measure the particle size of the burden materials charged into the furnace and mixing degree of coke and ore.[7–9] However, these techniques cannot understand the direct correlation between the measured states of burden materials in a furnace and the sequence of the burden materials discharged onto the conveyor.

Therefore, this study uses radio frequency identification (RFID) tags that can identify IDs without contact, which has been used in many fields in recent years, as a technique to understand the relationship between the sequence of burden materials discharged onto a charging conveyor and time variation of the particle size and mixing degree of the burden materials discharged from the furnace top bunker. In our technique, RFID tags mixed into burden materials work as tracers and the IDs are detected while they are transported to the blast furnace. This study selects coke and ore, which are the main blast furnace burden materials, as tracking targets and reports the principle of and problems with the blast furnace burden material tracking using the RFID and the details of RFID tags imitating burden materials. This report also compares the results of performance evaluation of the RFID tracking on an actual blast furnace to the prediction results simulated using the conventional 3D bunker model.

2. Burden Material Tracking by the RFID

2.1 Measurement principle

Recently, use of an authentication technology called RFID that utilizes radio (non-contact) communications and IC chips has been increasing.[10, 11] **Figure 1** illustrates the configuration of an RFID system. In the RFID, IC chips with pattern antennas that are formed into a tag or a label shape called RFID tags are attached to objects and persons; and devices called tag readers are used to read the stored information remotely to recognize objects and authenticate persons. Compared to conventional ID authentication using bar codes, RFID is superior because RFID tags resist stains and targets can be remotely recognized and authenticated. If, immediately after burden materials to be tracked are discharged from the bins onto the conveyor, imitation burden materials with RFID tags are put onto the conveyor at the positions of the tracked materials and the IDs can be detected while the burden materials are transported to the blast furnace top, a burden material tracking technique that can be applied to operating blast furnaces can be realized.

Figure 2 illustrates the principle of this burden material tracking in a direct charge-type blast furnace with the RFID, as an example application to an operating blast furnace. The burden materials directly discharged from the burden material bins onto the charging belt conveyor (charging BC) are transported to the furnace top by the charging BC and kept in the furnace top bunker once. Then, they are discharged into the furnace via the collection hopper and tilting chute. It was planned to put RFID tags into burden materials moving on the BC on the outlet side of the burden material bins at certain intervals. Installing antennas at the end of the charging BC and at the collection hopper for detecting IDs allows us to gauge the influence of segregation and funnel flow in the top bunker and timing at which the burden materials are charged into the furnace precisely.

2.2 Basic characteristics of RFID tags

Figure 3 shows the relationship between the carrier frequency of the main RFID systems that are currently commercially used and detectable distance. There are passive-type and active-type RFIDs. The advantages of the passive type are that RFID tags operate using radio waves from tag readers as the energy source and thereby they do not require batteries embedded inside and function almost per-

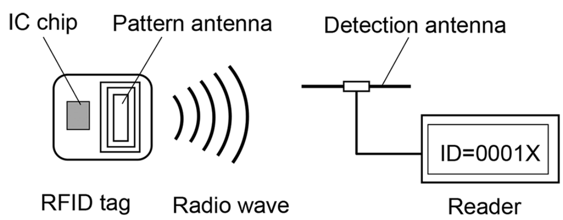

Fig. 1 Configuration of RFID system

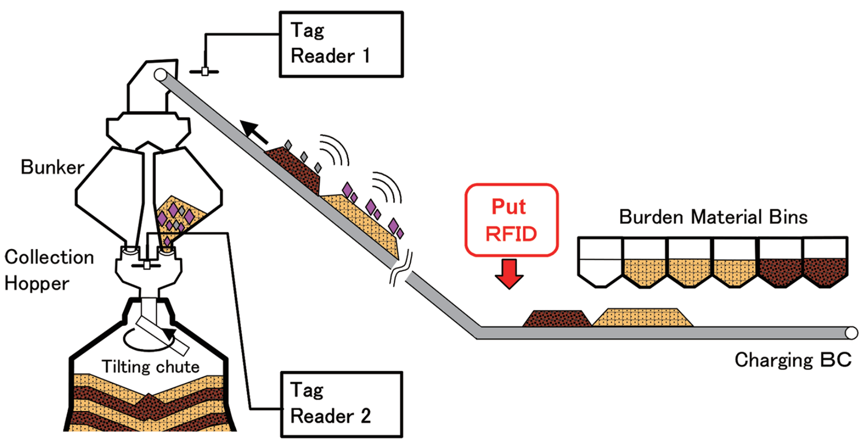

Fig. 2 Burden material tracking by using RFID for direct charge type

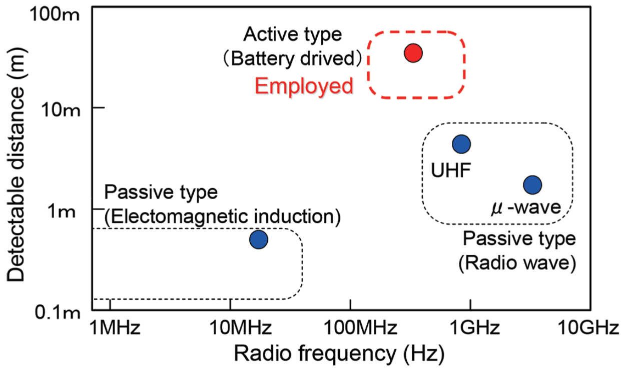

Fig. 3 Carrier frequency and identification distance of RFID systems

manently without maintenance. However, this type requires intensive radio wave emission to secure the sensing distance. On the other hand, active-type RFID tags contain batteries. They emit radio waves on their own and send the IDs in a predetermined cycle. Therefore, their advantage is that even when the radio wave output is low, the communication distance can be relatively long.

This study adopted the active-type RFID system because its radio wave output was low and thereby it would not have much effect on the surrounding equipment, and the communication distance of at least a few meters could be secured. The size of active-type tags depends on the size of the battery and transmitting antenna. The size of commercially available tags is around 20 to 30 mm and it is close to that of the raw materials to be imitated, so we considered that it could easily imitate the characteristics of the raw materials. In addition, antennas could be selected from various alternatives and thereby the application to the steelmaking processes was easy.

Table 1 lists the specifications of the RFID system used. The Japanese Radio Law prohibits the use of systems with a frequency higher than 322 MHz and a power higher than 500 μV/m without license. Therefore, an extremely low power radio station that satisfied such requirements was selected as the system in this study. The size of the board in the tag used is 24 × 34 mm that was determined based on the size of the button battery used. The tag sends the seven-hexadecimal-digit ID at intervals of 0.5 seconds. The cycle sending the IDs should be short so that the IDs of the tags can be read in a short time during which burden materials are falling after being discharged from the hopper; however, if it is too short, the battery life shortens. In consideration of the preparation time for the actual test, the cycle was determined as 0.5 seconds where the battery would last approximately one month. The maximum operating temperature of 60°C was determined based on the stability of the built-in IC chips and it means that IDs could be detected immediately before burden materials are charged into the blast furnace. High-sensitive dipole antennas with low directivity were used for detection. The reader used can read up to 40 IDs per second and can detect the received signal strength indicators (RSSI) at the same time when detecting IDs.

Next, to evaluate the permeability of radio waves through raw materials to be charged into the blast furnace, RFID tags were inserted into 15-cm-thick raw materials to check if IDs could be detected from the outside 1.8 meters away, as shown in **Fig. 4**. The IDs from tags in the sintered ore and lump ore were able to be detected while IDs were not able to be detected in the case of coke. This is because the electric conductivity of Fe_2O_3, which is a main component of iron ore and sintered ore, is 1.3 × 10^{-3} S/m (insulator)

Table 1 Specifications of evaluated RFID system

Item		Specification
System	Type	Active type (battery operation)
	Carrier frequency	300 MHz band
	Output power	< 500 μV/m
Tag	Substrate size	24 mm × 34 mm
	Operating temperature	0 to 60°C
	ID sending duration time	0.5 s
Reader	Antenna	Dipole type
	Modulation method	ASK (amplitude shift keying)
	ID code	Hexadecimal, 7 digits
	Recognition ability	40 IDs/s

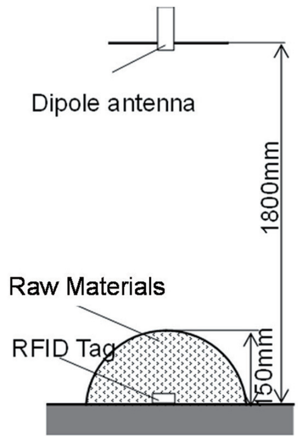

Fig. 4 Influence of material on ID detectability

while that of carbon, a main component of coke, is 3.0 × 10^4 S/m (electric conductor). The radio waves emitted from the RFID tags inserted in a stack of coke are shielded by the coke particles surrounding the tags. When tracking research is applied to coke batches, it is recommended that RFID tags be placed on the surface of the coke particle or an antenna be installed at the outlet from the hopper or bunker where the clearances between burden materials are larger.

2.3 Imitation burden materials with RFID tags

RFID boards alone cannot withstand the impacts applied until the burden materials are charged into an actual blast furnace and their segregation behavior differs from that of burden materials due to differences in the shape and specific gravity, so the tracking accuracy cannot be secured. Therefore, we fabricated highly-durable imitation burden material tag cases with specific gravity and particle size that would allow the behavior of actual burden materials to be imitated.

Cases for protecting RFID boards were prototyped under various conditions and their durability was tested with a drum tester for coke[12] to create protection cases that would not malfunction even after rotational impacts of 500 times or more were applied. Plastic protection cases were finally adopted considering the permeability of radio waves. An RFID board and battery were secured inside the case and the surface of the protection case was wrapped with thick tape to reduce damage.

Burden materials to be charged into blast furnaces can be re-

Fig. 5 RFID particles imitating burden materials

garded as an aggregate consisting of coke, sintered ore, lump ore, and auxiliary raw materials—an aggregate of a large number of particles with different density and particle size. When focusing on the segregation behavior of one particle of many particles, as the density is higher and the particle size is smaller compared to surrounding particles, it tends to easily sink and thereby it does not roll much. To reproduce segregation behavior similar to that of actual raw materials, the particle size and density of RFID tags should closely resemble those of actual raw materials. For imitation coke tags, plastic for which the specific gravity closely resembled that of actual coke was selected to fabricate protection cases. For imitation tags for ore, an iron weight was attached to the plastic protection cases to allow the apparent density to closely resemble that of actual raw materials.

Meanwhile, the particle size could not be smaller than 20 mm due to the limitation of the size of an RFID board. Therefore, a weight was attached to increase the density intentionally such that the apparent segregation behavior would be similar. **Figure 5** shows the two types of imitation particles containing an RFID tag fabricated (imitation burden material tags). The imitation coke tag imitates a 55-mm coke particle and the imitation ore tag imitates a 10-mm ore particle.

3. Evaluation of the Performance of the Burden Material Tracking on an Operating Blast Furnace

3.1 Evaluation of detection characteristics

In this study, RFID tags were used in the burden material transportation process to an operating blast furnace to study the detection characteristics of RFID tags. The study was conducted at Kashima Blast Furnace No. 1 that discharges burden materials directly into the charging BC from the burden material bins shown in Fig. 2. Antennas were installed near the top of the charging BC and in the collection hopper and a receiver was connected to each device. Twenty RFID tags (imitation ore tags) were put on sintered ore discharged onto the charging BC at regular intervals.

Figure 6 shows the RFID detection results at the top of the charging BC. **Figure 7** shows the detection results in the collection hopper. The horizontal axis is the time in reference to the time when the radio wave from the RFID tags was first detected and the vertical axis shows the identification numbers simply expressing the RFID tag IDs according to the discharge sequence into the charging BC. A total of 20 RFID tags were used and all of the 20 pieces were detected at the top of the charging BC and inside the collection hopper. At the top of the charging BC, the same RFID tag was continuously detected for approximately 30 seconds. When looking at the median values between the early stage and later stage of the radio wave detection, they show that the sequence is almost the same as the charge sequence. On the other hand, the detection results inside

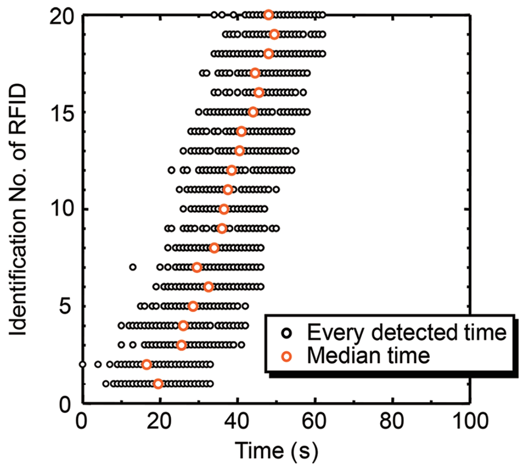

Fig. 6 RFID detection time chart at charging BC top of Kashima No. 1 BF

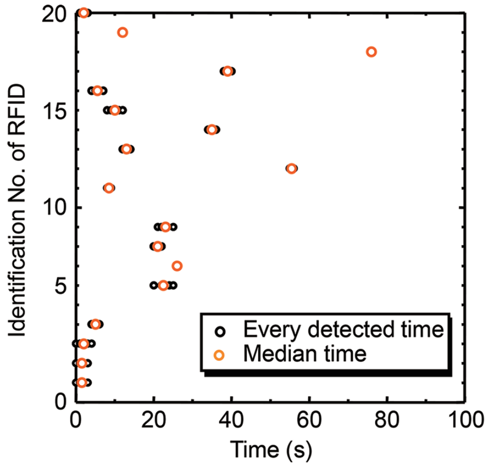

Fig. 7 RFID detection time chart at collection hopper of Kashima No. 1 BF

the collection hopper show that the charge sequence of the burden materials into the furnace is significantly different from the initial sequence. In addition, inside the collection hopper, the same RFID tag was continuously detected for approximately three seconds. Thus, the continued detection time in the collection hopper indicates the residence time during which the burden materials remained in the collection hopper because the metal wall of the collection hopper shut off radio waves from the outside and no coke had been charged at the time of measurement, which means there were no coke particles that shut off radio waves.

3.2 Evaluation of the detection success ratio

The previous section has shown that on the bell-less blast furnace with the direct burden material charge system, a total of 20 RFID tags were used and all of them were detected at the top of the charging BC and inside the collection hopper. However, to evaluate the accuracy of the burden material tracking using RFID tags, the number of RFID tags used needs to be increased and the impacts and imposed conditions in the transportation process of RFID tags imitating burden materials need to more closely resemble those of actual raw materials.

At Kashima Blast Furnace No. 1 with the direct charge system,

Table 2 Detection success ratio of RFID

Target furnace (charge type)	Batch	Charging BC top	Collection hopper
Kashima No.1 BF (direct charge system)	Ore 1	100%	89%
	Coke	100%	96%
	Ore 2	99%	97%

200 RFID tags imitating burden materials were used to evaluate the detection success ratio for the RFID tags. The ratio of the total number of RFID tags detected to the total number of RFID tags used is defined as the detection success ratio. A decrease in the RFID tag detection success ratio may be caused by damage to the RFID tags by mechanical impacts in the burden material transportation process and shutoff of the radio waves by coke particles around the RFID tags.

Table 2 lists the tag detection success ratio for each detection antenna in the burden material tracking test using the RFID at the operating blast furnace. The table shows the detection success ratio at each antenna location for each of the ore and coke batches. The detection success ratios are 89% or higher for both the top of the charging BC and collection hopper. This list shows that the targeted detection success ratio of 80% or higher that is required for burden material tracking has been achieved.

4. Application of Evaluation of Burden Material Charge Characteristics on an Operating Blast Furnace

As described previously, the detection success ratio of RFID tags on the operating blast furnace is high and it satisfies the requirements necessary as a burden material tracking means. Next, to evaluate the measurement accuracy, the correlation with the simulation results using the 3D bunker model[6] that we developed was evaluated.

4.1 Outline of the 3D bunker model

We have been using the 3D bunker model to predict the behavior of burden materials charged into blast furnace tops. In the 3D bunker model as shown in **Fig. 8**, for the charge of burden materials into a bunker, the vertex of the burden materials stacked in the bunker and stacked burden angle θ_1 are provided to simulate the accumulation state in the bunker; and for the discharge of the burden materials from the bunker, rat-hole angle θ_2 and collapse angle θ_3 are given to express funnel flow to simulate the burden material discharge sequence. Here, the vertex of the burden materials stacked in the bunker and stacked burden angle θ_1 given to the model reflect the results obtained through researches performed during periods of pause of operation. Rat-hole angle θ_2 and collapse angle θ_3 are temporarily determined in a model experiment in advance and finally determined after fine adjustment based on the results of sampling of burden materials discharged from the tilting chute performed during pause.

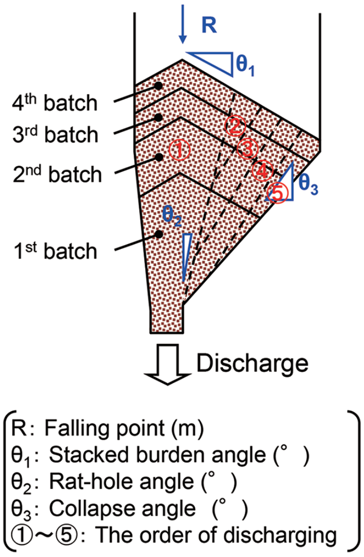

Fig. 8 Parameters in the 3-dimensional bunker model in the process of charging and discharging burdens

4.2 Comparison of burden material charge conditions and 3D bunker model simulation results

This section evaluates the correlation of the 3D bunker model simulation results that were adjusted based on the results of sampling performed during periods of pause of operation at Kashima Blast Furnace No. 1 with the burden material tracking test results using RFID tags.

Figure 9 shows the conditions on the discharging amounts of burden materials in coke dump and ore dump batches in the burden material tracking test using RFID tags. RFID tags that imitated each type of raw materials were put on the burden materials discharged onto the charging BC at regular intervals. The number of RFID tags was 7 or 8 per ton in the case of coke and 2 or 3 per ton in the case of ore.

Figure 10 shows the accumulation states of the coke and ore in the bunkers before dump simulated using the 3D bunker model along with the rat-holes and collapse lines when the burden materials are discharged.

In the figure, the coke is divided into the first to third batches and the ore is divided into the first to fourth batches in the bunkers. The burden materials in the rat-hole are discharged first and those near the surrounding wall are discharged lastly. **Figure 11** shows the correlation between the time variation of the discharge for each batch simulated by the 3D bunker model and the detection frequency of the RFID tags at the collection hopper for each batch while the burden materials were discharged from the bunkers. Regarding the

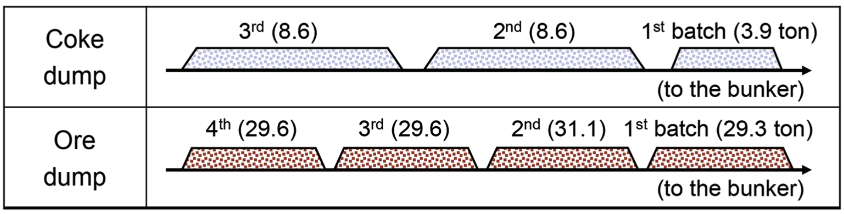

Fig. 9 Conditions on discharging amount of burdens from burden material bins

burden material discharge sequence from the bunker, the burden materials in the rat-hole, which was formed immediately above the outlet, are discharged first and then those near the wall are discharged later as mentioned above. The RFID tag detection results show that there are peaks in the early and later stages of the discharge of the first and second batches for both coke and ore, so the simulation succeeded in capturing the aforementioned behavior qualitatively. The RFID tag detection results, including the discharge behavior of the other batches, mostly agree with the burden material discharge patterns simulated by the 3D bunker model.

Thus, the burden material tracking using RFID tags can be applied to measurement while blast furnaces are operating and thereby that can increase the measurement frequency easily. It can serve as an effective means to improve the accuracy of burden distribution control on blast furnaces. In addition, although raw material sampling used during periods of pause of operation was the only means to improve the simulation accuracy of the 3D bunker model, this burden material tracking using RFID tags can collect much information to improve it. Combining the burden material tracking using RFID tags for understanding actual states with the 3D bunker model simulation results under unknown charge conditions would lead to more accurate burden distribution control.

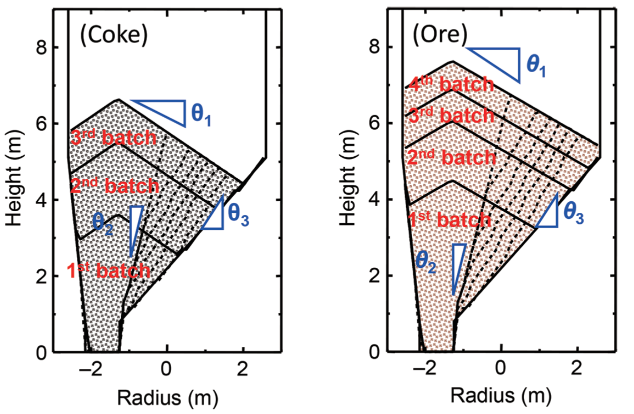

Fig. 10 Stacked profile of each batch of burdens and lines of discharging behavior predicted by the 3-dimensional bunker model

5. Conclusion

Nippon Steel Corporation has developed a new technique for tracking burden materials charged into blast furnaces using non-contact ID authentication technology RFID to improve the accuracy of the burden distribution control on bell-less blast furnaces. As a characteristic of this technique, particles imitating coke or ore containing active-type RFID tags are mixed into burden materials and the IDs are detected during the transportation until the burden materials are charged into the blast furnace tops. This report evaluated the detection timing accuracy and detection success ratio on an actual blast furnace. The results have shown that the technique can accurately detect the timing at which the burden materials pass inside the collection hopper immediately before being charged into the blast furnace. The detection success ratio for all the tags used is 83% or higher. In addition, the results were compared to the 3D bunker model simulation results that had been adjusted based on the sampling results during periods of pause of operation, which is a conventional prediction technique. It has been confirmed that the burden material discharge patterns generally match between the test and simulation.

These results confirm that the developed technique to track burden materials charged into blast furnaces is effective to improve the accuracy of the burden distribution control on blast furnaces and blast furnace operation.

References

1) Matsuzaki, S., Taguchi, Y.: Tetsu-to-Hagané. 88 (12), 823–830 (2002)
2) Kashihara, Y., Iwai, Y., Ishiwata, N., Oyama, N., Matsuno, H., Horikoshi, H., Yamamoto, K., Kuwabara, M.: Tetsu-to-Hagané. 102 (1), 9–16 (2016)
3) Murao, A., Kashihara, Y., Oyama, N., Sato, M., Watakabe, S., Yamamoto, K., Fukumoto, Y.: Tetsu-to-Hagané. 102 (11), 614–622 (2016)
4) Mio, H., Kadowaki, M., Matsuzaki, S., Kunimoto, K.: Minerals Engineering. 33, 27 (2012)

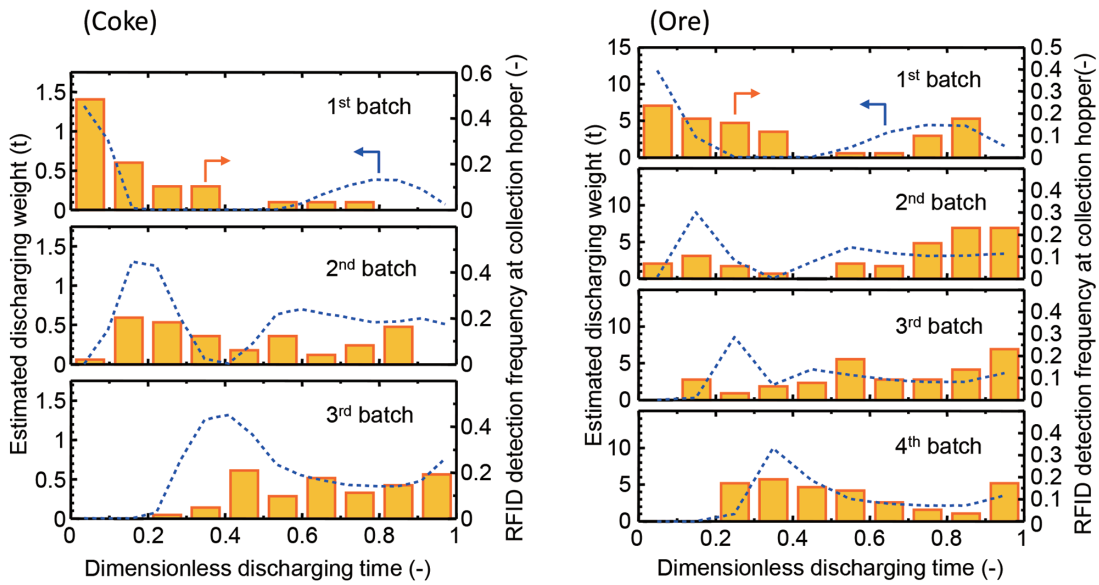

Fig. 11 Discharging behavior of each burden measured with the RFID detection at the collection hopper and predicted by the 3-dimensional bunker model

5) Narita, Y., Mio, H., Orimoto, T., Nomura, S.: ISIJ International. 57, 429–434 (2017)
6) Nakano, K., Sunahara, K., Inada, T.: ISIJ Int. 50 (7), 994–999 (2010)
7) Ashimura, T., Morishita, N., Inoue, Y., Higuchi, M., Baba, M., Kanamori, K., Wakuri, S.: Tetsu-to-Hagané. 80 (6), 457–462 (1994)
8) Ohno, J., Yashiro, H., Shirakawa, Y.: Transactions of the Society of Instrument and Control Engineers. 24 (2), 112–118 (1988)
9) Murakawa, S., Konishi, Y., Taguchi, S., Hamada, T.: Kawasaki Steel Technical Report. 20 (3), 228–229 (1988)
10) Mitsugi, J.: The Journal of The Institute of Electrical Engineers of Japan. 126 (8), 521–524 (2006)
11) Shimizu, M.: The Journal of The Institute of Electrical Engineers of Japan. 126 (8), 534–537 (2006)
12) JIS K 2151:1957, Coke — Testing methods

Kaoru NAKANO
Chief Researcher
Ironmaking Research Lab.
Process Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

Kenta WATANABE
Senior Manager
Ironmaking Technical Dept.
Iron Making Div.
Kashima Works

Yoshito ISEI
Senior Researcher
Instrumentation & Control Research Lab.
Process Research Laboratories

Tomoyasu KISHINO
Manager, Head of Section
Sintering & Ore Treating Plant, Sintering Section
Iron Making Div.
Kashima Works

Takuya NATSUI
Senior Researcher
Ironmaking Research Lab.
Process Research Laboratories