MEASURING BLAST FURNACE SLAG FLOW RATE AT SLAG RUNNER BY IMAGE ANALYSIS METHOD

BY

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SYNOPSIS:

Tapping is critical in blast furnace or melter gasifier process because it can affect inner state of the furnace greatly. Improper drain results blast pressure increase, burden level irregularity, unstable burden descent and thermal level instability and so on. Hence, furnace operators try to optimize tapping by controlling tapping sequence, tap hole opening/closure, bit size and tap-hole clay mineralogy. Most important data used for such decision is liquid(iron/slag) level at hearth.

Iron level can be easily calculated by mass balance because out flow mass of iron is always monitored at TLC weigher. Nevertheless, it is difficult to measure slag out flow mass because most of slag tapped from the recent blast furnace is directly quenched by water to produce granulated slag. So it is very difficult to know slag level inside furnace and hard to optimize tapping strategy.

In this study, image analysis method was developed to measure slag out flow mass at slag trough where slag is liquid state(before water granulation). Camera and Laser marker was installed in cast house for slag flow rate calculation. By image analysis method, slag flow rate was monitored in real time and slag level could be calculated based on slag out flow rate data. Accuracy of the system was found to be more than 95% which was verified by comparing calculated data with water granulated slag weighing data.

Keywords : Blast furnace, Melter gasifier, Liquid level, Slag, Flowrate, Image analysis, Camera, Laser, Tapping

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1. Introduction

To meet the demand of environmental issues and tightened production cost, fuel rate of ironmaking process must be minimized. In blast furnace (or melter gasifier), RAR (Reducing agent ratio) can be reduced by gas dynamics control, low carbon burden (CCA, DRI, Scrap, etc.) charging, injection of auxiliary fuel and so on. Smooth liquid level control is also a critical for blast furnace stability and fuel efficiency because it can affect temperature profile inside furnace greatly. Liquid level at hearth can be controlled by 1) tapping sequence, 2) tap hole opening/closure, 3) bit size and 4) tap hole clay mineralogy. To design best tapping strategy, blast furnace operators always monitor tapping information such as casting speed, iron temperature, tap hole situation, blast pressure. Especially, liquid level at hearth is most important data for operators because when liquid level is too high, tuyere could be damaged by molten slag/iron and when liquid level is too low, hot blast injected by tuyere could be evacuated through tap hole that can result splashy. So accurate prediction of liquid level is important for furnace stability.

Iron level can be calculated by mass balance because out flow mass of iron is always monitored at TLC weigher. Nevertheless, it is difficult to measure slag out flow mass because most of slag tapped from the recent blast furnace is directly quenched by water to produce granulated slag. So, it is difficult to know slag level inside furnace and hard to optimize tapping strategy. However, effect of slag mass inside furnace on liquid level is critical because density of slag is lower than that of iron.

Generally, inflow slag mass into hearth is calculated by burden composition and charging rate. In case of outflow slag mass, theoretical value is used as follows:

Slag outflow (t/min)

= Iron outflow (T/min, TLC weighing) X Theoretical Slag ratio (t-slag/t-iron)

Theoretical value is straightforward and easy to calculate but it cannot reflect real situation at hearth because outflow rate of iron and slag is not always linear. Another option is estimation of slag outflow mass base on water granulation data. Slag tapped from hearth pass through slag trough and quenched by water at granulation tower or cooled by air at dry pit. When tapped slag is granulated at granulation tower, water quenched slag slurry is transported to dehydration bath through pipeline or conveyor belt. There are several technical data at granulation tower pipe or conveyor belt that can be used to predict slag slurry mass. So, by using those data, it is possible to predict more accurate slag outflow mass than theoretical value. Problem is that the method cannot estimate slag outflow mass that goes into dry pit.

In this study, image analysis method was developed to measure slag outflow mass at slag trough where slag is liquid state (before water granulation). By measuring slag outflow mass at slag trough, both of slag mass goes to granulation tower and dry pit can be monitored.

2. Methods

Slag flowrate measurement system was installed and tested at No.2 & 3 FINEX melter gasifier at Pohang works. In this study, laser marker and high-resolution camera were employed to measure slag flowrate at slag trough just behind skimmer. As shown in **figure 1**, line laser marker was installed ceiling of cast house so that green laser marking line can be projected at the surface of slag trough. Projected marking line laser is shown in **figure 2**. High resolution camera was also installed at cast house to record images of surface of slag stream and marking laser continuously. Camera was installed so that enough angle between laser device-measuring point-camera to be secured as shown in figure 1. In this case, 40~50degree angle was enough to calculate slag flow rate. Recorded video data was transmitted to data processing computer to convert raw data into slag outflow mass value.

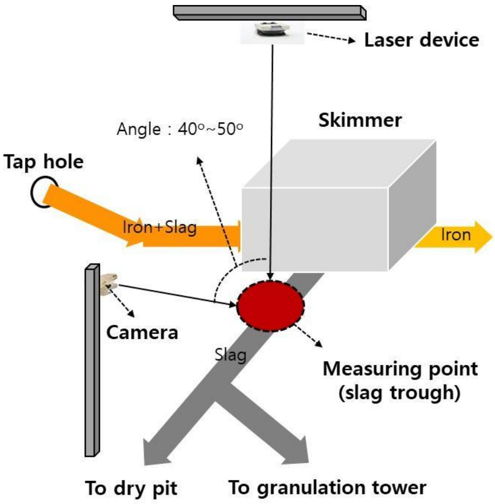

Figure 1. Slag flowrate measurement system

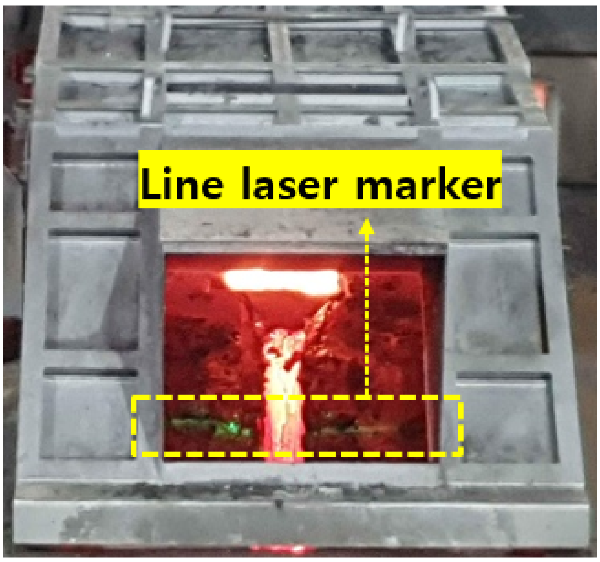

Figure 2. Line laser marker at slag trough

At slag trough, slag rate of specific moment can be calculated by following equation (1) and **figure 3**.

Slag mass flow (kg/min) = Vertical cross-section area of slag at trough (m^2)

× Slag surface velocity (m/min) × Density of slag(m^3/kg)

----------- Eq. (1)

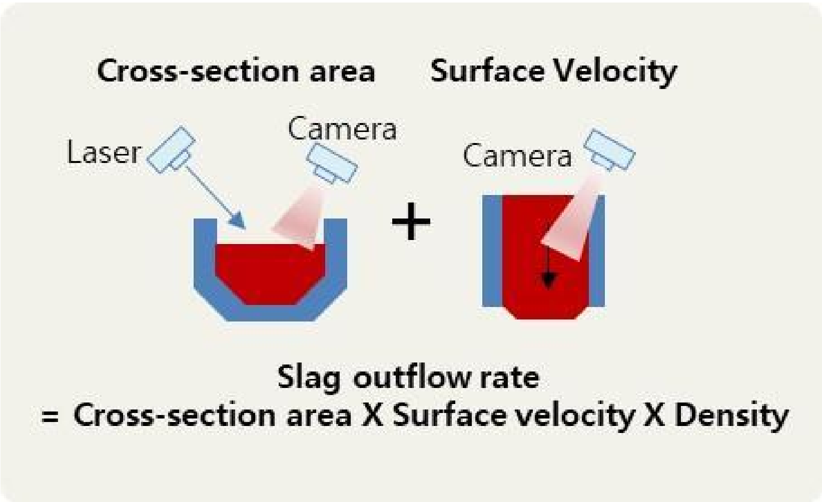

Figure 3. Principle of slag outflow rate measurement

Firstly, vertical cross-section area of slag at trough was measured by camera image. Vertical cross-section area of slag at trough is a function of trough inner profile and slag surface height. Inner profile could be changed every tap because of solidification of slag during previous tap. So just before each tap start, vertical cross-section of the slag trough without slag was measured by laser marking line image. This vertical cross-section area value of the slag trough was stored at system and used to calculate slag flow rate by assuming inner profile of slag trough does not change during following tap. When slag start to flow through slag trough, slag surface height can be easily measured from camera image. Normally, slag surface is hard to observe with camera because it is very bright. Nevertheless, green color laser at the slag surface is relatively easier to observe than slag surface itself. Hence, height of slag level at slag trough can be continuously measured by tracking green laser line location at camera image. By combining inner profile stored just before tap start and slag height during slag flow, vertical cross-section area of slag can be calculated continuously.

Secondly, slag surface velocity was measured continuously by camera image. When slag flows, solidified particles are observed at the surface of slag. In addition, slag surface shows highly irregular pattern with light and shade area randomly distributed as shown in **figure 4**.

So, by tracking particles or shade pattern at the slag surface every defined time gap, surface velocity was measured every second. In this study, two camera images with time gap of less than 0.5 seconds were continuously compared.

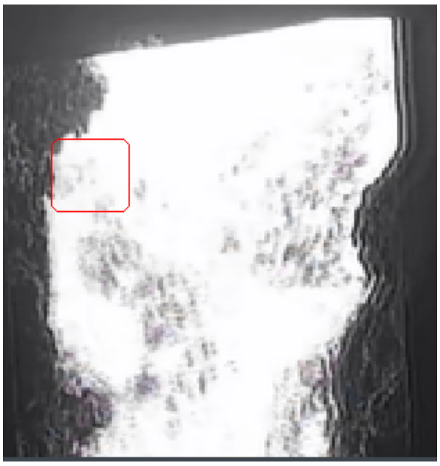

Figure 4. Image of slag surface at slag trough

Finally, slag outflow mass was calculated by multiply 1) vertical cross-section area of slag, 2) slag surface velocity and 3) pre-defined slag density constant. When slag flows, slag mass can be continuously calculated every second. Calculated slag flowrate was compared with water granulation tower data based real time slag outflow mass data and actual granulation tower slag weighing data of single tap.

3. Results & Discussion

Figure 5 shows slag flowrate of single tap measured by image analysis method. As shown in figure 5, only iron was drained from tap hole at the initial stage of tap(①). At this first stage, iron flowrate was decreased as tap continues but it was increased at second stage with slag discharge. It should be noted that at second stage, it was possible to detect slag flowrate by image analysis method while there was no signal of slag flowrate by granulation data. At stage ②, slag stream was clearly observed with eye at slag trough so it was possible to detect and measure slag flowrate by image analysis method since image used to calculate flowrate was taken at slag trough. However, it took some time for slag to flow from slag trough to granulation tower which means it is impossible to detect slag flowrate by granulation tower data at this stage. Generally, there exists 5~10 minutes gap between actual slag discharge start time at skimmer and granulation tower pump start time for transporting slag slurry to dehydration bath. So, slag flowrate measured by image analysis method in this study is more realistic than slag granulation data based one since time delay between actual slag discharge start time at tap hole and slag flowrate observation start time can be minimized.

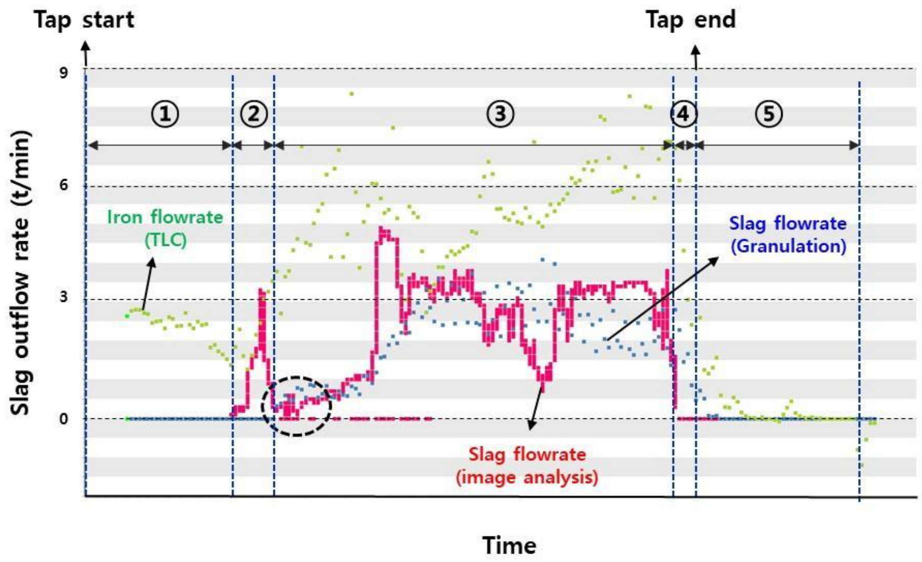

Figure 5. Slag outflow rate measured by image analysis method

After stage ②, granulation tower pump started running and slag flowrate could be calculated as well. Basically, flowrate data by image analysis method is not stable compared with the other one so temporarily it shows differences. Nevertheless, at stage ③, slag flowrate calculated by image analysis method and granulation tower data method showed similar trend except a few moments. At stage ④ when slag flow stops, slag flowrate calculated by image analysis immediately becomes 0 while slag granulation data based one still shows positive slag flowrate. Granulation tower data based slag flowrate showed positive value even after tap hole had been closed(stage ⑤) at the end of stage ④. It is clear that image analysis method has less time delay than the other method. Definitely, superior responsibility of the new method is helpful in calculating accumulated slag level at hearth.

In figure 5, tap accumulated slag mass was calculated as 220t/tap in case of image analysis method which was similar with granulation value based slag mass. The actual slag weighing mass after granulation tower was 210t/tap so it showed about 4.8% difference. In many other cases, image analysis method showed 5% error with actual weighing value or granulation data based calculated one which is reasonable to use. The advantage of image analysis method is that flowrate can be calculated even when slag flows to dry pit not granulation tower.

To calculate slag flowrate shown in figure 5, height of slag, velocity of slag surface should be measured respectively. **Figure 6** shows measured (a) height and (b) speed of slag surface, (c) vertical cross-section area of slag and (d) calculated mass flowrate of slag within a single tap at slag trough respectively. Here, all the data except mass flowrate were relative value.

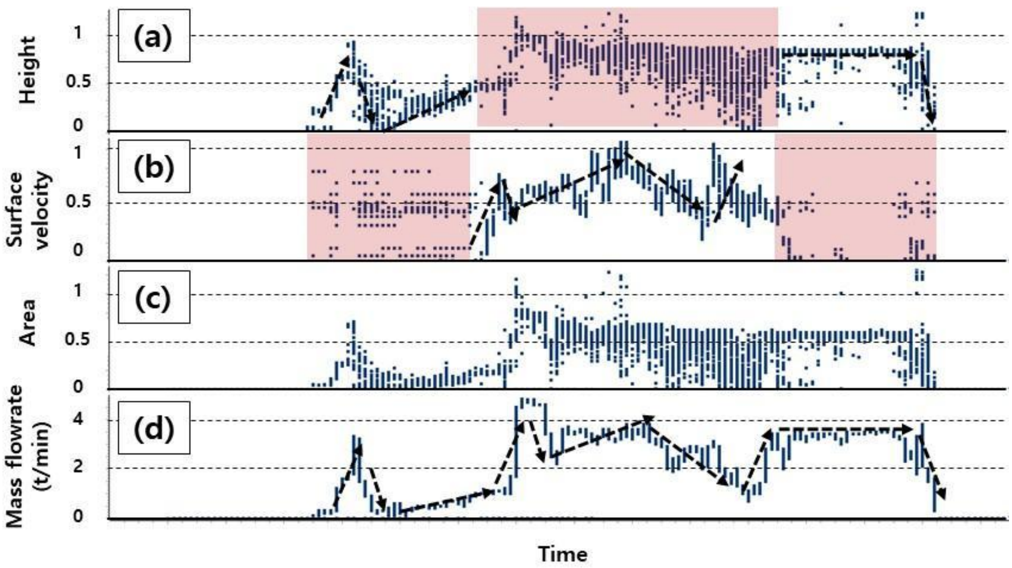

Figure 6. Measured slag flowrate data from image analysis. (a) height and (b) speed of slag surface, (c) vertical cross-section area of slag and (d) calculated mass flowrate of slag within a single tap at slag trough. (a), (b) and (c) are represented as relative value.

Missing value rate of height of slag surface is lower compared with surface velocity of the slag. So it is possible to calculate vertical cross-section area (c) easily by combining value of vertical cross-section of the slag trough without slag and slag surface height data measured from camera image. Slag surface height and vertical cross-section area value is gradually changed at the initial stage of tap but is steady at rest of the tap. This is because at the initial stage of the tap where slag trough is almost empty, inflowing slag to slag trough mainly increases slag level while surface flow velocity is low. Meanwhile, slag surface velocity data is clear at the middle of the tap while it is unstable and has lots of missing value at the initial and last period of the tap. Generally at the initial stage of the tap, temperature of slag is low so that specific region of slag trough is covered by solidified slag as shown in **figure 7** (a). Once solidified slag covers slag trough, it is impossible to track particles at the surface. On the other hands, at the last period of the tap, temperature of slag is high that result good dissolution of solid slag particle. In this case, it is also impossible to compare two images captured sequentially because optically, two images are too “clean”.

So calculated slag flow rate(d) based on surface height(a) and velocity(b) in figure 6 shows similar trend with surface height at the initial stage and last period of tap while it is similar with surface velocity at the middle of the tap.

It should be noted that at the last stage of tap, height value is steady and mass flowrate of slag is also steady as well. In other words, surface velocity is most important data for calculating mass flowrate of slag and if laser device is not installable at cast house due to interference with other cast house instrument, high resolution camera itself would be enough to predict slag flowrate. In this case, correlation between surface velocity and mass flowrate should be clarified with data analysis. With several tap data, correlation has been derived between accumulated tap slag mass by granulation data and sum of slag surface velocity obtained by image analysis method. From correlation factor, it was possible to predict slag surface velocity into slag flow rate as shown in **figure 8**. As shown in figure 8, trend is similar with granulation data based slag flowrate and difference in tap accumulated slag mass is less than 7%. However, image analysis based flowrate data is not stable so it is hard to use as an on-line data. For this reason, combining line laser with camera seems best option if laser is installable at cast house.

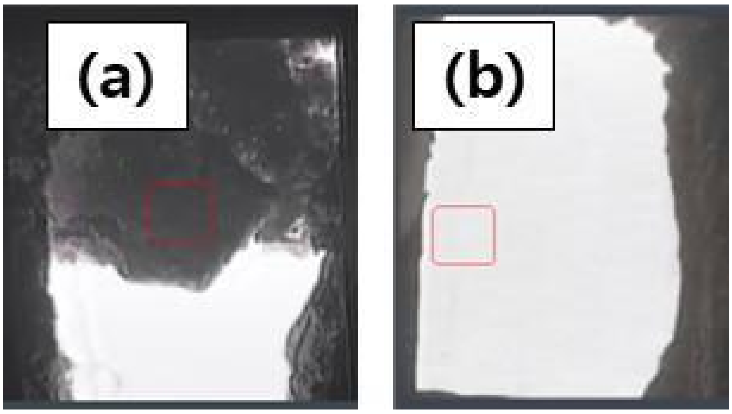

Figure 7. Slag surface images taken at the (a) initial and (b) last period of tap

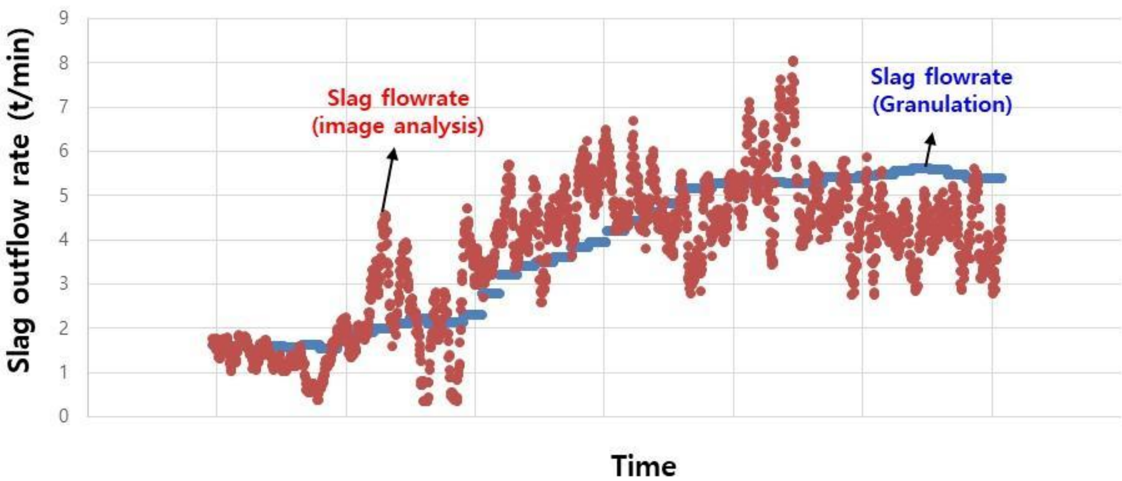

Figure 8. Slag flowrate calculated with camera only

4. Summary

In this study, image analysis method was developed to measure slag out flow mass at slag runner where slag is liquid state(before water granulation). Camera and Laser marker was installed in cast house for slag flow rate calculation. By image analysis method, slag flow rate was monitored continuously and slag level could be calculated based on slag out flow rate data. Accuracy of the system was found to be more than 95% which was verified by comparing calculated data with water granulated slag weighing data. Although flowrate can be calculated without line laser marker, combining line laser with camera was found to be a best option because of data stability. By image analysis method, on-line slag flowrate data can be achieved without time delay and independent of slag water granulation.