Effect of Nozzle Twisted Lance on Jet Behavior and Spitting Rate in Top Blown Process

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It is important to well-design the shape of lance nozzle to suppress the spitting phenomena in top blown process such as a converter. Normal lance in which axes of lance and nozzles intersect one another has been used in spite of its limitations conventionally.

In the present work, 6 nozzle lances with twisted nozzles in which axes of lance and nozzles have no points in common were newly designed and the effects on the spitting behavior and the characteristics of jets were investigated by cold model experiments.

“Nozzle twisted lance” showed a lower spitting rate at the optimum twist angles of 11.4 degrees which was lower than that of normal lance. Jet behaviors were also different from those of the normal lances and changed according to the twist angle. Suppression effect of “nozzle twisted lance” on the spitting rate could be partially explained by an increase of the shift of the jet pressure from the lance axis.

KEY WORDS: converter; lance; nozzle; jet; spitting; twist; dynamic pressure.

1. Introduction

In steelmaking processes such as BOF and combination blowing, oxygen is supplied to the molten iron through nozzles in the form of a gas jet for decarburization. The gas jet tears off the liquid and generates droplets. These phenomena are generally referred to as “spitting” or “splash”. They are causes of operational problems and lead to lower productivity and lower metallic recovery in the commercial plant. Therefore, it is necessary to suppress formation of the droplets and reduce “spitting” or “splash” by using well-designed lances.

In many experiments, it is reported that the critical condition for spitting formation depends on cavity depth and surface tension and that spitting rate can be represented as a function of jet momentum or cavity depth. These experiments are carried out using single-nozzle lances, whereas recent converters are operated invariably using multi-nozzle lances with appropriate nozzle inclination. Experiments of multi-nozzle lances were carried out by Mori et al. and Maya et al., and they reported that spitting rate increases with an increase in overlap ratio of hot spot which is defined by geometrical arrangement in lances with multiple nozzles.

They adopted conventional “normal lances” with multiple nozzles for their researches as shown in Fig. 1(a). Normal lances have the same characteristic that axes of lance and nozzles invariably intersect one another as depicted in Fig. 2(a). In such lances, the jets simply proceed in the radial direction on the projected plane normal to the lance axis and the spitting particles ejected from the bath surface also fly upward in the radial direction. Therefore, there are little operational factors to control the behavior of spitting and jets except for diameter and inclination angle of nozzles. Furthermore, the normal lances have some limitations. They are necessary to increase the inclination angle of the nozzles to avoid coalescence between the jets. However, the angle is restricted to some extent due to a limited lance diameter in a commercial operation. Consequently, some measures are desired to control jet behavior and to suppress spitting phenomena without increasing lance diameter.

In the present study, a new type of lance, “nozzle twisted lance” is newly designed as shown in Figs. 1(b) and 2(b) to control jet behavior and to suppress spitting phenomena. In the new lance, axes of lance and nozzles do not intersect or have no points in common and “twist angle” of the nozzle can be introduced as a new operational factor. It may give...
new effects on the spitting and jet behavior by choosing optimum “twist angle”. However, there exist little researches on the characteristics of this type of lance in top blown process. Therefore, the effect of the new lance on the jet behavior and spitting rate is investigated by cold model experiments.

2. Experimental Apparatus and Procedure

2.1. Nozzle Twisted Lance

All lances used in the experiment were composed of 6 straight-type nozzles. All of them were fabricated from brass material and the lance diameter was 0.045 m and the distance between nozzle and lance axis was 0.010 m at the lance tip. The nozzles had the same inclination angle of 20 degrees and the same diameter of $4.8 \times 10^{-3}$ m.

Twist angle of the new lance, “nozzle twisted lance”, is changed from 0 to 66.4 degrees. The lance with twist angle of 0 degrees corresponds to the “normal lance”. Twist angle ($\theta$) is defined as in Fig. 2(b). The figure shows a top view of the lance tip. The lance axis is the origin P, the nozzle inlet is the point A and the nozzle exit is the point B, respectively. Arrow (→) indicates the nozzle axis and cross mark (×) is intersection of nozzle axis and bath surface. Twist angle is defined as an angle between the line PB and the line AB.

2.2. Measurement of Spitting Rate

Cold model experiments were carried out with a water model shown in Fig. 3 using compressed air on behalf of oxygen gas in the commercial converters. The cylindrical vessel was made of acrylic resin with an inner diameter of 0.5 m and a height of 1.1 m. It was filled with tap water to the 0.195 m level from the bottom. The compressed air was blown to the bath surface from the nozzle tip of the top lance for a period of 120 s.

Gas flow rate and lance height were set to be $1.4 \times 10^{-3}$ m$^3$ (normal)/s and 0.2 m, respectively. Impinging jets from nozzles generated water droplets on the bath surface and the droplets moved upward through the vessel. Spitting weight was measured as a weight of total droplets trapped in absorbent cotton which was set inside the vessel at heights of 0.4 to 0.6 m from bath surface. Spitting rate was obtained by dividing the spitting weight by blowing time and area of absorbent cotton.

The cylindrical vessel is built at about 1/10 scale of a typical 250 t commercial converter. The lance height and sampling height at the cold model correspond to 2 m, 6 m at a commercial converter. The sampling position is located at the mouse or the upper part of converter where adhesion of metal to the wall is one of the problems on a commercial operation.

2.3. Distribution of Dynamic Pressure

The radial distribution of the dynamic pressure of the jet was measured with a Pitot tube which was set as shown in Fig. 4. The measured direction was rotated from 0 to 50 degrees considering symmetrical geometry. The measurements were performed on the plane 0.2 m distant from the lance tip. The pressure outputs of the tube were transformed into voltage signals, converted into digital signals, processed into time-averaged values and finally stored in the memory of a personal computer.

The length of the potential core is important for estimation of coalescence among the jets. It is thought to be constant independent of the twist angle because the dimension of the nozzles is same. It is generally estimated to be 5–8 times of the nozzle diameter, or $24–38 \times 10^{-3}$ m in this ex-
The measurement of the length of the potential core was not performed because it is small as mentioned above and it is difficult to measure it with high accuracy.

3. Results of Experiment

The measured spitting rates in the cold model experiments were plotted against the sampling height as shown in Fig. 5. The spitting rate decreased with an increase in the sampling height and changed dependent on the twist angle ($\theta$). The spitting rates at sampling height of 0.6 m, $S$ (kg/m$^2$·s), were plotted against the twist angle as shown in Fig. 6. The spitting rate, $S$, showed a minimum value at the twist angle of 11.4 degrees. The reason that the spitting rate showed a minimum value at the twist angle of 11.4 degrees will be discussed later.

The radial distributions of the jet pressure in the measured directions were plotted in Fig. 7. The radial distribu-

![Fig. 4. Experimental apparatus for dynamic pressure measurement.](image1)

![Fig. 5. Relationship between spitting rate and sampling height in cold model experiments.](image2)

![Fig. 6. Relationship between spitting rate and twist angle of "nozzle twisted lance" in cold model experiments.](image3)

![Fig. 7. Radial distributions of jet pressure in each twist angle of "nozzle twisted lance".](image4)
4. Discussion

Experimental results showed that the newly designed "nozzle twisted lance" could suppress the spitting rate by selecting a proper "twist angle" and that the distribution of dynamic pressure could be controlled by changing the new operational factor of "twist angle". They suggest that the controlled pressure distributions could have a reducing effect on spitting rate. Therefore, it is necessary to abstract the characteristics of the jets to discuss the relationship between jet and spitting behavior because the pressure distributions are too complex and it is difficult to treat them entirely.

In the previous work, the present authors chose the maximum value of the dynamic pressure ($P_{\text{max}}$) and the shift of the maximum pressure location from the lance axis ($D_{\text{max}}$) as the characteristic values of the jets because they were very suitable for relating the jet behavior to the spitting rate. Then the two characteristic values are defined as in Fig. 8 and are used as the previous work.

The maximum values of the dynamic pressures ($P_{\text{max}}$) were plotted against the twist angle as shown in Fig. 9. They were independent of the twist angle and were kept to be around 240 Pa. The shifts of the maximum pressure location from the lance axis ($D_{\text{max}}$) were also plotted against the twist angle as shown in Fig. 10. The shifts showed a maximum value at the twist angle of 11.4 degrees. Inclination angles of jet path, $\beta$ (deg.), were calculated using $D_{\text{max}}$ according to Eq. (1).

$$D_{\text{max}}=D_0+H \tan \beta$$  \hspace{1cm} (1)

where $D_{\text{max}}$: shift of pressure peak from the center (m), $D_0$: the distance from the lance axis to the nozzle center at the lance tip(m), $H$: height of lance tip from the bath surface (m).

Figure 11 shows the relationship between the inclination angle of jet path ($\beta$) and the twist angle of nozzle ($\theta$). The lance with the twist angle of 11.4 degrees shows maximum jet angle, $\beta$, the value is closest to the nozzle inclination angle of 20 degrees in all lances. It suggests that the jets from the nozzles with the twist angle of 11.4 degrees are not apt to coalesce with one another and are likely to proceed more straight than the jets from the nozzles with the different twist angles. The reason why the jets from the nozzle with a particular twist angle proceed straight was not clarified in the present work and it is necessary to be taken into consideration as a future work.

Figures 9, 10, and 11 suggest that the shifts of the maximum location have an influence on the spitting rate because the maximum pressure of the jets was maintained constant regardless of the twist angle. The normalized spitting rates, $S/S_0$, were plotted against the shift of the
maximum pressure location in Fig. 12. This figure shows that the spitting rates decrease with an increase in the shift. In the previous paper,10) the present authors proposed the relationship between the spitting values and $P_{\text{max}}, D_{\text{max}}$ based on the experimental results of the 4-nozzle or 6-nozzle normal lances shown in Fig. 13 in the same cold model experiments.

The spitting rates of normal lances were obtained by giving observed 240 Pa as $P_{\text{max}}$ and were plotted against $D_{\text{max}}$ as shown in Fig. 14. This figure shows that the observed spitting rates of “nozzle twisted lance” are lower than those of normal lances for the same maximum pressure and the higher $D_{\text{max}}$. It suggests that the suppression effect of the twist nozzles on the spitting rate can be explained not only by increasing the shift of maximum pressure location from the lance axis but also by the effect of something else.

In the nozzle twisted lance, velocity vectors of jets emitted from the nozzle tips contain tangential component. Therefore, it is possible that the tangential flow has an additional influence on the spitting rate because the jet flow can change the flying direction of droplet torn off from the bath surface. However, the effect of tangential flow could not be estimated in the present work because of difficulty of measurements. The effect of tangential flow is necessary to be estimated by computational fluid flow analysis in the future.

As mentioned above, it is necessary to make an optimum pressure distribution of jet by designing nozzle arrangement in order to decrease the spitting rate. “Nozzle twisted lance” used in the present work is clearly convenient for that purpose because it can control the shifts of the maximum pressure location just by adjusting the twist angle.

5. Conclusions

“Nozzle twisted lance” was newly designed and the behavior of dynamic pressure of jets and spitting phenomena were investigated by the cold model experiments. New operational factor of twist angle was changed from 0 to 66.4 degrees. The results obtained are as follows:

(1) The spitting rate in the “nozzle twisted lance” showed lower than that of normal lance except for the lance with twist angle of 66.4 degrees. The effect of the new lance depended on the twist angles and the spitting rate showed a minimum value at the twist angle of 11.4 degrees.

(2) Observed dynamic pressure distribution of jets showed almost the same maximum pressures independent of the twist angle and the shifts of maximum pressure location from the lance axis showed a maximum value at the twist angle of 11.4 degrees.

(3) The suppression effect of “nozzle twisted lance” on the spitting rate can be partly explained by the increase of the shift of maximum pressure location. Therefore, it is necessary to choose the optimum twist angles of the nozzles in order to decrease the spitting rate.

(4) It is suggested that the tangential flow induced by new lance has an additional influence on the spitting rate by changing the flying direction of droplets torn off from the bath surface.

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