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ISSN 0543-5846
METABK 59(3) 299-301 (2020)
UDC – UDK 669.14: 669.184: 621.6: 531.717 = 111

THE CHARACTERISTIC CAVITY SIZE IN BASIC OXYGEN STEELMAKING CONVERTER

Received – Primljeno: 2019-12-11
Accepted – Prihvaćeno: 2020-03-15
Original Scientific Paper – Izvorni znanstveni rad

It is important to understand the physical interaction between top-blown oxygen jet and liquid bath in basic oxygen furnaces (BOF). In the present study, cold model experiments were carried out to investigate the cavity depth and diameter. Images of the cavities were captured by high speed video camera to study cavity performances. The experimental results show that the depth of bath has little influence on the shape of the cavity and the critical jet flow. The cavity depth and diameter exhibit linear growth by raising the jet flow rate with a fixed jet height. At the same gas flow rate, the cavity diameter has little relation with the nozzle diameter, but the cavity depth becomes deeper with the decrease of the nozzle diameter.

Key words: steel, convertor, nozzle diameter, cavity size, critical jet flow

INTRODUCTION

In steelmaking converter, the top blowing oxygen jet of porous oxygen lance forms a cavity on the surface of liquid bath [1]. The cavity is composed of immiscible metal (heavier) and slag (lighter with much smaller volume), which causes splashing of different size droplets. The cavity is one of the main parts of the key refining reactions such as decarbonization [2-3]. The cavity size is mainly affected by the variables related to the gas flow rate and lance height, which determines the mixing of the molten pool and controls most of the chemical reactions and slagging [4]. For example, the larger the cavity surface, the higher the oxidation rate of decarburization. Therefore, to study the cavity in the gas-liquid two-phase flow system suitable for converter steelmaking is conducive to improving the performance of converter and has greater economic benefits in actual production.

Banks and Chandrasekhara served as the pioneers have launched comprehensive researches on the cavity size (depth, width and peripheral lip height) by stagnation-pressure and weight displaced analyses and then proposed the dimensionless results with experimental verification [5]. After the work of Banks and Chandrasekhara, extensive experimental studies have been carried out to study the cavity size caused by jet impinging on the liquid surface [6-8].

In liquid surface impinged behaviors, droplet splashing is also a fascinating phenomenon attracting wide studies. The ejection of the liquid phase by splashing is an important issue in the oxygen steel making process. The droplets splatter accompanying the unstable penetrating cavity generates the metal/slag/gas emulsion but also causes spitting of metal and slag from the vessel in the BOF. Therefore, the determination of the critical penetration parameters is of great significance for improving the BOF performance.

In this paper, the cavity size of gas jet impinging on a single-layer liquid bath was studied experimentally. In order to achieve this goal, the cavity image was recorded with high-speed camera under different conditions. The effects of the height of the lance, gas flow rate and other factors on the performance of the cavity size were studied.

MATERIALS AND METHODS

Water model experiment was carried out with the experimental apparatus shown in Figure 1. In order to eliminate the refraction effect and to observe the cavity shape accurately, the cylindrical vessel with an inner diameter (D) of 400 mm and a height of 500 mm was set inside the square vessel which has a side length of 500 mm. The depth of the water bath (h) was maintained at 500 mm, 700 mm and 1,000 mm respectively. Five different single-hole nozzles were employed. The inner diameter and the corresponding number were listed in Figure 2.

Experiments were carried out at the temperature of 20 °C and the environment pressure of 101,3 kPa. A rotameter with a range of 0 - 5 m^3/h for air was used to regulate the flow. To record the pressure of the gas, a pressure gauge was connected just before the jet. Compressed air was used for water model experiments and a surge tank with an effective volume of 0,3 m^3 was used to establish a stable pressure of the system.

The jet was positioned at different heights above the surface of liquid metal ranging between 30 mm and 130 mm. The lance height H vertically from the nozzle to the liquid level of the container was adjusted by a lifting plat-

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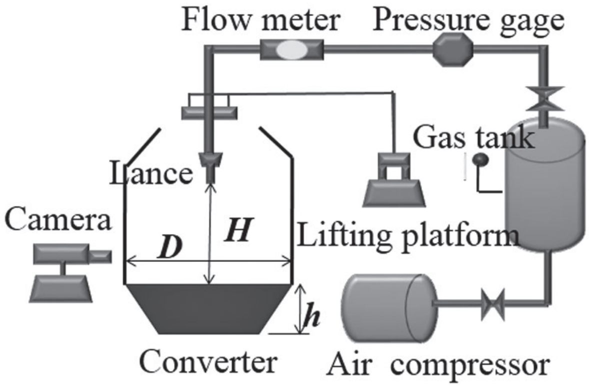

Figure 1 Schematic of experimental setup

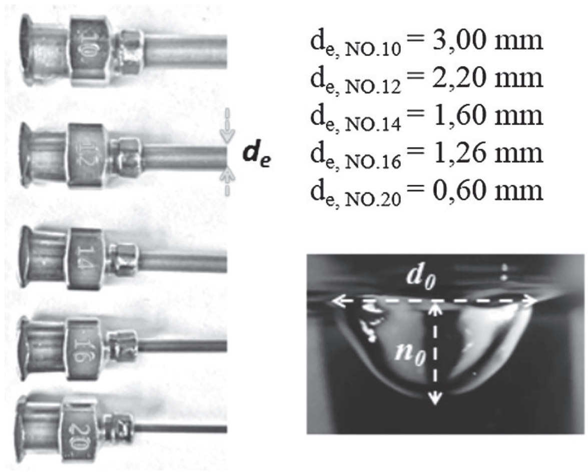

Figure 2 Nozzles and cavity shape

form with an accuracy of 1 mm. The momentum of the gas jet would create droplets and the violent swing of the cavity at higher gas flow rates. Thus, the characteristic behaviors were observed in the stable and unstable states of gas-liquid interface by a video camera and still images were captured from the movie to measure the depth and diameter of the cavity. The cavity size obtained by reproducing six times the same experiment. An example of the observed cavity shape was illustrated in Figure 2.

RESULTS AND DISCUSSION

The effect of the bath depth

Plenty of penetrating experiments were carried out to find out how the cavity size was determined by the various penetrating parameters and then to scientifically summarize the correlation between them. Therefore, an initial set of experiments was conducted with a nozzle of NO.10 using three different bath depths at a variety of jet flow rates. The effects of the bath depth on the depth (n_0) and the diameter (d_0) of the cavity were investigated for a jet height of 70 mm. The results are shown in Figure 3 and Figure 4 respectively. It was obvious that the depth of bath has little influence on the penetration depth and the diameter of the cavity. For example, as the bath depth increases from 50 mm to 100 mm, the cavity depth only changes from 25,5 mm to 27 mm and the cavity diameter only changes from 37,5 mm to 35 mm when the gas flow rate is fixed at 2,0 m^3/h. The results are in agreement with previous findings of Banks [5] for a single liquid bath system. They found that the depth of jet penetration is solely governed by the mechanical forces of the oxygen jet.

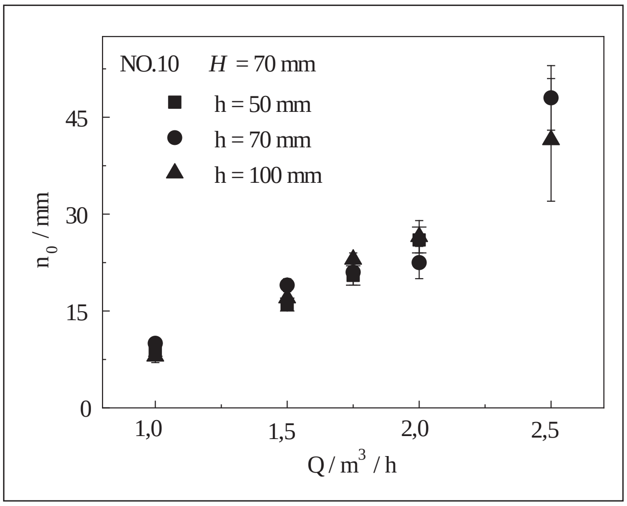

Figure 3 The effect of the bath depth on the penetration depth

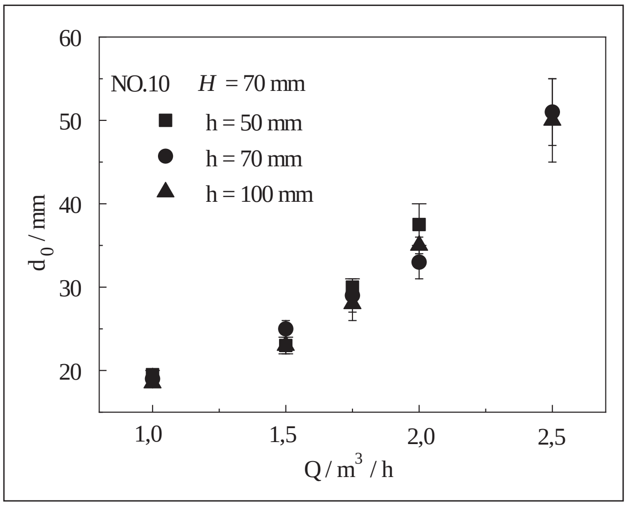

Figure 4 The effect of the bath depth on the cavity diameter

The critical jet flow was obtained by the characteristic phenomenon of droplets splatter as the instability criterion. The experimental results of the critical jet flow under different bath depths were shown in Figure 5. The bath depth has made little difference on the critical jet flow. For example, as the bath depth increases from 50 mm to 100 mm, the critical jet flow only changes from 1,63 m^3/h to 1,82 m^3/h when the lance height is fixed at 100 mm.

Cavity size affected by penetrating parameters

Obviously, the cavity size was determined by the penetrating parameters. Various sets of penetrating parameters can be found to generate in equable cavity size. Thus, giving a correlation between the cavity size and all penetrating parameters is significant to guide jet controls in industrial applications.

Figure 6 presents the penetration depth versus the jet height at different gas flow rates with different nozzles. It

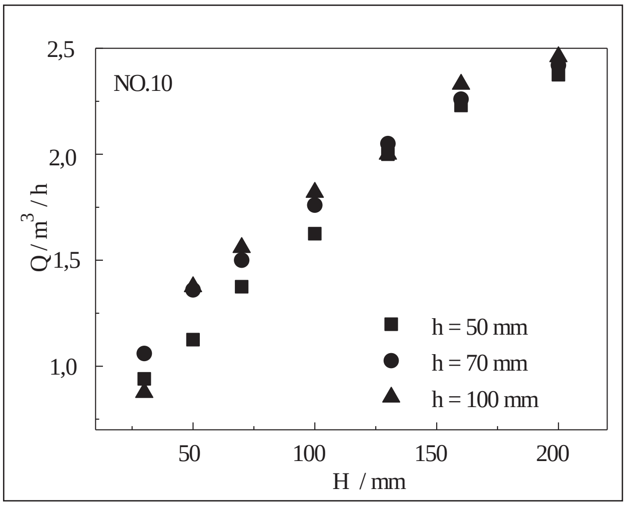

Figure 5 The effect of the bath depth on the critical jet flow

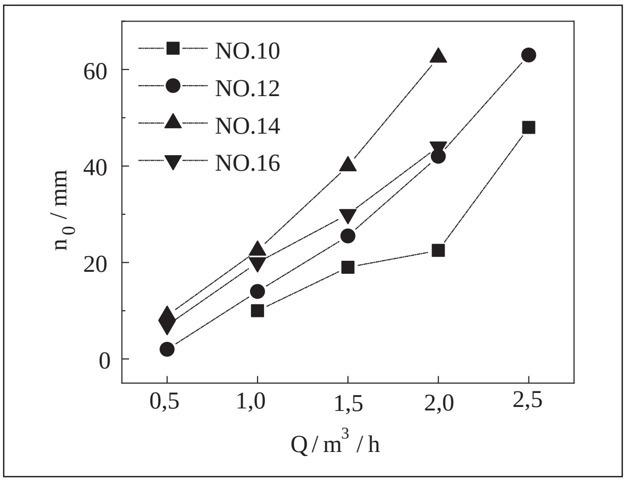

Figure 6 Cavity depth as a function of the flow rate

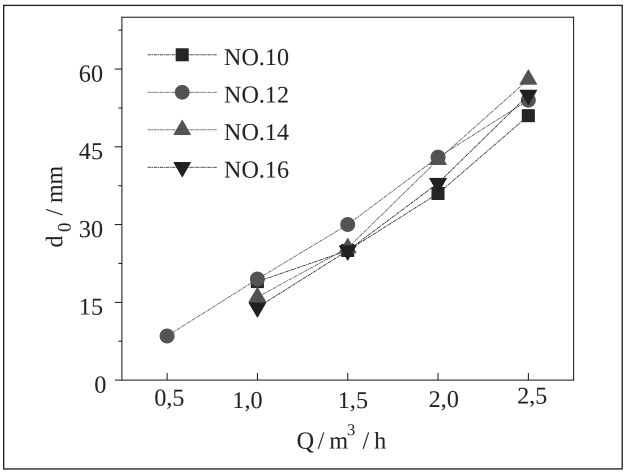

Figure 7 Cavity diameter as a function of the flow rate

was found that the depth of cavity nearly linearly increases by raising the jet flow rate with a fixed jet height. The reason is that the greater gas flow rate provides more impact energy to push away more liquid and therefore, generates a deeper cavity. Comparisons of Figure 6 seem to suggest that smaller nozzle diameter creates deeper cavity under the same operating parameters.

Besides, we plotted the cavity diameter versus the jet height at different gas flow rates with different nozzle in Figure 7. Similar as the cavity depth, the diameter of cavity also exhibits linear growth by raising the jet flow rate with a same jet height,

However, it is impossible to increase the cavity diameter by increase the nozzle diameter. From Figure 7, as the nozzle diameter increases from NO.16 to NO.10 at a fixed jet height, the cavity diameter is found changes little.

CONCLUSIONS

The interface profile formed by an impinging jet under different penetration conditions is described, including different nozzle diameters, bath depths, gas flow rates and jet heights. The results are summarized as follows:

The depth of bath has little influence on the shape of the cavity and the critical jet flow.

The cavity depth and diameter exhibit linear growth by raising the jet flow rate with a same jet height.

Under the same flow rate, the cavity diameter has little relation with the nozzle diameter, but smaller nozzle diameter creates deeper cavity.

Acknowledgments

This research was funded by the National Key R & D Program of China, grant number 2017YFC0805100, and The Science and Technology Projects of Liaoning province, grant number 2018307003.

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Note: Kun Liu is the responsible translator and the corresponding author, Anshan, LiaoNing, China.