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Simulation study on distribution of void fraction in copper converter bath①

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[Abstract] A water model was constructed with an inner diameter and depth 1/6.5 of those of the copper converter bath in Guixi Smelter. The length of the model was cut shorter containing 5 tuyeres. Modified Froud numbers for model and prototype were equal to fulfill the dynamic similarity. The void fraction in the bath was measured using the electroresistivity probe method in cases of using a single tuyere as four tuyeres. In the lower region near tuyeres, the void fraction showed a distribution similar with Gaussian function in horizontal direction, above this region, it became uniform. Near the two ends, the void fraction decreased linearly with decreasing distance to two vertical walls.

[Key words] void fraction; distribution; copper converter
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1 INTRODUCTION

The distribution characteristics of void fraction, bubble size, bubble velocity in the molten bath of a metallurgical reactor play an important role in the process kinetics. A great number of experimental studies have been carried out to study the physical characteristics of gas-injection into liquids. These studies have primarily dealt with bottom-centered upward injection[1~7]. Studies on the physical behavior of a gas jet injected horizontally into liquid mercury through a single tuyere have been carried out by Oryall and Brimacombe[8]. The remarkable differences between their model and industrial converter may make it difficult to apply their results to describe the two phase region in an industrial copper converter.

The present authors attempted to experimentally study the major characteristics of the two-phase zone in a copper converter. The molten converter bath can be regarded as a dispersed bubble-liquid system. Such a two-phase system can be characterized using parameters, such as void fraction, mean bubble velocity and mean bubble diameters[9]. The process kinetics in the system would be affected by these parameters. Void fraction in a two-phase zone is defined as the ratio of gas volume to the total volume of gas and liquid, which is a measure of the intensity of a bath agitation and to characterize the gas-liquid interaction. Since measurements of void fraction is relatively easier among others, as a start of a series experimental study regarding copper converter, the spatial distribution of void fraction was measured in a sectional converter model. In order to examine the effects of the interaction between the adjacent gas-liquid streams(plumes) through adjacent tuyeres in a copper converter bath, two series of experiments, air-blowing through a single tuyere as well as through multi-tuyeres, were carried out. The void fraction measurements were performed at room temperature using an electro-resistivity probe and a computer data acquisition system.

2 EXPERIMENTAL

2.1 Apparatus

The experimental assembly of the measurements is shown in Fig. 1. It consists of a converter model, an electroresistivity probe as well as an attached device for the computer data acquisition. Fig. 2 is the schematic diagram of the sectional model of copper converter. Fig. 3 is the coordinate system set up in the model.

The model is a horizontally placed cylinder with an inner diameter of 0.476 m. The model body is geometrically similar with copper converters in Guixi Smelter. The depth of water in model was kept at a height level of 238 mm. The ratio of these dimensions between the model and the prototype was 1∶6.5. However, as a sectional model the length of the cylinder was much shorter of only 0.192 m containing just 5 tuyeres. The tuyere inner diameter was 3 mm.

2.2 Experimental procedure

The air flow rate through each of the tuyere was 1.74 m^3/h (S.T.P.), so that the equality of the

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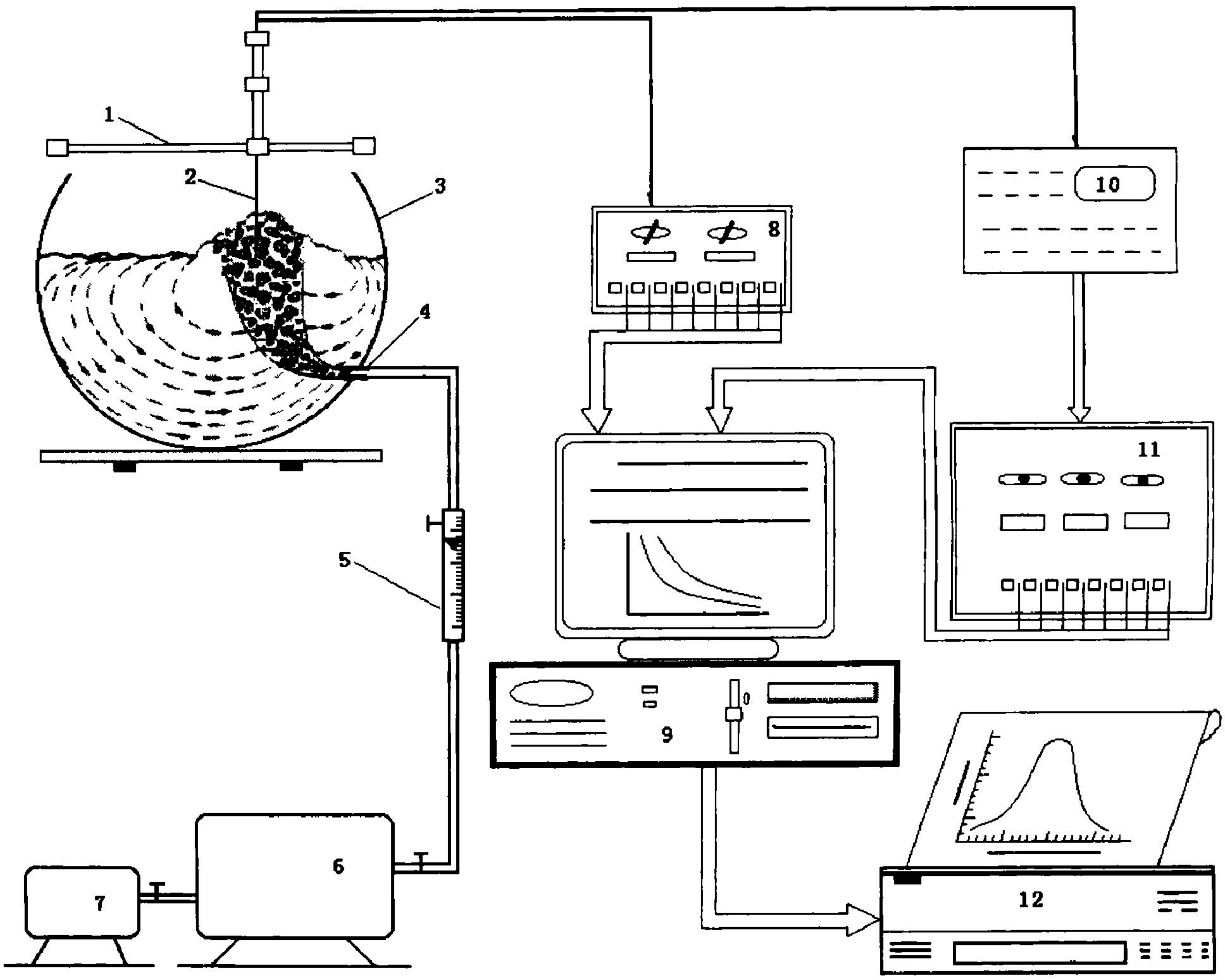

Fig. 1 Schematic diagram of experimental assembly
1 —Traversing mechanism; 2 —Sensor; 3 —Vessel; 4 —Nozzel; 5 —Flow meter; 6 —Gas container; 7 —Compressor; 8 —Sensor driver; 9 —Computer; 10 —Differential amplifier; 11 —KDAC 500/ I data acquisition system; 12 —Printer

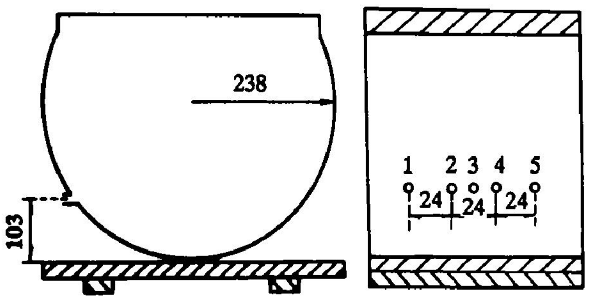

Fig. 2 Schematic diagram of converter model (1~ 5: Tuyeres No. 1-5)

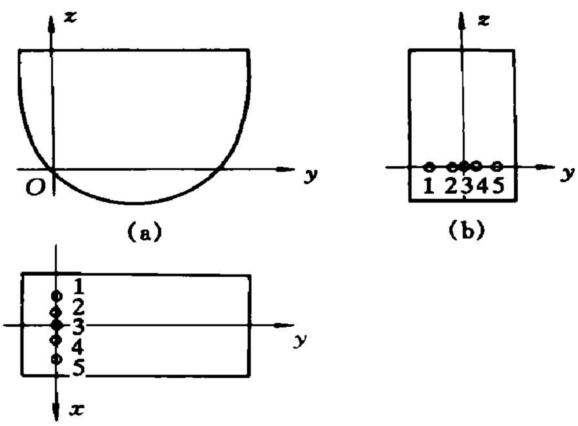

Fig. 3 Coordinate system set up in model (1~ 5: Tuyeres No 1~ 5)

modified Froude number Fr' between the model and prototype shown in Eqn. (1) could be fulfilled.

$$Fr'_m = Fr'_p \quad (1)$$

Modified Froud number is defined as the ratio of inertial force to gravitation force[10]. In the present study,

$$Fr' = \frac{\rho_g u^2}{(\rho_l - \rho_g) g D} \quad (2)$$

where ρ_l and ρ_g are the density for gas and liquid respectively; u denotes the linear velocity of gas flow passing through the tuyere orifice; D is the diameter of the bath, and g is the gravitation.

As illustrated in Fig. 2, tuyeres 1, 2, 4, 5 were used for gas blowing through multi-tuyeres. Tuyere 3 in the middle way between 2 and 4 was used for the single-tuyere gas blowing. This figure also gives the coordinate set-up for the measurements, the center of the orifice of tuyere 3 is set as the origin for the coordinate system.

It is known from its definition that the void fraction at a defined location in a two-phase zone can be determined by the ratio of the passing through probability of gas to the total probability of gas and liquid. Here a commonly used electro-resistivity probe has been adopted to measure the void fraction at every ascertained location in the model. The details of the method can be found in Refs. [1, 11]. In order to ensure reasonable accuracy and precision, data acquisition was lasted at least 2 min with sampling frequency $10^4\ s^{-1}$ at each pre-determined location. The arithmetic mean of the acquired data was taken for converting to the void fraction at the point being measured.

3 RESULTS

3.1 Gas-blowing through single tuyere

Fig. 4 illustrates the distribution of void fraction measured at vertical section XOZ. It is seen that the distributions at different height levels are similar in this plane.

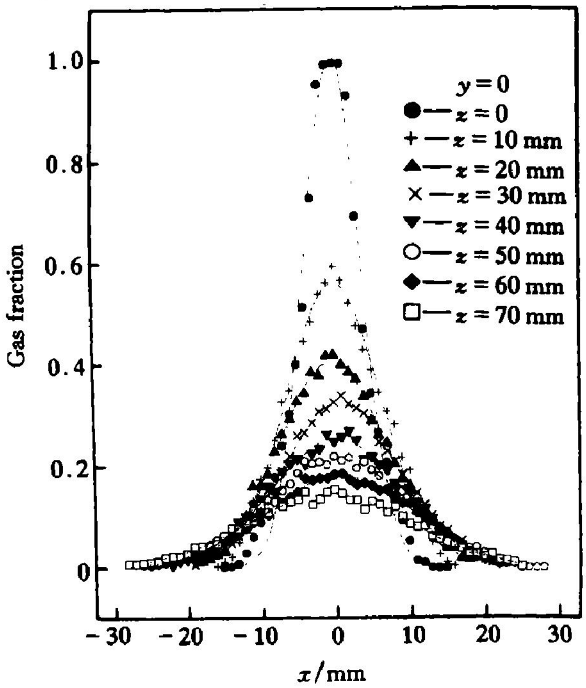

Fig. 4 Void fraction distribution at section XOZ using single tuyere

The rregression of experimental data gives:

$$\varepsilon = \varepsilon_{max} \exp\left[-0.7\left(\left|\frac{|x|}{|x_{\varepsilon_{max/2}}|}\right|\right)^{1.7}\right] \qquad (3)$$

where ε and ε_{max} denote the void fraction at x and the maximum void fraction which occurs at the central line ($x = 0$) respectively. $x_{\varepsilon_{max/2}}$ is the X coordinate where the ε equals half of ε_{max}. It is noted that Eqn. (3) is similar with the Gaussian function. In Fig. 5 the XZ sections are parallel and with a small distance to section XOZ. It can be seen that in low part of the XZ sections, the void faction data fit well with Eqn. (3).

The measured void fraction data were plotted as contour maps. A typical contour plot of void fraction is shown in Fig. 6 for a horizontal XY section at $z = 30$ mm. Clearly, the highest void fraction in this plane is about 30% at the location where x, y are about 0 and 20 mm respectively. The contour plot also shows that the center of the gas-liquid plume penetrates only 20 mm in the bath at this level. From the location where void fraction is close to zero, the width of the two phase region can be defined about 40 mm in a XY section at $z = 30$. Above this section, the two-phase areas slightly become wider. In general, at the middle and upper vertical level the shape of the

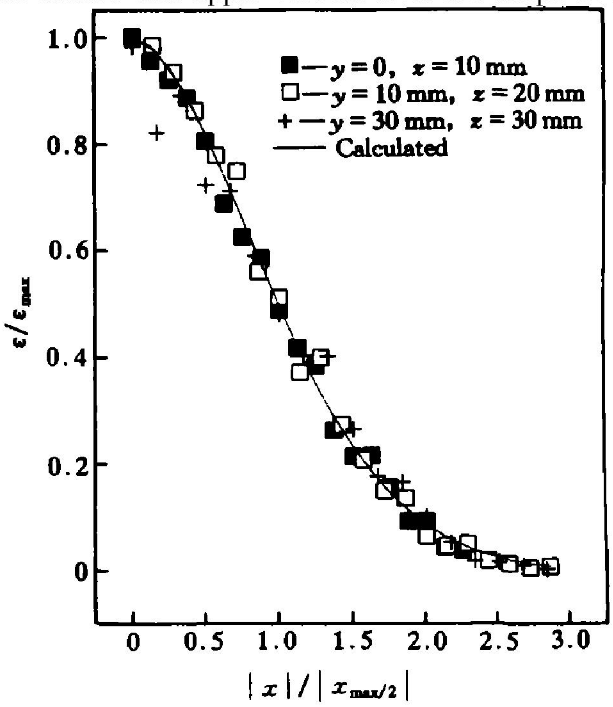

Fig. 5 Normalized void fraction distribution in lower region of XZ sections using single tuyere

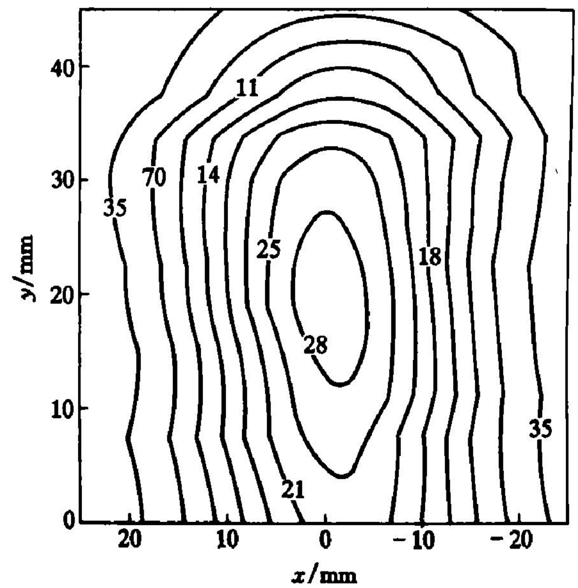

Fig. 6 Contour map of void fraction (%) for XY section at $z = 30$ mm using single tuyere

two-phase zone is somewhat similar with that caused by a vertical injection.

Section YOZ passing through Y and Z axes and containing origin O is defined as the main plane. It is one of the most important planes in characterizing the distribution of void fraction. As $x = 0$ in this section, all the maximum void fraction values present in XZ section family are contained in section YOZ. The distribution of the void fraction in this plane is shown in Fig. 7, while its contour map is shown in Fig. 8. As shown in Fig. 7, close to the surface of the bath, the void fraction of each curve almost remains unchanged. It is seen that the 'jet' trajectory could be defined by line a in Fig. 8. The void fraction decreases from about 90% near the tuyere to 10% at 40 mm to the tuyere in Y direction. In other words, the gas-liquid stream only penetrates 40 mm into the bath before rising vertically under the effect of the buoyancy force. In an industrial converter, the short-distance penetration and rapid upward rising gas-liquid stream can cause the impingement to the back-wall and result in the refractory lining erosion observed there.

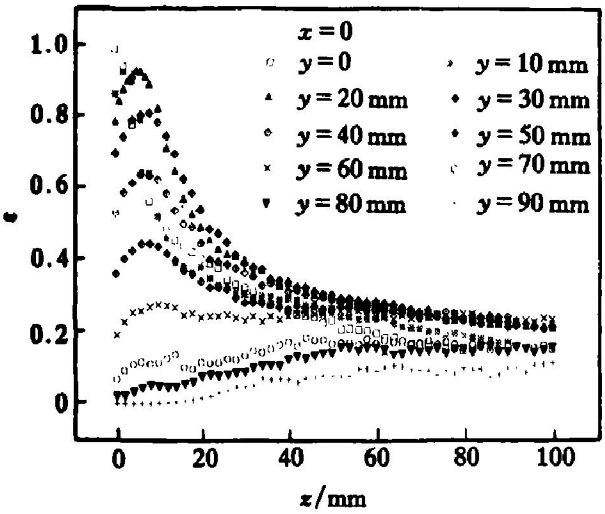

Fig. 7 Distribution of void fraction in section YOZ using single tuyere

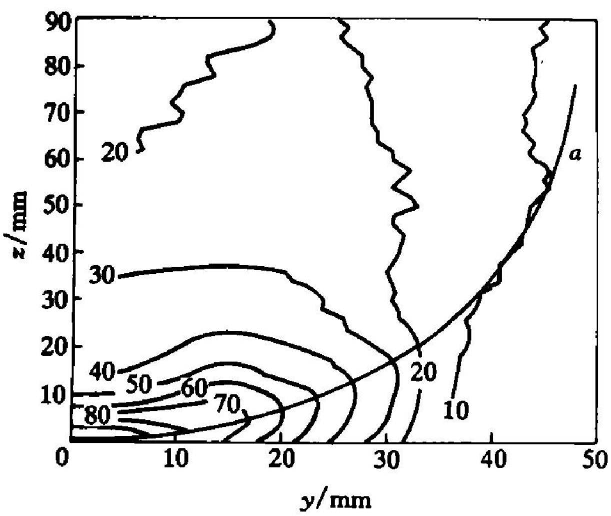

Fig. 8 Contour map of void fraction (%) in section YOZ using single tuyere

3.2 Gas flow through four tuyeres

In the copper converter operation, air is blown through closely and horizontally fixed 40~60 tuyeres into the bath. In order to clarify the effects of the interaction between the gas-liquid plumes, the void fraction was also measured in the case when four tuyeres were simultaneously used for air blowing. Fig. 9 shows the distribution of void fraction in the lower region of section XOZ near the tuyeres. The distribution of void fraction in Fig. 9 is similar to that in the case of gas blowing through a single tuyere. At a slightly higher level, the variation of the void fraction in X direction becomes smooth and its peaks and valleys between the adjacent tuyeres quickly disappear. At the level where $z = 20$ mm, the void fraction between the tuyeres nearly remains unchanged. This faster changing rate with z is probably resulted from the interactions between the adjacent gas-liquid streams. Fig. 10 shows that more close to surface, the void fraction where right x varies between those of tuyeres 2 and 4 remains constant, while beyond this range the void fraction decreased with $|x|$ value almost linearly. 'a' and 'b' in Fig. 10 respectively stand for these two distinct regions. By regressing the experimental data, Eqns. (4) and (5) were obtained for describing these characteristics in 'a' and 'b' regions respectively.

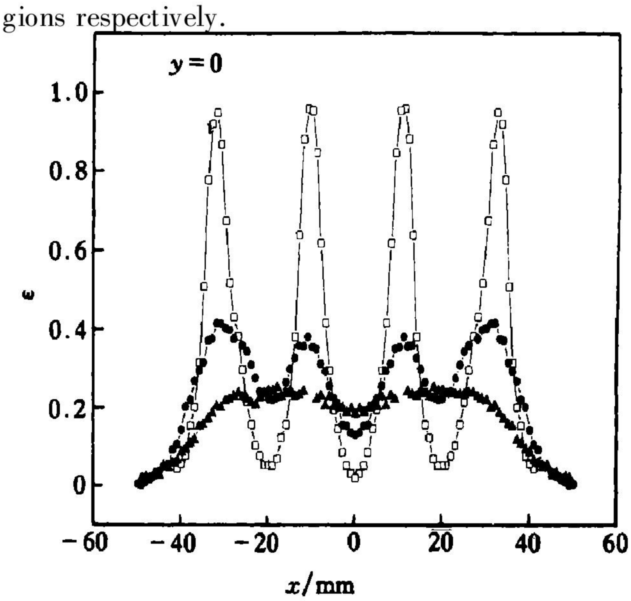

Fig. 9 Distribution of void fraction at section XOZ using four tuyeres
□ —Z= 0; ● —Z= 10 mm; ▲ —Z= 20 mm;

$$\varepsilon = 24.00 \cdot \left[\frac{z}{h_0}\right]^{-0.35} \quad (4)$$

$$\varepsilon = 27.10 \cdot \left[\frac{z}{h_0}\right]^{-0.51} - 0.51 \cdot \left[\frac{z}{h_0}\right]^{-0.58} \cdot |x| \quad (5)$$

where h_0 is the distance of the tuyere orifice center to the bottom of the converter. It is evident in Figs. 11 and 12 that the experimental data at the XZ sections where y varies up to 25 mm can fit Eqns. (4) and (5) well.

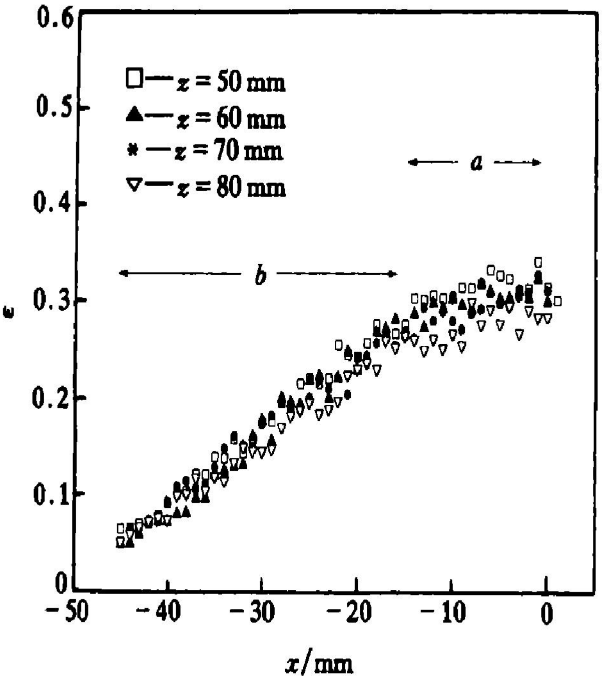

Fig. 10 Distribution of void fraction at XZ section at y= 20 mm using four tuyeres

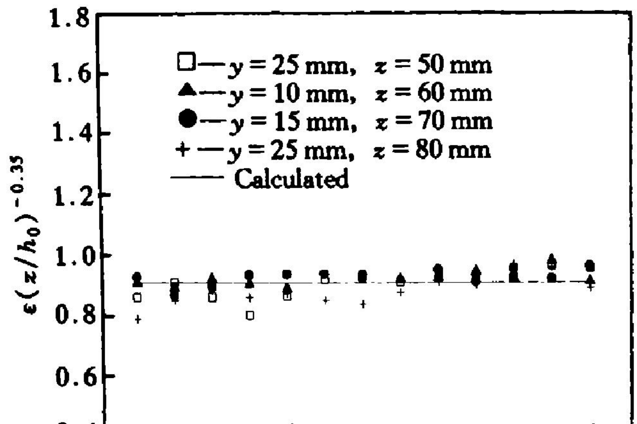

Fig. 11 Comparison of experimental data with those in Eqn. (4) using four tuyeres

There are nearly 50 tuyeres in an industrial copper converter. The distribution characteristics of the void fraction in region ' a' in Fig. 10 may stand for that in the region right above the tuyeres in copper converter. While close to the two ends, the void traction may decrease linearly with the decreasing distance from the first or last tuyere to the vertical wall as shown in region ' b'.

4 DISCUSSION

In the present study, only Fr' has been used for determining the experimental parameters. This may

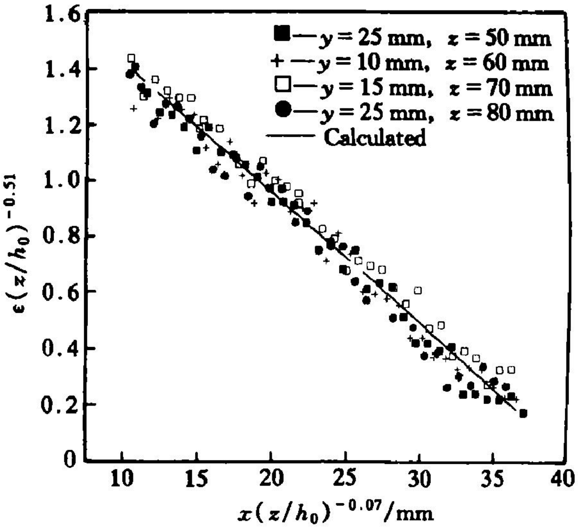

Fig. 12 Comparison of experimental data with those in Eqn. (5) using four tuyeres

imply that interaction between gas and liquid phase, as an key factor, has been the emphasis in this work. A completely physical modeling of bubbles behavior of two-phase zone in a copper converter, more similarity numbers, such as Weber number or Archimedes number needs to be taken. While the considerable differences of physical properties, such as density, viscosity and surface tension between water and copper matte exist, an ideal physical modeling is difficult to be reached. More sophisticated work has to be carried out using a melt with more close physical properties to copper matte. As the initial effort, the present work provides the information regarding major features in the copper converter caused by the interaction between the horizontal gas injection and the molten bath.

The chemical reactions, the un-uniform distribution in temperature and pressure in a copper converter may affect the void faction values in different locations in the molten bath, however the above mentioned main characteristics obtained from the water model would valid for describing the two phase zone in copper converter. This information together with the bubble size and velocity distributions being investigated in the present group would be helpful for a better understanding of the kinetic aspect of the operation process in copper converter.

5 SUMMARY AND CONCLUSIONS

The spatial distribution of void fraction in a sectional water model of copper converter has been measured in the cases of gas injection through a single as well as four tuyeres. The modified froud number for the model experiments is equal to that in the converter operation of Guixi Smelter.

The result observed shows a short distance penetrated by the gas injection compared with the converter radius. The gas-liquid plumes in the bath from the forward direction tern to the upward direction rapidly.

In the case of using a single tuyere, the results indicate that void fraction along horizontal direction are similar and exhibits a quasi-Gaussian distribution where the height level is less than 1/3 of the total depth of the bath. While in the case of using four tuyeres, the region with a void fraction distribution similar to Gaussion function is much smaller and limited within a very short distance to the tuyeres in vertical level. Above this small region, the distribution is likely uniform. However close to the two ends, the void fraction may decrease in the horizontal direction from the first and last tuyeres to their adjacent vertical walls of the converter respectively.

The measured results also show that the penetrated distance by the gas 'jet' is short, only 1/5 of the radius of the bath, indicating the gas streams in the bath would turn their flow direction upwards rapidly.

In the case of using 4 tuyeres, the measured results indicates that in the upper region above the tuyeres, the distribution of the void fraction are likely uniform. While the void fraction gradually decreases from the two ending tuyeres to the adjacent two vertical walls.

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