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MEASUREMENT OF PHYSICAL CHARACTERISTICS OF A SUBMERGED GAS INJECTION SYSTEM

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ABSTRACT

A cold model study was carried out where the gas was injected into a liquid bath through an annulus of a vertically positioned lance in the centre of the bath. This was designed to simulate the top submerged gas injection system of ladle metallurgy operation. Swirl and non-swirl gas injections were investigated. The swirl motion was generated with the aid of a helical spiral centred in the annular region of the lance. Instantaneous three dimensional liquid phase flow fields were measured using the Laser Doppler Anemometry (LDA) technique for different gas flow rates, levels of lance submergence and depths of liquid. These measurements were carried out for both axial and swirl gas injections for two gas flow Reynolds numbers, namely, 4000 and 8000.

The experimental results showed that high magnitudes of velocity and turbulent kinetic energy are achieved with gas injection at an initial swirl angle of 57.5°. Furthermore, the turbulent kinetic energy in the plume region was found to be always higher than the rest of the bath and high levels of lance submergence were found to promote mixing. The rate of gas injection had little effect on the flow patterns.

INTRODUCTION

Top submerged injection, which is the subject of the present work, is used in many industrial applications. Other modes of gas injection include bottom injection and horizontal injection. Submerged gas injection was first utilised in the production of steel in the last century. Since then gas injection into liquid metal is commonplace in the metallurgical industry for the purpose of metal extraction or refining. In such a process, jets are turbulent and provide efficient mixing of both gas and liquid phases resulting in an efficient reacting system. The effectiveness of the process mainly depends on the interaction between the gas and liquid metal. This in turn depends on the motion of the material in the reaction vessel and the distribution of the gas in the melt. The fluid flow phenomena of such a system is quite complex and as a result actual measurements are rare in the literature. Obtaining measurements for this type of system is difficult due to the opaqueness of the melt and high temperatures encountered. Furthermore, mathematical modelling of gas injection is still in the developing stage. A detailed description of the phase interaction is necessary to understand the exchange of momentum, heat and mass transfer in such a system. Recently, however cold model studies have been used to shed some light on bath hydrodynamics.

Mazumdar and Guthrie (1985) used a water model of a steel making ladle to investigate the flow patterns generated by fully submerged and partially submerged gas injection lances. The experimental data on the velocity fields were obtained on the basis of a video recording of a specially constructed grid network and tufts. A comparison was made of the flows generated in the 0.3 scale model for 1/2 lance submergence and those generated by gas entering at the base of the model. Izmesteva et al. (1993), with the aid of pH measurement and visualisation/photography techniques, studied the interaction between a top submerged swirled gas jet and a liquid in a cold model. The effect of swirl intensity on the height of the splashes and the mixing was investigated. They found that swirling gas was more effective in mixing and the optimum swirl angle for their model was 38°.

Grevet et al., (1982) and Mazumdar and Guthrie, (1985) used multi sensor hot films and LDA to determine instantaneous velocity components. However, as being pointed out by Sheng and Irons (1992) and Atapattu et al. (1992), these techniques can only give reliable data in the regions of low void fraction (< 0.1). To the authors' knowledge there are no reliable techniques to distinguish between the liquid and gas velocities in the plume.

In one of our previous papers (Morsi et al 1995 a) tangential and axial velocity results were discussed. In this paper some results on the distribution of the radial velocity component will be discussed while the aim is to investigate the interaction between liquid in a cylindrical tank and the injected gas (swirl and non-swirl).

EXPERIMENTAL APPARATUS AND CONDITIONS

Experimental Apparatus

A 1/16 scale cold model of a steel making ladle was constructed to allow the measurement of the flow fields and the turbulent characteristics. A schematic of the model is shown in Figure 1. The cylindrical tank was made of transparent PVC and had a diameter of 230 mm and a height of 560 mm, which was filled with water to a level of 150 mm. In order to minimise the parallel axis effects the tank was enclosed in a glass square tank filled with water. The lance was supported vertically and connected to an air supply. A helical insert fixed in the annular region of the lance was used to give air an initial swirl angle (ψ) of 57.5°. The flow rate of air was controlled and monitored with the aid of a mass flow meter. A baffle was used 25 mm above the water level to minimise wave motion and sloshing. The model was placed on a 2-D traversing mechanism. The Co-ordinate system as well as the measurement planes are also given in Figure 1.

The measuring system was based on the LDA technique. The system consists of a 4W Argon-Ion laser combined with Dantec LDA/PDA fibre optic module. The system is capable of measuring either two velocity components or one velocity component and the size of bubbles or particles simultaneously. In this study only the LDA mode was utilised to determine the axial, radial and tangential velocity vectors and turbulence parameters. The fibre optic module was fitted with a lens of 250 mm focal length. The measuring volume obtained under these conditions had the dimensions 0.1153 mm × 0.1150 mm × 1.5183 mm. The refractive indices of the wall and water were used to accurately determine the measurement point. A frequency shift of 40 MHz was introduced in one crossing beam from each colour to overcome the sign ambiguity of the velocity measurements. After a number of experiments with different types of seeding particles, 9 μm metallic coated powders which have small terminal velocities in water, were found to give satisfactory signals. The signal processor used was the burst spectrum analyser (BSA) which can be used at very low values of signal to noise ratio.

EXPERIMENTAL CONDITIONS

Results discussed here are for the following experimental conditions:

Injection mode:	swirl,	non-swirl
Gas flow rate:	$1.5x10^{-3}$,	$2.67x10^{-3}$ m^3/s
Lance submergence (H/L):	1/3,	2/3
Initial swirl angle (Ψ):	0°,	57.5°.

A more complete description of the study is given by Morsi et al (1995 b).

DATA ANALYSIS

The residence time weighting technique (Buchhave et al. 1979) was used to process data. This method avoids most of the sources of bias associated with other processing techniques. All the velocities were weighted by the residence times of the individual scattering particles.

RESULTS AND DISCUSSION

The results presented here are for a plain lance (axial gas injection) and a lance with a helical insert in the annular region, which introduced an initial swirl angle of 57.5° to the incoming air.

The velocity vectors and stream functions of the flow within the tank on a vertical plane going through the centre of the tank are shown in Figures 2(a)-2(f). They show a formation of a recirculating vortex near the tank top and displaced toward the wall of the tank. In all the cases it can be seen that high velocity liquid is moving down the wall of the tank and then turns back toward the rising plume at the centre. What is necessary in a smelting bath is good mixing not only in the vicinity of the lance exit but also in the regions away from the lance. The challenge is to create higher velocities in the regions away from the lance. The effect of swirl gas injection on the movement of the location of recirculation can be seen in Figures 2(c)-2(d). For the two flow rates studied ($1.5x10^{-3}$ and $2.67x10^{-3}$ m^3/s) there is a significant movement of recirculating region toward the wall creating high velocity gradients away from the lance particularly in the case of swirl injection.

Results for the tangential (swirl) component of liquid velocity show similar increases in velocity for swirl gas injection particularly near the lance exit, within a radius of about 40 mm as shown in Figure 3. This Figure compares the tangential velocity distributions, measured at different levels, for swirled and plain gas jets of the same injection rate. Outside of this 40 mm radius a similar trend can be observed although the effect is less pronounced. As shown, the maximum value of the tangential velocity occurs at a level of $Y \approx 90$ mm which is just below the lance exit for 1/3 lance submergence.

The turbulent kinetic energy distributions for swirl and non-swirl gas injection for a 2/3 lance submergence show a significant increase in turbulent kinetic energy within the bath for swirl gas injection (see Figure 4).

The maximum value of the turbulent kinetic energy is in the region adjacent to the plume. Mixing is most intense in this region which expands radially outward for the swirled flow. The maximum turbulence kinetic energy is between 0.50 and 0.03 m^2/s^2 for the swirled flow and between 0.13 and 0.01 m^2/s^2 for the non swirled case. However near the free surface the difference between the two cases appears to be small.

It was also observed that bubbles generated by swirl gas injection were much smaller than those by non-swirl injection.

For the swirled jet submerged at a level H/L = 2/3 the injection rate on the velocity vectors, as shown in Figures 2(b) and 2(d), appears to influence the flow field significantly although it was found that the axial velocity is only slightly affected (Morsi et al 1995 a). This means that the radial velocity component is more sensitive to the changes in the gas flow rate.

Figures 2(c) and 2(e) show the velocity vectors on a vertical plane for a gas injection rate of 2.67×10^{-3} m^3/s for 1/3 and 2/3 lance submergence levels. For non-swirl gas injection and 2/3 submergence there is a high velocity region beneath the exit of the lance whereas for 1/3 submergence the area beneath the lance exit has very small velocity vectors. The tangential velocity components in this region also have similar magnitudes (Morsi et al, 1995 b). For swirl injection however the magnitudes of the velocity vectors below the lance exit were relatively large for both levels of submergence studied although as expected 2/3 submergence resulted in higher values of velocity.

The axial velocity distributions shown in Figure 5 for swirl gas injection show that there are two distinct high velocity regions in the bath for 2/3 lance submergence. The decrease in axial velocity between the two regions could be attributed to the break up of bubbles which will result in slower movement of the liquid. For the 1/3 submergence the high velocity region is near the top of the bath and in the region below the level of Y= 80 mm the flow was found to be quite inactive. In the vicinity of the bath wall the axial velocity is about 30% of the maximum velocity obtained near the top of the bath for 1/3 submergence and is about 38% for 2/3 submergence.

CONCLUSIONS

The interaction between the injected gas and the liquid was studied experimentally using the LDA technique. The effects of the level of lance submergence and the rate of gas injection were investigated for swirl and non-swirl gas injection.

For the range of injection rates studied, swirl gas injection promoted high liquid velocities in the bath. The turbulent kinetic energy was also high indicating better mixing for swirl gas injection. The effect of swirl angle on the turbulent kinetic energy near the free surface appears to be minimal.

The level of lance submergence had a more pronounced effect on the flowfields for non-swirl gas injection. The 2/3 submergence resulted in better mixing and higher liquid velocities for both modes of injection.

High gas injection rates are always associated with high liquid velocities throughout the bath, as one would expect.

NOMENCLATURE

H	Depth of lance submergence, mm
L	Liquid depth, mm
Q	Gas injection rate, m^3/s
U,u	Mean and fluctuating axial velocity components, m/s
V,v	Mean and fluctuating radial velocity components, m/s
W,w	Mean and fluctuating tangential velocity components, m/s
X	Distance in the radial direction, mm
Y	Distance in the axial direction, mm
Z	Distance in the tangential direction, mm
ψ	Swirl angle, degrees

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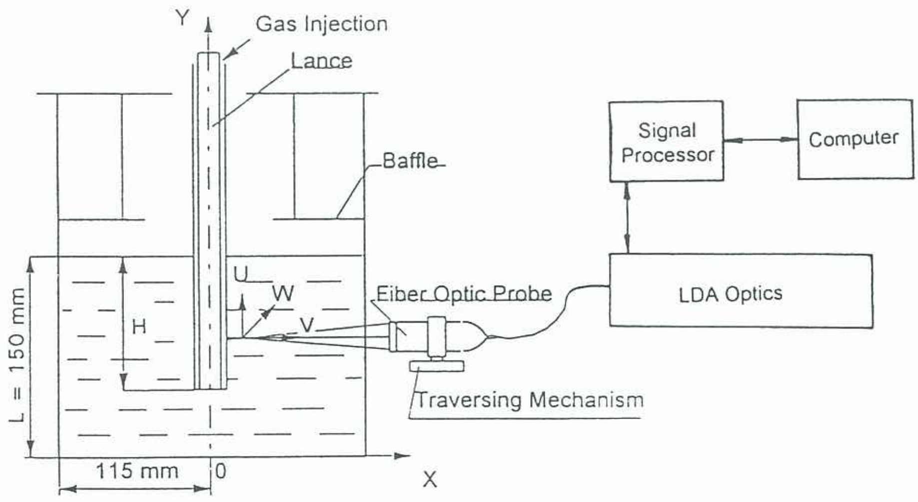

FIGURE 1 EXPERIMENTAL APPARATUS

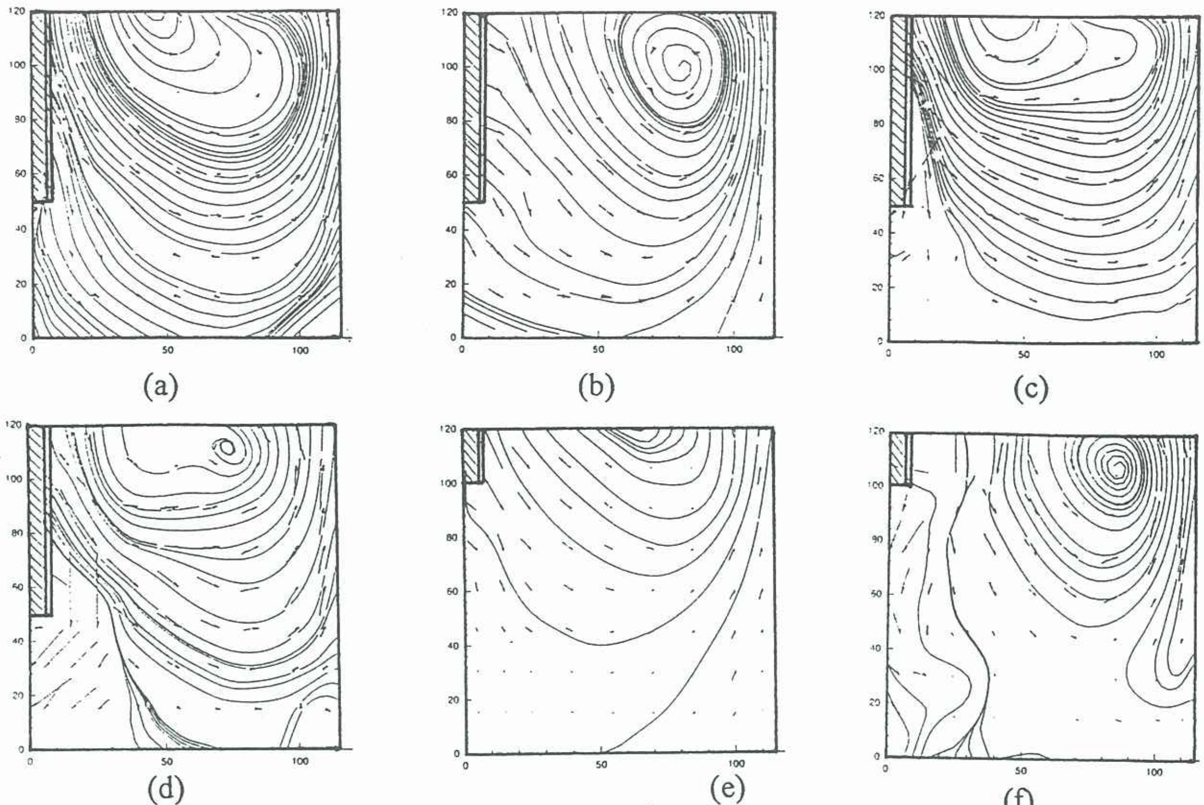

FIGURE 2 Velocity Vectors and Stream Function
(a) Q=1.50×10^{-3} m^3/s; H/L=2/3; ψ=0°, (b) Q=1.50×10^{-3} m^3/s; H/L=2/3; ψ=57.5°
(c) Q=2.67×10^{-3} m^3/s; H/L=2/3; ψ=0°, (d) Q=2.67×10^{-3} m^3/s; H/L=2/3; ψ=57.5°
(e) Q=2.67×10^{-3} m^3/s; H/L=1/3; ψ=0°, (f) Q=2.67×10^{-3} m^3/s; H/L=1/3; ψ=57.5°

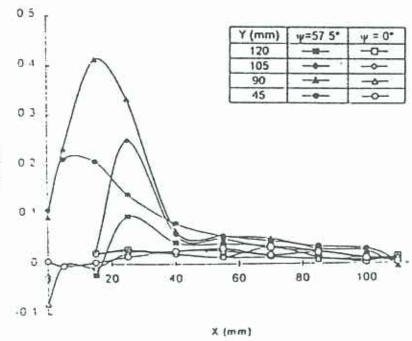

Figure 3 Mean Tangential Velocity Distributions
for 1/3 Lance Submergence
(Comparison between swirl and no-swirl injections)

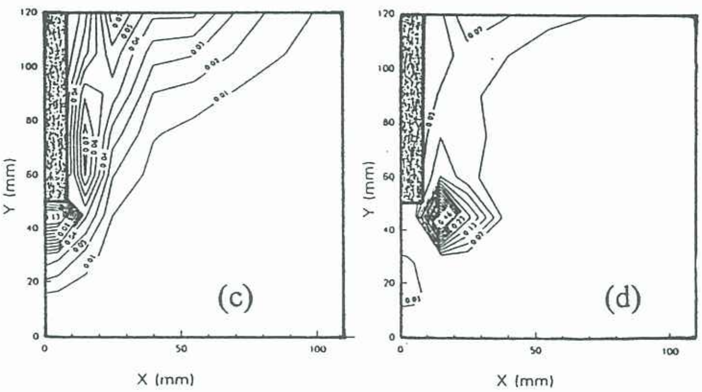

Figure 4 Turbulent Kinetic Energy Distributions

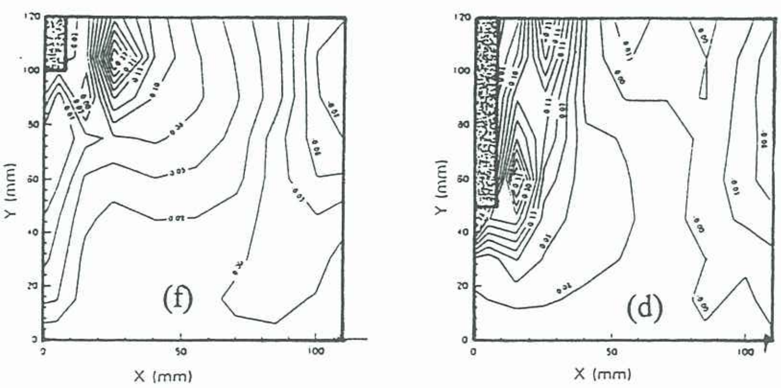

Figure 5 MEAN AXIAL VELOCITY DISTRIBUTIONS