# WATER MODEL OF SLAG-METAL DISPERSION IN HIGH-STRENGTH BOTTOM BLOWN CONVERTER

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## Abstract

A water model study has been carried out to characterize the slag-metal dispersion phenomena in CLU converter induced by a high-strength bottom gas injection. Water and kerosene were used to simulate metal and slag phases respectively. The volume of kerosene in the bath ranged from 8% to 43%. Air is purged into the bath by using three off-centered triangular nozzles each having 3mm diameter. The air flow rates varied from 279 NL/min to 650 NL/min. Dispersed phase holdup (simulated slag dispersed in simulated metal) was determined with respect to the operating conditions such as gas flow rate, height ratio of the two phases, and height of the heavy phase.

The variation of dispersed phase holdup (ratio of volume of dispersed simulated slag phase to total volume of liquid-liquid emulsion) versus normalized axial (vertical) distance from the original position of the interface along the center of the bath indicated that increase in gas injection rates increases the centerline dispersed phase holdup at any normalized axial distance. The results also revealed that the dispersed phase holdup decreased with vertical distance from the original interface. As the vertical distance from the original surface increased, the dispersed-phase holdup values in the regions where the nozzles are situated were found to be greater than those obtained on the opposite axis. In the regions nearer to the original surface, the holdup decreased with the radial distance and then increased towards the wall side of the tank. At a constant radial distance from the center the dispersed-phase holdup increased with the height ratio of the simulated slag to metal. The change in the dispersed-phase holdup with the operating conditions and sampling locations was correlated by a single equation involving a set of dimensionless numbers. The experimental holdup values were found to be in satisfactory agreement with those calculated by the correlation equation.

## Introduction

The emulsification process caused by gas bubbles rising through a slag/metal interface creates a large interfacial area between slag and molten metal resulting in rapid chemical reaction and mass transfer between the two phases encountered in metallurgical processes. Dispersion of one liquid in another immiscible liquid was studied using oil/water, oil/mercury systems by a number of researchers. Poggi et al[(1)] investigated mercury/water-glycerine system to simulate the dispersion of fine droplets of copper in slags found in Norando process. Oeters and Wei[(2)] studied emulsification of slag droplets into molten metal in bottom stirred ladles. They reported that the number of slag droplets increased with an increase in gas flow rate. Lin and Guthrie[(3)] examined the droplet generation in oil/aqueous and oil/mercury systems at gas flow rates ranging from 0.4 Nl/min to 2.5 Nl/min for a simulated slag/metal thickness ratio of 0.3 to 1.5. They observed that the dispersion of metal phase into slag phase was more significant than the inverse emulsion. Zaidi and Sohn[(4)] studied liquid-liquid emulsions formed by bottom gas injection to characterize the drop size distribution in kerosene/water system at gas flow rates from 54 Nl/min to 282 Nl/min for a slag volume of 33-75%. Lee and Sohn[(5)] carried out liquid-liquid emulsion experiments by bottom gas injection using water at gas flow rates from 60 to 300 Nl/min. The height ratio of simulated slag to metal ranged from 0.45 to around 2. They found that the dispersed phase holdup increased with gas velocity and decreased with axial and radial distances.

In the literature, the previous studies concentrated on liquid-liquid emulsions of either low gas flow rate-low slag volume or high flow rate-high slag volume. The objective of the present study was to investigate the dispersion behavior in high gas flow rate - low slag volume operations. For this purpose, a water model of CLU converter utilized in ferroalloy refining was used in order to characterize the dispersed phase holdup in high strength bottom blown reactors for various injection rates and oil-water heights.

## Experimental Technique

The experimental set-up consisted of a cylindrical clear PVC tank, which is one-seventh model of a CLU converter tapered from 0.5m in diameter at the top to 0.35m in diameter at the bottom. The experimental set-up and has been described in detail elsewhere[(6)] and only the more important aspects will be given here. For simulation purposes, water and kerosene were used as metal and slag phases respectively. Air was purged into the bath through three nozzles placed at the bottom of the tank. In this investigation, the off-center nozzle orientation was utilized. This is illustrated in Figure 1. For this orientation, three nozzles having an inner diameter of 3 mm are placed at off-center, two nozzles are placed at 22 mm from center line and 118 mm from each other. The third nozzle is placed at 53 mm from the centerline in the same semi circle as the first two.

After filling water and kerosene into the tank to the desired heights, experiments were run by injecting compressed air into the tank. About 30 minutes of air injection was sufficient for obtaining steady bath circulation. An emulsion sample of about 30 ml was collected rapidly by using a specially made syringe, so that it represented the actual emulsion at the particular location. After the phase separation, the volumes of water and kerosene were read, and the dispersed-phase holdup was determined by dividing the volume of kerosene by the volume of the emulsion. The syringe was immersed vertically into the bath and was fixed firm into position using clamps, and thereafter the sample was taken. The axial and radial position from where the samples were taken was recorded together with the gas flow rate and the heights of water and kerosene before gas injection. Samples were taken only from the Left-axis (directly above the nozzles ) of the tank and the Right-axis ( side opposite to the side of the nozzles ). Samples were taken five times for one sampling location at a time interval of less than 3 minutes, and then the mean value of the holdup was calculated. It was observed that the standard deviation varied from 0.003 to 0.02.

## Results and Discussion

The results of the experimental work done are represented according to the parameters which affect the dispersed-phase holdup such as the gas flow rate, ratio of the two phases and height of the heavy phase.

Experimental runs are coded according to the operating conditions, e.g., 1.8-23-0.00599-R. In this code, the first number is the height of the kerosene phase in cm in the tank before gas injection, The second number is the height of water in cm before gas injection, the third number is the flow rate of air in $Nm^3/s$.The letter R indicate that the samples were taken from the Right-axis of the vessel.

### Axial distribution of the dispersed-phase holdup

The variation of dispersed phase holdup (ratio of volume of dispersed light (oil) phase to total volume of emulsion) versus normalized axial (vertical) distance ( Z/Hh, where Z is axial distance and Hh is height of heavy phase (water)) from the original position (before gas purging) of the interface with respect to various bottom gas injection rates is shown in Figure 2 and 3.

As seen from Figures 2 and 3, at a fixed gas injection rate, the dispersed phase holdup at centerline ($Dph_C$) decreased with an increase in the normalized axial distance which was observed in previous studies[5,7]. This phenomenon might be explained by the decrease in kinetic energy of the dispersed phase because of collision and viscous friction as the axial distance increases.

### Radial distribution of the dispersed-phase holdup

The radial distribution of the dispersed-phase holdup in a bottom gas-injected water model of a CLU converter process is shown in Figures 4 and 5. Nearer to the nozzles the dispersed phase holdup increases with the radial distance and eventually decrease as the wall of the tank is approached. Nearer to the original interface, the holdup decrease with the radial distance and eventually increases as the wall of the tank is approached. Overall the holdup show an increasing trend with the radial distance (r).

The nozzles are situated on one side of the tank away from the centerline ( Left-axis of the tank ). Since the gas jet rises as a plume, the jet is stronger in the middle of the plume. This implies that on the Left-axis of the tank somewhere between the center and the wall of the tank, a region of maximum holdup of the dispersed phase exists. On the Right-axis, one expects that the holdup should decrease with the radial distance because the gas jet is lighter on that side. Contrary to that, the dispersed-phase holdup increased with the radial distance. It is noticed that nearer to the original interface, the values of the holdup on the Right-axis are larger than those on the Left-axis (Figure 5).

### Effect of gas flow rate on the dispersed-phase holdup

The effect of the gas flow rate on the dispersed-phase holdup was determined while keeping both the height of the kerosene and water phases constant at 1.8 cm and 23 cm respectively. The results shown in Figure 6 indicate that the holdup at the centerline of the tank increases with the gas injection rate. These results are also in line with the findings of and Lin and Guthrie(3) , Zaidi and Sohn(4) , Lee and Sohn(5) , and Akdogan and Eric(7), where the researchers found that the dispersed phase holdup and droplet nucleation rate increased with gas injection rate.

### Effect of the height ratio of the two phases on the dispersed-phase holdup

The effect of the height ratio of the two phases on the dispersed-phase holdup was determined while keeping the gas flow rate constant at 0.00599 $Nm^3/s$ and the height of water at 23 cm.

The results of the variation of the dispersed-phase holdup with the height ratio of the two phases at the centerline of the tank are shown in Figure 7. The holdup increases with an increase in the relative height of the light (oil) phase (Hl).

### Correlation of the dispersed-phase holdup with the operating conditions

The correlation of the dispersed-phase holdup with the operating conditions is determined for centerline position using the Froude number, Nfr, which represents the combined effects of the gas flow rate, injector diameter, and height of the heavy phase. The dispersed phase holdup along the centerline of the tank was determined against the Froude number. The following correlation equation was obtained:

$$Dph_c = 0.2034\left[(Nfr)^{0.1206}\left(\frac{H_l}{H_h}\right)^{0.7389}\left[1-\left(\frac{Z}{H_h}\right)^2\right]^{0.4831}\right]^{1.0223} \qquad (1)$$

The standard deviation between the measured values and those calculated was 0.0638 indicating a fairly good agreement (Figure 8). R-squared value for the correlation equation is 0.9587.

## Conclusions

From a cold model study on the variation of the dispersed phase holdup with operating conditions in a bottom gas injected liquid-liquid emulsion process, the following conclusions can be drawn:

1. The dispersed-phase holdup decreases with the vertical distance from the original interface of the two liquids.
2. The radial distribution of the dispersed-phase holdup has a maximum somewhere between the center and the wall of the tank.
3. Nearer to the nozzles the dispersed-phase holdup values on the Left-axis are larger than those on the Right-axis. Nearer to the original interface between the two liquids the dispersed-phase holdup values on the Right-axis are larger than that on the Left-axis.
4. The dispersed-phase holdup increases with the height ratio of the light to heavy phases.
5. The variation of the dispersed-phase holdup within the bath s is correlated by a single equation involving operating conditions and sampling location. The experimental holdup values are in satisfactory agreement with those calculated by the correlation.

## References


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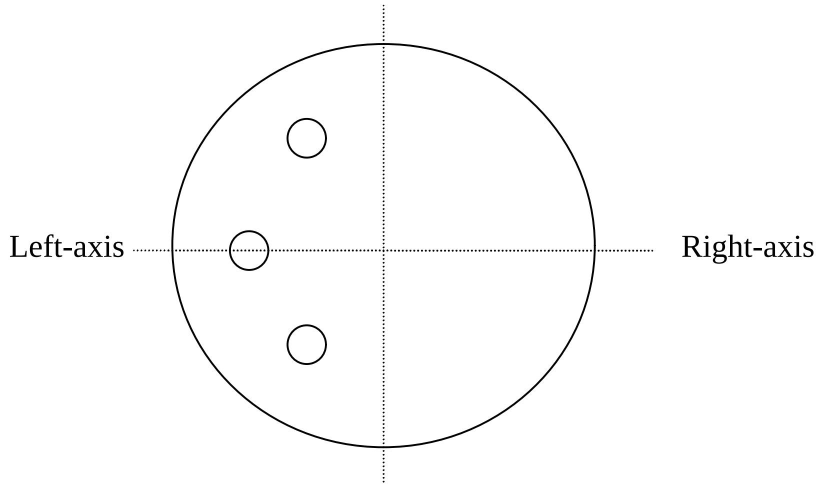


Figure 1. Triangular off-center nozzle orientation

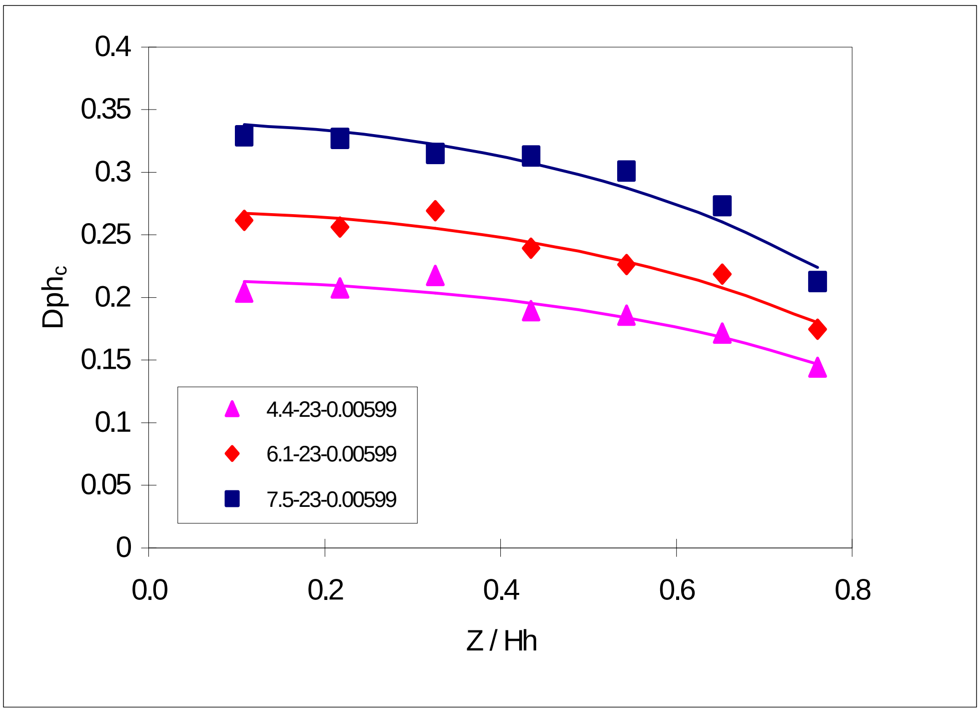


Figure 2. Axial variation of the dispersed phase holdup with respect to height of light phase

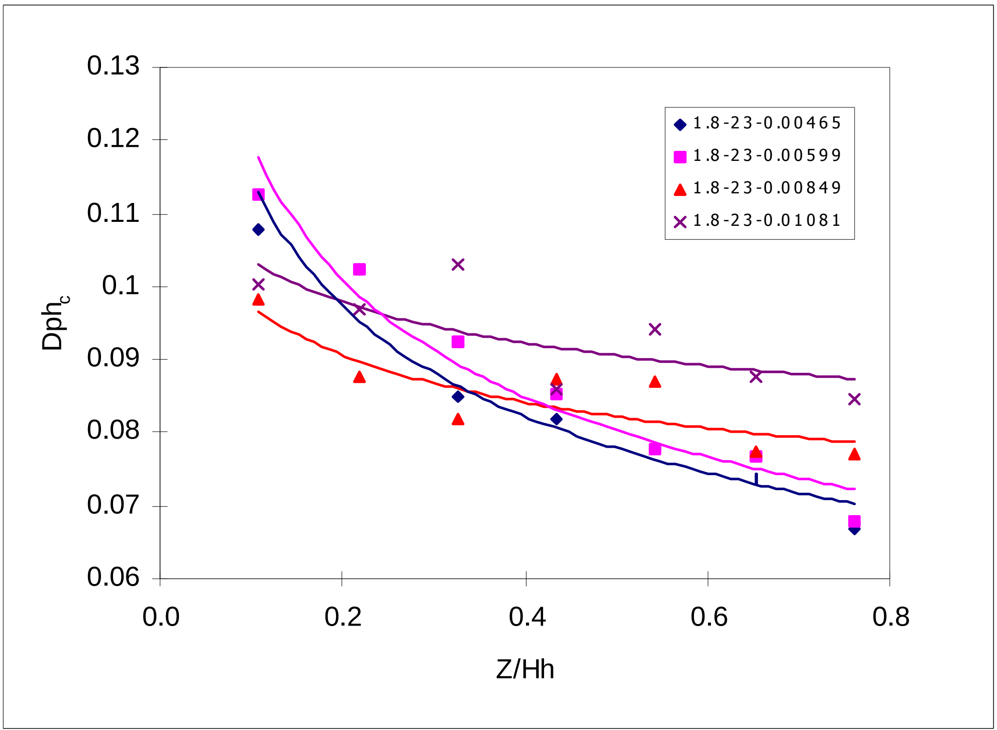


Figure 3. Axial variation of the dispersed phase holdup with respect to gas injection rate

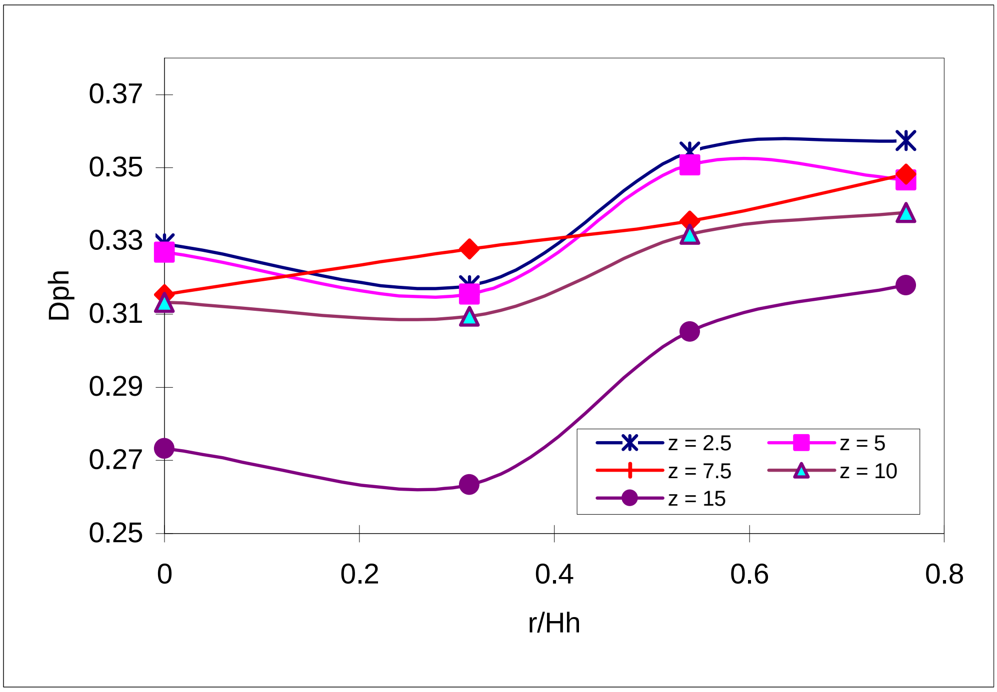


Figure 4. Radial variation of dispersed phase holdup for (7.5-23-0.00599-L) at different axial positions

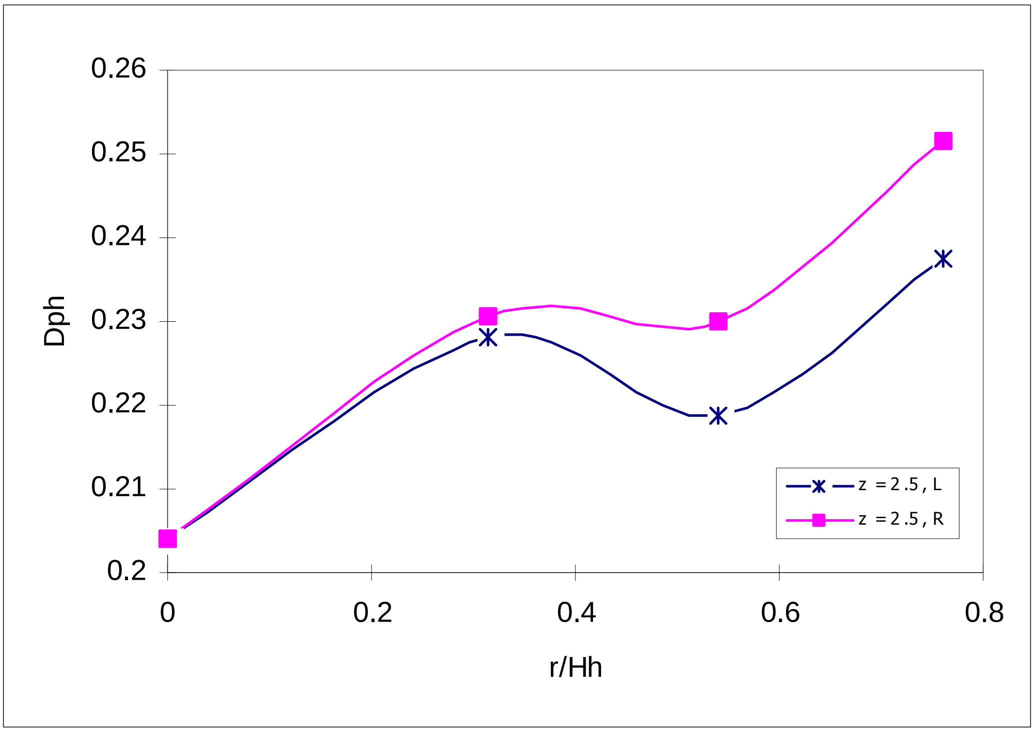


Figure 5. Radial variation of dispersed phase holdup for (4.4-23-0.00599-L) at different axial positions

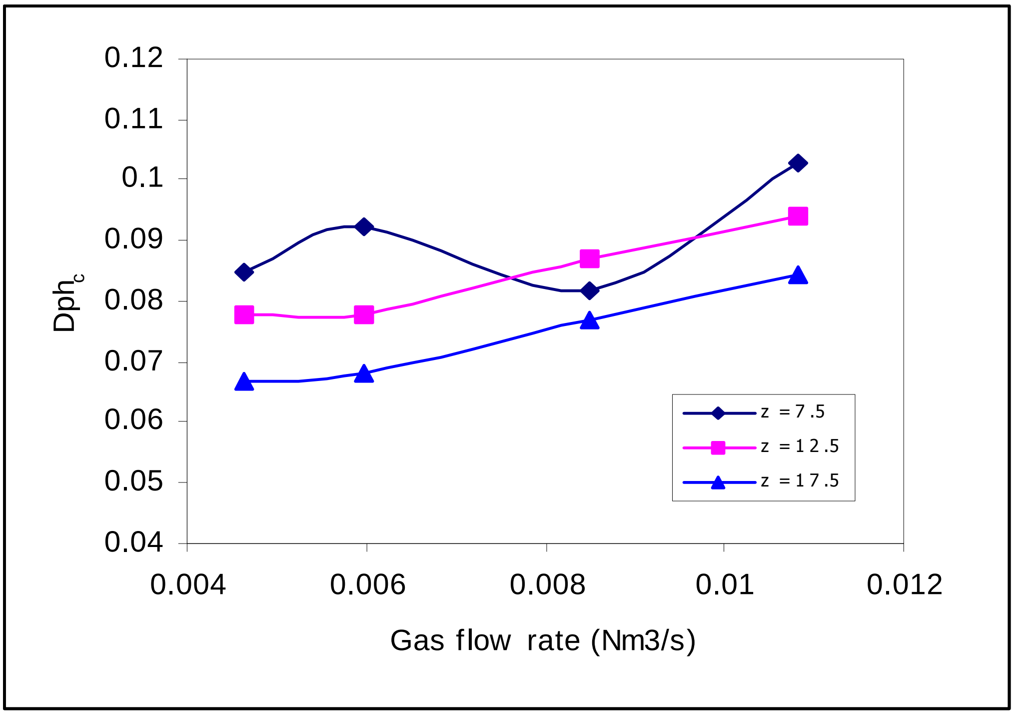


Figure 6. Effect of gas flow rate on the dispersed phase holdup for (1.8-23) at different axial positions

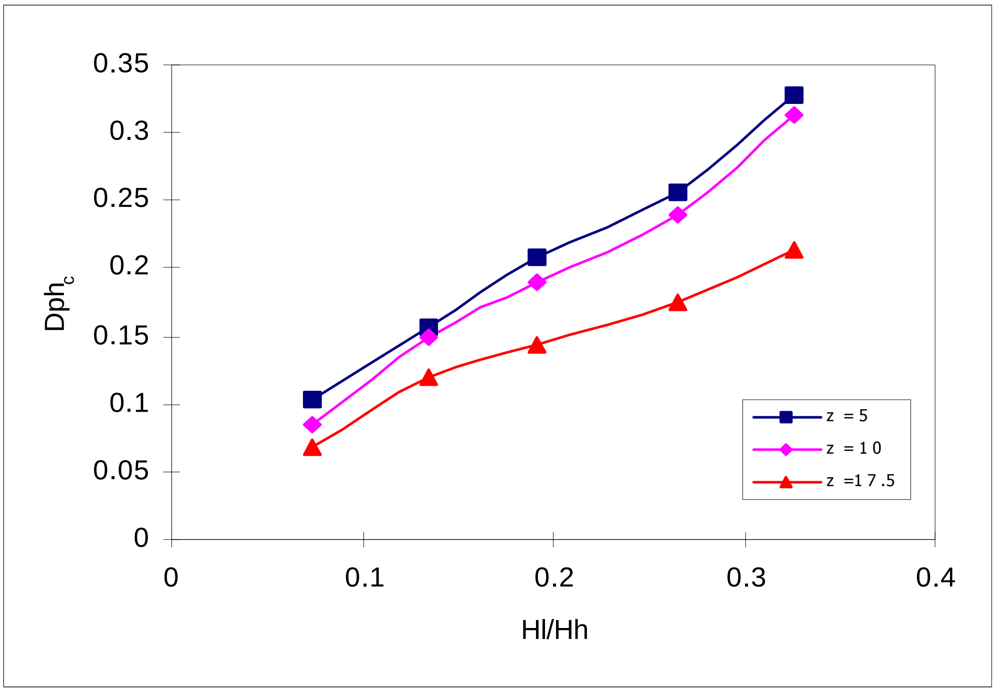


Figure 7. Effect of height ratio of light phase to heavy phase on the dispersed phase holdup for (23-0.00599) at different axial positions

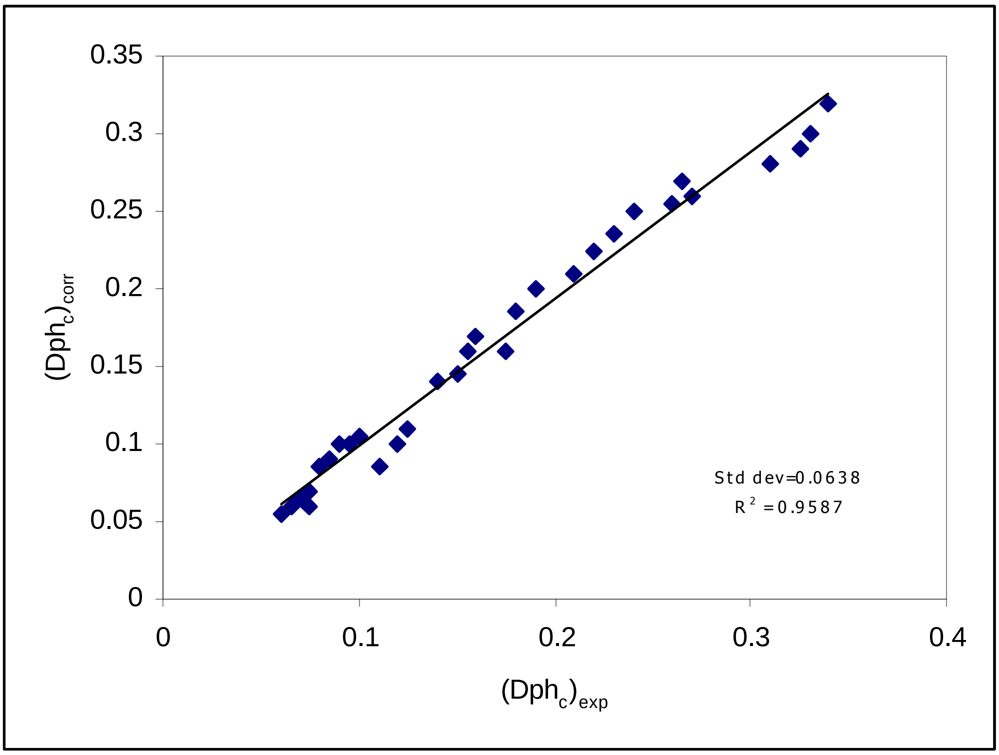


Figure 8. Comparison between the experimental and the calculated values of the dispersed phase holdup