UMR/NE-TFTL-05-03

# TASK 4-5: INTERFACIAL AREA TRANSPORT IN HORIZONTAL TWO-PHASE FLOW THROUGH VARIOUS FLOW RESTRICTIONS

## Data Report for Slug Flow in Air/Water Horizontal Two-phase Flow with 90-degree Elbow

Submitted to

The U.S. Nuclear Regulatory Commission
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852

by

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# NOMENCLATURE

| | |
|---|---|
| $A_i$ | surface area [$m^2$] |
| $a_i$ | interfacial area concentration [$m^{-1}$] |
| $D$ | diameter [m] |
| $D_e$ | volume equivalent diameter [m] |
| $D_s$ | surface equivalent diameter [m] |
| $D_{sm}$ | bubble Sauter mean diameter [m] |
| $f_b$ | bubble frequency [$s^{-1}$] |
| $j$ | total superficial velocity [m $s^{-1}$] |
| $j_f$ | liquid superficial velocity [m $s^{-1}$] |
| $j_g$ | gas superficial velocity [m $s^{-1}$] |
| $j_{g,atm}$ | gas superficial velocity under the atmospheric pressure condition [m $s^{-1}$] |
| $j_{g,loc}$ | gas superficial velocity under the local pressure condition [m $s^{-1}$] |
| $p$ | pressure [pa] |
| $p_{atm}$ | atmospheric pressure [pa] |
| $p_{back}$ | static pressure at the exit of gas flow meter [psig] |
| $p_{loc}$ | static pressure at a local point of interest [psig] |
| $Q_f$ | liquid volumetric flow rate [$m^3$ $s^{-1}$] or [gpm] |
| $Q_g$ | gas volumetric flow rate [$m^3$ $s^{-1}$] or [acfm] |
| $Re$ | Reynolds number |
| $t$ | time [s] |
| $u_r$ | relative velocity [m $s^{-1}$] |
| $u_b$ | bubble velocity [m $s^{-1}$] |
| $V$ | volume [$m^3$] |

GREEK SYMBOL

$\alpha$ gas void fraction

$\mu$ viscosity [Kg $m^{-1}s^{-1}$]

MATHEMATICAL SYMBOL

$\langle\ \rangle$ area average

$\langle\langle\ \rangle\rangle$ void weighted area average

SUBSCRIPTS

*1* group 1

*2* group 2

*atm* atmospheric condition

*b* bubble

*f* liquid phase

*g* gas phase

*i* interface

*loc* local

## ABSTRACT

The present report summarizes the experimental data acquired in the air-water slug flow through a horizontal pipe of 50.3 mm inner diameter with a 90-degee Elbow junction. The data presented in this report is a part of experimental investigations performed at the University of Wisconsin, Milwaukee (UWM) as Task 4-5 of Thermal-hydraulic Task (RS-RES-03-048) sponsored by the US Nuclear Regulatory Commission. As of October 25, 2004, the remaining assignments of Task 4-5 were transferred to the Two-phase Flow and the Thermal-hydraulics Laboratory (TFTL) of the University of Missouri-Rolla (UMR), subcontracted through the Institute of Thermal-hydraulics of Purdue University. In the efforts of performing data analysis studies, the UMR has organized the data transferred by the UWM and interpreted in view of developing predictive models for interfacial area transport and pressure loss due to the flow restriction. This is the second data report for the flow with 90-degee Elbow junction, summarizing the data acquired in the slug flow condition.

# 1. INTRODUCTION

## 1.1 Experimental Facility

The data presented in this report was acquired in the air-water bubbly two-phase flow through a horizontal tube of 50.3 mm inner diameter (ID) with a 90-degee Elbow flow restriction. The experiments were performed at the University of Wisconsin, Milwaukee (UWM). The simplified schematic diagram of the test facility is shown in Figure 1.1. The test section is made of Pyrex glass tubes and the measurement ports were made of clear acrylic. In the test section, a 90-degree Elbow was installed at *L/D*=197. The Elbow has a radius of curvature of 76.2 mm with an $(L/D)_{elbow}$ of approximately 6. The detailed dimension of the elbow is shown in the inset of Figure 1.1.

There are four local measurement ports installed along the test section (*P1* through *P4* in Fig. 1.1), and the first port (*P0*) is located right after the two-phase mixing chamber and was used only for the local pressure measurement. The port P1 is located at *L/D*=197 (9.91 meters from P0), just before the start of 90-degree Elbow, and the ports *P2, P3* and *P4* are located at *L/D*=225, 250 and 329 from the mixing chamber, or 1.39, 2.69, 6.65 meters downstream of the start of 90-degree Elbow, respectively. It is noted that the present data are acquired at *P1, P3* and *P4*, and no data was acquired at *P2*.

For a given flow condition, the local two-phase flow parameters were acquired by both the double-sensor and four-sensor conductivity probes. The double-sensor probe was used to process the data registered by small bubbles, while the four-sensor probe was used to process the data registered by slug (or Taylor) bubbles. The local parameters acquired by the probe included: bubble frequency ($f_b$), bubble velocity ($u_g$), void fraction ($\alpha$) and interfacial area concentration ($a_i$) for both small and slug bubbles. The local bubble Sauter mean diameter ($D_{sm}$) was calculated by the measured void fraction and interfacial area concentration with the mathematical relation given by

$$D_{sm} = 6\alpha / a_i \text{ : bubble Sauter mean diameter} \tag{1}$$

The local data was acquired by traversing the probe along the radial direction of the tube cross-section. Accounting for the asymmetric distribution of bubbles in the horizontal two-phase flow, the local measurements were made along the entire diameter of the tube. Unlike the previous experiment in bubbly flow conditions, the local measurements in slug flow were made along the vertical radius, $R_V$ of the tube only as shown in Figure 1.2. This assumes that the flow is fully developed and symmetric along the horizontal radius direction. In total, measurements were made at 20 local points along the vertical radius of the tube such that the measurement locations are given by $r/R$=0.9054, 0.8175, 0.7296, 0.6417, 0.5539, 0.4660, 0.3781, 0.2903, 0.2024, 0.1145, 0.0266, -0.0612, -0.1491, -0.2370, -0.3249, -0.4127, -0.5006, -0.5885, -0.6763, and -0.7642. Here $r/R$=0 indicates the center of the tube. In addition, the positive sign indicates the upper half of the tube radius, whereas the negative sign indicates the lower half of the tube radius. The detailed coordinate system on the elbow is shown in Figure 1.2.

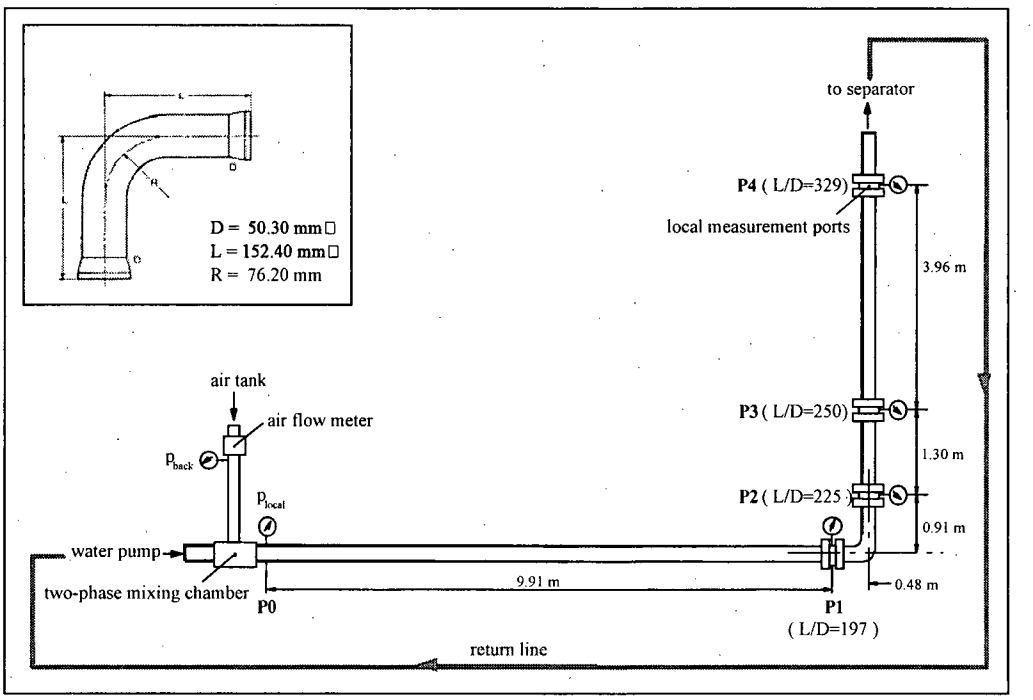


Figure 1.1 Simplified schematic diagram of the 50.3 mm ID horizontal two-phase flow test facility with 90-degree Elbow junction (Top view / Not scaled).

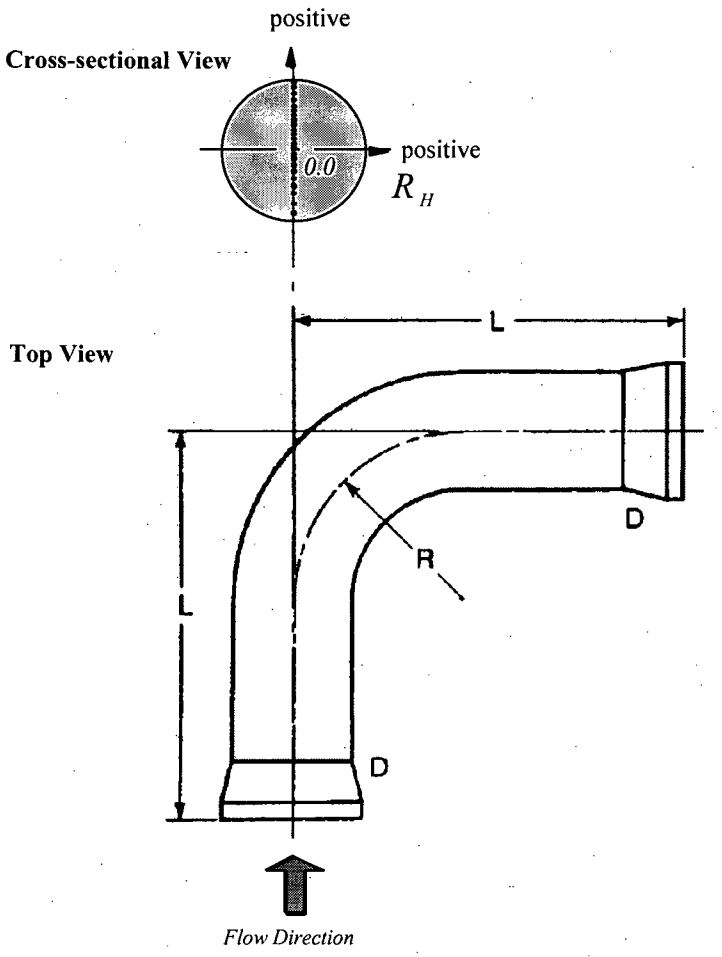


Figure 1.2 Definition of measurement coordinate system for the Elbow junction

## 1.2 Local Two-phase Flow Parameters Acquired by the Probe

The local data was acquired by traversing the probe along the radial direction of the flow. The acquired two-phase flow parameters and their mathematical definitions are given by:

$$\alpha = \frac{\sum_{j=1}^{N_b} t_j}{\Delta T} \quad : \text{ void fraction} \tag{2}$$

where $t_j$ is the time occupied by the $j^{th}$ bubble as it passes through the upstream sensor of the probe, $N_b$ is the total number of bubbles passed through the upstream sensor, and $\Delta T$ is the total measurement time at each location.

$$u_g = \frac{\Delta s}{\Delta t} \quad : \text{ bubble velocity} \tag{3}$$

where $\Delta s$ is the distance between the two tips of probe sensors, and $\Delta t$ is the time difference between the signals registered at the upstream and downstream of the sensors by the front interface of a bubble passing through the two sensor tips.

$$f_b = \frac{N_b}{\Delta T} \quad : \text{ bubble frequency} \tag{4}$$

and

$$a_i = \frac{1}{\Delta T}\sum_j \left(\frac{1}{\boldsymbol{u}_i \cdot \boldsymbol{n}_i}\right)_j \quad : \text{ interfacial area concentration} \tag{5}$$

where $\boldsymbol{u}_i$ and $\boldsymbol{n}_i$ are the interface velocity vector and unit normal vector to the interface, respectively. As discussed earlier, the bubble Sauter mean diameter was calculated by Eq. (1).

## 1.3 Data Process Schemes

### *1.3.1 Flow conditions*

Noting that the local gas flow rate depends on the local pressure, the gas flow rate for each Run was defined by that equivalent under the standard atmospheric pressure condition. Hence, the local gas flow rate measured by the flow meter under a back pressure $p_{back}$ was converted into the value equivalent to that under the atmospheric pressure condition by

$$Q_{g,atm} = \frac{p_{atm} + p_{back}}{p_{atm}} Q_{g,back} \quad \text{where } Q_{g,back} \text{ measured in acfm} \tag{6}$$

Furthermore, it was noted that the back pressure for a given Run varied as the measurements were made at different ports. This was also true when probes were exchanged between the double sensor and four-sensor probes for a given Run. Therefore, the gas superficial velocity of a Run was defined as the average value of $Q_{g,atm}$ acquired at different ports employing the double-sensor probe. Hence:

$$j_{g,atm} = \frac{1}{4}\sum_{i=1}^{4}\left(\frac{Q_{g,atm}}{A}\right)_{Pi} \quad : \text{ gas flow rate for each test run, where } i = \text{port number} \tag{7}$$

Similarly, the local volumetric gas flow rate was calculated by

$$Q_{g,loc} = \frac{p_{atm}}{p_{atm} + p_{loc}} Q_{g,atm} \quad : \text{ local gas flow rate at a measurement port} \tag{8}$$

where $p_{loc}$ is the local static pressure. Then, the local gas superficial velocity was obtained by

$$j_{g,loc} = {Q_{g,loc}}/{A} \quad : \text{local } j_g \text{ at the } i^{th} \text{ port} \tag{9}$$

### *1.3.2 Area-averaging Scheme*

In order to obtain the area-averaged two-phase flow parameters, the local two-phase flow parameters were averaged by

$$\langle \psi \rangle = \frac{1}{A}\int \psi dA \doteq \frac{1}{A}\sum_{i=1}^{N} \psi_i \Delta A_i \tag{10}$$

where $\psi$, $A$ and $\Delta A_i$ are any two-phase flow parameters of interest, total flow area and the $i^{th}$ partial area segment, respectively. The area-averaging method employed in defining the $\Delta A_i$ based on the vertical measurement orientation is shown in Figure 1.3.

Hence, for the data acquired along $R_V$, the $\Delta A_i$ is defined by

$$\Delta A_i = \frac{R_i^2}{2}(\theta_i - \theta_{i-1}) - R\left(h_i \cdot \sin\frac{\theta_i}{2} - h_{i-1} \cdot \sin\frac{\theta_{i-1}}{2}\right) \tag{11}$$

Here, $R_V$ and is the vertical radius with respect to the top and bottom of the Elbow cross-section, respectively. Therefore, Eq. (11) was employed to calculate the area-averaged parameters from the data acquired in Ports 1, 3 & 4.

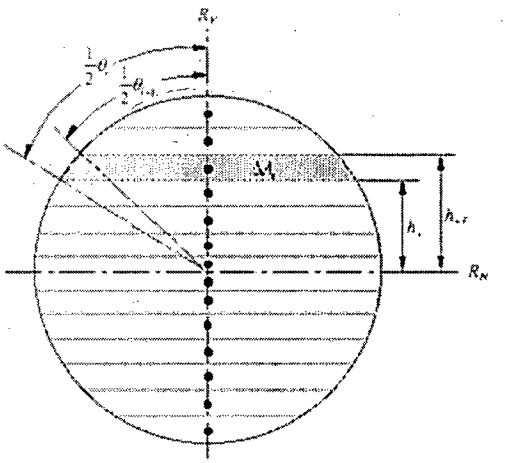

Figure 1.3 The definition of $\Delta A_i$ in the area-averaging scheme for the data obtained along vertical radius, $R_V$ (Ports 1,3 and 4)

As the area-averaged values of the two-phase flow parameters were obtained, other averaged parameters were calculated. Considering that there are two types of bubbles, namely dispersed small bubbles and slug bubbles, they were categorized into two groups, i.e., group 1 for small dispersed bubbles and group 2 for slug bubbles. Then the area averaged two-phase flow parameters are defined as follows:

$$\langle \alpha_T \rangle = \langle \alpha_1 + \alpha_2 \rangle \text{ : average total void fraction} \tag{12}$$

$$\langle a_{i,T} \rangle = \langle a_{i1} + a_{i2} \rangle \text{ : average total interfacial area concentration} \tag{13}$$

$$\langle D_{sm,j} \rangle = \left\langle \frac{6\alpha_j}{a_{i,j}} \right\rangle \text{: average bubble Sauter mean diameter for the } j^{th} \text{ group} \tag{14}$$

$$\langle\langle u_{gj} \rangle\rangle = \frac{\langle \alpha_j u_{gj} \rangle}{\langle \alpha_j \rangle} \text{ : void-weighted average bubble velocity for the } j^{th} \text{ group, and} \tag{15}$$

$$\langle\langle u_g \rangle\rangle = \frac{\langle \alpha_1 u_{g1} + \alpha_2 u_{g2} \rangle}{\langle \alpha_1 + \alpha_2 \rangle} \text{ : void-weighted average bubble velocity} \tag{16}$$

where the subscripts 1 and 2 denote the group 1 and 2. In calculating the average Sauter mean diameter, it was weighted by the bubble frequency and given by

$$\langle\langle D_{sm} \rangle\rangle_{f_b} = \frac{\langle f_b D_{sm} \rangle}{\langle f_b \rangle} \text{ : frequency-weighted average bubble Sauter mean diameter} \tag{17}$$

Furthermore, the superficial gas velocity at a local measurement port obtained by the flow meter was compared with that obtained by the area-averaged two-phase flow parameters by

$$j_{g,loc} = \left[ \langle \alpha_T \rangle \langle\langle u_g \rangle\rangle \right]_{loc} \tag{18}$$

## 2. EXPERIMENTAL CONDITIONS

The present experiments were performed in the air-water two-phase flow through a horizontal tube of 50.3 mm in inner diameter (ID) with a 90-degee Elbow located at *L/D*=197. In total, 15 different $j_g$ & $j_f$ combinations were investigated, all in slug flow conditions. The test conditions were labeled as Runs 1 through 15 and they are summarized in Table 2.1.

In view of the measurement error, the superficial gas velocity at a local measurement port obtained by the flow meter was compared with that obtained by the area-averaged two-phase flow parameters in Fig. 2.1. Here, the $j_{g,local}$ was obtained by both the flow rate and the pressure measurements and was calculated by Eq. (9). Then it was compared to the local gas superficial velocity, calculated based on the $\alpha$ and $u_g$ measured by the

local conductivity probe. As can be found in the figure, there are significant deviations in flow conditions with higher gas flow rates ($j_g$ > 1 m/s). This may stem from errors associated with both the probe application and the local pressure measurements.

Table 2.1 Summary of the test conditions in the present report

| | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 |
|---|---|---|---|---|---|
| $j_{g,atm}$ [m/s]* | 0.287 | 0.293 | 0.300 | 0.587 | 0.603 |
| $j_f$ [m/s]** | 0.56 | 1.65 | 2.2 | 0.56 | 1.65 |

| | Run 6 | Run 7 | Run 8 | Run 9 | Run 10 |
|---|---|---|---|---|---|
| $j_{g,atm}$ [m/s]* | 0.625 | 1.186 | 1.218 | 1.186 | 2.371 |
| $j_f$ [m/s]** | 2.2 | 0.56 | 1.65 | 2.2 | 0.56 |

| | Run 11 | Run 12 | Run 13 | Run 14 | Run 15 |
|---|---|---|---|---|---|
| $j_{g,atm}$ [m/s]* | 2.526 | 2.648 | 3.243 | 3.528 | 3.812 |
| $j_f$ [m/s]** | 1.65 | 2.2 | 0.56 | 1.65 | 2.2 |

* $j_{g,atm}$ is the gas superficial velocity equivalent to the atmospheric pressure condition, calculated based on Eqs. (6) and (7). The local pressure and the volumetric gas flow rates used in the calculations are the values when the local data were acquired by the double-sensor conductivity probe.

** $j_f$ shown in this table is the average of the liquid superficial velocities acquired at four measurement ports for each Run when double-sensor conductivity probe was employed for local measurements.

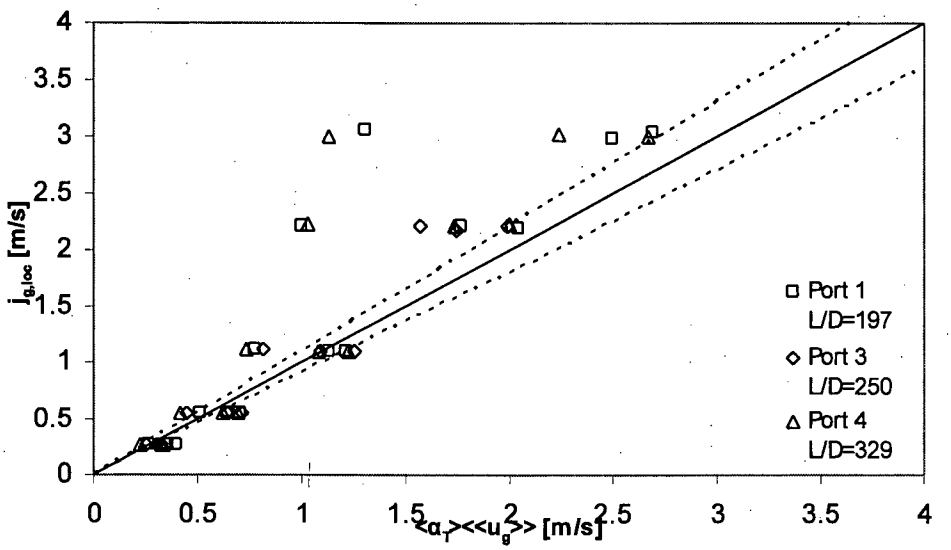


Figure 2.1 Comparison of the $j_{g,local}$ measured by the flow meter with $\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle$ calculated based on the probe measurement. ±10 % shown in dotted lines.

## 3. EXPERIMENTAL DATA

The comprehensive data acquired in the present experiments are summarized in this Chapter. First, the averaged data are presented, followed by the detailed local data acquired by the double-sensor and four-sensor conductivity probes. In summary, they are:

Section 3.1 The averaged data

(1) A comprehensive table that summarizes the experimental conditions and area-averaged two-phase flow parameters for all test Runs, including both the group 1 (small dispersed bubbles) and group 2 (slug bubbles) data.

Section 3.2 The local data

(1) A table that summarizes the local experimental conditions and the local two-phase flow parameters acquired by the double-sensor conductivity probe (per Run / per axial measurement location), and

(2) Profiles of local two-phase flow parameters at each measurement port (per Run / per axial measurement location)

Notations for figure identification numbers

The figure numbers are determined based on the following protocols:

- Figure 3.(data type) :

  Data type = 1 for area-averaged data

  Data type = 2 for local data

- Figure 3.2.(Run Number).(Axial Measurement Location):

  Run number: 1 through 15

  Axial location: Since no measurements were acquired at port 2, the following numbering scheme was used:
  Port 1 is denoted as the axial measurement location 1
  Port 3 is denoted as the axial measurement location 2
  Port 4 is denoted as the axial measurement location 3

## 3.1 Averaged Two-phase Flow Parameters.

Table 3.1 Summary of data acquired in air-water slug flow through a horizontal tube of 50.3 mm inner diameter with a 90-degree elbow junction

| Test No. | Data Port Location | | | Flow Condition | | | Local Gas Superficial Velocity | | Pressure [psig] | | Area Averaged Two-phase Flow Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Port No. | L [m] | L/D | $Q_g$ [acfm] | $Q_f$ [gpm] | $j_f$ [m/s] | $j_{g,loc}$ [m/s] | $j_{g,atm}$ [m/s] | $p_{back}$ | $p_{loc}$ | $\langle\alpha_1\rangle$ | $\langle\alpha_2\rangle$ | $\langle\alpha_T\rangle$ | $\langle a_{i1}\rangle$ [1/m] | $\langle a_{i2}\rangle$ [1/m] | $\langle a_{iT}\rangle$ [1/m] | $\langle\langle u_{g1}\rangle\rangle$ [m/s] | $\langle\langle u_{g2}\rangle\rangle$ [m/s] | $\langle\langle u_g\rangle\rangle$ [m/s] |
| Run 1 [m/s] $j_{g,atm}$ = 0.287 $j_f$ = 0.56 | P0 | 0.00 | – | 0.512 | 17.5 | 0.556 | 0.2639 | 0.2854 | 19.80 | 1.20 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 0.512 | 17.5 | 0.556 | 0.2672 | 0.2854 | 19.80 | 1.00 | 0.001 | 0.218 | 0.219 | 0.15 | 0.51 | 0.66 | 1.398 | 1.155 | 1.220 |
| | P3 | 12.60 | 250 | 0.541 | 17.7 | 0.562 | 0.2701 | 0.2884 | 18.30 | 1.00 | 0.001 | 0.252 | 0.253 | 0.09 | 0.46 | 0.55 | 1.492 | 0.961 | 1.026 |
| | P4 | 16.56 | 329 | 0.552 | 17.7 | 0.562 | 0.2697 | 0.2881 | 17.60 | 1.00 | 0.001 | 0.243 | 0.244 | 0.12 | 0.46 | 0.58 | 1.306 | 0.873 | 0.933 |
| Run 2 [m/s] $j_{g,atm}$ = 0.293 $j_f$ = 1.65 | P0 | 0.00 | – | 0.578 | 51.9 | 1.648 | 0.2560 | 0.2960 | 17.00 | 2.30 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 0.578 | 51.9 | 1.648 | 0.2703 | 0.2960 | 17.00 | 1.40 | 0.013 | 0.131 | 0.144 | 4.99 | 2.16 | 7.15 | 1.846 | 2.778 | 2.784 |
| | P3 | 12.60 | 250 | 0.529 | 51.9 | 1.648 | 0.2689 | 0.2872 | 18.90 | 1.00 | 0.010 | 0.105 | 0.115 | 4.38 | 1.52 | 5.90 | 1.922 | 2.727 | 2.676 |
| | P4 | 16.56 | 329 | 0.547 | 51.9 | 1.648 | 0.2704 | 0.2943 | 18.60 | 1.30 | 0.008 | 0.115 | 0.123 | 3.08 | 1.77 | 4.85 | 1.909 | 2.667 | 2.700 |
| Run 3 [m/s] $j_{g,atm}$ = 0.300 $j_f$ = 2.2 | P0 | 0.00 | – | 0.553 | 69.5 | 2.207 | 0.2558 | 0.2993 | 18.80 | 2.50 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 0.553 | 69.5 | 2.207 | 0.2667 | 0.2993 | 18.80 | 1.80 | 0.028 | 0.083 | 0.111 | 14.37 | 1.65 | 16.02 | 2.278 | 3.587 | 3.300 |
| | P3 | 12.60 | 250 | 0.528 | 69.3 | 2.200 | 0.2683 | 0.3011 | 20.60 | 1.80 | 0.018 | 0.078 | 0.096 | 9.54 | 1.34 | 10.88 | 2.315 | 3.572 | 3.400 |
| | P4 | 16.56 | 329 | 0.536 | 69.3 | 2.200 | 0.2694 | 0.3005 | 20.00 | 1.70 | 0.011 | 0.089 | 0.100 | 6.02 | 1.42 | 7.44 | 2.347 | 3.393 | 3.352 |
| Run 4 [m/s] $j_{g,atm}$ = 0.587 $j_f$ = 0.56 | P0 | 0.00 | – | 0.975 | 17.8 | 0.565 | 0.5384 | 0.5860 | 22.50 | 1.30 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 0.975 | 17.8 | 0.565 | 0.5487 | 0.5860 | 22.50 | 1.00 | 0.002 | 0.428 | 0.430 | 0.43 | 0.54 | 0.97 | 1.498 | 1.111 | 1.190 |
| | P3 | 12.60 | 250 | 0.915 | 17.5 | 0.556 | 0.5509 | 0.5884 | 25.10 | 1.00 | 0.002 | 0.441 | 0.443 | 0.69 | 0.39 | 1.08 | 1.280 | 0.960 | 1.026 |
| | P4 | 16.56 | 329 | 0.954 | 17.4 | 0.552 | 0.5513 | 0.5888 | 23.50 | 1.00 | 0.002 | 0.420 | 0.422 | 0.44 | 0.40 | 0.84 | 1.436 | 0.926 | 0.991 |
| Run 5 [m/s] $j_{g,atm}$ = 0.603 $j_f$ = 1.65 | P0 | 0.00 | – | 1.019 | 52.2 | 1.657 | 0.5178 | 0.6059 | 22.10 | 2.50 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 1.019 | 52.2 | 1.657 | 0.5498 | 0.6059 | 22.10 | 1.50 | 0.013 | 0.225 | 0.238 | 5.91 | 1.84 | 7.75 | 2.180 | 2.614 | 2.729 |
| | P3 | 12.60 | 250 | 0.921 | 51.9 | 1.648 | 0.5510 | 0.5997 | 25.60 | 1.30 | 0.015 | 0.199 | 0.214 | 7.26 | 1.50 | 8.76 | 2.058 | 2.930 | 2.998 |
| | P4 | 16.56 | 329 | 0.898 | 51.9 | 1.648 | 0.5505 | 0.5992 | 26.60 | 1.30 | 0.012 | 0.208 | 0.220 | 5.50 | 1.49 | 6.99 | 2.221 | 2.729 | 2.837 |
| Run 6 [m/s] $j_{g,atm}$ = 0.625 $j_f$ = 2.2 | P0 | 0.00 | – | 1.019 | 69.5 | 2.207 | 0.5212 | 0.6240 | 23.20 | 2.90 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 1.019 | 69.5 | 2.207 | 0.5492 | 0.6240 | 23.20 | 2.00 | 0.025 | 0.157 | 0.182 | 13.25 | 2.08 | 15.33 | 2.634 | 3.905 | 3.855 |
| | P3 | 12.60 | 250 | 0.923 | 69.3 | 2.200 | 0.5526 | 0.6278 | 27.40 | 2.00 | 0.023 | 0.169 | 0.192 | 12.25 | 1.92 | 14.17 | 2.634 | 3.712 | 3.756 |
| | P4 | 16.56 | 329 | 0.917 | 69.2 | 2.197 | 0.5510 | 0.6223 | 27.30 | 1.90 | 0.020 | 0.163 | 0.183 | 10.24 | 1.68 | 11.92 | 2.665 | 3.787 | 3.813 |
| Run 7 [m/s] $j_{g,atm}$ = 1.186 $j_f$ = 0.56 | P0 | 0.00 | – | 1.616 | 17.6 | 0.559 | 1.0761 | 1.193 | 31.00 | 1.60 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 1.616 | 17.6 | 0.559 | 1.1172 | 1.193 | 31.00 | 1.00 | 0.007 | 0.554 | 0.561 | 3.25 | 0.31 | 3.56 | 1.859 | 1.297 | 1.390 |
| | P3 | 12.60 | 250 | 1.504 | 17.4 | 0.552 | 1.1035 | 1.179 | 33.80 | 1.00 | 0.007 | 0.590 | 0.597 | 3.46 | 0.26 | 3.72 | 1.862 | 1.294 | 1.378 |
| | P4 | 16.56 | 329 | 1.520 | 17.3 | 0.549 | 1.1037 | 1.179 | 33.30 | 1.00 | 0.006 | 0.568 | 0.574 | 2.97 | 0.27 | 3.24 | 1.849 | 1.211 | 1.293 |
| Run 8 [m/s] $j_{g,atm}$ = 1.218 $j_f$ = 1.65 | P0 | 0.00 | – | 1.580 | 52.1 | 1.654 | 1.0336 | 1.230 | 33.50 | 2.80 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 1.580 | 52.1 | 1.654 | 1.1029 | 1.230 | 33.50 | 1.70 | 0.028 | 0.338 | 0.366 | 14.63 | 0.84 | 15.47 | 2.850 | 2.899 | 3.082 |
| | P3 | 12.60 | 250 | 1.455 | 51.9 | 1.648 | 1.0946 | 1.199 | 36.30 | 1.40 | 0.030 | 0.308 | 0.338 | 16.19 | 0.76 | 16.95 | 2.651 | 3.081 | 3.231 |
| | P4 | 16.56 | 329 | 1.470 | 52.0 | 1.651 | 1.0991 | 1.211 | 36.30 | 1.50 | 0.028 | 0.319 | 0.347 | 14.74 | 0.71 | 15.45 | 2.848 | 2.954 | 3.125 |

Table 3.1 continued from previous page

| Test No. | Data Port Location | | | Flow Condition | | | Local Gas Superficial Velocity | | Pressure [psig] | | Area Averaged Two-phase Flow Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Port No. | L [m] | L/D | $Q_g$ [acfm] | $Q_f$ [gpm] | $j_f$ [m/s] | $j_{g,loc}$ [m/s] | $j_{g,atm}$ [m/s] | $p_{back}$ | $p_{loc}$ | $\langle\alpha_1\rangle$ | $\langle\alpha_2\rangle$ | $\langle\alpha_T\rangle$ | $\langle a_{i1}\rangle$ [1/m] | $\langle a_{i2}\rangle$ [1/m] | $\langle a_{iT}\rangle$ [1/m] | $\langle\langle u_{g1}\rangle\rangle$ [m/s] | $\langle\langle u_{g2}\rangle\rangle$ [m/s] | $\langle\langle u_g\rangle\rangle$ [m/s] |
| Run 9 [m/s] $j_{g,atm}$ = 1.186 $j_f$ = 2.2 | P0 | 0.00 | – | 1.663 | 69.5 | 2.207 | 1.0525 | 1.282 | 33.00 | 3.20 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 1.663 | 69.5 | 2.207 | 1.1017 | 1.282 | 33.00 | 2.40 | 0.049 | 0.223 | 0.272 | 25.63 | 1.20 | 26.83 | 3.407 | 4.486 | 4.485 |
| | P3 | 12.60 | 250 | 1.566 | 69.2 | 2.197 | 1.1003 | 1.257 | 35.00 | 2.10 | 0.045 | 0.251 | 0.296 | 23.90 | 1.02 | 24.92 | 3.187 | 4.169 | 4.255 |
| | P4 | 16.56 | 329 | 1.556 | 69.2 | 2.197 | 1.1021 | 1.275 | 36.00 | 2.30 | 0.041 | 0.247 | 0.288 | 21.16 | 0.88 | 22.04 | 3.441 | 4.118 | 4.258 |
| Run 10 [m/s] $j_{g,atm}$ = 2.371 $j_f$ = 0.56 | P0 | 0.00 | – | 3.763 | 17.5 | 0.556 | 2.1253 | 2.371 | 24.30 | 1.70 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 3.763 | 17.5 | 0.556 | 2.2060 | 2.371 | 24.30 | 1.10 | 0.018 | 0.686 | 0.704 | 8.95 | 0.10 | 9.05 | 2.705 | 1.304 | 1.419 |
| | P3 | 12.60 | 250 | 3.160 | 17.6 | 0.559 | 2.1989 | 2.349 | 31.30 | 1.00 | 0.020 | 0.676 | 0.696 | 10.72 | 0.14 | 10.86 | 2.716 | 2.119 | 2.259 |
| | P4 | 16.56 | 329 | 3.160 | 17.3 | 0.549 | 2.2278 | 2.394 | 32.20 | 1.10 | 0.017 | 0.672 | 0.689 | 8.93 | 0.11 | 9.04 | 2.445 | 1.393 | 1.501 |
| Run 11 [m/s] $j_{g,atm}$ = 2.526 $j_f$ = 1.65 | P0 | 0.00 | – | 3.400 | 51.8 | 1.645 | 2.1243 | 2.543 | 31.60 | 2.90 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 3.400 | 51.8 | 1.645 | 2.1993 | 2.543 | 31.60 | 2.30 | 0.059 | 0.453 | 0.512 | 21.14 | 0.35 | 21.49 | 3.509 | 3.215 | 3.452 |
| | P3 | 12.60 | 250 | 2.381 | 51.9 | 1.648 | 2.1644 | 2.474 | 49.60 | 2.10 | 0.067 | 0.421 | 0.488 | 33.13 | 0.33 | 33.46 | 3.250 | 3.408 | 3.588 |
| | P4 | 16.56 | 329 | 3.113 | 51.7 | 1.641 | 2.2268 | 2.545 | 35.90 | 2.10 | 0.057 | 0.438 | 0.495 | 29.51 | 0.33 | 29.84 | 3.452 | 3.856 | 4.044 |
| Run 12 [m/s] $j_{g,atm}$ = 2.648 $j_f$ = 2.2 | P0 | 0.00 | – | 3.447 | 69.5 | 2.207 | 2.0907 | 2.645 | 32.80 | 3.90 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 3.447 | 69.5 | 2.207 | 2.1847 | 2.645 | 32.80 | 3.10 | 0.064 | 0.348 | 0.412 | 30.68 | 0.51 | 31.19 | 4.150 | 4.772 | 4.975 |
| | P3 | 12.60 | 250 | 3.324 | 69.4 | 2.203 | 2.1989 | 2.648 | 34.60 | 3.00 | 0.074 | 0.348 | 0.422 | 36.56 | 0.41 | 36.97 | 4.111 | 4.541 | 4.717 |
| | P4 | 16.56 | 329 | 3.210 | 69.3 | 2.200 | 2.2053 | 2.655 | 36.50 | 3.00 | 0.063 | 0.367 | 0.430 | 32.97 | 0.33 | 33.30 | 4.182 | 3.734 | 4.041 |
| Run 13 [m/s] $j_{g,atm}$ = 3.243 $j_f$ = 0.56 | P0 | 0.00 | – | 3.775 | 17.3 | 0.549 | 2.8962 | 3.251 | 38.60 | 1.80 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 3.775 | 17.3 | 0.549 | 3.0055 | 3.251 | 38.60 | 1.20 | 0.028 | 0.707 | 0.735 | 12.23 | 0.11 | 12.34 | 3.001 | 1.633 | 1.783 |
| | P3 | 12.60 | 250 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | P4 | 16.56 | 329 | 4.550 | 17.5 | 0.556 | 3.0025 | 3.227 | 29.20 | 1.10 | 0.027 | 0.727 | 0.754 | 13.23 | 0.09 | 13.32 | 2.823 | 1.367 | 1.500 |
| Run 14 [m/s] $j_{g,atm}$ = 3.528 $j_f$ = 1.65 | P0 | 0.00 | – | 3.960 | 51.8 | 1.645 | 3.1350 | 3.519 | 40.30 | 1.80 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 3.960 | 51.8 | 1.645 | 2.9901 | 3.519 | 40.30 | 2.60 | 0.064 | 0.480 | 0.544 | 29.17 | 0.43 | 29.60 | 3.908 | 4.381 | 4.586 |
| | P3 | 12.60 | 250 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | P4 | 16.56 | 329 | 4.600 | 51.7 | 1.641 | 3.0123 | 3.545 | 33.00 | 2.60 | 0.069 | 0.505 | 0.574 | 32.22 | 0.29 | 32.51 | 3.920 | 3.653 | 3.908 |
| Run 15 [m/s] $j_{g,atm}$ = 3.812 $j_f$ = 2.2 | P0 | 0.00 | – | 4.390 | 69.5 | 2.207 | 3.0382 | 3.844 | 39.50 | 3.90 | – | – | – | – | – | – | – | – | – |
| | P1 | 9.91 | 197 | 4.390 | 69.5 | 2.207 | 3.0382 | 3.844 | 39.50 | 3.90 | 0.074 | 0.412 | 0.486 | 31.50 | 0.52 | 32.02 | 4.587 | 5.307 | 5.529 |
| | P3 | 12.60 | 250 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | P4 | 16.56 | 329 | 4.231 | 69.1 | 2.194 | 2.9928 | 3.746 | 40.10 | 3.70 | 0.072 | 0.433 | 0.505 | 31.26 | 0.40 | 31.66 | 4.677 | 5.013 | 5.268 |

## 3.2 Local Two-phase Flow Parameters.

### 3.2.1 Summary of results for Run 1.

Table 3.2.1.1 Local two-phase flow parameters for Run 1 acquired along the vertical axis at measurement port 1 (P1)

**Run 1:** $j_{g,atm}$ = 0.287 [m/s] & $j_f$ = 0.559 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.512 | $P_{back}$ [psig] = 19.8 | $j_{g,loc}$ [m/s] = 0.267 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.50 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.556 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 3.3 | 0.7 | 0.038 | 0.663 | 0.700 | 6.68 | 2.39 | 9.07 | 0.727 | 1.939 | 33.7 | 1663.9 |
| 0.8175 | 1.4 | 0.7 | 0.008 | 0.624 | 0.632 | 0.00 | 1.87 | 1.87 | 2.576 | 1.470 | | 2002.1 |
| 0.7296 | 0.4 | 0.5 | 0.002 | 0.513 | 0.515 | 0.00 | 1.13 | 1.13 | 2.609 | 1.399 | | 2723.9 |
| 0.6417 | 0.3 | 0.5 | 0.001 | 0.490 | 0.491 | 0.00 | 1.21 | 1.21 | 3.886 | 1.375 | | 2430.7 |
| 0.5539 | 0.2 | 0.7 | 0.001 | 0.439 | 0.440 | 0.21 | 1.29 | 1.50 | 1.743 | 1.361 | 34.3 | 2040.5 |
| 0.4660 | 0.2 | 0.6 | 0.001 | 0.429 | 0.430 | 0.00 | 1.43 | 1.43 | 2.079 | 1.329 | | 1798.7 |
| 0.3781 | 0.1 | 0.5 | 0.001 | 0.421 | 0.421 | 0.00 | 1.31 | 1.31 | 1.996 | 1.371 | | 1926.4 |
| 0.2903 | 0.1 | 0.6 | 0.001 | 0.408 | 0.409 | 0.18 | 1.00 | 1.18 | 1.165 | 1.113 | 23.3 | 2447.4 |
| 0.2024 | 0.1 | 0.7 | 0.001 | 0.352 | 0.353 | 0.00 | 1.03 | 1.03 | 1.393 | 1.380 | | 2047.6 |
| 0.1145 | 0.1 | 0.6 | 0.001 | 0.315 | 0.315 | 0.00 | 0.09 | 0.09 | 1.185 | 0.263 | | 20980.0 |
| 0.0266 | 0.1 | 0.5 | 0.001 | 0.254 | 0.254 | 0.00 | 0.00 | 0.00 | 3.007 | 0.000 | | |
| -0.0612 | 0.1 | 0.5 | 0.000 | 0.092 | 0.092 | 0.00 | 0.00 | 0.00 | 0.271 | 0.000 | | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.001 | $\langle a_{i1}\rangle$ [1/m] = 0.15 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.398 |
| $\langle\alpha_2\rangle$ = 0.218 | $\langle a_{i2}\rangle$ [1/m] = 0.51 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.155 |
| $\langle\alpha_T\rangle$ = 0.219 | $\langle a_{iT}\rangle$ [1/m] = 0.66 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.220 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 0.10\%$$

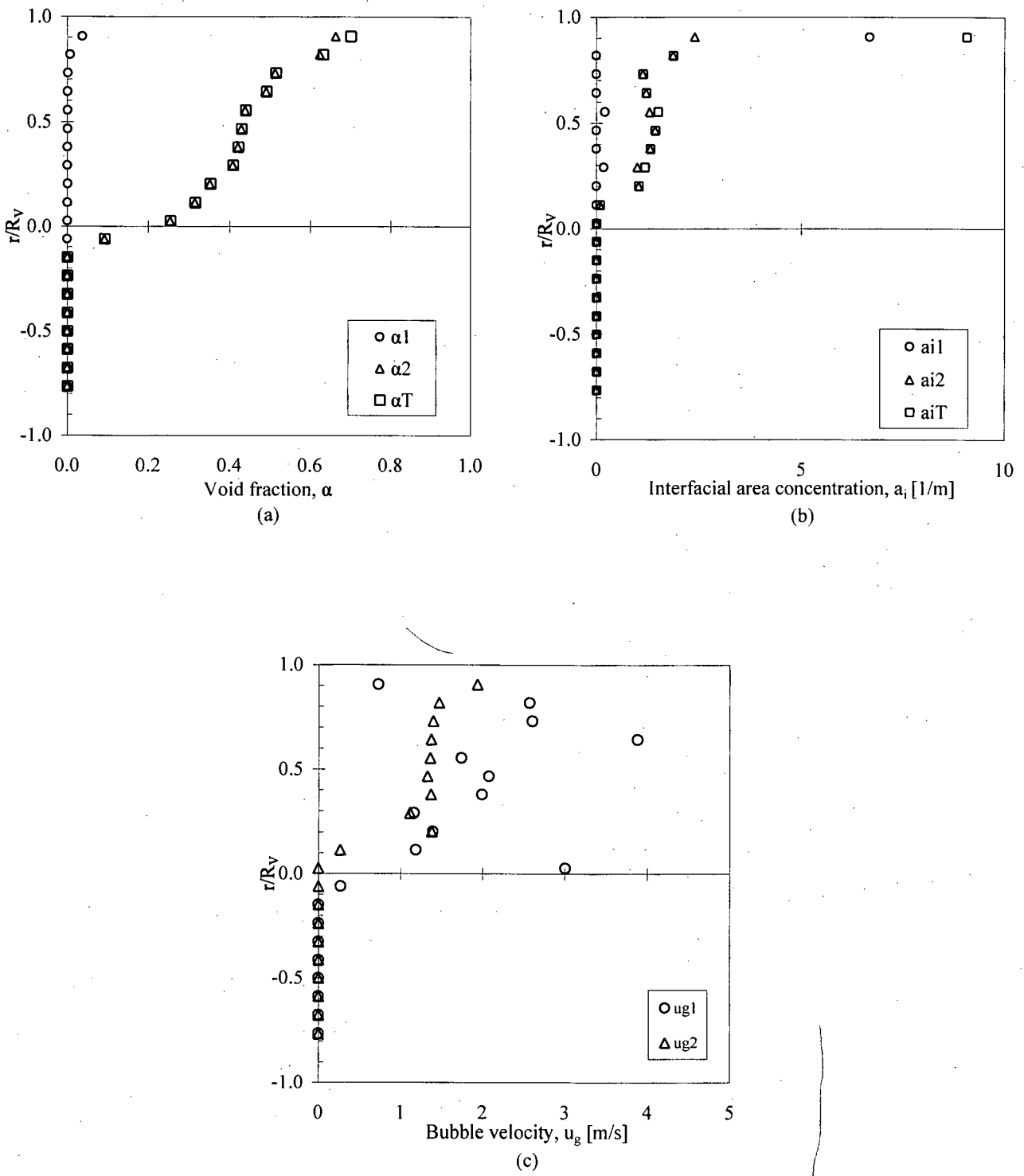


Figure 3.2.1.1 Profiles of local two-phase flow parameters for Run 1 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.1.2 Local two-phase flow parameters for Run 1 acquired along the vertical axis at measurement port 3 (P3)

**Run 1:** $j_{g,atm}$ = 0.287 [m/s] & $j_f$ = 0.559 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.541 | $P_{back}$ [psig] = 18.3 | $j_{g,loc}$ [m/s] = 0.270 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.70 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.562 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 1.3 | 0.9 | 0.014 | 0.660 | 0.674 | 1.27 | 1.55 | 2.82 | 1.113 | 0.871 | 67.6 | 2554.1 |
| 0.8175 | 1.0 | 1.1 | 0.009 | 0.656 | 0.665 | 1.61 | 2.75 | 4.36 | 1.428 | 1.824 | 33.5 | 1431.3 |
| 0.7296 | 0.5 | 0.5 | 0.002 | 0.541 | 0.542 | 0.00 | 0.95 | 0.95 | 2.012 | 1.011 | | 3414.3 |
| 0.6417 | 0.2 | 0.5 | 0.001 | 0.504 | 0.505 | 0.25 | 1.16 | 1.41 | 1.553 | 1.465 | 26.4 | 2605.9 |
| 0.5539 | 0.3 | 0.5 | 0.001 | 0.488 | 0.489 | 0.00 | 1.30 | 1.30 | 1.984 | 1.311 | | 2250.9 |
| 0.4660 | 0.6 | 0.5 | 0.003 | 0.514 | 0.517 | 0.00 | 1.29 | 1.29 | 1.739 | 1.374 | | 2389.8 |
| 0.3781 | 0.3 | 0.6 | 0.002 | 0.484 | 0.486 | 0.00 | 1.45 | 1.45 | 1.508 | 1.633 | | 2002.3 |
| 0.2903 | 0.2 | 0.7 | 0.001 | 0.479 | 0.479 | 0.00 | 1.15 | 1.15 | 1.732 | 1.349 | | 2497.0 |
| 0.2024 | 0.2 | 0.6 | 0.001 | 0.454 | 0.455 | 0.00 | 0.00 | 0.00 | 1.777 | 0.000 | | |
| 0.1145 | 0.1 | 0.6 | 0.000 | 0.389 | 0.389 | 0.00 | 0.00 | 0.00 | 1.530 | 0.000 | | |
| 0.0266 | 0.1 | 0.9 | 0.000 | 0.346 | 0.346 | 0.00 | 0.00 | 0.00 | 2.500 | 0.000 | | |
| -0.0612 | 0.0 | 0.5 | 0.000 | 0.108 | 0.108 | 0.00 | 0.00 | 0.00 | 2.117 | 0.000 | | |
| -0.1491 | 0.0 | 0.2 | 0.000 | 0.039 | 0.039 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.001 | $<a_{i1}>$ [1/m] = 0.09 | $<<u_{g1}>>$ [m/s] = 1.492 |
| $<\alpha_2>$ = 0.252 | $<a_{i2}>$ [1/m] = 0.46 | $<<u_{g2}>>$ [m/s] = 0.961 |
| $<\alpha_T>$ = 0.253 | $<a_{iT}>$ [1/m] = 0.55 | $<<u_g>>$ [m/s] = 1.026 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 3.88\%$$

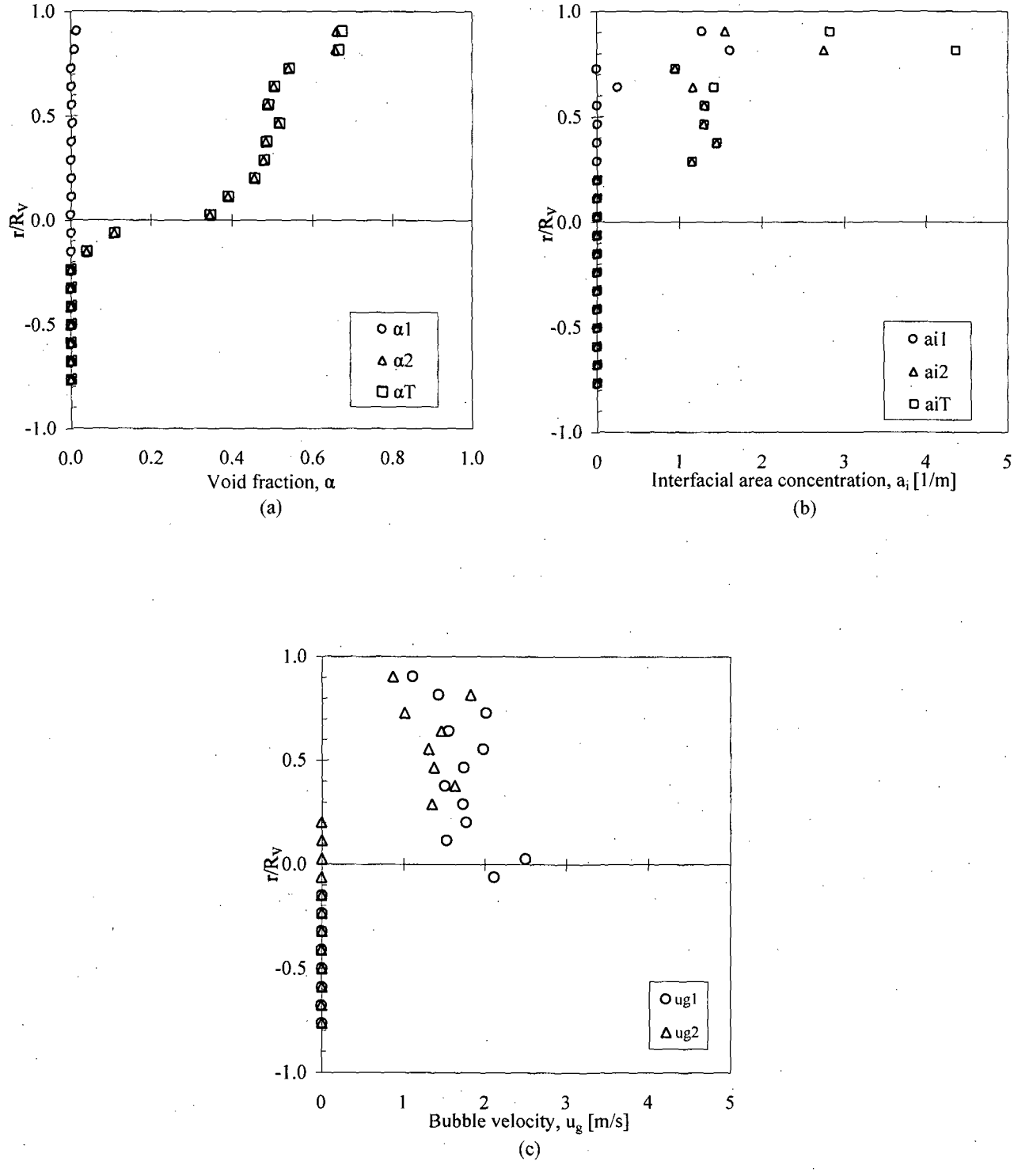


Figure 3.2.1.2 Profiles of local two-phase flow parameters for Run 1 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.1.3 Local two-phase flow parameters for Run 1 acquired along the vertical axis at measurement port 4 (P4)

**Run 1:** $j_{g,atm}$ = 0.287 [m/s] & $j_f$ = 0.559 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.522 | $P_{back}$ [psig] = 17.6 | $j_{g,loc}$ [m/s] = 0.270 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.70 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.562 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 1.3 | 0.6 | 0.014 | 0.646 | 0.660 | 3.85 | 1.69 | 5.54 | 0.764 | 1.338 | 21.7 | 2293.1 |
| 0.8175 | 0.7 | 0.6 | 0.005 | 0.575 | 0.579 | 1.31 | 1.45 | 2.76 | 1.309 | 1.394 | 22.0 | 2377.7 |
| 0.7296 | 0.4 | 0.5 | 0.002 | 0.498 | 0.500 | 0.00 | 1.51 | 1.51 | 3.651 | 1.244 | | 1978.0 |
| 0.6417 | 0.1 | 0.6 | 0.000 | 0.496 | 0.497 | 0.00 | 1.58 | 1.58 | 4.001 | 1.264 | | 1884.7 |
| 0.5539 | 0.2 | 0.5 | 0.001 | 0.458 | 0.459 | 0.00 | 1.68 | 1.68 | 2.018 | 1.370 | | 1635.4 |
| 0.4660 | 0.2 | 0.5 | 0.001 | 0.492 | 0.493 | 0.00 | 1.77 | 1.77 | 1.661 | 1.344 | | 1667.8 |
| 0.3781 | 0.2 | 0.5 | 0.001 | 0.454 | 0.454 | 0.00 | 0.86 | 0.86 | 1.576 | 1.068 | | 3164.0 |
| 0.2903 | 0.1 | 0.5 | 0.001 | 0.434 | 0.434 | 0.00 | 0.65 | 0.65 | 1.491 | 1.148 | | 4001.5 |
| 0.2024 | 0.2 | 0.6 | 0.001 | 0.424 | 0.425 | 0.00 | 0.14 | 0.14 | 1.453 | 0.266 | | 18158.6 |
| 0.1145 | 0.2 | 0.6 | 0.002 | 0.412 | 0.414 | 0.00 | 0.00 | 0.00 | 0.631 | 0.000 | | |
| 0.0266 | 0.2 | 0.7 | 0.001 | 0.336 | 0.338 | 0.00 | 0.00 | 0.00 | 1.618 | 0.000 | | |
| -0.0612 | 0.0 | 0.7 | 0.000 | 0.154 | 0.154 | 0.00 | 0.00 | 0.00 | 2.255 | 0.000 | | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.457 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.001 | $<a_{i1}>$ [1/m] = 0.12 | $<<u_{g1}>>$ [m/s] = 1.306 |
| $<\alpha_2>$ = 0.243 | $<a_{i2}>$ [1/m] = 0.46 | $<<u_{g2}>>$ [m/s] = 0.873 |
| $<\alpha_T>$ = 0.244 | $<a_{iT}>$ [1/m] = 0.57 | $<<u_g>>$ [m/s] = 0.933 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 15.51\%$$

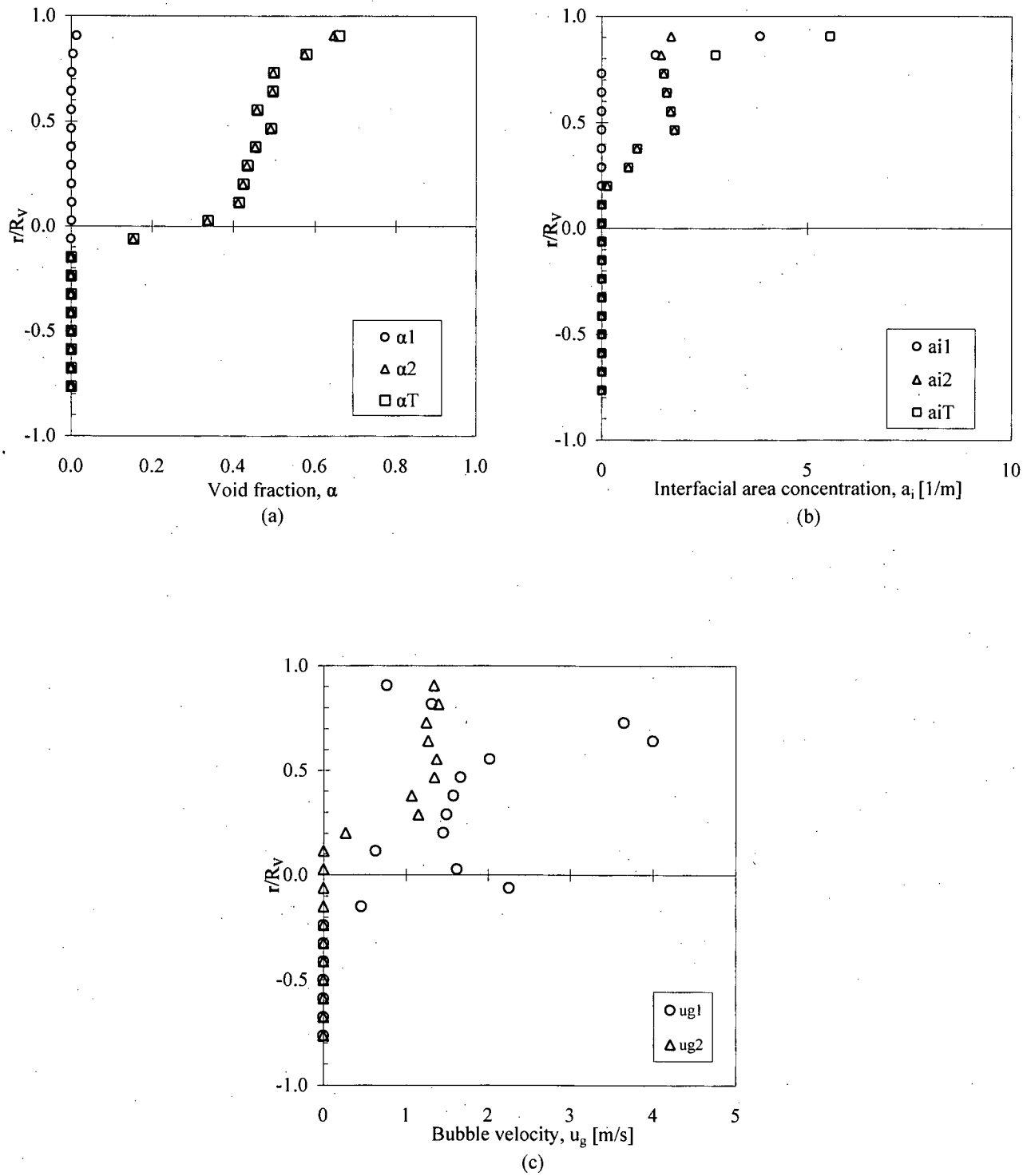


Figure 3.2.1.3 Profiles of local two-phase flow parameters for Run 1 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.2 Summary of results for Run 2.

Table 3.2.2.1 Local two-phase flow parameters for Run 2 acquired along the vertical axis at measurement port 1 (P1)

**Run 2:** $j_{g,atm}$ = 0.293 [m/s] & $j_f$ = 0.1.648 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.578 | $P_{back}$ [psig] = 17 | $j_{g,loc}$ [m/s] = 0.270 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 1.4 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 48.4 | 3.4 | 0.191 | 0.453 | 0.644 | 73.34 | 6.33 | 79.67 | 1.561 | 2.721 | 15.6 | 429.6 |
| 0.8175 | 28.3 | 3.6 | 0.082 | 0.445 | 0.527 | 34.67 | 6.78 | 41.45 | 1.733 | 3.255 | 14.1 | 393.9 |
| 0.7296 | 9.7 | 3.6 | 0.027 | 0.385 | 0.412 | 10.52 | 5.68 | 16.20 | 2.402 | 2.992 | 15.6 | 406.6 |
| 0.6417 | 5.7 | 3.5 | 0.014 | 0.343 | 0.357 | 5.56 | 5.84 | 11.40 | 2.570 | 2.888 | 15.3 | 352.6 |
| 0.5539 | 4.1 | 3.4 | 0.011 | 0.306 | 0.317 | 5.61 | 5.55 | 11.16 | 2.477 | 3.137 | 11.2 | 330.8 |
| 0.4660 | 3.5 | 3.5 | 0.010 | 0.270 | 0.280 | 3.98 | 5.17 | 9.15 | 2.510 | 2.923 | 14.3 | 313.7 |
| 0.3781 | 3.4 | 3.5 | 0.011 | 0.241 | 0.252 | 3.90 | 4.90 | 8.80 | 2.586 | 2.943 | 17.1 | 294.6 |
| 0.2903 | 2.7 | 3.3 | 0.009 | 0.219 | 0.228 | 3.85 | 4.40 | 8.25 | 2.242 | 2.795 | 14.2 | 298.5 |
| 0.2024 | 3.4 | 3.3 | 0.012 | 0.201 | 0.213 | 4.35 | 3.67 | 8.02 | 2.075 | 2.888 | 16.3 | 328.4 |
| 0.1145 | 3.9 | 2.6 | 0.016 | 0.144 | 0.160 | 5.07 | 2.30 | 7.37 | 2.160 | 2.903 | 18.9 | 375.7 |
| 0.0266 | 4.2 | 2.0 | 0.014 | 0.086 | 0.101 | 4.51 | 0.40 | 4.91 | 2.088 | 1.163 | 19.2 | 1296.0 |
| -0.0612 | 1.6 | 0.9 | 0.004 | 0.035 | 0.039 | 2.03 | 0.00 | 2.03 | 1.530 | 0.000 | 12.7 | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.013 | $<a_{i1}>$ [1/m] = 4.99 | $<<u_{g1}>>$ [m/s] = 1.846 |
| $<\alpha_2>$ = 0.131 | $<a_{i2}>$ [1/m] = 2.16 | $<<u_{g2}>>$ [m/s] = 2.778 |
| $<\alpha_T>$ = 0.144 | $<a_{iT}>$ [1/m] = 7.15 | $<<u_g>>$ [m/s] = 2.784 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 48.22\%$$

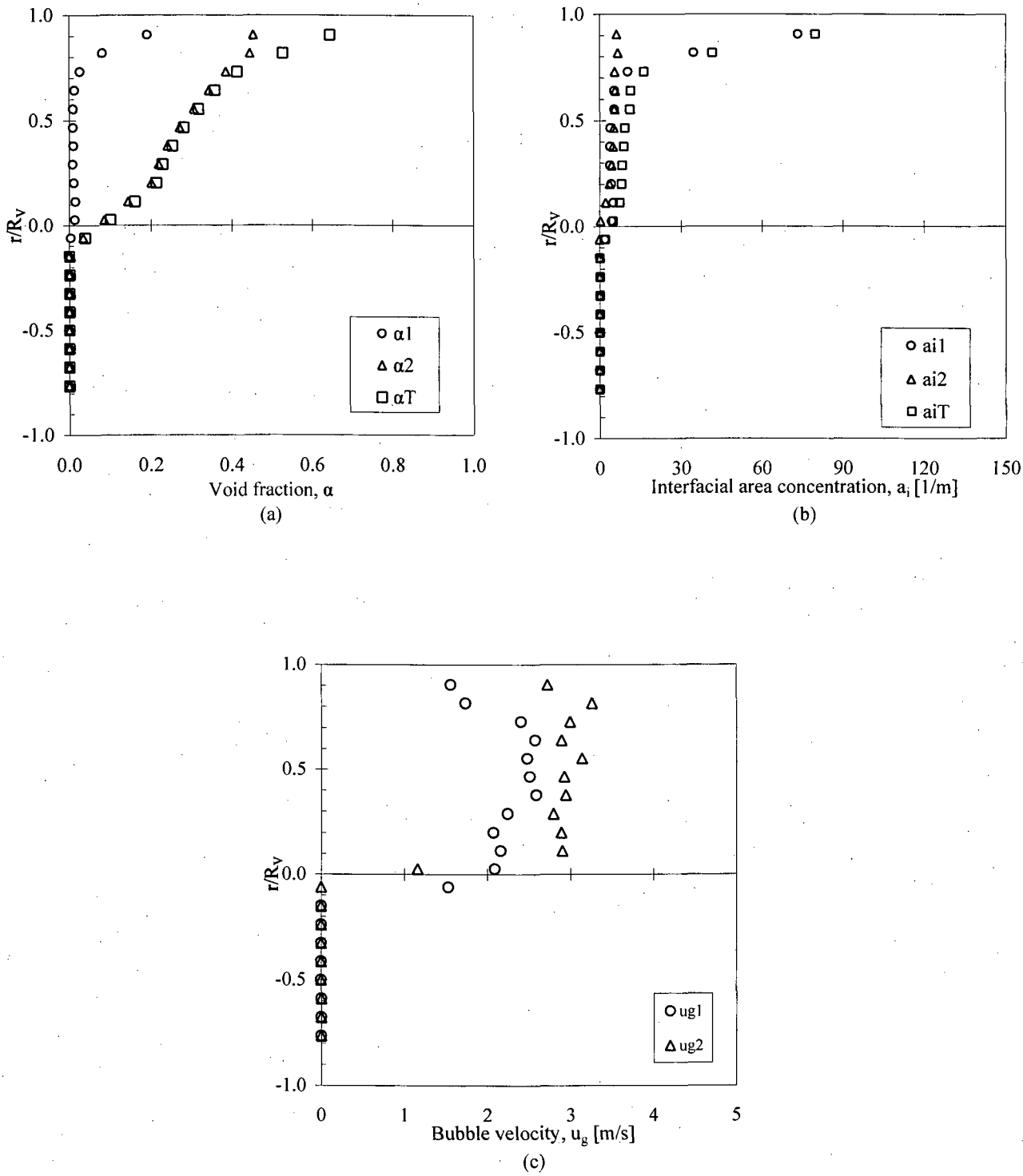


Figure 3.2.2.1 Profiles of local two-phase flow parameters for Run 2 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.2.2 Local two-phase flow parameters for Run 2 acquired along the vertical axis at measurement port 3 (P3)

**Run 2:** $j_{g,atm}$ = 0.293 [m/s] & $j_f$ = 1.648 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.529 | $P_{back}$ [psig] = 18.9 | $j_{g,loc}$ [m/s] = 0.269 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 48.8 | 4.2 | 0.149 | 0.424 | 0.572 | 65.44 | 7.72 | 73.16 | 1.681 | 3.209 | 13.6 | 329.3 |
| 0.8175 | 21.6 | 4.2 | 0.058 | 0.392 | 0.450 | 25.56 | 6.52 | 32.08 | 1.884 | 2.995 | 13.6 | 360.5 |
| 0.7296 | 9.2 | 3.5 | 0.024 | 0.340 | 0.364 | 10.86 | 5.15 | 16.01 | 2.223 | 2.958 | 13.4 | 396.1 |
| 0.6417 | 6.6 | 3.6 | 0.018 | 0.305 | 0.324 | 8.15 | 4.81 | 12.96 | 2.304 | 2.897 | 13.5 | 380.8 |
| 0.5539 | 5.0 | 3.2 | 0.014 | 0.276 | 0.290 | 6.52 | 4.34 | 10.86 | 2.119 | 2.882 | 12.7 | 381.4 |
| 0.4660 | 3.9 | 3.3 | 0.010 | 0.238 | 0.248 | 4.82 | 4.42 | 9.24 | 2.234 | 2.847 | 12.8 | 322.7 |
| 0.3781 | 3.3 | 3.0 | 0.008 | 0.218 | 0.227 | 4.13 | 3.40 | 7.53 | 2.125 | 2.757 | 11.9 | 385.2 |
| 0.2903 | 3.3 | 2.9 | 0.010 | 0.193 | 0.204 | 4.44 | 2.30 | 6.74 | 2.086 | 2.783 | 13.8 | 504.5 |
| 0.2024 | 3.3 | 2.3 | 0.013 | 0.129 | 0.141 | 4.24 | 0.81 | 5.05 | 2.001 | 2.325 | 17.7 | 951.9 |
| 0.1145 | 3.5 | 1.6 | 0.012 | 0.080 | 0.092 | 5.00 | 0.00 | 5.00 | 1.797 | 0.000 | 14.5 | |
| 0.0266 | 1.0 | 0.3 | 0.003 | 0.015 | 0.018 | 1.00 | 0.00 | 1.00 | 1.264 | 0.000 | 18.0 | |
| -0.0612 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.010 | $<a_{i1}>$ [1/m] = 4.38 | $<<u_{g1}>>$ [m/s] = 1.922 |
| $<\alpha_2>$ = 0.105 | $<a_{i2}>$ [1/m] = 1.52 | $<<u_{g2}>>$ [m/s] = 2.727 |
| $<\alpha_T>$ = 0.115 | $<a_{iT}>$ [1/m] = 5.91 | $<<u_g>>$ [m/s] = 2.676 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 14.63\%$$

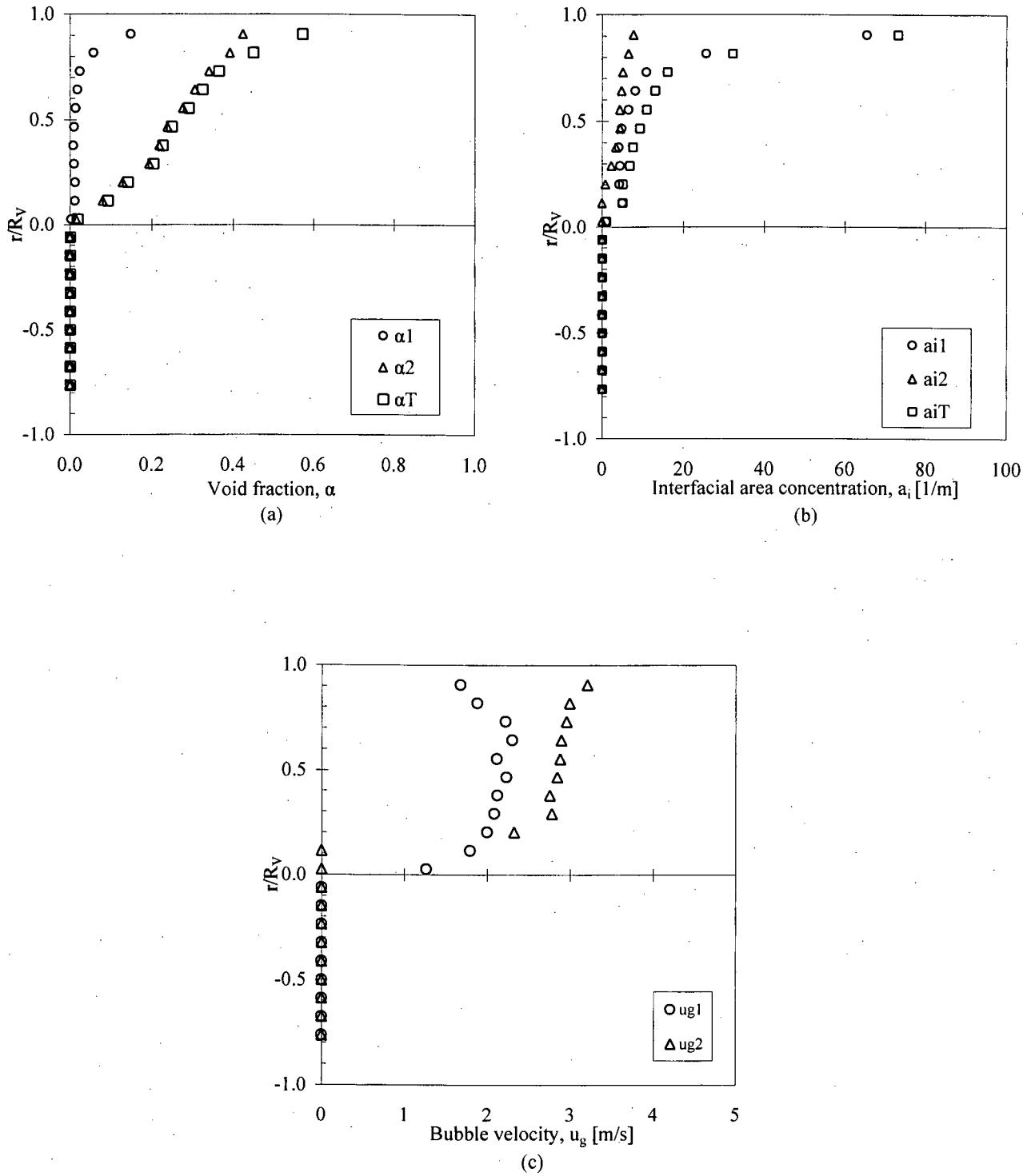


Figure 3.2.2.2 Profiles of local two-phase flow parameters for Run 2 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.2.3 Local two-phase flow parameters for Run 2 acquired along the vertical axis at measurement port 4 (P4)

**Run 2:** $j_{g,atm}$ = 0.293 [m/s] & $j_f$ = 1.648 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.547 | $P_{back}$ [psig] = 18.6 | $j_{g,loc}$ [m/s] = 0.270 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 1.3 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 36.2 | 3.0 | 0.108 | 0.391 | 0.499 | 49.98 | 5.96 | 55.94 | 1.629 | 3.165 | 13.0 | 393.9 |
| 0.8175 | 12.3 | 3.1 | 0.030 | 0.367 | 0.397 | 13.98 | 6.74 | 20.72 | 1.992 | 3.144 | 12.8 | 326.5 |
| 0.7296 | 3.8 | 3.1 | 0.010 | 0.342 | 0.352 | 4.04 | 6.44 | 10.48 | 2.580 | 2.943 | 14.3 | 318.8 |
| 0.6417 | 2.6 | 3.1 | 0.006 | 0.316 | 0.323 | 2.32 | 5.57 | 7.89 | 3.001 | 2.951 | 16.3 | 340.7 |
| 0.5539 | 2.6 | 3.1 | 0.007 | 0.284 | 0.291 | 3.30 | 5.22 | 8.52 | 2.699 | 2.944 | 12.7 | 326.8 |
| 0.4660 | 3.0 | 3.1 | 0.009 | 0.267 | 0.276 | 3.65 | 4.75 | 8.40 | 2.547 | 2.728 | 14.1 | 337.1 |
| 0.3781 | 2.7 | 3.0 | 0.009 | 0.244 | 0.253 | 3.12 | 4.02 | 7.14 | 2.437 | 2.784 | 17.3 | 363.6 |
| 0.2903 | 2.6 | 3.0 | 0.009 | 0.224 | 0.233 | 3.27 | 3.31 | 6.58 | 2.066 | 2.905 | 16.5 | 406.2 |
| 0.2024 | 3.2 | 2.7 | 0.013 | 0.164 | 0.177 | 4.58 | 1.39 | 5.97 | 1.978 | 2.104 | 16.4 | 708.3 |
| 0.1145 | 3.5 | 1.8 | 0.014 | 0.104 | 0.117 | 4.17 | 0.25 | 4.42 | 2.114 | 0.604 | 19.6 | 2484.0 |
| 0.0266 | 2.7 | 1.4 | 0.009 | 0.073 | 0.082 | 3.82 | 0.00 | 3.82 | 1.881 | 0.000 | 14.0 | |
| -0.0612 | 0.9 | 0.0 | 0.004 | 0.000 | 0.004 | 0.79 | 0.00 | 0.79 | 1.243 | 0.000 | 31.1 | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.008 | $\langle a_{i1}\rangle$ [1/m] = 3.08 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.909 |
| $\langle\alpha_2\rangle$ = 0.115 | $\langle a_{i2}\rangle$ [1/m] = 1.77 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 2.667 |
| $\langle\alpha_T\rangle$ = 0.123 | $\langle a_{iT}\rangle$ [1/m] = 4.85 | $\langle\langle u_g\rangle\rangle$ [m/s] = 2.700 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 22.43\%$$

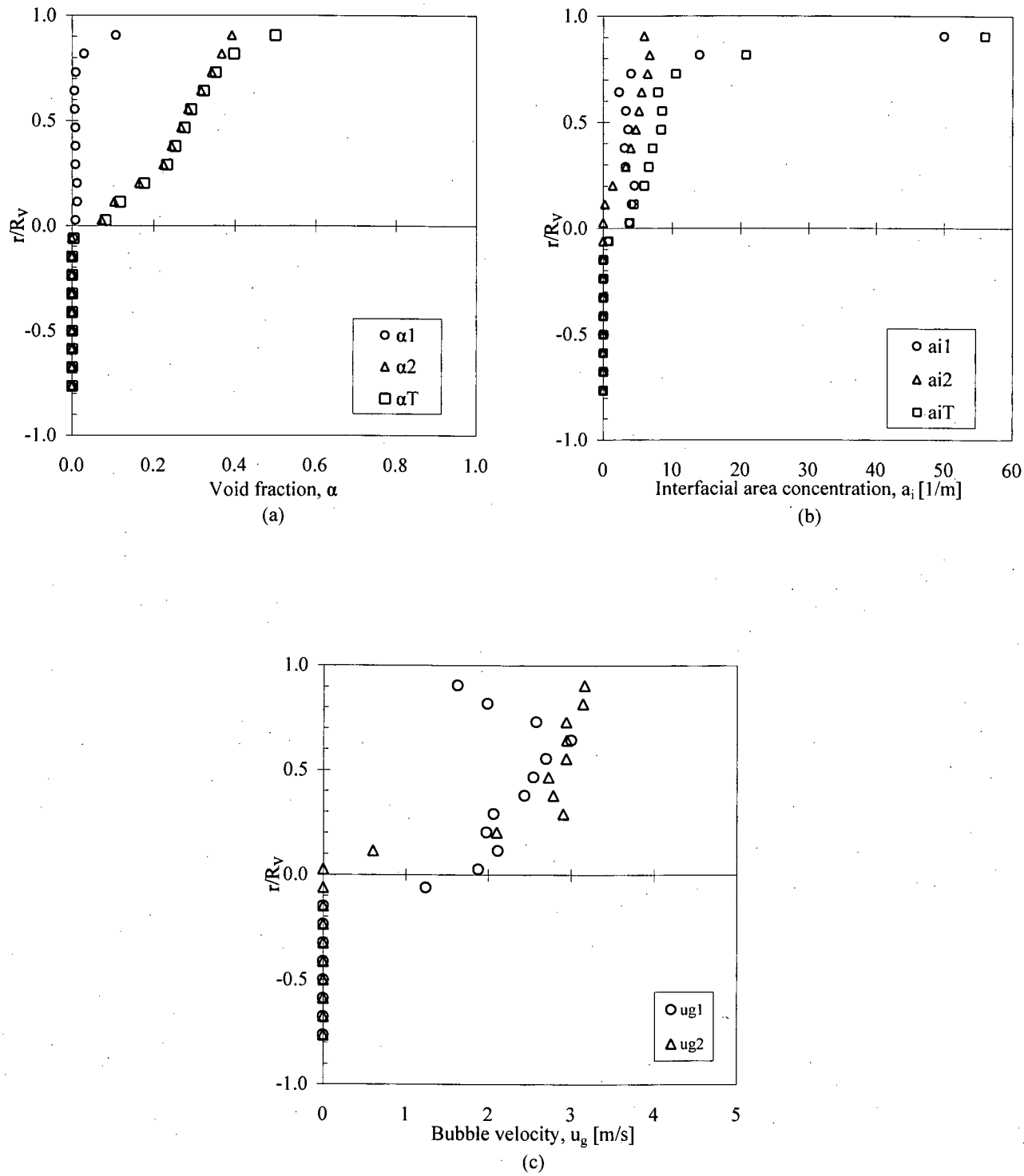


Figure 3.2.2.3 Profiles of local two-phase flow parameters for Run 2 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.3 Summary of results for Run 3.

Table 3.2.3.1 Local two-phase flow parameters for Run 3 acquired along the vertical axis at measurement port 1 (P1)

**Run 3:** $j_{g,atm}$ = 0.300 [m/s] & $j_f$ = 2.203 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.553 | $P_{back}$ [psig] = 18.8 | $j_{g,loc}$ [m/s] = 0.267 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.50 | $P_{loc}$ [psig] = 1.8 | $j_f$ [m/s] = 2.207 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 146.8 | 3.9 | 0.412 | 0.293 | 0.705 | 184.45 | 7.41 | 191.86 | 1.963 | 4.244 | 13.4 | 237.0 |
| 0.8175 | 110.1 | 4.1 | 0.210 | 0.286 | 0.496 | 124.11 | 5.69 | 129.80 | 2.169 | 4.011 | 10.1 | 301.5 |
| 0.7296 | 69.7 | 4.1 | 0.112 | 0.268 | 0.380 | 70.31 | 5.64 | 75.95 | 2.347 | 3.815 | 9.5 | 284.8 |
| 0.6417 | 32.0 | 4.1 | 0.050 | 0.247 | 0.297 | 29.29 | 4.92 | 34.21 | 2.590 | 3.764 | 10.3 | 301.1 |
| 0.5539 | 17.2 | 4.1 | 0.031 | 0.220 | 0.251 | 16.06 | 4.71 | 20.77 | 2.712 | 3.635 | 11.6 | 280.8 |
| 0.4660 | 11.9 | 4.0 | 0.024 | 0.191 | 0.214 | 11.43 | 4.06 | 15.49 | 2.793 | 3.678 | 12.4 | 281.8 |
| 0.3781 | 8.8 | 3.4 | 0.019 | 0.169 | 0.188 | 8.19 | 3.76 | 11.95 | 2.802 | 3.709 | 14.2 | 268.9 |
| 0.2903 | 7.3 | 3.0 | 0.016 | 0.147 | 0.163 | 6.89 | 3.09 | 9.98 | 2.761 | 3.578 | 14.2 | 285.6 |
| 0.2024 | 6.4 | 2.7 | 0.016 | 0.113 | 0.129 | 6.24 | 1.58 | 7.82 | 2.736 | 2.549 | 15.3 | 430.6 |
| 0.1145 | 6.3 | 1.7 | 0.016 | 0.066 | 0.082 | 6.78 | 0.64 | 7.42 | 2.487 | 2.569 | 14.2 | 620.6 |
| 0.0266 | 2.0 | 0.7 | 0.005 | 0.025 | 0.030 | 2.16 | 0.00 | 2.16 | 1.047 | 0.000 | 14.4 | |
| -0.0612 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.028 | $\langle a_{i1}\rangle$ [1/m] = 14.37 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.278 |
| $\langle\alpha_2\rangle$ = 0.083 | $\langle a_{i2}\rangle$ [1/m] = 1.65 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.587 |
| $\langle\alpha_T\rangle$ = 0.110 | $\langle a_{iT}\rangle$ [1/m] = 16.02 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.300 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 36.58\%$$

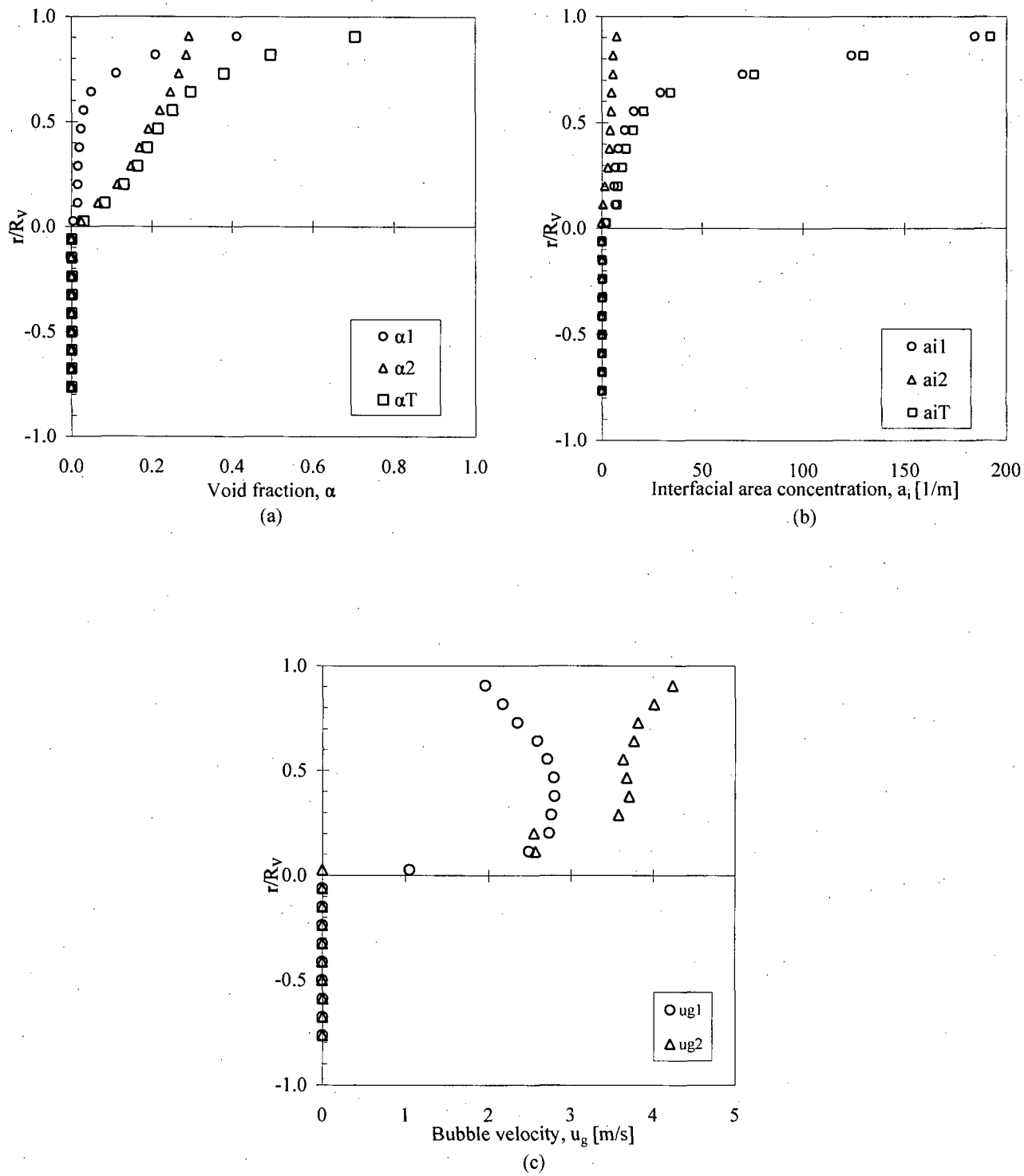


Figure 3.2.3.1 Profiles of local two-phase flow parameters for Run 3 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.3.2 Local two-phase flow parameters for Run 3 acquired along the vertical axis at measurement port 3 (P3)

**Run 3:** $j_{g,atm}$ = 0.300 [m/s] & $j_f$ = 2.203 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.528 | $P_{back}$ [psig] = 20.6 | $j_{g,loc}$ [m/s] = 0.268 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.30 | $P_{loc}$ [psig] = 1.8 | $j_f$ [m/s] = 2.200 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 118.3 | 3.8 | 0.246 | 0.266 | 0.512 | 129.39 | 5.06 | 134.45 | 2.211 | 4.318 | 11.4 | 315.3 |
| 0.8175 | 70.4 | 4.1 | 0.131 | 0.264 | 0.395 | 72.80 | 5.48 | 78.28 | 2.325 | 3.862 | 10.8 | 289.2 |
| 0.7296 | 35.6 | 3.9 | 0.062 | 0.251 | 0.313 | 35.69 | 4.50 | 40.19 | 2.388 | 3.790 | 10.4 | 334.8 |
| 0.6417 | 16.8 | 3.5 | 0.030 | 0.226 | 0.256 | 15.16 | 3.84 | 19.00 | 2.655 | 3.657 | 11.9 | 353.6 |
| 0.5539 | 10.3 | 3.6 | 0.020 | 0.202 | 0.222 | 9.90 | 3.75 | 13.65 | 2.702 | 3.653 | 11.8 | 323.2 |
| 0.4660 | 8.5 | 3.5 | 0.017 | 0.182 | 0.199 | 8.45 | 3.23 | 11.68 | 2.746 | 3.531 | 12.1 | 338.1 |
| 0.3781 | 7.9 | 3.1 | 0.015 | 0.168 | 0.184 | 8.15 | 2.94 | 11.09 | 2.601 | 3.712 | 11.3 | 343.3 |
| 0.2903 | 6.3 | 2.9 | 0.014 | 0.151 | 0.165 | 6.18 | 2.29 | 8.47 | 2.763 | 3.727 | 13.8 | 394.3 |
| 0.2024 | 5.8 | 2.8 | 0.015 | 0.117 | 0.132 | 5.73 | 2.13 | 7.86 | 2.706 | 3.592 | 15.6 | 330.1 |
| 0.1145 | 6.9 | 1.5 | 0.018 | 0.051 | 0.070 | 7.80 | 0.18 | 7.98 | 2.445 | 0.700 | 14.0 | 1710.0 |
| 0.0266 | 6.6 | 0.7 | 0.018 | 0.025 | 0.043 | 7.53 | 0.00 | 7.53 | 2.353 | 0.000 | 14.6 | |
| -0.0612 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.018 | $\langle a_{i1}\rangle$ [1/m] = 9.54 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.315 |
| $\langle\alpha_2\rangle$ = 0.078 | $\langle a_{i2}\rangle$ [1/m] = 1.34 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.572 |
| $\langle\alpha_T\rangle$ = 0.097 | $\langle a_{iT}\rangle$ [1/m] = 10.88 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.400 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 22.77\%$$

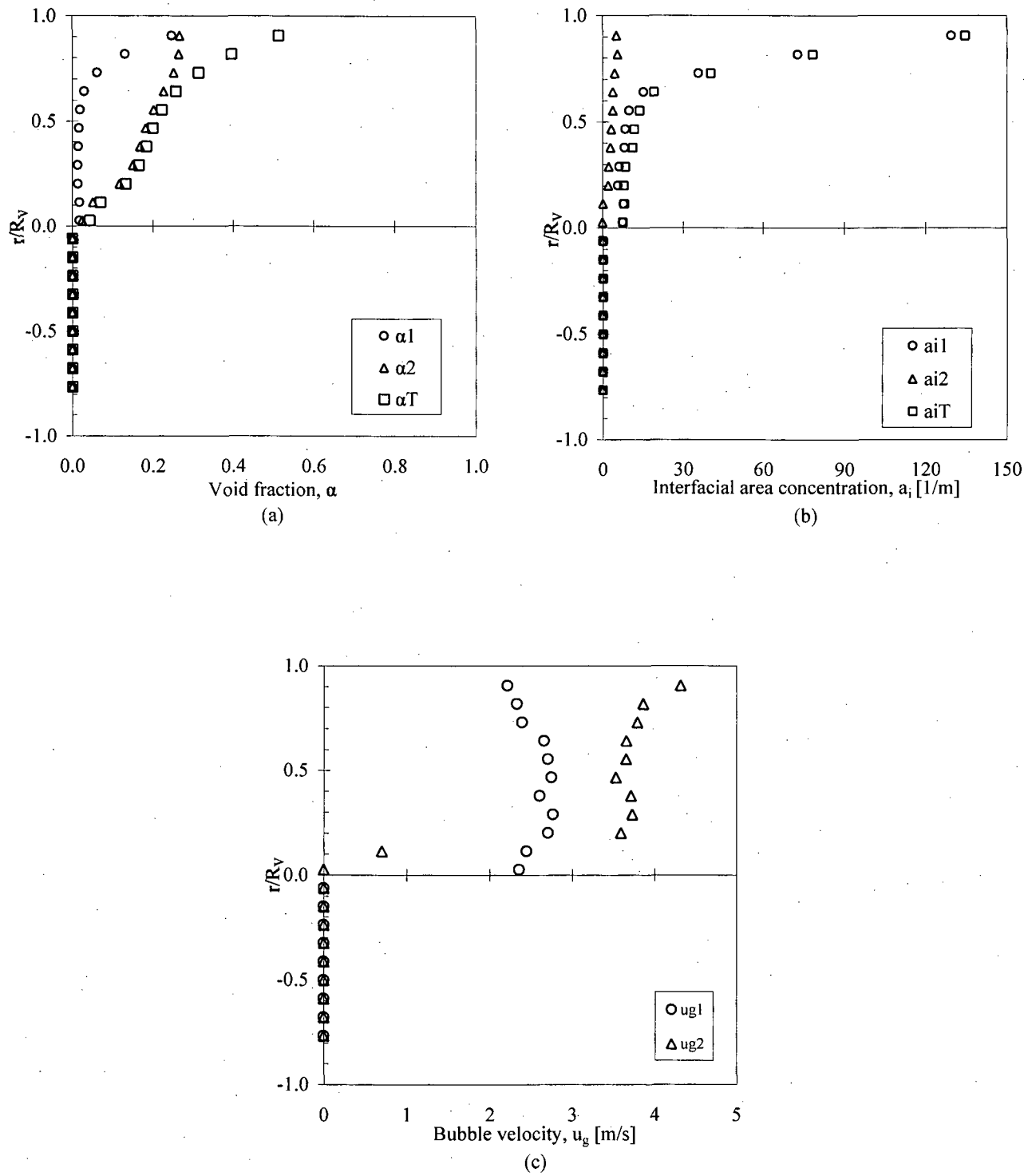


Figure 3.2.3.2 Profiles of local two-phase flow parameters for Run 3 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.3.3 Local two-phase flow parameters for Run 3 acquired along the vertical axis at measurement port 4 (P4)

**Run 3:** $j_{g,atm}$ = 0.300 [m/s] & $j_f$ = 2.203 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.536 | $P_{back}$ [psig] = 20 | $j_{g,loc}$ [m/s] = 0.269 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.30 | $P_{loc}$ [psig] = 1.7 | $j_f$ [m/s] = 2.200 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 89.3 | 3.4 | 0.151 | 0.269 | 0.420 | 101.11 | 5.19 | 106.30 | 2.069 | 3.717 | 8.9 | 311.2 |
| 0.8175 | 41.7 | 3.5 | 0.060 | 0.264 | 0.325 | 42.73 | 4.92 | 47.65 | 2.284 | 3.618 | 8.5 | 322.3 |
| 0.7296 | 17.0 | 3.8 | 0.027 | 0.263 | 0.290 | 15.71 | 4.75 | 20.46 | 2.641 | 3.913 | 10.1 | 332.6 |
| 0.6417 | 8.7 | 3.7 | 0.015 | 0.244 | 0.259 | 8.25 | 4.83 | 13.08 | 2.728 | 4.037 | 11.0 | 303.4 |
| 0.5539 | 5.7 | 3.7 | 0.013 | 0.236 | 0.249 | 5.40 | 4.07 | 9.47 | 2.914 | 3.660 | 14.4 | 347.5 |
| 0.4660 | 6.1 | 3.7 | 0.015 | 0.215 | 0.230 | 5.34 | 3.79 | 9.13 | 2.912 | 3.544 | 16.9 | 340.7 |
| 0.3781 | 4.5 | 3.5 | 0.011 | 0.195 | 0.207 | 4.07 | 3.44 | 7.51 | 2.904 | 3.717 | 16.8 | 340.6 |
| 0.2903 | 4.1 | 3.2 | 0.010 | 0.178 | 0.188 | 3.87 | 2.60 | 6.47 | 2.855 | 3.423 | 16.0 | 411.0 |
| 0.2024 | 5.5 | 2.8 | 0.015 | 0.131 | 0.146 | 5.33 | 1.13 | 6.46 | 2.741 | 2.586 | 17.1 | 694.5 |
| 0.1145 | 5.2 | 1.9 | 0.015 | 0.081 | 0.096 | 5.45 | 0.19 | 5.64 | 2.555 | 0.658 | 16.5 | 2545.3 |
| 0.0266 | 5.1 | 1.0 | 0.014 | 0.037 | 0.051 | 5.31 | 0.21 | 5.52 | 2.502 | 0.435 | 16.0 | 1054.3 |
| -0.0612 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.1491 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.011 | $<a_{i1}>$ [1/m] = 6.02 | $<<u_{g1}>>$ [m/s] = 2.347 |
| $<\alpha_2>$ = 0.089 | $<a_{i2}>$ [1/m] = 1.42 | $<<u_{g2}>>$ [m/s] = 3.393 |
| $<\alpha_T>$ = 0.100 | $<a_{iT}>$ [1/m] = 7.44 | $<<u_g>>$ [m/s] = 3.352 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 24.39\%$$

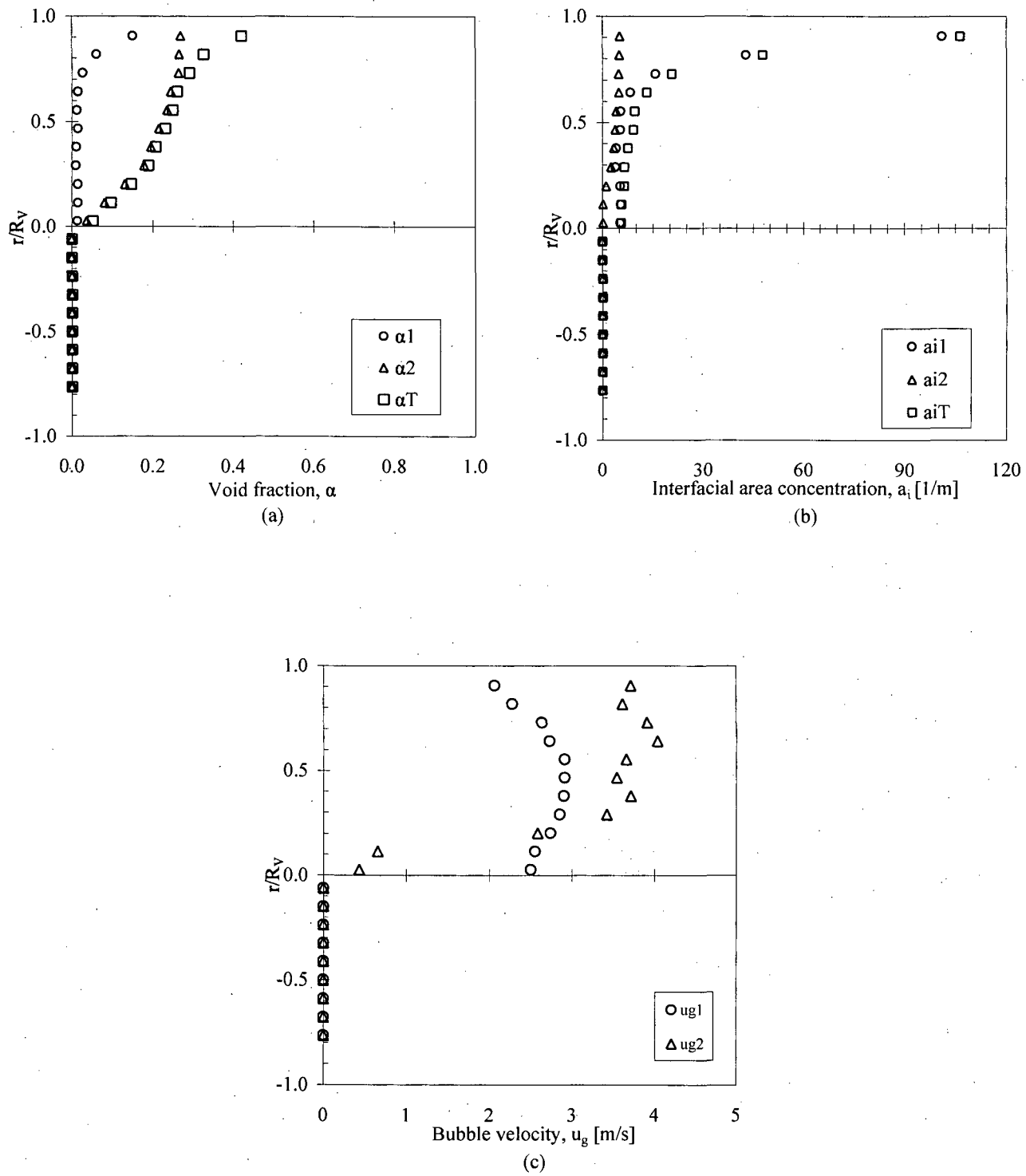


Figure 3.2.3.3 Profiles of local two-phase flow parameters for Run 3 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.4 Summary of results for Run 4.

Table 3.2.4.1 Local two-phase flow parameters for Run 4 acquired along the vertical axis at measurement port 1 (P1)

**Run 4:** $j_{g,atm}$ = 0.587 [m/s] & $j_f$ = 0.560 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.975 | $P_{back}$ [psig] = 22.5 | $j_{g,loc}$ [m/s] = 0.549 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.80 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.565 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 3.6 | 0.6 | 0.019 | 0.721 | 0.741 | 7.89 | 0.78 | 8.67 | 1.054 | 1.124 | 14.5 | 5549.2 |
| 0.8175 | 1.1 | 0.7 | 0.006 | 0.730 | 0.736 | 2.25 | 1.88 | 4.13 | 1.315 | 2.021 | 15.2 | 2329.5 |
| 0.7296 | 0.4 | 0.7 | 0.002 | 0.717 | 0.719 | 0.53 | 1.66 | 2.19 | 2.170 | 1.895 | 24.9 | 2591.6 |
| 0.6417 | 0.4 | 0.7 | 0.002 | 0.673 | 0.674 | 0.10 | 1.66 | 1.76 | 2.415 | 1.788 | 96.0 | 2431.1 |
| 0.5539 | 0.4 | 0.7 | 0.002 | 0.654 | 0.656 | 0.15 | 1.73 | 1.88 | 2.254 | 1.837 | 88.0 | 2267.5 |
| 0.4660 | 0.4 | 0.6 | 0.002 | 0.645 | 0.647 | 0.00 | 1.25 | 1.25 | 2.177 | 1.721 | | 3094.1 |
| 0.3781 | 0.4 | 0.5 | 0.002 | 0.647 | 0.649 | 0.00 | 1.21 | 1.21 | 1.940 | 1.757 | | 3208.8 |
| 0.2903 | 0.2 | 0.6 | 0.001 | 0.648 | 0.649 | 0.08 | 1.09 | 1.17 | 1.810 | 1.652 | 67.5 | 3569.2 |
| 0.2024 | 0.5 | 0.7 | 0.003 | 0.643 | 0.645 | 0.66 | 1.01 | 1.67 | 1.620 | 1.700 | 23.6 | 3818.0 |
| 0.1145 | 0.5 | 0.6 | 0.003 | 0.619 | 0.621 | 1.27 | 0.18 | 1.45 | 1.555 | 0.641 | 11.8 | 20630.0 |
| 0.0266 | 0.6 | 0.7 | 0.003 | 0.618 | 0.621 | 0.56 | 0.00 | 0.56 | 1.558 | 0.000 | 33.2 | |
| -0.0612 | 0.3 | 0.8 | 0.002 | 0.555 | 0.557 | 0.32 | 0.00 | 0.32 | 1.662 | 0.000 | 31.9 | |
| -0.1491 | 0.2 | 0.7 | 0.001 | 0.357 | 0.358 | 0.00 | 0.00 | 0.00 | 1.666 | 0.000 | | |
| -0.2370 | 0.1 | 0.8 | 0.000 | 0.291 | 0.292 | 0.00 | 0.00 | 0.00 | 1.763 | 0.000 | | |
| -0.3249 | 0.0 | 0.2 | 0.000 | 0.073 | 0.073 | 0.00 | 0.00 | 0.00 | 0.924 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.002 | $\langle a_{i1}\rangle$ [1/m] = 0.43 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.498 |
| $\langle\alpha_2\rangle$ = 0.428 | $\langle a_{i2}\rangle$ [1/m] = 0.54 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.111 |
| $\langle\alpha_T\rangle$ = 0.429 | $\langle a_{iT}\rangle$ [1/m] = 0.97 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.190 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 6.87\%$$

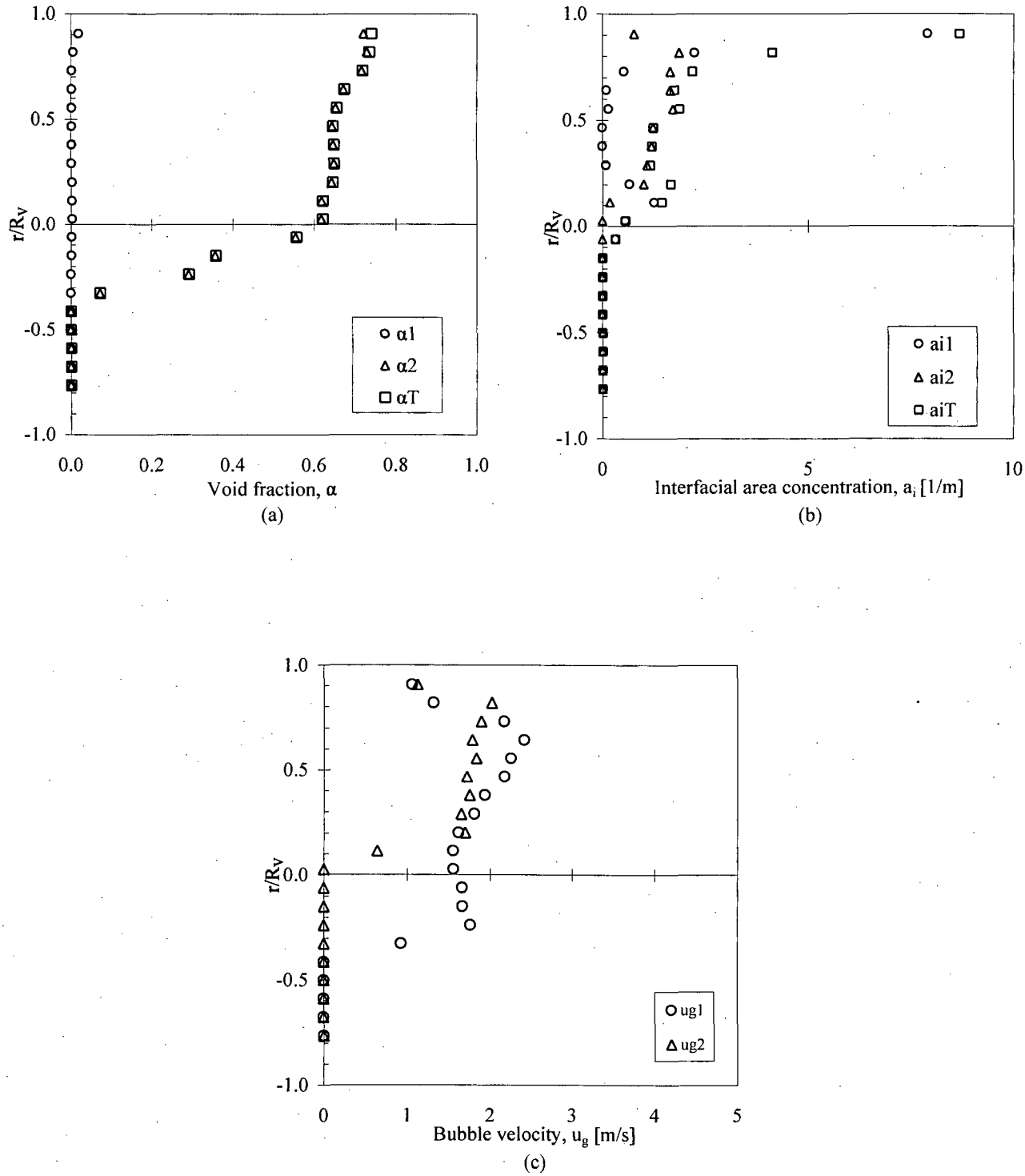


Figure 3.2.4.1 Profiles of local two-phase flow parameters for Run 4 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.4.2 Local two-phase flow parameters for Run 4 acquired along the vertical axis at measurement port 3 (P3)

**Run 4:** $j_{g,atm}$ = 0.587 [m/s] & $j_f$ = 0.560 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.915 | $P_{back}$ [psig] = 25.1 | $j_{g,loc}$ [m/s] = 0.551 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.50 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.556 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 4.8 | 0.6 | 0.034 | 0.698 | 0.732 | 11.42 | 1.11 | 12.53 | 0.946 | 2.178 | 18.0 | 3774.1 |
| 0.8175 | 1.9 | 0.6 | 0.012 | 0.679 | 0.691 | 3.92 | 1.34 | 5.26 | 1.281 | 1.990 | 18.8 | 3040.3 |
| 0.7296 | 0.7 | 0.6 | 0.003 | 0.694 | 0.697 | 0.80 | 1.12 | 1.92 | 1.816 | 1.884 | 23.3 | 3718.9 |
| 0.6417 | 0.3 | 0.5 | 0.002 | 0.673 | 0.674 | 0.33 | 1.10 | 1.43 | 1.852 | 1.852 | 29.1 | 3668.2 |
| 0.5539 | 0.5 | 0.6 | 0.002 | 0.660 | 0.662 | 0.31 | 1.32 | 1.63 | 1.574 | 1.741 | 40.6 | 2998.6 |
| 0.4660 | 0.4 | 0.5 | 0.003 | 0.656 | 0.659 | 0.66 | 0.94 | 1.60 | 1.590 | 1.946 | 22.7 | 4189.8 |
| 0.3781 | 0.3 | 0.6 | 0.002 | 0.671 | 0.673 | 0.25 | 1.34 | 1.59 | 1.702 | 1.946 | 45.6 | 3005.8 |
| 0.2903 | 0.4 | 0.6 | 0.002 | 0.657 | 0.659 | 0.76 | 0.88 | 1.64 | 1.575 | 1.503 | 15.0 | 4479.5 |
| 0.2024 | 0.5 | 0.6 | 0.003 | 0.661 | 0.664 | 0.68 | 0.14 | 0.82 | 1.408 | 0.285 | 22.1 | 28341.4 |
| 0.1145 | 0.6 | 0.5 | 0.003 | 0.634 | 0.637 | 1.31 | 0.00 | 1.31 | 1.263 | 0.000 | 12.4 | |
| 0.0266 | 0.4 | 0.7 | 0.002 | 0.621 | 0.624 | 0.76 | 0.00 | 0.76 | 1.442 | 0.000 | 17.4 | |
| -0.0612 | 0.4 | 0.8 | 0.002 | 0.583 | 0.585 | 0.38 | 0.00 | 0.38 | 1.417 | 0.000 | 30.0 | |
| -0.1491 | 0.3 | 0.8 | 0.002 | 0.424 | 0.426 | 0.00 | 0.00 | 0.00 | 1.801 | 0.000 | | |
| -0.2370 | 0.1 | 0.5 | 0.000 | 0.323 | 0.324 | 0.11 | 0.00 | 0.11 | 1.831 | 0.000 | 16.4 | |
| -0.3249 | 0.1 | 0.3 | 0.000 | 0.131 | 0.131 | 0.00 | 0.00 | 0.00 | 1.415 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.002 | $\langle a_{i1}\rangle$ [1/m] = 0.69 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.280 |
| $\langle\alpha_2\rangle$ = 0.441 | $\langle a_{i2}\rangle$ [1/m] = 0.39 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 0.960 |
| $\langle\alpha_T\rangle$ = 0.443 | $\langle a_{iT}\rangle$ [1/m] = 1.07 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.026 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 17.41\%$$

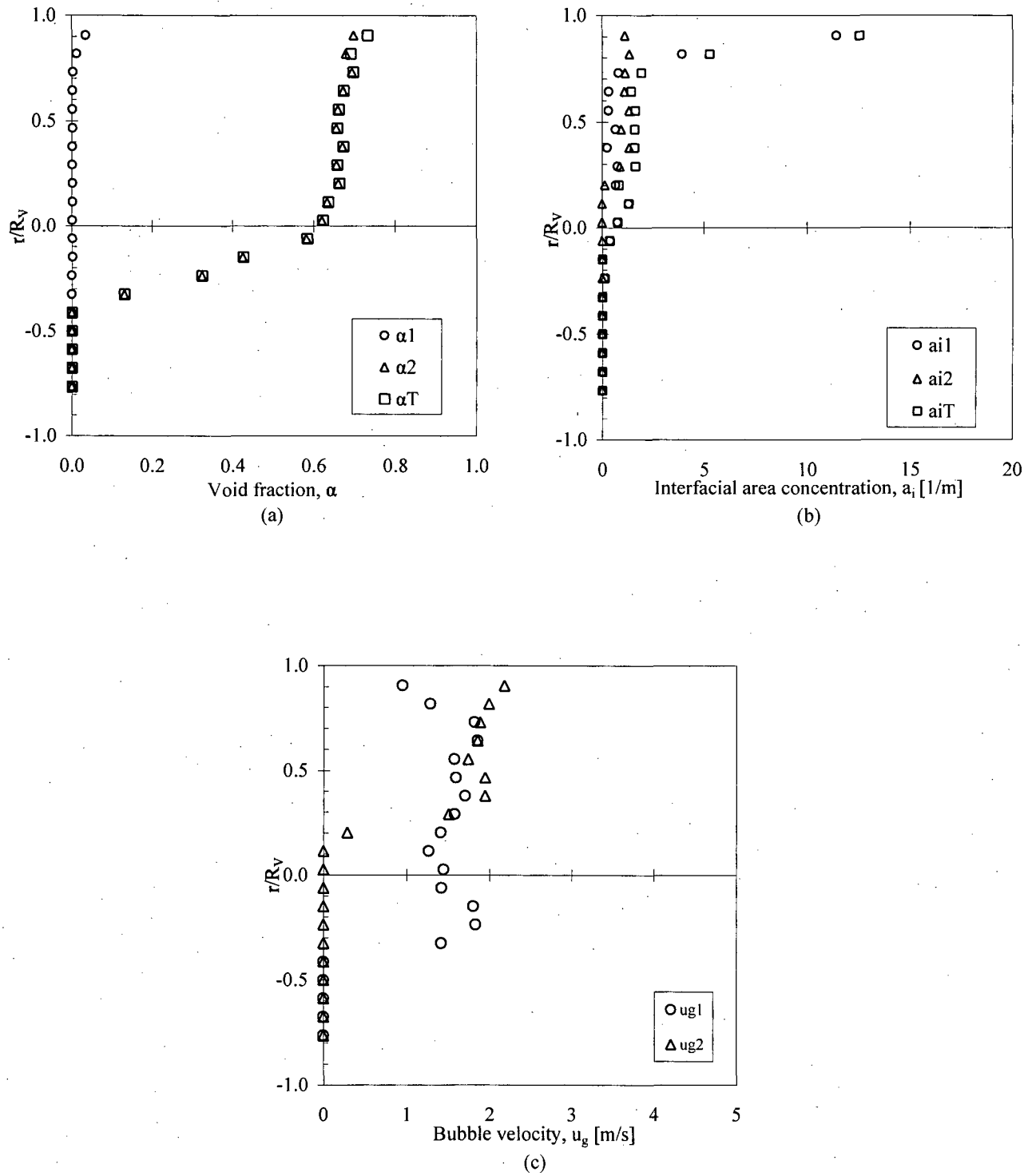


Figure 3.2.4.2 Profiles of local two-phase flow parameters for Run 4 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.4.3 Local two-phase flow parameters for Run 4 acquired along the vertical axis at measurement port 4 (P4)

**Run 4:** $j_{g,atm}$ = 0.587 [m/s] & $j_f$ = 0.560 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.954 | $P_{back}$ [psig] = 23.5 | $j_{g,loc}$ [m/s] = 0.551 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.40 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.552 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 2.1 | 0.5 | 0.011 | 0.700 | 0.711 | 5.22 | 1.59 | 6.81 | 1.053 | 1.913 | 12.8 | 2639.6 |
| 0.8175 | 0.4 | 0.5 | 0.002 | 0.680 | 0.682 | 0.00 | 1.29 | 1.29 | 2.248 | 1.842 | | 3164.2 |
| 0.7296 | 0.4 | 0.5 | 0.001 | 0.678 | 0.679 | 0.10 | 1.38 | 1.48 | 2.190 | 1.750 | 84.0 | 2945.7 |
| 0.6417 | 0.4 | 0.6 | 0.002 | 0.680 | 0.681 | 0.00 | 1.54 | 1.54 | 3.337 | 1.890 | | 2647.4 |
| 0.5539 | 0.3 | 0.5 | 0.001 | 0.656 | 0.657 | 0.26 | 1.08 | 1.34 | 2.054 | 1.682 | 18.5 | 3646.1 |
| 0.4660 | 0.2 | 0.5 | 0.001 | 0.640 | 0.642 | 0.52 | 1.11 | 1.63 | 1.456 | 1.718 | 13.8 | 3461.1 |
| 0.3781 | 0.3 | 0.6 | 0.001 | 0.665 | 0.666 | 0.39 | 1.18 | 1.57 | 1.595 | 1.763 | 21.5 | 3381.4 |
| 0.2903 | 0.3 | 0.5 | 0.002 | 0.661 | 0.663 | 0.14 | 0.74 | 0.88 | 1.647 | 1.576 | 81.4 | 5361.9 |
| 0.2024 | 0.6 | 0.6 | 0.004 | 0.646 | 0.650 | 0.64 | 0.00 | 0.64 | 1.511 | 0.000 | 37.5 | |
| 0.1145 | 0.5 | 0.6 | 0.003 | 0.630 | 0.633 | 0.79 | 0.00 | 0.79 | 1.163 | 0.000 | 22.0 | |
| 0.0266 | 0.5 | 0.6 | 0.003 | 0.599 | 0.602 | 1.37 | 0.00 | 1.37 | 1.124 | 0.000 | 11.8 | |
| -0.0612 | 0.3 | 0.6 | 0.001 | 0.567 | 0.568 | 0.67 | 0.00 | 0.67 | 1.554 | 0.000 | 10.7 | |
| -0.1491 | 0.5 | 0.7 | 0.004 | 0.360 | 0.364 | 0.81 | 0.00 | 0.81 | 1.409 | 0.000 | 25.9 | |
| -0.2370 | 0.1 | 0.5 | 0.000 | 0.211 | 0.211 | 0.00 | 0.00 | 0.00 | 1.621 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 1.440 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.002 | $<a_{i1}>$ [1/m] = 0.44 | $<<u_{g1}>>$ [m/s] = 1.436 |
| $<\alpha_2>$ = 0.420 | $<a_{i2}>$ [1/m] = 0.40 | $<<u_{g2}>>$ [m/s] = 0.926 |
| $<\alpha_T>$ = 0.421 | $<a_{iT}>$ [1/m] = 0.83 | $<<u_g>>$ [m/s] = 0.991 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 24.30\%$$

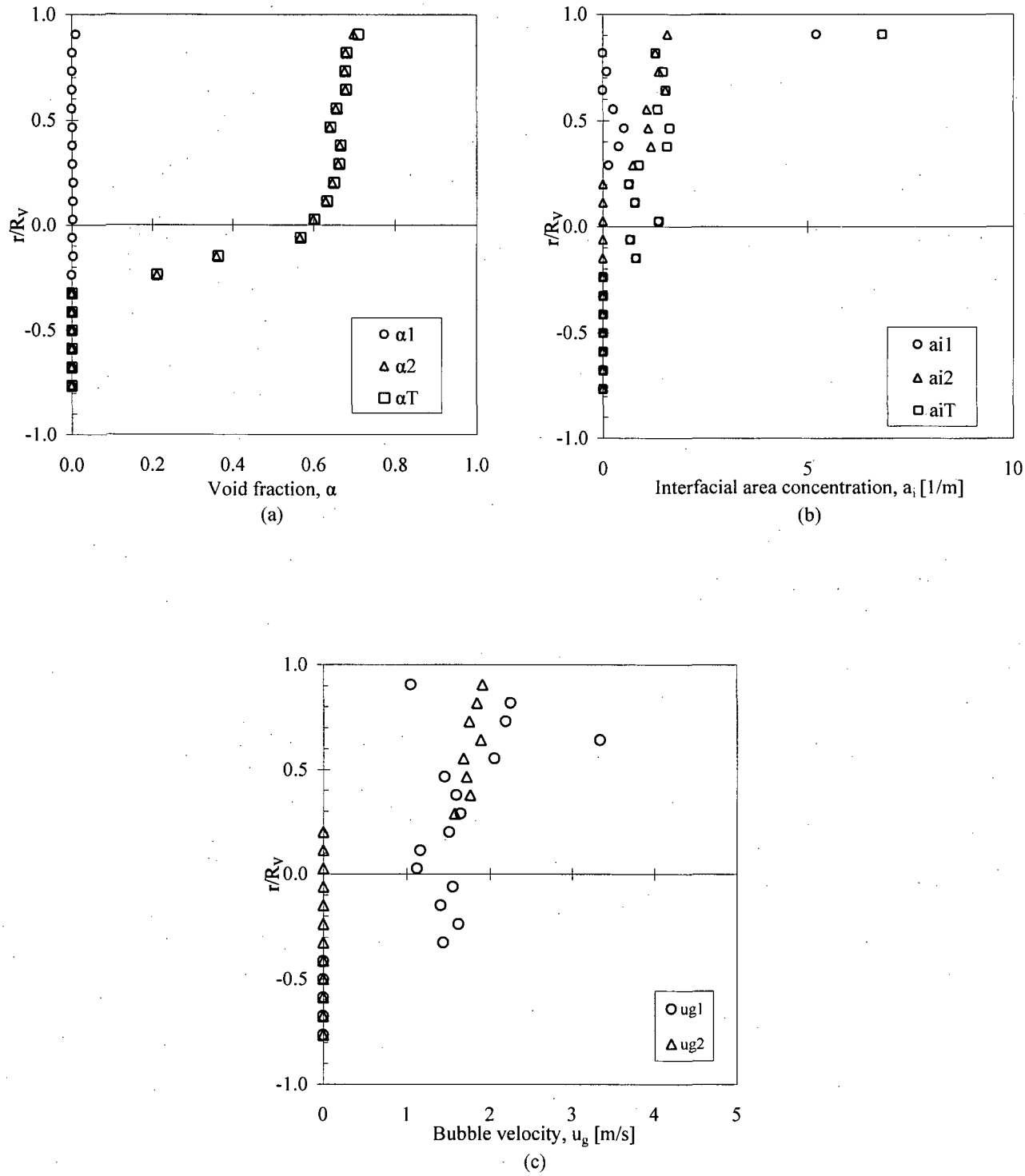


Figure 3.2.4.3 Profiles of local two-phase flow parameters for Run 4 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.5 Summary of results for Run 5.

Table 3.2.5.1 Local two-phase flow parameters for Run 5 acquired along the vertical axis at measurement port 1 (P1)

**Run 5:** $j_{g,atm}$ = 0.603 [m/s] & $j_f$ = 0.1.653 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.019 | $P_{back}$ [psig] = 22.1 | $j_{g,loc}$ [m/s] = 0.550 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 52.20 | $P_{loc}$ [psig] = 1.5 | $j_f$ [m/s] = 1.657 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 6 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 54.6 | 3.6 | 0.124 | 0.468 | 0.592 | 68.05 | 2.08 | 70.13 | 1.903 | 1.812 | 11.0 | 1349.1 |
| 0.8175 | 25.6 | 4.3 | 0.046 | 0.493 | 0.539 | 28.58 | 7.17 | 35.75 | 2.033 | 3.556 | 9.7 | 412.9 |
| 0.7296 | 11.5 | 4.0 | 0.022 | 0.481 | 0.503 | 11.79 | 4.71 | 16.50 | 2.468 | 3.344 | 11.1 | 613.2 |
| 0.6417 | 6.0 | 4.1 | 0.012 | 0.468 | 0.480 | 6.25 | 5.91 | 12.16 | 2.746 | 3.568 | 11.8 | 474.8 |
| 0.5539 | 4.5 | 4.1 | 0.010 | 0.463 | 0.473 | 4.29 | 4.57 | 8.86 | 2.748 | 3.319 | 14.0 | 608.3 |
| 0.4660 | 3.9 | 4.4 | 0.010 | 0.440 | 0.450 | 3.94 | 4.91 | 8.85 | 2.894 | 3.476 | 15.5 | 537.8 |
| 0.3781 | 4.0 | 3.8 | 0.010 | 0.418 | 0.428 | 4.11 | 4.14 | 8.25 | 2.762 | 3.418 | 14.7 | 605.9 |
| 0.2903 | 4.9 | 3.9 | 0.013 | 0.401 | 0.414 | 5.06 | 3.57 | 8.63 | 2.654 | 3.464 | 15.1 | 674.5 |
| 0.2024 | 5.4 | 4.3 | 0.014 | 0.398 | 0.412 | 5.68 | 3.45 | 9.13 | 2.543 | 3.115 | 14.7 | 692.7 |
| 0.1145 | 7.5 | 3.8 | 0.022 | 0.319 | 0.341 | 7.59 | 0.77 | 8.36 | 2.474 | 1.040 | 17.2 | 2487.3 |
| 0.0266 | 7.4 | 3.6 | 0.021 | 0.249 | 0.270 | 7.87 | 0.88 | 8.75 | 2.362 | 0.720 | 15.7 | 1697.7 |
| -0.0612 | 5.2 | 3.1 | 0.015 | 0.166 | 0.182 | 5.79 | 0.00 | 5.79 | 2.383 | 0.000 | 16.0 | |
| -0.1491 | 4.5 | 2.1 | 0.014 | 0.075 | 0.089 | 5.58 | 0.00 | 5.58 | 2.290 | 0.000 | 15.5 | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.013 | $<a_{i1}>$ [1/m] = 5.91 | $<<u_{g1}>>$ [m/s] = 2.180 |
| $<\alpha_2>$ = 0.225 | $<a_{i2}>$ [1/m] = 1.84 | $<<u_{g2}>>$ [m/s] = 2.614 |
| $<\alpha_T>$ = 0.238 | $<a_{iT}>$ [1/m] = 7.75 | $<<u_g>>$ [m/s] = 2.729 |

Calculated Error:

$$\left[\frac{< j_{g,loc} >_{probe}}{< j_{g,loc} >_{flowmeter}} - 1\right] = \left[\frac{< \alpha_T >< < u_g >>}{< j_{g,loc} >} - 1\right] = 18.01\%$$

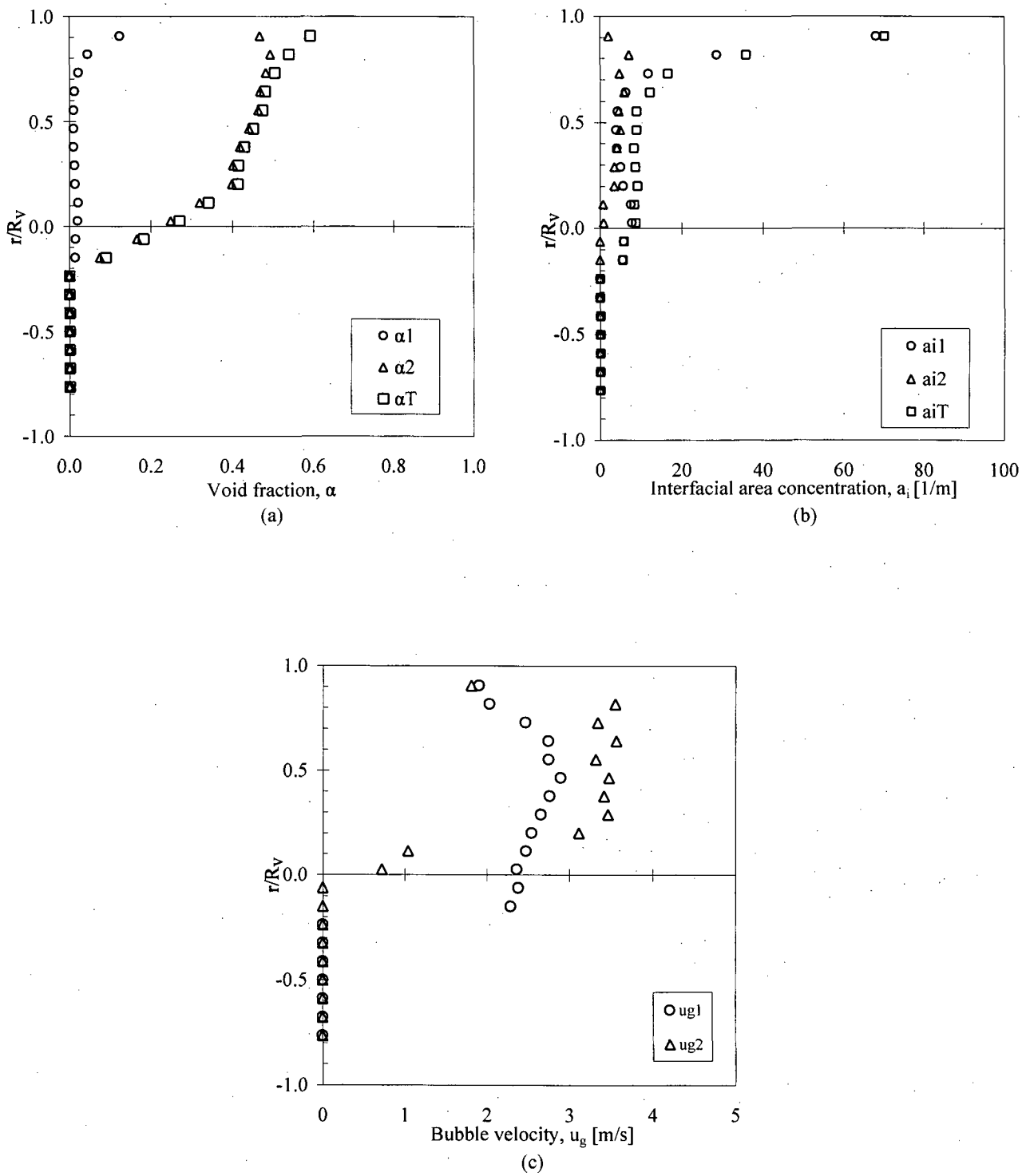


Figure 3.2.5.1 Profiles of local two-phase flow parameters for Run 1 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.5.2 Local two-phase flow parameters for Run 5 acquired along the vertical axis at measurement port 3 (P3)

**Run 5:** $j_{g,atm}$ = 0.603 [m/s] & $j_f$ = 1.653 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.921 | $P_{back}$ [psig] = 25.6 | $j_{g,loc}$ [m/s] = 0.551 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 1.3 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 59.5 | 3.6 | 0.116 | 0.477 | 0.593 | 67.83 | 4.94 | 72.77 | 2.071 | 3.672 | 10.2 | 579.6 |
| 0.8175 | 29.0 | 3.7 | 0.059 | 0.477 | 0.535 | 31.49 | 4.58 | 36.07 | 2.116 | 3.364 | 11.1 | 624.6 |
| 0.7296 | 12.5 | 3.6 | 0.021 | 0.471 | 0.493 | 13.18 | 4.72 | 17.90 | 2.291 | 3.463 | 9.7 | 598.9 |
| 0.6417 | 6.7 | 3.7 | 0.013 | 0.450 | 0.463 | 6.54 | 4.12 | 10.66 | 2.594 | 3.275 | 11.7 | 655.9 |
| 0.5539 | 4.9 | 3.5 | 0.010 | 0.444 | 0.454 | 5.23 | 4.01 | 9.24 | 2.591 | 3.518 | 11.0 | 664.8 |
| 0.4660 | 5.3 | 3.6 | 0.011 | 0.431 | 0.443 | 5.29 | 3.81 | 9.10 | 2.587 | 3.185 | 12.7 | 679.4 |
| 0.3781 | 5.7 | 3.7 | 0.013 | 0.417 | 0.430 | 6.32 | 3.49 | 9.81 | 2.598 | 3.287 | 12.5 | 716.2 |
| 0.2903 | 6.8 | 3.7 | 0.015 | 0.402 | 0.418 | 7.54 | 3.01 | 10.55 | 2.474 | 3.049 | 12.0 | 802.1 |
| 0.2024 | 7.8 | 4.0 | 0.018 | 0.354 | 0.372 | 8.99 | 2.29 | 11.28 | 2.377 | 3.169 | 12.3 | 927.5 |
| 0.1145 | 9.4 | 3.4 | 0.024 | 0.270 | 0.295 | 10.42 | 0.94 | 11.36 | 2.351 | 2.299 | 14.0 | 1724.7 |
| 0.0266 | 8.9 | 2.8 | 0.024 | 0.183 | 0.207 | 10.16 | 0.19 | 10.35 | 2.198 | 0.400 | 13.9 | 5785.3 |
| -0.0612 | 8.2 | 1.8 | 0.026 | 0.078 | 0.104 | 9.26 | 0.00 | 9.26 | 2.126 | 0.000 | 16.7 | |
| -0.1491 | 3.4 | 0.1 | 0.012 | 0.005 | 0.017 | 5.09 | 0.00 | 5.09 | 1.085 | 0.000 | 13.7 | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.015 | $\langle a_{i1}\rangle$ [1/m] = 7.26 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.058 |
| $\langle\alpha_2\rangle$ = 0.199 | $\langle a_{i2}\rangle$ [1/m] = 1.50 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 2.930 |
| $\langle\alpha_T\rangle$ = 0.214 | $\langle a_{iT}\rangle$ [1/m] = 8.76 | $\langle\langle u_g\rangle\rangle$ [m/s] = 2.998 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 16.64\%$$

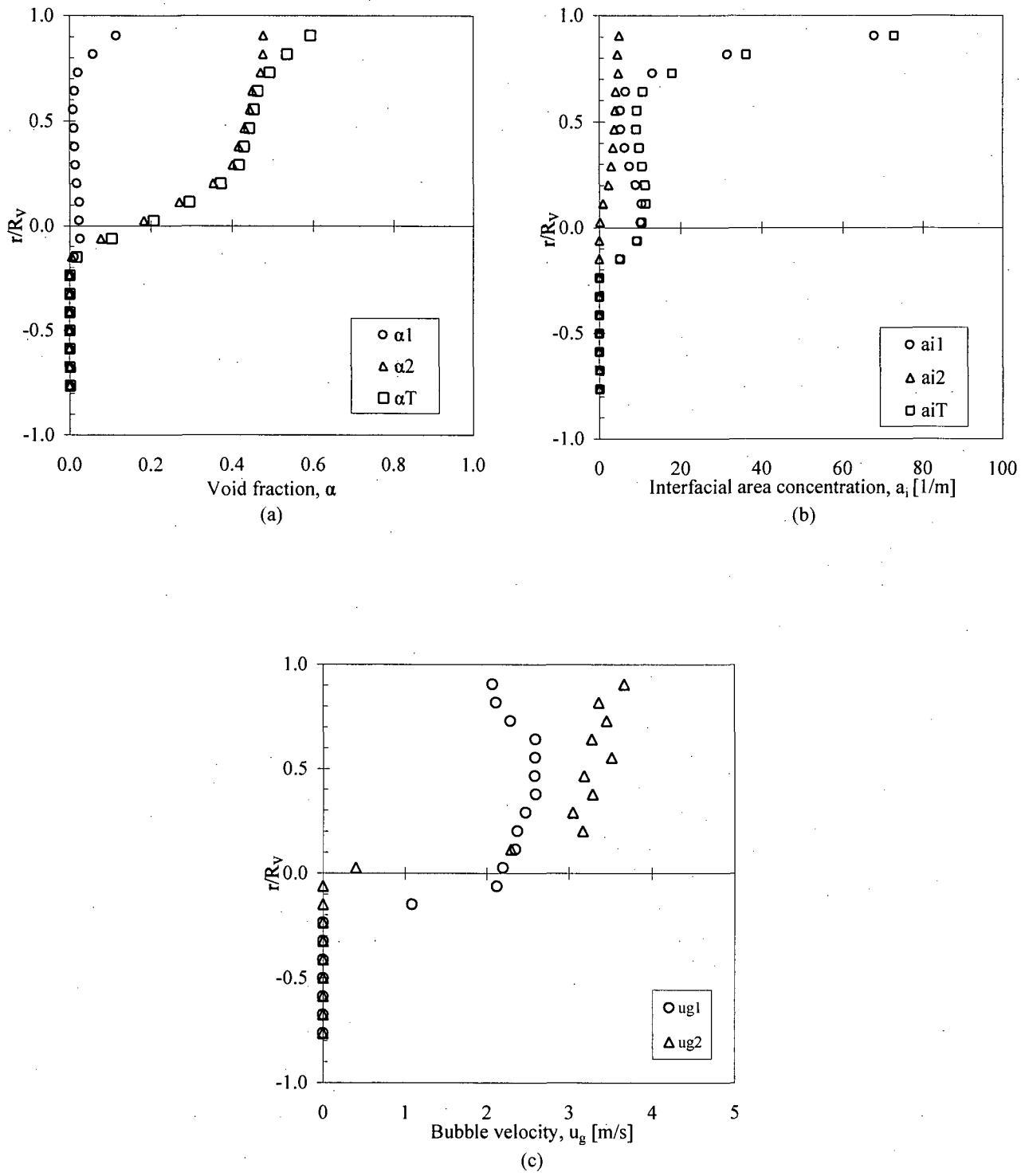


Figure 3.2.5.2 Profiles of local two-phase flow parameters for Run 5 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.5.3 Local two-phase flow parameters for Run 5 acquired along the vertical axis at measurement port 4 (P4)

**Run 5:** $j_{g,atm}$ = 0.603 [m/s] & $j_f$ = 1.653 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.898 | $P_{back}$ [psig] = 26.6 | $j_{g,loc}$ [m/s] = 0.551 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 1.3 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 43.1 | 3.2 | 0.080 | 0.471 | 0.551 | 50.86 | 5.16 | 56.02 | 1.985 | 4.210 | 9.4 | 547.8 |
| 0.8175 | 20.7 | 3.4 | 0.033 | 0.477 | 0.510 | 22.15 | 4.89 | 27.04 | 2.150 | 3.451 | 9.0 | 584.8 |
| 0.7296 | 8.8 | 3.4 | 0.015 | 0.466 | 0.481 | 8.87 | 4.64 | 13.51 | 2.527 | 3.666 | 9.8 | 603.1 |
| 0.6417 | 5.9 | 3.5 | 0.012 | 0.454 | 0.467 | 5.97 | 4.31 | 10.28 | 2.663 | 3.443 | 12.4 | 632.4 |
| 0.5539 | 4.6 | 3.5 | 0.009 | 0.450 | 0.459 | 4.61 | 4.44 | 9.05 | 2.715 | 3.328 | 12.1 | 608.2 |
| 0.4660 | 3.9 | 3.6 | 0.009 | 0.431 | 0.440 | 3.93 | 4.12 | 8.05 | 2.743 | 3.283 | 13.0 | 628.0 |
| 0.3781 | 4.9 | 3.7 | 0.013 | 0.433 | 0.446 | 4.87 | 3.81 | 8.68 | 2.741 | 3.255 | 15.9 | 681.7 |
| 0.2903 | 4.1 | 3.8 | 0.010 | 0.405 | 0.415 | 4.27 | 2.98 | 7.25 | 2.642 | 3.391 | 14.2 | 814.4 |
| 0.2024 | 6.4 | 3.4 | 0.018 | 0.357 | 0.375 | 6.84 | 1.46 | 8.30 | 2.554 | 2.584 | 15.6 | 1467.5 |
| 0.1145 | 7.2 | 3.3 | 0.021 | 0.283 | 0.304 | 7.32 | 0.23 | 7.55 | 2.546 | 0.540 | 16.9 | 7390.4 |
| 0.0266 | 7.2 | 3.1 | 0.021 | 0.214 | 0.235 | 7.49 | 0.34 | 7.83 | 2.359 | 0.384 | 16.7 | 3778.2 |
| -0.0612 | 6.0 | 2.3 | 0.017 | 0.115 | 0.132 | 6.57 | 0.00 | 6.57 | 2.401 | 0.000 | 15.3 | |
| -0.1491 | 5.9 | 0.6 | 0.020 | 0.025 | 0.044 | 7.53 | 0.00 | 7.53 | 2.253 | 0.000 | 15.5 | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.012 | $<a_{i1}>$ [1/m] = 5.50 | $<<u_{g1}>>$ [m/s] = 2.221 |
| $<\alpha_2>$ = 0.208 | $<a_{i2}>$ [1/m] = 1.49 | $<<u_{g2}>>$ [m/s] = 2.729 |
| $<\alpha_T>$ = 0.220 | $<a_{iT}>$ [1/m] = 6.99 | $<<u_g>>$ [m/s] = 2.837 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 13.44\%$$

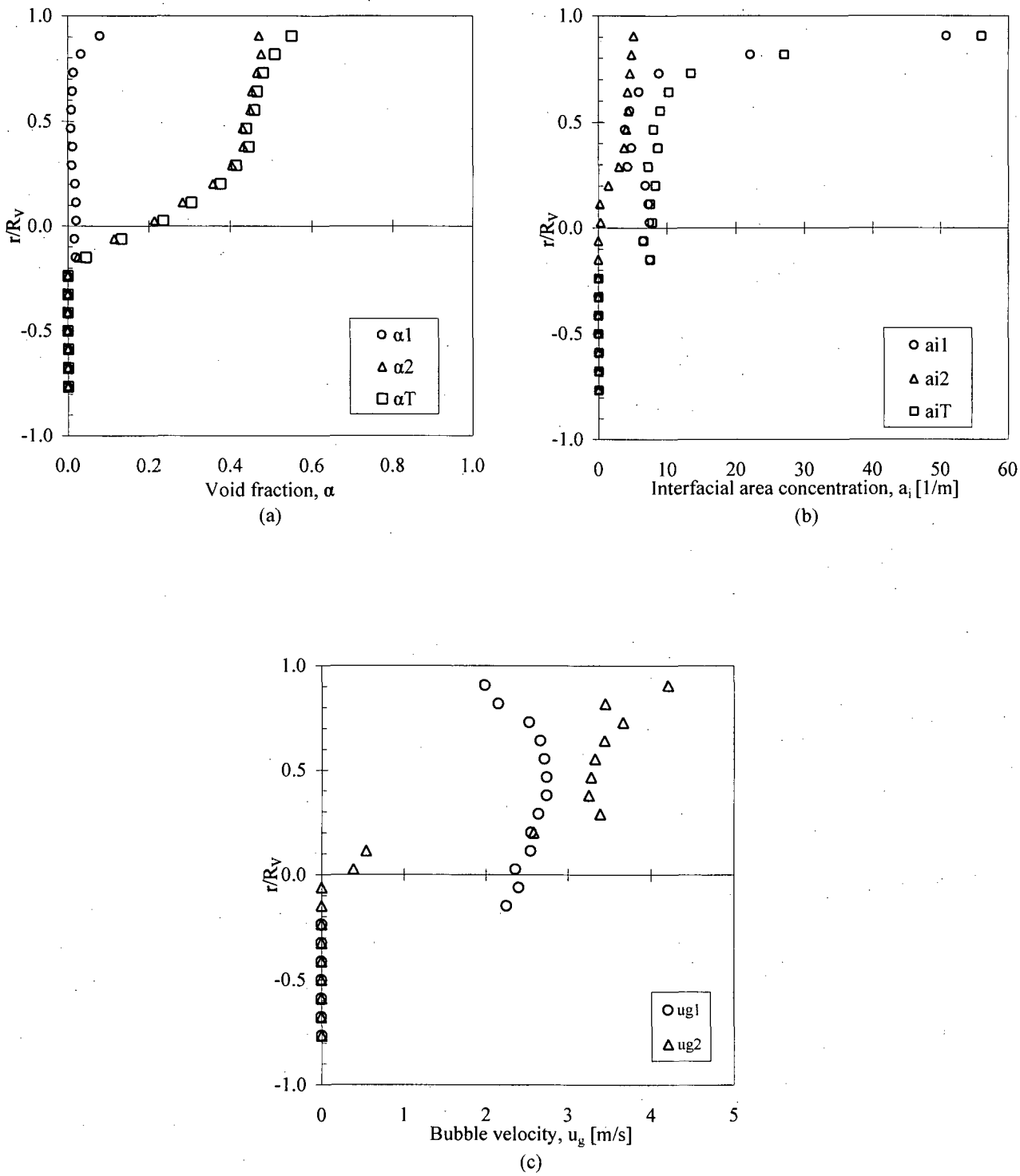


Figure 3.2.5.3 Profiles of local two-phase flow parameters for Run 5 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.6 Summary of results for Run 6.

Table 3.2.6.1 Local two-phase flow parameters for Run 6 acquired along the vertical axis at measurement port 1 (P1)

**Run 6:** $j_{g,atm}$ = 0.625 [m/s] & $j_f$ = 2.203 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.019 | $P_{back}$ [psig] = 23.2 | $j_{g,loc}$ [m/s] = 0.549 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.50 | $P_{loc}$ [psig] = 2.0 | $j_f$ [m/s] = 2.207 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 124.0 | 5.3 | 0.212 | 0.405 | 0.616 | 129.66 | 6.55 | 136.21 | 2.329 | 4.525 | 9.8 | 370.7 |
| 0.8175 | 78.2 | 5.5 | 0.106 | 0.406 | 0.511 | 74.35 | 6.82 | 81.17 | 2.565 | 4.918 | 8.5 | 356.8 |
| 0.7296 | 51.0 | 5.5 | 0.069 | 0.404 | 0.473 | 45.09 | 5.83 | 50.92 | 2.813 | 4.200 | 9.1 | 416.1 |
| 0.6417 | 30.8 | 5.4 | 0.041 | 0.390 | 0.431 | 26.18 | 5.34 | 31.52 | 2.981 | 4.374 | 9.3 | 438.5 |
| 0.5539 | 21.4 | 5.9 | 0.034 | 0.382 | 0.416 | 18.06 | 5.46 | 23.52 | 3.066 | 4.111 | 11.3 | 419.7 |
| 0.4660 | 15.1 | 5.5 | 0.027 | 0.362 | 0.389 | 12.28 | 5.16 | 17.44 | 3.317 | 4.120 | 13.0 | 420.9 |
| 0.3781 | 12.4 | 5.8 | 0.021 | 0.347 | 0.368 | 9.44 | 5.12 | 14.56 | 3.438 | 4.225 | 13.6 | 406.4 |
| 0.2903 | 10.8 | 5.5 | 0.020 | 0.324 | 0.345 | 8.37 | 4.05 | 12.42 | 3.507 | 3.860 | 14.6 | 480.6 |
| 0.2024 | 11.4 | 5.2 | 0.023 | 0.267 | 0.291 | 9.46 | 3.24 | 12.70 | 3.337 | 3.827 | 14.8 | 494.8 |
| 0.1145 | 13.8 | 4.3 | 0.034 | 0.180 | 0.214 | 11.66 | 1.85 | 13.51 | 3.006 | 2.911 | 17.2 | 584.8 |
| 0.0266 | 15.4 | 2.6 | 0.039 | 0.095 | 0.134 | 13.26 | 0.25 | 13.51 | 2.934 | 0.535 | 17.6 | 2277.6 |
| -0.0612 | 12.1 | 1.0 | 0.027 | 0.032 | 0.059 | 10.76 | 0.00 | 10.76 | 2.772 | 0.000 | 15.1 | |
| -0.1491 | 1.6 | 0.0 | 0.004 | 0.000 | 0.004 | 1.50 | 0.00 | 1.50 | 0.572 | 0.000 | 17.6 | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.025 | $\langle a_{i1}\rangle$ [1/m] = 13.25 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.634 |
| $\langle\alpha_2\rangle$ = 0.157 | $\langle a_{i2}\rangle$ [1/m] = 2.08 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.905 |
| $\langle\alpha_T\rangle$ = 0.182 | $\langle a_{iT}\rangle$ [1/m] = 15.33 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.855 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 27.77\%$$

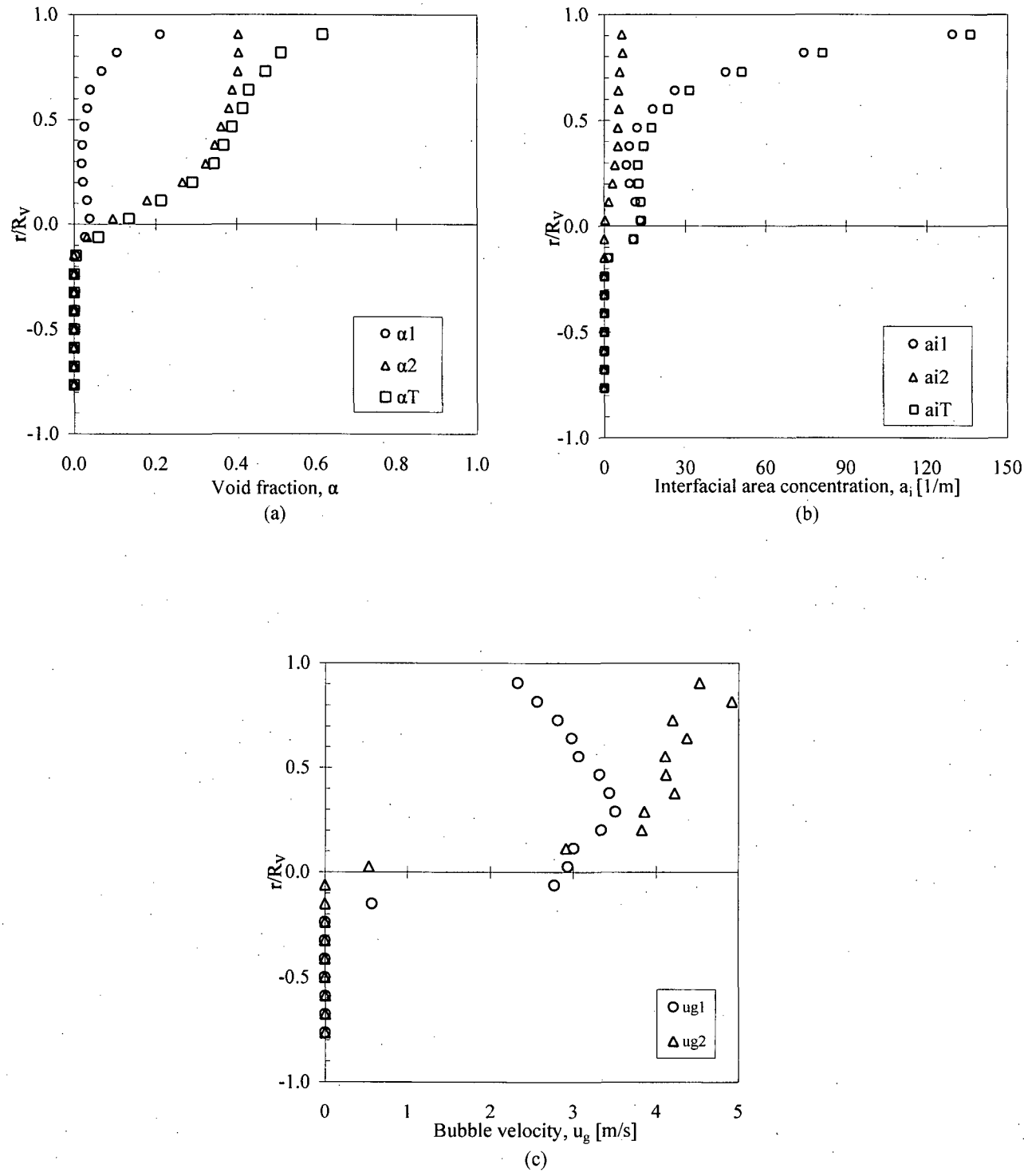


Figure 3.2.6.1 Profiles of local two-phase flow parameters for Run 6 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.6.2 Local two-phase flow parameters for Run 6 acquired along the vertical axis at measurement port 3 (P3)

**Run 6:** $j_{g,atm}$ = 0.625 [m/s] & $j_f$ = 2.203 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.923 | $P_{back}$ [psig] = 27.4 | $j_{g,loc}$ [m/s] = 0.553 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.30 | $P_{loc}$ [psig] = 2.0 | $j_f$ [m/s] = 2.200 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 105.6 | 5.0 | 0.162 | 0.353 | 0.515 | 101.64 | 1.81 | 103.45 | 2.589 | 2.682 | 9.5 | 1171.2 |
| 0.8175 | 72.4 | 5.0 | 0.103 | 0.380 | 0.482 | 64.34 | 4.73 | 69.07 | 2.802 | 4.132 | 9.6 | 481.5 |
| 0.7296 | 43.4 | 5.0 | 0.061 | 0.382 | 0.444 | 38.30 | 5.01 | 43.31 | 2.879 | 4.321 | 9.6 | 458.0 |
| 0.6417 | 26.9 | 5.1 | 0.038 | 0.375 | 0.413 | 22.92 | 4.67 | 27.59 | 2.972 | 4.036 | 9.8 | 481.9 |
| 0.5539 | 16.0 | 5.2 | 0.025 | 0.368 | 0.394 | 13.92 | 4.54 | 18.46 | 3.081 | 4.397 | 10.9 | 486.9 |
| 0.4660 | 14.2 | 5.3 | 0.025 | 0.360 | 0.385 | 11.90 | 4.44 | 16.34 | 3.106 | 4.158 | 12.6 | 485.8 |
| 0.3781 | 13.1 | 5.3 | 0.023 | 0.351 | 0.374 | 11.07 | 4.25 | 15.32 | 3.146 | 4.112 | 12.5 | 495.5 |
| 0.2903 | 12.0 | 5.1 | 0.021 | 0.335 | 0.356 | 10.52 | 3.84 | 14.36 | 3.058 | 4.126 | 11.9 | 523.4 |
| 0.2024 | 12.3 | 5.5 | 0.023 | 0.313 | 0.336 | 11.29 | 3.86 | 15.15 | 3.034 | 4.037 | 12.3 | 486.2 |
| 0.1145 | 14.2 | 5.2 | 0.031 | 0.251 | 0.282 | 13.89 | 3.01 | 16.90 | 2.871 | 4.097 | 13.5 | 500.7 |
| 0.0266 | 16.9 | 3.8 | 0.039 | 0.156 | 0.195 | 16.08 | 1.65 | 17.73 | 2.701 | 4.068 | 14.4 | 568.4 |
| -0.0612 | 10.8 | 2.3 | 0.023 | 0.076 | 0.100 | 10.78 | 0.23 | 11.01 | 2.613 | 0.699 | 13.0 | 1990.4 |
| -0.1491 | 0.0 | 0.5 | 0.000 | 0.017 | 0.017 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.023 | $\langle a_{i1}\rangle$ [1/m] = 12.25 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.634 |
| $\langle\alpha_2\rangle$ = 0.169 | $\langle a_{i2}\rangle$ [1/m] = 1.92 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.712 |
| $\langle\alpha_T\rangle$ = 0.192 | $\langle a_{iT}\rangle$ [1/m] = 14.17 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.756 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 30.27\%$$

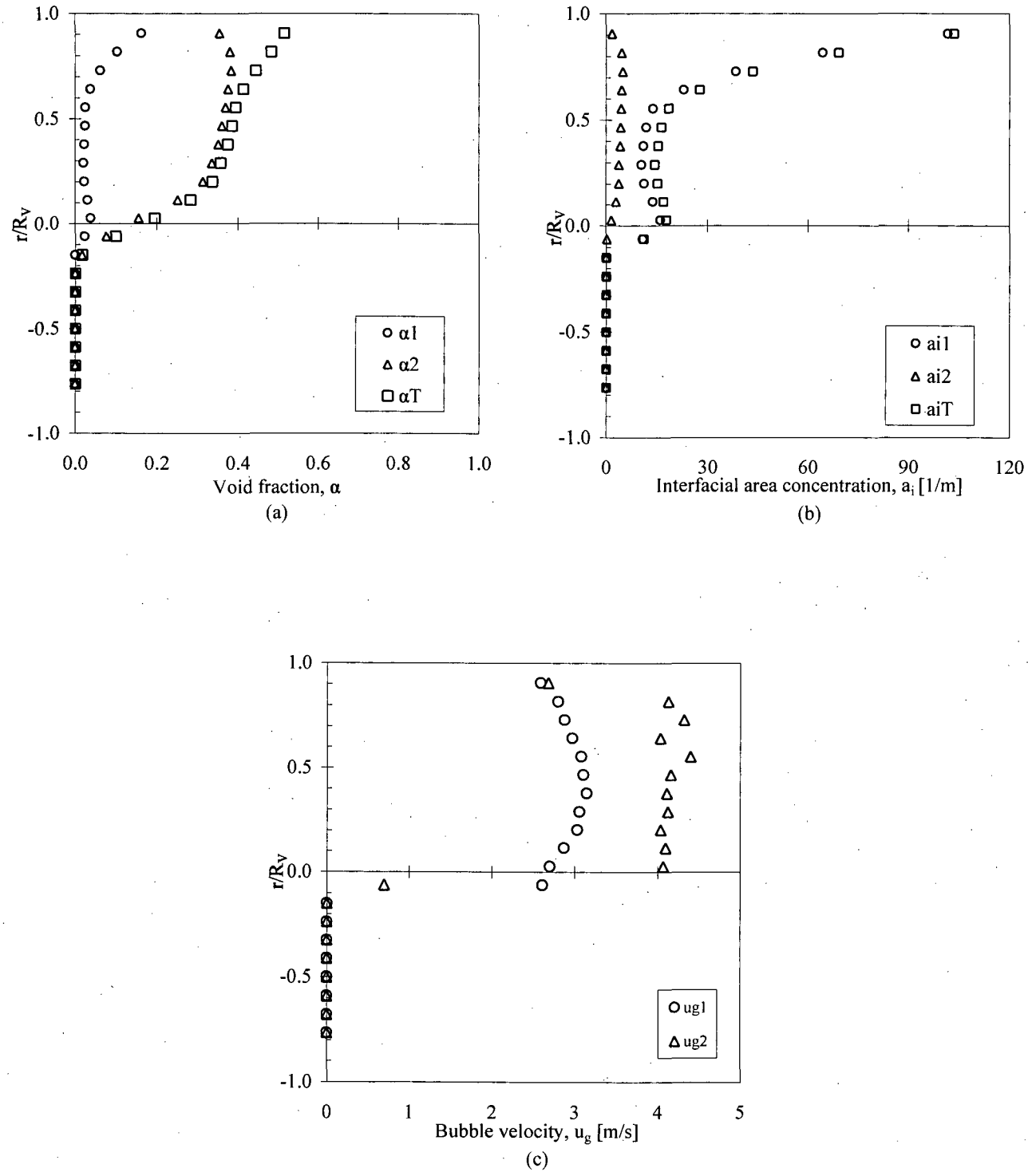


Figure 3.2.6.2 Profiles of local two-phase flow parameters for Run 6 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.6.3 Local two-phase flow parameters for Run 6 acquired along the vertical axis at measurement port 4 (P4)

**Run 6:** $j_{g,atm}$ = 0.625 [m/s] & $j_f$ = 2.203 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 0.917 | $P_{back}$ [psig] = 27.3 | $j_{g,loc}$ [m/s] = 0.551 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.20 | $P_{loc}$ [psig] = 1.9 | $j_f$ [m/s] = 2.197 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 86.9 | 4.5 | 0.119 | 0.394 | 0.514 | 85.48 | 5.79 | 91.27 | 2.513 | 4.136 | 8.4 | 408.5 |
| 0.8175 | 54.0 | 4.6 | 0.068 | 0.398 | 0.466 | 49.52 | 5.09 | 54.61 | 2.725 | 4.556 | 8.2 | 469.0 |
| 0.7296 | 34.7 | 4.8 | 0.045 | 0.397 | 0.442 | 31.55 | 4.73 | 36.28 | 2.834 | 4.397 | 8.6 | 504.1 |
| 0.6417 | 23.5 | 4.6 | 0.033 | 0.385 | 0.417 | 20.48 | 4.29 | 24.77 | 2.999 | 3.967 | 9.5 | 538.3 |
| 0.5539 | 16.8 | 5.1 | 0.025 | 0.380 | 0.406 | 14.71 | 4.62 | 19.33 | 3.041 | 4.539 | 10.4 | 493.6 |
| 0.4660 | 11.8 | 5.0 | 0.020 | 0.369 | 0.388 | 9.35 | 4.31 | 13.66 | 3.331 | 4.197 | 12.8 | 513.0 |
| 0.3781 | 9.8 | 4.8 | 0.018 | 0.360 | 0.379 | 7.90 | 3.65 | 11.55 | 3.267 | 3.938 | 14.0 | 591.9 |
| 0.2903 | 9.1 | 4.9 | 0.019 | 0.338 | 0.357 | 7.31 | 3.31 | 10.62 | 3.324 | 4.022 | 15.7 | 611.8 |
| 0.2024 | 10.7 | 5.3 | 0.026 | 0.281 | 0.307 | 9.00 | 2.87 | 11.87 | 3.206 | 3.924 | 17.1 | 588.1 |
| 0.1145 | 14.0 | 4.1 | 0.036 | 0.206 | 0.243 | 12.24 | 1.44 | 13.68 | 3.030 | 2.861 | 17.8 | 859.2 |
| 0.0266 | 13.5 | 3.0 | 0.036 | 0.122 | 0.158 | 12.16 | 0.20 | 12.36 | 2.889 | 0.916 | 17.9 | 3657.0 |
| -0.0612 | 10.7 | 1.5 | 0.025 | 0.050 | 0.075 | 9.61 | 0.00 | 9.61 | 2.790 | 0.000 | 15.3 | |
| -0.1491 | 1.5 | 0.0 | 0.004 | 0.000 | 0.004 | 1.72 | 0.00 | 1.72 | 0.507 | 0.000 | 12.2 | |
| -0.2370 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.020 | $\langle a_{i1}\rangle$ [1/m] = 10.24 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.665 |
| $\langle\alpha_2\rangle$ = 0.163 | $\langle a_{i2}\rangle$ [1/m] = 1.68 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.787 |
| $\langle\alpha_T\rangle$ = 0.183 | $\langle a_{iT}\rangle$ [1/m] = 11.92 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.813 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 26.66\%$$

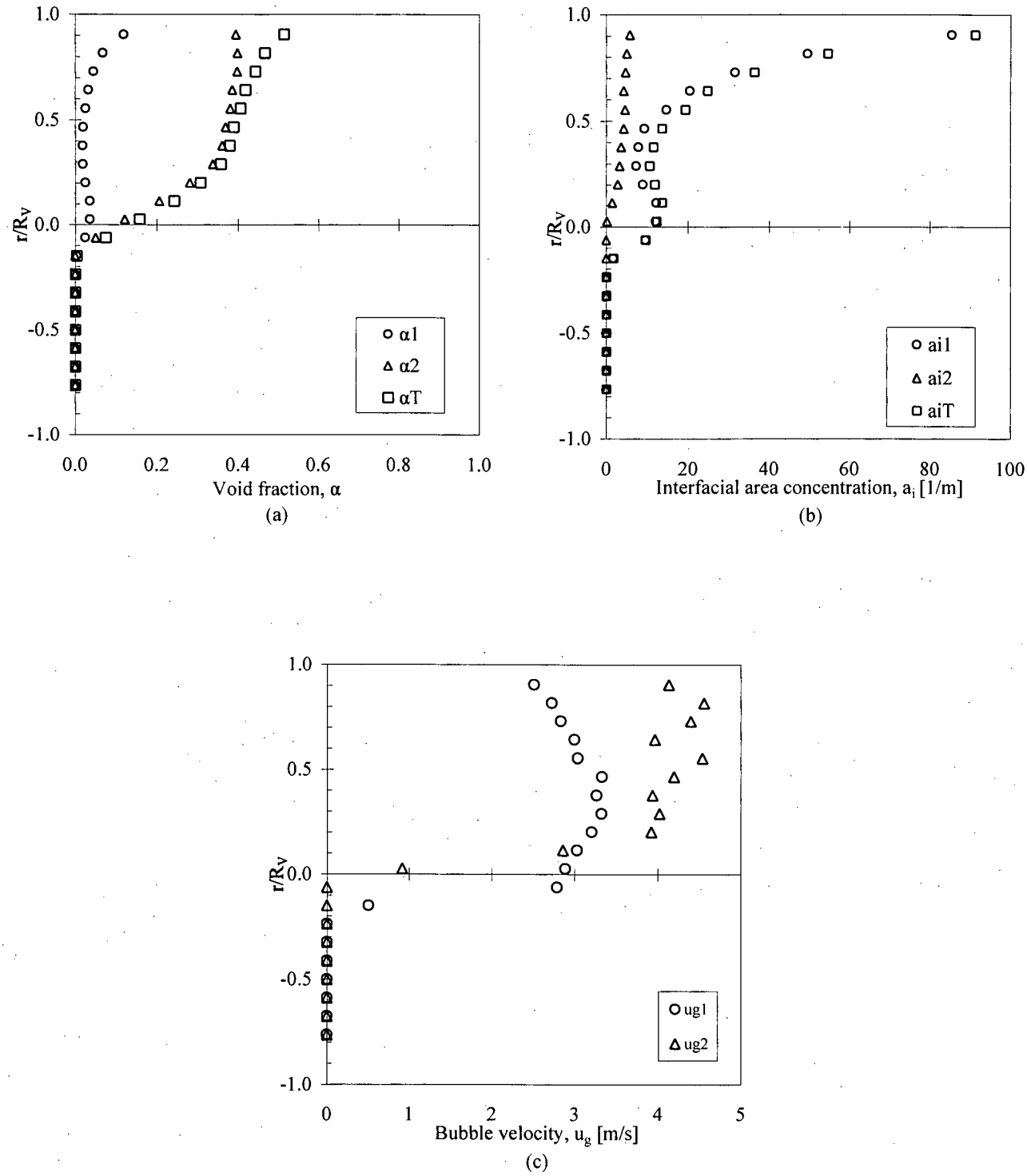


Figure 3.2.6.3 Profiles of local two-phase flow parameters for Run 6 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.7 Summary of results for Run 7.

Table 3.2.7.1 Local two-phase flow parameters for Run 7 acquired along the vertical axis at measurement port 1 (P1)

**Run 7:** $j_{g,atm}$ = 1.186 [m/s] & $j_f$ = 0.553 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.616 | $P_{back}$ [psig] = 31 | $j_{g,loc}$ [m/s] = 1.117 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.60 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.552 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 12.8 | 0.7 | 0.033 | 0.794 | 0.827 | 16.20 | 1.50 | 17.70 | 1.849 | 2.978 | 12.2 | 3174.4 |
| 0.8175 | 6.2 | 0.6 | 0.013 | 0.798 | 0.811 | 6.84 | 0.98 | 7.82 | 2.084 | 2.753 | 11.1 | 4884.5 |
| 0.7296 | 4.1 | 0.6 | 0.008 | 0.812 | 0.819 | 4.46 | 0.90 | 5.36 | 2.256 | 2.822 | 10.5 | 5410.0 |
| 0.6417 | 2.6 | 0.7 | 0.005 | 0.824 | 0.830 | 3.03 | 0.95 | 3.98 | 2.291 | 2.927 | 10.1 | 5206.7 |
| 0.5539 | 2.1 | 0.8 | 0.004 | 0.810 | 0.814 | 2.53 | 0.97 | 3.50 | 2.210 | 2.508 | 8.8 | 5012.2 |
| 0.4660 | 2.5 | 0.6 | 0.006 | 0.808 | 0.814 | 3.01 | 0.84 | 3.85 | 2.291 | 2.321 | 11.2 | 5770.7 |
| 0.3781 | 2.2 | 0.6 | 0.004 | 0.811 | 0.815 | 2.47 | 0.72 | 3.19 | 2.359 | 3.010 | 10.4 | 6754.2 |
| 0.2903 | 2.3 | 0.7 | 0.005 | 0.786 | 0.791 | 2.85 | 0.71 | 3.56 | 2.260 | 1.900 | 11.4 | 6639.7 |
| 0.2024 | 2.7 | 0.7 | 0.007 | 0.791 | 0.797 | 3.51 | 0.17 | 3.68 | 2.099 | 0.435 | 11.5 | 27907.1 |
| 0.1145 | 2.6 | 0.7 | 0.008 | 0.781 | 0.789 | 3.32 | 0.00 | 3.32 | 2.090 | 0.000 | 14.1 | |
| 0.0266 | 3.1 | 0.8 | 0.009 | 0.768 | 0.777 | 3.84 | 0.00 | 3.84 | 2.131 | 0.000 | 13.9 | |
| -0.0612 | 3.1 | 0.8 | 0.008 | 0.693 | 0.701 | 3.86 | 0.00 | 3.86 | 1.989 | 0.000 | 12.4 | |
| -0.1491 | 2.9 | 0.8 | 0.009 | 0.641 | 0.650 | 3.65 | 0.00 | 3.65 | 2.029 | 0.000 | 14.5 | |
| -0.2370 | 3.1 | 0.8 | 0.011 | 0.506 | 0.516 | 5.13 | 0.00 | 5.13 | 1.715 | 0.000 | 12.5 | |
| -0.3249 | 3.3 | 0.8 | 0.015 | 0.296 | 0.311 | 5.59 | 0.00 | 5.59 | 1.728 | 0.000 | 15.9 | |
| -0.4127 | 1.4 | 0.1 | 0.005 | 0.064 | 0.070 | 2.03 | 0.00 | 2.03 | 1.165 | 0.000 | 16.0 | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.007 | $\langle a_{i1}\rangle$ [1/m] = 3.25 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.859 |
| $\langle\alpha_2\rangle$ = 0.554 | $\langle a_{i2}\rangle$ [1/m] = 0.31 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.297 |
| $\langle\alpha_T\rangle$ = 0.561 | $\langle a_{iT}\rangle$ [1/m] = 3.56 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.390 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 30.19\%$$

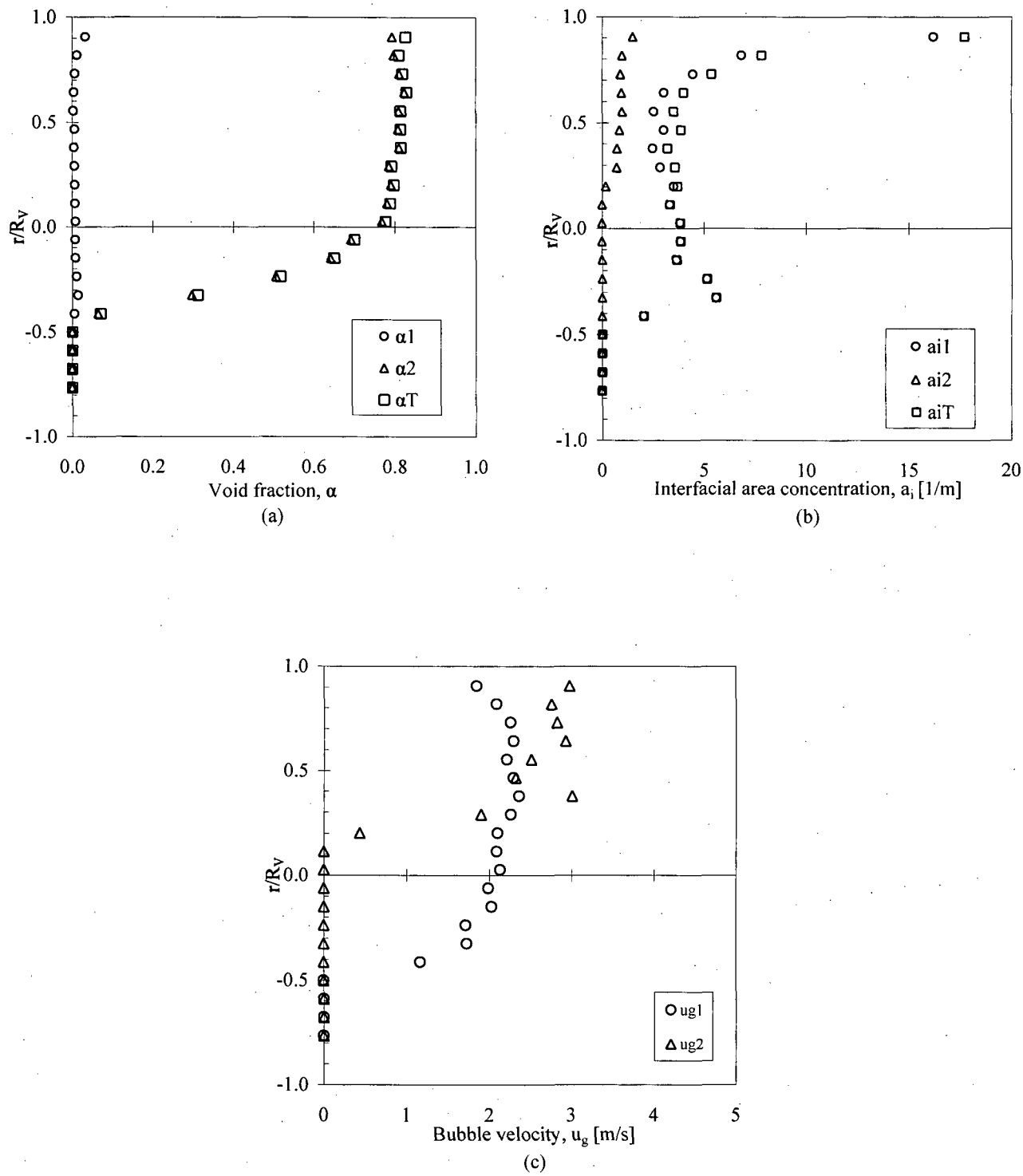


Figure 3.2.7.1 Profiles of local two-phase flow parameters for Run 7 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.7.2 Local two-phase flow parameters for Run 7 acquired along the vertical axis at measurement port 3 (P3)

**Run 7:** $j_{g,atm}$ = 1.186 [m/s] & $j_f$ = 0.553 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.504 | $P_{back}$ [psig] = 33.8 | $j_{g,loc}$ [m/s] = 1.104 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.40 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.552 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 14.5 | 0.6 | 0.044 | 0.799 | 0.843 | 20.90 | 0.99 | 21.89 | 1.633 | 2.980 | 12.5 | 4843.6 |
| 0.8175 | 11.1 | 0.6 | 0.030 | 0.815 | 0.845 | 13.72 | 0.73 | 14.45 | 1.933 | 1.914 | 12.9 | 6701.1 |
| 0.7296 | 5.0 | 0.6 | 0.009 | 0.814 | 0.823 | 6.17 | 0.79 | 6.96 | 1.962 | 2.742 | 9.0 | 6178.5 |
| 0.6417 | 2.7 | 0.6 | 0.006 | 0.806 | 0.812 | 3.35 | 0.75 | 4.10 | 2.138 | 2.596 | 10.0 | 6449.6 |
| 0.5539 | 2.7 | 0.6 | 0.005 | 0.795 | 0.800 | 3.02 | 0.69 | 3.71 | 2.268 | 2.887 | 8.9 | 6914.8 |
| 0.4660 | 1.6 | 0.6 | 0.003 | 0.820 | 0.823 | 2.21 | 0.82 | 3.03 | 2.085 | 2.759 | 9.0 | 5999.3 |
| 0.3781 | 1.9 | 0.5 | 0.004 | 0.793 | 0.797 | 2.35 | 0.60 | 2.95 | 2.245 | 2.347 | 10.5 | 7926.0 |
| 0.2903 | 1.9 | 0.5 | 0.004 | 0.795 | 0.799 | 2.29 | 0.64 | 2.93 | 2.234 | 2.697 | 10.2 | 7456.9 |
| 0.2024 | 2.0 | 0.6 | 0.006 | 0.794 | 0.800 | 2.68 | 0.17 | 2.85 | 2.114 | 0.977 | 13.4 | 28005.9 |
| 0.1145 | 2.0 | 0.6 | 0.006 | 0.764 | 0.770 | 2.61 | 0.09 | 2.70 | 2.161 | 0.483 | 13.6 | 50906.7 |
| 0.0266 | 2.5 | 0.6 | 0.006 | 0.749 | 0.755 | 3.01 | 0.00 | 3.01 | 2.267 | 0.000 | 12.0 | |
| -0.0612 | 2.5 | 0.4 | 0.007 | 0.746 | 0.752 | 3.50 | 0.00 | 3.50 | 2.008 | 0.000 | 11.1 | |
| -0.1491 | 3.2 | 0.6 | 0.010 | 0.695 | 0.706 | 4.94 | 0.00 | 4.94 | 1.872 | 0.000 | 12.5 | |
| -0.2370 | 3.9 | 0.7 | 0.012 | 0.622 | 0.635 | 5.76 | 0.00 | 5.76 | 1.877 | 0.000 | 12.8 | |
| -0.3249 | 2.6 | 0.6 | 0.010 | 0.476 | 0.485 | 3.85 | 0.00 | 3.85 | 1.731 | 0.000 | 14.8 | |
| -0.4127 | 1.3 | 0.3 | 0.004 | 0.309 | 0.313 | 2.51 | 0.00 | 2.51 | 1.808 | 0.000 | 10.3 | |
| -0.5006 | 0.3 | 0.1 | 0.001 | 0.030 | 0.030 | 0.00 | 0.00 | 0.00 | 1.930 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.007 | $\langle a_{i1}\rangle$ [1/m] = 3.46 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.862 |
| $\langle\alpha_2\rangle$ = 0.590 | $\langle a_{i2}\rangle$ [1/m] = 0.26 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.294 |
| $\langle\alpha_T\rangle$ = 0.597 | $\langle a_{iT}\rangle$ [1/m] = 3.71 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.378 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 25.45\%$$

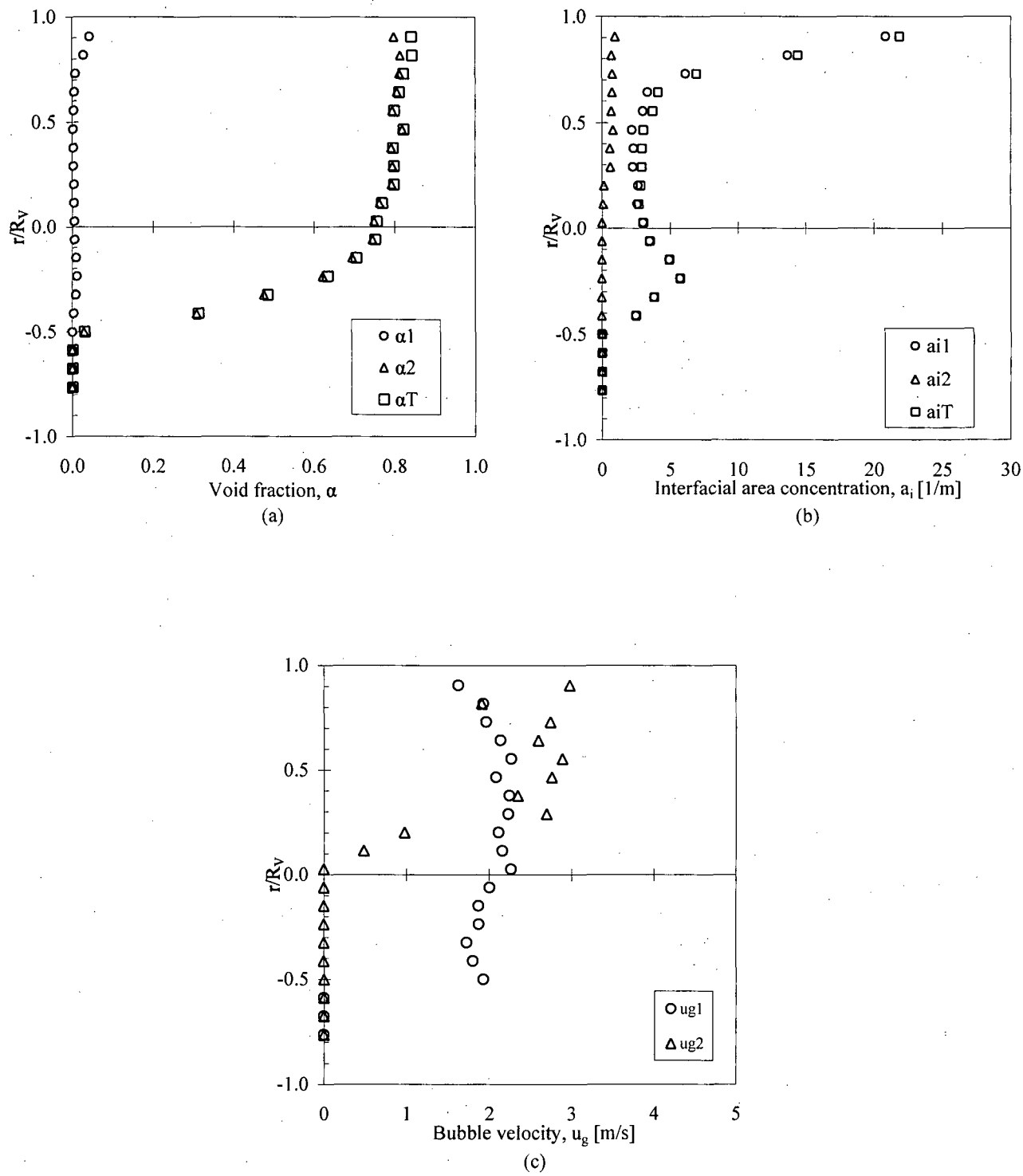


Figure 3.2.7.2 Profiles of local two-phase flow parameters for Run 7 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.7.3 Local two-phase flow parameters for Run 7 acquired along the vertical axis at measurement port 4 (P4)

**Run 7:** $j_{g,atm}$ = 1.186 [m/s] & $j_f$ = 0.553 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.520 | $P_{back}$ [psig] = 33.3 | $j_{g,loc}$ [m/s] = 1.104 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.30 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.549 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 13.8 | 0.5 | 0.033 | 0.805 | 0.838 | 19.74 | 0.88 | 20.62 | 1.603 | 2.109 | 10.0 | 5491.4 |
| 0.8175 | 6.6 | 0.6 | 0.013 | 0.819 | 0.832 | 7.70 | 1.22 | 8.92 | 1.951 | 3.283 | 10.1 | 4029.8 |
| 0.7296 | 2.8 | 0.6 | 0.005 | 0.802 | 0.807 | 3.12 | 0.99 | 4.11 | 2.013 | 2.863 | 9.2 | 4861.2 |
| 0.6417 | 1.6 | 0.5 | 0.003 | 0.793 | 0.796 | 2.04 | 0.75 | 2.79 | 2.183 | 3.263 | 8.8 | 6341.6 |
| 0.5539 | 1.3 | 0.6 | 0.002 | 0.808 | 0.811 | 1.64 | 0.89 | 2.53 | 2.352 | 2.289 | 8.4 | 5448.5 |
| 0.4660 | 1.5 | 0.6 | 0.003 | 0.816 | 0.819 | 1.97 | 0.93 | 2.90 | 2.182 | 2.443 | 8.8 | 5265.8 |
| 0.3781 | 1.2 | 0.5 | 0.002 | 0.785 | 0.788 | 1.58 | 0.58 | 2.16 | 2.317 | 2.505 | 8.7 | 8123.8 |
| 0.2903 | 1.7 | 0.5 | 0.003 | 0.787 | 0.791 | 2.05 | 0.35 | 2.40 | 2.307 | 1.614 | 9.4 | 13496.6 |
| 0.2024 | 2.0 | 0.6 | 0.006 | 0.790 | 0.796 | 2.43 | 0.14 | 2.57 | 2.203 | 0.367 | 14.3 | 33861.4 |
| 0.1145 | 2.7 | 0.6 | 0.007 | 0.764 | 0.771 | 3.52 | 0.00 | 3.52 | 2.026 | 0.000 | 12.1 | |
| 0.0266 | 2.3 | 0.6 | 0.005 | 0.746 | 0.750 | 2.89 | 0.00 | 2.89 | 2.085 | 0.000 | 9.6 | |
| -0.0612 | 2.0 | 0.6 | 0.004 | 0.726 | 0.731 | 2.57 | 0.00 | 2.57 | 2.133 | 0.000 | 10.3 | |
| -0.1491 | 2.7 | 0.6 | 0.009 | 0.679 | 0.687 | 3.90 | 0.00 | 3.90 | 1.942 | 0.000 | 13.7 | |
| -0.2370 | 3.0 | 0.7 | 0.011 | 0.548 | 0.559 | 4.35 | 0.00 | 4.35 | 2.131 | 0.000 | 15.6 | |
| -0.3249 | 3.5 | 0.5 | 0.013 | 0.400 | 0.413 | 6.10 | 0.00 | 6.10 | 1.620 | 0.000 | 13.1 | |
| -0.4127 | 2.3 | 0.4 | 0.010 | 0.138 | 0.148 | 5.10 | 0.00 | 5.10 | 1.397 | 0.000 | 11.3 | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.006 | $\langle a_{i1}\rangle$ [1/m] = 2.97 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 1.849 |
| $\langle\alpha_2\rangle$ = 0.568 | $\langle a_{i2}\rangle$ [1/m] = 0.27 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.211 |
| $\langle\alpha_T\rangle$ = 0.573 | $\langle a_{iT}\rangle$ [1/m] = 3.24 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.293 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 32.79\%$$

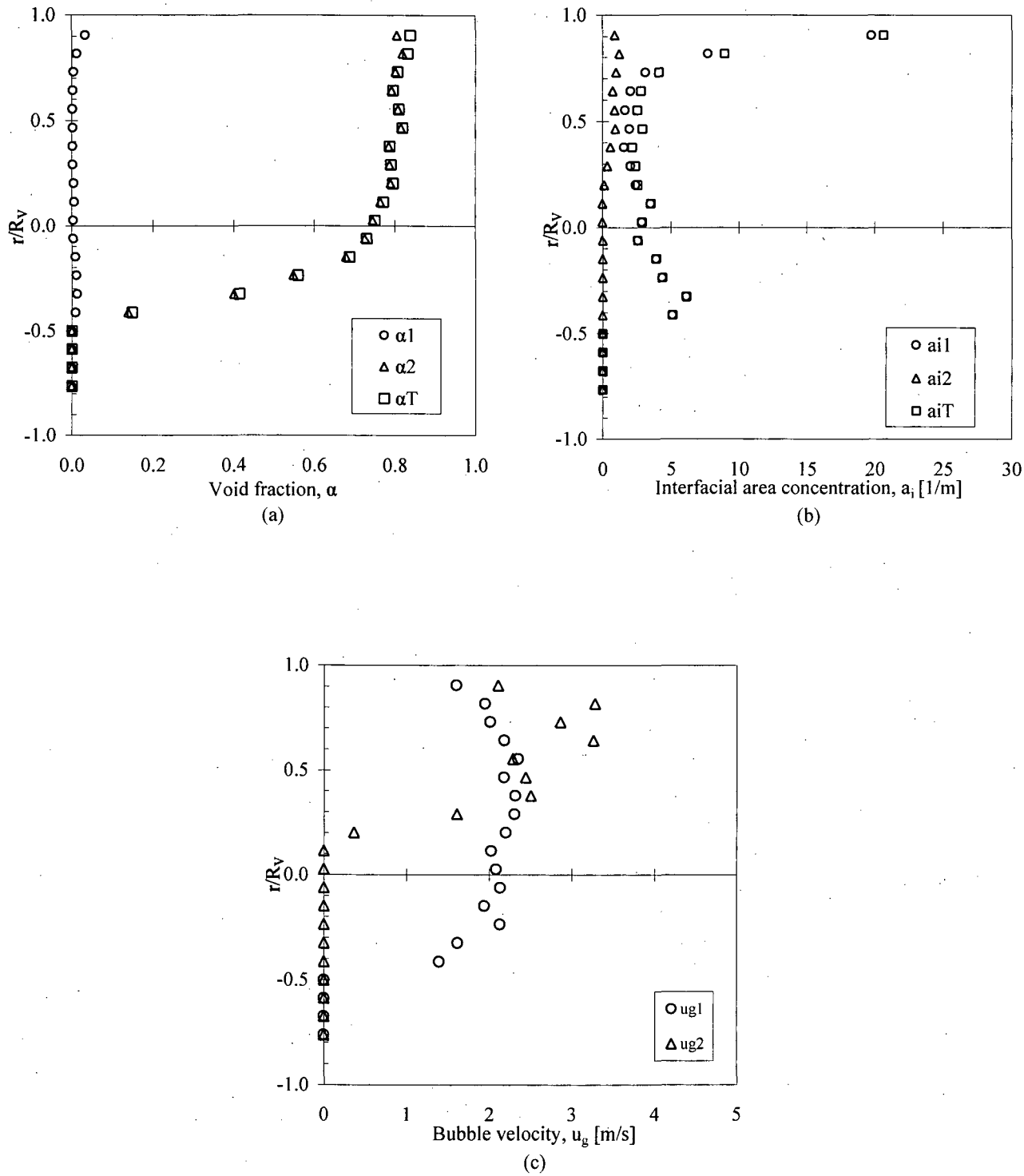


Figure 3.2.7.3 Profiles of local two-phase flow parameters for Run 7 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.8 Summary of results for Run 8.

Table 3.2.8.1 Local two-phase flow parameters for Run 8 acquired along the vertical axis at measurement port 1 (P1)

**Run 8:** $j_{g,atm}$ = 1.218 [m/s] & $j_f$ = 1.652 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.580 | $P_{back}$ [psig] = 33.5 | $j_{g,loc}$ [m/s] = 1.103 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 52.10 | $P_{loc}$ [psig] = 1.7 | $j_f$ [m/s] = 1.654 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 70.1 | 2.7 | 0.097 | 0.542 | 0.639 | 62.89 | 0.60 | 63.49 | 2.801 | 0.378 | 9.3 | 5417.0 |
| 0.8175 | 53.2 | 2.7 | 0.065 | 0.575 | 0.640 | 45.39 | 1.51 | 46.90 | 2.949 | 2.908 | 8.6 | 2284.4 |
| 0.7296 | 36.6 | 3.0 | 0.043 | 0.583 | 0.627 | 29.45 | 2.77 | 32.22 | 3.122 | 4.545 | 8.8 | 1263.2 |
| 0.6417 | 28.8 | 2.9 | 0.036 | 0.574 | 0.610 | 22.91 | 2.38 | 25.29 | 3.213 | 4.634 | 9.4 | 1447.6 |
| 0.5539 | 22.3 | 2.8 | 0.029 | 0.568 | 0.597 | 17.79 | 2.21 | 20.00 | 3.327 | 4.179 | 9.7 | 1542.9 |
| 0.4660 | 19.1 | 2.8 | 0.027 | 0.565 | 0.592 | 14.71 | 2.12 | 16.83 | 3.477 | 4.401 | 11.1 | 1598.5 |
| 0.3781 | 16.7 | 2.7 | 0.024 | 0.557 | 0.581 | 12.51 | 1.83 | 14.34 | 3.660 | 4.098 | 11.3 | 1826.6 |
| 0.2903 | 16.1 | 2.9 | 0.026 | 0.558 | 0.585 | 12.33 | 1.87 | 14.20 | 3.495 | 4.020 | 12.8 | 1790.7 |
| 0.2024 | 16.4 | 2.8 | 0.029 | 0.551 | 0.580 | 13.30 | 1.83 | 15.13 | 3.404 | 3.925 | 13.0 | 1805.9 |
| 0.1145 | 18.9 | 2.7 | 0.038 | 0.507 | 0.545 | 15.54 | 1.20 | 16.74 | 3.234 | 4.164 | 14.7 | 2532.5 |
| 0.0266 | 21.5 | 2.8 | 0.043 | 0.453 | 0.496 | 17.65 | 0.00 | 17.65 | 3.112 | 0.000 | 14.5 | |
| -0.0612 | 21.3 | 2.6 | 0.043 | 0.392 | 0.436 | 18.60 | 0.00 | 18.60 | 3.002 | 0.000 | 14.0 | |
| -0.1491 | 20.4 | 2.1 | 0.041 | 0.259 | 0.300 | 18.95 | 0.00 | 18.95 | 2.801 | 0.000 | 13.1 | |
| -0.2370 | 20.3 | 1.3 | 0.046 | 0.152 | 0.198 | 20.63 | 0.00 | 20.63 | 2.671 | 0.000 | 13.4 | |
| -0.3249 | 3.6 | 0.1 | 0.008 | 0.014 | 0.022 | 4.41 | 0.00 | 4.41 | 0.422 | 0.000 | 11.0 | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.028 | $\langle a_{i1}\rangle$ [1/m] = 14.63 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.850 |
| $\langle\alpha_2\rangle$ = 0.338 | $\langle a_{i2}\rangle$ [1/m] = 0.84 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 2.899 |
| $\langle\alpha_T\rangle$ = 0.367 | $\langle a_{iT}\rangle$ [1/m] = 15.47 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.082 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 2.46\%$$

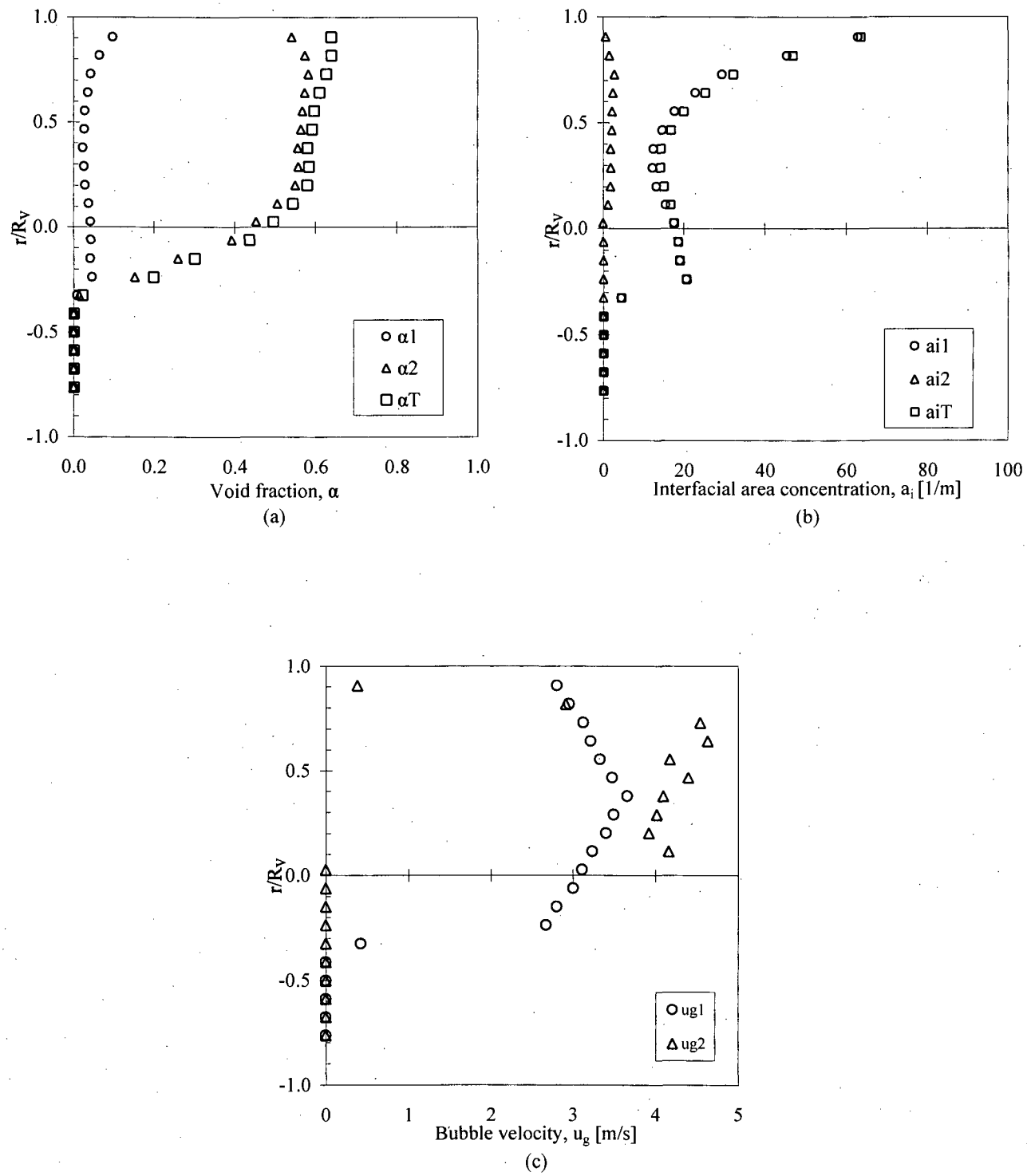


Figure 3.2.8.1 Profiles of local two-phase flow parameters for Run 8 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.8.2 Local two-phase flow parameters for Run 8 acquired along the vertical axis at measurement port 3 (P3)

**Run 8:** $j_{g,atm}$ = 1.218 [m/s] & $j_f$ = 1.652 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.455 | $P_{back}$ [psig] = 36.3 | $j_{g,loc}$ [m/s] = 1.095 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 1.4 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 81.3 | 2.5 | 0.123 | 0.575 | 0.698 | 73.52 | 1.03 | 74.55 | 2.840 | 1.652 | 10.0 | 3348.3 |
| 0.8175 | 62.6 | 2.5 | 0.088 | 0.583 | 0.671 | 55.19 | 2.48 | 57.67 | 2.881 | 4.588 | 9.6 | 1409.8 |
| 0.7296 | 41.4 | 2.7 | 0.053 | 0.589 | 0.642 | 34.86 | 2.22 | 37.08 | 3.017 | 4.428 | 9.1 | 1591.4 |
| 0.6417 | 27.2 | 2.5 | 0.033 | 0.583 | 0.616 | 22.20 | 2.10 | 24.30 | 3.146 | 4.300 | 8.9 | 1664.6 |
| 0.5539 | 18.7 | 2.6 | 0.024 | 0.578 | 0.602 | 15.71 | 2.00 | 17.71 | 3.225 | 3.992 | 9.2 | 1733.7 |
| 0.4660 | 16.0 | 2.5 | 0.022 | 0.577 | 0.599 | 12.38 | 1.89 | 14.27 | 3.378 | 4.220 | 10.5 | 1831.7 |
| 0.3781 | 13.6 | 2.7 | 0.020 | 0.575 | 0.595 | 10.92 | 2.05 | 12.97 | 3.339 | 3.935 | 11.0 | 1683.5 |
| 0.2903 | 13.6 | 2.7 | 0.022 | 0.562 | 0.584 | 11.08 | 1.85 | 12.93 | 3.306 | 4.005 | 11.9 | 1822.1 |
| 0.2024 | 14.1 | 2.6 | 0.025 | 0.518 | 0.543 | 12.48 | 1.26 | 13.74 | 3.204 | 4.014 | 12.2 | 2464.3 |
| 0.1145 | 20.1 | 2.7 | 0.037 | 0.474 | 0.511 | 16.99 | 0.42 | 17.41 | 3.110 | 2.184 | 12.9 | 6770.0 |
| 0.0266 | 19.7 | 2.4 | 0.040 | 0.400 | 0.440 | 17.35 | 0.00 | 17.35 | 2.971 | 0.000 | 13.8 | |
| -0.0612 | 22.1 | 2.1 | 0.044 | 0.293 | 0.337 | 20.56 | 0.00 | 20.56 | 2.785 | 0.000 | 12.9 | |
| -0.1491 | 23.3 | 1.0 | 0.050 | 0.117 | 0.167 | 25.71 | 0.00 | 25.71 | 2.451 | 0.000 | 11.7 | |
| -0.2370 | 28.0 | 0.1 | 0.066 | 0.009 | 0.075 | 32.90 | 0.00 | 32.90 | 2.127 | 0.000 | 12.1 | |
| -0.3249 | 3.0 | 0.0 | 0.007 | 0.000 | 0.007 | 3.50 | 0.00 | 3.50 | 0.389 | 0.000 | 11.3 | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.030 | $\langle a_{i1}\rangle$ [1/m] = 16.19 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.651 |
| $\langle\alpha_2\rangle$ = 0.308 | $\langle a_{i2}\rangle$ [1/m] = 0.76 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.081 |
| $\langle\alpha_T\rangle$ = 0.338 | $\langle a_{iT}\rangle$ [1/m] = 16.95 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.231 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 0.28\%$$

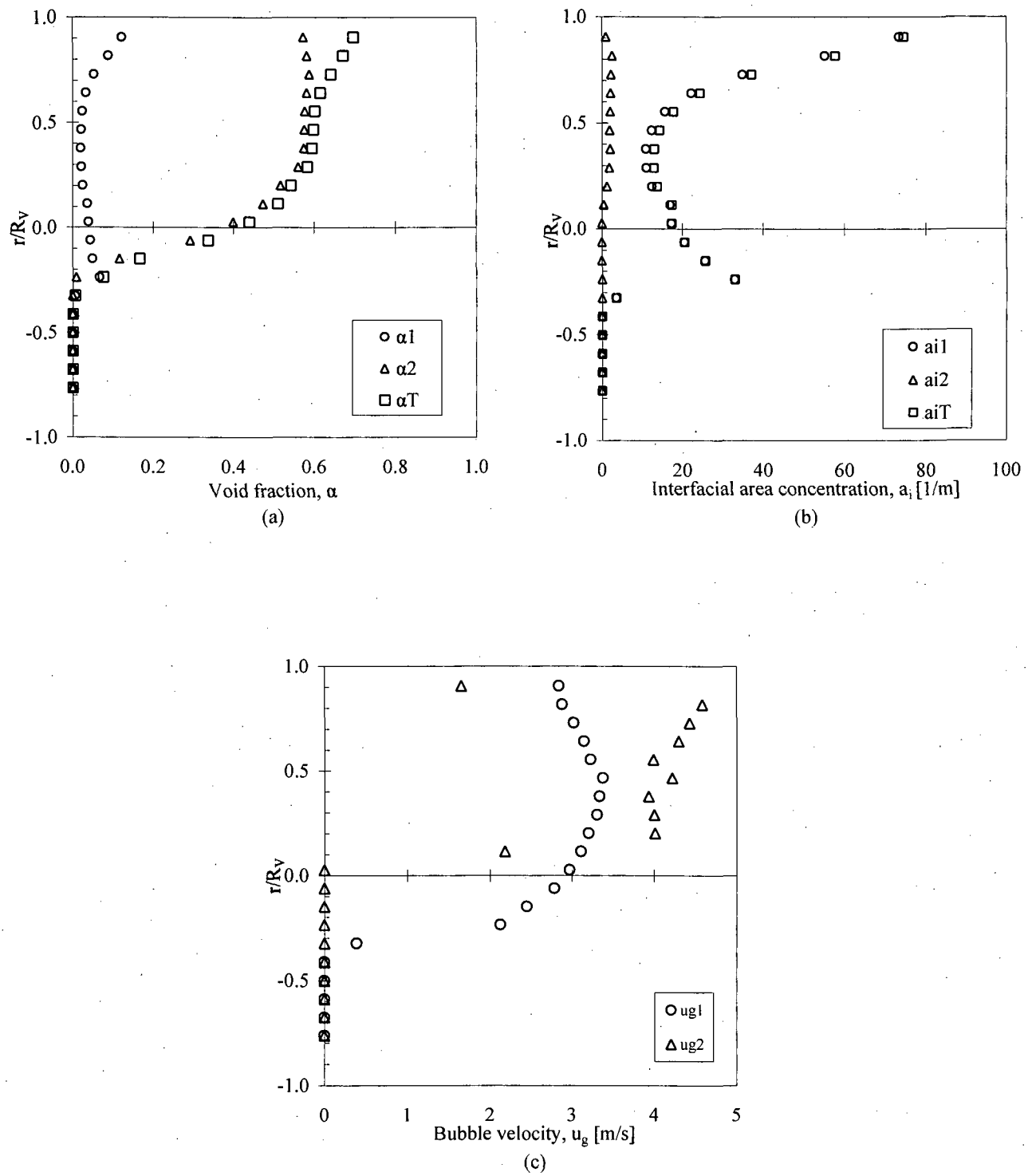


Figure 3.2.8.2 Profiles of local two-phase flow parameters for Run 8 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.8.3 Local two-phase flow parameters for Run 8 acquired along the vertical axis at measurement port 4 (P4)

**Run 8:** $j_{g,atm}$ = 1.218 [m/s] & $j_f$ = 1.652 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.470 | $P_{back}$ [psig] = 36.3 | $j_{g,loc}$ [m/s] = 1.099 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 52.00 | $P_{loc}$ [psig] = 1.5 | $j_f$ [m/s] = 1.651 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 77.3 | 2.3 | 0.103 | 0.577 | 0.680 | 72.77 | 1.91 | 74.68 | 2.652 | 3.388 | 8.5 | 1813.2 |
| 0.8175 | 56.2 | 2.3 | 0.067 | 0.582 | 0.649 | 48.43 | 2.25 | 50.68 | 2.968 | 3.705 | 8.3 | 1552.3 |
| 0.7296 | 38.2 | 2.6 | 0.044 | 0.585 | 0.630 | 31.17 | 2.43 | 33.60 | 3.147 | 4.926 | 8.5 | 1445.2 |
| 0.6417 | 28.7 | 2.4 | 0.035 | 0.582 | 0.617 | 23.25 | 2.00 | 25.25 | 3.240 | 4.099 | 9.0 | 1746.0 |
| 0.5539 | 22.7 | 2.4 | 0.028 | 0.583 | 0.611 | 17.57 | 1.88 | 19.45 | 3.365 | 4.199 | 9.4 | 1861.3 |
| 0.4660 | 16.8 | 2.4 | 0.024 | 0.571 | 0.594 | 12.77 | 1.83 | 14.60 | 3.568 | 4.164 | 11.2 | 1870.8 |
| 0.3781 | 13.7 | 2.5 | 0.019 | 0.573 | 0.593 | 10.36 | 1.81 | 12.17 | 3.644 | 4.473 | 11.1 | 1900.4 |
| 0.2903 | 12.7 | 2.5 | 0.020 | 0.552 | 0.571 | 10.00 | 1.58 | 11.58 | 3.575 | 4.096 | 11.8 | 2095.4 |
| 0.2024 | 14.8 | 2.4 | 0.026 | 0.517 | 0.543 | 12.04 | 1.02 | 13.06 | 3.459 | 3.689 | 13.0 | 3040.6 |
| 0.1145 | 17.6 | 2.4 | 0.035 | 0.469 | 0.504 | 14.80 | 0.18 | 14.98 | 3.292 | 1.344 | 14.4 | 15633.3 |
| 0.0266 | 18.1 | 2.4 | 0.036 | 0.409 | 0.445 | 15.44 | 0.00 | 15.44 | 3.179 | 0.000 | 13.9 | |
| -0.0612 | 20.2 | 2.1 | 0.038 | 0.346 | 0.384 | 17.46 | 0.00 | 17.46 | 3.008 | 0.000 | 13.2 | |
| -0.1491 | 18.3 | 1.4 | 0.039 | 0.200 | 0.239 | 16.86 | 0.00 | 16.86 | 2.828 | 0.000 | 13.9 | |
| -0.2370 | 20.4 | 0.4 | 0.049 | 0.037 | 0.086 | 20.51 | 0.00 | 20.51 | 2.749 | 0.000 | 14.4 | |
| -0.3249 | 14.8 | 0.0 | 0.034 | 0.000 | 0.034 | 15.39 | 0.00 | 15.39 | 1.899 | 0.000 | 13.2 | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.028 | $\langle a_{i1}\rangle$ [1/m] = 14.74 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.848 |
| $\langle\alpha_2\rangle$ = 0.319 | $\langle a_{i2}\rangle$ [1/m] = 0.71 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 2.954 |
| $\langle\alpha_T\rangle$ = 0.347 | $\langle a_{iT}\rangle$ [1/m] = 15.45 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.125 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 1.23\%$$

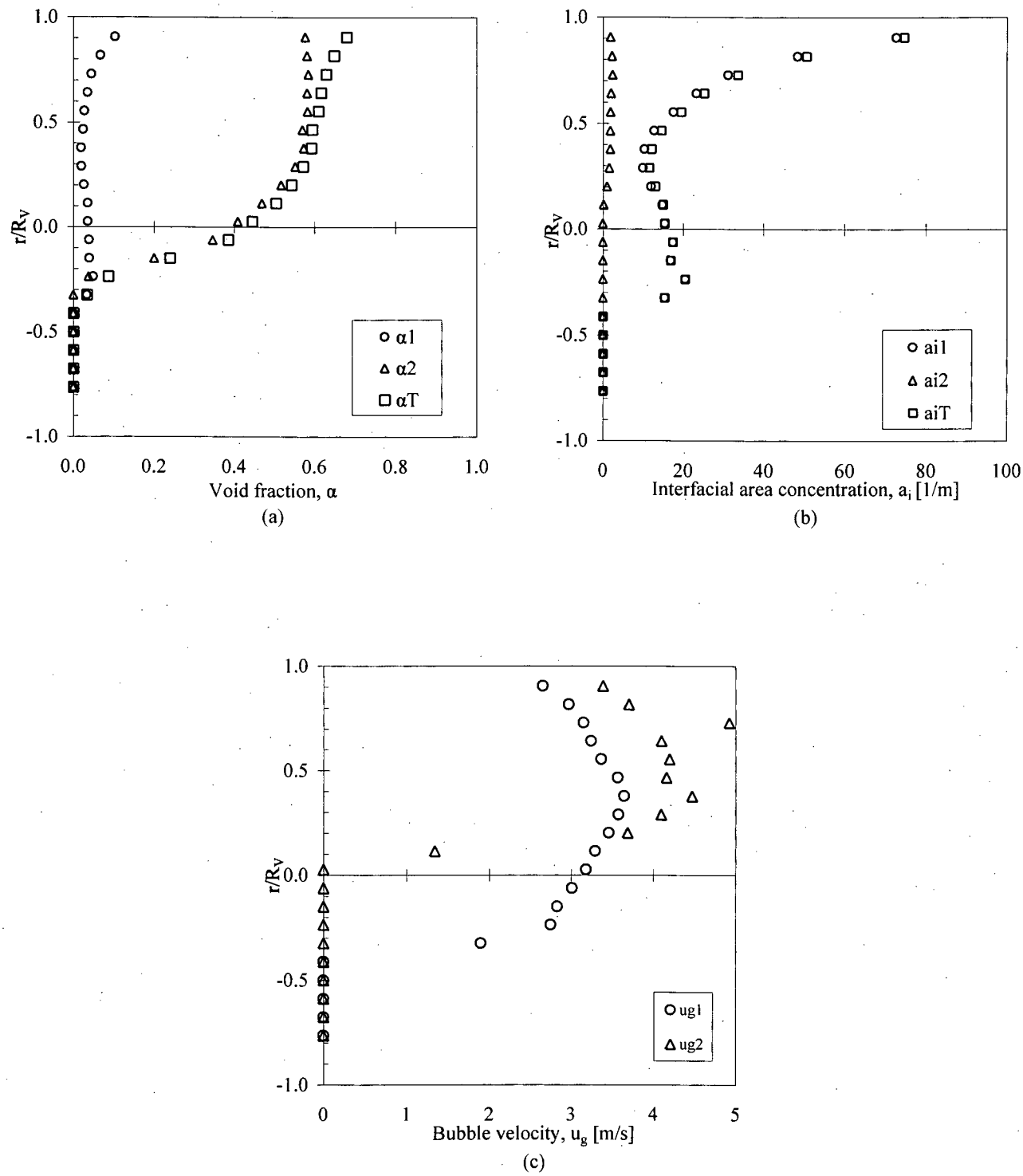


Figure 3.2.8.3 Profiles of local two-phase flow parameters for Run 8 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.9 Summary of results for Run 9.

Table 3.2.9.1 Local two-phase flow parameters for Run 9 acquired along the vertical axis at measurement port 1 (P1)

**Run 9:** $j_{g,atm}$ = 1.186 [m/s] & $j_f$ = 2.202 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.663 | $P_{back}$ [psig] = 33.0 | $j_{g,loc}$ [m/s] = 1.102 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.50 | $P_{loc}$ [psig] = 2.4 | $j_f$ [m/s] = 2.207 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 121.2 | 3.9 | 0.164 | 0.474 | 0.638 | 100.22 | 3.89 | 104.11 | 3.148 | 4.813 | 9.8 | 730.8 |
| 0.8175 | 98.6 | 4.0 | 0.119 | 0.488 | 0.607 | 76.97 | 3.42 | 80.39 | 3.338 | 5.415 | 9.3 | 855.6 |
| 0.7296 | 78.0 | 4.3 | 0.086 | 0.502 | 0.588 | 55.71 | 3.61 | 59.32 | 3.723 | 5.707 | 9.3 | 833.7 |
| 0.6417 | 64.3 | 4.2 | 0.072 | 0.499 | 0.571 | 45.24 | 3.00 | 48.24 | 3.783 | 5.239 | 9.5 | 997.8 |
| 0.5539 | 54.4 | 4.3 | 0.062 | 0.496 | 0.559 | 37.76 | 2.86 | 40.62 | 3.867 | 4.943 | 9.9 | 1041.4 |
| 0.4660 | 40.3 | 4.3 | 0.049 | 0.478 | 0.527 | 26.92 | 2.58 | 29.50 | 4.065 | 4.907 | 10.9 | 1111.6 |
| 0.3781 | 38.6 | 4.2 | 0.050 | 0.469 | 0.519 | 25.91 | 2.40 | 28.31 | 4.044 | 5.091 | 11.5 | 1172.3 |
| 0.2903 | 34.2 | 4.4 | 0.048 | 0.456 | 0.504 | 22.70 | 2.71 | 25.41 | 4.124 | 4.745 | 12.7 | 1008.7 |
| 0.2024 | 34.4 | 4.1 | 0.050 | 0.410 | 0.460 | 24.11 | 2.14 | 26.25 | 4.017 | 4.715 | 12.5 | 1149.5 |
| 0.1145 | 38.0 | 3.4 | 0.063 | 0.317 | 0.380 | 27.53 | 1.56 | 29.09 | 3.852 | 4.251 | 13.7 | 1220.8 |
| 0.0266 | 45.1 | 2.3 | 0.078 | 0.185 | 0.263 | 33.08 | 0.33 | 33.41 | 3.767 | 2.160 | 14.1 | 3363.6 |
| -0.0612 | 47.2 | 1.4 | 0.079 | 0.107 | 0.185 | 35.44 | 0.00 | 35.44 | 3.577 | 0.000 | 13.3 | |
| -0.1491 | 39.8 | 0.2 | 0.064 | 0.015 | 0.079 | 30.58 | 0.00 | 30.58 | 3.435 | 0.000 | 12.6 | |
| -0.2370 | 28.6 | 0.0 | 0.048 | 0.001 | 0.049 | 22.78 | 0.00 | 22.78 | 3.170 | 0.000 | 12.6 | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.049 | $\langle a_{i1}\rangle$ [1/m] = 25.63 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.407 |
| $\langle\alpha_2\rangle$ = 0.223 | $\langle a_{i2}\rangle$ [1/m] = 1.20 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 4.486 |
| $\langle\alpha_T\rangle$ = 0.272 | $\langle a_{iT}\rangle$ [1/m] = 26.83 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.485 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 10.77\%$$

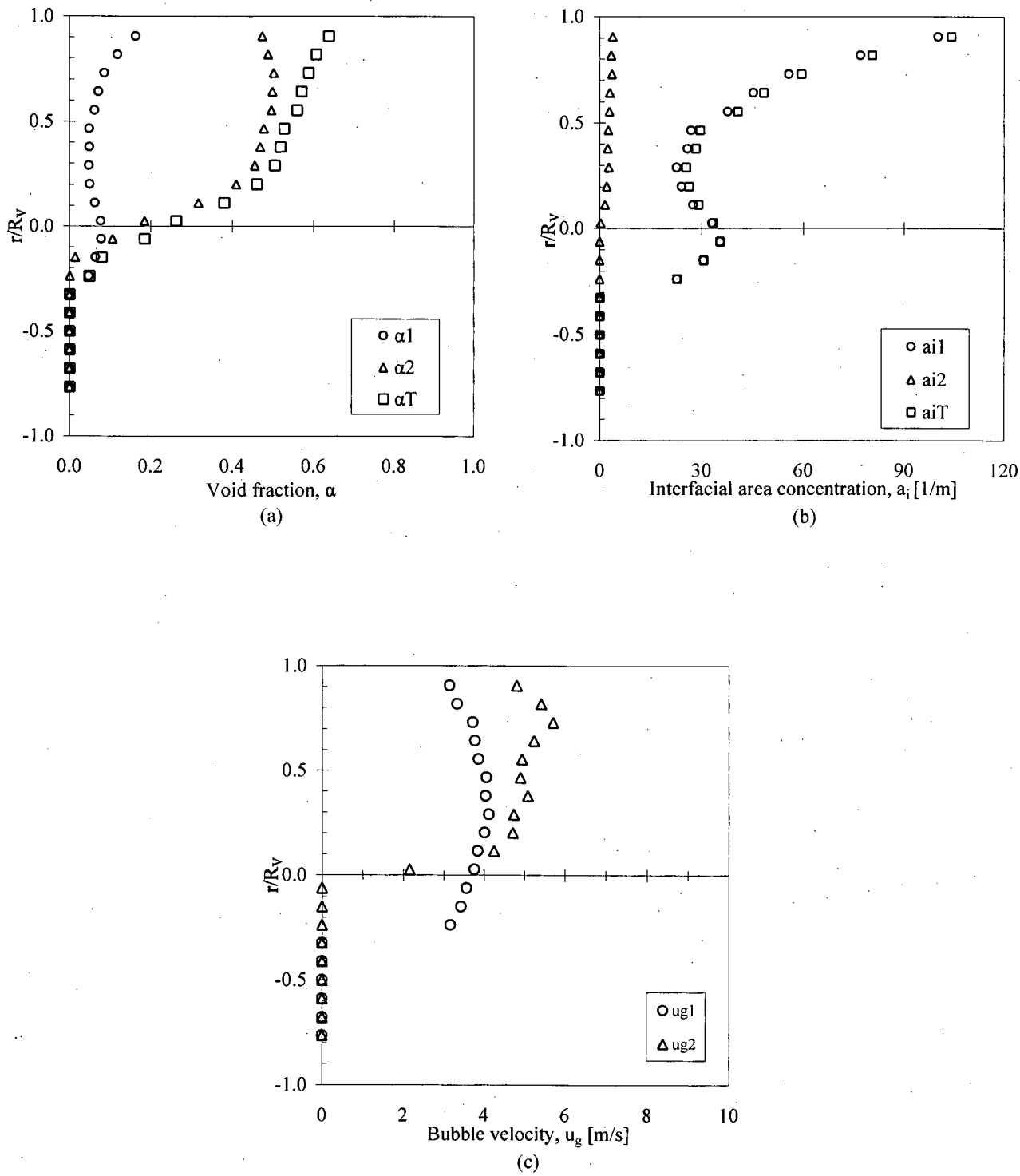


Figure 3.2.9.1 Profiles of local two-phase flow parameters for Run 9 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.9.2 Local two-phase flow parameters for Run 9 acquired along the vertical axis at measurement port 3 (P3)

**Run 9:** $j_{g,atm}$ = 1.186 [m/s] & $j_f$ = 2.202 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.566 | $P_{back}$ [psig] = 35.0 | $j_{g,loc}$ [m/s] = 1.100 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.20 | $P_{loc}$ [psig] = 2.1 | $j_f$ [m/s] = 2.197 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 105.5 | 3.5 | 0.142 | 0.428 | 0.571 | 82.56 | 0.00 | 82.56 | 3.344 | 0.000 | 10.3 | |
| 0.8175 | 91.8 | 3.9 | 0.118 | 0.487 | 0.605 | 68.93 | 1.16 | 70.09 | 3.522 | 1.984 | 10.3 | 2520.0 |
| 0.7296 | 72.9 | 3.8 | 0.086 | 0.505 | 0.591 | 52.39 | 2.85 | 55.24 | 3.676 | 5.909 | 9.9 | 1062.3 |
| 0.6417 | 53.6 | 3.8 | 0.060 | 0.497 | 0.557 | 37.70 | 2.65 | 40.35 | 3.780 | 5.287 | 9.6 | 1125.1 |
| 0.5539 | 39.3 | 4.0 | 0.046 | 0.510 | 0.556 | 27.46 | 2.59 | 30.05 | 3.807 | 5.498 | 10.0 | 1181.9 |
| 0.4660 | 31.5 | 3.8 | 0.037 | 0.501 | 0.537 | 21.78 | 2.42 | 24.20 | 3.958 | 5.403 | 10.1 | 1241.7 |
| 0.3781 | 25.8 | 4.0 | 0.033 | 0.504 | 0.537 | 18.03 | 2.69 | 20.72 | 3.966 | 5.385 | 10.9 | 1124.8 |
| 0.2903 | 24.3 | 4.0 | 0.033 | 0.492 | 0.525 | 17.60 | 2.25 | 19.85 | 3.891 | 5.187 | 11.1 | 1312.5 |
| 0.2024 | 27.7 | 3.9 | 0.042 | 0.462 | 0.505 | 20.49 | 2.30 | 22.79 | 3.825 | 5.190 | 12.4 | 1205.7 |
| 0.1145 | 34.4 | 3.6 | 0.054 | 0.396 | 0.450 | 26.20 | 1.77 | 27.97 | 3.671 | 5.296 | 12.3 | 1342.7 |
| 0.0266 | 42.6 | 3.0 | 0.073 | 0.292 | 0.365 | 33.39 | 0.75 | 34.14 | 3.521 | 3.834 | 13.1 | 2335.2 |
| -0.0612 | 46.4 | 2.1 | 0.081 | 0.174 | 0.255 | 38.67 | 0.00 | 38.67 | 3.116 | 0.000 | 12.6 | |
| -0.1491 | 40.3 | 0.8 | 0.072 | 0.070 | 0.141 | 35.31 | 0.00 | 35.31 | 2.985 | 0.000 | 12.1 | |
| -0.2370 | 32.6 | 0.1 | 0.052 | 0.007 | 0.059 | 29.17 | 0.00 | 29.17 | 2.795 | 0.000 | 10.7 | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.045 | $\langle a_{i1}\rangle$ [1/m] = 23.90 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.187 |
| $\langle\alpha_2\rangle$ = 0.251 | $\langle a_{i2}\rangle$ [1/m] = 1.02 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 4.169 |
| $\langle\alpha_T\rangle$ = 0.296 | $\langle a_{iT}\rangle$ [1/m] = 24.92 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.255 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 14.52\%$$

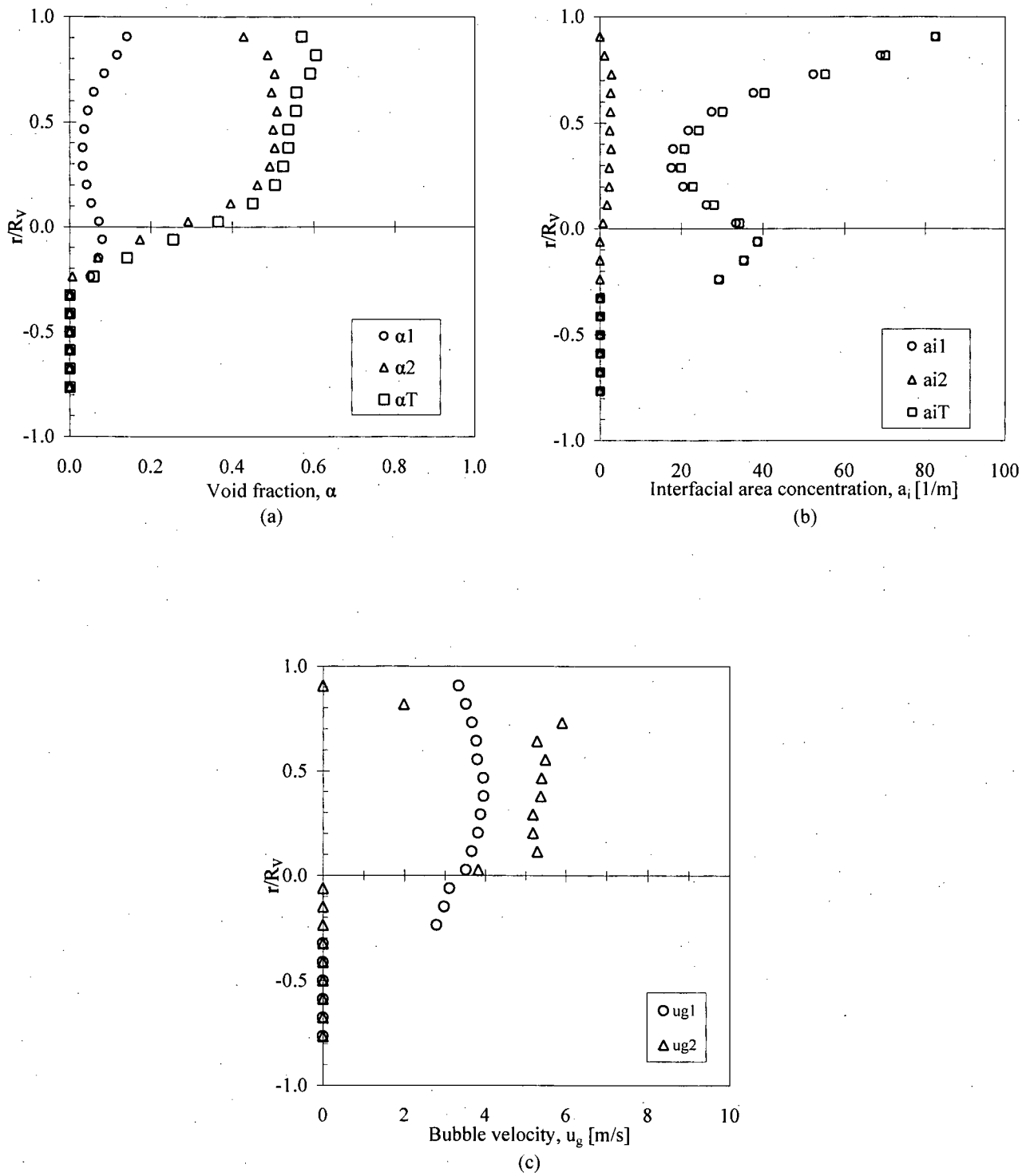


Figure 3.2.9.2 Profiles of local two-phase flow parameters for Run 9 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.9.3 Local two-phase flow parameters for Run 9 acquired along the vertical axis at measurement port 4 (P4)

**Run 9:** $j_{g,atm}$ = 1.186 [m/s] & $j_f$ = 2.202 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 1.556 | $P_{back}$ [psig] = 36.0 | $j_{g,loc}$ [m/s] = 1.102 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.20 | $P_{loc}$ [psig] = 2.3 | $j_f$ [m/s] = 2.197 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 101.7 | 3.3 | 0.118 | 0.490 | 0.608 | 81.42 | 2.44 | 83.86 | 3.291 | 3.704 | 8.7 | 1203.7 |
| 0.8175 | 83.1 | 3.4 | 0.093 | 0.501 | 0.594 | 64.15 | 2.91 | 67.06 | 3.459 | 4.467 | 8.7 | 1033.8 |
| 0.7296 | 68.2 | 3.6 | 0.074 | 0.510 | 0.584 | 49.35 | 2.63 | 51.98 | 3.720 | 5.408 | 8.9 | 1164.0 |
| 0.6417 | 55.8 | 3.5 | 0.062 | 0.504 | 0.567 | 39.26 | 2.21 | 41.47 | 3.824 | 5.482 | 9.5 | 1368.9 |
| 0.5539 | 46.0 | 3.4 | 0.052 | 0.504 | 0.556 | 31.47 | 2.40 | 33.87 | 3.927 | 5.369 | 9.9 | 1260.8 |
| 0.4660 | 39.4 | 3.6 | 0.048 | 0.498 | 0.546 | 26.52 | 2.16 | 28.68 | 4.020 | 4.681 | 10.9 | 1382.8 |
| 0.3781 | 30.5 | 3.3 | 0.038 | 0.483 | 0.521 | 20.41 | 1.79 | 22.20 | 4.216 | 5.169 | 11.3 | 1617.3 |
| 0.2903 | 28.4 | 3.6 | 0.039 | 0.480 | 0.519 | 19.54 | 1.77 | 21.31 | 4.163 | 5.235 | 12.0 | 1625.4 |
| 0.2024 | 26.5 | 3.6 | 0.039 | 0.435 | 0.474 | 18.03 | 1.49 | 19.52 | 4.190 | 5.430 | 13.0 | 1750.5 |
| 0.1145 | 31.2 | 3.1 | 0.052 | 0.358 | 0.410 | 21.96 | 0.65 | 22.61 | 3.923 | 2.615 | 14.3 | 3303.7 |
| 0.0266 | 37.0 | 3.0 | 0.069 | 0.289 | 0.359 | 26.55 | 0.40 | 26.95 | 3.839 | 1.439 | 15.7 | 4336.5 |
| -0.0612 | 33.2 | 2.0 | 0.061 | 0.175 | 0.236 | 25.02 | 0.00 | 25.02 | 3.629 | 0.000 | 14.6 | |
| -0.1491 | 32.8 | 0.8 | 0.061 | 0.059 | 0.120 | 25.32 | 0.00 | 25.32 | 3.475 | 0.000 | 14.5 | |
| -0.2370 | 28.5 | 0.1 | 0.053 | 0.006 | 0.059 | 23.90 | 0.00 | 23.90 | 3.112 | 0.000 | 13.4 | |
| -0.3249 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.4127 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.041 | $\langle a_{i1}\rangle$ [1/m] = 21.16 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.441 |
| $\langle\alpha_2\rangle$ = 0.247 | $\langle a_{i2}\rangle$ [1/m] = 0.88 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 4.118 |
| $\langle\alpha_T\rangle$ = 0.288 | $\langle a_{iT}\rangle$ [1/m] = 22.03 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.258 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle \alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 11.35\%$$

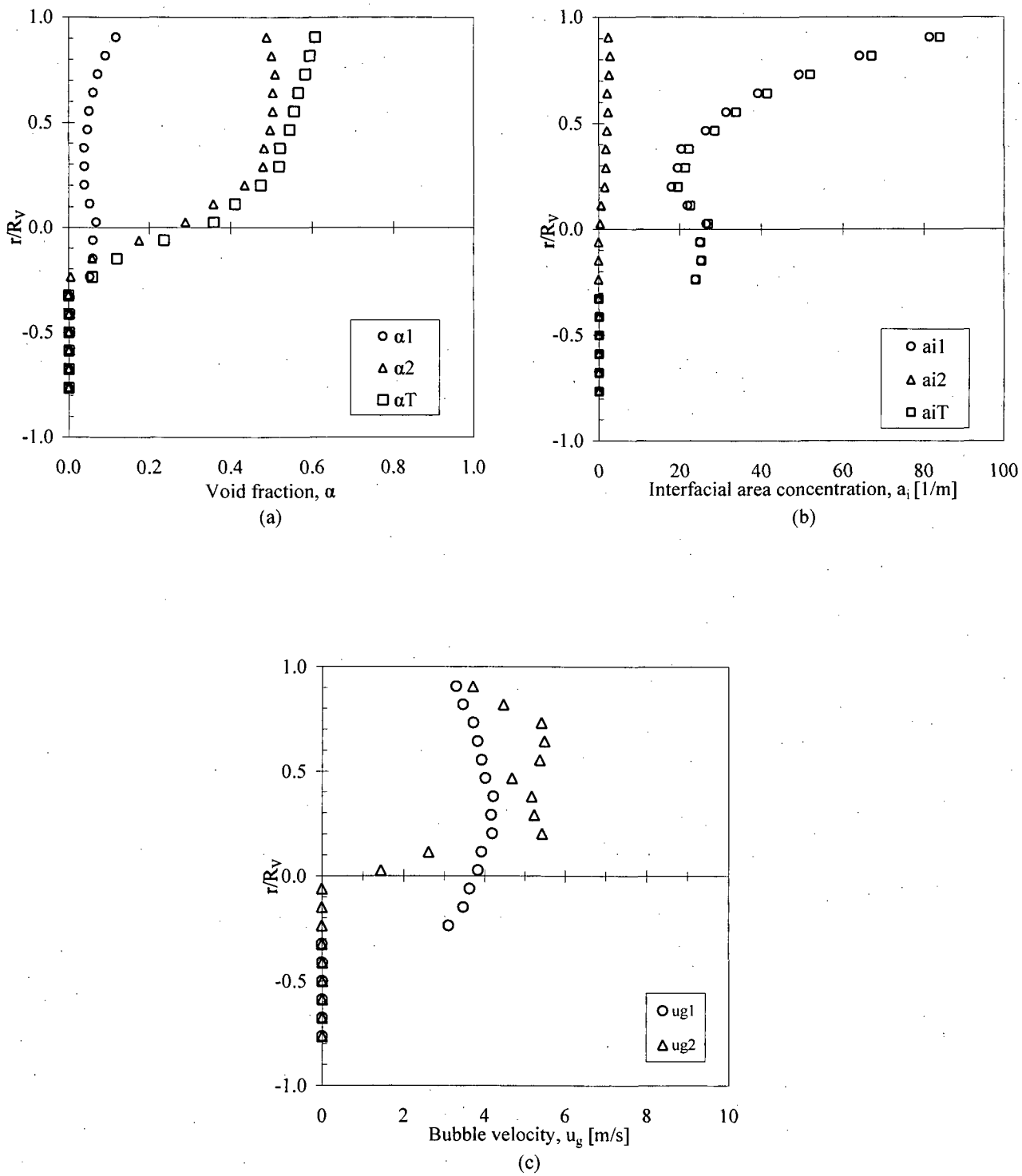


Figure 3.2.9.3 Profiles of local two-phase flow parameters for Run 9 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.10 Summary of results for Run 10.

Table 3.2.10.1 Local two-phase flow parameters for Run 10 acquired along the vertical axis at measurement port 1 (P1)

**Run 10:** $j_{g,atm}$ = 2.371 [m/s] & $j_f$ = 0.555 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.763 | $P_{back}$ [psig] = 24.3 | $j_{g,loc}$ [m/s] = 2.206 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.50 | $P_{loc}$ [psig] = 1.1 | $j_f$ [m/s] = 0.556 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 19.1 | 0.6 | 0.031 | 0.874 | 0.905 | 17.73 | 0.00 | 17.73 | 2.926 | 0.000 | 10.5 | |
| 0.8175 | 19.0 | 0.6 | 0.024 | 0.892 | 0.916 | 15.78 | 0.32 | 16.10 | 3.103 | 2.004 | 9.1 | 16726.9 |
| 0.7296 | 16.6 | 0.5 | 0.021 | 0.900 | 0.921 | 13.48 | 0.44 | 13.92 | 3.291 | 3.047 | 9.5 | 12270.0 |
| 0.6417 | 10.6 | 0.5 | 0.014 | 0.885 | 0.899 | 7.29 | 0.43 | 7.72 | 3.785 | 4.603 | 11.4 | 12348.8 |
| 0.5539 | 8.6 | 0.6 | 0.010 | 0.897 | 0.907 | 5.68 | 0.10 | 5.78 | 3.950 | 0.741 | 10.8 | 53802.0 |
| 0.4660 | 9.4 | 0.5 | 0.011 | 0.888 | 0.899 | 6.78 | 0.18 | 6.96 | 3.771 | 1.452 | 10.0 | 29586.7 |
| 0.3781 | 6.9 | 0.6 | 0.009 | 0.885 | 0.894 | 4.84 | 0.29 | 5.13 | 3.902 | 2.472 | 11.0 | 18302.1 |
| 0.2903 | 8.4 | 0.7 | 0.012 | 0.882 | 0.894 | 5.93 | 0.10 | 6.03 | 3.833 | 0.915 | 12.0 | 52908.0 |
| 0.2024 | 7.7 | 0.6 | 0.011 | 0.897 | 0.908 | 5.64 | 0.19 | 5.83 | 3.818 | 2.429 | 12.0 | 28310.5 |
| 0.1145 | 9.3 | 0.6 | 0.017 | 0.862 | 0.879 | 7.02 | 0.23 | 7.25 | 3.821 | 3.917 | 14.3 | 22497.4 |
| 0.0266 | 7.8 | 0.5 | 0.013 | 0.865 | 0.878 | 5.87 | 0.00 | 5.87 | 3.593 | 0.000 | 13.3 | |
| -0.0612 | 8.1 | 0.8 | 0.014 | 0.797 | 0.811 | 6.43 | 0.00 | 6.43 | 3.292 | 0.000 | 13.3 | |
| -0.1491 | 9.8 | 0.6 | 0.021 | 0.809 | 0.830 | 8.94 | 0.00 | 8.94 | 3.007 | 0.000 | 14.2 | |
| -0.2370 | 9.2 | 0.8 | 0.020 | 0.792 | 0.812 | 8.60 | 0.00 | 8.60 | 3.022 | 0.000 | 13.9 | |
| -0.3249 | 15.6 | 1.0 | 0.040 | 0.647 | 0.687 | 20.64 | 0.00 | 20.64 | 2.193 | 0.000 | 11.6 | |
| -0.4127 | 21.8 | 0.9 | 0.065 | 0.543 | 0.608 | 30.93 | 0.00 | 30.93 | 1.799 | 0.000 | 12.7 | |
| -0.5006 | 15.9 | 0.8 | 0.048 | 0.264 | 0.312 | 19.21 | 0.00 | 19.21 | 1.809 | 0.000 | 15.0 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.018 | $\langle a_{i1}\rangle$ [1/m] = 8.95 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.705 |
| $\langle\alpha_2\rangle$ = 0.686 | $\langle a_{i2}\rangle$ [1/m] = 0.10 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.304 |
| $\langle\alpha_T\rangle$ = 0.705 | $\langle a_{iT}\rangle$ [1/m] = 9.05 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.419 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 54.66\%$$

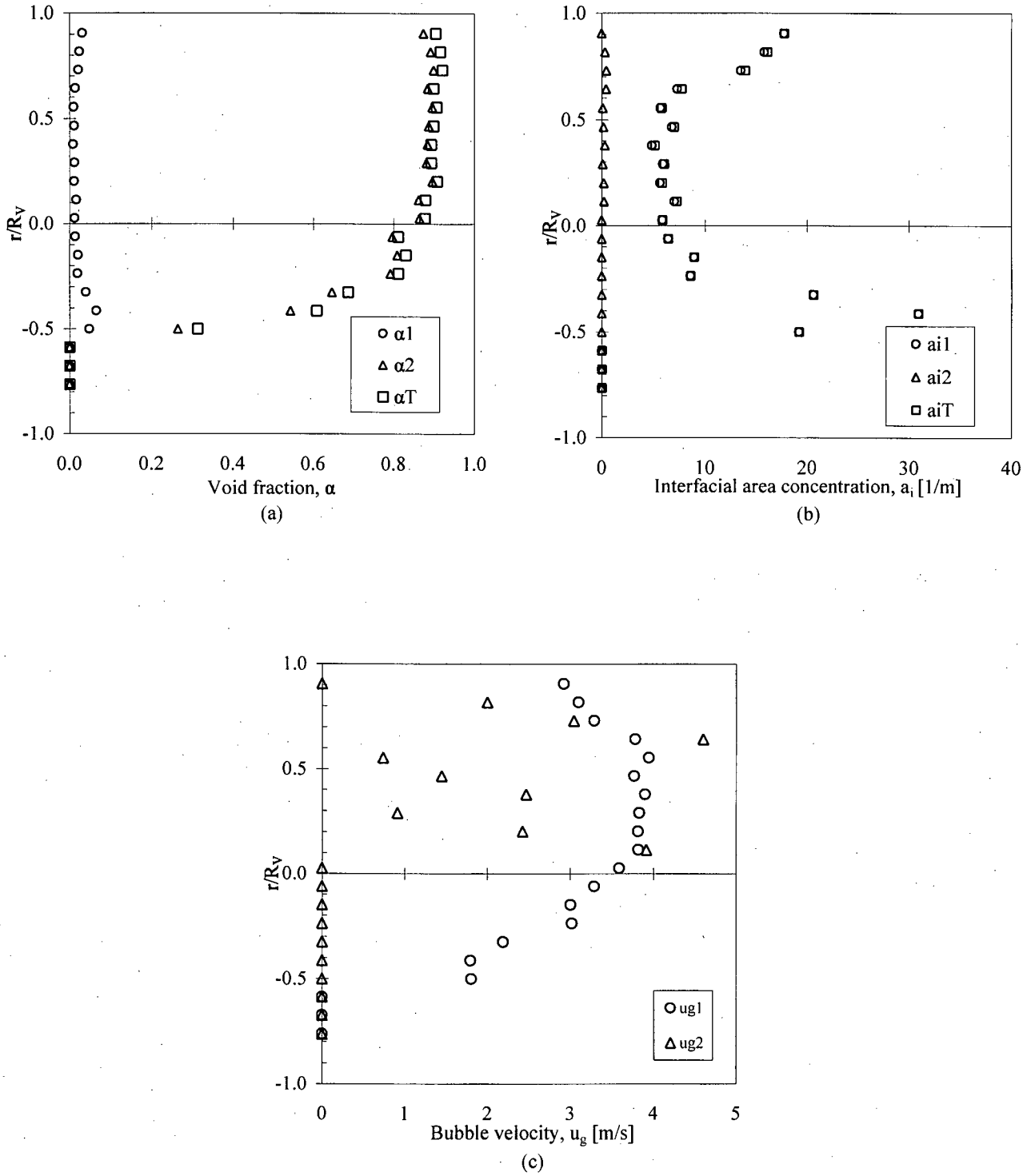


Figure 3.2.10.1 Profiles of local two-phase flow parameters for Run 10 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.10.2 Local two-phase flow parameters for Run 10 acquired along the vertical axis at measurement port 3 (P3)

**Run 10:** $j_{g,atm}$ = 2.371 [m/s] & $j_f$ = 0.555 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.160 | $P_{back}$ [psig] = 31.3 | $j_{g,loc}$ [m/s] = 2.199 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.60 | $P_{loc}$ [psig] = 1.0 | $j_f$ [m/s] = 0.559 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 29.1 | 0.5 | 0.055 | 0.877 | 0.932 | 26.09 | 0.00 | 26.09 | 2.978 | 0.000 | 12.7 | |
| 0.8175 | 30.3 | 0.4 | 0.051 | 0.880 | 0.930 | 26.94 | 0.11 | 27.05 | 2.971 | 0.698 | 11.2 | 47972.7 |
| 0.7296 | 29.2 | 0.5 | 0.038 | 0.871 | 0.909 | 24.84 | 0.41 | 25.25 | 3.076 | 5.605 | 9.1 | 12742.0 |
| 0.6417 | 21.8 | 0.5 | 0.027 | 0.883 | 0.909 | 17.50 | 0.35 | 17.85 | 3.283 | 3.481 | 9.2 | 15128.6 |
| 0.5539 | 13.4 | 0.6 | 0.015 | 0.877 | 0.892 | 10.16 | 0.35 | 10.51 | 3.421 | 3.592 | 8.8 | 15039.4 |
| 0.4660 | 11.5 | 0.6 | 0.013 | 0.878 | 0.890 | 8.52 | 0.35 | 8.87 | 3.590 | 4.508 | 8.9 | 15044.6 |
| 0.3781 | 8.1 | 0.6 | 0.010 | 0.871 | 0.881 | 5.97 | 0.44 | 6.41 | 3.670 | 4.431 | 10.4 | 11877.3 |
| 0.2903 | 7.9 | 0.5 | 0.010 | 0.872 | 0.881 | 5.58 | 0.31 | 5.89 | 3.879 | 4.387 | 10.2 | 16871.6 |
| 0.2024 | 6.5 | 0.6 | 0.008 | 0.870 | 0.878 | 4.95 | 0.31 | 5.26 | 3.837 | 3.689 | 9.8 | 16829.0 |
| 0.1145 | 7.1 | 0.6 | 0.010 | 0.848 | 0.858 | 5.61 | 0.22 | 5.83 | 3.614 | 3.644 | 10.7 | 23135.5 |
| 0.0266 | 7.4 | 0.6 | 0.011 | 0.829 | 0.840 | 5.72 | 0.03 | 5.75 | 3.768 | 0.813 | 11.0 | 165840.0 |
| -0.0612 | 9.6 | 0.7 | 0.016 | 0.823 | 0.839 | 8.13 | 0.00 | 8.13 | 3.292 | 0.000 | 12.0 | |
| -0.1491 | 10.0 | 0.8 | 0.016 | 0.801 | 0.818 | 8.32 | 0.00 | 8.32 | 3.234 | 0.000 | 11.8 | |
| -0.2370 | 13.9 | 0.7 | 0.029 | 0.750 | 0.779 | 13.34 | 0.00 | 13.34 | 2.832 | 0.000 | 13.0 | |
| -0.3249 | 13.5 | 0.8 | 0.032 | 0.681 | 0.713 | 15.23 | 0.00 | 15.23 | 2.431 | 0.000 | 12.7 | |
| -0.4127 | 18.7 | 0.8 | 0.050 | 0.523 | 0.574 | 23.83 | 0.00 | 23.83 | 1.941 | 0.000 | 12.7 | |
| -0.5006 | 16.1 | 1.0 | 0.052 | 0.179 | 0.231 | 23.82 | 0.00 | 23.82 | 1.727 | 0.000 | 13.0 | |
| -0.5885 | 3.4 | 0.0 | 0.010 | 0.000 | 0.010 | 4.01 | 0.00 | 4.01 | 0.796 | 0.000 | 15.6 | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.020 | $<a_{i1}>$ [1/m] = 10.72 | $<<u_{g1}>>$ [m/s] = 2.716 |
| $<\alpha_2>$ = 0.676 | $<a_{i2}>$ [1/m] = 0.14 | $<<u_{g2}>>$ [m/s] = 2.119 |
| $<\alpha_T>$ = 0.696 | $<a_{iT}>$ [1/m] = 10.86 | $<<u_g>>$ [m/s] = 2.259 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 28.49\%$$

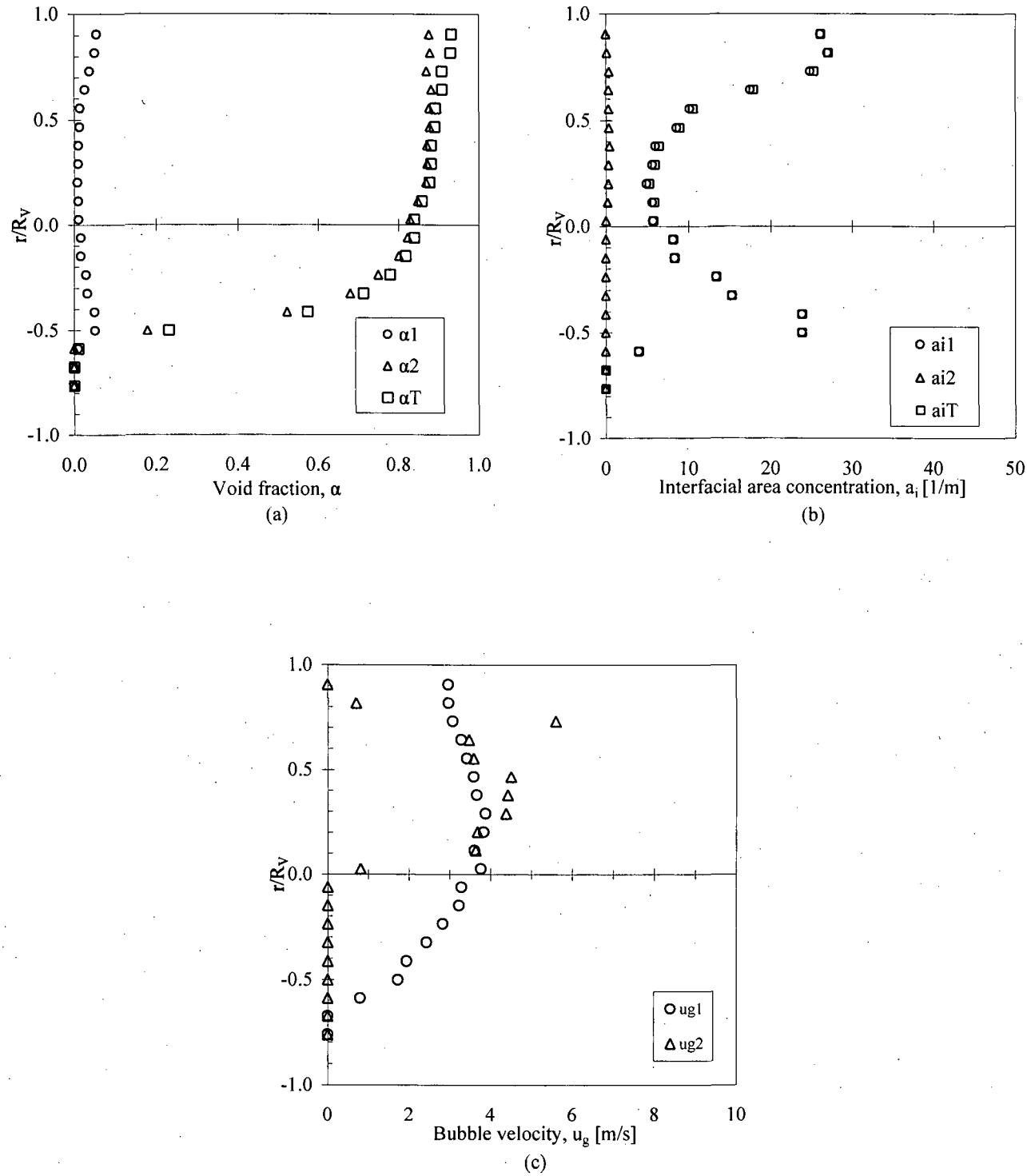


Figure 3.2.10.2 Profiles of local two-phase flow parameters for Run 10 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.10.3 Local two-phase flow parameters for Run 10 acquired along the vertical axis at measurement port 4 (P4)

**Run 10:** $j_{g,atm}$ = 2.371 [m/s] & $j_f$ = 0.555 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.160 | $P_{back}$ [psig] = 32.2 | $j_{g,loc}$ [m/s] = 2.228 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.30 | $P_{loc}$ [psig] = 1.1 | $j_f$ [m/s] = 0.549 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 24.1 | 0.5 | 0.036 | 0.876 | 0.911 | 24.10 | 0.00 | 24.10 | 2.594 | 0.000 | 8.8 | |
| 0.8175 | 20.2 | 0.5 | 0.024 | 0.886 | 0.910 | 17.64 | 0.60 | 18.24 | 2.880 | 2.886 | 8.2 | 8858.0 |
| 0.7296 | 15.2 | 0.5 | 0.017 | 0.877 | 0.894 | 13.23 | 0.35 | 13.58 | 2.928 | 3.376 | 7.7 | 15029.1 |
| 0.6417 | 10.9 | 0.5 | 0.012 | 0.881 | 0.894 | 8.53 | 0.31 | 8.84 | 3.358 | 3.181 | 8.7 | 17057.4 |
| 0.5539 | 6.6 | 0.5 | 0.007 | 0.880 | 0.887 | 5.16 | 0.16 | 5.32 | 3.459 | 1.479 | 8.5 | 32992.5 |
| 0.4660 | 6.3 | 0.5 | 0.007 | 0.888 | 0.896 | 4.74 | 0.32 | 5.06 | 3.657 | 3.337 | 9.2 | 16657.5 |
| 0.3781 | 6.6 | 0.5 | 0.007 | 0.865 | 0.873 | 4.97 | 0.34 | 5.31 | 3.636 | 3.081 | 8.9 | 15268.2 |
| 0.2903 | 5.2 | 0.5 | 0.006 | 0.886 | 0.891 | 3.99 | 0.25 | 4.24 | 3.509 | 2.734 | 8.4 | 21252.0 |
| 0.2024 | 5.5 | 0.5 | 0.007 | 0.869 | 0.876 | 4.09 | 0.03 | 4.12 | 3.707 | 0.893 | 10.4 | 173840.0 |
| 0.1145 | 6.4 | 0.6 | 0.009 | 0.862 | 0.872 | 4.80 | 0.09 | 4.89 | 3.680 | 2.156 | 11.6 | 57493.3 |
| 0.0266 | 6.2 | 0.5 | 0.009 | 0.832 | 0.842 | 4.67 | 0.00 | 4.67 | 3.606 | 0.000 | 11.8 | |
| -0.0612 | 6.2 | 0.5 | 0.012 | 0.838 | 0.850 | 5.55 | 0.00 | 5.55 | 3.228 | 0.000 | 13.2 | |
| -0.1491 | 6.8 | 0.7 | 0.012 | 0.813 | 0.826 | 5.56 | 0.00 | 5.56 | 3.348 | 0.000 | 13.4 | |
| -0.2370 | 13.3 | 0.8 | 0.030 | 0.778 | 0.808 | 14.40 | 0.00 | 14.40 | 2.713 | 0.000 | 12.5 | |
| -0.3249 | 17.1 | 0.8 | 0.041 | 0.638 | 0.679 | 22.22 | 0.00 | 22.22 | 2.035 | 0.000 | 11.0 | |
| -0.4127 | 20.7 | 0.7 | 0.064 | 0.467 | 0.531 | 31.09 | 0.00 | 31.09 | 1.696 | 0.000 | 12.4 | |
| -0.5006 | 16.3 | 0.3 | 0.051 | 0.058 | 0.109 | 22.36 | 0.00 | 22.36 | 1.607 | 0.000 | 13.7 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.017 | $\langle a_{i1}\rangle$ [1/m] = 8.93 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 2.445 |
| $\langle\alpha_2\rangle$ = 0.672 | $\langle a_{i2}\rangle$ [1/m] = 0.11 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.393 |
| $\langle\alpha_T\rangle$ = 0.688 | $\langle a_{iT}\rangle$ [1/m] = 9.04 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.501 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 53.63\%$$

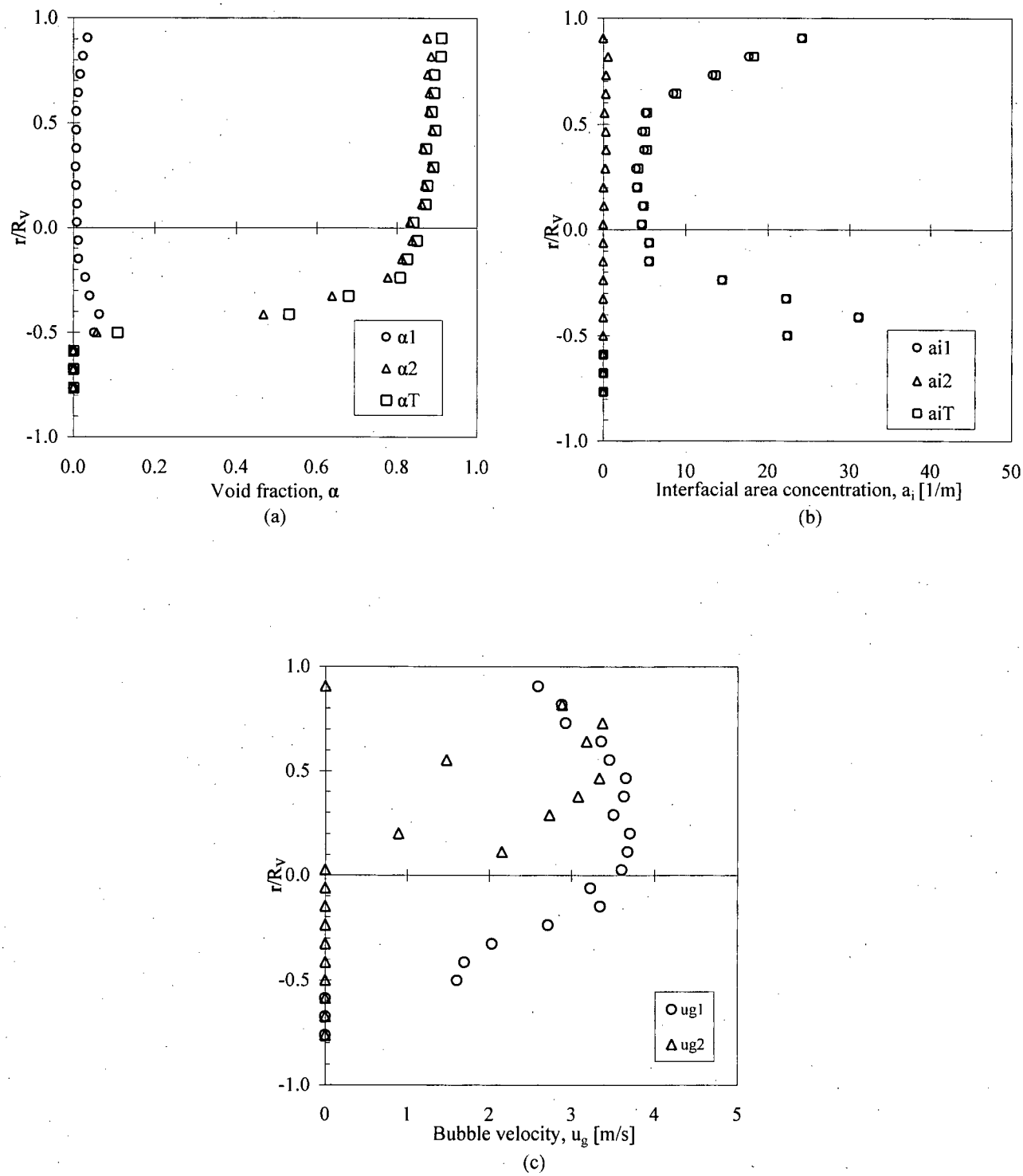


Figure 3.2.10.3 Profiles of local two-phase flow parameters for Run 10 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.11 Summary of results for Run 11.

Table 3.2.11.1 Local two-phase flow parameters for Run 11 acquired along the vertical axis at measurement port 1 (P1)

**Run 11:** $j_{g,atm}$ = 2.526 [m/s] & $j_f$ = 1.645 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.400 | $P_{back}$ [psig] = 31.6 | $j_{g,loc}$ [m/s] = 2.199 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.80 | $P_{loc}$ [psig] = 2.3 | $j_f$ [m/s] = 1.645 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 53.5 | 2.0 | 0.063 | 0.674 | 0.738 | 38.24 | 0.00 | 38.24 | 3.744 | 0.000 | 9.9 | |
| 0.8175 | 47.7 | 2.0 | 0.054 | 0.702 | 0.756 | 32.32 | 0.73 | 33.05 | 4.008 | 3.213 | 10.0 | 5771.5 |
| 0.7296 | 45.0 | 1.8 | 0.051 | 0.701 | 0.752 | 30.23 | 0.61 | 30.84 | 4.144 | 3.650 | 10.0 | 6897.0 |
| 0.6417 | 41.0 | 2.0 | 0.046 | 0.697 | 0.743 | 27.59 | 0.54 | 28.13 | 4.170 | 3.631 | 10.0 | 7744.4 |
| 0.5539 | 36.5 | 2.0 | 0.041 | 0.707 | 0.748 | 23.66 | 1.15 | 24.81 | 4.343 | 6.189 | 10.5 | 3686.1 |
| 0.4660 | 31.9 | 1.9 | 0.038 | 0.696 | 0.734 | 21.03 | 0.87 | 21.90 | 4.392 | 6.717 | 10.8 | 4798.6 |
| 0.3781 | 28.1 | 2.2 | 0.037 | 0.696 | 0.733 | 18.39 | 0.86 | 19.25 | 4.524 | 4.990 | 12.2 | 4855.8 |
| 0.2903 | 27.4 | 2.1 | 0.036 | 0.696 | 0.732 | 17.40 | 0.91 | 18.31 | 4.603 | 6.279 | 12.3 | 4591.6 |
| 0.2024 | 32.1 | 2.0 | 0.048 | 0.667 | 0.714 | 20.63 | 0.93 | 21.56 | 4.463 | 5.859 | 13.9 | 4300.0 |
| 0.1145 | 39.4 | 2.1 | 0.062 | 0.666 | 0.728 | 26.65 | 0.40 | 27.05 | 4.228 | 3.143 | 13.9 | 9985.5 |
| 0.0266 | 37.6 | 2.3 | 0.059 | 0.611 | 0.670 | 24.25 | 0.31 | 24.56 | 4.397 | 2.022 | 14.6 | 11818.1 |
| -0.0612 | 50.8 | 2.1 | 0.084 | 0.572 | 0.655 | 36.12 | 0.00 | 36.12 | 3.985 | 0.000 | 13.9 | |
| -0.1491 | 55.9 | 2.3 | 0.093 | 0.492 | 0.585 | 41.40 | 0.00 | 41.40 | 3.752 | 0.000 | 13.5 | |
| -0.2370 | 70.7 | 2.1 | 0.124 | 0.340 | 0.464 | 59.02 | 0.00 | 59.02 | 3.273 | 0.000 | 12.6 | |
| -0.3249 | 96.6 | 0.9 | 0.180 | 0.100 | 0.280 | 91.96 | 0.00 | 91.96 | 2.807 | 0.000 | 11.8 | |
| -0.4127 | 64.8 | 0.0 | 0.102 | 0.001 | 0.104 | 58.86 | 0.00 | 58.86 | 2.555 | 0.000 | 10.4 | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.059 | $\langle a_{i1}\rangle$ [1/m] = 29.14 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.509 |
| $\langle\alpha_2\rangle$ = 0.453 | $\langle a_{i2}\rangle$ [1/m] = 0.35 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.215 |
| $\langle\alpha_T\rangle$ = 0.512 | $\langle a_{iT}\rangle$ [1/m] = 29.49 | $\langle\langle u_g\rangle\rangle$ [m/s] = 3.452 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 19.58\%$$

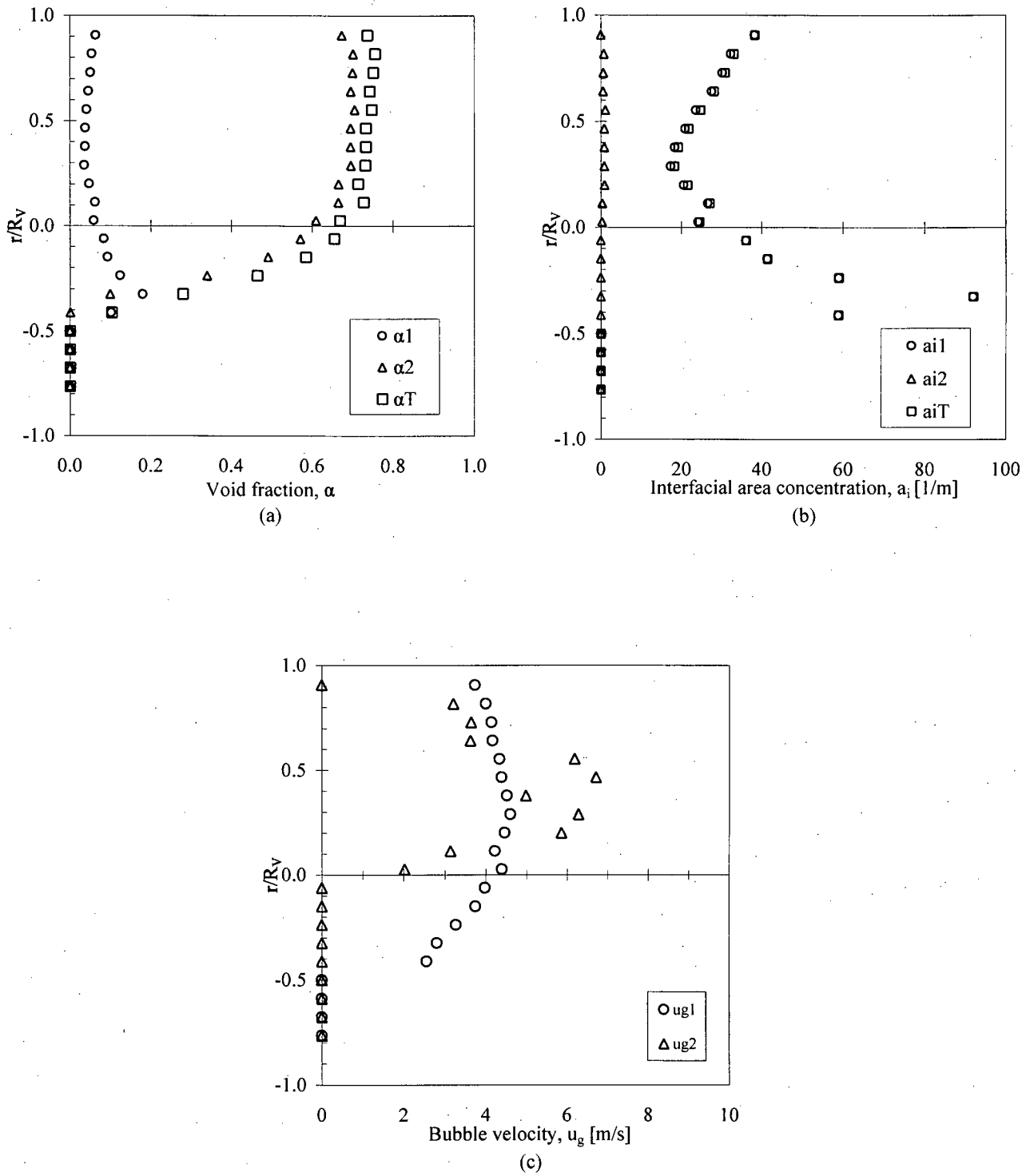


Figure 3.2.11.1 Profiles of local two-phase flow parameters for Run 11 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.11.2 Local two-phase flow parameters for Run 11 acquired along the vertical axis at measurement port 3 (P3)

**Run 11:** $j_{g,atm}$ = 2.526 [m/s] & $j_f$ = 1.645 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 2.381 | $P_{back}$ [psig] = 49.6 | $j_{g,loc}$ [m/s] = 2.164 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.90 | $P_{loc}$ [psig] = 2.1 | $j_f$ [m/s] = 1.648 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 74.9 | 2.0 | 0.104 | 0.678 | 0.782 | 50.89 | 0.31 | 51.20 | 3.958 | 1.346 | 12.3 | 13124.5 |
| 0.8175 | 68.7 | 1.9 | 0.093 | 0.685 | 0.778 | 46.01 | 0.42 | 46.43 | 4.122 | 2.309 | 12.1 | 9790.0 |
| 0.7296 | 58.0 | 1.9 | 0.070 | 0.681 | 0.750 | 36.25 | 0.96 | 37.21 | 4.109 | 5.754 | 11.5 | 4254.4 |
| 0.6417 | 51.9 | 2.1 | 0.060 | 0.700 | 0.759 | 31.86 | 1.22 | 33.08 | 4.183 | 6.700 | 11.3 | 3440.7 |
| 0.5539 | 43.4 | 2.0 | 0.051 | 0.686 | 0.737 | 26.93 | 1.16 | 28.09 | 4.170 | 6.168 | 11.3 | 3549.8 |
| 0.4660 | 37.9 | 2.0 | 0.042 | 0.678 | 0.721 | 23.29 | 0.94 | 24.23 | 4.272 | 5.161 | 10.8 | 4330.2 |
| 0.3781 | 33.8 | 2.0 | 0.040 | 0.669 | 0.709 | 20.54 | 0.94 | 21.48 | 4.319 | 6.057 | 11.7 | 4269.6 |
| 0.2903 | 30.3 | 2.1 | 0.037 | 0.667 | 0.704 | 18.63 | 0.62 | 19.25 | 4.309 | 5.144 | 11.8 | 6458.7 |
| 0.2024 | 31.2 | 2.2 | 0.040 | 0.645 | 0.685 | 19.23 | 0.79 | 20.02 | 4.309 | 7.155 | 12.5 | 4898.0 |
| 0.1145 | 37.1 | 2.0 | 0.053 | 0.613 | 0.666 | 25.02 | 0.00 | 25.02 | 4.083 | 0.000 | 12.8 | |
| 0.0266 | 41.6 | 2.0 | 0.060 | 0.554 | 0.614 | 27.93 | 0.00 | 27.93 | 4.016 | 0.000 | 12.9 | |
| -0.0612 | 50.2 | 2.2 | 0.080 | 0.493 | 0.572 | 35.42 | 0.00 | 35.42 | 3.723 | 0.000 | 13.5 | |
| -0.1491 | 47.1 | 2.1 | 0.075 | 0.414 | 0.489 | 34.44 | 0.00 | 34.44 | 3.647 | 0.000 | 13.1 | |
| -0.2370 | 59.2 | 1.6 | 0.108 | 0.236 | 0.343 | 50.99 | 0.00 | 50.99 | 3.082 | 0.000 | 12.6 | |
| -0.3249 | 86.3 | 0.7 | 0.169 | 0.086 | 0.255 | 83.77 | 0.00 | 83.77 | 2.697 | 0.000 | 12.1 | |
| -0.4127 | 88.5 | 0.1 | 0.179 | 0.013 | 0.192 | 92.24 | 0.00 | 92.24 | 2.345 | 0.000 | 11.7 | |
| -0.5006 | 47.8 | 0.0 | 0.089 | 0.000 | 0.089 | 47.36 | 0.00 | 47.36 | 1.767 | 0.000 | 11.3 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.067 | $<a_{i1}>$ [1/m] = 33.13 | $<<u_{g1}>>$ [m/s] = 3.250 |
| $<\alpha_2>$ = 0.421 | $<a_{i2}>$ [1/m] = 0.33 | $<<u_{g2}>>$ [m/s] = 3.408 |
| $<\alpha_T>$ = 0.488 | $<a_{iT}>$ [1/m] = 33.46 | $<<u_g>>$ [m/s] = 3.588 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 19.02\%$$

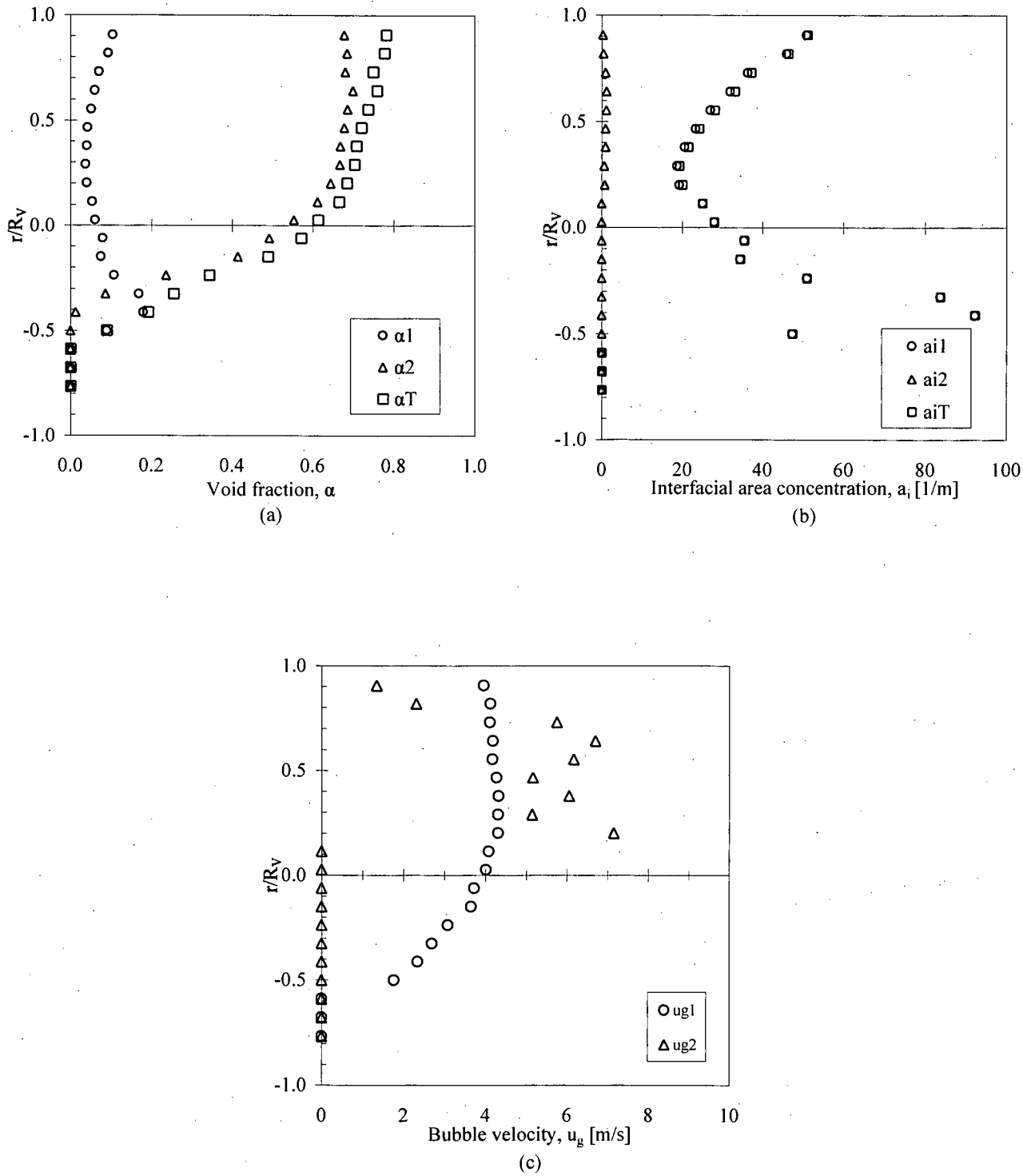


Figure 3.2.11.2 Profiles of local two-phase flow parameters for Run 11 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.11.3 Local two-phase flow parameters for Run 11 acquired along the vertical axis at measurement port 4 (P4)

**Run 11:** $j_{g,atm}$ = 2.526 [m/s] & $j_f$ = 1.645 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.113 | $P_{back}$ [psig] = 35.9 | $j_{g,loc}$ [m/s] = 2.227 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.70 | $P_{loc}$ [psig] = 2.1 | $j_f$ [m/s] = 1.641 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 58.3 | 1.7 | 0.069 | 0.699 | 0.768 | 42.26 | 0.79 | 43.05 | 3.785 | 2.814 | 9.8 | 5307.3 |
| 0.8175 | 51.0 | 1.7 | 0.056 | 0.694 | 0.751 | 35.56 | 0.66 | 36.22 | 3.884 | 3.594 | 9.5 | 6311.8 |
| 0.7296 | 45.8 | 1.8 | 0.048 | 0.702 | 0.750 | 30.94 | 1.03 | 31.97 | 4.189 | 6.009 | 9.3 | 4087.6 |
| 0.6417 | 42.0 | 1.8 | 0.045 | 0.706 | 0.750 | 28.26 | 1.14 | 29.40 | 4.256 | 6.329 | 9.5 | 3714.2 |
| 0.5539 | 37.9 | 1.7 | 0.040 | 0.687 | 0.726 | 25.04 | 0.95 | 25.99 | 4.374 | 6.799 | 9.5 | 4338.3 |
| 0.4660 | 31.9 | 1.8 | 0.035 | 0.708 | 0.743 | 21.44 | 1.05 | 22.49 | 4.514 | 6.204 | 9.9 | 4044.0 |
| 0.3781 | 27.8 | 1.9 | 0.031 | 0.706 | 0.737 | 18.21 | 0.84 | 19.05 | 4.664 | 5.943 | 10.3 | 5043.6 |
| 0.2903 | 26.2 | 1.9 | 0.033 | 0.687 | 0.720 | 16.98 | 0.83 | 17.81 | 4.590 | 6.990 | 11.7 | 4964.8 |
| 0.2024 | 24.7 | 1.8 | 0.030 | 0.678 | 0.708 | 15.93 | 0.27 | 16.20 | 4.851 | 4.313 | 11.4 | 15071.1 |
| 0.1145 | 26.6 | 1.9 | 0.038 | 0.661 | 0.699 | 16.88 | 0.00 | 16.88 | 4.808 | 0.000 | 13.5 | |
| 0.0266 | 30.7 | 1.8 | 0.044 | 0.593 | 0.638 | 20.58 | 0.00 | 20.58 | 4.534 | 0.000 | 12.9 | |
| -0.0612 | 35.4 | 1.9 | 0.052 | 0.558 | 0.610 | 22.84 | 0.08 | 22.92 | 4.361 | 2.202 | 13.8 | 41812.5 |
| -0.1491 | 43.6 | 2.1 | 0.067 | 0.443 | 0.511 | 30.97 | 0.00 | 30.97 | 4.016 | 0.000 | 13.0 | |
| -0.2370 | 54.6 | 2.1 | 0.093 | 0.221 | 0.314 | 41.94 | 0.00 | 41.94 | 3.665 | 0.000 | 13.3 | |
| -0.3249 | 101.6 | 0.1 | 0.201 | 0.012 | 0.213 | 97.46 | 0.00 | 97.46 | 2.930 | 0.000 | 12.3 | |
| -0.4127 | 108.6 | 0.0 | 0.199 | 0.000 | 0.199 | 110.12 | 0.00 | 110.12 | 2.493 | 0.000 | 10.8 | |
| -0.5006 | 35.1 | 0.0 | 0.050 | 0.000 | 0.050 | 30.32 | 0.00 | 30.32 | 1.533 | 0.000 | 9.8 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.057 | $\langle a_{i1}\rangle$ [1/m] = 29.51 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.452 |
| $\langle\alpha_2\rangle$ = 0.438 | $\langle a_{i2}\rangle$ [1/m] = 0.33 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 3.856 |
| $\langle\alpha_T\rangle$ = 0.495 | $\langle a_{iT}\rangle$ [1/m] = 29.84 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.044 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 10.18\%$$

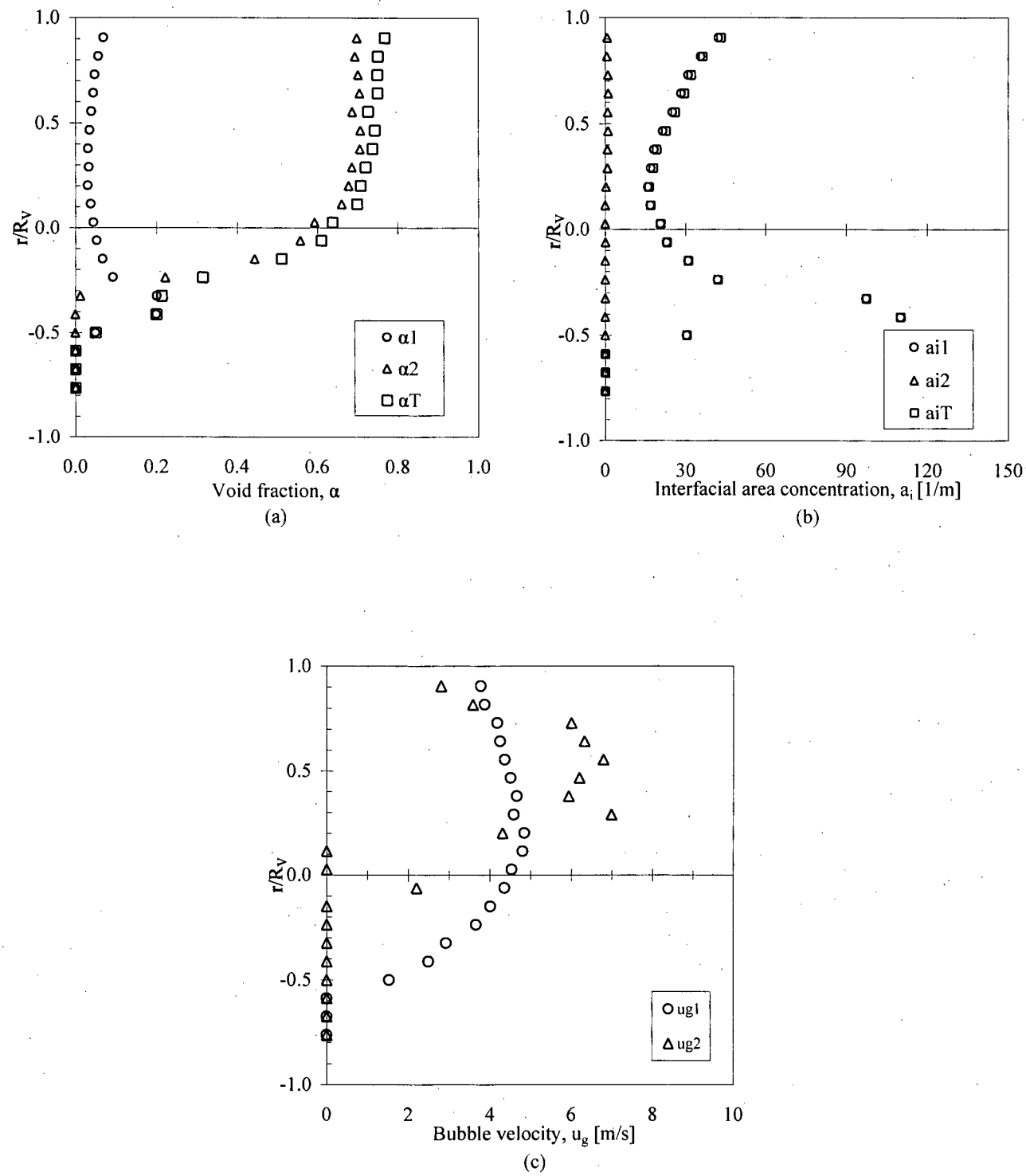


Figure 3.2.11.3 Profiles of local two-phase flow parameters for Run 11 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.12 Summary of results for Run 12.

Table 3.2.12.1 Local two-phase flow parameters for Run 12 acquired along the vertical axis at measurement port 1 (P1)

**Run 12:** $j_{g,atm}$ = 2.648 [m/s] & $j_f$ = 2.204 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.477 | $P_{back}$ [psig] = 32.8 | $j_{g,loc}$ [m/s] = 2.185 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.50 | $P_{loc}$ [psig] = 3.1 | $j_f$ [m/s] = 2.207 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 67.8 | 2.5 | 0.081 | 0.591 | 0.672 | 44.71 | 0.36 | 45.07 | 4.121 | 1.511 | 10.9 | 9843.3 |
| 0.8175 | 62.4 | 2.6 | 0.073 | 0.603 | 0.675 | 40.86 | 1.26 | 42.12 | 4.287 | 4.862 | 10.7 | 2869.0 |
| 0.7296 | 55.8 | 2.5 | 0.063 | 0.597 | 0.660 | 35.85 | 1.14 | 36.99 | 4.428 | 5.229 | 10.5 | 3142.6 |
| 0.6417 | 56.5 | 2.6 | 0.064 | 0.613 | 0.677 | 35.87 | 1.45 | 37.32 | 4.596 | 7.298 | 10.8 | 2536.1 |
| 0.5539 | 49.5 | 2.7 | 0.054 | 0.596 | 0.651 | 30.27 | 1.07 | 31.34 | 5.106 | 5.267 | 10.8 | 3343.2 |
| 0.4660 | 48.3 | 2.6 | 0.056 | 0.596 | 0.652 | 29.92 | 1.16 | 31.08 | 5.144 | 6.715 | 11.2 | 3084.8 |
| 0.3781 | 42.0 | 2.8 | 0.050 | 0.607 | 0.657 | 26.16 | 1.32 | 27.48 | 5.170 | 6.931 | 11.5 | 2756.8 |
| 0.2903 | 38.0 | 2.9 | 0.050 | 0.589 | 0.639 | 23.66 | 1.22 | 24.88 | 5.192 | 7.360 | 12.6 | 2898.7 |
| 0.2024 | 37.5 | 2.8 | 0.048 | 0.577 | 0.626 | 23.34 | 0.97 | 24.31 | 5.103 | 6.616 | 12.4 | 3570.3 |
| 0.1145 | 36.3 | 2.9 | 0.050 | 0.535 | 0.585 | 22.58 | 0.89 | 23.47 | 5.200 | 6.260 | 13.2 | 3609.4 |
| 0.0266 | 47.7 | 2.6 | 0.069 | 0.482 | 0.551 | 29.63 | 0.00 | 29.63 | 4.859 | 0.000 | 13.9 | |
| -0.0612 | 55.6 | 2.7 | 0.086 | 0.401 | 0.486 | 35.67 | 0.12 | 35.79 | 4.566 | 0.980 | 14.4 | 20035.0 |
| -0.1491 | 64.7 | 2.6 | 0.101 | 0.240 | 0.341 | 43.12 | 0.00 | 43.12 | 4.305 | 0.000 | 14.0 | |
| -0.2370 | 77.2 | 0.7 | 0.123 | 0.052 | 0.175 | 54.20 | 0.00 | 54.20 | 4.043 | 0.000 | 13.6 | |
| -0.3249 | 96.6 | 0.0 | 0.155 | 0.001 | 0.156 | 73.73 | 0.00 | 73.73 | 3.568 | 0.000 | 12.6 | |
| -0.4127 | 78.6 | 0.0 | 0.108 | 0.000 | 0.108 | 60.24 | 0.00 | 60.24 | 3.142 | 0.000 | 10.7 | |
| -0.5006 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.064 | $\langle a_{i1}\rangle$ [1/m] = 30.68 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 4.150 |
| $\langle\alpha_2\rangle$ = 0.348 | $\langle a_{i2}\rangle$ [1/m] = 0.51 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 4.772 |
| $\langle\alpha_T\rangle$ = 0.411 | $\langle a_{iT}\rangle$ [1/m] = 31.19 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.975 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 6.33\%$$

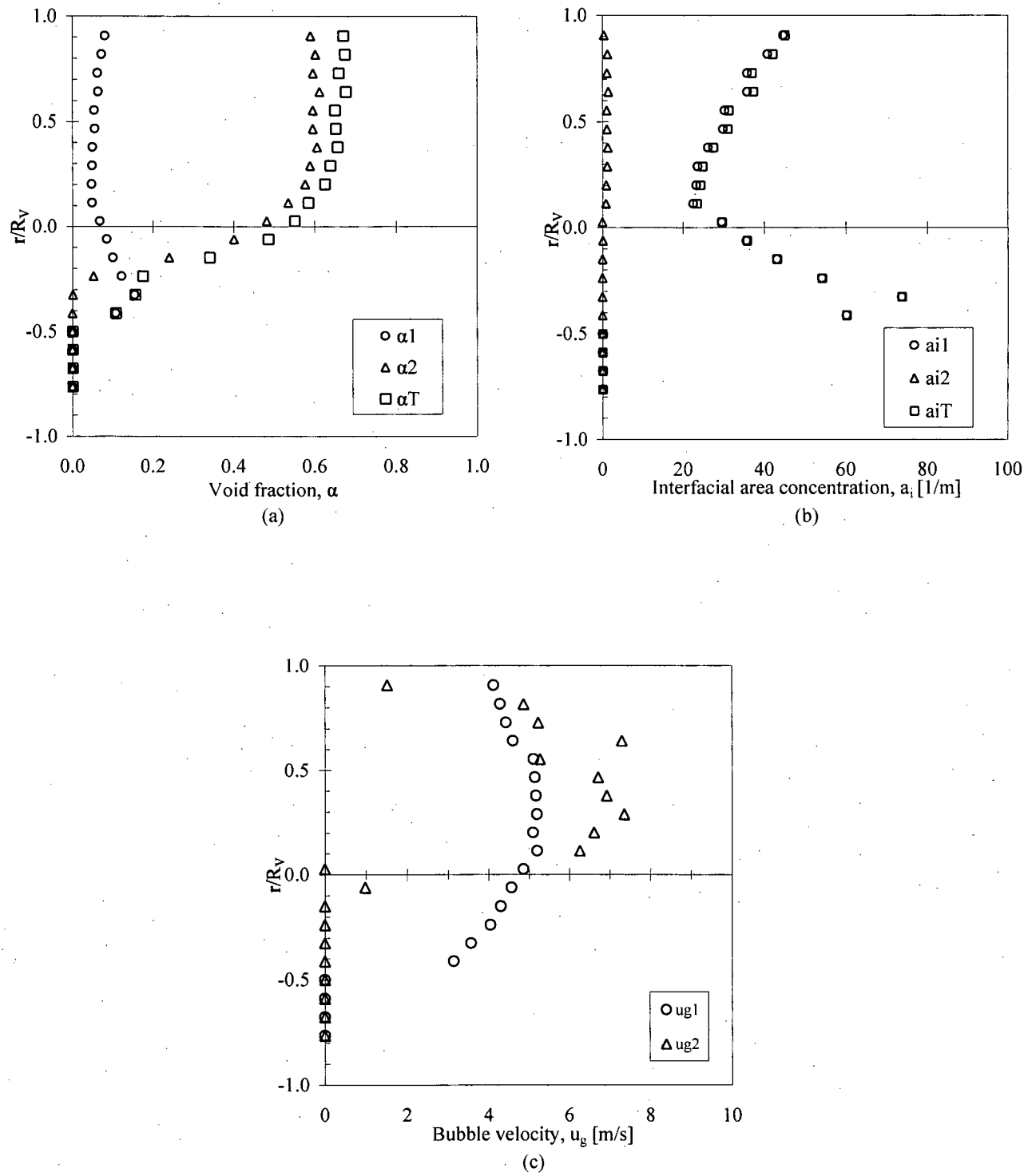


Figure 3.2.12.1 Profiles of local two-phase flow parameters for Run 12 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.12.2 Local two-phase flow parameters for Run 12 acquired along the vertical axis at measurement port 3 (P3)

**Run 12:** $j_{g,atm}$ = 2.648 [m/s] & $j_f$ = 2.204 [m/s]

Measurement Location: L/D = 250 (Port 3)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.324 | $P_{back}$ [psig] = 34.6 | $j_{g,loc}$ [m/s] = 2.199 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.40 | $P_{loc}$ [psig] = 3.0 | $j_f$ [m/s] = 2.203 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 78.2 | 2.5 | 0.099 | 0.590 | 0.689 | 48.37 | 0.00 | 48.37 | 4.502 | 0.000 | 12.3 | |
| 0.8175 | 72.1 | 2.7 | 0.089 | 0.610 | 0.699 | 44.36 | 0.62 | 44.98 | 4.853 | 3.339 | 12.0 | 5900.3 |
| 0.7296 | 66.9 | 2.6 | 0.079 | 0.608 | 0.687 | 40.60 | 0.90 | 41.50 | 5.148 | 4.335 | 11.7 | 4050.7 |
| 0.6417 | 60.7 | 2.7 | 0.069 | 0.603 | 0.672 | 37.64 | 1.12 | 38.76 | 5.158 | 7.145 | 11.0 | 3230.4 |
| 0.5539 | 51.9 | 2.7 | 0.060 | 0.614 | 0.674 | 32.66 | 0.87 | 33.53 | 5.195 | 5.550 | 11.0 | 4232.4 |
| 0.4660 | 48.1 | 2.5 | 0.054 | 0.603 | 0.657 | 29.87 | 1.30 | 31.17 | 5.208 | 8.088 | 10.9 | 2783.1 |
| 0.3781 | 43.8 | 2.8 | 0.049 | 0.606 | 0.654 | 27.85 | 1.18 | 29.03 | 5.249 | 8.104 | 10.5 | 3078.8 |
| 0.2903 | 41.8 | 2.9 | 0.050 | 0.587 | 0.637 | 26.56 | 1.00 | 27.56 | 5.283 | 7.064 | 11.2 | 3522.0 |
| 0.2024 | 43.1 | 2.8 | 0.051 | 0.539 | 0.590 | 27.06 | 0.66 | 27.72 | 5.273 | 5.520 | 11.3 | 4900.0 |
| 0.1145 | 46.3 | 2.5 | 0.059 | 0.496 | 0.556 | 29.63 | 0.68 | 30.31 | 5.138 | 5.551 | 12.0 | 4379.1 |
| 0.0266 | 52.3 | 2.7 | 0.072 | 0.431 | 0.503 | 33.74 | 0.00 | 33.74 | 4.925 | 0.000 | 12.8 | |
| -0.0612 | 60.0 | 2.4 | 0.088 | 0.354 | 0.442 | 40.04 | 0.10 | 40.14 | 4.438 | 0.858 | 13.1 | 21252.0 |
| -0.1491 | 68.9 | 2.3 | 0.102 | 0.275 | 0.377 | 46.74 | 0.00 | 46.74 | 4.236 | 0.000 | 13.1 | |
| -0.2370 | 78.9 | 1.4 | 0.133 | 0.155 | 0.287 | 59.47 | 0.00 | 59.47 | 3.809 | 0.000 | 13.4 | |
| -0.3249 | 92.0 | 0.8 | 0.161 | 0.078 | 0.238 | 71.06 | 0.00 | 71.06 | 3.612 | 0.000 | 13.6 | |
| -0.4127 | 101.6 | 0.0 | 0.170 | 0.001 | 0.171 | 84.61 | 0.00 | 84.61 | 3.144 | 0.000 | 12.1 | |
| -0.5006 | 62.6 | 0.0 | 0.090 | 0.000 | 0.090 | 49.98 | 0.00 | 49.98 | 3.030 | 0.000 | 10.8 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.074 | $\langle a_{i1}\rangle$ [1/m] = 36.56 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 4.111 |
| $\langle\alpha_2\rangle$ = 0.348 | $\langle a_{i2}\rangle$ [1/m] = 0.41 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 4.541 |
| $\langle\alpha_T\rangle$ = 0.422 | $\langle a_{iT}\rangle$ [1/m] = 36.97 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.717 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 9.41\%$$

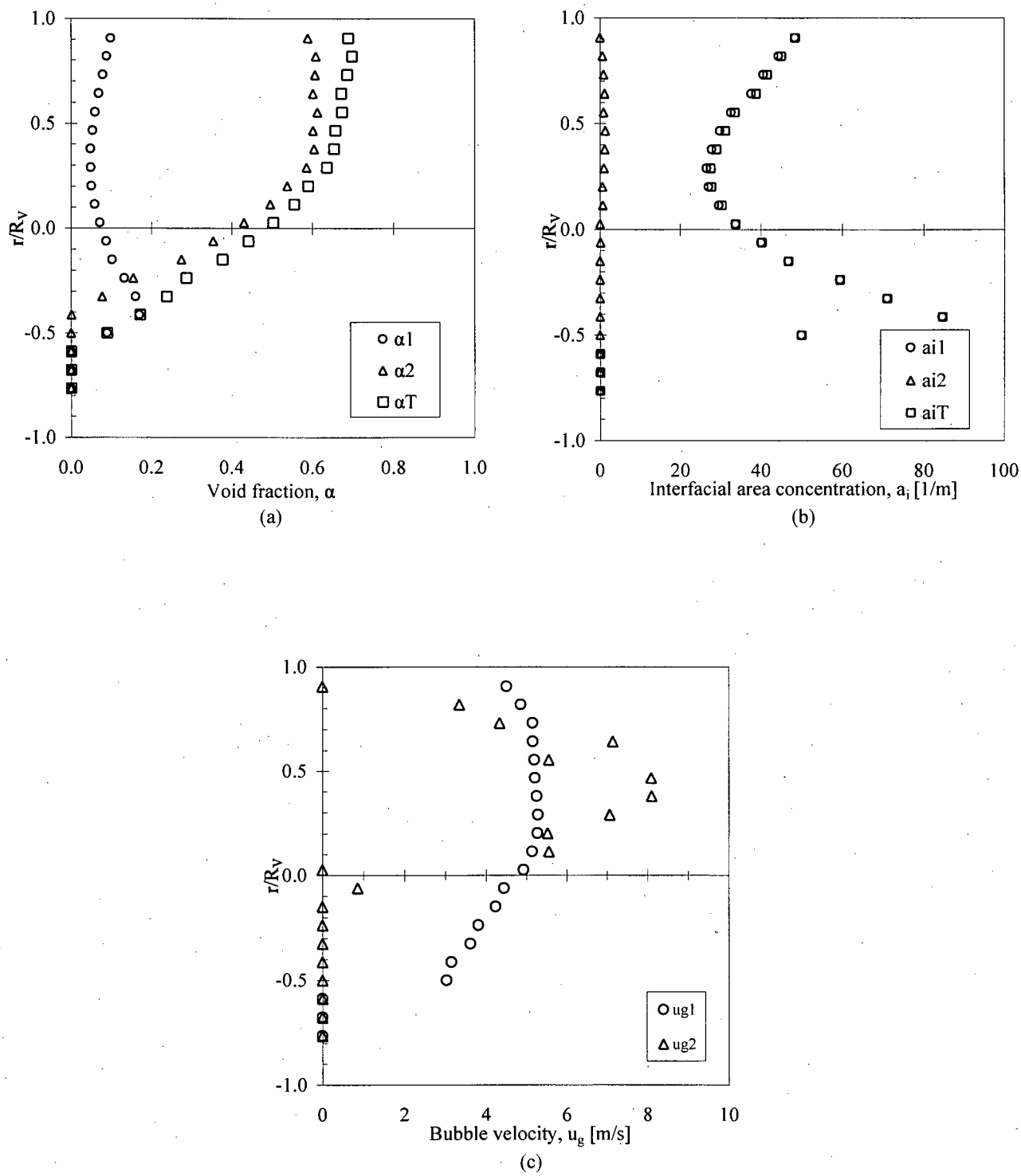


Figure 3.2.12.2 Profiles of local two-phase flow parameters for Run 12 acquired along the vertical radius of the tube at measurement port 3 (P3). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.12.3 Local two-phase flow parameters for Run 12 acquired along the vertical axis at measurement port 4 (P4)

**Run 12:** $j_{g,atm}$ = 2.648 [m/s] & $j_f$ = 2.204 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.210 | $P_{back}$ [psig] = 36.5 | $j_{g,loc}$ [m/s] = 2.205 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.30 | $P_{loc}$ [psig] = 3.0 | $j_f$ [m/s] = 2.200 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 57.9 | 2.5 | 0.065 | 0.619 | 0.683 | 39.32 | 0.00 | 39.32 | 4.217 | 0.000 | 9.9 | |
| 0.8175 | 60.0 | 2.3 | 0.066 | 0.615 | 0.681 | 40.40 | 0.63 | 41.03 | 4.328 | 3.026 | 9.7 | 5857.1 |
| 0.7296 | 53.4 | 2.3 | 0.057 | 0.621 | 0.678 | 36.53 | 0.75 | 37.28 | 4.544 | 5.164 | 9.4 | 4970.4 |
| 0.6417 | 48.8 | 2.4 | 0.053 | 0.631 | 0.684 | 33.06 | 0.98 | 34.04 | 5.010 | 6.725 | 9.6 | 3861.4 |
| 0.5539 | 45.8 | 2.4 | 0.050 | 0.620 | 0.670 | 31.38 | 1.23 | 32.61 | 5.164 | 6.467 | 9.5 | 3024.9 |
| 0.4660 | 44.2 | 2.5 | 0.048 | 0.621 | 0.669 | 29.88 | 0.89 | 30.77 | 5.198 | 6.195 | 9.6 | 4189.2 |
| 0.3781 | 40.5 | 2.7 | 0.045 | 0.617 | 0.662 | 27.34 | 0.75 | 28.09 | 5.229 | 4.538 | 9.9 | 4938.4 |
| 0.2903 | 37.6 | 2.6 | 0.044 | 0.614 | 0.658 | 26.05 | 1.02 | 27.07 | 5.208 | 8.169 | 10.1 | 3610.0 |
| 0.2024 | 33.1 | 2.9 | 0.041 | 0.599 | 0.640 | 22.60 | 0.43 | 23.03 | 5.249 | 4.051 | 10.8 | 8363.7 |
| 0.1145 | 36.8 | 2.7 | 0.047 | 0.554 | 0.602 | 24.99 | 0.00 | 24.99 | 5.237 | 0.000 | 11.4 | |
| 0.0266 | 41.7 | 2.6 | 0.057 | 0.515 | 0.573 | 27.79 | 0.00 | 27.79 | 5.168 | 0.000 | 12.3 | |
| -0.0612 | 48.4 | 2.6 | 0.069 | 0.432 | 0.501 | 31.45 | 0.14 | 31.59 | 5.121 | 1.555 | 13.2 | 18514.3 |
| -0.1491 | 64.2 | 2.8 | 0.104 | 0.289 | 0.393 | 42.67 | 0.00 | 42.67 | 4.454 | 0.000 | 14.7 | |
| -0.2370 | 75.4 | 1.2 | 0.117 | 0.089 | 0.206 | 52.61 | 0.00 | 52.61 | 4.185 | 0.000 | 13.4 | |
| -0.3249 | 111.1 | 0.0 | 0.182 | 0.003 | 0.184 | 86.26 | 0.00 | 86.26 | 3.614 | 0.000 | 12.6 | |
| -0.4127 | 103.3 | 0.0 | 0.144 | 0.000 | 0.144 | 83.53 | 0.00 | 83.53 | 3.122 | 0.000 | 10.4 | |
| -0.5006 | 31.1 | 0.0 | 0.036 | 0.000 | 0.036 | 24.66 | 0.00 | 24.66 | 1.825 | 0.000 | 8.7 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.063 | $<a_{i1}>$ [1/m] = 32.97 | $<<u_{g1}>>$ [m/s] = 4.182 |
| $<\alpha_2>$ = 0.367 | $<a_{i2}>$ [1/m] = 0.33 | $<<u_{g2}>>$ [m/s] = 3.734 |
| $<\alpha_T>$ = 0.430 | $<a_{iT}>$ [1/m] = 33.30 | $<<u_g>>$ [m/s] = 4.041 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 21.29\%$$

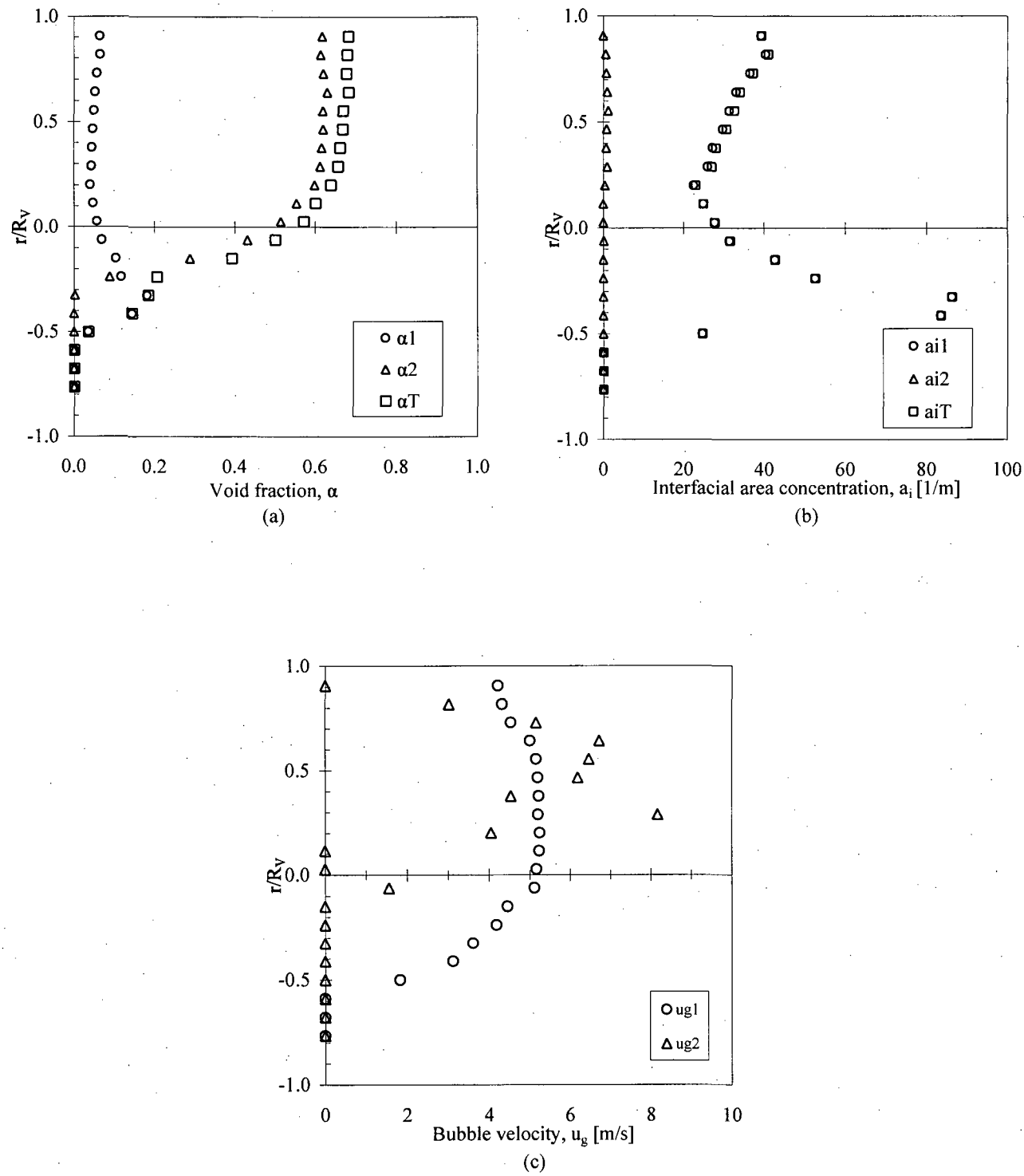


Figure 3.2.12.3 Profiles of local two-phase flow parameters for Run 12 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.13 Summary of results for Run 13.

Table 3.2.13.1 Local two-phase flow parameters for Run 13 acquired along the vertical axis at measurement port 1 (P1)

**Run 13:** $j_{g,atm}$ = 3.243 [m/s] & $j_f$ = 0.551 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.775 | $P_{back}$ [psig] = 38.6 | $j_{g,loc}$ [m/s] = 3.006 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.30 | $P_{loc}$ [psig] = 1.2 | $j_f$ [m/s] = 0.549 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 17.1 | 0.6 | 0.025 | 0.918 | 0.943 | 12.63 | 0.02 | 12.65 | 3.565 | 1.630 | 11.7 | 275370.0 |
| 0.8175 | 10.5 | 0.6 | 0.014 | 0.926 | 0.939 | 7.14 | 0.11 | 7.25 | 3.893 | 1.079 | 11.6 | 50487.3 |
| 0.7296 | 11.0 | 0.7 | 0.014 | 0.937 | 0.951 | 7.08 | 0.20 | 7.28 | 4.343 | 1.958 | 12.1 | 28113.0 |
| 0.6417 | 10.5 | 0.7 | 0.012 | 0.927 | 0.940 | 6.55 | 0.40 | 6.95 | 4.224 | 3.517 | 11.3 | 13911.0 |
| 0.5539 | 9.4 | 0.7 | 0.012 | 0.928 | 0.940 | 5.86 | 0.31 | 6.17 | 4.344 | 3.546 | 11.9 | 17965.2 |
| 0.4660 | 8.8 | 0.7 | 0.011 | 0.931 | 0.942 | 5.26 | 0.42 | 5.68 | 4.351 | 5.667 | 12.4 | 13297.1 |
| 0.3781 | 10.6 | 0.9 | 0.014 | 0.923 | 0.937 | 6.61 | 0.44 | 7.05 | 4.390 | 3.480 | 12.6 | 12590.5 |
| 0.2903 | 9.2 | 0.9 | 0.012 | 0.923 | 0.934 | 5.61 | 0.39 | 6.00 | 4.465 | 3.673 | 12.4 | 14193.8 |
| 0.2024 | 10.4 | 0.7 | 0.016 | 0.916 | 0.931 | 6.90 | 0.00 | 6.90 | 4.240 | 0.000 | 13.6 | |
| 0.1145 | 14.7 | 0.6 | 0.025 | 0.906 | 0.931 | 10.15 | 0.07 | 10.22 | 3.980 | 1.411 | 14.6 | 77640.0 |
| 0.0266 | 15.9 | 1.0 | 0.026 | 0.875 | 0.900 | 11.14 | 0.00 | 11.14 | 3.821 | 0.000 | 13.8 | |
| -0.0612 | 19.2 | 0.8 | 0.037 | 0.852 | 0.888 | 15.76 | 0.00 | 15.76 | 3.383 | 0.000 | 13.9 | |
| -0.1491 | 15.5 | 0.8 | 0.025 | 0.850 | 0.875 | 11.21 | 0.04 | 11.25 | 3.789 | 1.114 | 13.4 | 127485.0 |
| -0.2370 | 16.6 | 1.0 | 0.032 | 0.748 | 0.780 | 14.40 | 0.00 | 14.40 | 3.236 | 0.000 | 13.1 | |
| -0.3249 | 29.9 | 1.4 | 0.072 | 0.655 | 0.728 | 28.42 | 0.00 | 28.42 | 2.805 | 0.000 | 15.3 | |
| -0.4127 | 43.3 | 1.4 | 0.104 | 0.494 | 0.598 | 46.15 | 0.00 | 46.15 | 2.303 | 0.000 | 13.6 | |
| -0.5006 | 34.5 | 0.7 | 0.088 | 0.234 | 0.322 | 35.62 | 0.00 | 35.62 | 2.168 | 0.000 | 14.7 | |
| -0.5885 | 0.0 | 0.1 | 0.000 | 0.017 | 0.017 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.028 | $\langle a_{i1}\rangle$ [1/m] = 12.23 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.001 |
| $\langle\alpha_2\rangle$ = 0.707 | $\langle a_{i2}\rangle$ [1/m] = 0.11 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 1.633 |
| $\langle\alpha_T\rangle$ = 0.735 | $\langle a_{iT}\rangle$ [1/m] = 12.34 | $\langle\langle u_g\rangle\rangle$ [m/s] = 1.783 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 56.39\%$$

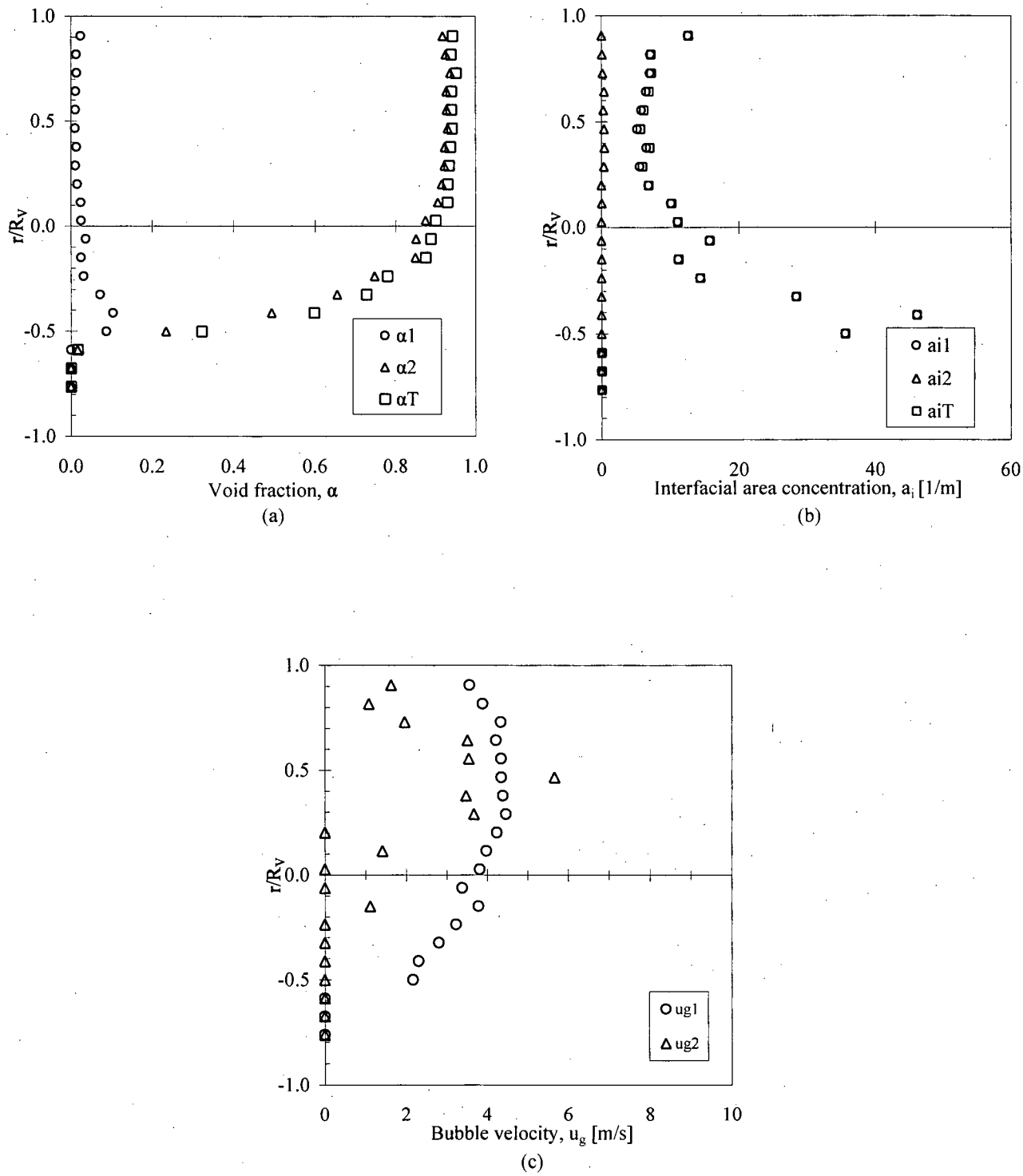


Figure 3.2.13.1 Profiles of local two-phase flow parameters for Run 13 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.13.2 Local two-phase flow parameters for Run 13 acquired along the vertical axis at measurement port 4 (P4)

**Run 13:** $j_{g,atm}$ = 3.243 [m/s] & $j_f$ = 0.551 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 4.550 | $P_{back}$ [psig] = 29.2 | $j_{g,loc}$ [m/s] = 3.003 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 17.50 | $P_{loc}$ [psig] = 1.1 | $j_f$ [m/s] = 0.556 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 27.3 | 0.5 | 0.040 | 0.905 | 0.946 | 24.37 | 0.00 | 24.37 | 2.796 | 0.000 | 9.9 | |
| 0.8175 | 23.0 | 0.5 | 0.030 | 0.895 | 0.925 | 18.29 | 0.00 | 18.29 | 3.242 | 0.000 | 9.9 | |
| 0.7296 | 18.8 | 0.5 | 0.021 | 0.915 | 0.936 | 13.41 | 0.22 | 13.63 | 3.524 | 2.383 | 9.4 | 24954.5 |
| 0.6417 | 14.2 | 0.6 | 0.014 | 0.913 | 0.928 | 9.34 | 0.22 | 9.56 | 3.794 | 2.141 | 9.1 | 24910.9 |
| 0.5539 | 15.4 | 0.5 | 0.016 | 0.908 | 0.924 | 9.67 | 0.22 | 9.89 | 3.947 | 2.572 | 10.0 | 24771.8 |
| 0.4660 | 10.7 | 0.6 | 0.011 | 0.918 | 0.929 | 6.62 | 0.26 | 6.88 | 4.108 | 2.613 | 9.8 | 21193.8 |
| 0.3781 | 9.9 | 0.6 | 0.011 | 0.911 | 0.922 | 6.12 | 0.37 | 6.49 | 4.111 | 4.035 | 10.8 | 14769.7 |
| 0.2903 | 8.1 | 0.8 | 0.009 | 0.914 | 0.923 | 4.62 | 0.37 | 4.99 | 4.408 | 5.548 | 11.4 | 14828.1 |
| 0.2024 | 10.2 | 0.7 | 0.016 | 0.897 | 0.913 | 6.71 | 0.07 | 6.78 | 4.166 | 1.278 | 13.9 | 76877.1 |
| 0.1145 | 9.2 | 0.7 | 0.012 | 0.888 | 0.900 | 5.64 | 0.04 | 5.68 | 4.282 | 1.511 | 13.1 | 133125.0 |
| 0.0266 | 10.9 | 0.6 | 0.016 | 0.884 | 0.900 | 6.77 | 0.00 | 6.77 | 4.315 | 0.000 | 14.4 | |
| -0.0612 | 11.5 | 0.7 | 0.018 | 0.865 | 0.883 | 7.62 | 0.00 | 7.62 | 3.905 | 0.000 | 14.5 | |
| -0.1491 | 14.1 | 0.7 | 0.024 | 0.857 | 0.881 | 10.74 | 0.00 | 10.74 | 3.552 | 0.000 | 13.6 | |
| -0.2370 | 13.9 | 0.9 | 0.024 | 0.785 | 0.810 | 10.75 | 0.00 | 10.75 | 3.511 | 0.000 | 13.6 | |
| -0.3249 | 23.4 | 1.0 | 0.052 | 0.735 | 0.787 | 22.34 | 0.00 | 22.34 | 2.976 | 0.000 | 13.9 | |
| -0.4127 | 36.9 | 0.9 | 0.085 | 0.609 | 0.694 | 41.15 | 0.00 | 41.15 | 2.358 | 0.000 | 12.4 | |
| -0.5006 | 45.8 | 0.8 | 0.120 | 0.479 | 0.598 | 57.51 | 0.00 | 57.51 | 1.981 | 0.000 | 12.5 | |
| -0.5885 | 21.8 | 0.3 | 0.064 | 0.063 | 0.127 | 27.45 | 0.00 | 27.45 | 1.744 | 0.000 | 14.0 | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.027 | $<a_{i1}>$ [1/m] = 13.23 | $<<u_{g1}>>$ [m/s] = 2.823 |
| $<\alpha_2>$ = 0.727 | $<a_{i2}>$ [1/m] = 0.09 | $<<u_{g2}>>$ [m/s] = 1.367 |
| $<\alpha_T>$ = 0.754 | $<a_{iT}>$ [1/m] = 13.32 | $<<u_g>>$ [m/s] = 1.500 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 62.32\%$$

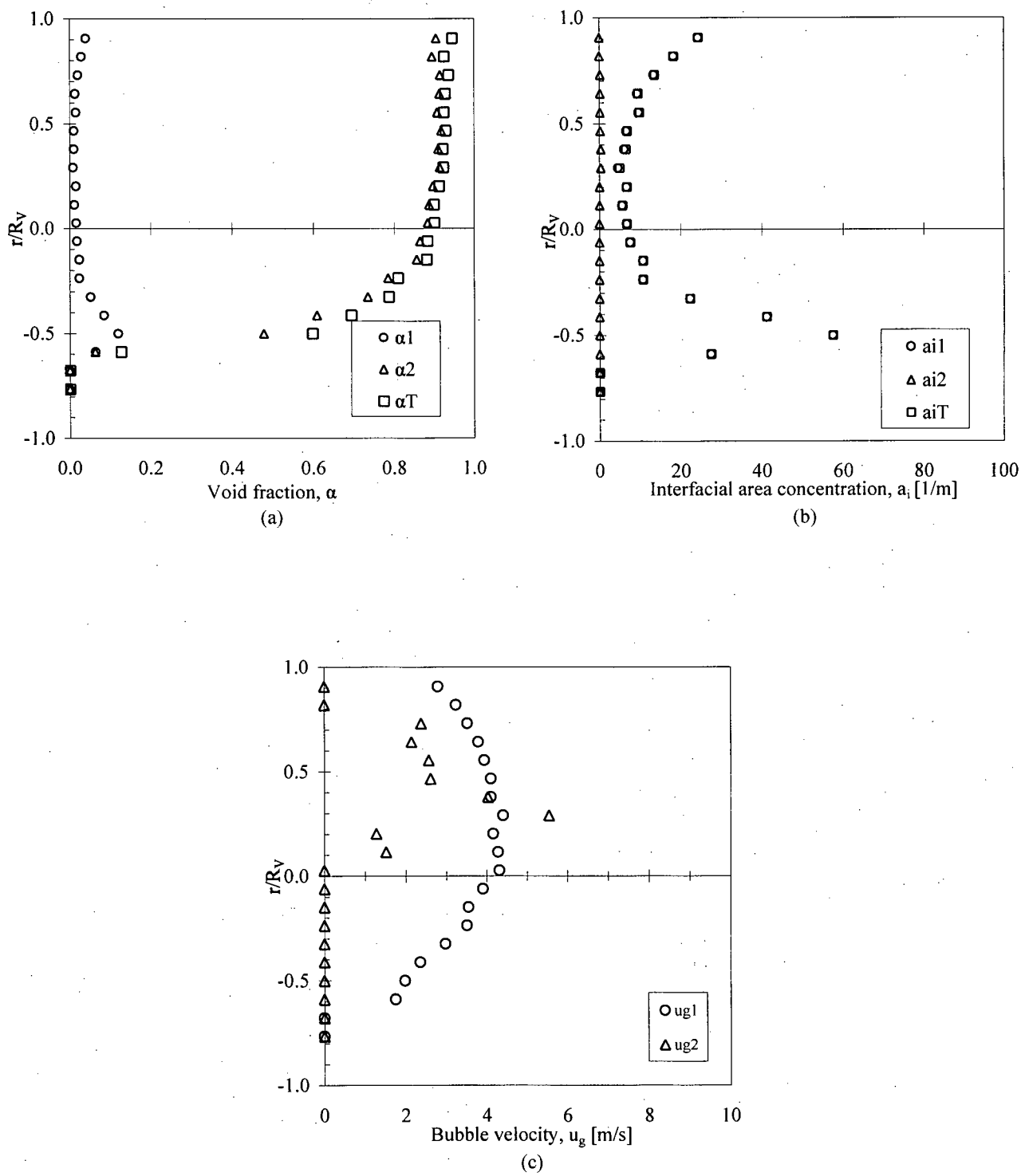


Figure 3.2.13.2 Profiles of local two-phase flow parameters for Run 13 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.14 Summary of results for Run 14.

Table 3.2.14.1 Local two-phase flow parameters for Run 14 acquired along the vertical axis at measurement port 1 (P1)

**Run 14:** $j_{g,atm}$ = 3.528 [m/s] & $j_f$ = 1.644 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 3.960 | $P_{back}$ [psig] = 40.3 | $j_{g,loc}$ [m/s] = 2.990 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.80 | $P_{loc}$ [psig] = 2.6 | $j_f$ [m/s] = 1.645 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 34.1 | 1.8 | 0.044 | 0.732 | 0.776 | 21.79 | 0.00 | 21.79 | 4.037 | 0.000 | 12.1 | |
| 0.8175 | 30.0 | 2.1 | 0.035 | 0.765 | 0.800 | 17.65 | 1.30 | 18.95 | 4.473 | 7.414 | 11.8 | 3531.7 |
| 0.7296 | 30.6 | 1.9 | 0.035 | 0.766 | 0.801 | 16.93 | 1.27 | 18.20 | 4.628 | 6.724 | 12.5 | 3618.9 |
| 0.6417 | 27.8 | 2.0 | 0.033 | 0.754 | 0.787 | 15.18 | 0.83 | 16.01 | 4.958 | 5.578 | 12.9 | 5450.6 |
| 0.5539 | 27.8 | 2.0 | 0.033 | 0.779 | 0.811 | 14.70 | 0.87 | 15.57 | 5.271 | 6.319 | 13.3 | 5369.7 |
| 0.4660 | 27.1 | 2.2 | 0.031 | 0.751 | 0.782 | 13.86 | 0.93 | 14.79 | 5.520 | 5.991 | 13.4 | 4845.2 |
| 0.3781 | 27.0 | 2.4 | 0.032 | 0.757 | 0.789 | 13.87 | 1.05 | 14.92 | 5.445 | 6.634 | 13.6 | 4327.4 |
| 0.2903 | 28.1 | 2.4 | 0.035 | 0.741 | 0.776 | 14.53 | 0.81 | 15.34 | 5.542 | 6.625 | 14.5 | 5488.9 |
| 0.2024 | 27.5 | 2.5 | 0.035 | 0.717 | 0.752 | 14.52 | 0.27 | 14.79 | 5.549 | 2.384 | 14.4 | 15935.6 |
| 0.1145 | 30.2 | 2.5 | 0.039 | 0.699 | 0.738 | 16.08 | 0.17 | 16.25 | 5.509 | 1.205 | 14.6 | 24660.0 |
| 0.0266 | 41.8 | 2.8 | 0.062 | 0.628 | 0.691 | 24.24 | 0.34 | 24.58 | 4.696 | 2.742 | 15.4 | 11089.4 |
| -0.0612 | 45.5 | 2.6 | 0.069 | 0.578 | 0.647 | 26.01 | 0.56 | 26.57 | 4.720 | 5.217 | 15.9 | 6190.7 |
| -0.1491 | 56.9 | 2.9 | 0.087 | 0.502 | 0.589 | 35.43 | 0.00 | 35.43 | 4.472 | 0.000 | 14.8 | |
| -0.2370 | 69.8 | 1.9 | 0.113 | 0.328 | 0.442 | 47.36 | 0.05 | 47.41 | 4.067 | 3.128 | 14.4 | 39396.0 |
| -0.3249 | 116.2 | 0.9 | 0.202 | 0.105 | 0.307 | 90.12 | 0.09 | 90.21 | 3.506 | 1.056 | 13.4 | 7000.0 |
| -0.4127 | 126.9 | 0.1 | 0.216 | 0.012 | 0.228 | 109.29 | 0.00 | 109.29 | 3.093 | 0.000 | 11.9 | |
| -0.5006 | 97.4 | 0.0 | 0.142 | 0.000 | 0.142 | 83.20 | 0.00 | 83.20 | 2.847 | 0.000 | 10.2 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.064 | $\langle a_{i1}\rangle$ [1/m] = 29.17 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 3.908 |
| $\langle\alpha_2\rangle$ = 0.480 | $\langle a_{i2}\rangle$ [1/m] = 0.43 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 4.381 |
| $\langle\alpha_T\rangle$ = 0.544 | $\langle a_{iT}\rangle$ [1/m] = 29.59 | $\langle\langle u_g\rangle\rangle$ [m/s] = 4.586 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 16.53\%$$

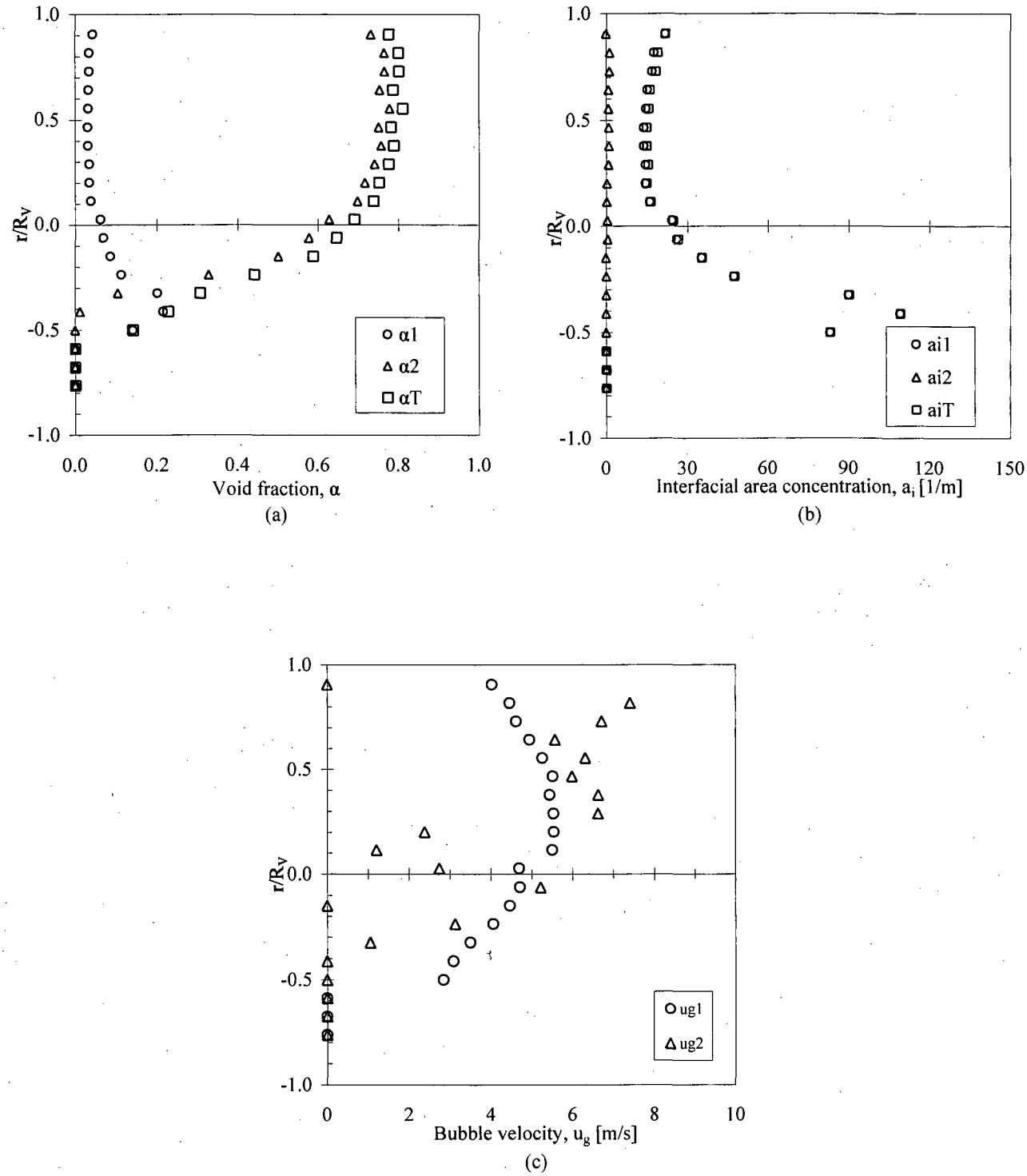


Figure 3.2.14.1 Profiles of local two-phase flow parameters for Run 14 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.14.2 Local two-phase flow parameters for Run 14 acquired along the vertical axis at measurement port 4 (P4)

**Run 14:** $j_{g,atm}$ = 3.528 [m/s] & $j_f$ = 1.644 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 4.600 | $P_{back}$ [psig] = 33.0 | $j_{g,loc}$ [m/s] = 3.012 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 51.70 | $P_{loc}$ [psig] = 2.6 | $j_f$ [m/s] = 1.641 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 44.1 | 1.7 | 0.056 | 0.728 | 0.784 | 30.60 | 0.00 | 30.60 | 3.755 | 0.000 | 11.0 | |
| 0.8175 | 38.4 | 1.7 | 0.044 | 0.753 | 0.797 | 22.57 | 0.84 | 23.41 | 4.378 | 6.553 | 11.6 | 5376.4 |
| 0.7296 | 34.9 | 1.6 | 0.038 | 0.745 | 0.783 | 20.41 | 0.77 | 21.18 | 4.475 | 4.738 | 11.2 | 5803.6 |
| 0.6417 | 33.6 | 1.6 | 0.038 | 0.750 | 0.788 | 18.54 | 0.86 | 19.40 | 4.735 | 6.731 | 12.2 | 5231.2 |
| 0.5539 | 32.2 | 1.7 | 0.033 | 0.749 | 0.782 | 16.88 | 0.72 | 17.60 | 5.407 | 5.483 | 11.7 | 6242.5 |
| 0.4660 | 32.4 | 1.8 | 0.034 | 0.749 | 0.784 | 17.19 | 0.94 | 18.13 | 5.274 | 6.491 | 12.0 | 4781.5 |
| 0.3781 | 28.0 | 1.6 | 0.031 | 0.744 | 0.776 | 14.78 | 0.72 | 15.50 | 5.488 | 6.937 | 12.7 | 6202.5 |
| 0.2903 | 27.6 | 1.8 | 0.030 | 0.739 | 0.769 | 14.64 | 0.50 | 15.14 | 5.452 | 5.254 | 12.5 | 8862.0 |
| 0.2024 | 27.6 | 1.8 | 0.032 | 0.732 | 0.764 | 14.61 | 0.51 | 15.12 | 5.579 | 5.651 | 13.1 | 8608.2 |
| 0.1145 | 26.0 | 1.8 | 0.032 | 0.721 | 0.752 | 14.00 | 0.24 | 14.24 | 5.598 | 2.547 | 13.7 | 18012.5 |
| 0.0266 | 32.6 | 1.9 | 0.043 | 0.688 | 0.730 | 17.60 | 0.00 | 17.60 | 5.502 | 0.000 | 14.6 | |
| -0.0612 | 45.8 | 2.0 | 0.065 | 0.645 | 0.709 | 26.28 | 0.07 | 26.35 | 5.034 | 1.252 | 14.7 | 55260.0 |
| -0.1491 | 45.6 | 1.9 | 0.063 | 0.565 | 0.628 | 26.26 | 0.00 | 26.26 | 4.862 | 0.000 | 14.5 | |
| -0.2370 | 57.0 | 2.2 | 0.082 | 0.449 | 0.531 | 34.74 | 0.00 | 34.74 | 4.491 | 0.000 | 14.2 | |
| -0.3249 | 120.4 | 1.6 | 0.199 | 0.203 | 0.401 | 88.28 | 0.00 | 88.28 | 3.755 | 0.000 | 13.5 | |
| -0.4127 | 161.1 | 0.3 | 0.288 | 0.031 | 0.319 | 135.15 | 0.00 | 135.15 | 3.225 | 0.000 | 12.8 | |
| -0.5006 | 137.5 | 0.0 | 0.221 | 0.000 | 0.221 | 117.33 | 0.00 | 117.33 | 2.923 | 0.000 | 11.3 | |
| -0.5885 | 29.3 | 0.0 | 0.041 | 0.000 | 0.041 | 23.48 | 0.00 | 23.48 | 1.709 | 0.000 | 10.5 | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $<\alpha_1>$ = 0.069 | $<a_{i1}>$ [1/m] = 32.22 | $<<u_{g1}>>$ [m/s] = 3.920 |
| $<\alpha_2>$ = 0.505 | $<a_{i2}>$ [1/m] = 0.29 | $<<u_{g2}>>$ [m/s] = 3.653 |
| $<\alpha_T>$ = 0.574 | $<a_{iT}>$ [1/m] = 32.50 | $<<u_g>>$ [m/s] = 3.908 |

Calculated Error:

$$\left[\frac{<j_{g,loc}>_{probe}}{<j_{g,loc}>_{flowmeter}} - 1\right] = \left[\frac{<\alpha_T><<u_g>>}{<j_{g,loc}>} - 1\right] = 25.59\%$$

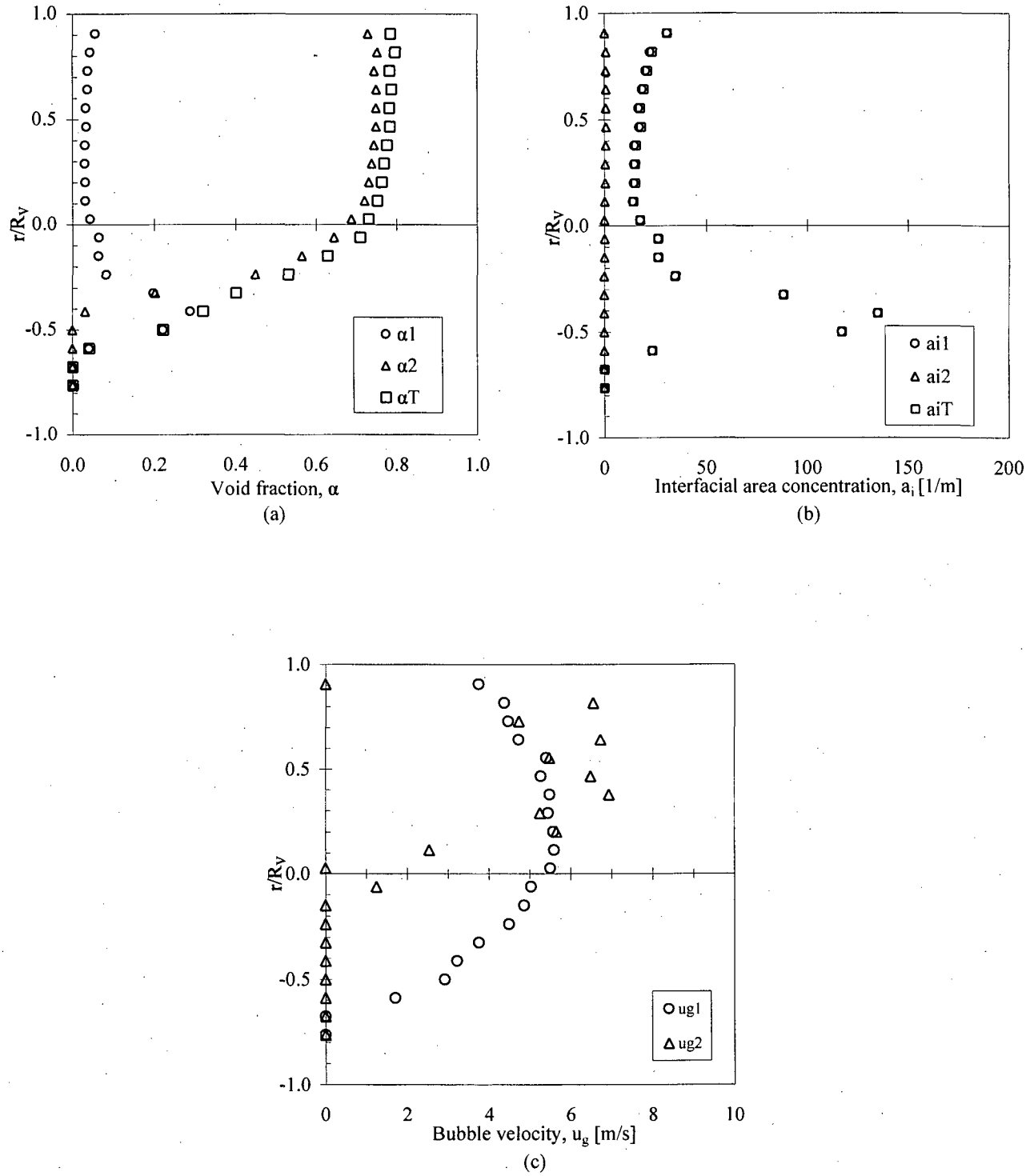


Figure 3.2.14.2 Profiles of local two-phase flow parameters for Run 14 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

### 3.2.15 Summary of results for Run 15.

Table 3.2.15.1 Local two-phase flow parameters for Run 15 acquired along the vertical axis at measurement port 1 (P1)

**Run 15:** $j_{g,atm}$ = 3.812 [m/s] & $j_f$ = 2.202 [m/s]

Measurement Location: L/D = 197 (Port 1)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 4.390 | $P_{back}$ [psig] = 39.5 | $j_{g,loc}$ [m/s] = 3.038 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.50 | $P_{loc}$ [psig] = 3.9 | $j_f$ [m/s] = 2.207 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 36.4 | 2.7 | 0.045 | 0.640 | 0.685 | 20.99 | 0.00 | 20.99 | 4.446 | 0.000 | 13.0 | |
| 0.8175 | 34.5 | 2.4 | 0.043 | 0.674 | 0.717 | 18.49 | 1.52 | 20.01 | 5.256 | 5.279 | 14.1 | 2659.3 |
| 0.7296 | 33.8 | 2.5 | 0.039 | 0.674 | 0.713 | 17.41 | 1.59 | 19.00 | 5.515 | 8.256 | 13.4 | 2543.0 |
| 0.6417 | 36.8 | 2.6 | 0.044 | 0.677 | 0.722 | 18.63 | 1.43 | 20.06 | 5.541 | 8.383 | 14.3 | 2841.8 |
| 0.5539 | 37.4 | 2.6 | 0.044 | 0.667 | 0.711 | 18.69 | 1.15 | 19.84 | 5.519 | 6.984 | 14.2 | 3480.0 |
| 0.4660 | 36.4 | 2.7 | 0.044 | 0.661 | 0.705 | 18.68 | 1.09 | 19.77 | 5.619 | 7.889 | 14.2 | 3637.4 |
| 0.3781 | 35.5 | 2.7 | 0.044 | 0.661 | 0.705 | 18.25 | 1.04 | 19.29 | 5.638 | 7.997 | 14.5 | 3814.0 |
| 0.2903 | 37.2 | 2.8 | 0.048 | 0.652 | 0.700 | 19.12 | 1.17 | 20.29 | 5.687 | 8.605 | 15.1 | 3344.6 |
| 0.2024 | 38.0 | 3.1 | 0.049 | 0.633 | 0.682 | 19.19 | 0.77 | 19.96 | 5.622 | 5.929 | 15.4 | 4933.2 |
| 0.1145 | 45.4 | 2.9 | 0.063 | 0.618 | 0.682 | 24.14 | 0.38 | 24.52 | 5.598 | 3.557 | 15.7 | 9762.6 |
| 0.0266 | 46.7 | 3.2 | 0.066 | 0.584 | 0.650 | 24.57 | 0.00 | 24.57 | 5.613 | 0.000 | 16.1 | |
| -0.0612 | 60.7 | 3.3 | 0.086 | 0.499 | 0.586 | 32.95 | 0.41 | 33.36 | 5.521 | 3.399 | 15.7 | 7308.3 |
| -0.1491 | 80.3 | 2.9 | 0.121 | 0.378 | 0.499 | 46.89 | 0.15 | 47.04 | 4.789 | 1.683 | 15.5 | 15100.0 |
| -0.2370 | 106.8 | 2.4 | 0.167 | 0.221 | 0.388 | 66.14 | 0.00 | 66.14 | 4.439 | 0.000 | 15.1 | |
| -0.3249 | 146.6 | 0.6 | 0.226 | 0.045 | 0.271 | 98.78 | 0.00 | 98.78 | 4.006 | 0.000 | 13.7 | |
| -0.4127 | 143.3 | 0.0 | 0.195 | 0.003 | 0.197 | 95.70 | 0.00 | 95.70 | 3.888 | 0.000 | 12.2 | |
| -0.5006 | 71.5 | 0.0 | 0.080 | 0.000 | 0.080 | 45.40 | 0.00 | 45.40 | 3.810 | 0.000 | 10.6 | |
| -0.5885 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.074 | $\langle a_{i1}\rangle$ [1/m] = 31.50 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 4.587 |
| $\langle\alpha_2\rangle$ = 0.412 | $\langle a_{i2}\rangle$ [1/m] = 0.52 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 5.307 |
| $\langle\alpha_T\rangle$ = 0.487 | $\langle a_{iT}\rangle$ [1/m] = 32.02 | $\langle\langle u_g\rangle\rangle$ [m/s] = 5.529 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 11.43\%$$

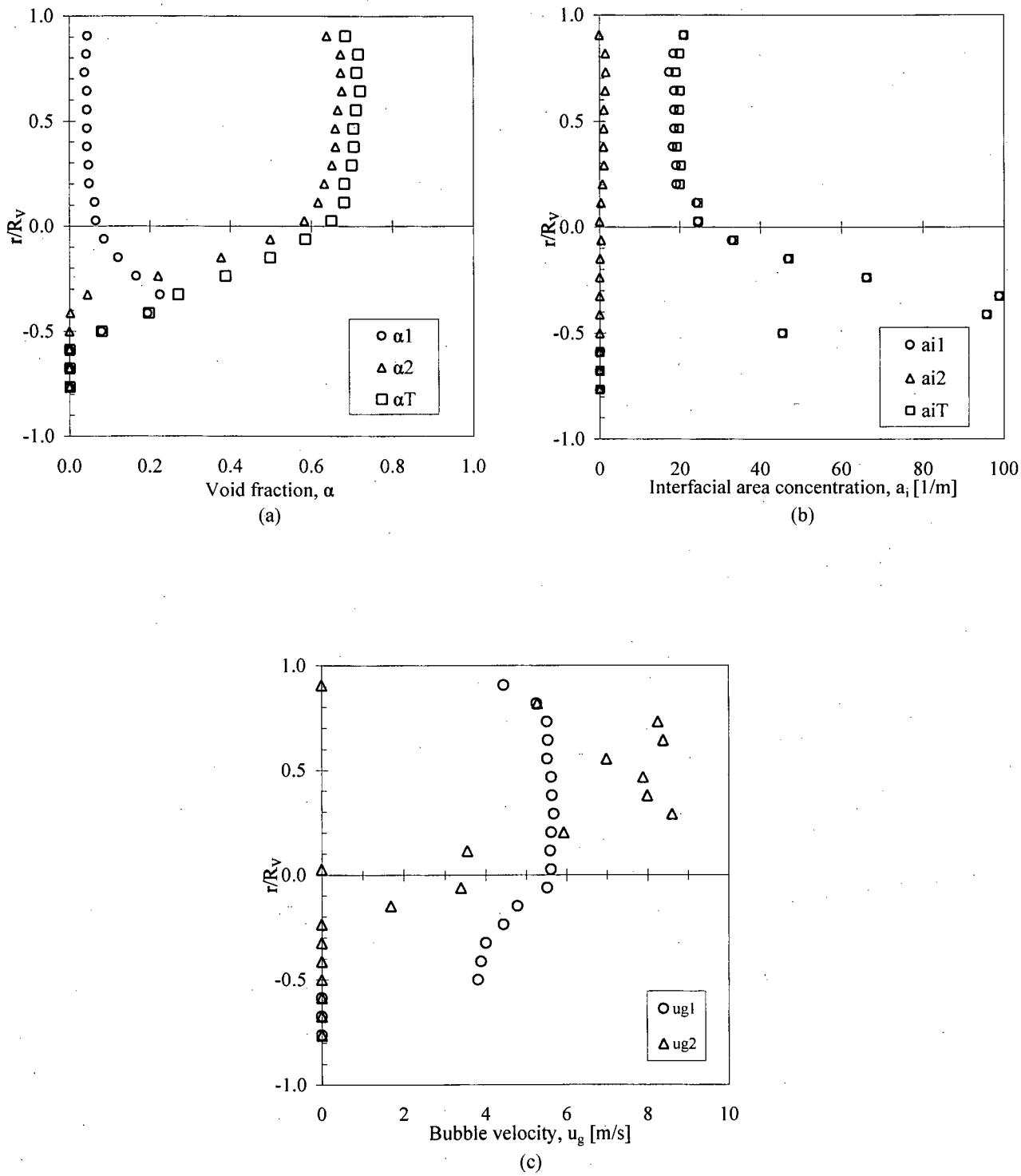


Figure 3.2.15.1 Profiles of local two-phase flow parameters for Run 15 acquired along the vertical radius of the tube at measurement port 1 (P1). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.

Table 3.2.15.2 Local two-phase flow parameters for Run 15 acquired along the vertical axis at measurement port 4 (P4)

**Run 15:** $j_{g,atm}$ = 3.812 [m/s] & $j_f$ = 2.202 [m/s]

Measurement Location: L/D = 329 (Port 4)

| Test Conditions: | | | Sampling frequency: | Measurement Time: |
|---|---|---|---|---|
| $Q_g$ [acfm] = 4.231 | $P_{back}$ [psig] = 40.1 | $j_{g,loc}$ [m/s] = 2.993 | $f_{s1}$ [ 1/s] = 10,000 | $\Delta T_1$ [s] = 10 |
| $Q_f$ [gpm] = 69.10 | $P_{loc}$ [psig] = 3.7 | $j_f$ [m/s] = 2.194 | $f_{s2}$ [ 1/s] = 10,000 | $\Delta T_2$ [s] = 10 |

| r/R | $fb_1$ [1/s] | $fb_2$ [1/s] | $\alpha_1$ | $\alpha_2$ | $\alpha_T$ | $a_{i1}$ [1/m] | $a_{i2}$ [1/m] | $a_{iT}$ [1/m] | $u_{g1}$ [m/s] | $u_{g2}$ [m/s] | $D_{sm1}$ [mm] | $D_{sm2}$ [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9054 | 39.0 | 2.3 | 0.050 | 0.646 | 0.696 | 22.94 | 0.00 | 22.94 | 4.396 | 0.000 | 13.0 | |
| 0.8175 | 33.3 | 2.4 | 0.038 | 0.681 | 0.720 | 17.81 | 0.48 | 18.29 | 5.207 | 2.802 | 12.9 | 8517.5 |
| 0.7296 | 33.8 | 2.4 | 0.039 | 0.677 | 0.716 | 17.47 | 0.42 | 17.89 | 5.500 | 3.102 | 13.4 | 9667.1 |
| 0.6417 | 34.4 | 2.3 | 0.038 | 0.676 | 0.714 | 17.67 | 1.01 | 18.68 | 5.557 | 7.540 | 12.9 | 4015.8 |
| 0.5539 | 34.9 | 2.4 | 0.039 | 0.682 | 0.721 | 17.79 | 0.91 | 18.70 | 5.579 | 6.597 | 13.1 | 4495.4 |
| 0.4660 | 34.5 | 2.6 | 0.039 | 0.693 | 0.732 | 17.71 | 0.98 | 18.69 | 5.690 | 7.380 | 13.3 | 4242.9 |
| 0.3781 | 35.1 | 2.5 | 0.040 | 0.672 | 0.712 | 17.91 | 0.94 | 18.85 | 5.708 | 7.851 | 13.3 | 4289.4 |
| 0.2903 | 33.7 | 2.4 | 0.039 | 0.670 | 0.709 | 13.89 | 0.96 | 14.85 | 6.218 | 8.492 | 16.8 | 4189.4 |
| 0.2024 | 33.2 | 3.0 | 0.039 | 0.655 | 0.694 | 10.87 | 0.80 | 11.67 | 6.701 | 9.509 | 21.5 | 4909.5 |
| 0.1145 | 35.4 | 2.8 | 0.044 | 0.639 | 0.683 | 14.94 | 0.64 | 15.58 | 6.215 | 6.294 | 17.6 | 5993.4 |
| 0.0266 | 43.9 | 2.7 | 0.057 | 0.591 | 0.649 | 23.38 | 0.30 | 23.68 | 5.734 | 2.928 | 14.7 | 11828.0 |
| -0.0612 | 51.1 | 3.1 | 0.069 | 0.527 | 0.596 | 27.45 | 0.25 | 27.70 | 5.523 | 2.662 | 15.0 | 12657.6 |
| -0.1491 | 57.9 | 2.8 | 0.078 | 0.464 | 0.541 | 31.57 | 0.00 | 31.57 | 5.550 | 0.000 | 14.7 | |
| -0.2370 | 83.0 | 3.3 | 0.116 | 0.299 | 0.415 | 46.55 | 0.20 | 46.75 | 5.162 | 2.247 | 15.0 | 8961.0 |
| -0.3249 | 139.3 | 1.0 | 0.211 | 0.081 | 0.291 | 88.22 | 0.00 | 88.22 | 4.418 | 0.000 | 14.3 | |
| -0.4127 | 181.8 | 0.0 | 0.279 | 0.001 | 0.280 | 125.72 | 0.00 | 125.72 | 3.914 | 0.000 | 13.3 | |
| -0.5006 | 134.2 | 0.0 | 0.167 | 0.000 | 0.167 | 87.18 | 0.00 | 87.18 | 3.852 | 0.000 | 11.5 | |
| -0.5885 | 38.1 | 0.0 | 0.038 | 0.000 | 0.038 | 22.66 | 0.00 | 22.66 | 3.120 | 0.000 | 10.0 | |
| -0.6763 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |
| -0.7642 | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.000 | 0.000 | | |

Calculated Results:

| | | |
|---|---|---|
| $\langle\alpha_1\rangle$ = 0.072 | $\langle a_{i1}\rangle$ [1/m] = 31.26 | $\langle\langle u_{g1}\rangle\rangle$ [m/s] = 4.677 |
| $\langle\alpha_2\rangle$ = 0.433 | $\langle a_{i2}\rangle$ [1/m] = 0.40 | $\langle\langle u_{g2}\rangle\rangle$ [m/s] = 5.013 |
| $\langle\alpha_T\rangle$ = 0.506 | $\langle a_{iT}\rangle$ [1/m] = 31.66 | $\langle\langle u_g\rangle\rangle$ [m/s] = 5.268 |

Calculated Error:

$$\left[\frac{\langle j_{g,loc}\rangle_{probe}}{\langle j_{g,loc}\rangle_{flowmeter}} - 1\right] = \left[\frac{\langle\alpha_T\rangle\langle\langle u_g\rangle\rangle}{\langle j_{g,loc}\rangle} - 1\right] = 11.01\%$$

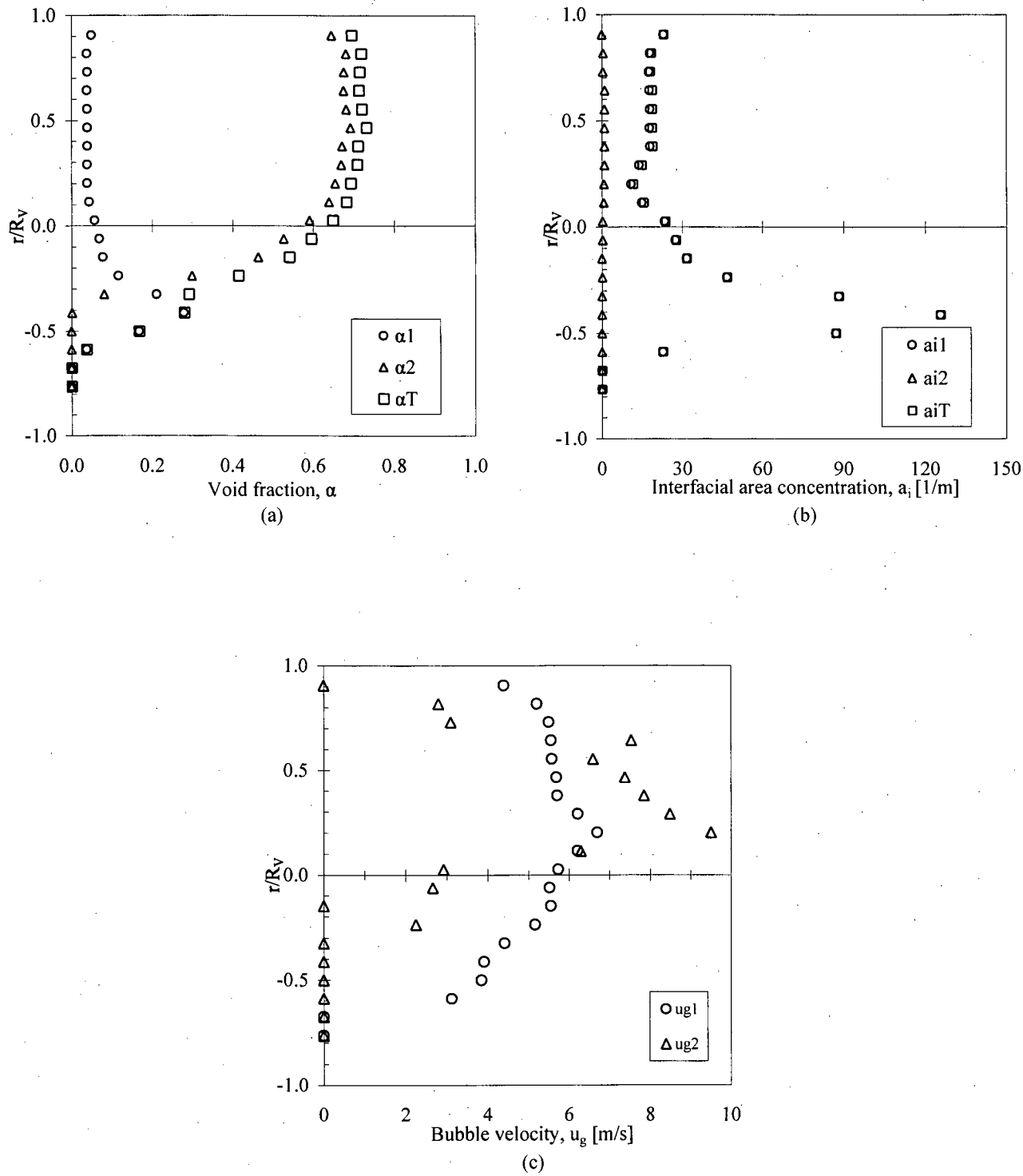


Figure 3.2.15.2 Profiles of local two-phase flow parameters for Run 15 acquired along the vertical radius of the tube at measurement port 4 (P4). (a) void fraction, (b) interfacial area concentration and (c) bubble velocity.