4. COMPUTER AUTOMATED RADIOACTIVE PARTICLE TRACKING IN HIGH PRESSURE BUBBLE COLUMN

4.1. Introduction

A number of gas conversion processes utilize bubble columns and are operated at high pressure and temperature in order to promote the volumetric productivity. Information on the liquid hydrodynamics at high pressure is very limited. Traditionally, researchers in the field of multiphase flows have used fiber optics or electrical capacitance probes and hot wire or film anemometry for local velocity measurements. The disadvantages of such techniques are that they are intrusive and they yield only the measurements at a single point in the vicinity of the probe. The most recent non-intrusive techniques for studies of multiphase flow are Laser-Doppler Anemometry (LDA), Particle Image Velocimetry (PIV) and Computer Automated Radioactive Particle Tracking (CARPT). The LDA technique is handicapped by the multiple measurements that must be made at various points in the flow field. Both laser based techniques (LDA and PIV) suffer from severe scattering effects particularly when the gas or solids holdup are higher than 10%. In such opaque multiphase flows they are not appropriate methods. At CREL, a non-intrusive technique, Computer Automated Radioactive Particle Tracking (CARPT), has been developed to measure the liquid phase velocities and turbulent parameters in bubble columns. It has been shown to be an excellent technique to study flow patterns in multiphase systems and has been used successfully to monitor liquid and solids motion in slurry bubble columns (Devanathan *et al*., 1990; Moslemian *et al*., 1992; Yang *et al*., 1992, 1993) in gas-solid fluidized beds (Lin *et al*., 1985) and in liquid-solid and gas-liquid-solid fluidized beds (Limtrakul, 1996). As part of this project we have compared CARPT results with data obtained by PIV in dilute bubbly flow where PIV data can be assumed to be very accurate. Excellent agreement was established (Second Technical Annual Report). This provided the needed confidence to apply CARPT to opaque flow systems in which other techniques cannot be used.

In this report, the effect of pressure on liquid hydrodynamics in bubble columns is studied using CARPT. The velocity plots and turbulence parameters are evaluated and compared with existing data.

4.2. High Pressure Experimental Setup

The high pressure column fabricated at CREL was already described in Section 3.2. Here we briefly review the CARPT facility at CREL and introduce the new calibration device for high pressure operation.

4.2.1. CARPT Facility

Figure 4.1 shows the CARPT setup for the high-pressure column. Devanathan (1991) describes the detail of the software and hardware. In this study, a radioactive Scandium-46 particle (1.59 mg weight and 2.89 g/cm^3 in density with total strength of 491 μCi) emitting γ rays of constant energy at 0.89 and 1.12 MeV was embedded into a polypropylene particle with a diameter of 2.38 mm. In order to match the density of the liquid phase, an air void is created inside the polypropylene particle so that the composite density (Scandium-polypropylene-air) is equal to the density of the liquid phase being tracked. With the particle density the same as that of the liquid, the radioactive tracer particle is neutrally buoyant, and is able to mimic successfully the dynamic behavior of the recirculating liquid phase. The intersection of the gamma rays emitted by the tracer particles is continuously monitored by an array of 24 NaI (Tl) scintillation detectors (5 cm in diameter), which are strategically located around the column. In order to determine the exact position of the tracer particle at each instant in time, calibrations are performed for each detector, providing a relationship between the distance from the detector to the particle and the intensity count received by the detector. It should be noted that for this set of runs our standard calibration method was still employed as we were still perfecting the Monte Carlo procedure. Using this calibration information and the intensities of radiation received by detectors at each sampling period (50 Hz), the instantaneous position of the particle is calculated by an inverse mapping algorithm. The instantaneous velocity could then be obtained by time differentiation. Ensemble averaged velocities and turbulence quantities can be calculated for all column locations upon running the experiment for many hours in order to get good statistics.

4.2.2. Experimental Apparatus

The high pressure bubble column system was described in Chapter 3.2 where we discussed the gas holdup measurements and results. The CARPT experiments were conducted at the conditions summarized in Table 4.1.

Table 4.1: Operating Conditions for the High Pressure System

Diameter of column, in. (cm)	6.359 (16.15)
Distributon	Perforated plate with 61 holes (each of 0.4 mm diameter), open area 0.05% (Figure 3.4)
Superficial gas velocity, cm/s	5 and 15
Liquid (water)	Batch
Pressure, Mpa (atm)	0.3 (3)
Temperature, ° C	25

Before performing CARPT experiments, approximately 1500 to 2000 calibration points in the column have to be collected first. At atmospheric conditions, when the column is open, a fishing line was used to perform the calibrations. This technique is impossible to adapt to the high-pressure closed system. A new calibration device (Figure 4.2) was designed in order to accommodate the high pressure as well as to improve the accuracy of the calibration. The device can be adjusted azimuthally, radially and axially, without any gas leaks or decrease in the pressure, to obtain the calibration points anywhere in the column. In this study, the velocity plots and turbulence parameters are obtained at a pressure of 3 atm, and a superficial gas velocity of 5 cm/s. Therefore, calibration was performed at the same conditions.

The calibration curves for each detector exhibit an exponential trend of particle distance to the detector versus the intensity counts as shown in Figure 4.3:

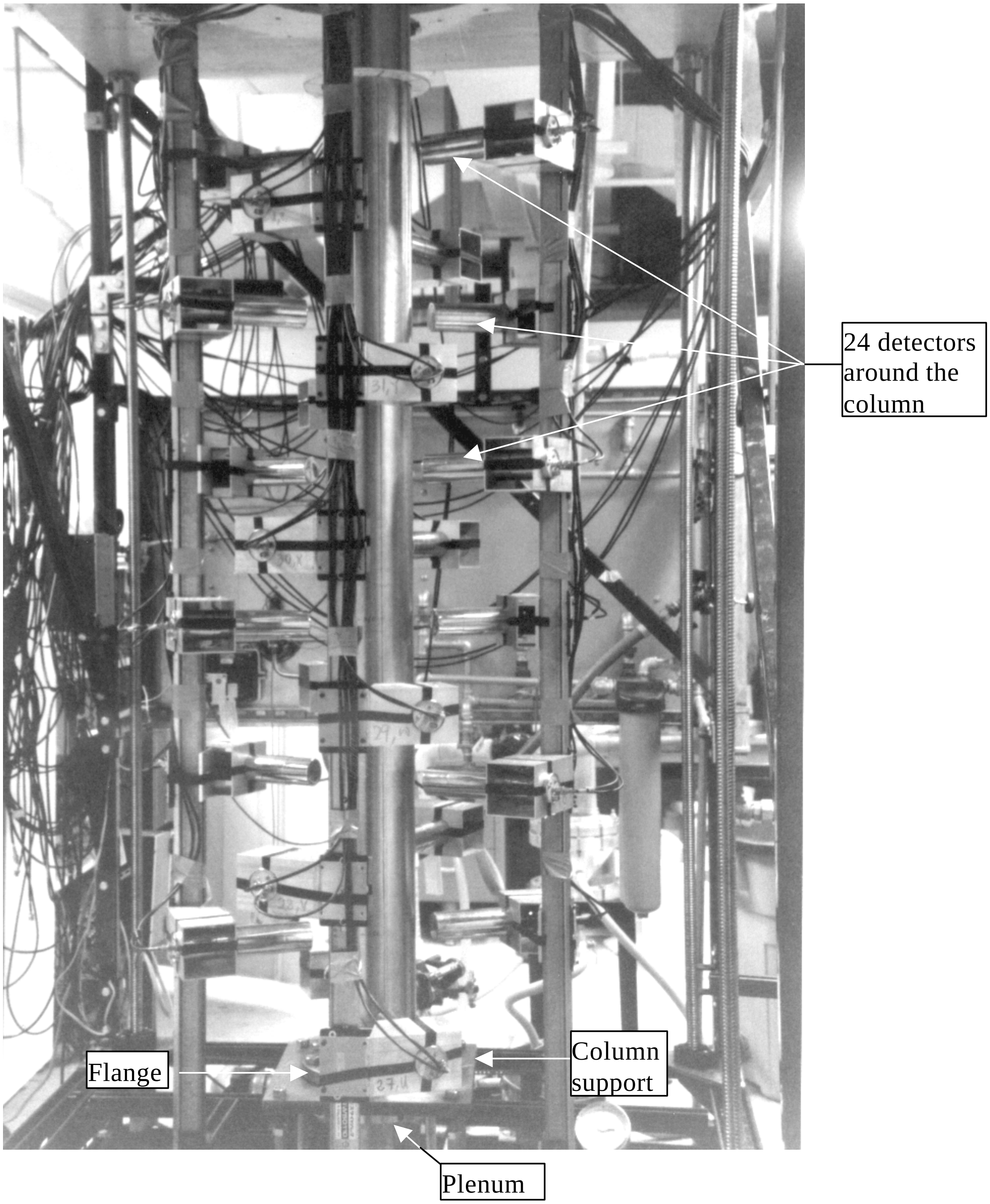


Figure 4.1. CARPT Setup for the High Pressure Bubble Column in CREL

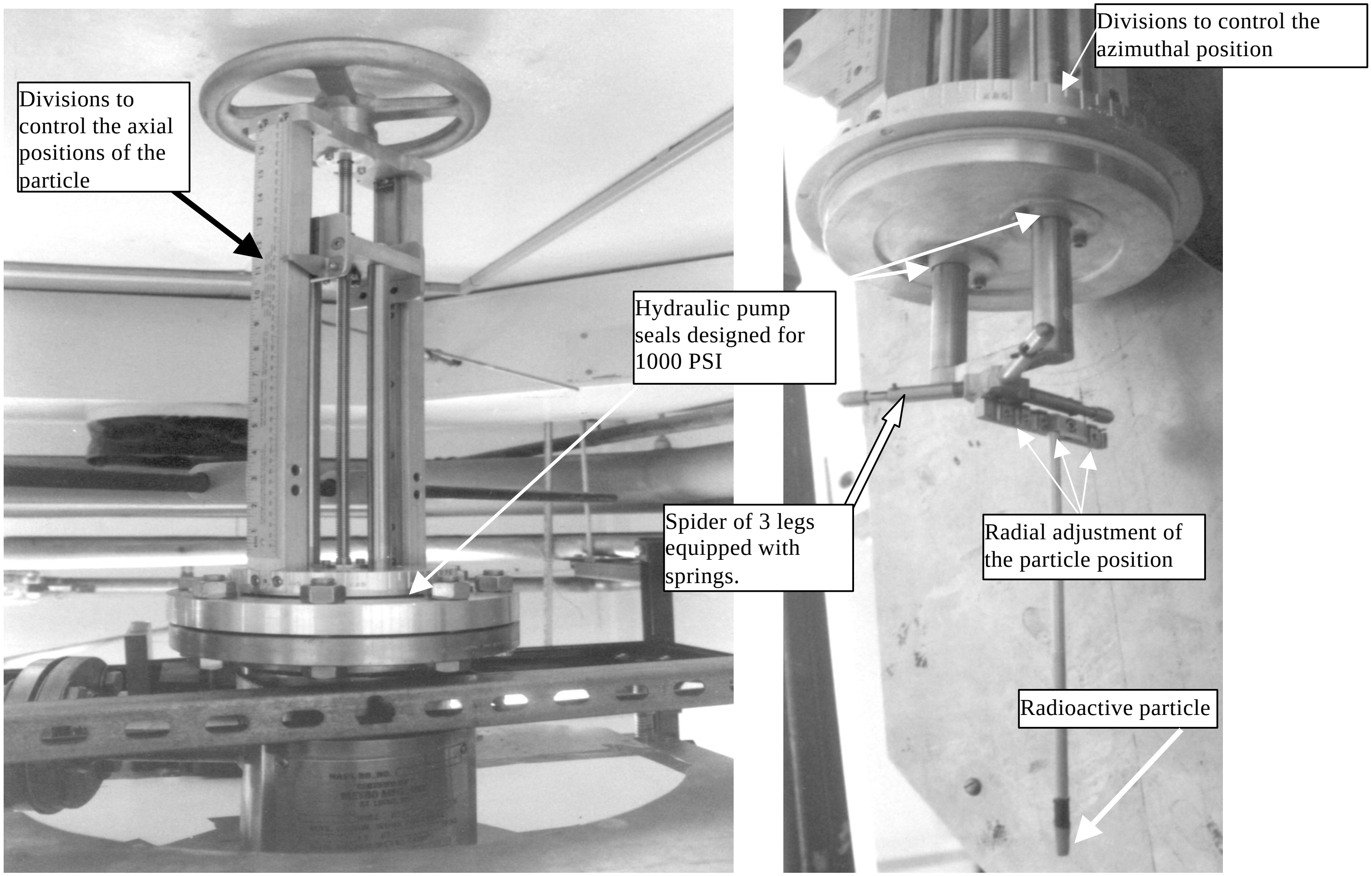


Figure 4.2: Calibration Device for High Pressure Bubble Column

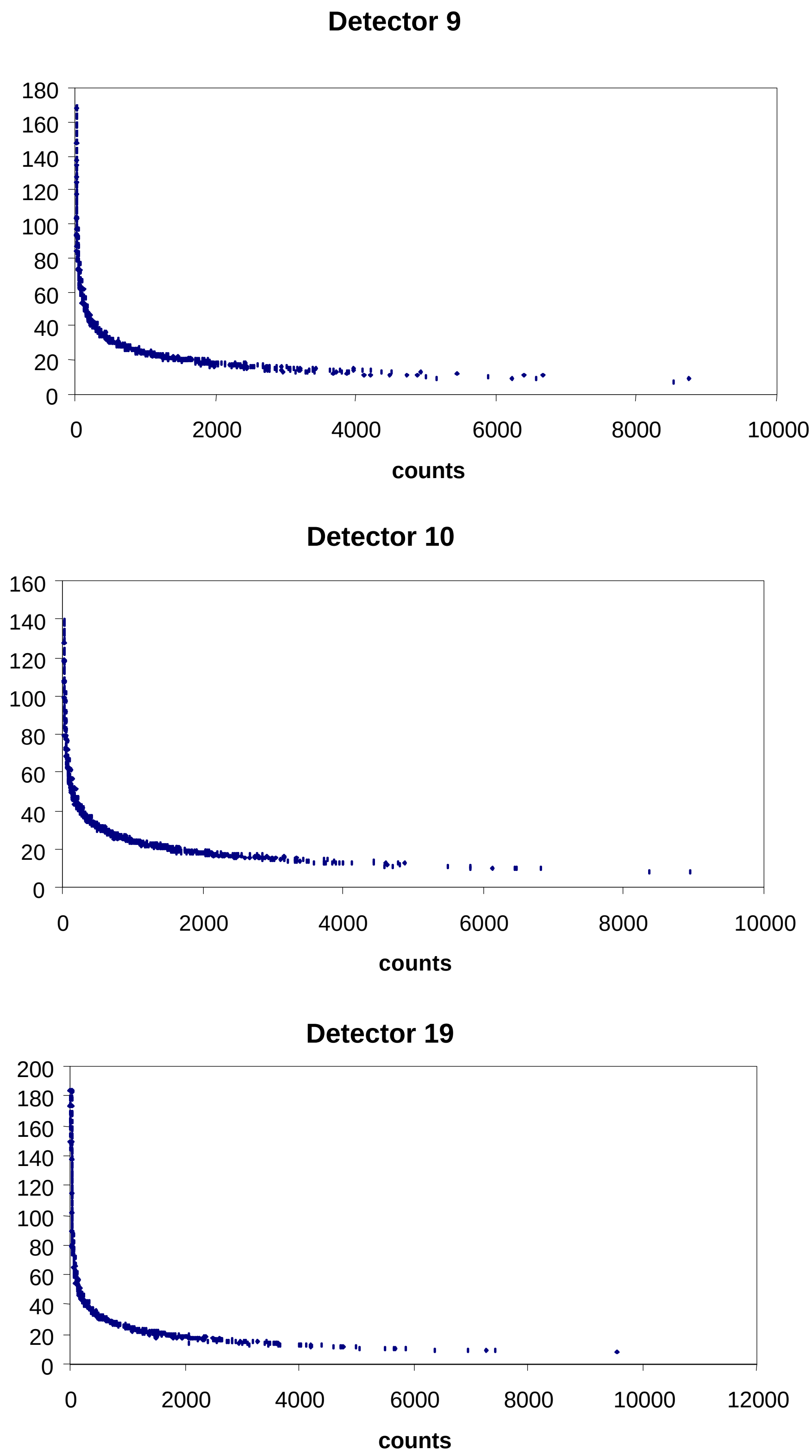


Figure 4.3: Calibration Curves of Different Detectors

These calibration curves allow us to determine the position (X, Y, Z) of the radioactive particle as a function of time, as shown in Figure 4.4:

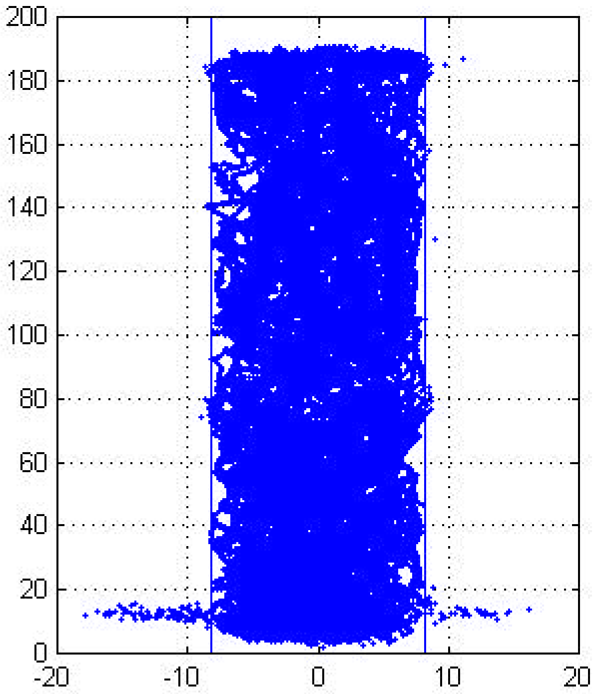


Figure 4.4: Tracer Particle Locations (X(t), Z(t)) During 20 Minutes of the Run

In the lower part of the column there are several computed positions of the tracer which are situated outside the column. This problem is due to the presence of the flange and ports in that region of the column.

During processing such data is handled appropriately as described below. Figure 4.5 shows that the accuracy near the sparger increases when the number of detectors increases in the horizontal plane situated at 6 inches above the flange.

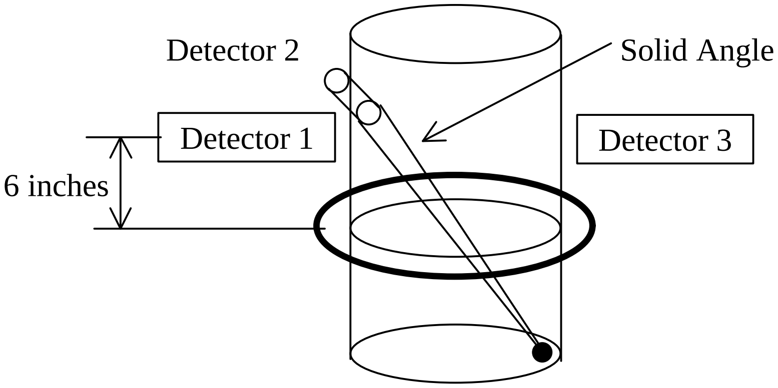


Figure 4.5: Increased Accuracy Near the Sparger with Increased Number of Detectors

The detectors at the opposite side of the radioactive particle (detector 1 and 2) receive high counts compared to the ones close to the particle (detector 3) due to the presence of the flange. The particle position is properly computed only from the detectors situated on the left side of Figure 2.5 and the erroneous counts of the detectors such as detector 3 can be excluded from the computation of tracer position.

4.3. Results and Discussion

The CARPT run at 5 cm/s superficial gas velocity at 0.3 MPa is discussed here. The ensemble averaged axial liquid velocity profile is displayed in Figure 4.6 at two elevations of z = 30 cm and z = 90 cm above the distributor. Clearly the velocities are much higher in the distributor zone and the distributor effect is still noticeable at z = 30 cm which is the distance equal almost to two diameters. It should be noted that the gas velocity at the hole of the perforated plate is almost 100 m/s. Evidently small bubbles are injected at high speed, and are gradually slowed down by the liquid. CT scans confirm bubbly flow at these conditions and relatively flat holdup profiles. At 90 cm above the distributor one can safely assume that the fully developed velocity region is reached. The center line velocity is only about 5 cm/s and reaches values of about –7 cm/s close to the wall, with zero averaged axial velocity at r = 5.6 cm. In contract, Degaleesan (1997) reported (Figure 4.7a) a center line velocity of about 30 cm/s at atmospheric pressure and gas superficial velocity of 4.8 cm/s. Her column was equipped with the same perforated plate distributor. Several phenomena contribute to this. It is well know that flow regime transition occurs earlier at lower pressure, and that velocities in the churn turbulent regime are larger. Increased pressure also decreases bubble size, leading to smaller bubble rise velocity, and increased gas density diminishes the driving force for liquid recirculation.

The fact that the axial liquid velocities obtained at atmospheric pressure at almost the same superficial gas velocity are 6 times higher than the liquid velocities obtained at 3 atm seems to indicate that the atmospheric column was in churn turbulent flow while the high pressure column was still in bubbly flow. CT scans seem to confirm this.

The behavior of liquid axial velocity profile and turbulent kinetic energy at atmospheric pressure as a function of superficial gas velocity is displayed in Figure 4.7 taken from Degaleesan (1997). Studies to determine the dependence on superficial gas velocity at elevated pressure are being planned.

The kinetic turbulent energy profile obtained from the CARPT run at 3 atm is shown in Figure 4.8. Specific turbulent kinetic energy decays seven fold from the high values of 350 dynes/cm^2 at z = 30 cm to 50 dynes/cm^2 at z = 90 cm. The kinetic energy in the fully developed region is 4 to 5 times lower than found at the same superficial gas velocity at atmospheric conditions (Figure 4.7b). This also indicates that the flow at elevated pressure remains in the bubbly flow regime.

Based on these limited results we reach two important conclusions. First, CARPT can be used successfully to measure velocity and turbulence parameters in high pressure columns. Second the flow at high pressure remains in the bubbly flow regime until higher superficial gas velocities are reached and this reduces the liquid recirculation rate and reduces liquid turbulence.

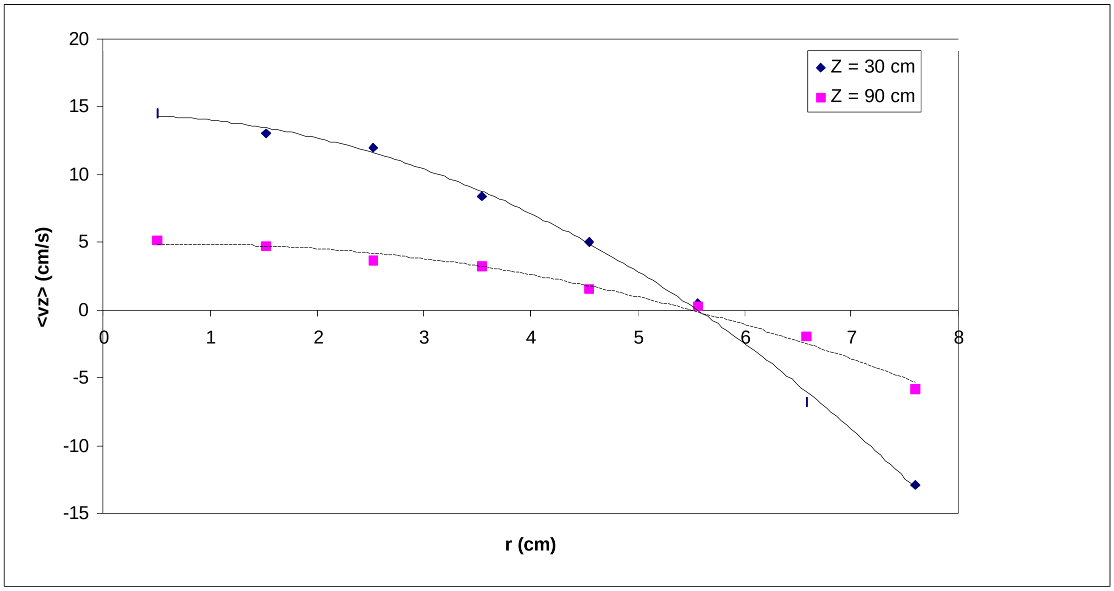
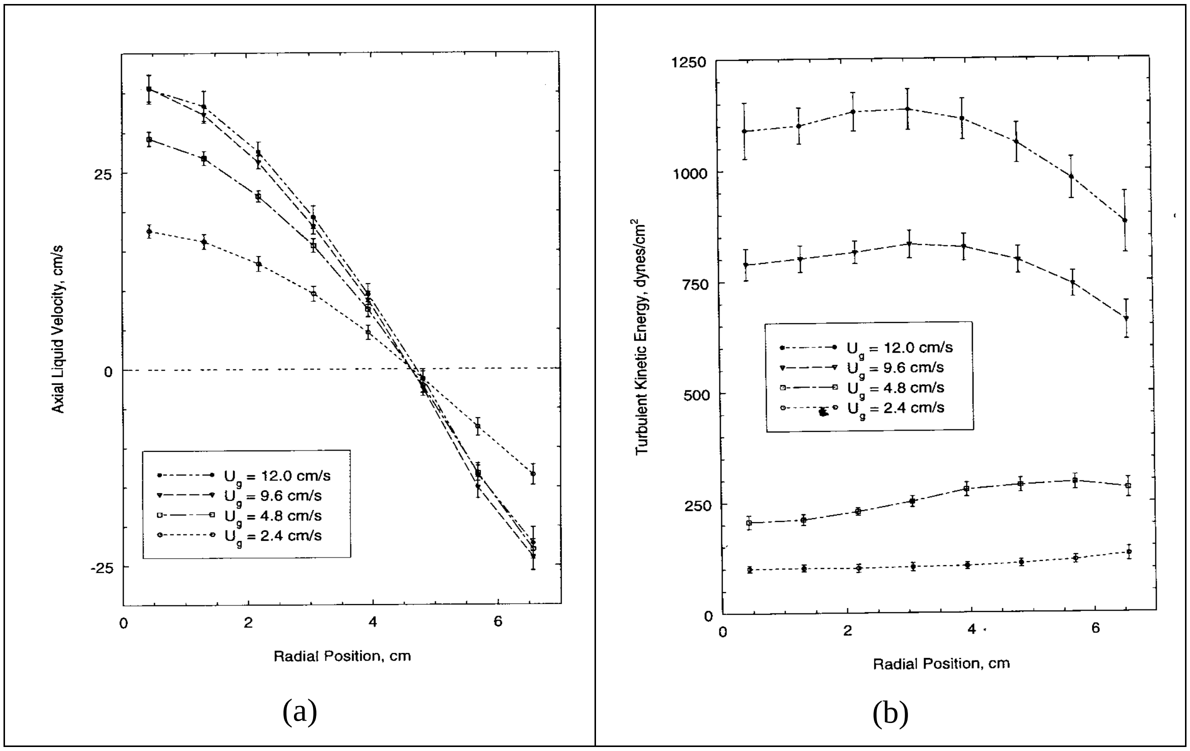


Figure 4.6: Axial Mean Velocities at Different z Level (30 and 90 cm) for a Superficial Gas Velocity of 5cm/s at Pressure of 0.3 MPa



(a) (b)

Figure 4.7: Axial Liquid Velocity Profiles (a), Turbulent Kinetic Energy (b) For an Atmospheric Column of 6 Inches Diameter

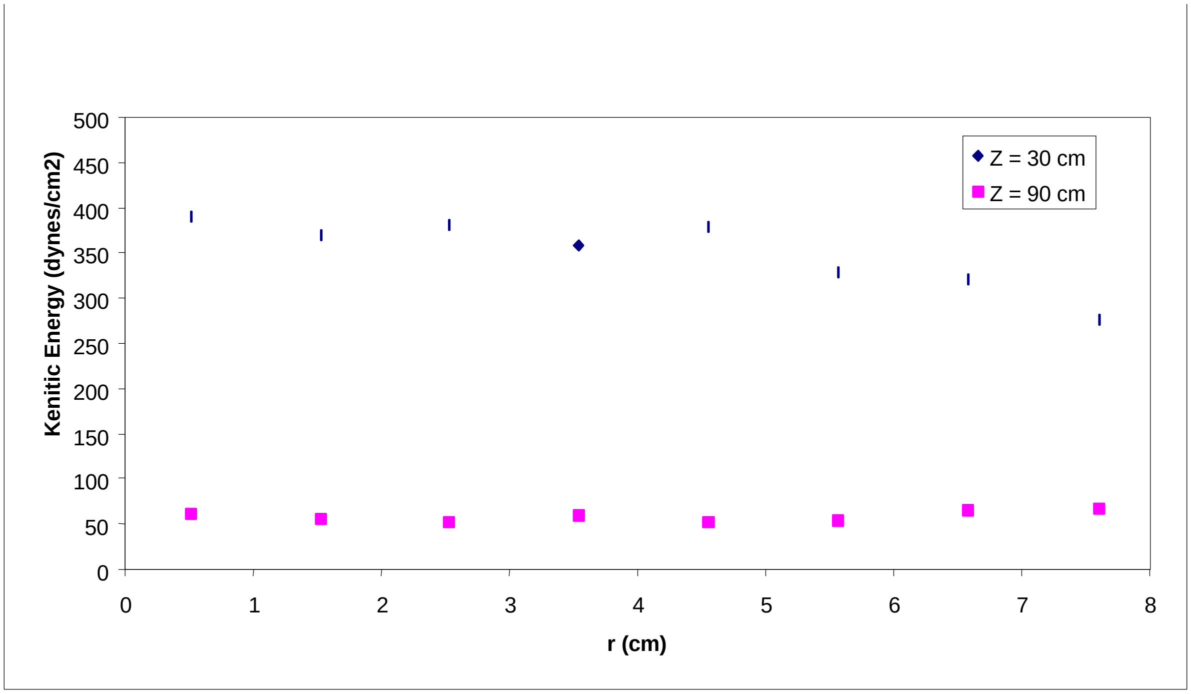


Figure 4.8: Kinetic Energy Profile. Superficial Gas Velocity: 5cm/s. Pressure:0.3 MPa

4.4. References

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Yang, Y. B., Devanathan, N., Dudukovic, M. P., “Liquid Backmixing in Bubble Columns via Computer Automated Radioactive Particle Tracking (CARPT),” *Exp. Fluids*, 16, 1-9, 1993.