The Ohio State University Reesearch

The following report from Ohio ɔ State University for the period January - March 1996 contains the following brief chapters:

1. Measurement of liquid densitity (Tasks 2-5)
2. Bubble effects on the transieient flow pattern in bubble columns (Task 3)
3. High-pressure and -temperatature slurry column shakedown (Task 2)
4. Work to be performed next c quarter (Task 7)
5. References

WORK PERFORMED

1. *Measurement of liquid density*

An area of high pressure and high temperature operation of slurry bubble column systems which is not fully understood is the effect of the physical property (densities, viscosity, surface tension, etc.) of the gas and liquid phases on the transport phenomena as the pressure and temperature increase. It may be possible to characterize the transport phenomena of slurry bubble column systems operated at high pressure and high temperature based on the physical properties of the phases rather than the operating pressure and temperature

The liquid density changes with pressure and temperature due to its compressibility and gas absorption. The hydrostatic weighing method was adopted to measure the effective liquid density, i.e., the density of a mixture of liquid and absorbed gas. The experimental setup is shown in Fig. 1. The submerged volume of a floating body in the liquid changes with the density of the liquid based on the Archimedes principle. Thus, the liquid density can be determined from the submerged float volume change. The densities of Paratherm NF heat transfer fluid were measured at a various temperatures and various pressures, and the experimental results are shown in Fig. 2. In general, the liquid compressibility can be negligible for a small variation of pressures. However, for a large variation of pressures, the intermolecular distance significantly decreases causing the density to increase. This is specially true for organic liquids. As shown in Fig. 2, the liquid density increases by about 5% when the pressure increases from atmospheric pressure to 3000 psig at a room temperature. An increase in temperatures results in an increase in the free energy, thereby enhancing intermolecular movement and yielding a reduction in the density. An increase in temperature from 68 to 250 F causes the liquid density to increase by about 6% for the entire pressure range tested.

2. *Bubble effects on the transient flow pattern in bubble columns*

The instantaneous flow structure in bubble columns was examined this quarter with emphasis on the scale-up effects. The experiments were carried out in 2-D bubble columns. The column width was varied from 4" to 24".

As reported in the last quarteterly report, the transient flow structure in a bubble column can be characterized by a 4-region or a 3-region flow patterns. Columns operated in the 4-region flow condition are comprised of the descending flow region, the vortical flow region, the fast bubble flow region and the central plume region. The fast bubble flow region is observed to move in a wave-like manner, and thus, the flow in the vicinity of this region can be characterized macroscopically in terms of wave properties. In small columns, the central plume region becomes indistinguishable from the fast bubble flow region yielding a 3-region flow. Based on flow visualization and the description of the flow regimes given above, the approximate dependency of the flow regimes on gas velocity and column width can be determined. Figure 3 shows that in columns less than 8" in width, by increasing the gas velocity, the flow regime will change directly from the dispersed bubble flow regime to 3-region flow. However, in larger columns, the flow regime will change from dispersed bubble flow, to 4-region flow, and then to 3-region flow. In large columns when the gas velocity reaches 1 cm/s the vortex size does not increase. Therefore, by continuously increasing the gas velocity the fast bubble flow regions will gradually grow and merge together to form a central fast bubble region in which the bubbles coalesce and break-up violently. However, in small columns, the bubbles merge together quickly to form a central bubble flow region which occupies the central plume region directly. Figure 3 shows that 1 cm/s and 3 cm/s are the demarcations between the dispersed bubble flow regime to the 4-region flow, and 4 to 3-region flow, respectively. Figure 3 was compared with the regime classification for 3-D systems reported by Shah et al. (1982), the two figures (Figure 3 and Figure 2.2 of Shah et al., 1982) bear considerable resemblance for dispersed bubble regime and coalesced bubble regime. Thus, it is apparent that the 2-D column results obtained in this study reveal that the coalesced bubble regime (or churn-turbulent flow) can be subdivided into 4-region flow and 3-region flow. In a 3-D system the flow will change from the dispersed bubble flow regime at lower gas velocities, to the coalesced bubble regime which has been found to consist of the vortical-spiral and turbulent flow conditions at high gas velocities (Chen et al., 1994). Here, the 3-region flow in a 2-D system, which exhibits coherent flow structures, will transform to the turbulent flow condition in the 3-D system when the gas velocity continues to increase. Even though the flow field in a 2-D column deviates to some extent from that in a 3-D column, the present results provide the qualitative and quantitative similarities of dynamic flow structure between 2-D and 3-D bubble columns.

The flow regime transition and subsequently the gas holdup distribution, in small columns differs from that in large columns. In small columns, the bubbles coalesce at the bottom of the column right above the bubble injectors and, therefore, the flow structure develops quickly in the axial direction. Thus, the gas holdup distribution remains constant through the entire region above injector. Figure 4 shows the effect of the gas velocity on the radial distribution of the gas holdup measured at L_m = 31.5" (L_m / L_s = 0.5, where L_m is the height above the bubble injectors) in a 6" wide bubble column. The figure illustrates that the shape of the radial gas holdup distribution shifts from a uniform bubbly distribution at low gas velocity to a central bubble distribution at higher gas velocities. This result asserts that in small columns the flow regime transforms directly from the dispersed bubble flow regime to the 3-region flow condition.

In large columns, as noted, the flow structure changes with gas velocities from the dispersed bubble flow to 4-region flow, and from 4-region flow to 3-region flow. Figure 5 shows the radial gas holdup distribution in the entire 19" cm column for a gas velocity of 1.54 cm/s; the figure reveals the radial symmetric behavior of the gas holdup.

3. *High pressure and temperature slurry column shakedown*

Two differential pressure transducers were mounted on the high pressure and temperature column. The differential pressure transducers were calibrated against liquid hydrostatic pressure in the column with liquid only. The zero points of the pressure transducers were found to shift with increasing pressure. A correlation was developed for the zero point shift of these two transducers. The calibration curve obtained the high pressure system is shown in Fig. 6. A computer data acquisition system was also connected to the transducers for the on-line measurements of differential pressures.

Liquid flow meter used in the high pressure and high temperature system was calibrated this quarter. The liquid flow rate is measured by a pneumatic flow meter installed before the column.

In the high pressure and temperatuure system, liquid in the supply tank is initially preheated to a desired operating temperature, and isis then pumped into the column through a flow control valve and a flow meter. The gas enters at the b bottom of the column via a sparger, mixes with the liquid in the plenum section; then the mixture is i introduced into the column through a distributor. The gas and liquid streams from the column passs through a back pressure regulator and flow into the exhaust reservoir where gas-liquid separatition is achieved. The system can be operated in either non-circulation or liquid-continuous moode of operation. In the non-circulation mode of operation, the liquid accumulates in the exhaust rereservoir; in the liquid-continuous mode of operation the liquid is recirculated back into the supply ttank. The flow meter's readings vary with operating conditions and physical properties of liquid. The readings were correlated with the flow rates obtained by measuring the liquid volume changges in the liquid supply tank in a given time interval in the non-circulation mode of operation.

In a non-coalescence bubble e column, the ultimate bubble size distribution depends primarily on the initial bubble size distributioon. Initial bubble sizes are function of distributor geometry and operating parameters. To study thhe distributor effects on the initial bubble size, a porous plate distributor and a perforated plate c distributor were made this quarter for the high pressure and temperature bubble column. In the hhigh pressure system, a flanged closure is used for the connection between the plenum section and the t test section. It is also use for facilitating distributor exchange. A groove is made on the flanged cldosure to house an exchangeable distributor plate.

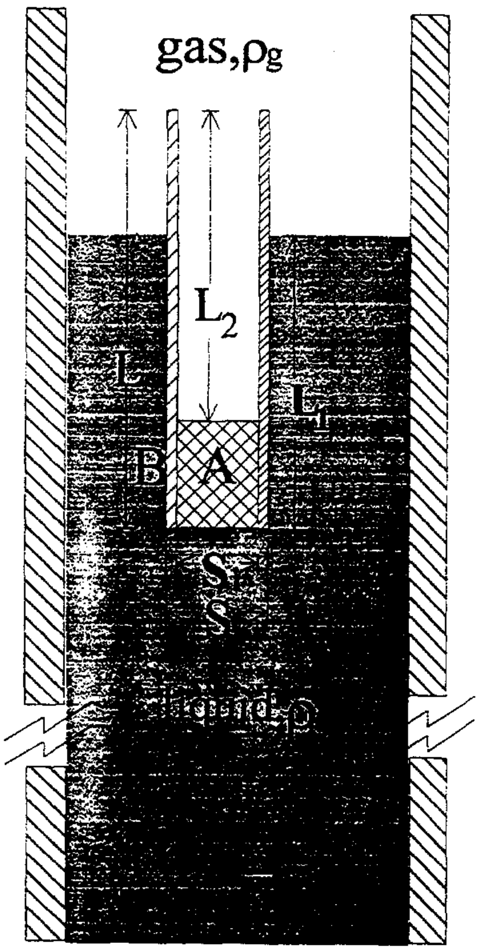
WORK TO BE PERFORMED NNEXT QUARTER

1. Quantitative analysis of the t transient flow pattern in bubble columns will be continued next quarter with emphasis on thhe Reynold stress.
2. Gas holdup in the high presssure and temperature bubble column will be studied next quarter.

REFERENCES

Chen, R.C., J. Reese, and L.-S. FFan, "Flow Structure in a Three-Dimensional Bubble Column and Three-Phase Fluidized I Bed," *AIChE J.*, **40**, 1093 (1994).

Shah, Y.T., B.G. Kelkar, S.P. CGodbole, and W.D. Deckwer, "Design Parameters Estimations for Bubble Column Reactctors," *AIChE J.*, **28**, 353 (1982).



Force Balance Equation

$$S[\rho_l L_1 + \rho_l (L - L_1)]\, g = (W_1 + W_2) + \rho_g L_2 S_1 g$$

W_1 : weight of metal A
W_2 : weight of tube B

Figure 1. Experimental seetup for the measurements of liquid density in the high pressure and hhigh temperature system

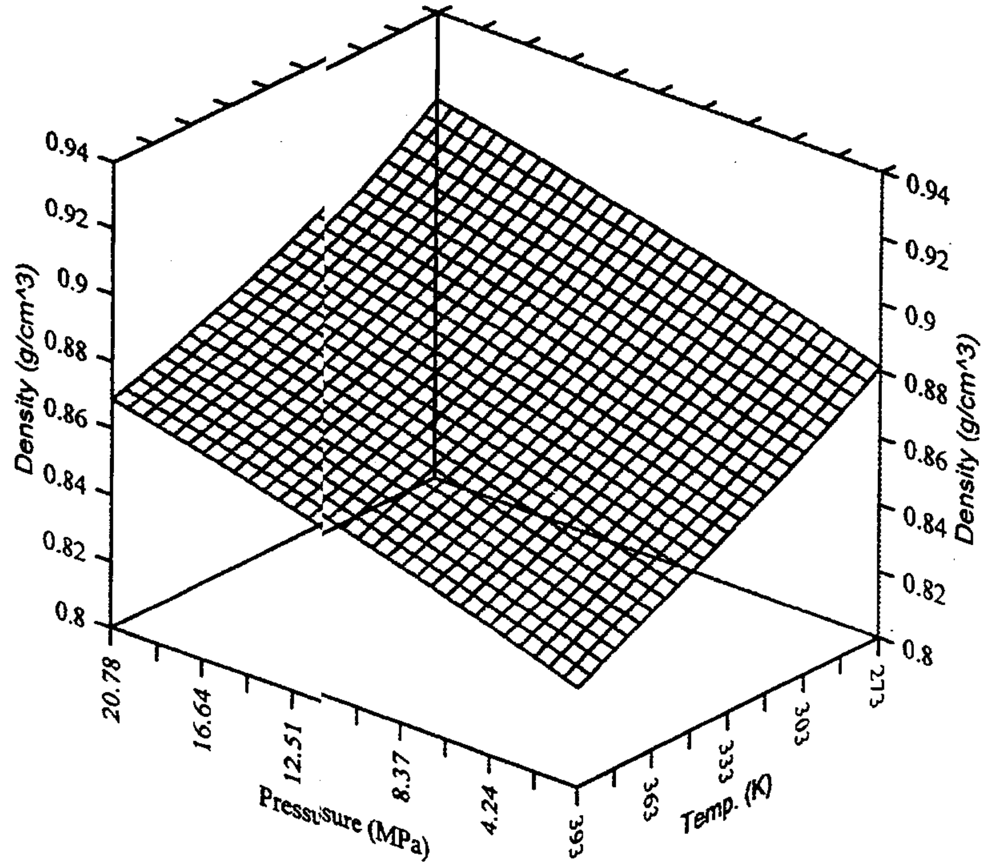


Figure 2. Variation in thee density of Paratherm NF heat transfer fluid with pressures and tempeeratures.

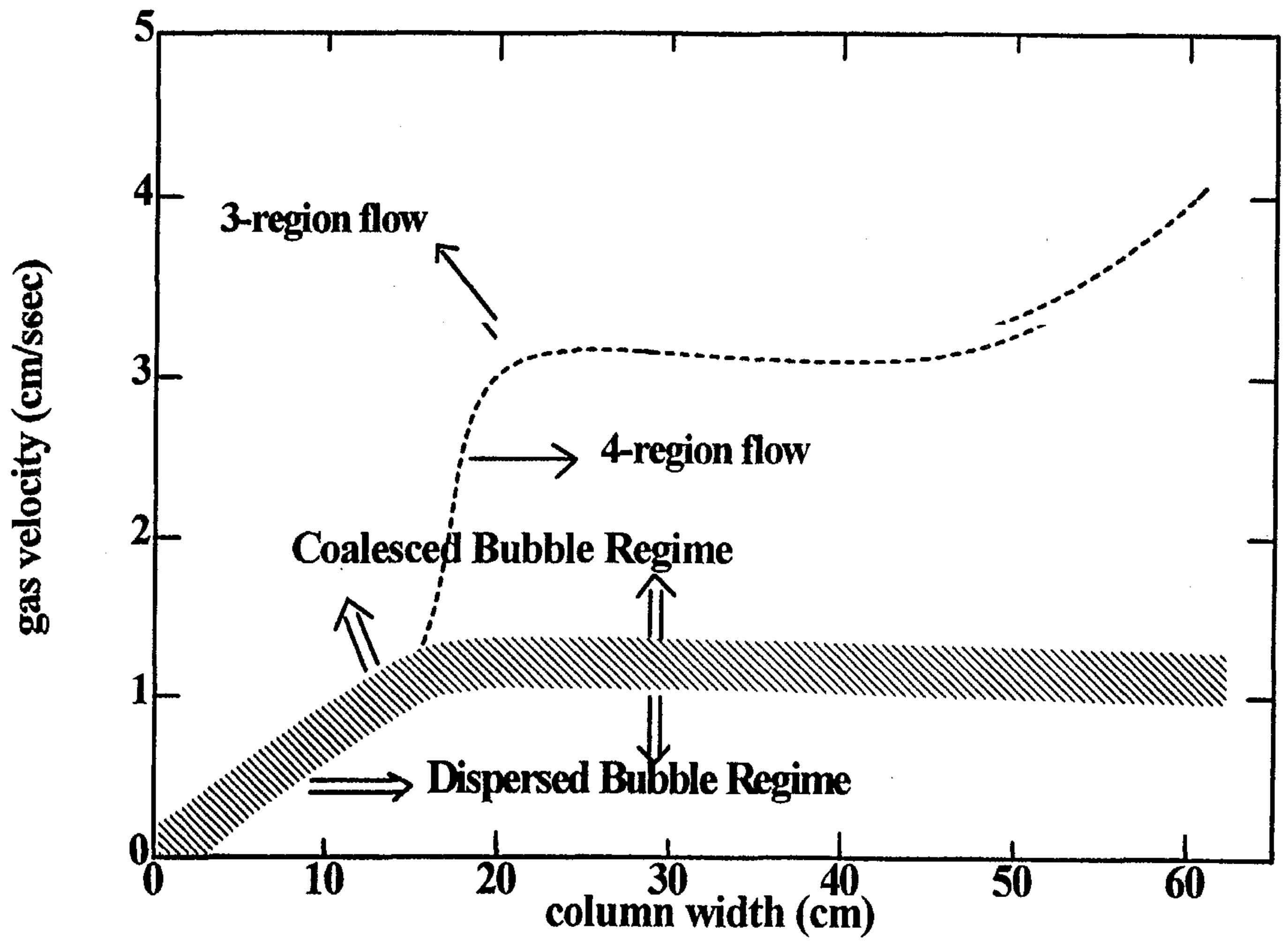


Figure 3 Operating regimes of two-dimensional bubble columns

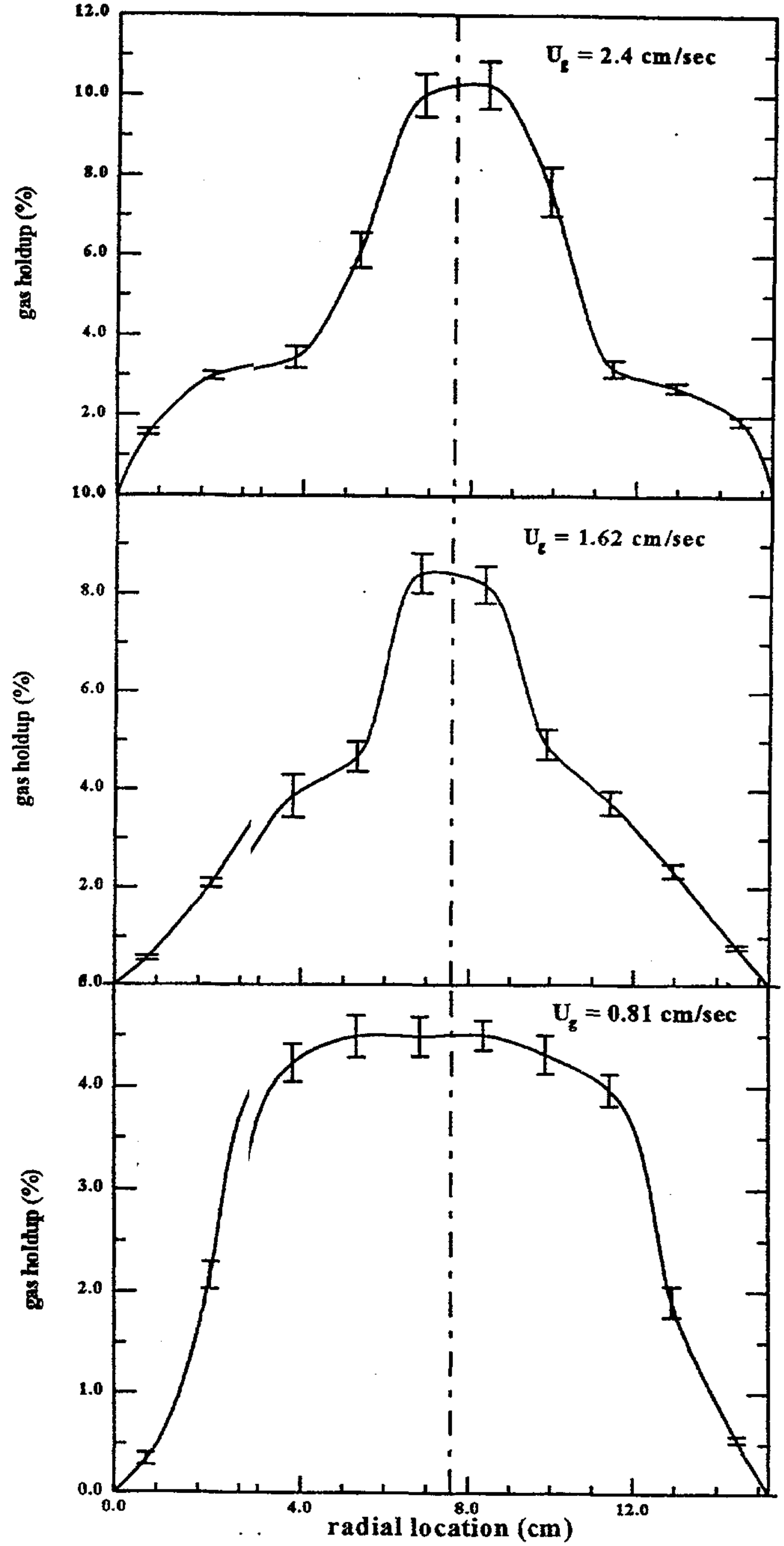


Figure 4 Radial gas l holdup distribution in 15.24 cm column for L_m/L_s== 0.5 and U_g= 0.81, 1.63, 2.4 cm/sec

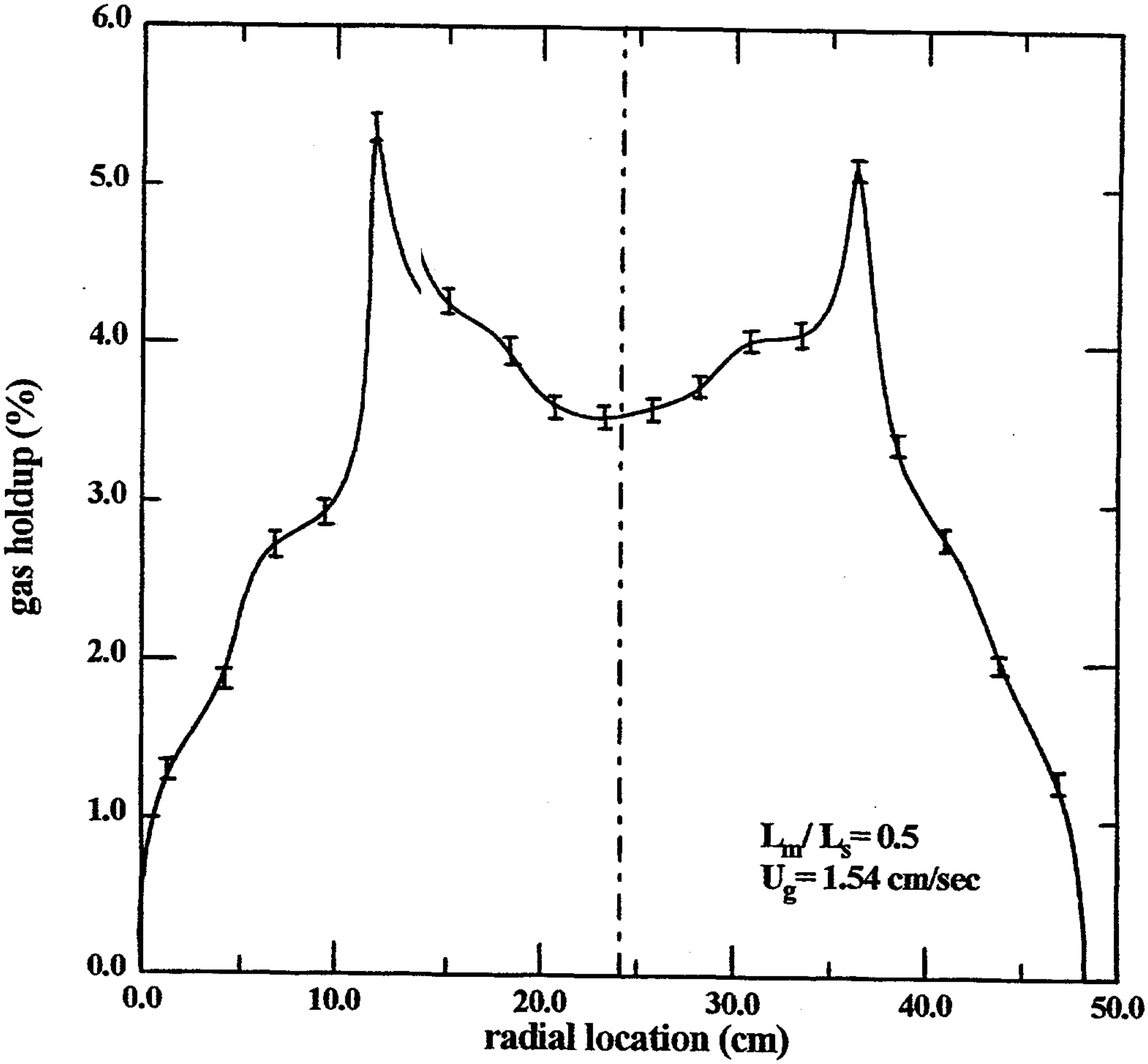
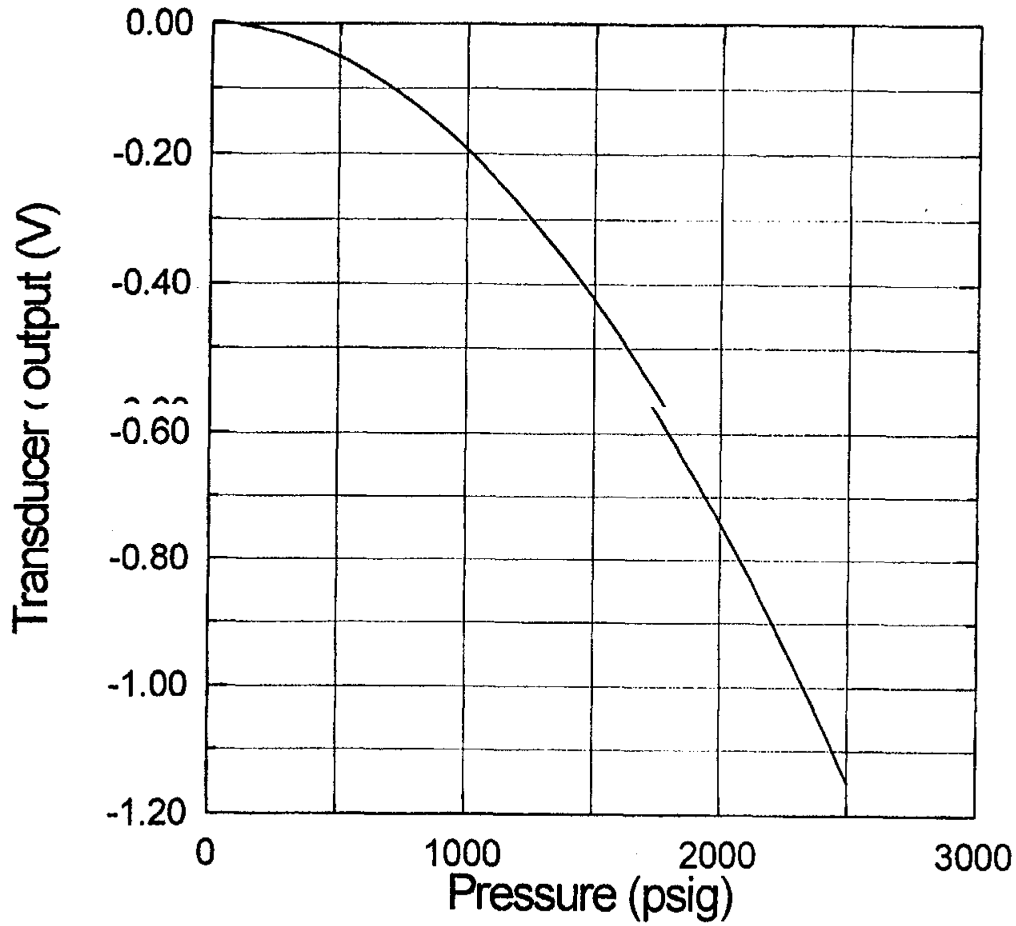


Figure 5 Radial gas holdupp distribution in 48.3 cm column, demonstrating that the holdup t behavior in the column is symmetric



$$DV = 0.00249 - 1.999E\text{-}5 \cdot P - 1.764E\text{-}7 \cdot P^2$$

Figure 6. The calibration curve for zero point shift of a pressure transducer obtained in the high pressure column.